Future potential of Forest and Agriculture Residues for the energy production in Thailand - Strategies for a better utilization

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Pongsak Hengniran

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A. Temming

Professor Dr. Axel Temming
Leiter des Fachbereichs Biologie

Declaration

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Pongsak Hengniran

Pongsak Hengniran
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Foreword

The need for more and more energy across the countries to drive their economic development has resulted in an exponential growth of fossil fuel utilization by various forms since the industrial revolution (Lloyd and Subbarao, 2009). A unique and essential fossil energy source, petroleum is chiefly used as the principal fuel for transportation, in producing many chemicals, and for numerous other purposes (Frumkin et al., 2009). However, global petroleum production is expected to reach a maximum in the near future then to decline thereafter, this phenomenon known as "Peak Petroleum". Additionally, since petroleum values have doubled when the monthly spot market price for West Texas Intermediate (WTI) at Cushing, Oklahoma, averaged 53.70 US$ per barrel (Fig. 1), and this situation has continued upwards till now adding a worry about an unsustainable draw down on finite resources that it is now coming to a head (Schnepf, 2008).

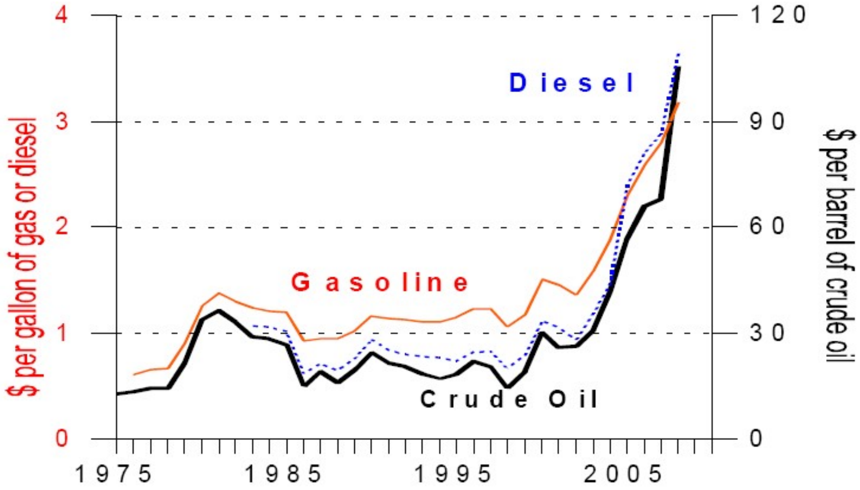

Fig. 1: Energy costs: annual average prices since 1975 for gasoline, diesel, and crude oil
Source: Schnepf (2008)

The high energy price at present is not the first experience, the oil shocks during the 1970s used to crest over the advanced industrial world. However, the current situation is different from the past, because it is highlighted that existing resource limits are being reached and the inevitable gap between demand and supply energy must be solved not only for finding suitable ways to balance and harness it, but also for creating commercially viable routes suitable for current consumption needs. These challenges being faced today will affect every aspect of civilization, including transport, resource use, food production, water supply, recent lifestyle, and the environment. Energy requirement is, therefore, indeed one of the most intensely debated issues at the global level. The linkages between energy and -economy, -social and health issues, as well as -environment, with the goal of sustainable development is widely discussed around the world - especially dependence on imported energy countries, like Thailand, where vulnerable to disruptions in energy supply causes physical hardships and economic burdens.

From the above mentioned world energy problem, a number of alternative energy sources are considered to alleviate the shortcoming of global energy. Renewable energy, one of the alternative energies, has a great potential to overcome the problem with sustainable energy supply. Although renewable energy technologies vary extensively in their technical and economic development, they offer progressively more attractive options whilst producing little or no recurrent greenhouse gas emissions as they depend on inexhaustible natural energy flows. Besides, some of these technologies are already competitive (Teske et al., 2007). Among various present renewable energies, modern biomass energy being produced by clean and high efficient technologies is highly interesting, because its source is generally abundant and normally under utilized, especially in developing countries. However, the future energy from biomass depends on providing reliable energy services at competitive cost with a sustainable development option; therefore the challenge in biomass utilization for energy is still open.

The interest in biomass energy is not new. It has begun since the first oil crisis in the 1970s, however many investments in biofuels made in the 1980s collapsed shortly after oil prices returned to their original levels (IBDF, 1979; Tomaselli, 1982). A new technology for converting biomass into usable energy forms is suggested as one of the possible options to overcome the challenges of sustainable development. It should produce less costly energy services and lower energy-related pollution and emissions. Additionally, the concerns about the new technology adoption can be met by many encouragements - such as regulations to improve market performance, temporary subsidies, tax incentives, or other mechanisms - if it occurs in a timely fashion. A sustainable use of biomass resources would require a large-scale adoption of interventions aimed at enhancing the supply, improved energy conversion and elimination of harmful emissions through fuel and technology improvements (Goldemberg and Johansson, 2004).

As a country that is highly dependent on imported energy (see Ch. 1.2), Thailand is also facing the weakness from its energy supply. The energy security is widely debated across the country; many endeavours are devoted to look for indigenous sustainable energy supply to maintain economic growth of the country. Energy conversion from biomass is believed to be the most potential opportunity among the current possible renewable technology choices, since many biomass residues from agriculture and forestry are generated in the country. Regarding the success of the biomass energy scheme, however, some of the concrete policy, financing, capacity development, technology, and knowledge management are actually required. The challenge to address the quantity of biomass for utilization as energy source and the link between these biomass amounts and their suitable technology is a key factor to achieve the country’s goal. Therefore, the purpose in this work is to reveal the potentials of biomass across the country and to select the proper conversion technology for generating modern energy forms from them.

This thesis is divided in to six chapters, namely:

Chapter 1 **Situation of Energy Utilization in Thailand** elucidates about general aspects about Thailand and its general situation of energy demand and production, as well as the main policy about energy in the future.

Chapter 2: **Raw Materials for Energy Utilization in Thailand** has the purpose to prepare supply curves/datum for energy utilization in terms of qualities and quantities that will be analysed in the chapter 4.

Chapter 3: **Technologies for energy production** is focused on all technologies to produce energy from biomass worldwide. The main purpose of this chapter is to review the possible technologies that may suitable for Thailand's circumstance.

Chapter 4: **Analysis of Bioenergy Potential and its suitable conversion technologies for Thailand** examines the potential of biomass as energy source for Thailand for the year 2010, 2015, and 2020. Finally, the technology selection for rice straw and cassava rhizome is modelled for other biomass residues, by applying ***the Fuzzy TOPSIS method***.

Chapter 5: **The prospect for biomass energy generation in Thailand** reveals the ambitious requirement owing to a suspicious within biomass energy generation to find the solution concerning of environment, social impact issue, the future of biomass in commercial energy market, and its opportunity to compete with other commercial energies, especially from other renewable technologies.

Chapter 6: **Conclusion** summarizes all knowledge from the previous chapters which will be comprehended to briefly give the main outcomes from this research.

Finally, the challenge of sustainable development, energy security, environmental benign, and socio-economical impact is a major factor that arouses the world to find the best solutions for this problem, and biomass for energy is a hopeful candidate to be one of the answers dealing with this challenge.

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> “The reward of a thing well done is to have done it.”
>
> Ralph Waldo Emerson

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Abbreviations

ADB	Asian Development Bank
AFTA	ASEAN Free Trade Agreement
ASEAN	Association of Southeast Asian Nations
BIG/CC	Biomass Integration Gasification using Combined Cycle
BMR	Bangkok Metropolitan Region
BMTA	Bangkok Metropolitan Transit Authority
BOI	Board of Investment
BOT	Bank of Thailand
BtL	biomass to liquid
BTS	Bangkok Transit System
CAI	Center for Agricultural Information
CDM	Clean Development Mechanism
CEERD	Centre for Energy Environment Resources Development
CHP	Combined Heat and Power
CIA	Central Intelligence Agency
CNG	Compress Natural Gas
DANIDA	Danish International Development Agency
DEDE	Department of Energy Development and Efficiency
DSM	Demand-side Management
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental Impact Assessment
EIA/DOE	Energy Information Administration within Department of Energy
EPA	Environmental Protection Agency
EPPO	Energy Policy and Planning Office
EPRI	Electric Power Research Institute
ERM	Environmental Resource Management
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
FDI	Foreign Direct Investments
FIO	Forest Industry Organization
FRA	Global Forest Resources Assessment
FT	Fischer-Tropsch
FTA	Free Trade Area
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
GMS	Greater Mekong Sub-region
GTZ	Thai-German Programme for enterprise competitiveness
IEA	International Energy Agency
IEO	International Energy Outlook
IPCC	Intergovernmental Panel on Climate Change
IMF	International Monterey Fund
IPP	Independent Power Producer
IPSR	Institute for Population and Social Research
ITTO	International Tropic Timber Organization
LCA	Life Cycle Assessment

LDFC	Local Development Financial Corporation
LNG	Liquefied natural gas
MDF	Medium Density Fiberboard
MEA	Metropolitan Electricity Authority
MOE	Ministry of Energy
MONRE	Ministry of Natural Resources and Environment
MOTE	Million Tones of Crude Oil Equivalent
MW	megawatt
NEB	National Environmental Board
NEPC	National Energy Policy Council
NEPO	National Energy Policy and Planning Office
NESDB	National Economic and Social Development Board
NGO	Non-government Organization
NSO	National Statistics Organization
NRC	National Research Council
NSO	National Statistical Office
OAE	Office of Agricultural Economics
OECD	Organization for Economic Cooperation and Development
OEPP	Office of Environmental Policy and Planning
ONEP.	Office of Natural Resources and Environmental Policy and Planning
PCD	Pollution Control Department
PDP	Power Development Plan
PEA	Provincial Electricity Authority
PMO	Prime Minister’s Office
PTT	Petroleum Authority of Thailand
PV	photovoltaic
R&D	Research and Development
RE	Renewable Energy
RFD	Royal Forest Department
RIT	Royal Institute of Thailand
RTG	Royal Thai Government
SET	Stock Exchange of Thailand
SMEs	Small and Medium-sized
SPP	Small Power Producer
SRT	State Railway of Thailand
TBOD	Thousand Barrels per day of Crude Oil Equivalent
TDRI	Thailand Development Research Institute
TEENET	Thailand Energy and Environment Network
TFP	Total Factor Productivity
TGO	Thailand Greenhouse Gas Management Organization
TPPIA	Thai Pulp and Paper Industries Association
TRF	Thailand Research Fund
TTFITA	Thai Tapioca Flour Industries Trade Association
UEMOA	West African Economic and Monetary Union
UK	the United Kingdom
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
US	the United State of America
USAID	United States Agency for International Development

VSPP	Very Small Power Producers
WEC	World Energy Council
WEF	World Economic Forum
WEO	World Energy Outlook
WPCD	Wildlife and Plant Conservation Department
WTO	World Trade Organization

Units abbreviations

CO_2eq	carbon dioxide equivalents
EJ	exajoule (1018 joules)
G t	gigatonne (109 tonnes)
GW	gigawatt (109 watts)
GWh	gigawatt hour
GW_{th}	Gigawatt thermal
ha	hectare
kcal	kilocalorie
kg	kilogram (10^3 grams)
kW	kilowatt (10^3 watts)
kWh	kilowatt hour
kW_{th}	kilowatt thermal
M	Million
m^2	square meters
M ha	million hectares
MJ	megajoule (106 joules)
M t	million tonne (10^6 tonnes)
MTOE	million tonnes of oil equivalent
MW	megawatt (106 watts)
MW_e	megawatt electrical
MW_{th}	megawatt thermal
PJ	petajoule (10^{15} joules)
t	tonne
TW	terawatt (10^{12} watts)
TWh	terawatt hour
W	watt

Chemical abbreviations

CH_4	methane
CO_2	carbon dioxide
DME	dimethyl ether
DMF	dimethylfuran
ETBE	ethyl-tertiary-butyl-ether
EtOH	ethanol
FAME	fatty acid methyl ester
H_2	hydrogen
MeOH	methanol
MTBE	methyl-tertiary-butyl-ether
N	nitrogen
N_2O	nitrous oxide
NO_x	nitrogen oxide
P	phosphorous
RME	rape methyl ester

Unit Conversions

Area	km^2	hectare	acre	rai
km^2	1	100	247.1	625
hectare	0.01	1	2.471	6.25
acre	0.00404686	0.404686	1	2.5293
rai	0.0016	0.16	0.39537	1

Example 1 rai = 0.16 hectare

Weight	ton	lb.	kg	g	tonne
ton	1	2240	1016.064	1,016,064	1.016064
lb.	0.000446	1	0.4536	453.6	0.0004536
kg	0.000984	2.20458	1	1000	0.001
g	9.8419×10^{-7}	0.00220458	0.001	1	10^{-6}
tonne	0.98419	2204.58	1000	10^{6}	1

Example 1 lb. = 0.4536 kg

Volume	gallons	ft^3	m^3	litres	US gal
gallons	1	0.16054	0.0045461	4.5461	1.20091
ft^3	6.228835	1	0.0283169	28.3169	7.480288
m^3	219.9688	35.314589	1	1000	264.1633
litres	0.21997	0.035315	0.001	1	0.2641633
US gal	0.8327	0.1336847	0.0037855	3.7855	1

Example 1 ft^3 = 0.0283169 m^3

Energy

- 1 BTU = 1,054:8 Joules = 252 Calories
- 1.0 kilowatt-hour (kWh) = 3.6 MJ = 3413 Btu

Power

- 1.0 watt = 1.0 J/s = 3.413 Btu/hr
- 1.0 kilowatt (kW) = 3413 Btu/hr = 1.341 horsepower
- 1.0 horsepower (hp) = 550 foot-pounds per second = 2545 Btu per hour = 745.7 watts = 0.746 kW

Abstract

One of the world leaders in agriculture, Thailand is looking for a renewable energy mix to fulfill its soaring energy demand and to reduce the high importation rates of fossil fuel. Biomass is considered to be one of the compromising choices for this endeavour thanks to nature of the country. Besides, biomass is already economically competitive in certain instances, and its cost for conversion into green energy is expected to continually decline further resulting from more developing technologies. Although biomass has been a traditional energy source in rural and local small-scale industry in Thailand for decades, its utilization as actual raw material for energy generation based on modern conversion technology is still in the initial stage. The old technology, i.e. traditional boiler, is rather low in efficiency and creates enormous pollutions, effecting environmental surroundings. In the beginning of this work, the energy situation in Thailand was focused on to get the policy direction about energy in both resource potentials and promotion programmes. A number of problems related to biomass energy scheme are also analysed and suggested. Consequently, biomass residues from the forestry/agricultural sector and wood-based industry were studied to reveal their potential as an alternative energy resource. The study shows that a biomass supply chain has a significant potential for energy production equivalent 596 PJ by 2009, 648 PJ by 2011, and 872 PJ by 2016, or about 13%, 10%, and 9% of total energy demand in each year, respectively.

To overcome the inherent limitations of biomass for the purpose of energy, the suitable technology selections for chosen crop residues (rice straw and cassava rhizome) is exemplified for power generation in the given geographical areas by applying one of the well-known multi criteria decision making tools, the Fuzzy TOPSIS method. The different technologies for power generation from biomass such as direct combustion, co-firing, and gasification are compared to optimise a number of criteria including project cost, technical availability, environment, regulatory and state policy, as well as social and logical constraints. The result shows that the low temperature circulating fluidised bed combustor (LT-CFB) is the best option for rice straw feedstock to generate electricity between 4-6 MW_e, while the downdraft fixed bed (DFB) gasifier is the promising technology for cassava rhizome with capacity below 1 MW_e.

The future biomass energy in Thailand will only succeed if they are able - during the development phase – to utilize higher energy efficiency technology with lower investment cost, to be flexible with fuel mix and load adjustments, to reduce emissions (resulting in better environment apart from promoting soil protection, avoid further deforestation, as well as salinity mitigation and land repair), to be technically feasible and economically viable, and to acquire enough social support, regional development (e.g. adding new jobs), and positive contribution to the national economy. To support this ambitious goal in bioenergy programmes, Thailand requires not only huge investment from both local finances and foreign direct investment, but also the role of the Government to encourage further actions in this promising business. Finally, most of the communities in Thailand are still inattentive to different types of sustainable energy technologies and their benefits. Therefore, this kind of barrier must be overcome by training programmes to assist public understanding of the actual benefits from these technologies

Key Words: *Biomass; Power supply; Energy generation; Thailand*

Zusammenfassung

Als eine der führenden agrarwirtschaftlichen Nationen bemüht sich Thailand einen Energiemix aus erneuerbaren Quellen zu etablieren, um den steigenden Energiebedarf des Landes zu decken und die hohen Importmengen fossiler Energieträger zu mindern. In Anbetracht der landestypischen Vegetation wird hierbei die Verwendung von Biomasse als erfolgversprechender Ansatz gesehen, wobei Biomasse in verschiedenen Anwendungsfällen bereits wirtschaftlich rentabel ist. Die Kosten für die Wandlung von Biomasse in „grüne“ Energie auf Grund der technologischen Fortschritte werden dabei voraussichtlich sinken. Obwohl die Verwendung von Biomasse als Energiequelle in ländlichen Regionen und kleinen Betrieben eine jahrzehntelange Tradition hat, befindet sich die Anwendung als Rohstoff für moderne Energiewandlungstechnologien noch in der Anfangsphase. Ältere Technologien, wie traditionelle Feuerungskessel, arbeiten hingegen wenig effizient und verursachen enorme Emissionen mit entsprechender Wirkung auf die Umwelt. Zu Beginn der vorliegenden Arbeit wird die Energiesituation in Thailand beschrieben und die gesetzlichen Rahmenbedingungen und staatlichen Fördermaßnahmen für beide Technologietypen untersucht sowie zahlreiche Probleme diesbezüglich thematisiert. Daraufhin werden die vorhandenen Nebenprodukte der Land- und Forstwirtschaft hinsichtlich ihrer Eignung als Energieträger untersucht und gezeigt, dass die Biomasseverwendung ein erhebliches Potential für die Energieerzeugung besitzt, wobei Energieäquivalente von 596 PJ bis 2009, 648 PJ bis 2011, und 872 PJ bis 2016 bzw. 13%, 10%, und 9% des gesamten jährlichen Energieverbrauchs aufgezeigt werden.

Um die inhärenten Grenzen der Verwendung von Biomasse als Energieträger zu überschreiten werden die möglichen technologischen Verfahren für ausgewählte Ernterückstände (Reisstroh und Erdstämme der Kassave) anhand der weit bekannten „multi criteria decision making tools“, die Fuzzy TOPSIS Methode, für die Stromerzeugung in gegebenen Regionen beispielhaft dargestellt. Die verschiedenen Verfahren zur Stromerzeugung aus Biomasse, wie die direkte Verbrennung, die Zufeuerung und die Vergasung werden miteinander auf Basis der Kosten, der technischen Verfügbarkeit, der Umweltwirkung, der gesetzlichen Rahmenbedingungen sowie sozialer und logischer Aspekte verglichen. Die Ergebnisse zeigen, dass die zirkulierende Niedrigtemperatur-Wirbelschicht-Feuerung (LT-CFB) die beste Option für die Stromerzeugung aus Reisstroh für Anlagen zwischen 4 und 6 MW_e, und die Vergasung im Gleichstromvergaser (DFB) für die Verwertung von Erdstämmen der Kassave bei Anlagengrößen von kleiner 1 MW_e ist.

Die Zukunft der Biomasseenergie in Thailand wird nur Erfolg haben, wenn es während der Entwicklungsphase gelingt, effizientere Wandlungstechnologie mit niedrigeren Investitionskosten zu nutzen, flexible Brennstoffmixe und Beladungsmengen zu ermöglichen, sowie die Emissionen zu reduzieren (Verminderung der Umwelteinflüsse neben einer Förderung des Bodenschutzes, Vermeidung weiterer Entwaldung, Reduzierung des Salzgehaltes und Rehabilitierung der Böden). Außerdem sollte versucht werden, genügend gesellschaftlichen Akzeptanz und ausreichende regionale Entwicklung (etwa neue Arbeitsplätze) zu fördern um einen positiven Beitrag für die nationale Volkswirtschaft zu leisten. Um die anspruchsvollen Ziele von Bioenergie- Programmen zu unterstützen, werden in Thailand nicht nur riesige direkte lokale wie ausländische Investitionen benötigt, sondern es müssen auch entsprechende staatliche Rahmenbedingungen für eine Förderung geschaffen werden. Derzeit werden die technischen Möglichkeiten und deren Vorteile in den meisten Kommunen in Thailand nicht wahrgenommen. Daher sollte durch Initiierung von Bildungsprogrammen die Öffentlichkeit auf die Vorteile der beschriebenen Technologien sensibilisiert werden.

Schlagwörter: *Energie aus Biomasse; Stromerzeugung; Energieerzeugung; Biomasse in Thailand*

Chapter 1: Situation of Energy Utilization in Thailand

As other developing countries with limited domestic commercial energy sources and reserves, Thailand has heavily relied on fuel imports in which almost half of total energy supply comes from abroad, especially petroleum products. This causes a high impact on monetary and fiscal system of the country. Because energy is basically one of the main driving factors for economic development in the long term, the Thai government has sought other energy supply sources to reduce vulnerabilities from the long-term energy insecurity. Therefore, the main objectives in this chapter are to introduce a country's background, and to reveal a current situation/problem in energy sector of Thailand.

1.1 General aspects about Thailand

1.1.1 Geographical and social aspects

Located in the heart of **South-East Asia** and situated in between 15° 00' North latitude and 100° 00' East longitude, **Thailand** is bordered to the North by ***Laos*** and ***Burma***, to the East by Laos and ***Cambodia***, to the South by ***Malaysia*** and the ***Gulf of Thailand***, and to the West by the ***Andaman Sea*** and Burma (Fig. 1.1). As a result of its location regards to the particular latitude and longitude, the Standard Time of Thailand runs 7 hours ahead from the Greenwich Mean Time. The surface area of the country is approximately 513,115 km^2, which is about 1.4 times the size of Germany (CIA, 2010). The population is about 63.776 Million (M) at midyear 2010 (IPSR, 2010) and consists of 75% Thais, 14% Thais-Chinese, and 11% Thais-other (CIA, 2010). About 34 M people are the labor force, and 94% of this labor force is employed. The national religion is Theravada Buddhism, practiced by more than 95% of all Thais, while the rest is Muslim 3.8%, Christianity 0.5%, Hinduism 0.1%, and other 0.6%, respectively (NSO, 2010). The Thai language is both the official language and the mother tongue of the local people, while English is being taught as a second language since primary education onwards (CIA, 2010; Kachru et al., 2006).

Not only is **Bangkok** the capital and principal city, but also the country's centre of political, commercial, industrial, and cultural activities. The Bangkok special administrative area covers 1,568.7 km^2 and its latitude and longitude are 13° 45' North and 100° 31' East, respectively. With approximately 8,160,522 residents registered (Perera et al., 2007; NSO, 2010), but due to the large unregistered influxes of migrants from other parts of Thailand and from many nations across Asia, the population of greater Bangkok is estimated at nearly 15 M people (Webster and Patharaporn, 2004; World Bank, 2009). Economic activities in Bangkok and the metropolitan area account for almost 60% of the national **G**ross **D**omestic **P**roduct (GDP), though it has fewer than 20% of the country's population. Thailand is divided into 76 provinces, gathered into 5 groups of provinces by location[1] (Fig. 1.1) including **the Central** (19 provinces), **the East** (7 provinces), **the North** (17 provinces), **the Northeast** (19 provinces), and **the South** (14 provinces). Each of the regions differs from the others in populations, basic resources, natural features, level of socials, and economic developments.

The local climate is tropical and characterized by monsoons. There is a rainy, warm, and cloudy southwest monsoon from mid-May to September, as well as a dry and cool northeast monsoon from November to mid-March. However, the southern isthmus is always hot and humid. As above-mentioned, the weather in Thailand is generally hot and has high

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[1] See also http://en.wikipedia.org/wiki/Provinces_of_Thailand and http://www.statoids.com/uth.html

humidity level, or savanna climate. Countrywide, temperatures normally range from an average annual high of 38 °C (100 ^{o}F) to a low of 19 °C (66 ^{o}F). During the dry season, the temperature rises dramatically in the second half of March, spiking to well over 40 °C (104 ^{o}F) in some areas by mid April when the Sun passes the Zenith. Southwest monsoons arriving between May and July (except in the South) signal the advent of the rainy season, which lasts into October, with average annual precipitation about 1700 mm. The cloud covering reduces the temperature again, but the high humidity is experienced as 'hot and sticky' [see footnote 2].

Fig. 1.1: Map of Thailand

There are two main rivers in Thailand: **the Chao Phraya** and **the Mekong**. Together, these rivers support the irrigation for agricultural economy of the country. Other than these two large systems, there are a number of other waterway systems and individual riverheads which drain the lands within Thailand's borders into the Gulf of Thailand and the Andaman Sea. However, the Mekong is the only river system in Thailand which drains into the South China Sea. The most conspicuous features of Thailand's terrain are high mountains, a central plain, and an upland plateau. Mountains cover much of the North and extend along the Myanmar border down through **the Kra Isthmus**, the narrow landbridge connecting the Malay Peninsula with the mainland of Asia. The central plain is a lowland area drained by the Chao Phraya and its tributaries. The Chao Phraya system drains about one-third of the nation's territory. A region of gently rolling low hills and shallow lakes, **the Khorat Plateau** located in the Northeast drains into the Mekong through the Mun River. In contrast, the distinguishing natural features of peninsular Thailand are long coastlines, offshore islands, and diminishing mangrove swamps [see footnote 3].

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[2] See also http://www.tourismthailand.org/about-thailand/weather/

[3] See also http://www.tourismthailand.org/about-thailand/geography/

1.1.2 Agriculture and Forestry

Thailand is moderately forested, although its forest cover has roughly halved since 1960. About 25.28% or 12.97 M ha of total land areas are covered by forests, which can be classified into two major types: **Evergreen Forest** (sharing 53.46% of total forested areas) and **Deciduous Forest** (accounting for 46.54%). *Dipterocarpus* spp., *Shorea* spp., and *Hopea* spp. are among the most prevalent species. Teak (*Tectona grandis*) has generally been the most important timber species (Tanaka et al., 2008). Pragtong and Thomas (1990) distinguish 4 periods of forest management since the establishment of the **R**oyal **F**orest **D**epartment (RFD) of Thailand. ***The first*** one continued until 1953 and covered the period before the Land Act. It was characterized by development of forest management systems for commercial timber production. ***The second*** period from 1954 to 1967 was marked by use of forest land to promote economic development. During ***the third*** phase, which started in 1968, long-term timber concessions were extended. Therefore, this period, up to 1980, was characterized by rapid deforestation. ***The fourth*** phase from 1981 onwards can be called a transition period when the focus began to shift towards conservation, and the role of communities in natural resource management started becoming recognized. This change of focus was particularly notable since the 1988 national logging ban in the natural forests.

The main outcome from the logging ban was possibly that managing objectives in the natural forests officially shifted towards conservation, and the era of commercial exploitation ended. The RFD also started to implement a zoning system in the forest reserves, whereby the lands were divided into 3 groups: conservation, economic, and agricultural zones. The criteria applied in this zoning were arability, forest cover, and forest condition. The conservation zone was defined as the land with healthy forest cover, while the economic zone was the degraded forest with soil unsuitable for growing crops. The agricultural zone, also called the land reform zone, was specified as the deforested area that had permanent settlement or where the land was used for agriculture. Additionally, the state has instituted supporting measures to protect the remaining forests and to promote private sector involvement in forest management and plantations. Currently, primary sources of industrial wood are plantation forests, non-forest trees, agricultural crops (particularly rubber wood). They are, however, unable to meet the demand of the domestic wood industry. Imports of logs, sawnwood, long fiber pulp, and recovered paper are therefore imperative constituents of Thailand's wood processing sector (see also Ch. 2.3: Thailand).

Although sawn timber, wood-based panels, and paper are the main products of wood processing sector, the downstream processing industry - mainly furniture and joinery - is also thriving. As a result of the logging ban, however, the decrease in forest production over the past 20 years has reduced the contribution of forestry to GDP to only about 0.1%. Neighboring countries remain major suppliers of hardwoods to Thailand. Hardwoods imported from Malaysia and Indonesia are mainly used for construction purposes. Meanwhile, high-value tropical hardwoods (such as teak, rose wood, and Ma-ka) are normally imported from Myanmar, Laos, and Cambodia. The household sector uses about 20 M tones (t) of wood annually for woodfuel, which is met by local supplies (from home gardens, woodlots, and public forests). However, there is still a shortage of woodfuel in the industrial sector, which requires about 6.5 M t annually (see also Ch. 2.3: Thailand, and Ch. 2.3.4).

Thailand is one of the world leading agricultural suppliers. Agriculture is a major sector of the national economy even now, although Thailand has made great achievements in its economic development process. With nearly 27% of its total area, Thailand has the biggest arable land in the **G**reater **M**ekong **S**ub-region (GMS), a geological region which includes nations and territories located in Mekong River basin, namely: Vietnam, Cambodia, Laos, Thailand, Burma, and Yunnan Province of China with 0.795 M km^2 (ADB, 2007). Besides, most of Thailand's labor force - reported at about 36.9 M or 49% of total in 2007 - is still engaged in the agricultural sector. They cultivate about 20.4-21.01 M ha of farmland, of which only 24% is under irrigation systems. Around 10.51 M ha or about 55% of farmland is used mainly for rice production, however other important crops such as sugarcane, cassava, and oil palm are also cultivated (see also Ch. 2.2). The rest of the national farmland is allocated to upland crops (4.61 M ha), horticulture (4.17 M ha), and residents and idle land (1.03 M ha) (Thepent, 2009; Roonnaphai, 2005). Apart from the world's leading exporter of aforesaid crops, Thailand sends out other crops including coconuts, corn, rubber, soybeans and tapioca too. Exports of industrially processed foods such as canned tuna, pineapples, and frozen shrimp are on the rise (FAO, 2005).

The success of Thai agriculture has been shown by the country's diversified agriculture taking advantage of world demand for a wide range of commodities, starting with cassava, kenaf, maize, and sugarcane in the 1960s and 1970s, moving on to soybeans, oil palm, and coffee in the 1980s, then pioneering in the production and export of prawns, frozen fowl, fruits, and flowers in the 1990s (Bello, 1998). The shrimp industry is one of the major Thai success stories. Thailand became the world's largest producer of farmed shrimp by the mid-1990s, and shrimp became Thailand's second largest agricultural export earner by the late 1990s, with over 20,000 farms employing about 0.3 M people directly and indirectly (Centex Shrimp, n.d; Morakot, n.d., p. 65). However, Thai agricultural exports have long faced the problems of world market price fluctuation, particularly in the 1980s. Moreover, Thailand's trading partner has issued more restricted rules and regulations in importing agricultural products culminating in difficulty to export their products to those countries. Thai commodities exports are also confronting effective competitors, such as China and Vietnam (Thaiprasert, 2006). Presently, the relative contribution of agriculture to GDP has been continuously declining, while industry and services have increased (see Fig. 1.2). In 2007, agriculture, forestry, and fishing contributed only 11.4% to GDP, accounted close to US$ 71.478 billion.

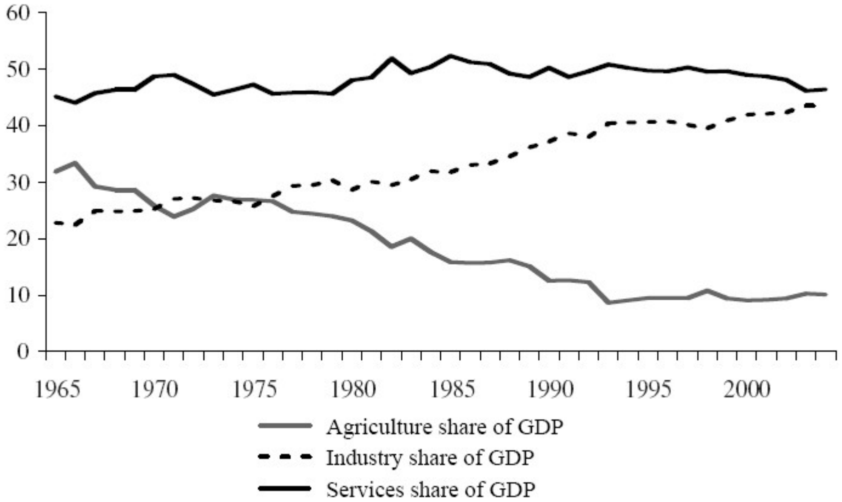

Fig. 1.2: Shares of Thai GDP by Sector, 1965-2005 (%)

Source: World Bank, World Development Indicators, various issues

The condition of Thai agriculture reflects a strong contrast to the country's export achievement and contrast to the high **T**otal **F**actor **P**roductivity (TFP) growth found in this sector. The yield figures reveal surprisingly low per area in Thai agriculture. As shown in table 1.1, yield of rice in Thailand was the lowest among major rice producing countries, although Thailand has long been the world's top rice exporter. The yields of other crops, such as sugarcane and maize, were also in the low ranges. Other commodity yields were in middle ranges. None of the highest yields shown in the table were counted for Thailand. The low productivity has its causes. Outputs are usually low, when inputs are poor. Thai agriculture usually receives very poor inputs. Apart of the shortage of good irrigation systems and technology development, it obtains low capital inputs and consumes low amounts of fertilizer. For the reason, why Thailand can still be a world-top net exporter of agricultural produce despite Thai agriculture's low productivity is the extensive deforestation before 1989 to expand production area.

Table 1.1: Yield of Major Crop Production in Thailand and Selected Major Exporters in Year 2000 (Kg per rai)

Coutry	**Rice**	**Cassva**	**Sugacane**	**Mize**	**Soghum**	**Soybean**	**Jute**	**Cotton**	**Coffee Bean**
Thailand	420	2,695	9,052	582	277	230	284	228	197
Australia			14,102					587	
Bangladesh	536		10,795				619		
Brazil	487	2,152		438		384		372	124
China	998		11,334	747		273	444	518	
France				1,449					
India	481	3,711	12,004	283	145	152	265	110	161
Indonesia	708	1,923				198			76
Japan	1,072								
Mexico			11,954	347	472				75
Myanmar	533						142		
Nigeria		1,703			180				
Pakistan			7,342					311	
Philippines	492		14,409						
the USA				1,376	611	410		289	
Vietnam	680						306		441

Remark: 6.25 Rai = 1 hectare

Source: Thaiprasert (2006)

1.1.3 Industry and trade

Although Thailand is an agricultural country, other industries are also developing such as car industry, metal industry, electric power, agricultural processing, textile & garment industry, and construction etc. Thai industry and agriculture sectors, however, were traditionally intertwined. Thailand's economic policy utilized agriculture as an engine of industrial growth and a key for export. The move into industrialization starting in the 1960s was characterized by import substitution, which mainly involved the processing of its bountiful agricultural produce (Medhi, 1995; Thaiprasert, 2006). By the end of the 1960s economic development became clearly based on the expansion of agricultural production and exports and import substitution industrialization (ISI) (Medhi, 1995). In 1972, a new Industrial Promotion Act signaled the shift in government policy to an export-oriented economy. This new emphasis began the hasty diversification of the industry sector which thrived markedly in its several industries, including petrochemicals, textiles, transportation equipment, electronics, iron & steel, and minerals. Nevertheless, the Financial Crisis in 1997 (see Ch. 1.1.4) heavily impacted industries and caused the closure of 8,000 businesses[4]. The increasing cost of labor has also led to a departure from labor-intensive ventures. Hitherto, only the manufacturing sector contributes considerably to national income which accounted for 34.5% of GDP in 2004, particularly the 4 sub-sectors; food processing, automobiles, electronics, and petrochemicals.

Most of Thai agro-industries are medium-size investment and its primary industry investments, which most are cluster and contract farms, are expanded. The investment is typically in the Central, the East, and the Northeast. Thailand is also becoming a center of automobile manufacturing for the **A**ssociation of **S**outheast **A**sian **N**ations (ASEAN)[5] market. Thai automobile industry has emerged during the 1990s and grew rapidly after the Financial Crisis to become one of the leading exporting sectors of the country. The extension of the automotive industry has led to a boom in domestic steel production. This industry has performed robustly in terms of expanding its share of world exports. For microelectronics industry, it has long been a major contributor to exports regularly accounting for more than 30% of total exports (Woon et al., 2007). The petrochemical industry began in Thailand about 5 decades ago, but it was only towards the end of the 1970s that the industry really began to take shape as a significant regional and global force. Going into 2009, the Thai petrochemicals industry is likely to be one of the main beneficiaries of the massive investment program in infrastructural developments, but aside from market performance there are two main risk factors: the changing regulatory environment and the appreciation of Thai currency.

Industry expanded at an average annual rate of 3.4% during the 1995 to 2005 period. In terms of GDP sharing, manufactures has grown from merely 12% in 1960 to 40% in 2008, while agriculture has declined from 40% to about 10%. Presently, manufactured products account for more than 80% of Thai export values, while agricultural products contribution has decreased to more or less 10% only. In 2007, industry sector contributed 43.9% of GDP, but employed only 14% of the workforce who are among the highest paid workers in the country along with those working in the service industry (Tambunlertchai, 2009). The employment share in agricultural sectors fell from 59.5% in 1990 to 45.3% in 1999. In return, shares of the employment in manufacturing, trade, and service sectors have increased gradually (table 1.2) (Manprasert, 2004). Like many countries, the service industries have been one of the growing sectors in Thailand, accounting for nearly half of aggregate production and 40% of national employment. Although government policies in emerging economies tend to focus on the growth of manufacturing, the service industries in Thailand have been the dominant source of new job creation in recent years, expanding by 2.6 M jobs between 2000 and 2005 compared to just 1.6 M in the industrial sector. They typically offer services in transportation, construction, retailing & wholesale, finance, and tourism (Kasikorn Research Centre, 2006).

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[4] See also <http://en.wikipedia.org/wiki/1997_Asian_Financial_Crisis>

[5] ASEAN was first officially established in 1967 in Bangkok, Thailand, with the signing of the Bangkok declaration by the five original member nations: Indonesia, Malaysia, Philippines, Singapore, and Thailand. After that, Brunei Darussalam, Vietnam, Lao People’s Republic, Myanmar, and Cambodia joined, making the ASEAN a group of 10 (Karki et al., 2005).

Table 1.2: Employment share by sector

Sector	1984	1994	2004
Agriculture	68%	52%	42%
Manufacturing	11%	20%	21%
Service	21%	28%	37%

Source: Labor Force Surveys, National Statistical Office (Thailand)

Thanks to increasingly diversified manufacturing sector, industries registering rapid increases in production included computers & electronics, furniture, wood products, canned food, toys, plastic products, gems, and jewelry. High-technology products such as integrated circuits & parts, hard disc drives, electrical appliances, vehicles, and vehicle parts are now leading Thailand's strong growth in exports. The top 3 importing countries are Japan (20%), China (11%), and USA (7%). Therefore, the Thai economy heavily depends on these three countries, namely, USA, China, and Japan. If these countries face trouble such as recession, it affects Thailand directly (Kagami, 2008). Economic recovery among Thailand's regional trading partners has helped the Thai export growth (21.6% in 2004, 15.0% in 2005, 17.4% in 2006, and 18.6% in 2007). Export growth has been highest in some of Thailand's non-traditional export markets including India, China, and the Middle East. Tourism contributes significantly to the Thai economy (about 6%). Tourist arrivals, which declined in 2005 due to the tsunami catastrophe, recovered strongly in 2006. Because of domestic political uncertainty and concern about government's economic policies, Thai domestic demand and private investment were stagnant from early 2006 through late 2007.

The other half of Thailand is still overshadowed by several problems. Between the 1980s and 1990s, Thailand’s economy was one of the fastest growing in the world, but this coincided with the rapid depletion of its natural resources. The major problems were that of inequality between the urban and rural areas, and between agricultural and non-agricultural sectors, not only in terms of income, but also attention, promotions, and investments received (Thaiprasert, 2006). As in other cases of the rapid spread of capitalism and industrialization, it promoted social differentiation and triggered social stress. The fast-growing urban-manufacturing industrial sectors have long been the receivers of net capital inflows, investments, and government’s attention more than those of the slower growing rural-agricultural sectors (Thaiprasert, 2006). Manufacturing facilities are mostly located in Bangkok and on **the Eastern Seaboard**, launched in 1977 as the long-term large scale site for small, medium, and heavy industries. Other Problems also occur in these sectors, as Thai manufacturing production and exports are not based on advanced technology (Diao et al., 2006). Moreover, they have complexity in inter-industrial linkages, then low ability to achieve significant sectoral rates of TFP growth. According to several international business indicators, Thailand still lags well behind Singapore, Malaysia, Taiwan, and Korea (Thaiprasert, 2006).

The export ratios were high in agricultural crops, agro-industry; textile & leather; wood, paper, and rubber (table 1.3). These ratios suggest the importance of these sectors to bring in foreign exchange earnings. However, Thai manufacturing sectors alone are not able to finance the balance of trade deficits because of their high dependency on imported materials, especially forestry, mining, agricultural machinery, chemicals, crude oil & fuels, and electronics industry (Thaiprasert, 2006; Manprasert, 2004). The reasons are clear for forestry and mining, because their domestic resources have been depleted. For agricultural machinery, a large number of farm tractor engines and machinery parts were imported to be assembled in Thailand for both domestic use and export to neighboring countries (Thaiprasert, 2006). The persistence of unproductive manufacturing industrial sectors could, therefore, hinder Thailand’s economic growth in the future. To boot, outbreaks of diseases such as the bird flu that hit Thai poultry in 2004, and strict quarantine standards setting by trading partners are another obstacle that can directly affect Thai food processing (Thaiprasert, 2006; Manprasert, 2004). For the microelectronics industry, the majority of enterprises in this sector are 100% foreign-owned, with a limited number of joint ventures and very few wholly Thai-owned companies. Currently, Thailand’s electronics industry faces competition from Malaysia and Singapore, while its textile industry fronts competition from China and Vietnam.

Table 1.3: Top 10 Commodities in Thailand's Export in 1990, 2005, and 2009

NO.	1990	2005	2009
1	Office equipment parts/accessories	Computer equipment	Computer equipments
2	Rice	Valves/transistors/etc.	Auto and compartments
3	Crustaceans, mollusks etc	Natural rubber/latex/etc.	Electric circuit equipments
4	Fish/shellfish (prepared or preserved)	Office equipment parts/accessories	Natural rubber/latex/etc.
5	Natural rubber/latex/etc.	Goods/service vehicles	Petroleum polymer products
6	Valves/transistors/etc.	Telecoms equipment nes	Jewelry products
7	Vegetables - fresh/chilled/frozen	Electric circuit equipment	Petroleum oils
8	Pearls/precious stones	Heavy petrol/bituminous oils	Metal and Steel products
9	Footwear	Fish/shellfish (prepared or preserved)	Telecoms equipment nes
10	Men’s/boy’s wear, woven	Industrial heating/cooling equipment	Petrochemical

Note: nes refers to “not elsewhere specified”
Source: UN Commodity trade

1.1.4 Economy and Currency

Thanks to a well developed infrastructure, a free-enterprise economy, and a welcome foreign investment, economic expansion of Thailand has been quite successful in terms of achieving high growth rate and reasonable per capita income. The economic structure has transformed from a low income of agrarian rural economy during the post war period to a more industrialized one with substantially higher per capita income as present (2005) (Thaiprasert, 2006). In terms of the share of world exports, the relative performance of Thai export clusters from 1997 to 2005 reveal the structural shift from factor-driven to investment-driven economic development over the past decade (see Fig. 1.3) (EIU, 2007). The increase in TFP contributed about one percentage point to aggregate growth of the country between 1977 and 2004 (World Bank and NESDB, 2008). However, after enjoying the world highest growth rate from 1985 to 1996 - averaging 9.4% GDP annually - these increased pressure on Thailand's currency, **the Baht**. In 1997, the economy contracting by 1.9% led to a crisis that uncovered financial sector weaknesses and forced the government to float the currency. The Baht was pegged at 25 to the US$ from 1978 to 1997, however it reached its lowest point of 56 to the US$ in January 1998 and the economy compressed by 10.8% that year. This collapse prompted **the Asian Financial Crisis** in 1997 (Tambunlertchai, 2009).

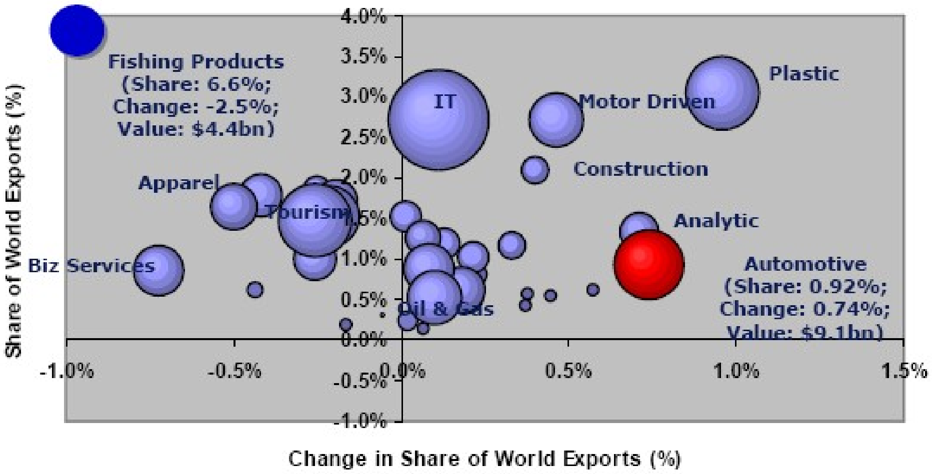

Fig. 1.3: Thai export performance (1997-2005)
Source: Woon et al. (2007)

Strongly starting from scratch, the Thai economy expanded to 4.2% in 1999 and 4.4% in 2000, largely owing to vigorous exports. Growth (2.2%) was dampened by the softening of the global economy in 2001, but picked up in the subsequent years as the forceful growth of Asia, the relatively weak Baht encouraging exports, and the increase of domestic spending thanks to several mega projects and incentives by the state. During this time, the Baht stabilized again at a rate of about 40 Bath equaling to US$ 1. Growth in 2002, 2003, and 2004 was 5 to 7% annually. Growth in 2005, 2006, and 2007 hovered around 4 to 5% due to both the weakening of the US$ and an increasingly strong Thai currency, which has continually strengthened from 40 to 33 Bath/ US$ 1 mark since 2001. Ambitions of Thailand to become a financial center have been hurt by the imposition of capital controls, the political turmoil, and the halting privatization of state-owned companies. A capital market plan adopted early in 2006 set a target to double the size of the domestic bond market by 2010. This plan also called for more privatization to broaden the equity market. However, privatization has been on hold since a late-2005 decision by the supreme administrative court that a share offering by **E**lectricity **G**enerating **A**uthority of **T**hailand (EGAT), the state power generating company, may violate the constitution, and no privatization is expected until present (ADB Bank, 2007).

Net **F**oreign **D**irect **I**nvestment (FDI) in Thailand has been significant since the early 1990s. The average annual FDI jumped from 13 billion Baht annually during the 1980s to 83 billion Baht in the 1990s. The most important sources of net capital inflows, in order of size, were Japan, USA, Hong Kong, and Taiwan respectively. Other important sources include the **E**uropean **U**nion (EU) and Singapore, while in these past few years FDI from South Korea and China have also been increasing in both value and importance (Tambunlertchai, 2009; Manprasert, 2004). Thai FDI have been most vital in manufacturing, trade, and services. However, the country has not been as successful in attracting FDI since the Crisis, particularly private investments. Inward FDI as a ratio of GDP has fallen below 3% since 2001, while private investment growth has fallen from a high of 18% in 2004 to about 6% in 2006 despite capacity utilization recovering to their pre-Crisis levels(see Fig. 1.4) (Manprasert, 2004; Woon et al., 2007). Additionally, the growth of FDI in the post-crisis period was characterized by a dramatic increase in mergers and acquisitions as foreign firms took over Thai companies that faced severe debt and liquidity problems (Brimble, 2002). To attract and facilitate foreign investors while ensuring their confidence in its economic and political situation, the **B**oard **O**f **I**nvestment (BOI) of Thailand was found in 1959 to overlook investment promotion programs under the law of the country (Tambunlertchai, 2009).

Thai economy is heavily export-dependent, with exports sharing more than two thirds of the GDP (Diao et al., 2006). Thai economic performances in terms of production and export transformation are tending toward the average path of increasing share of manufactured products. However, the major problems that Thailand is still facing are agonies from the emerging competition in the manufacturing sector from China besides rise in global oil prices. The appreciation of the Baht to the US$ relative to other regional currencies during the 2006 to 2007 period has dampened Thai exports. Furthermore, the financial sector is still not completely recovered from the Crisis. Recently, economic growth of Thailand has been slowing down because of weak private consumption and investment demand, following the September 2006 coup and subsequent political uncertainty and chaos. Bank Thai believes that 2009 will be another challenging year for Thailand. Although the political tension has gradually eased, the external environment will remain hostile to Thai economy. The global economic recession is likely to continue to depress Thai exports, may decline about 20 to 25%, throughout 2009. Despite the jumpstart by the state, Bank Thai still believes that the performance of Thai economy will be rather reserved. However, the National Economic and Social Development Board (NESDB)[6] of Thailand forecast that Thai economy will slightly contract by about 2% in line with economies in the region and global economic conditions (BankThai, 2008).

To sustain growth, Thailand needs to improve its productivity and make a transition from a Factor/Investment-driven phase of growth into an Innovation-driven phase one, by addressing its skills, regulatory, and infrastructure bottlenecks (Woon et al., 2007; Menkhoff and Suwanaporn, 2007). There is a need to increase the value-add and productivity of the Thai economy. Rather than compete on factor cost with its neighbors, Thailand can leverage on its neighborhood by positioning itself as the hub for common clusters in the GMS. However, Thailand does not seem to be making significant gains in its national competitiveness. Its competitive position seems to have stagnated and slightly slipped over the past 5 years (Woon et al., 2007). Thailand spending on Research and Development (R&D) hovers around 0.26% of the GDP, but the share of R&D spending by private firms is trivially small. In addition, the number of personnel engaged in R&D is low and few Thai companies file for patents. Amazingly, FDI by multinational corporations (MNCs) has transferred only little tacit knowledge and technology through vertical or horizontal spillovers (World Bank and NSDB, 2008).

1.2 Situation of Energy Utilization

As a result of its splendid development, Thailand is one of the fastest growing energy-intensive economies in Southeast Asia. The country has also recorded strong growth in energy consumption (Shrestha et al., 2007). Because of very limited reserves of **commercial fuels** (depleted fuels and trading fuel in the market for a monetary price such as coal, gas, and electricity), Thailand is heavily dependent on imported fuels to fulfill its energy requirements. During the 1970s, about 90% of Thailand’s primary commercial energy consumption[7] was imported, mostly petroleum products. However, the discovery of natural gas in the Gulf of Thailand (see Ch. 1.2.1) and lignite in the North (see Ch. 1.2.4) has gradually reduced the

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[6] The NESDB has developed five year National Socio-economic Development plans since 1961. This organization is legally responsible for assessing and approving annual investment plans of the state enterprises, as well as approving new large projects. Currently, the latest version is the 11th Plan for the year 2012-2016 (Webster and Patharaporn, 2004).

[7] Primary energy consumption refers to the direct use at the source or supply to users without modification of crude energy, that is, energy that has not been subjected to any conversion or transformation process.

reliance on imported energy. Simultaneously continuous unearthing of both oil and gas in Thailand, the domestic demand for primary commercial energy, however, has also been growing at an annual compound growth rate of 7.6% during the period 1985 to 2007, resulting in import dependence remaining at about 60%.

The growth of Thai energy consumption was considerably hit by the Financial Crisis in 1997 (see Ch. 1.1.4). The sluggish economic growth has also impacted strongly on the electricity consumption (Amranand, 2008). With an advent of its economic recovery, the energy consumption, however, has remarkably boosted again, reflected by the increasing growth rate of its GDP (see Fig. 1.4) (Mulugetta et al., 2007). The energy consumption growth climbed up from less than 4 to 7% in 2004, and maintained at an average of 4.5% per annum during 2004 to 2007. In 2007, total commercial primary energy consumption of Thailand was 80,019 TBOD[8], while peak generation of the electric power system was recorded at 22,586 MW. Fossil fuels accounted for approximately 80% of the total primary energy consumption and above 90% of total electricity production. It was estimated that around 74% of total primary energy imported was crude oil, nevertheless the demand increased for all energy types, especially for natural gas and coal/lignite. Hereinbefore, energy consumption of Thailand still depends on huge oil import bills, thus the continuous oil price hike and volatility inevitably leads to national account imbalances.

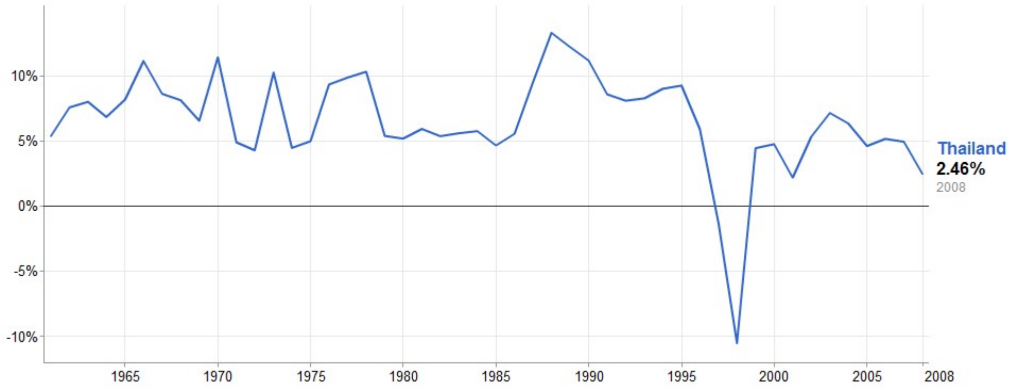

Fig. 1.4: Thailand GDP annual growth
Note: 1997 is the Financial Crisis
Source: World Development Indicators and Bank of Thailand

The shares of commercial energy demand were the following: 46% petroleum products, 37% natural gas, 14% coal/lignite, and 3% imported electricity. Due to the soaring oil prices during the past 5 years, the crude oil demand of Thailand is slightly decreasing from 67% to 63%, but expenditure on crude oil import pushed the net energy import to US$19.5 billion in 2007, equivalent to 7.9% of its GDP (EPPO, 2008). Commercial energy demand of the country in 2008 totalled 1,283 TBOD, an increase of 6.6% from the demand in 2007 (EPPO, 2009).

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[8] TBOD = **T**housand **B**arrels per day of **C**rude **O**il **E**quivalent. The BOE is a unit of energy based on the approximate energy released by burning one barrel (42 US gallons or 158.9873 liters) of crude oil. The US Internal Revenue Service defines it as equal to 5.8 × 10^6 BTU.
<see also http://en.wikipedia.org/wiki/Barrel_of_oil_equivalent>

For **final energy consumption**[9] by economic segments, **the industrial sector** (manufacturing, mining, and construction) was the largest end-user, accounting for 37.1% in 2008, closely followed by **the transportation sector** (primarily for passenger travel and freight movements) at 36.7%. **The residential**[10], **commercial**[11] and **agricultural**[12] **sector** showed generally 14.1%, 6.5%, and 5.7% respectively. The transportation and agricultural sector relied heavily upon the petroleum products, almost 100% of its final energy consumption. From statistical data in 2008, the transportation sector devoured 68% of all petroleum products due to its diesel and gasoline usage, while the agricultural sector consumed about 10% of total petroleum products in the same year. Final energy consumption in the industrial sector was divided among all types of fuel, i.e. coal (25%), petroleum products (24%), renewable energy (23%), electricity (19%), and natural gas (9%). Final energy consumption in the commercial sector was majorly contributed by electricity, 80%, and the rest by petroleum products (diesel and fuel oil). Consumption in the residential sector was divided among three types of fuel, i.e. renewable energy (60%), electricity (27%), and petroleum products (13%) (EPPO, 2009).

In term of electricity consumption in 2008, the industrial sector was the largest end-user for electricity. The **D**epartment of Alternative **E**nergy **D**evelopment and **E**fficiency (DEDE) of Thailand estimated that 44.1% of total annual electrical generation was utilized by the industrial sector, the commercial sector ranked second at 32.4%, followed by the residential sector at 23.3%. However, electricity consumption by the agricultural and transportation sector had a tiny share, only 0.3%, of the total consumption (EPPO, 2009).

1.2.1 Natural Gas

In Thailand, the potential of natural gas production is quite substantial. A large amount of the gas reserves are off-shore in the Gulf of Thailand. As of December 2006, the total volume of natural gas reserves was estimated at 635.23 billion m^3 (22,433 billion ft^3) and proven reserves were evaluated at 377.775 billion m^3 (13,341 billion ft^3). In 2007, the total natural gas production was 26.9 billion m^3 (950 billion ft^3). The largest production field in the Gulf of Thailand, ***Bongkot*** yielded 28% of the total domestic production. To assure a long term supply of this energy type, the country, however, started its gas import from Myanmar in 2000. Natural gas was imported from ***Yadana*** and ***Yetakun*** fields in 2007 at the level of 4.3 billion m^3 (152 billion ft^3) and 2.04 billion m^3 (72 billion ft^3) respectively. Yadana field is located in the Andaman Sea, approximately 60 km offshore the nearest landfall in Myanmar. Yetakun field is situated in the Andaman Sea, at southeast of the Yadana field (see Fig. 1.5) (EPPO, 2008).

Natural gas has become the preferred fuel for electricity generation worldwide, including Thailand, because of its environmental appeal, lower capital cost, shorter gestation period, higher efficiency, and the modular technology (IEA, 1995) that challenges 'the bigger the beautiful' notion of the past. In Thailand, natural gas has become a dominant fuel source for power generation since 2001 (see also Ch. 1.3). The consumption of natural gas in this

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[9] Final energy consumption is referred to the use of energy which is received and consumed after conversions into other forms of energy such as electricity.

[10] Residential sector is pointed to occupied or unoccupied, owned or rented, single-family or multifamily, housing units and mobile homes, excluding institutional housing such as hostels or school dormitories, hospitals, night shelters, and military barracks.

[11] Commercial sector comprises of service-providing facilities and equipment of businesses.

[12] Agricultural sector consists of agriculture, forestry, hunting, and fishing.

sector was 70% in 2007. The amount of natural gas available for power generation was provided by the **P**etroleum **A**uthority of **T**hailand (PTT). Generally, the unrefined natural gas is transferred to a gas separation plant. The first portion (80%) of separated natural gas, containing methane, is exploited as fuel for power generation, in the manufacturing sector, and by vehicles. The next portion containing ethane and propane is applied as feedstock for the petrochemical industry, whereas the last portion containing propane and butane is burned as cooking gas and as fuel in industrial factories and by vehicles. However, the reserve to production ratio for indigenous natural gas was estimated that Thai natural gas will adequate for only 21 years (EPPO, 2008; BP, 2005). In addition, the Thai government has announced the target of compressed natural gas (CNG) utilization in the transport sector for the decrease of imported petroleum oil dependency. Promotion CNG for natural gas vehicles (NGV) in the transport sector to achieve the energy elasticity target will boost this reserved indigenous natural gas (Tia et al., 2006).

1.2.2 Petroleum Condensate

An associated product in gas-bearing basins, ***petroleum condensate*** is a low-density mixture of hydrocarbon liquids that are present as gaseous components in the raw natural gas. It condenses out of the raw gas, if the temperature is reduced to below the hydrocarbon dew point temperature of the raw gas[13]. The amount of petroleum condensate is increasingly in proportion according to the production of natural gas. In 2007, the reserve of condensate was estimated at 76,525 M l (481.33 M barrels), with proven reserves of 41,085.49 M l (258.42 M barrels). The production of condensate was 8,442.225 M l (53.1 M barrels), mostly utilized by domestic refineries, while the forecast of condensate production will reach 10,079.79 M l (63.4 M barrels) in 2007 (EPPO, 2008).

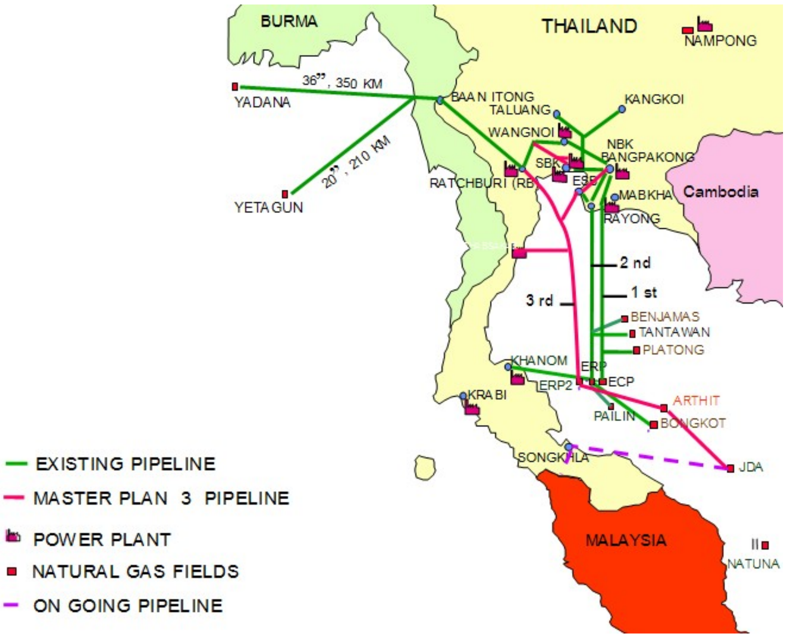

Fig. 1.5: Natural gas pipeline in Thailand
Source: EPPO (2009)

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[13] See also http://en.wikipedia.org/wiki/Natural_gas_condensate

1.2.3 Crude Oil

Crude oil reserve of Thailand was estimated at 75,693.85 M l (476.1 M barrels), of which 51,654.97 M l (324.9 M barrels) was proven reserve. In 2002, the overall crude oil production was 12,019.44 thousand l/d (75.6 thousand barrels/d), of which 35.1 and 20.6 TBOD obtained from the ***Benjamas***[14] and ***Sirikit***[15] Oil Fields, accounting for 74% of the total local crude oil production. The domestic productivity of crude oil was still exactly low, when compared with the domestic demand. Therefore, imported crude oil is inevitably at a high rate of 90%. In 2007 the total imported crude oil was 107,634.4 thousand l/d (677 thousand barrels/d). The total domestic refining capacity in 2001 was 158,112.9 thousand l/d (994.5 thousand barrels/d), increasing from 134,264.8 thousand l/d (844.5 thousand barrels/d) in 2006, due to the increase of **T**hai **P**etrochemical **I**ndustry (TPI)'s refining capacity (EPPO, 2008).

1.2.4 Coal

Domestically produced coal of Thailand is low-rank coal, mainly lignite and sub-bituminous both having lower heating value but high sulphur content. In 2007, the total reserve was about 2,155 M t. The main reserve locate in the North and the ***Mae Moh*** basin is the biggest coal reserve with 52.16% of all reserves, following by *Wiang Haeng*, *Ngao* and *Mae Tha*, with a measured reserve of 93, 48, and 25 M t respectively. Lignite found in the Mae Moh basin, however, consists of high sulphur (about 2.4%). In the South, the *Krabi* basin has a measured reserve of 112 M t, the *Saba Yoi* basin in Songkhla Province, with a measured reserve of 350 M t, and the *Sin Pun* basin, with a measured reserve of 91 M t (EPPO, 2008).

In 2007, lignite production was 19.6 M t, 76% of which came from the Mae Moh Mine in order to utilize in power generation by EGAT, the state power generator. Produced by private mines, the remaining at 24% was used by the industrial sector, increased at an average rate of 22.2%, including cement (70% of remaining), pulp & paper, food processing, and tobacco-curing industries (EPPO, 2008).

1.3 Power Development Plan in Thailand

It is generally known that electricity is one of the vital infrastructures to heighten the competitiveness of the country at the global level (IEA, 2002; NRC, 1986). With the fact that power demand is always increasingly, the addition of the number of power plants, electrical transmission lines, and high-voltage stations should be projected to meet the rising demand in line with the national development plan. In Thailand, The power consumption, supplied by both local generation and neighboring countries purchasing, has increased steadily at an average rate of 5.9% per year. Thai electricity production predominantly reckons on thermal and combined cycle generation. Based on the most recent statistical information (2008), 74% of Thai power comes from gas-based technology and natural gas accounted for about 70% of the total electricity generation. The remaining was made up of 17% lignite/coal-fired power plants, 9% large-scale hydropower, 3% fuel oil, and only about 1% from renewable energy. Just about 80% of natural gas was produced from Thai Gulf and the rest 20% was imported from Myanmar.

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[14] Benjamas Oil Field is offshore in the Gulf of Thailand.
[15] Sirikit Oil Field is in Kamphaeng Phet Province, in the North.

High dependence on natural gas in power generation raises concerns about security of electricity supply. The country therefore could encounter problems similar to those faced by the United Kingdom. Nakawiro (2007) stated that for every 10% change in natural gas price, electricity tariff in Thailand would change by 3.5%. In addition, gas dependence in power generation is almost similar to that of crude oil import dependence. To reduce the vulnerability of the country from power generation, what state has to do is either decrease gas dependence or increase the efficiency of gas-fired power plants. For the first choice, lignite can not be increasingly employed for power generation due to social sanction of pollution problems with lignite-fired power plant in the past, although it is both indigenous and abundant natural resource in the North of Thailand (see Ch. 1.2.4). Meanwhile, **coal**, higher quality than lignite, must be absolutely imported from neighboring countries. As a part of EGAT's implementation plan of the 4 modern units of coal-fired power plants (main fuel is imported coal) to be in operation by 2015 to 2017, EGAT is now engaging with the potential coal producers in Indonesia, Vietnam, and Australia for the supply of high quality coal throughout the power plant's period of operation (EGAT, 2008).

In the case of **hydropower** for power generation, it has been developed steadily since 1964. The potential of hydropower in Thailand is estimated at about 15,155 MW, however the usage of these resources are difficult as a result of ever increasing constraints with regards finding suitable areas as well as the environmental impacts on the surrounding areas. For those reasons, future development of hydropower resources will be limited to a few small-scale projects, considered most economical and environmentally friendly to ensure that new development will protect the environment, contribute to reducing poverty, and enhance the living standards of project affected people. As of December 2007, EGAT produced 7,366.9 GWh of hydropower, which accounted for 6.6% of the total EGAT's power generation by fuel type. As part of the rural electrification program, having already brought electricity to 99% of villages in Thailand, **small hydropower** (installed capacity less than 100 kW) sites have been identified as economically appropriate for more accurate cost estimates and detailed engineering work. It should be noted, moreover, that a thorough feasibility study of a small hydropower project tends to show that the cost of electricity generated from a suitable hydropower site can be more economical than that from a set of photovoltaic plants (Chamamahattana et al., 2004; EGAT, 2008).

The participations of private power generation were also promoted under the policy framework of the Ministry of Energy, in terms of power supply reliability, state investment decline, and feed in tariff competition. Selling the generated power to EGAT, the **I**ndependent **P**ower **P**roducers (IPPs) were the prominent power producers in private sector with installed capacity larger than 90 MW each. The fuel used in the IPPs could be natural gas, coal, or heavy oil. Electricity is sold to Thailand's distribution utilities **P**rovincial **E**lectricity **A**uthority (PEA) or **M**etropolitan **E**lectricity **A**uthority (MEA). In contrast to IPPs, the **S**mall **P**ower **P**roducers (SPPs), generating capacity of each contract within the range of 10 to 90 MW, partaken in the electricity supply industry not only to use renewable energy as energy resource, but to generate power by cogeneration as well. SPPs generators were divided into '***firm***' and '***non-firm***' based on their ability to guarantee availability. Firm projects received both a capacity payment and an energy payment indexed to natural gas prices, while non-firm generators received only the energy payment. These tariffs were based on the long-run avoided capacity and energy cost for electricity generated by EGAT. As of September 2006, firm SPP generators received 0.054 Euro/kWh (2.56 Baht/kWh) and non-firm generators received, on average, 0.044 Euro/kWh (2.10 Baht/kWh) (Mulugetta et al., 2007; Greacen, 2007).

Under the SPP procedure, 78 generators are currently trading power to the grid, with installed capacity of 4,145 MW (see Appendix A). The generators are under contract to sell 2,333 MW to the grid (the disparity is used for self-consumption). Of this, 989 MW of installed capacity (430 MW sold to grid) are renewable energy. The remains are fossil fuel fired, mostly natural gas (2,277 MW) and coal (392 MW). Additionally, the **V**ery **S**mall **P**ower **P**roducer (VSPP) regulations were drawn up to provide streamlined interconnection arrangements for power generation from fossil fuel by **C**ombined **H**eat and **P**ower (CHP) generator or smaller renewable energy. Approved by Thai Cabinet in May 2002, the original VSPP regulations were modelled on net metering laws in the USA and other countries. The regulations allow customers with renewable energy generators (solar, wind, micro-hydro, biomass, biogas, etc.) up to 1 MW power export to connect their generators to the grid and offset their consumption at retail rates. (**Note** that if the customer's load is significant, this means that their renewable energy generator could actually be larger than 1 MW as long as the net maximum outflow to the grid remained 1 MW or less.) (Greacen, 2007)

In December 2006, the Thai government launched an important upgrade to the VSPP regulations. The upgrade has several important features. Firstly, eligibility was expanded to clean fossil-fuel-fired CHP generator in which waste-heat utilization leads to an overall **P**rimary **E**nergy **S**avings (PES[16]) of greater than 10%. Compared with the SPP procedure, the requirements regarding use of waste heat are more stringent similar to those used in CHP procedure of Germany. The second feature of the new regulations is that the net export threshold is expanded tenfold to 10 MW. This opens up significant opportunities for generators that would not have been cost-competitive at the 1 MW level. Accompanying the expansion is a requirement that generators must meet Thai air quality standards; for example, a 10 MW biomass plant using an inefficient boiler could have a significant local environmental impact. The third key commitment launched is that state will provide a subsidy addition for electricity from renewable power plants. With attractive feed-in tariffs that will be paid for the first seven years after each generator's commissioning date, Renewable energy fuels receive subsidy adder of 0.006 to 0.16 Euro (0.3 to 8 Baht) per kWh (table 1.4) from previously paid to VSPP generators depending on the fuel type.

Table 1.4: "Adder" to the Normal Tariff for SPPs and VSPPs in Thailand

Fuel/Technology	**Adder (Baht/kWh)**	**Number of Years**
Biomass	0.30	7
Biogas	0.30	7
Mini-hydro **(50-200 kW)**	0.40	7
Micro-hydro (< 50 kW)	0.80	7
Municipal Wastes	2.5	7
Wind	3.5	10
Solar	8.0	10

Exchange Rate: 50 Bath/Euro
Source: Amranand (2008)

To boost the utilization of renewable energy in power generation section, the Government of Thailand aims to set up Renewable Portfolio Standard (RPS), a regulatory policy which forces EGAT to develop renewable energy sources not less than 5% of EGAT's new generating capacity during 2008 to 2010. The total capacity of EGAT's renewable energy plants required by the RPS is 140.7 MW, while the share target of renewable power generation has been proposed at 6% of the total generating capacity in 2021. The first lot of renewable energy source projects of EGAT with the total capacity of 81.7 MW was proposed by the Committee on Energy Policy Administration (CEPA) in November 2006, and was then

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[16] PES refers to the energy savings from CHP compared with a reference case in which an equivalent amount of electricity and heat are produced by conventional means (conventional non-CHP power plant and boiler).

approved by the NEPC* in December 2006. The NEPC also waived EGAT's obligation to construct the remaining 59 MW of renewable energy plants and substituted by the commitment to purchase current from renewable energy plants developed by private power producers under SPPs and VSPPs solicitation. This new policy was adopted for the construction of new generating units to be commissioned from 2011 onwards. The approved EGAT renewable energy projects comprised of:

Small Hydropower Plants	78.7	MW
Solar Energy Power Plant	1.0	MW
Wind Energy Power Plants	2.0	MW
	81.7	MW

Nevertheless, about 56% of total electricity generation was still generated by the EGAT. The residual was made up of 36% IPPs, 7% SPPs, and roughly 1% imported from neighboring countries: Laos, Myanmar, and Malaysia. As provide information of November 2007, the total installed capacity was 28,530.3 MW, comprising 15,793.6 MW (55.4%) from EGAT's power plants, 12,097 MW (42.4%) from private power producers (IPPs and SPPs) and 640 MW (2.2%) from foreign power purchase.

According to ***Thailand power development plan 2007-2021 (PDP 2007 revision 1)***, approved by the **N**ational **E**nergy **P**olicy **C**ouncil (NEPC*) and endorsed by the cabinet in June 2007, the next power plants to be commissioned during this period are now under construction. The generation expansion plan consists of the development of EGAT's new power plants, the power purchase from IPPs, SPPs, and neighboring countries as well as the generation from renewable energy. The whole capacity of the new generating units categorized by power producers are:

EGAT power plant projects	3,227.70	MW
IPPs power plant projects	3,541.25	MW
SPPs power plant projects	329.80	MW
Power purchased from neighboring countries	920.00	MW

The total additional generation capacity during the period of 2007 to 2021 netted the retirement of aging power plants is 29,669.3 MW. The total installed capacity will increase from 28,530.3 MW in 2007 to 58,199.6 MW by the end of this plan in 2021. Based on the PDP 2007: Revision 1, the new power plants to be in operation during the planning horizon of 2011 to 2021; consisting of:

Combined Cycle Power Plants (Natural Gas-Fired)	8,800	MW
Coal-Fired Power Plants	4,000	MW
Nuclear Power Plants	4,000	MW
SPP (Co-generation and Renewable Energy)	1,700	MW

Although SPP procedure led to a significant increase in renewable energy capacity, the production of electricity is still highly depended on the fossil fuel. As said by the PDP 2007 Revision 1, the share of natural gas in electricity generation will remain around 70 % through the year 2012. The generation from lignite will remain relatively unchanged for the next 8 years and slightly decreases slowly through the year 2021. The imported coal share will increase gradually, from 8.4% in 2007 to 16.8% in 2017. Net imports of energy from neighboring countries are expected to continue to meet a major share of total electricity demand.

1.4 Renewable/Alternative Energy Resources

As a result of the continuous raises of fossil fuel prices and global concerns on greenhouse gas emissions from utilizations of fossil fuels, more endeavors have been made to explore and develop other potential energy sources to accommodate the augmentation of energy demand. Renewable and **alternative energy** both are considered potential options, which will diminish not only the country's dependency on imported energy but also risks of the volatility of imported fuel prices. These give renewable resources a great chance of being competed with fossil fuels. Inexhaustible, **renewable energy** is mostly derived from natural resources and hence considered clean and environmentally friendly, however there still exist several hindrances for the development of renewable energy. Mainly, the cost of harnessing renewable energy resources (particularly solar and wind energy) is hither to high when compare to that of commercial energy.

In Thailand, renewable energy that has high potential to be used in place of fossil energy includes hydropower, biogas as well as biomass energy, wind energy, solar energy, and geothermal energy. Since Thailand is one of biomass rich countries, varieties of crops are abundant and largely produced particularly from, agricultural, agro industrial, and commercial as well as residential sectors (more details in Ch. 2). Renewable energy, especially biomass, is therefore responsible as a target of the national strategic energy plan to increase the utilization from 0.5% of the total final energy consumption in 2002 to 8%, which is equivalent to 6.5 MTOE by 2011 . Strives of research on these energy sources have also incessantly been undertaken to meet the state’s target by several agencies, both at the local level initiated by local intellect and at the national level. These studies will help the country to achieve the sustainable energy and environment development that provides benefit to Thailand as a whole.

1.4.1 Biomass

As main renewable energy recourse in Thailand, biomass is a kind of fuel derived from organic substances such as agricultural residues like woodchips, bagasse, paddy husks, or wastes from agricultural processing as well as wastewater from factories, including animal manure from livestock farms. The waste biomass streams can be considered as an environmental problem or an energy resource. Each of these biomasses has unique characteristics which influence how it is suitably used and which technology it requires for utilization as fuel. Normally exploited as fuel mainly in residential sector (especially in rural areas) and in small industrial factories, biomass can be burned directly to release its stored chemical energy ,or be converted to other energy forms such as liquid biofuel (more details in Ch. 3).

Agricultural goods are still the important export products of Thailand, and they are the gold mines of the country. However, in processing these agricultural goods, a large amount of residues, generally used as fuel in the industrial plants, are also created. For instance, paddy husks are burned to generate steam for driving turbine in rice mills; biogases and palm residues are used to turn out both steam and electricity for on-site manufacturing process; and rubber wood chips are utilized to produce hot air for rubber wood seasoning. Prasertsan (2005) stated that the amount of agricultural residues is about 61 M t/y, of which 41 M t (equivalent to about 426 PJ) was unused. Thanks to a vast agricultural crop that distributes across Thailand (see Ch. 2.2), a lot of projects in the energy section have become more interesting with biomass being utilized as an energy resource. Apart from the utilization of biomass residues and sewage containing organic matters for energy production, several efforts have been done in recent years on either new biofuel raw materials strike or how to convert biomass to bio-liquid fuels more efficiently, subsequently to alleviate the dependency on oil imports. However, data compilation on the entire utilization of all biomass sources is still not comprehensive.

1.4.2 Ethanol

The use of agricultural products for ethanol production - such as sugar cane, cassava, and molasses - has been given particular attention, since ethanol - 99.5% pure alcohol by volume - can substitute the use of **M**ethyl **T**ertiary **B**utyl **E**ther (MTBE), a gasoline additive used as an oxygenate in order to raise the octane number for preventing engine knocking. MTBE is a volatile, flammable, and colorless liquid which is immiscible, but reasonably soluble in water. When gasoline with MTBE is spilled or leaked from Underground Storage Tank at gas stations, it has been found to easily pollute enormous quantities of groundwater. Moreover, it is difficult to clean up from groundwater due to its high solubility in water and its sluggish degradation. Inasmuch as its contamination in drinking water aquifers - an underground layer of water-bearing permeable rock - is a serious concern in many countries, its application has been banned in many parts of the world in response to environmental and health concerns.

To supplant MTBP in Thailand, which must be fully imported at about 0.04 billion Euro (2 billion Baht) each year, ethanol is initially blended with regular gasoline at ratio 1:9 by weight to generate ***gasohol*** called **E10** (Thepent, 2009). Therefore, the employ of domestically produced ethanol can contribute to foreign currency saving as well as mitigation of pollution problems resulting from both underground water contamination and fossil fuel combustion. Really not the first time, efforts to use ethanol as an alternative fuel actually commenced in 1977, but the cost of ethanol production was much higher than that of oil prices. Commercial production at that time was, therefore, not materialized. Nonetheless, given the continually increasing oil prices at present, ethanol is considered a viable alternative fuel for the transportation sector again.

In December 2003, the cabinet resolution approved the strategy to promote ethanol as a gasoline additive. A target was set to increase the use of ethanol to 1 M l/d by the year 2006 and 3 M l/d by the year 2011, respectively (Thepent, 2009). Thai cabinet also ratified the establishment of a Joint Working Group, comprising the Ministry of Energy, the Ministry of Industry, and the Ministry of Agriculture & Cooperatives, to determine measures promoting the establishment of ethanol production plants and to develop the management plan for raw materials, including the implementation approach to effectively achieve the target. The NEPC resolution of 4 September 2006 affirmed the liberalization of the establishment of fuel ethanol production plants and fuel ethanol distribution both so as to achieve the target set by the Ministry of Energy. As of April 2008, 11 ethanol plants have a production capacity of 1.57 M l/d. Ethanol demand is predicted to exceed 3 M l/d by 2011, which is nearly double the current supply (BOI, 2008).

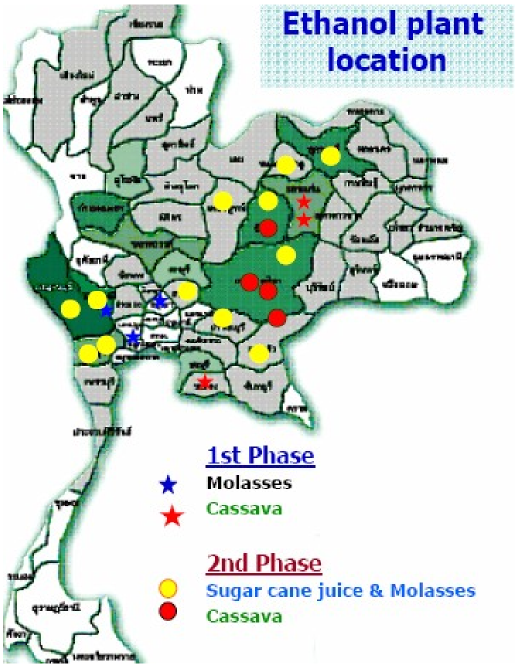

Fig. 1.6: locations of Ethanol plant in Thailand
Source: BOI (2008)

1.4.3 Gasohol

An admixture between ethanol and standard gasoline called ***gasohol*** was introduced to Thailand over a decade (see also Ch. 3.3.2). At the beginning, ethanol was only assigned to replace MTBP and gasohol was simply available at some gas stations in Bangkok & its suburbs/circumference. Under the policy framework of the Ministry of Energy, it tried to set up E10 for all districts of Thailand to complete substitute MTBP in 2008. With heavy promotion by the government, E10 sale initially rose rapidly to reach 17.4% of premium gasoline sale in December 2005, but started to stagnate from the beginning of 2006 onwards while the promotion of ethanol production rooted a surplus of ethanol supply to develop. The slow down in sale of E10 was due to consumer perception that E10 caused underperformance in vehicles, insufficiently clear information regarding types of vehicles capable of using E10, the price differential being too small as the net benefit was only 3% if lower heating value of gasohol was taken into account, and the relatively high price of ethanol charged by ethanol manufacturers.

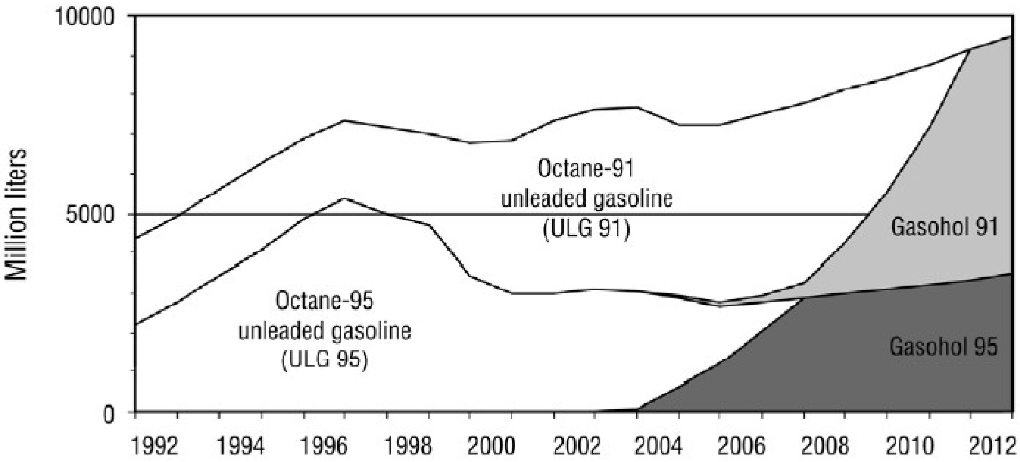

Fig. 1.7: Projection of Gasoline and Gasohol consumption following the Thai Gasohol Plan
Source: EPPO (2004)

The government immediately implemented a number of policy changes from the end of 2006. ***The first*** and most important was the pricing policy whereby the oil fund levy for normal gasoline was gradually increased to a level substantially higher than that of gasohol (which also helped to speed up debt payment of the fund), and a benchmark price was established for the ex-factory price of ethanol based on CIF price of Brazilian ethanol price. The latter immediately lowered the ex-factory price of ethanol by about 20%. The lower ex-factory price together with the lower level of oil fund contribution for E10 effectively increased the differential between the normal gasoline and E10 prices from 0.03 Euro (1.50 Baht) per liter to 0.08 Euro (4.00 Baht) per liter in November 2007. ***The second*** measure undertaken was to indefinitely postpone the previous government's policy to end the sale of premium gasoline by the end of 2006 as there were still many carburetor cars which required normal premium gasoline. As a result, if the distribution of gasoline is abrogated, around 0.5 M of such old-modeled cars that are still in use would be adversely affected. However, an intensive education campaign was launched to provide information and assurance for motorists. Oil companies were asked to provide guarantees; and auto companies were asked to grant assurance and warranty for customers, and narrow down the list of cars and motorcycles which are not capable of using gasohol (Amranand, 2008).

The government also provided additional price incentive for the refineries, and sought cooperation from oil companies to market E10 regular gasoline as regular gasoline accounted for over 60% of gasoline sale. A higher marketing margin was allowed for gasohol to encourage service stations to sell gasohol rather than the normal unleaded gasoline. Later in 2007 the government also announced a reduction in excise tax for new cars capable of using E20 (a blend of 20% ethanol and 80% gasoline) for new ones produced from January 2008. At the same time additional pricing incentive was provided for E20 and cooperation from oil companies were sought for the sale of E20 from January 2008 onwards. Discussion between the government, ethanol producers, oil companies, and automobile manufactures started the future plan to introduce E85 as Thailand should have enough agricultural raw materials for all gasoline vehicles to eventually run on E85, but a sufficient amount of time is required for the automobile and oil industries to adjust (Amranand, 2008).

Besides, potential **S**mall and **M**edium **E**nterprise (SME) practitioners and farmer organizations or entities are encouraged to establish ethanol producing plants so that production of ethanol from agricultural products could be distributed across the country. Such measures as provision of financial assistance, in the form of concessional loan or soft loan, and provision of technical assistance from the government agencies will also be introduced for this purpose.

1.4.4 Biodiesel or Ester

The statistic during 2003 to 2007 shows that 65% of petroleum consumption in Thailand was diesel, which implicated to expenditure on imported crude oil. Therefore, to calculate the money saving from reducing imported crude oil procurement for diesel production at around 20% (4.79 M l/day), the equivalent value of diesel within imported crude oil (without refinery cost) is around 1,343.56 M Euro (67,178 M Bath) per annum. Meanwhile, Thailand, with high capability in agricultural production or biomass, is able to provide the local substitute primary energy for diesel fuel, this amount of money will therefore circulate within the country. Produced popularly from vegetal oils via chemical process, blended with standard diesel in various percentages, and used in unmodified diesel engines immediately with comparable properties to those of diesel, ***biodiesel*** is now usually referring to esters modified from triglyceride of fatty acids. It can be produced from plant oils, animal fats, or waste oils by transesterification (alcoholysis), using alkaline or acid as a catalyst to transform fatty acids with alcohol into ester, called ***B100*** (see also Ch. 3.3.2).

There are several factors encouraging research on biodiesel. These include: 1) the key reason, problems of oil price hikes that impacts to Thailand economy since 2005; 2) continuous price drops of agricultural products during 2003 to 2007; 3) Increasing investment cost of agricultural products caused by rising in transportation and fertilizer costs, influenced by escalation of world crude oil price; and 4) the environmental impact resulting from diesel combustion. Currently, several institutes have undertaken studies and developments to determine the quality of blended diesel (a mixture between diesel and crude or refined veggie oil, without any chemical process) and biodiesel both, compared with the specified diesel standards. Several researches have been reported that blended oil has advantages over diesel in that it contains lower sulphur content and aids with engine lubrication; however, the quality of different bulks of blended oil still varies although it is sold at the same distribution station. Research is also being carried out on biodiesel production from crude coconut oil ("***cocodiesel***") and on the impact of cocodiesel utilization on the environment.

In Thailand, biodiesel has been on market since 2005. Despite the rapid increase in the production capacity of B100, particularly those using palm oil as feedstock, sale of B5 (a blend of 5% B100 and 95% diesel) remained very low during the period 2005 to 2006. In 2006 the sale of B5 amounted to 0.12 M l/d compared with total diesel retailing of 50 M l/d which was equivalent to only 6,000 M l/d of B100 consumption. This was due to unclear pricing policy, unclear standards & enforcement of B100 standards, and refusal by automobile companies to provide warranty for vehicles using B5. At the end of 2006, the government introduced a number of measures to boost the market of biodiesel. A benchmark was established for the ex-factory price of B100, based on the price of palm oil and methanol (the main raw materials for B100 production). This resulted in a 25% increase in the price of B100 which encouraged more investment in B100 production, but the oil fund had to be used to provide a subsidy to oil companies so that B5 could be sold at 0.014 Euro/l (0.70 Baht/l) lower than normal diesel. This subsidy is intended to be temporary and eventually it is hoped that the biodiesel industry would become competitive in the same way as the ethanol industry (Suksri et al., 2008; Amranand, 2008)

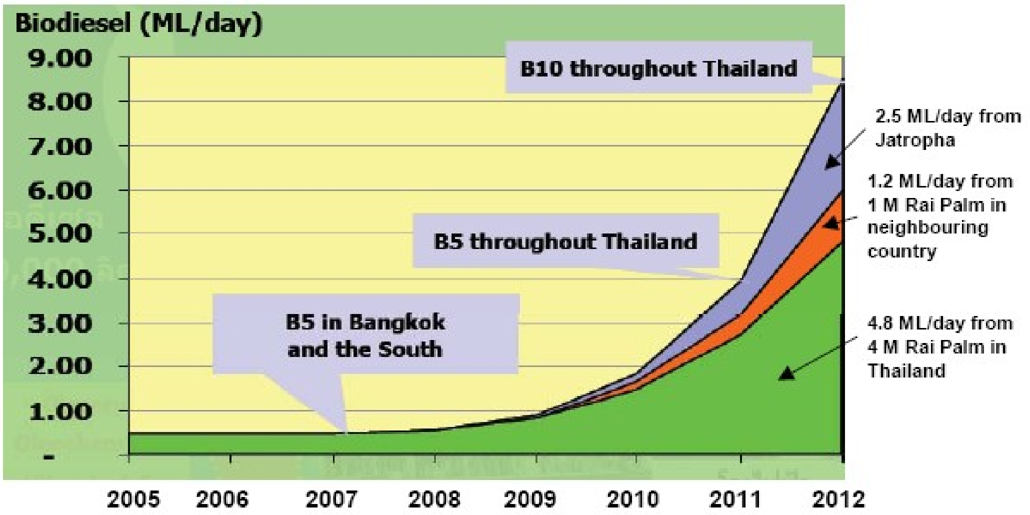

Fig. 1.8: Projection of Gasoline and Gasohol consumption following the Thai Gasohol Plan
Source: EPPO (2004)

In 2007, Thai government also issued a policy to require all diesel fuel to be B2 in 2008 allowing a period of about one year for all related parties to make adjustments. Clearer and stricter standards were issued for B100, B2, and B5, and they were actually enforced which provided sufficient assurance to automobile companies to provide warranty. The automobile manufactures eventually agreed that all diesel vehicles in Thailand could run on B5. Mandating B5 as the common grade for diesel requires 2.5 M l/d of B100, and there is clearly insufficient amount of raw palm oil and other feedstocks. The government, therefore, provided soft loans for the expansion of oil palm plantation and yields with preliminary target of mandating B5 by 2011.B2 became mandatory on 1 February 2008 with B5 being an alternative grade for motorists with a slightly lower retail price. Since diesel users are much more price sensitive than gasoline users, the sale of B5 rose from 0.12 M l/d in 2006 to 9.8 M l/d in July 2008. With B2 becoming compulsory in February 2008, total demand for B100 reaches 1.16 M l/d during the first 7 months of 2008. The only constraint to B5 is now the sufficiency of raw materials. With the gradual increase in production of palm oil expected in the next few years, the target for making B5 mandatory by 2011 should be accomplished (Gonsalves, 2006).

Recently, the Thai government has plans to increase boidiesel production to 8.5 M l/day by 2012. As of April 2008, 9 biodiesel plants with a total production capacity of 2.19 M l/day operate in Thailand. In 2009, it is expected that the number of biodiesel plants will more than double to 21 plants, with a total production capacity of 5.3 M l/day (BOI, 2008). Alike to the promotion and support to ethanol and gasohol, the excise tax and the contribution to the Oil Fund are exempted for the portion of biodiesel produced and mixed with diesel with the intention of expediting consumption of biodiesel. As a long-term measure, through use of the ENCON Fund, the government will continue supporting R&D to ameliorate biodiesel production efficiency as well as research on other oil plants to diversify supplies of production; the standards for engine adjustment to enable them to run on biodiesel will be established, from upstream to downstream.

1.4.5 Biogas

Comprised of 60 to 65% methane, 35 to 40% carbon dioxide, 0.5 to 1% hydrogen sulfide, and vapor, ***biogas*** can readily be produced from current waste streams which are allowed for naturally fermentation (see Ch. 3.2.3). Besides changeover of current sewage plants into biogas plants, the development has also been undertaken on power generation from landfill biogas. As outgrowth, the remains are suitable as fertilizer other than the original biomass, when a biogas plant has extracted all the methane it can. In Thailand, biogas fashions mainly from animal manure, especially that of pigs and cows, as fuel for power generation and farm cooking. When the ten industries that produced large wastewater volumes with high COD loading were studied based on 1997 data, it was found that potential of energy production from wastewater was 7,848 TJ. The first four high potential industries were starch, sugar, distillery, and monosodiumglutamate production, respectively (see also Ch. 2.2.4). In addition, about 3.2 M t of dry matter of animal wastes was estimated to be recoverable. This amount of wastes can be used to produce 620 M m^3 of biogas, which is equivalent to about 13,000 TJ or 308 KTOE of energy, in anaerobic digesters.

Several biogas projects in Thailand have chiefly been financed by the ***ENCON Fund***[17], such as the biogas from animal manure for power generation in ranchland, R&D on the feasibility of biogas from wastewater treatment systems, and the development of a biogas map which provides information on pig farms and diary farms nationwide in order to facilitate the planning of biogas utilization in the future. Additionally, EPPO[*] reported that during 1995 to 2004 the energy conservation fund has financed 15 biomass and 21 biogas projects. The total investments for the two energy sources were 42.5 M Euro (2,125 M Bath) and 26.4 M Euro (1,320 M Baht), respectively (EPPO, 2008).

1.4.6 Solar Energy

Referring to the utilization of the radiant energy from the sun, solar energy projects in Thailand have been upheld by the state. Using ***solar cells*** or ***photovoltaic*** (PV) cells, about 5 MW of PV power generation systems have been until now installed. Most of them are in remote areas beyond the grid systems where the transmission systems break even not, however the majority of solar energy utilization and its integrated systems with hydropower or wind energy are still only demo projects, financed by the state. Several government agencies under the Ministry of Energy have been undertaking development of the PV technology. For instances, the DEDE (2003a) has been demonstrating various installations of PV-pumping systems for either water supply or PV power generation system, in various rural villages or Border Patrol Police Schools located outside the grid system. EGAT has also developed several projects including power generation using the PV technology, PV power generation without use of batteries, and rooftop PV grid-connected systems. Development has further been undertaken on the integrated system for power generation of solar/wind energy at ***Phromthep Cape*** in Phuket Province, in the South, and of solar/hydro energy at ***Klong Chong Klum*** in Sakaew Province, in the Ease (Thepent, 2009).

Annual average photometry of Thailand is 18.2 MJ/m^2/d (maximum in April to May, ranging from 20-24 MJ/m^2/d), and energy capacity is 554,071 KTOE. Opportunities abound in all aspects of solar energy production and on many scales. The capacity in 2007 was 32 MW and is expected to reach 45 MW by 2011 (BOI, 2008). The country continues to make significant strides in solar generated electric facility. The ENCON fund allots grant for R&D on solar energy too. Examples of funded projects are: the development of solar radiation measuring station network; the demonstration project of electricity generation and distribution system using solar cells in Mae Hong Sorn Province in the North where most areas are mountainous with a scattered population; and the establishment of "Solar Energy Park" to serve as the center for demonstration and information dissemination on solar energy technology (Rakwichian and Thanarak, 2004). An independent organization under the Office of the Prime Minister, the **T**hailand **R**esearch **F**und (TRF), moreover, is another institute undertaking R&D and facilitating information on solar cells. In 2001, TRF approved a research project on how from paddy husk to produce silicon, which can be eventually utilized as domestic staple for solar cell production (Thepent, 2009).

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[17] Established under the Energy Conservation Promotion Act and monitored by the EPPO, the **E**nergy **C**onservation **P**romotion **F**und (ENCON Fund) provides financial support to government organizations and individuals both who wish to implement measures to increase efficiency in energy utilization. The fund also allocates grant for renewable energy projects.

1.4.7 Wind Energy

As the result of moderate to relatively low wind speed with usually lower than 4 m/s, ***wind energy*** in Thailand is currently applied almost only exclusively for propelling rooftop ventilators or water-pumping turbines, however wind speed along the Thai coastline is high enough to generate electricity. The power output of a turbine is certainly a function of the cube of the wind speed, so as wind speed increases, power output increases exponentially. To show wind characteristics that pertain potentialities of wind energy such as wind resource distribution, prevailing wind, or wind speed & directions, a wind resource assessment in various regions of Thailand has been developed to explore the suitable sites. Currently, a further detailed study is being carried out in areas where wind energy developments do stand a chance, mainly along the southern coastlines from Nakhon Si Thammarat Province downwards, to obtain comprehensive data with a view to determining the feasibility to develop projects using wind energy for power generation. Thailand aims to increase generated electricity by wind power from 1 MW to 115 MW by 2011. The government offers subsidies for electricity produced by wind power, with prices at 0.05 Euro (2.5 Baht) per unit of kW/hr (Thepent, 2009; BOI, 2008).

Table 1.5: Land resource according to wind speeds of Thailand

Characteristic	Poor (<6m/s)	Fair (6–7m/s)	Good (7–8m/s)	Very Good (8–9m/s)
Land area (square km)	470,000	37,000	748	13
Percentage of total land area	93%	7%	0.2%	0.003%
MW potential	–	150,000	2990	52

Source: Cabrera and Lefevre (2002)

Although wind power generation technology has been introduced in Thailand since 1983, there are some constraints affecting the development of wind energy in Thailand. These are summarised as: 1) the deficiency of specific financing schemes designed to support wind energy development; 2) the absence of grid for connection in many rural areas; 3) the lack of wind data, which is sufficiently accurate and industry standards to allow wind site identification; 4) the fact that some existing wind turbines are not functioning, which provides a negative reinforcement of the effectiveness of wind installations; and 5) a low level of technology capacity in wind energy and no local manufacturing or distribution capacity (ABCSE, 2005).

1.4.8 Geothermal Energy

Generally referred to any heat contained in the ground, geothermal energy offers a number of advantages over traditional fossil fuel based sources, primarily that the heat source requires no purchase of fuel. The temperature varies with respect to the distance from the earth’s surface (the deeper from the earth’s surface, the higher temperature and energy). At the depth of about 25 to 30 km, the average temperature will be around 250 to 1000 °C (EPPO, 2007). From the report of the DOE, there are approximately 64 geothermal resources in Thailand and major ones locate in the North, especially ***the geyser field*** at Fang District, Chiangmai Province. In 1978, the first survey on the potential of geothermal energy development commenced at Fang District, in Chiangmai, with technical assistance and experts from France later in 1981. Currently at Fang District, EGAT is operating a 300 kW binary cycle geothermal power plant, generating electricity at about 1.2 M kWh/y. Moreover, hot water, used in the geothermal power plant with dropped temperature from 130 to 77°C, is properly utilized later for drying agricultural products and feeding the cooling system for

EGAT's site-office space. For non-energy uses, hot water from geothermal sources is mainly applied for physical therapy or tourism.

1.5 Conclusion

A middle-income country in Southeast Asia (World Bank, 2001), Thailand is an agricultural country with a huge agricultural output, such as rice, sugarcane, rubber sheets, palm oil, and cassava. Although agriculture continued to be the main export, manufactured goods also began to dominate in Thai economy. Less than one quarter of Thailand is now forested despite government policy stating that forest coverage should not fall below 40% (Trebuil, 1993), because mainly from economic growth in the past has occurred through the harvestion of forest products and deforestation to allow additional farming area. As industrialization in Thailand will continue to progress, comparative advantage in agriculture will decline further. Industry (44% GDP) and services (47% GDP) dominate the economy of the country, with agriculture contributing only about 9% of GDP. However, most of Thai labor force is still working in agricultural sector. After recovering from the Asian Financial Crisis in 1997/1998, the Thai economy took off again. From 2002 to 2006, Thailand’s growth averaged at 5.6%, but it has been stagnant at around 4% since then because of weak private consumption & investment demand, political uncertainty & chaos, and slow down of economies in both region and global level. Depending heavily on export, its economy ranges the second highest in the ASEAN after Indonesia (BOT, 2006), so the Thai government still continues to pursue the explicit policy focus on the duality of the export and the domestic sectors (***dual track policy***) to bring economic growth with stability.

To save foreign currency and increase energy security of the country, Thailand has a big ambition to reduce its expenditure on energy import (about 60% of its energy demand) through a diversity of energy types and sources since August 2003. However, fossil energy still plays a major role, especially petroleum products and natural gas. Transportation sector is the main petroleum products devourer, accounting for 68% of all petroleum products. Although the potential of natural gas production is quite substantial, it raises concerns about security of electricity supply if natural gas still accounts for about 70% of the total power generation. As it is projected that the energy demand will continue to increase, efforts by the state have been made to explore and develop other potential energy sources to accommodate its increasing demand. The development of renewable & alternative energy has become the focus of interest with wider utilization having been promoted to replace conventional energy consumption in parallel with the exertions to arouse the public to employ energy efficiently and economically. Besides, Thailand declared the objective to increase the level of renewable energy utilization from a level of just 0.5% in 2003, to a figure of 8%, (approximately 6,600 KTOE), by the year 2011.

Thailand possesses great potential of renewable energies, especially biomass and biogas (see also Ch. 1.4.1, Ch. 1.4.5, and Ch. 2.2), and the opportunities are open. Thai government has laid a strong foundation and infrastructures for supporting and promoting the energy conservation programme and the use of renewable energy, particularly in the form of necessary legislations and financial incentives. A sustainable energy plan has been recently set forth to address the country’s short & long-term supply and demand issues, in order to secure Thailand’s future energy sufficiency. As a result, more emphasis has been given to encourage the renewable energy technologies, chiefly biomass energy. Capitalizing on its massive agricultural base, alternative energy such as biofuels will play an increasingly important role in strengthening Thai domestic energy supplies. Together with an advanced solar energy sector and commitment to exploring the range of cost-effective alternative energy sources (wind and geothermal energy), the future for the alternative energy sector in Thailand has never been brighter. Although alternative energy policies adopted by the government are therefore in the right direction, these policies and signals must be clear and strong enough for all stakeholders to be confident and actively participate in the renewable energy projects. Restructuring and deregulation should ensure a real competitiveness in the energy market.

Chapter 2: Raw Materials for Energy Utilization in Thailand

As agricultural-based country, Thailand possesses great biomass energy potential and opportunities to utilize biomass as a modern energy source are open, therefore the purpose of this chapter has been to prepare supply curves/datum for biomass energy in terms of qualities and quantities by:

1) Classification of biomass sources according to fuel quality and supply sector;
2) Examination of the sectors that serve as biomass suppliers (i.e. agriculture, forestry, industries, wastes); and
3) Estimation of the energy potential from biomass.

2.1 Introduction

The world's total primary energy demand in 2005 amounted to about 11,400 MTOE/y. Fossil fuels were still by far the leading source of primary energy in the world, with oil, coal, and gas together supplying more than 80% of total primary energy supply (Fig. 2.1), while renewable energy sources represented around 13% only. Biomass (e.g. agricultural/forest products and organic wastes/residues) dominated the renewable sector, especially in developing countries, covering 10% of global primary energy demand (IEA, 2007). In 2006, biomass in world primary energy demand rose to about 10.11%, but its share was forecasted to decline slightly to 9.77% by 2030 in the reference scenario of WEO2008, because growth in the consumption of fossil fuels worldwide was expected to exceed that of renewable sources (Fig. 2.2). Total primary energy demand will rise from 11,730 to 17,014 MTOE during 2006 to 2030, an increase of 45% or 1.6% per year, a result of robust economic growth and expanding populations in developing countries. Therefore, fossil fuels will any way dominate the market, amounting to roughly 80% (IEA, 2008). The decline of biomass in the global energy share by 2030 in the reference scenario of WEO2008 was also in line with that of IEO2008, although the IEO2008 projections accounted for commercial energy use only meaning that traditional or non-marketed biomass energy in households of many non-OECD countries was excluded (EIA/DOE, 2008).

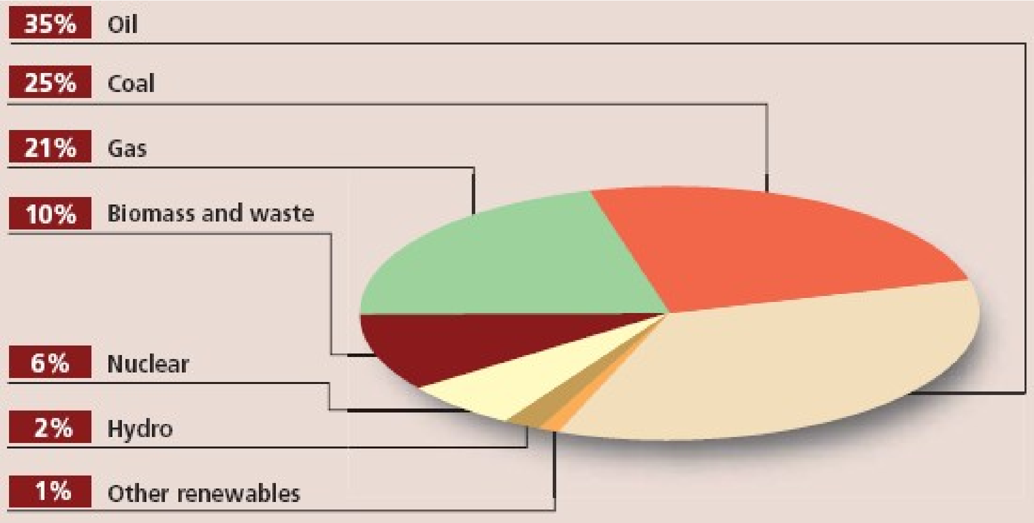

Fig. 2.1: World primary energy demand by source, 2005
Source: IEA (2007)

Coal will be the fastest grower in absolute terms in world electricity market, however petroleum oil will still overshadow the fuel mix in the reference case of IEO2008 (Fig. 2.2). Energy demand of non-OECD countries exceeded that of OECD countries in 2005 (Fig. 2.3) and this trend was forecasted to continue driving mainly by brisk growth in China and India. The share of non-OECD in world primary energy demand will rise from 51% in 2006 to 62% by 2030, accounting for 87% of the increase in global energy demand.

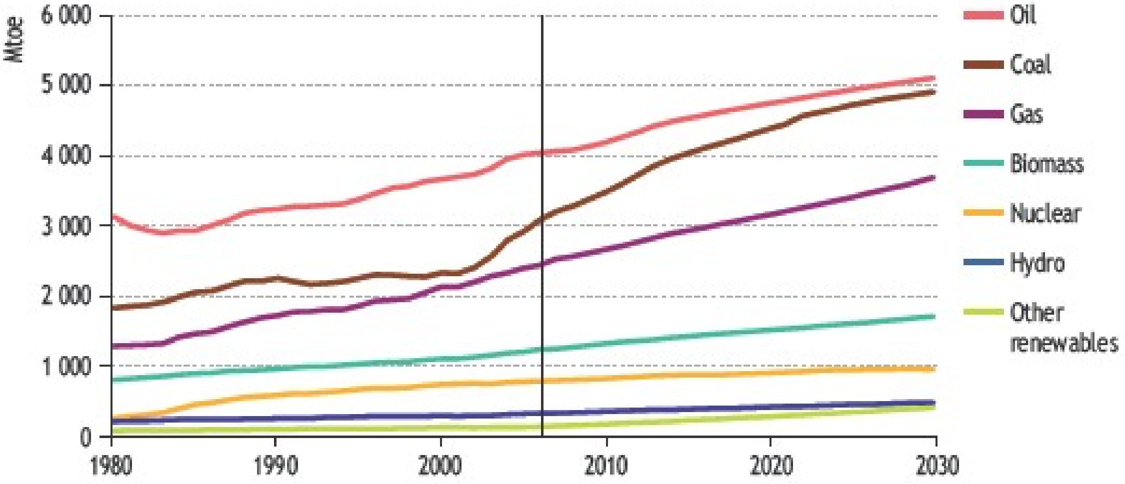

Fig. 2.2: World primary energy demand by fuel in the Reference Scenario
Source: IEA (2008)

As mention above, energy consumption is projected to increase at the highest rates in developing countries, particularly non-OECD Asia, with an average annual rate of 3.2% in EIA/DOE (2008) and 2.8% in IEA (2008) from 2005 to 2030 in the reference scenario. Fatefully, developing economies are especially sensitive to fluctuations in global energy supply and demand. The IEA estimates that a US$ 10 increase in the oil price per barrel can reduce their GDP growth by an average of 0.8% in Asia, and up to 1.6% in the region of poor highly indebted countries (IEA, 2004a). In industrialized countries, where national economies are mature and population growth is expected to be relatively low, the demand for energy is projected to grow at the lower rate of 0.5% per year, albeit from a much higher starting point. About half of the increase in global energy demand by 2030 will be for power generation and one-fifth for transport needs, mostly in the form of petroleum-based fuels (IEA, 2008).

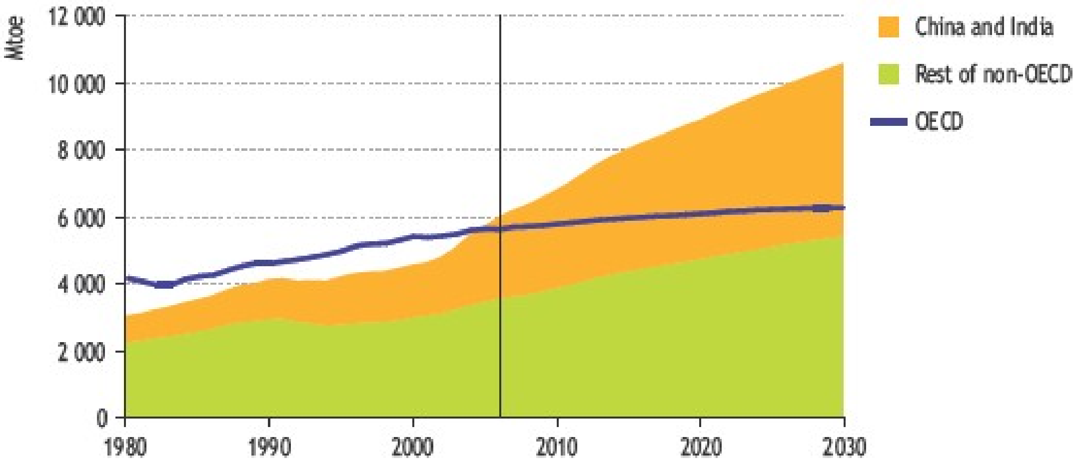

Fig. 2.3: World primary energy demand by region in the Reference Scenario
Source: IEA (2008)

With a growing gap between energy demand and supply along with depleting fossil fuel resources as in the present, concern in ***biomass***[18] as a modern energy source, especially for electricity generation, has been growing worldwide for a number of warrants (Schröder et al., 2008; Maung and McCarl, 2008; Saxena et al., 2007; Msangi et al., 2007; Faaij, 2006; Monique et al., 2003; Van den Broek, 2000; Lynd, 1996; Landucci et al., 1994; Bozell and Landucci, 1993; Lynd et al., 1991):

1) It is a renewable energy source as long as vegetation is managed appropriately. It is also more evenly distributed over the earth's surface than finite energy sources;
2) Recent developments in biomass production and energy conversion technology both make bioenergy to competitive with commercial energy in some situations;
3) It provides enhancement of energy security and diversity on energy supply, and also offers the opportunity for local, regional, and national energy self-sufficiency across the globe;
4) It provides an alternative to fossil fuels, restoration of degraded lands as a result of plantation and possibility of increase in bio-diversity, then helps to reduce climate change;
5) It helps local farmers who may be struggling and provides rural job opportunities;
6) It is an effective way to reduce the disposal problem of biomass residues and biomass wastes; and
7) The expansion of bioenergy market pushes it into the new global energy market.

Biomass is unique among all renewable energy supplies, because it is only one resource that can be processed in many ways leading to a variety of products such as food, chemicals, materials, electricity, and fuels (DOE, 2006; McKendry, 2002a; McKendry, 2001). The energy conversion from biomass (see Ch. 3), especially biofuel technology, has received considerable attention since the energy crisis in the mid-1970s (Maung and McCarl, 2008). However, biomass utilization in energy production is not free from problems. The consistent supply of biomass and its heterogeneous and variable composition offer challenges (Khan et al., 2008). The term biomass refers to all organic materials, particularly cellulosic or ligno-cellulosic matter, that originate from recently living organisms such as wood, agricultural residues, animal manure etc. Its sources are therefore diverse (Gerbens-Leenes et al., 2009; Schuck, 2006; NREL; Graboski and Bain, 1979). Biomass points also to organic materials that stem from plants. It stores energy from sunlight by photosynthesis in bonds of carbon, hydrogen, and oxygen molecules (IEA, 2005; KLASS, 2004). ***Biofuels***[19] are liquid fuels derived from matter of a biological origin or biomass, while the term ***bioenergy*** denotes all types of energy derived from biofuels (FAO, 2004a). Currently, bioenergy meets approximately 10% of global energy demand and around 80% of this number comes from a solid biomass for heating and cooking (IEA, 2007; IEA, 2008; FAO, 2009). Although liquid biofuels account for less than 2% of road transport fuels worldwide, they is projected to rise to nearly 5% by 2030 (FAO, 2009).

Many developing countries have a reasonable potential for biofuels production due to the availability of land and cheaper labour force, although they may lack in skills, capital, and finance. A number of studies have reported that biomass production for bioenergy will offer

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[18] Although the outlook paints a dark picture of the development until 2030, it makes a clear statement that biofuels and renewables could make up to 12 % of the global energy budget if the right measures will be taken (IEA, 2006).

[19] In EU, biofuels is defined as transport fuels, bioethanol and biodiesel, derived from biomass only (FAO, 2008c). For other definition, Biofuels are energy carriers that store the energy derived from biomass (FAO, 2008d).

developing countries new income sources, thereby reducing poverty and enhancing food security. There are, however, many variables which determine whether the expansion of bioenergy has a net positive or a net negative impact on livelihoods (Walter et al., 2008). When small-scale farmers have the opportunity to produce biomass independently or through outgrower schemes, there may be net benefits. But large-scale production of biofuels requires careful management to avoid direct competition with food production as well as constraints on water availability, and preserving biodiversity. There is a history of disputes. In Indonesia, the establishment of large palm oil plantations has been associated with alleged land grabbing and human rights abuses (Aglionby, 2008). The extent of employment opportunities resulting from bioenergy development is dependent on the crop and system of production. Generally, the planting of trees or other energy crops in such areas has been suggested as a way to reduce erosion, restore ecosystems, regulate water flows, and provide shelter as well as protection to communities and to agricultural lands (Risø**,** 2003).

The advantages of biomass based energy are also being recognized in industrialized countries. Several governments have successfully adopted articulate policies for promoting biomass energy. The increase in the price of fossil fuels and the political necessity for decision-makers, to take environmental constraints into consideration, have had very beneficial effects on the choice of biomass energy solutions since the 1980s. For example, at the end of 2005, the Biomass Action Plan of ***EU*** redefined an objective. ***The European Commission*** esteems that the measures provided for by the Action Plan shall lead to an increase in the utilization of biomass (solid biomass, biogas, biofuels, and renewable municipal waste) that should reach approximate 150 MTOE in 2010 (55 MTOE intended for electricity generation, 75 MTOE for production of heat, and 20 MTOE for transport). This scenario is found in the continuity of the community objectives for 2010 concerning renewable energies: a 12% share in total energy consumption, a 21% share in gross electricity consumption and a 5.75% share in vehicle fuel consumption (Siemons et al., 2004).

The short-term trend is that countries and regions with a stronger position in economy and development will increase their use and import of wood fuel, while less-developed countries will continue their development based on fossil fuels. This might be changed in the long term (Hillring, 2006). With the inclusion of traditional biomass, heating and cooking will remain the principal uses of renewable fuels over the next 25 years. The power generation sector, however, is expected to lead the global increase in renewable energy consumption. This sector accounted for a quarter of global renewable energy consumption in 2002, but its share is projected to rise to 38% by 2030 (IEA, 2004b). Currently, less than 1% of fuels used for transport are renewable. According to projections, this share will rise to 3% over the next 25 years (FAO, 2008c). For a given source of biomass, three factors have a strong impact on the cost of biomass utilization: 1) the end product (e.g. power, heat, or ethanol), 2) the technology of conversion, and 3) the scale of energy conversion plant (Cameron et al., 2007).

In Southeast Asia, the increase of energy demand in this region is chiefly driven by both hasty urbanization and industrialization. In the ASEAN-6 countries[20], the energy demand more than doubled from 230 MTOE in 1990 to 490 MTOE in 2007 (Fig. 2.4). Besides, energy resources are unevenly distributed across the region, with some countries being energy-rich and others energy-poor. Fossil fuel remains to be the key commercial energy source (accounted for 74% of the energy supply in the ASEAN-6 countries in 2007) and will still dominant for the next several years. Countries like Brunei, Cambodia, Myanmar,

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[20] Including: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam (where more than 95% of energy demand in Southeast Asia represented) (Ölz and Beerepoot, 2010).

Singapore, and Vietnam are heavily dependent on fossil fuels (almost up to 100%). Apart from the high cost of import fuels and the rapid increase in demand for power, its growing economy in the last two decades has raised the concern of sustainable energy development into a higher plane. Virtually, almost countries in Southeast Asia are major biomass energy's consumers as well as producers. More than 120 M t of biomass residues is generated in the region. Although biomass provides 26% of total primary energy supply and accounts for 87% of the renewable energy supply, it is mostly in the traditional form that meets the energy needs by the rural population and small-scale industries (Carlos and Khang, 2007). Traditional biomass is not an effective solution in this region, due to inefficient use (generally less than 10% efficiency) and associated environmental and health concerns (Ölz and Beerepoot, 2010).

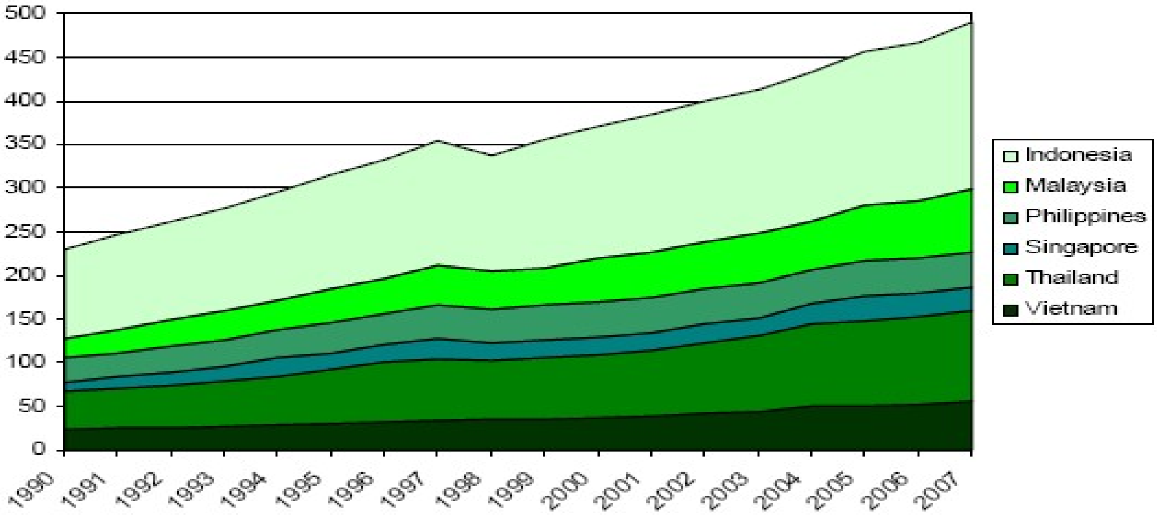

Fig. 2.4: Evolution of primary energy demand in ASEAN-6 (in MTOE)
Source: IEA (2009a)

As already mentioned above, the vast and variegated biomass in ASEAN countries has given it a very good position for development into energy forms; this biomass consists mainly of agricultural and wood residues such as rice husks, bagasse, corn leaves, tapioca, palm shell, and woodchips. More recently, ASEAN countries have deepened their interest in the modern use of agricultural residues as feedstock alternatives to fossil fuels, although all ASEAN-6 countries have some experience with modern biomass in combined heat and power plants. To date, regional policy making has focused on automotive fuel and power production from biomass rather than on heat - mostly for (agro-)industrial processes and to some extent for domestic hot water production (Ölz and Beerepoot, 2010). Biomass accounted for about 9% of renewable electricity generation in 2000 and the use of biomass in power generation is expected to increase substantially during the next decades (Balce et al., 2003). In Indonesia, there is a tariff for the purchase of electricity under the Small-Scale Renewable Energy Power Program, which is designed to help small-scale power investors. In Malaysia, local energy policy promotes renewable energy as the fifth fuel source both in the Third (OPP3 2001-2010) and the Eight (8MP-2001-2005) Outline Malaysia plan. In the Philippines, incentives have been introduced to increase power generation from indigenous resources, which has had a positive impact on the market for biomass technologies. For Vietnam, the use of traditional biomass in rural areas remains still very high, with 44% of energy needs of the country covered by solid biomass.

Table 2.1: Renewable energy targets in the ASEAN-6

Country	Year	RE Target	Renewable Sources
Indonesia	2025	5%	geothermal
		5%	biomass, hydro, solar, and wind energy (plus nuclear)
		5%	biofuels
Malaysia	2010	350 MW	grid-connected RE power
Philippines	2015	100% increase	RE capacity from 2005 level
	2009	5%	bioethanol blend
	2011	10%	bioethanol blend
Thailand	2011	15.6%	
	2016	19.1%	
	2022	20.3%	
Vietnam	2010	3%	0.1 M t of E5 and 0.05 M t of B5 (total 0.4% of oil demend)
	2015		5 M t of E5 (1% of projected gasoline demand)
	2020	5%	500 M t of E5 and 50 M t of B5
	2050	11%	

Source: Ölz and Beerepoot (2010)

Thailand enjoys favourable conditions for growing biomass, and produces a huge amount of biomass residues annually. The biggest portion area of the country, almost 41%, is allocated for crop cultivation (see Ch. 1.1.2) (OAE, 2004). Biomass has been the traditional energy source in rural and small-scale industry of Thailand for decades (Garivait et al., 2006). However, due to country modernization, commercial energy has continuously been increased. About 80% of the total energy used recently is from commercial energy sources, and around 60% of the energy demand is imported (see Ch. 1.2). Aiming to seek an alternative to imported fossil fuels for energy security and GHGs reduction, Thai government has laid a strong foundation and infrastructures for supporting and promoting the use of renewable energy, although its share was relatively constant during the last decade (table 2.2). Biomass energy is seen to be the most promising compared to other renewables. Its applications are focused on not only in the domestic sector and small-scale industries, but also increasingly in modern systems such as **C**ombined **H**eat and **P**ower (CHP) generation. At present, Thailand is the only one in ASEAN-6 country reporting biomass for power generation (chiefly from rice husk and bagasse) (Ölz and Beerepoot, 2010). However, constraints for optimal use as a modern energy source in Thailand are still to be resolved (Srisovanna, 2004). Main issues are institutional, policy, finance-related and public support barriers, as well as lack of information and technology. Some barriers have partially been understood, but some are not known at all (Shrestha et al., 2006; Prasertsan and Sajjakulnukit, 2005; Sajjakulnukit et al., 2005).

Table 2.2: Final Energy Consumption in Thailand, 1992-2001

Type of Energy	Energy consumption (kTOE)									
	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Renewable	9,818 28%	8,692 23%	8,430 21%	8,771 19%	8,861 18%	8,499 17%	7,885 17%	8,322 18%	8,599 18%	8,443 17%
Commercial	25,416 72%	28,926 77%	32,372 79%	36,958 81%	40,389 82%	40,956 83%	37,217 83%	38,807 82%	39,207 82%	41,099 83%
Total	35,234	37,618	40,802	45,729	49,250	49,455	45,102	47,129	47,806	49,542

Source: Srisovanna (2004)

Thailand possesses a great biomass energy potential[21] and opportunities are open. Supply of biomass in Thailand is available from various sources, namely, forests, wood plantations, agricultural & industrial residues, and municipal solid wastes. This supply source, however, is generally restricted by the availability of arable land, crop patterns, and season. The amount of agricultural residues is annually estimated around 61 M t, of which 41 M t (equivalent to about 426 PJ) was unused (Prasertsan and Sajjakulnukit, 2005). For another study, agricultural residues is annually amount a total of 98 M t, and 41 M t can be used as energy resource, but only 50% of this available quantity are currently used for energy purpose (TRF, 2006). These agricultural residues and biogas are the least expensive and most accessible. Biogas resources from industrial wastewater and live stocks manure have potential of 7.8 and 13 PJ/y, respectively (Prasertsan and Sajjakulnukit, 2005). The next cheap sources would be wood fuels and waste products available from plantations and wood-based industries. Although biomass energy contributes about 25 to 30% of the primary energy need, almost all this achieved energy are from traditional technologies. The use of bioenergy in the manufacturing sector by simple equipments increased considerably during last decade. However, the country's total biomass consumption was rather constant and the same situation of renewables (table 2.2); increase of biomass consumption in the manufacturing sector was actually offset by decrease of that in the residential sector (Sajjakulnukit et al., 2002).

Ten main agricultural products with high residue potential were studied in Thailand. Those agricultural products are sugarcane, paddy rice, oil palm, cassava, coconut, maize, groundnut, cotton, soybean, and sorghum (see also Ch. 1.4.1). The results from various studies showed that only the first four had the high potential to be utilized as an energy source for the country. ***Sugarcane*** and ***Rice*** are mostly concentrated in the North and Northeast, while oil palm is found mostly in the South and partially in the East of Thailand. As the result of thriving capability in poor soils and drought areas, ***Cassava*** cultivation is popular in many parts of Thailand. Rice and sugarcane, although are seasonal crops, the production are normally steady. Rice is the main staple food, while sugarcane is contract farming with sugar mills in practice. Cassava is also a year-round crop and the third most important cash crop after rice and sugar cane. Almost two-thirds of the cassava is now planted in the seasonally dry Northeast. ***Oil palm*** and ***Rubber wood*** are also focused on, because their long rotation period secures long-term supply of residues. Rotation period of both crops is 25 to 30 years, when yield drops then the trees are cut down for replantation. This implies biomass could be claimed from 3 to 4% of the planting area annually. The table 2.4 below shows the national production trends in tonne of sugarcane, paddy, cassava root and oil palm from 2002 to 2008.

Table 2.3: The main product of each selected crop for reference in this study

Crop	Main Product
Sugarcane	Fresh sugarcane stalk without leaves and top
Paddy Rice	Paddy
Cassava	Fresh cassava roots
Oil palm	Oil palm fruits attaching to the bunch
Maize	Grains
Cotton	Cotton lint with seed
Soybean	Grains
Kenaf	Retted kenaf
Para rubber	Unsmoked rubber sheets

Source: OAE (2007)

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[21] Total potential of biomass from agricultural residues, animal manure, fuelwood conservation, fuel substitution, municipal solid wastes, industrial wastewater, black liquor and palm oil mill effluent in 1997 was 525 PJ (Sajjakulnukit et al, 2005).

Table 2.4: Production trends of high potential crops for energy utilization in Thailand

Crop	Main Product (million ton)						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Sugarcane	60.013	74.259	64.996	49.586	47.658	64.365	73.502
Paddy Rice	27.992	29.474	28.538	30.292	29.642	32.099	31.651
Cassava	16.868	19.718	21.44	16.938	22.584	26.916	25.566
Oil Palm	4.001	4.903	5.182	5.003	6.715	6.39	9.265
Maize	4.23	4.178	4.216	3.943	3.716	3.661	4.178
Cotton	0.0140	0.0110	0.0140	0.0150	0.0060	0.0030	0.0021
Soybean	0.260	0.231	0.218	0.226	0.215	0.204	0.187
Kenaf							
Natural Rubber	2.633	2.860	3.007	2.980	3.071	3.024	3.167

Source: OAE (2010); OAE (2007)

Wood processing industry is also a major source for biomass energy. The major advantage of forests and trees as a source of biomass is their lower energy inputs and their ability to grow on sites with lower fertility than those required for agriculture. Furthermore, the wood utilization from sustainable sources for heat or power generation, or for both, is highly efficient in terms of energy conversion and greenhouse gas (GHG) emissions. At present, energy from wood is most competitive when produced as a byproduct of the wood processing industry (GreenFacts, 2009). In Thailand, saw mills and plywood mills are the main sources of biomass from wood processing industry. It was reported in 2003 that there were 599 sawmills, and wood residues including sawdust have been estimated to be about 5.8 M t, but the availability of unused residue was only 1.8 M t (Papong et al., 2004). Recently, most logs for wood processing are imported. The main local logs are obtained from rubber wood, mostly found in the South. After logging, rubber wood is both used as timber, mainly for furniture industry, or as fuel. In addition, the wood industry is also a source of residues from ***Teak*** logs, mostly concentrate in the North. Abounding in the Northeast, ***Eucalyptus*** is another source for wood-based industries. It is the most common fast species for pulp and wood fuel production. ***Dendrothermal*** plantation has still developed only to a very limited extent due to the concerns about the environmental and sociological impacts, despite the existence of significant opportunities (AIT, 2005).

Table 2.5: Exporting trends of wood timber in Thailand

	Exported Timber (m^3)						
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Teak	6,214	8,803	5,445	7,678	12,921	7,116	6,955
Rubberwood	351,237	1,514,385	1,064,815	1,743,208	1,323,987	1,271,421	1,661,368
Other Species	45,452	39,034	35,634	40,108	33,018	37,592	71,621
Total	402,903	1,562,222	1,105,894	1,790,994	1,369,926	1,316,129	1,739,944

Source: RDF (2007)

Generally considered wastes, agriculture residues in Thailand are disposed off through various methods such as open burning and dumping (Carlos and Khang, 2007). Handling these solid forms of biomass is expensive for several reasons including the number of operations required and the low bulk density of the feedstocks (Gadde et al., 2009). The agro-industrial mills also result in a huge production of residues. One of the main usages of these residues is as fuel for generating either heat or power to meet the mills demand, but generally utilization in rather inefficient conversion systems. As in other developing countries, various industries use wood or other biomass as their main fuel. Many of these industries are commonly small scale, are located in a rural or urban environment, and employ traditional production process. Some of these industries avail of modern technology to achieve more efficient utilization of biomass fuels in a local/cost-effective way. Based on ***Crop-to-Residues***

Ratio (CRR) from agriculture-based manufacturing (including rice, sugarcane, cassava, and oil palm) and from wood processing industries, it has been estimated that about 60 M t of residues were produced yearly in Thailand (TRF, 2006). The CRR and the energy content of each crop are summarized in the table 2.6 below.

Table 2.6: Moisture Content, CRR, and LHV of the residues from major crops in Thailand

Product	**Residue**	**Moisture (%)**	**CRR**	**LHV (MJ/kg) (as received)**
Sugarcane	Bagasse	50.00	0.250	6.43
	Top & trash	50.00	0.302	6.82
Paddy Rice	Husk	8.83	0.230	12.85
	Straw (top)	8.17	0.447	8.83
Oil palm	Empty bunches	8.81	0.428	16.44
	Fiber	10.11	0.147	16.19
	Shell	13.00	0.049	17.00
	Frond	48.34	2.604	7.97
	Male bunches	13.82	0.233	14.86
Cassava	Stalk	-	0.088	16.99
	Rhizome	59.4	0.2	5.49
	Leave	-	-	-
Maize	Corn cob	8.65	0.250	16.63
	Stalk	-	-	-
Cotton	Stalk	9.33	3.232	13.07
Soybean	Stalk, Leaves, Shell	-	2.663	18.00

Source: OAE (2010); OAE (2007)

2.2 Agricultural Sector

Since 1999, long-term tendencies of agricultural commodities resulting from slower growth in their production and rapid expansion in their demand had contributed to a sharp downtrend in their world aggregate stocks, especially *grains* and *oilseeds*. Production of agricultural commodities has stagnated in recent years owing to rising fossil fuel and chemical input costs. A shortage of their supply was also observed, caused by weather-related phenomena, by stockpiling of oilseeds, and by reduced export subsidies for dairy products in EU. On the demand side, the world market of agricultural commodities was further tightened by the emerging biofuel sector. The tangibly upward demand from large and dynamic economies such as Brazil, China, India, and the Russian Federation is also affecting the markets for raw materials (FAO, 2008d; Trostle, 2008; Schnepf, 2008). Besides, there are the devaluation of the U.S. dollar, growth in foreign exchange holdings by major food-importing countries, and protective policies adopted by some exporting and importing countries. Therefore, agricultural commodity prices have risen dramatically over the past 3 years (Trostle, 2008).

The real food price index began rising in 2002, after 4 decades of predominantly declining or flat trends, and spiked increasingly in 2006 and 2007. Furthermore, they jumped precipitously in early 2008. Only occurred the other notable period of rising real food price and the lowest global aggregate stock-to-use ratio for grains & oilseeds in the 1970s, in the wake of the first global oil crisis (FAPRI, 2008; Trostle, 2008; Schnepf, 2008). By early 2008, real food prices worldwide were 64% above the levels of 2002. The surge was led by vegetable oil prices, which on average increased by more than 97% during the same period, followed by cereals (87%), dairy products (58%), and rice (46%). Sugar and meat product prices also rose, but not to the same extent (see Fig. 2.5) (FAO, 2008d, 2008e). Several international organizations have announced that the sharply rising commodity prices are likely to have dire consequences for the world's vulnerable populations, particularly in import-dependent, less developed nations (Schnepf, 2008).

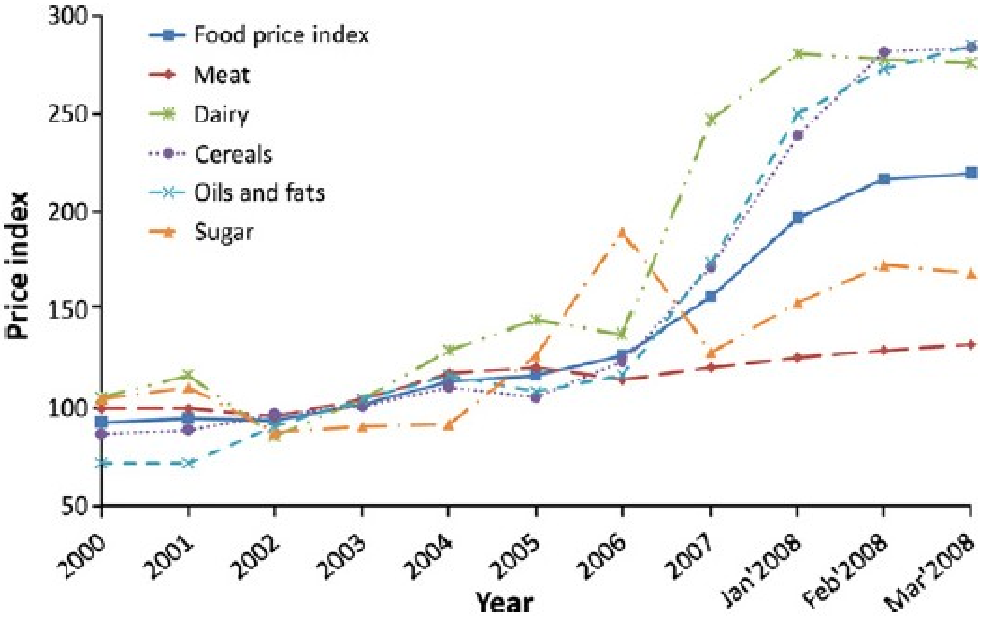

Fig. 2.5: Food commodity price indices from2000 to 2007, and the first three months of 2008
Source: Koh and Ghazoul (2008)

The annual growth rate worldwide in the production of aggregate grains and oilseeds has been slowing continuously. Between 1970 and 1990, production rose an average 2.2% per year. Since 1990, the growth rate has declined to about 1.3%. It was projected that the rate will be declining to 1.2 % per annum between 2009 and 2017. In terms of productivity, global aggregate yield growth average 2% annually between 1970 and 1990, but declined to 1.1% between 1990 and 2007. Undoubtedly, yield growth was also projected to keep on declining over the next 10 years to less than 1% per year. Growth in productivity, measured in term of average aggregate yield, has contributed much more to the growth in production globally than has expansion in the area pleated to grains and oilseeds. However, steady food prices during the last two decades have led to not only some complacency about global food concerns, but also a reduction in R&D funding levels which may have contributed to the slowing growth in crop yields. Although private sector funding of research has grown, it has generally focused on innovations that could be sold (Trostle, 2008).

In the case of cereal, past yield increases have been realized through genetic improvement in rice, wheat varieties, and maize hybrids, along with the alteration of agricultural practices such as the use of high levels of fertilizer, pesticides application, and irrigation (Borlaug, 1983; Feyerherm et al., 1988; Tollenaar, 1989; Duvick and Cassman, 1999; Khush, 1999; Reynolds et al., 1999). To determine what factors might be responsible for the presence of slowing yield growth and yield decline in some nations, Hafner (2003) used statistical method to analyze yield time series data of 188 nations for cereal, providing empirical evidence that slowing yield growth has not been due to general physiological limits to crop productivity. Instead, the occurrence of slowing growth and decline appear to be related to both economic and biophysical factors, reflected in per-capita GDP, fertilizer usage, and latitude, and are almost certainly dependent on additional factors as well.

Strong demand of livestock (in form of meat or dairy) refers to up requirement of cereal as feedstuff. Global consumption of meat has been growing much more rapidly than that of grains and oilseeds. Between 1985 and 1990, worldwide meat production rose more than 3% per year. Since this was well above the world's population growth rate of 1.7% per annum, per capita consumption was able to climb by 1.4% annually. Although the global average growth rates of meat in production and per capita consumption have declined somewhat since 1990, they are still well above those for aggregate use of grains and oilseeds. In the first decade of this century, the rapid enlargement in economy and urbanization of several developing countries led to greater global consumption of livestock. In global scale, projected population and socio-economic growth will double current food demand by 2050. Therefore, total cereal yields will need to increase by 40% and net irrigation water requirements will rise by 40 to 50%. Moreover, some 100 to 200 M ha of additional land may be needed, mainly in sub-Saharan Africa and Latin America (Trostle, 2008).

In the 20th century, agriculture became increasingly reliant on fossil fuel via chemical fertilizers and powered machinery. Food storage, processing, and distribution, are often energy-intensive activities too. Higher energy costs, therefore, have a direct and strong impact on agricultural production costs. In 2004, agricultural production costs began to rise, especially with energy-related inputs. The recent emergence of liquid biofuels based on agricultural crops as transport fuels (the first generation of biofuel, see Ch. 3.3.1) has reasserted the linkages between energy and agricultural output markets As a result, agriculture has always been a source of energy and energy is also a major input in modern agricultural production (FAO, 2008d). Generally annual crops such as corn, soybeans, vegetables and cereals have ***output:input*** ratios of energy between 1 and 5, before conversion into useable energy, while forest-based biomass from conventional forestry, have typical ratios of 10 to 25 (Mead and Pimentel, 2006). An estimated 80% of the increase in global food production must come from growth in crop yield. To this, the new demands for feedstock for an expanding bioenergy sector should be added (FAO 2008e).

The term ***agricultural residue*** is used to delineate all organic materials which are generated as the byproducts from harvesting and processing of farming crops. It can be used as animal fodder or soil amendment, and in manufacturing. Agricultural residues are becoming increasingly important sources for non-wood fiber. A byproduct of grain production, straw is utilized extensively for the production of pulp and paper. It is also possible to produce boards, with similar characteristics to MDF or particleboards. The fibrous residue that is left over after the extraction of juice from sugarcane, bagasse is used for producing paper in several countries. For rice husks, the production of reconstituted boards is being investigated, but results are still unsatisfactory. Agricultural residues can be divided into two categories: field residues and process residues. ***Field residues*** are materials left in an agricultural field after farming crop has been reaped. These residues include stalks & stubble (stems), leaves, and seed pods. Proper management of field residues can increase efficiency in both irrigation and control of erosion. ***Process residues*** are remnants of agricultural crop in agro-industry. These residues include husks, seeds, bagasse, and roots (Saeidy, 2004; Vest, 2003; Cooper and Laing, 2007)

Agricultural residues are likely to be among the lowest-cost liquid biofuel feedstocks. For example, bagasse and residues from the production of cereals are among the becoming feedstocks for bioethanol production (see Ch. 3.3.2.4). As bioenergy production increases, agricultural residues may become more important biofuel feedstock sources. However, only about 15% of total residue production would be available for energy generation after accounting for needs related to soil conservation, livestock feed, and factors such as seasonal variation (Bowyer and Stockmann, 2001). Over the past 5 decades, most of the enlargement in global agricultural commodity production (around 80%) has resulted from yield increases, with the remainder accounting for by expansion of cropped area and boosted frequency of cultivation. For this reason, availability of agricultural residues could increase through improved management practices, despite; one of the key factors via energy route, moisture content of residues normally varies widely at different stages of harvesting and storage (FAO, 2003a; Hazell and Wood, 2008).

Many Southeast Asian countries are among the top producers of agricultural commodities. There were over 150 sugar mills in the region. Philippines, Thailand, Indonesia, and Vietnam together accounted for about 7% (118 M t annually) of global sugar production. Bagasse was therefore produced over 34 M t yearly. In 2006, the region generated 102.12 M t of rice, accounting for 24.4% of world production. It was estimated that more than 100,000 rice mills were functional in Indonesia, Philippines, Malaysia, Thailand and Vietnam, and resulted in around 19 M t of rice husks per annum. The region is also the leading producer of palm oil. In 2006, Malaysia and Indonesia produced 33.7 M t of palm oil, accounting for more than 86% of total world production. Close to 600 palm oil mills in Malaysia, Indonesia, and Thailand since 2003, they manufactured more than 27 M t of oil palm residues (Carlos and Khang, 2007).

Availability of field residues in Thailand for energy application is usually low, since theirs compilation is rather laborious and they also have other utilization, that is to say, as fertilizer or animal feed etc. For process residues, they are usually obtainable in relatively large amounts at the processing site, and may largely be used as captive energy source for manufacturing itself with low transportation and handling cost. Agricultural residue potential for years 2003 and 2008 has been projected based on historical data of harvested land and production statistics from the **C**enter for **A**gricultural **I**nformation (CAI). Change in productions was estimated from historical trends of two essential parameters, namely harvested area and product yield. Other parameters, for instance, RPR ratio and residue availability factor were assumed to be constant. The energy potential estimation was performed based on **R**esidue **P**roduct **R**atio (RPR) and as received calorific values as shown in table 2.7. Most calorific values in this table were obtained from the tests conducted in the laboratories of the **D**epartment of **E**nergy **D**evelopment and **P**romotion (DEDP) of Thailand.

Table 2.7: RPR and calorific values of agricultural residues

Product	Residue	Moisture (%)	RPR	LHV (MJ/kg) (as received)
Sugarcane	Bagasse	50.00	0.250	6.43
	Top & trash	50.00	0.302	6.82
Paddy Rice	Husk	8.83	0.230	12.85
	Straw (top)	8.17	0.447	8.83
Oil palm	Empty bunches	8.81	0.428	16.44
	Fiber	10.11	0.147	16.19
	Shell	13.00	0.049	17.00
	Frond	48.34	2.604	7.97
	Male bunches	13.82	0.233	14.86
Cassava	Stalk	-	0.088	16.99
	Rhizome			
	Leave			
Maize	Corn cob	8.65	0.250	16.63
	Stalk			
Cotton	Stalk	9.33	3.232	13.07
Soybean	Stalk, Leaves, Shell	-	2.663	18.00

Source: Sajjakulnukit et al. (2005)

This topic is divided into 5 sections. Inside this section, agricultural plant, which is focused on, details about general data, cultivation trend in Thailand, processing technologies in Thailand and residues and their application in Thailand are shown. All details will be analyzed in the chapter 4 “Potential Energy from Biomass in Thailand Analysis” to analyze actual and potential energy that is conversed from biomass with suitable technology for Thailand. In 2.2.1, all emphasis about sugarcane is concentrated on. Paddy rice is presented in 2.2.2, while in 2.2.3 palm oil is discussed. The following part, 2.2.4, illustrates details about cassava. And the last issue (2.2.5) other potential crops are discussed.

2.2.1 Sugarcane

2.2.1.1 General Data of Sugarcane

Botanical Specification: Sugarcane, *Saccharum officinarum*, was originally from tropical South and Southeast Asia (Sharpe, 1998). Its cultivation requires a tropical or subtropical climate, with a minimum of 600 mm (24 in) annual rainfall. The thick stalk stores energy as sucrose in the sap. Sugar cane is classified as a C4 plant (tropical and semi-tropical plants of Gramineae family which includes maize). It has a high photosynthesis temperature, and is drought-resistant. It contains 8 to 16% sugar, 10 to 16% fiber and small amount of other organic and inorganic matters. The remainder, more than 70%, is water. Crushed from stalk where sugar accounts for 12 to 20% of the plant's dry weight, sugarcane juice is heated to evaporate its water, then it is further concentrated under a vacuum condition until it becomes supersaturated. Later refined into white sugar, raw sugar crystallizes out of the juice during cooling. The remaining liquid after crystalline sugars are separated is called ***Molasses***. Meanwhile, the fibrous residue left behind the extraction process of the juice is bagasse, containing 30 to 40% pith (Rainey et al., 2010), 45 to 55% fiber (cellulose, pentosan, and lignin), and 2 to 5% sugar. Its moisture content is 46 to 52%. The chemical analysis (dry base) shows C: 50.0%, H: 6.0%, O: 42%, and Ash: 2% with almost 0% of N or S (Wakamura, 2003).

Cultivation and Harvest: Between 12 and 16 months to fruition, sugarcane can be harvested by hand or machinery, leaving ***cane trash*** - consisting of sugarcane tops and leaves - as spin-off. In many countries, harvesting is done manually using various types of hand knives or axes. This method requires skilled labors. Traditionally, the field is normally first set on fire before reaping to remove retardation of harvest such as dry dead leaves, weeds, and other trash. However it is now common for sugarcane to be harvested green rather than burnt in order to recycle nitrogen by leaving harvesting trash in the field. The main disadvantage of green harvesting is potential to deliver more extraneous plant material to sugar factory, thereby reducing the sugar recovery. Sugarcane starts deteriorating as soon as it is cut and even more so if it is burnt (Meyer, 1997). For the machinery option, large motorized harvesters can travel up and down the field. Sugarcane will be cut at its base stalk, stripped off its unwanted leaves, and then bundled tidily in the back of the harvester where the trash is blown out. Damage inflicted on the cane during powered harvesting accelerates its decay too. The leaders in this industry are mainly harvesting using chopper or whole stalk harvesters like Brazil, USA, and Australia (Kaewtrakulpong, 2008).

Utilization: Sugar making from sugarcane is one of the most important agricultural industries in developing countries, especially Southeast Asia, Latin America, and Africa. This industry is in the process of increasing plant capacity or efficiency, also improving it power-generating section. In general, bagasse is burned to provide both heat used in the mill and electricity if surplus is typically sold to the grid. Bagasse may also, because of its high cellulose content, be used as an animal feed, or as raw material for churning out paper or cardboard. For molasses, its utilizations are diverse. In the past, it was often applied as a fertilizer for sugarcane soils. Apart from livestock and poultry feeds, especially in USA, molasses is also distilled and fermented to produce various items (Sharpe, 1998). Molasses, with up to 50% fermentable, can be used as a biofuel feedstock (JGSEE, 2009) (see Ch. 3.3.1). Bioenery from sugarcane has net CO_2 emissions associated with the upstream fossil-fuel consumption for plantation management, transportation and processing of the fibrous biomass. There is worldwide increased interest in utilizing cane trash as a fuel instead of open burning in fields too. Research has shown that up to 50% trash can be removed without leaving behind any negative effect on soil quality (Gabra, 1995).

World Productions, trade and trend: In the financial year 2007/2008, worldwide production of sugar amounted to 134.1 M t. Most cane sugar comes from warm climate countries such as Brazil, India, China, Thailand, Mexico, and Australia, the top sugar-producing countries in the world. With roughly 30 M t of produced cane sugar in 2007, Brazil is the leading country, while India produced 21 M, China 11 M, and Thailand as well as Mexico roughly 5 M each (http://faostat.fao.org). Brazil uses sugarcane to make more ethanol for transportation fuel than any other countries in the world (11.5 hm^3), while electricity is generated from the sugarcane bagasse (Wright, 2006). Because ethanol from sugarcane is steadily becoming a promising alternative to gasoline, it may be produced as a primary product instead of sugar. India is also a large producer of sugarcane ethanol, mostly used as a chemical feedstock. However, most of the sugarcane production is still aimed at its huge domestic sugar market. Table 2.8 below shows the cane production by leading countries from 2005 to 2007.

Table 2.8: Planted area, productivity, and yield rate of sugarcane by selected countries

Sugarcane	Planted Area (M ha)			Productions (M ton)			Yield Rate (t/ha)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
World Total	20.02	20.45	21.97	1,316.75	1,388.68	1,237.03	65.78	67.90	56.31
Brazil	5.81	6.14	6.71	422.96	457.25	514.08	72.86	74.42	76.59
China	1.36	1.22	1.22	87.51	100.44	105.65	64.11	82.64	86.25
Thailand	1.07	0.97	1.01	49.59	47.66	64.37	46.46	49.37	63.71
Pakistan	0.97	0.91	1.03	44.67	44.67	54.75	46.22	49.23	53.21
Mexico	0.67	0.68	0.68	51.65	50.68	50.68	77.11	74.52	74.53
Colombia	0.43	0.42	0.45	39.85	39.00	40.00	93.59	92.86	88.87
Australia	0.43	0.42	0.42	37.82	38.17	36.00	87.16	91.96	85.71
India	3.66	4.20	4.90	237.09	281.17	35.55	64.75	66.93	7.26
U.S.A.	0.37	0.37	0.36	24.14	27.03	27.75	64.69	73.49	77.60
Philippines	0.37	0.39	0.40	31.40	24.35	25.30	85.10	62.05	63.25
Others	4.88	4.74	4.78	290.08	278.28	282.90	59.45	58.68	59.15

Source: OAE (2010); OAE (2007)

Sugar prices enjoyed a strong and sustained upward trend starting in May 2005, in the wake of a 3 year consecutive shortfall in world production, high fossil fuel prices, steady growth in sugar consumption, and increased diversion of cane sugar for ethanol production in Brazil. The modification of the EU sugar regime, agreed upon by the Council of Agricultural Ministers of the EU in November 2005, is expected to put upward pressure on world prices. The reform package includes a 36% cut in the sugar support price over 4 years beginning with July 2006, and the abolition of the intervention price, which is to be replaced by a reference price. Looking ahead, world sugar prices should remain firm and stable around their current levels (see Fig. 2.5) as the supply and demand fundamentals in the world sugar market do not point to prices strengthening further, barring extreme weather events or a continuing rise in crude oil prices (FAO, 2007d). However, this project is different from that of USA: the price of sugar will increase by 10.7% over the next decade because exportable surplus is cut significantly in the EU as a result of its sugar reforms, and in Brazil on account of increased production of ethanol there from sugarcane (FAPRI, 2008).

2.2.1.2 Cultivation Trend of Sugarcane in Thailand

Thailand recently became one of the largest sugar exporters by enlarging plant capacities and improving equipments, thus reducing its production cost (Wakamura, 2003). Sugar is produced on average 5 M t annually, therefore 47 to 64 M t of sugarcane muse be cut and transport every year. The sugar sector in Thailand is characterized by large-area farm holdings with ownership ranging from individual farmers/families to large corporations. The success of Thailand is attributable to the totally separate ownership of sugarcane farms and processing plants that are privately owned and operated under free competition. Production is therefore highly concentrated and contained. Table 2.9 shows the sugarcane production statistic of Thailand from 2002 to 2008. A productive yield of raw sugarcane in Thailand is nowadays 65 t/ha annually, comparing to that of Brazil with productivity average of around 75 t/ha. Most of sugarcane is still gathered by hand, usually whole-stalk cutting, due to high labour availability and topography. Mechanical harvesting stays at an initial stage on development, because it necessitates more investment (Kaewtrakulpong, 2008).

Table 2.9: Planted area, productivity, and yield rate of sugarcane for Thailand

Sugarcane	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	1.011	1.139	1.122	1.067	0.965	1.010	1.054
Production (M ton)	60.013	74.259	64.996	49.586	47.658	64.365	73.502
Yield (t/ha)	59.348	65.176	57.933	46.464	49.372	63.713	69.710

Source: OAE (2010); OAE (2007)

In the Northeast of Thailand as the main sugarcane plantation (table 2.10), sugarcane grows during the rainy season from May to November and is harvested during the dry season beginning late November until mid-April. As soon as harvested, it must be sent to the sugar production plant, since it loses its sugar content quickly when stored. Consequently, sugar manufacturing developed with sugarcane farms within the 100 to150 km radius of such plants. In recent decades, sugar mills shifted from the Central to the Northeast owing to advantages over production cost and space for extending the scale of sugarcane production. However, Sandy soil is distributed widely in the Northeast and shows vulnerability to mechanical and chemical impacts. In addition to such problems, agriculture in this region seems to be confronted with new problems through the increase in sugarcane production, which requires higher amounts of chemical fertilizer and heavy machinery. In Northeast Thailand, sugar milling lasts from December to the following March, therefore harvesting of sugarcane stalks is conducted during this period in both cropping season areas (Wongwiwatchai et al., 2002).

Table 2.10: Planted area, productivity, and yield rate of sugarcane by regions for Thailand

Sugarcane		Country	North	Northeast	Central + East	South
Planted Area (M ha)	**2006**	0.965	0.270	0.333	0.362	n.s.
	2007	1.010	0.283	0.366	0.362	n.s.
	2008	1.054	0.288	0.403	0.363	n.s.
	2009	0.963	0.285	0.338	0.340	n.s.
Production (M ton)	**2006**	47.658	13.674	15.667	18.317	n.s.
	2007	64.365	19.046	22.469	22.850	n.s.
	2008	73.502	20.569	27.890	25.042	n.s.
	2009	66.783	20.847	22.839	23.097	n.s.
Yield Rate (t/ha)	**2006**	49.370	50.564	47.057	50.604	n.s.
	2007	63.710	67.409	61.432	63.125	n.s.
	2008	69.707	71.541	69.132	68.893	n.s.
	2009	69.337	73.182	67.596	67.846	n.s.

Source: OAE (2010); OAE (2007)

2.2.1.3 Processing of Sugarcane in Thailand

Thailand had 46 sugar mills, processed about 99% of the indigenous sugarcane, in crop year 2007/2008. There were 9, 17, 5, and 15 sugar factories in the North, Central, East, and Northeast, respectively. The milling season for each year starts from November and ends in May influenced by the quantity of sugarcane supplied to the sugar factory (Kaewtrakulpong, 2008). Most of sugar factories have their own lands to produce sugarcane, because they want to make sure that their factories will have enough sugarcane for their need. Alternatively, they also collect certain amounts of sugarcane from sugarcane farmers for their factories via a middleman. Almost all the sugarcane plants in Thailand are self-sufficient in terms of energy supply. Generally, low efficiency cogeneration systems based on steam cycle with live steam at 22 bar and 300 °C were found. The excess amount of sugar extracted from domestic consumption is prepared for export through 7 exporting companies. Each sugar factory is able to export a certain amount of refined sugar along with the quota.

With high variability in the international sugar price, sugar industries in Brazil, Australia, Thailand, and South Africa have been exploring co-products from sugarcane, these include ethanol, electricity, animal feed, and fiberboard (Higgins et al., 2007). For ethanol production, there are many economic crops in Thailand that can be used as the raw material for ethanol production including sugarcane, cassava, rice, sweet sorghum, and corn. However, the most promising ones are sugarcane, molasses, and cassava (Sriroth et al., 2003). The 135 kg of sucrose from 1 tonne of sugarcane can be transformed into 70 liters of ethanol with a **H**igh **H**eating **V**alue (HHV) of 1.7 GJ. The practical sucrose-ethanol conversion efficiency is 76%, compared with the theoretical 97%. However, the inadequate sugarcane productivity (60 M t/y) compared to sugar mill capacity (75 M t/y) implies that very limited surplus stock of sugarcane is available for ethanol production (DEDE, 2004).

In Thailand, the cost of sugarcane harvesting & transportation occupies nearly half of sugar production cost. Therefore, more effective cost reduction and efficiency improvement in sugarcane harvesting & transportation are needed in order to maintain its current status in a rigorously competitive international sugar market. Mechanical harvesting is key for reducing harvesting cost by around 8 to 57 US$/ha, while the transportation cost will vary depending on fluctuation of fuel price. For other problems, it was usually found that in the middle of harvesting season, sugarcane supply is peak and higher than milling capacity of sugar factory, then hundreds of trucks have to wait long hours in front of sugar factory (Takigawa et al., 2005). Moreover, the main determinant of Thai sugar output and export is likely to be the government policies, affecting price, production cost, and ethanol utilization of sugarcane. These policies may be affected by trends in international prices of sugar and crude oil.

2.2.1.4 Residues of Sugarcane and their Utilization in Thailand

In Thailand, each tonne of sugarcane yields 740 kg of sugar juice and 130 kg of dry bagasse. Normally, bagasse is mostly exploited in inefficient combustion devices connected to a steam cycle with low steam parameters (22 bar and 300 °C). Bagasse-firing boiler in sugar mills started relatively small of natural-circulation, water tube type, with the steam-making capacity of 10 to 20 t/h. Nevertheless, CHP has been applied in some modern sugar plants. Besides, to combat global warming, Thai government promotes power generation using bagasse, therefore sugar mills also plan to become a local power supplier during off-season of sugar making by adding a condensing turbine generator. The boilers will be in the class of 10 MPa/500 °C, with 90% efficiency, the same boiler efficiency as oil-burning boiler. However, bagasse without densification is very bulky and inhomogeneous making it difficult to introduce in modern conversion technologies (Erlich et al., 2006).

Molasses is produced during the process as a by-product that yields alcohol and sodium glutamate. At present, ethanol in the country is mainly produced from molasses in annexes distilleries. Regarding supply potentials, from the total national molasses production of about 3 M t a year, the surplus 30 to 35% is potentially available for the production of 0.8 M L ethanol a day (Sriroth et al., 2003). However the main disadvantages of molasses-based ethanol lie in supply versus demand and seasonal operation. High demands in both domestic and international market, have resulted in supply shortage and, consequently, strong fluctuation in price. Recently, after molasses-based ethanol producers raised their product prices to cope with sharp increased feedstock prices, cassava-based ethanol becomes an attractive commodity for Thai oil traders (Nguyen et al., 2006) (see Ch. 2.2.4).

Biogas recovered from anaerobic treatment of spent wash or stillage in **U**pflow **A**naerobic **S**ludge **B**lanket (UASB) reactors contributes only 2% to steam and electricity generation for ethanol conversion process. Due to the limited handling capacity of the UASB, it is able to handle only 12% of spent wash produced, leaving 88% to be stabilized in an anaerobic pond. With a fuel value of approximately 2.27 BOE/t, sugarcane trash was generated at about 200 kg/t of cane harvest (Methacanon, 2006; EFE, 2007). Encouraged not to burn in fields but instead utilize as a fuel, sugarcane trash is also considered a potential fuel supply competitive to fossil oil or other conventional energy sources, but now it is only in the study stage. For the last residue, the solid residue from sugarcane juice filtration, filter cake, can be used as fertilizer for sugarcane field.

2.2.2 Rice

2.2.2.1 General Data about Rice

Botanical Specification: Paddy rice, *Oryza sativa* L., is the important cereal food for many regions worldwide with nearly half the global population. Grown as a monocarp annual plant, rice is native to both tropical or subtropical southern Asia and southeastern Africa. It can be grown practically anywhere, even on a steep hill or mountain. Therefore, rice is currently the most significant staple in Southeast Asia, from Myanmar to Indonesia, and Latin America. For instance, 90% of the total agricultural area in Cambodia is used for rice production. Owing to high water demand to grow than other grains, rice cultivation, however, is well-suited for regions with high rainfall or good irrigation. Irrigated rice cultivation claims more than half of the water extracted for human activities in Asia, which accounts for 90% of the global rice production. Currently, 2,000 to over 5,000 L of water is used to produce one kg of rice in irrigated fields, while the theoretical minimum at the crop scale is as low as 600 L (FAO, 2005a). Obviously, with Asia producing more than 530 M t of rice annually, more efficient water exercised in rice cultivation could potentially make vast amounts of fresh water available for other uses.

Cultivation and Harvest: Paddy is cultivated in 2 types of areas; irrigated areas could produce 2 to 3 crops per year, whereas rained area could produce only 1 crop annually during rainy reason without irrigation (OAE, 2006). Rice straw is the main field based residues after harvesting. In traditional rice cropping systems, rice straw was either burnt in the field, or removed from the field at harvest time then stored as stock feed. One reason for the plowing may be that it is the cheapest way for rice straw disposing, but actually the plowing supplies organic compounds that facilitate the activity of microorganisms. Open burning of straw in the field is a common practice in Asia, when there is a short duration to prepare the field for the next crop (Gadde et al., 2009). From a study by (Gadde et al. (2007), **S**traw to **G**rain **R**atio (SGR) is 0.75. To remove a chaff (an outer husk of the rice grain), rice seeds are firstly milled to produce brown rice by a rice huller. The milling may be continued, removing the bran (i.e. the rest of the husk and the germ), to create white rice. Milled rice is about 68% of paddy rice by weight. Preferred by most, white rice can preserve for longer, but it lacks some significant nutrients causing possibly the deficiency disease beriberi.

Utilization: It is clear from the collected data that the most traditional uses of rice byproducts includes straw & hull for energy, animal feed, building materials, and paper production (Van Nguu Nguyen, 2000). With an increase in crop yields and cropping intensity, the management of rice byproducts is becoming a problem as well as an opportunity. Although Rice straw contains materials that can benefit the society, their apparent value is less than the cost of straw in collection, transportation, and processing it for beneficial use. Excepting as stock feed and for paper production, rice straw is also exploited as a fuel in domestic cook stoves especially in rural areas (i.e. India, Vietnam, Laos, and China), even if the quantity is not significant. Part of the rice straw remaining uncollected in the field and not burnt is subsequently ploughed into the soil to serve as a fertilizer for the next crop. Although soil incorporation of rice straw can provide a source of nutrients, it has also shown to be conducive to crop diseases (Hrynchuk, 1998) and to often affect rough rice yield due to short-term negative effect of nitrogen immobilization (Buresh and Sayre, 2007). This is one of the reasons why open field burning is often practiced for disposal of rice residues (Gadde et al., 2009).

Rice husk is extensively used as a bulking agent in making compost and bedding materials for poultry. Husk ash is produced as a byproduct of rice husk combustion and may be used for various purposes. For instance, husk ash has the potential to be utilized for ingredients of industrial materials such as cement, ceramic materials, insulator, absorbent, also cat-ion exchange resin, etc., because of its high silica content (FAO, 1997 cited by Ueda et al., 2007). Husk ash could be used as silicate supplement for farm soils - particularly in rice paddy fields -, because a rice crop actively absorbs silicate from soil, most of which is accumulated in the shoot and husk (Kato and Owa, 1997). The application of silicate to paddy fields has been reported to increase the structural strength of rice plants, augment their resistance against disease and elements, and improve their ability of photosynthesis and nutrient absorption (Kato and Owa, 1997; Fujii, 2002 cited by Ueda et al., 2007).

World Productions, trade and trend: World production of paddy rice has steadily risen from about 376.6 M t in 1979/80 to 654.4 M t in 2007/2008. Based on 644.49 M t of world production statistics in 2006, the top three producers were China (28.8% of world production), India (21.6%), and Indonesia (8.6%) (see table 2.11). However, the global trade figures were absolutely different, as only about 5 to 6% of world rice production is traded internationally. Although China and India are the top two largest producers of paddy rice in the world, both of countries devour umpteenth indigenous paddy rice leaving little or none to be traded internationally. The largest three exporting countries are Thailand (26% of world exports), Vietnam (15%), and the USA (11%), while the largest three importers are Indonesia (14% of world imports), Bangladesh (4%), and Brazil (3%) (http://faostat.fao.org). Global rice production for 2008/09 is projected at a record 441.1 M t (on a milled basis), about 2 % above 2007/08, due to expanded rice area, estimated at a record 155.4 M ha. The average yield of 4.2 t/ha, the highest on record, is virtually unchanged from last year (Childs and Baldwin, 2009). According to the projections by FAO, global rice stocks carried over to the current annual year are projected to be at a 7-year high of 118 M t which are 9 M t higher than last year and the highest since 2002.

Table 2.11: Planted area, productivity, and yield rate of paddy rice by selected countries

Rice	**Planted Area (M ha)**			**Productions (M ton)**			**Yield (t/ha)**		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	154.701	156.394	156.997	631.869	644.490	654.413	4.084	4.121	4.168
China	29.116	29.463	29.230	182.059	184.128	185.490	6.253	6.249	6.346
India	43.660	43.617	44.000	137.690	139.137	141.134	3.154	3.190	3.208
Indonesia	11.839	11.786	12.166	54.151	54.455	57.049	4.574	4.620	4.689
Bangladesh	10.524	11.200	11.200	39.796	43.504	43.504	3.781	3.884	3.884
Viet Nam	7.329	7.324	7.305	35.791	35.827	35.567	4.883	4.891	4.869
Myanmar	7.008	8.140	8.200	25.364	30.600	32.610	3.619	3.759	3.977
Thailand	10.225	10.165	10.669	30.292	29.642	32.099	2.963	2.916	3.009
Philippines	4.070	4.160	4.250	14.603	15.327	16.000	3.588	3.684	3.765
Brazil	3.916	2.971	2.901	13.193	11.527	11.080	3.369	3.880	3.819
Japan	1.706	1.688	1.678	11.342	10.695	10.970	6.648	6.336	6.537
Others	25.307	25.879	25.398	87.588	89.648	88.910	3.461	3.464	3.501

Source: OAE (2010); OAE (2007)

The prices of major cereals registered considerable gains in 2005/06 and edged upwards during the first quarter of 2006 (see Fig. 2.5). This was partly a result of lower production caused by unfavorable weather, as in the case of wheat and coarse grains. In spite of a larger crop, paddy rice prices rose as a result of sustained purchases by countries in Africa and Asia. Prices for coarse grains remained strong due to lower output and sustained demand for bio-ethanol and feed in the USA. After a robust growth in 2004/05, cereal utilization is forecast to expand at a slower pace. While industrial use of cereals is expected to expand markedly to meet the demand for ethanol, the increase in food usage should be more moderate. Cereal utilization for feed was expected to decline in the wake of avian influenza and lower coarse grain supply. Cereal trade is forecast to contract, as a larger wheat harvest in China will reduce its imports (FAO, 2007d).

Rice remains a basic food commodity, and its importance has extended beyond Asia. However, rapid income growth and diversification of diets is expected to depress per capita rice consumption, especially in Asia. In contrast, rice is expected to gain importance in African diets, where per capita consumption rises from 22 kg to more than 24 kg over the 10-year period. As a share of world production, rice trade is expected to fall slightly, indicating a lessening reliance on the global market that is consistent with a return to more stringent rice self-sufficiency policies in several countries. Much of the expansion in world imports is fuelled by demand in Africa and in Asia, with Thailand forecast to account for around one-third of all rice exports. The tendency for declining global rice stocks could be reversed over the course of the ***Outlook*** by FAO, as recent concerns over supply availability and price volatility foster a rebuilding of reserves (OECD/FAO, 2008). On the 30th of April 2008, Thailand announced a project naming "**the Organization of Rice Exporting Countries** (OREC)", of which members are Thailand, Vietnam, Cambodia, Laos, and Myanmar. Not only will the OREC make the rice price reasonable by helping each other in trading rice on the world market, but keeps it's supply stable to prevent a rice deficit as well. The success of this project will create a win-win situation for both purchasers and producers.

2.2.2.2 Cultivation Trend of Rice in Thailand

The total cultivated area in Thailand amounts to 20.9 M ha of which around half is devoted to rice farming. From the end of the 1960s until the early 1980s, land devoted to rice farming expanded rapidly due to the progress achieved with the ***Green Revolution*** and the efforts to increase rice production. Production increased from 12.4 to 21.2 M t of paddy during the revolution of first two decades (IRRI, 2000). Paddy production in Thailand remained steady over the years (28 to 31 M t) (see table 2.12), and cropping pattern for paddy is characterized by two kinds of paddy output: ***major rice*** during the rainy season of May to September, and ***second rice*** during the dry period of November to February. Production of second rice depends largely on the skill of the farmer and the available resources. Since this is done during the dry season, almost always, production hinges on irrigation practices. Paddy field ownership varies extremely in size, ranging from less than a hectare for an individual farmer to thousand hectares for farmer co-operatives and the like. All throughout the country, small-sized paddy fields are commonly found (Reference). Paddy production and production densities on the region level during 2005 to 2008 are shown in table 2.13, table 2.14, table 2.15, for total rice, major rice, and second rice, respectively.

Table 2.12: Planted area, productivity, and yield rate of paddy rice for Thailand

Paddy Rice	**Crop Year**						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	10.630	10.625	10.650	10.828	10.819	11.230	11.172
Production (M ton)	27.992	29.474	28.538	30.292	29.642	32.099	31.651
Yield (t/ha)	2.633	2.774	2.680	2.797	2.740	2.858	2.833

Source: OAE (2010); OAE (2007)

Table 2.13: Planted area, productivity, and yield rate of paddy rice by regions for Thailand

Paddy Rice (Total)		Country	North	Northeast	Central + East	South
Planted Area (M ha)	**2005**	10.828	2.574	5.386	2.500	0.368
	2006	10.819	2.602	5.378	2.469	0.369
	2007	11.230	2.761	5.446	2.646	0.377
	2008	11.172	2.717	5.525	2.560	0.370
Production (M ton)	**2005**	30.292	8.993	10.761	9.669	0.869
	2006	29.642	8.767	10.771	9.201	0.903
	2007	32.099	9.671	11.063	10.392	0.974
	2008	31.651	9.496	11.136	10.067	0.952
Yield Rate (t/ha)	**2005**	2.797	3.493	1.998	3.867	2.361
	2006	2.740	3.369	2.003	3.726	2.444
	2007	2.858	3.503	2.031	3.927	2.584
	2008	2.833	3.495	2.015	3.932	2.575

Source: OAE (2010); OAE (2007)

The average yield in 2006 was around 2.74 t/ha which is low compared to the world average of 4.1 or the Asian average of 4.2 t/ha (IRRI, 2007). Aside that most cultivation is done in the low percentage of irrigated farming areas, a reason for this low yield is that Thailand mainly produces traditional low-yielding but high quality rice varieties that acquire a higher world market price than the modern high-yielding varieties produced in other countries. However, Thai farmers are gradually changing the production towards new hybrid varieties, especially suitable for dry season cultivation (Wiboonpongse and Chaovanapoonphol, 2001). About 39% of the total national output comes from the Northeast, 30% from the Central, 27% from the North, and only 4% from the South. Although around 50% of the total rice farming areas is located in the Northeast, rice cultivation in this area is predominantly family farm with small land holdings, producing mostly for their own needs. In the Central and Northern, farms are commercialized to a much larger extent. Due to less suitable, the southern region has only a small rice production.

Table 2.14: Planted area, productivity, and yield rate of major rice by regions for Thailand

Paddy Rice (major rice)		Country	North	Northeast	Central + East	South
Planted Area (M ha)	**2005**	9.244	2.041	5.280	1.586	0.336
	2006	9.207	2.046	5.234	1.591	0.336
	2007	9.182	2.045	5.244	1.570	0.323
	2008	9.188	2.017	5.291	1.571	0.308
Production (M ton)	**2005**	23.539	6.725	10.442	5.597	0.775
	2006	22.840	6.455	10.293	5.291	0.800
	2007	23.308	6.610	10.378	5.515	0.805
	2008	23.235	6.597	10.298	5.586	0.754
Yield Rate (t/ha)	**2005**	2.546	3.294	1.977	3.530	2.304
	2006	2.481	3.155	1.967	3.325	2.383
	2007	2.539	3.233	1.979	3.512	2.493
	2008	2.529	3.271	1.946	3.555	2.450

Source: OAE (2010); OAE (2007)

Table 2.15: Planted area, productivity, and yield rate of second rice by regions for Thailand

Paddy Rice (second rice)		**Country**	**North**	**Northeast**	**Central + East**	**South**
Planted Area (M ha)	**2005**	1.584	0.533	0.105	0.915	0.032
	2006	1.612	0.556	0.144	0.878	0.034
	2007	2.048	0.716	0.202	1.076	0.054
	2008	1.984	0.700	0.234	0.989	0.062
Production (M ton)	**2005**	6.753	2.268	0.319	4.072	0.093
	2006	6.802	2.311	0.478	3.910	0.103
	2007	8.791	3.061	0.685	4.876	0.168
	2008	8.415	2.899	0.837	4.482	0.197
Yield Rate (t/ha)	**2005**	4.262	4.256	3.033	4.452	2.967
	2006	4.220	4.154	3.322	4.454	3.052
	2007	4.292	4.274	3.389	4.531	3.132
	2008	4.241	4.140	3.583	4.532	3.201

Source: OAE (2010); OAE (2007)

Thailand has managed to retain its position as the world leading rice exporter. Policies & strategies in rice sector are developed by the Ministry of Agriculture and Cooperatives together with the Ministry of Commerce. The most important influence on rice policies in Thailand has been the export orientation of the agricultural sector. Policies have aimed at stabilizing domestic prices and have been altered during the years according to the development in the world market. At the beginning of the 21st century, the policy evolved into markedly favoring producers when the mortgage program was introduced. Until this point, the domestic rice policies in Thailand had been very sensible and not very distorting. However, the reintroduction of the mortgage program for the first and second crops in 2008, at very high pledging prices, which aims at supporting the poor farmers, caused a lot of damage to the domestic rice industry. The short term results of the policy have been a slowdown in exports, high domestic prices, and large government expenditure. In the long run, the program will have more far reaching negative consequences, if it distorts the incentives for farmers to enhance productivity and decrease costs. The Thai rice sector might lose more of its competitiveness which has already been damaged due to the high prices of Thai rice compared to, for example, Vietnamese rice (Forssell, 2009).

2.2.2.3 Processing of Rice in Thailand

Independent of income, rice is the main staple food for the whole population, but consumption of rice tends to decrease as incomes increase. In 2007, Thailand produced, according to www.usda.gov, around 18.4 M t of milled rice. Of the total milled rice, around 9 M t were exported, making Thailand the leading exporter of rice in the world with a market share of around 30 % calculated from all varieties and qualities together. Around 50% of the exports are high quality long grain rice, which receives the highest price on the market (Vanichanont, 2004). The Ministry of Industry estimated that more than 39,811 rice mills existed in the country in 2006. Most of them located in the Northeast of Thailand (accounting for 73.05%), while the remains were in the North (14.69%), the South (6.39%), and the Central (5.87%). However, there are only 1,333 registered rice mill in Thailand (table 2.16). The rice mills varied extremely in their size and scattered across the country. Unlike the sugar industry where most of the harvest allots to only few processing mills, the structure of rice industry makes it difficult to trace the flow of processed paddy. Consequently, it is reasonable to assume that residue from the paddy processing is also widely scattered among the thousands of rice mill units across the country.

Table 2.16: Thai registered rice mills by regions

Region	Company limited	Limited partnership	Ordinary partnership	Public limited company	Toal
Bangkok	44	58	39	1	142
Central	147	263	24	1	435
North	102	163	10	-	275
Northeast	148	245	11	-	404
East	39	18	4	1	62
South	2	11	2		15
Total	**482**	**758**	**90**	**3**	**1,333**

Source: DBD (2010)

As the global rice industry had become more competitive, a lot of marginal rice mills in the country had to shut down their businesses due to their inability to compete with the more progressive mills in the country, particularly small and medium sized millers. In 2007, there were about 40,000 of mills scattered around the country, but only around 900 were large. Larger millers have upgraded their technology for both production and packing. Many of them have received standards such as **G**ood **M**anufacturing **P**ractices (GMP), **I**nternational **O**rganization for **S**tandardization (ISO), and **H**azard **A**nalysis and **C**ritical **C**ontrol **P**oints (HACCP) during the past decade (Vanichanont, 2004). One problem is that many of the mills, especially the smaller and medium sized ones, employ inefficient technology. Thanks to the financial system providing low interest loans in Thailand, there is opportunity to enlarge existing mills or set up new ones, which is competitiveness enhancing. Compared to countries like the Philippines though, mills in Thailand are more efficient (Dawe et al., 2008).

2.2.2.4 Rice Residues and their Utilization in Thailand

It is well known that rice husk is not only a potential source of energy, but also a value-added byproduct. However, burning husks in open air produces smoke. It was reported that airborne husks coming from open piles from gusty winds, have caused skin irritations for local residents. Therefore, various technologies for utilization of rice husk through biological and thermochemical conversion are being developed. Among various biomass-based energy resources relevant to Thailand, rice husk ranks second after bagasse regarding supply outputs (NEPO, 2000). In Thailand where about 21 to 26 M t of rice is annually produced, about 5.890 M t of rice husk is annually produced as a byproduct in rice processing at rice mills across the country. About a half (49.3%) is currently consumed, mainly as fuel in rice mills for drying, milling, and parboiling paddy rice. The amount of husk consumed at rice mills is greatly depended on the efficiency of rice processing machinery, therefore more energy-efficient processes for husk combustion at rice mills should be developed to mitigate possible competition for rice husk (Ueda et al., 2007). The remaining husk was for power generation, with generally an overall efficiency of only about 21%, for compost production, as filler in the brick-manufacturing industry, and as bedding material for animals.

The total quantity of rough rice produced yearly is 29.146 M t for an average from 2002 to 2006 (FAORAP-APCAS, 2007). It is estimated that average 21.859 M t of rice straw is produced (Gadde et al., 2007), and 48% of this amount or 10.451 M t (8 to 14 M t) is burnt in the field after rice harvest annually, contributing to local pollution problems (OAE, 2006; Fungtammasan, 2005; DEDE, 2005; PCD, 2005). 24 to 40% is utilized, namely, 15% for animal feed, 5% for organic fertilizer, 1.5% for trading (sold) out of which 0.18% as fuel and 0.27% for other activities. Only arout 30% is unused (DEDE, 2003b). Burning is still the most common practice in Thailand for rice straw disposal, especially the Central region to quickly facilitate planting the next crop. (PCD, 2005; Jiaranaikul, 2004; Wenuchan, 2004; Chamsing, 2005). In some provinces in the North and Northeast, rice straw is being used for animal feed. The rice straw does not have many nutrients and its cost is also quite high (30 Euro/t), but it is used because there are not many cheaper alternatives in those areas. Therefore, rice straw seems to have a greater potential for exploitation as energy source when managed properly.

2.2.3 Oil Palm

2.2.3.1 General Data about oil palm

Botanical Specification: Palm oil and its fractions fruited from African oil palm, *Elaeis guineensis*, is a practical and attractive choice for importers and food manufacturers, especially in 3rd world countries, thanks to its price competitiveness, year-round supply, diversity and versatility for edible & non-edible applications. In terms of energy expression, oil palm is an energy efficient crop that requires less energy input to produce its grease. The ratio energy output to input is wider for oil palm than any other commercially grown oil crops sources such as soybean and rapeseed (see Fig. 2.6). Oil palm tree is a tropical plant commonly growing in warm climates at altitudes of less than 1,600 feet (487.68 m) above sea level. There are two species of oil palm with generic name derived from the Greek for oil, **elaion**. The better known one is the one originating from the Gulf of Guinea in West Africa, first illustrated by Nicholaas Jacquin in 1763, hence its name - *Elaeis guineensis Jacq*. -. Another species, *Elaeis oleifera*, is native to America while the species name refers to its country of origin (Poku, 2002; Lotschert et al., 1991)

Mature tree is single-stemmed and can grow up to 30 m tall with a diameter of 20 to 75 cm. When the palm tree reaches height of 15 to 18 m (about 25 years), its fruits become difficult to harvest and as a result it is generally bulldozed down for the next rotation. Oil palm leaves are pinnate, and reach between 3 to 5 m long. A young tree produces about 30 leaves a year. Established trees over 10 years produce about 20 leaves a year (Lotschert et al., 1991). Oil palms are monoecious, producing male and female inflorescences in leaf axils. The flowers are produced in dense clusters; each individual flower is small, with three sepals and three petals. Although the palm fruit is drupe as in many palms, it is about the size of a small plum and grows in a large bunch weighing 10 to 20 kg. The bunch can have up to 2000 individual fruits. The fruit takes 5 to 6 months to mature from pollination to ripeness. The individual fruit, ranging from 6 to 20 g, are made up of an outer skin (the exocarp), a pulp (mesocarp), and a single seed. The mesocarp, from which palm oil is derived, is fibrous and oily. Encased in a brown shell (endocarp), the seed contains opaque white kernel, termed **P**alm **K**ernel **C**ake (PKC). PKC itself contains oil, quite different to palm oil but resembling coconut oil. Unlike other relatives, the oil palm does not produce offshoots; propagation is by sowing the seeds (Poku, 2002).

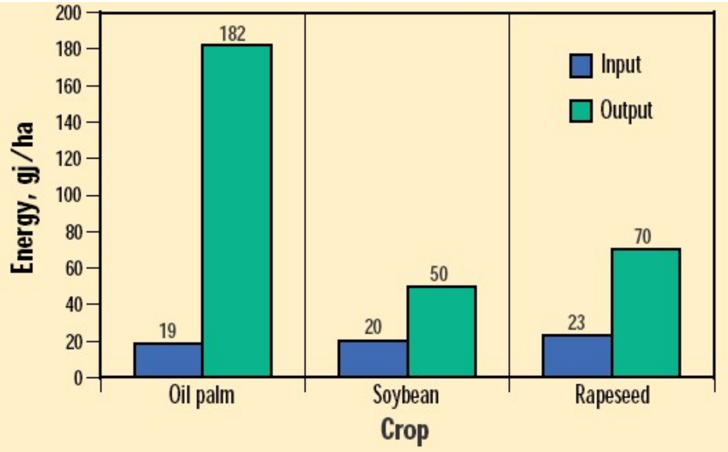

Fig. 2.6: Input and output energy consumption of crops
Source: Fairhurst and Mutert (1999)

Cultivation and Harvest: African oil palm is grown in tropical climates, particularly in Southeast Asia (Malaysia, Indonesia, and Thailand). Of the total land area in the world producing palm oil, 63% is in Southeast Asia accounting for 80% of the world palm oil (Rosillo-Calle et al., 2009). There are 3 naturally occurring forms of the oil palm fruit, termed *dura*, *tenera*, and *pisifera*. Most cultivars are the *tenera* form which produces fruit with higher oil content. For following rotation, new trees are planted among the dead and rotting trunks, and propagated by seed. As cash crop, seed is produced by companies specializing in oil palm breeding. During the first 3 years, little or no fruit is obtained. None of the old leaves are pruned off in order to facilely access to the fruit bunch. In the early stages of fruit formation, the oil content of the fruit is very low. As the fruit approaches maturity the formation of oil increases rapidly to about 50% of mesocarp weight. As the fruit ripen, they change from black to orange in *virescens* types, or from brown/black to red in the *nigrescens* types. However, fruit abscission is the best index of bunch ripeness. Fruit bunches are harvested using chisels or hooked knives attached to long poles, after that they will be carried to a oil palm mill. Each tree must examined every 10 to 15 days as bunches ripen throughout the year (Abdullah, 2008).

In an un-bruised fresh ripe fruit, the **F**ree **F**atty **A**cid (FFA) content of the oil is below 0.3%. However, the exocarp of the ripe fruit becomes soft, and is more easily attacked by lipolytic enzymes casing increase in the FFA content via hydrolysis, especially when the fruit becomes detached from the bunch. Research has shown that if the fruit is bruised, the FFA in the damaged part of the fruit increases rapidly to 60% in an hour. Oil palm is the highest yielding oil crop, producing on average about 4 to 5 t of oil/ha/y, about 10 times that of soybean oil (May et al., 2005). Under suitable climatic and soil conditions, oil palms may provide an oil yield higher than 4.5 t/ha/y. In Malaysia, oil palm yields an average of 3.68 t/ha/y (projected to reach 6 t/ha/y within the next decade due to crop improvement and good farm practice).

Utilization: The oil winning process, in summary, involves the reception of **F**resh **F**ruit **B**unch (FFB) of oil palm from the plantation, sterilizing and threshing of FFB to free the palm fruit, mashing the fruits and pressing out crude oils. Crude oils are further treated to purify and dry before storage and export. FFB is harvested and transported to factory then extracted within 24 hr, otherwise the quality of extracted palm oil will deteriorate rapidly. Moreover, about 1 t of water is needed to process 1 t of FFB, therefore they tend to be located close to a watercourse and the palm growing area (Rock, 2001). The extraction of Palm oils is a complex process. **C**rude **P**alm **O**il (CPO) derived from mesocarp is the primary product utilized in both food and non-food application, while **C**rude **P**alm **K**ernel **O**il (CPKO) drawn from the seed is applied mainly for soap manufacture. After oil removal, the residues are **P**alm **P**ressed **F**iber (PPF) and **P**alm **K**ernel **S**hell (PKS). In the past, palm oil was the second most important vegetable oil crop in the world after soy, however currently palm oil become the main grease oil source for the world (see Fig. 2.7). For liquid biofuel production, CPO is less suitable than other vegetable oils owing to its high viscosity, lower energy density and high flash point. However, oil palm gives high yields at low prices, and hence is likely to be important in meeting the biofuel demand (Carter et al., 2007; Koh, 2007).

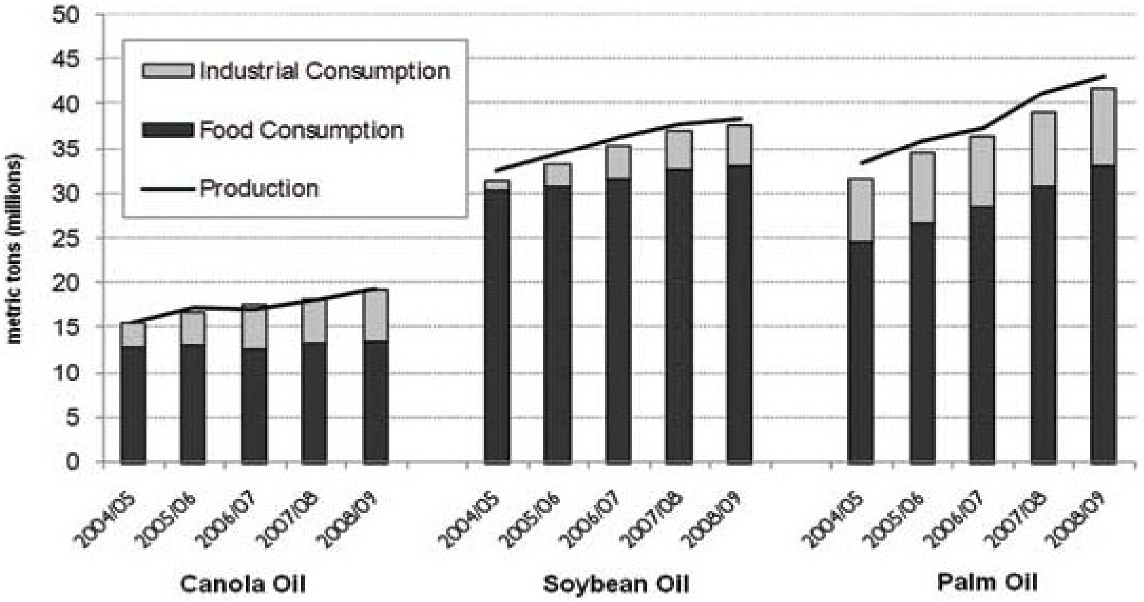

Fig. 2.7: World Vegetable Oil Production and Consumption (M t)
Source USDA cited by Christiansen (2008)

A residue after the separation of the palm fruit from the FFB, **E**mpty **F**ruit **B**unch (EFB) is the shortest fiber among fiber residues of oil palm, and has 2% of oil by weight. In general, it is not applied as fuel in boiler due to the emission of white smoke and fouling problem from its oil content. EFB is traditionally incinerated for its ash for fertilizer due to the high potassium content. The ash is high in alkalinity and useful for the oil palms on alluvial soils. Apart from as a soil cover material in the oil palm plantation to preserve moisture and reduce soil erosion, EFB can be used as pulp source. The Palm Oil Research Institute of Malaysia developed a method to apply fiber from EFB for pulp and paper making with high quality. For MDF production, Ramli et al. (2002) conclude that pretreatment of the fiber by using water or NaOH to remove its residual oil, significantly improved the MDF performance and eliminating delaminating during consolidation of panel. Two plants have been established in Sabah and Peninsular Malaysia (Durst et al., 2004). Another route is oil extraction from EFB to increase oil yield, while the pressed EFB can be used as fuel in the boiler with about 18,000 kJ/kg of the gross caloric value (Kittikun, 2002 cited by Chavalparit, 2006). However this method is still expensive. To reduce transportation cost of EFB from palm mill, composting is one of the attractive methods. From the experiment this process required 80 days for maturity and the addition of water to control the moisture (Unapumnuk, 1999).

The problem, associated with burning PPF (a pericarp fiber) and PKS, is the emissions of dark smoke and CO_2. PPF can be pressed into briquettes or pellets to improve their handling and combustion properties. Beside the combustion, pyrolysis of PKS is possible. From the research of Kawser and Nash (2000), it follows that pyrolysis yield liquid oil, solid, and gas. The liquid oil was found to contain a very high concentration (43.3%) of phenol and its derivative. However, costs of this process are very high. **P**alm **O**il **M**ill **E**ffluent (POME) contains about 94.2% water and 5.8% total solids. With evaporation technology, water can be recovered and the residual solids can be utilized as fertilizer. PKC has been commonly used to produce animal feed. Unlike coconut palm, the stem of the oil palm is not suitable for direct utilization as a wood substitute. Other potential uses for the stem include: moulded furniture, sawing & laminating palm stems, particleboard manufacture, and the production of activated charcoal (Razak, 2000).

World Productions, trade, and trend: relatively little oil palm is grown outside Southeast Asia, but 410 to 570 M ha of currently forested lands across Southeast Asia, Latin America, and Central Africa is potentially suitable for oil palm cultivation. Thanks to its high oil productivity (as high as 7,250 L/ha/y), oil palm is the prime source of vegetable oil for many tropical countries. Increased by 55% between 2001 and 2006 (see http://faostat.fao.org), worldwide palm oil production during 2007 to 2008 was 39.8 M t, of which 4.3 M t was palm kernel oil. It is thus by far the most widely-produced tropical oil, and constitutes 30% of total edible oil production worldwide. The world largest producer and exporter of palm oil today is Malaysia, producing about 47% of the world supply with a growing area of over 20,000 km^2 (see also table 2.17). Indonesia is the second, producing approximately 36% of world palm oil volume, while Thailand is the forth. According to USDOA (2007), since 2005 Indonesia became the world's largest producer of CPO. Both nations are expanding their palm oil production capacity and the market continues to grow.

Table 2.17: Planted area, productivity, and yield rate of oil palm by selected countries

Oil Palm	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	12.872	13.151	13.834	173.273	180.289	190.573	13.462	13.709	13.775
Indonesia	3.690	4.120	4.580	64.255	70.000	78.000	17.413	16.990	17.031
Malaysia	3.550	3.680	3.790	75.650	75.400	77.700	21.309	20.489	20.501
Nigeria	3.350	3.075	3.150	8.500	8.300	8.500	2.537	2.699	2.698
Thailand	0.324	0.380	0.426	5.003	6.715	6.390	15.434	17.678	14.997
Colombia	0.170	0.165	0.165	3.273	3.200	3.200	19.298	19.399	19.399
Ecuador	0.128	0.130	0.135	1.930	2.000	2.100	15.022	15.375	15.551
Ghana	0.325	0.333	0.300	2.025	2.097	1.900	6.225	6.298	6.333
Cote d'Ivoire	0.197	0.182	0.190	1.350	1.413	1.448	6.849	7.760	7.618
Papua New Guinea	0.088	0.092	0.096	1.300	1.350	1.400	14.773	14.674	14.583
Cameroon	0.058	0.058	0.058	1.300	1.300	1.300	22.383	22.383	22.383
Others	0.991	0.936	0.944	8.687	8.514	8.635	8.770	9.096	9.149

Source: OAE (2010); OAE (2007)

Vegetable oils are among the most rapidly expanding agricultural sectors, and more palm oil is produced than any other vegetable oil. Palm oil remains the most widely used edible oil, and world consumption is due to increase~~s~~ by 46% over the next 10 years. Global palm oil production is increasing by 9% every year, prompted largely by expanding biofuel markets in the EU and by food demand in Indonesia, India, and China (EC, 2006; Clay, 2004). The area for oil palm is rapidly increasing, and many rubber plantation owners are switching to oil palm due to the higher profit margins. By 2001, there were approximately 6

M ha of oil palm plantations, of which 80% are located in the Asia-Pacific region. Oilseeds stocks are high and are expected to increase further. There are conflicting signals on the demand side as higher oilseed utilization for the production of biodiesel may be offset by lower consumption for the production of feed as a result of the avian influenza epidemic. In the EU, oilseed imports are forecast to reach unprecedented levels as the domestic crop is increasingly used to satisfy rising demand for biofuels (FAO, 2007d).

2.2.3.2 Cultivation trend of Oil Palm in Thailand

During 1975 to 2000, the palm oil production in Thailand showed rapid growth. Since 1985 the area for oil palm cultivation in Thailand has more than doubled to 0.17 M ha in 1995. Under the government's 5-year plan (1996 to 2001) the area was doubled again to 0.313 M ha in 2002 (Chavalparit, 2006). This trend has been continued till now (table 2.18) under biodiesel mandate by the government. In Thailand, the major oil palm planting areas is located in the South, where main cultivating provinces include Krabi, Surat Thani, Chumporn, Satun, Trang, and Prachuab-Kirikan. A small portion of palm oil production is also found in the East, particularly Chonburi and Rayong (table 2.19). The main type of oil palm producers in Thailand is a smallholding farmer. Over 99.3% of total growers are smallholders and cooperatives. Their plantation areas cover around 64% of the total area. The rest is covered by commercial companies, but the FFB produced from them accounts for 43% of the total FFB production. Since the FFB is mostly harvested during August to November (the peak season) each year, output from this period accounts for 42% of total output year round (Chavalparit, 2006).

Table 2.18: Planted area, productivity, and yield rate of oil palm for Thailand

Oil Palm	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Planted Area (M ha)	0.313	0.329	0.385	0.440	0.473	0.512	0.580
Harvested Area (M ha)	0.263	0.288	0.309	0.324	0.380	0.426	0.460
Production (M ton)	4.001	4.903	5.182	5.003	6.715	6.39	9.265
Yield (t/ha)	15.211	17.034	16.764	15.434	17.678	14.997	20.155

Source: OAE (2010); OAE (2007)

The current average yield of a plantation in Thailand is between 14 to 18 t of FFB/ha/y (average 16.5). Each oil palm tree yields about 110 kg of FFB/y. the average total production of FFB is 2.75 t/palm tree or 413 t/ha/y (Chavalparit, 2006). Lower yields (3.25 t/ha/y) are referenced in this study. Due to a high competitive price of vegetable oils in world market, the Thai government has revealed its ambitious plans of oil palm industry in the 8th National Development Plan since 1997. The current policy of the Ministry of Agricultural and Cooperatives, outline in the oil palm and palm oil development plan of 2000 to 2006, has an objective to increase the average production of FFB to 18.75 t/ha/y and to increase oil content from 17 to 19%. It also aims to further expand the area for plantation (Chavalparit, 2006).

For the problem in the oil palm sector: 1) There is no systematic cooperation among the relevant actors, especially within the economic networks such as the crude palm oil association, research institutes/universities, and oil palm planters; 2) There is no central government institute that takes responsibility in generating and collecting relevant information on palm oil production; 3) Lack of good palm varieties, oil palm farmers purchase the seeds from a seed supplier nearby or recommended by other growers; 4) Most farmers sell their products to FFB suppliers, since transportation of FFB to a processing mill is costly and their amount is generally small. There is no direct contact between millers and growers. This is one of the most crucial barriers for reuse/recycle of the wastes/byproducts. 5) Like the sugar industry, during the highest season, FFB is more overwhelming than the total capacity of palm mills. The price of FFB is therefore bottomed out; 6) At present, farmers use chemical fertilizer and they are not aware of the fertilizer value of the factory waste.

Table 2.19: Planted area, productivity, and yield rate of oil palm by regions for Thailand

Oil Palm		**Country**	**North**	**Northeast**	**Central + East**	**South**
Planted Area (M ha)	**2005**	0.440	n.s.	n.s.	0.033	0.407
	2006	0.473	n.s.	n.s.	0.037	0.436
	2007	0.512	n.s.	n.s.	0.047	0.465
	2008	0.580	n.s.	n.s.	0.061	0.519
Havested Area (M ha)	**2005**	0.324	n.s.	n.s.	0.024	0.301
	2006	0.380	n.s.	n.s.	0.028	0.351
	2007	0.426	n.s.	n.s.	0.033	0.394
	2008	0.460	n.s.	n.s.	0.036	0.423
Production (M ton)	**2005**	5.003	n.s.	n.s.	0.320	4.683
	2006	6.715	n.s.	n.s.	0.413	6.302
	2007	6.390	n.s.	n.s.	0.371	6.019
	2008	9.265	n.s.	n.s.	0.673	8.591
Yield Rate (t/ha)	**2005**	15.431	n.s.	n.s.	13.581	15.576
	2006	17.677	n.s.	n.s.	14.507	17.934
	2007	14.996	n.s.	n.s.	11.407	15.292
	2008	20.154	n.s.	n.s.	18.468	20.299

Source: OAE (2010); OAE (2007)

2.2.3.3 Processing mill of Oil Palm in Thailand

Thai palm oil industries are agro-industrial units also located mainly around the southern part of country. Palm oil mills can be divided into two groups: 1) large scale mills where palm fruit is crushed separately from palm kernels (producing both CPO and CPKO), typically with an average capacity of 740 t/hr of FFB. In 2002, there were 25 large palm oil factories with an overall design capacity of 5.3 M t/y of FFB. They are utilizing the standard wet production processes and oil loss in wastewater is the most important indicator for a factory to improve the efficiency of the production process; 2) small scale whole palm crushing mills which have been adapted from conventional coconut oil mills. In 2002, there were 25 small palm oil mills of this size with a total capacity of around 0.32 M t/y of FFB. Palm oil from these mills is mixed palm oil between CPO and CPKO (Chavalparit, 2006).

The productivity of CPO has increased dramatically over the past 15 years (see Fig. 2.8). In 2006, CPO has produced 1.2 M t and tendency will be to increase it because of the plans by government to promote biodiesel produced from palm oil. All of the 71 palm oil mills have a more or less similar production process (wet process), and the current CPO yield is about 17 to 20% of FFB by weight. Their production capacity 1,600 to 1,800 t FFB/h or varies between 25 and 60 t FFB/h/mill. The price of palm oil in the world market is much lower than the domestic price, therefore palm oil export is low. The quantity and value of export of palm oil is only 5% of total production. The major export markets are Malaysia, India, and Burma. In the last few years, the value of import increased again due to shortage of CPO in the dry season. Major types of palm oil imported are hydrogenated palm oil, used as raw material in many industrial processes, and CPO (Chavalparit, 2006).

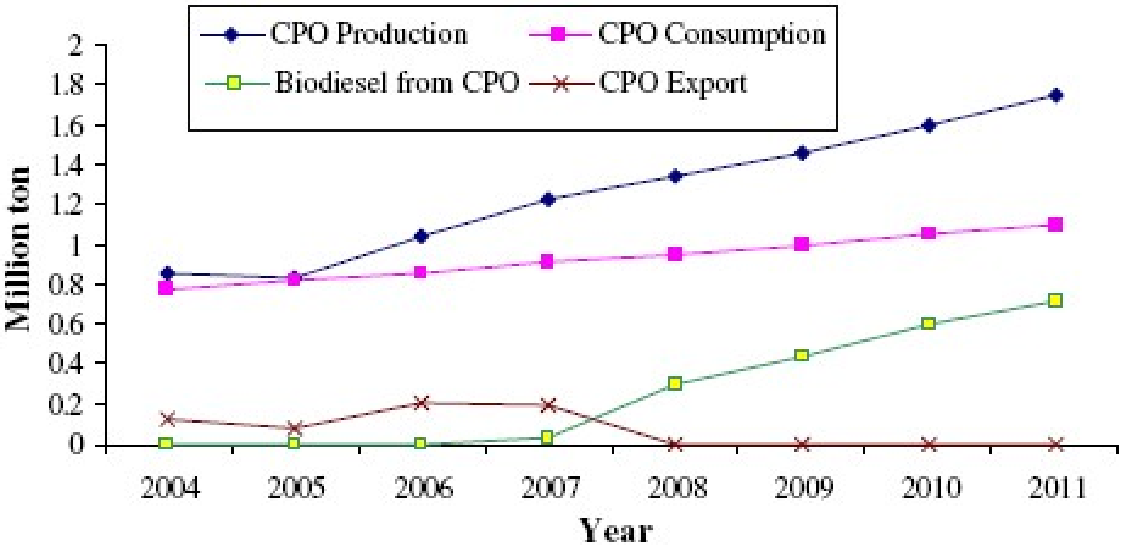

Fig. 2.8: Production trend of CPO and its utilization in Thailand
Source: Pleanjai and Gheewala (2009)

For domestic demand, around 90% of all CPO is sold to refineries, while the rest goes to soap and detergent industries. There are 11 refining factories in Thailand. Most refinery factories are set up in Bangkok and its environment, because the important market for palm oil is in the central region. At present (2003), the refinery capacity of crude palm oil is 0.84 M t/y. About 95% of refined palm oil is consumed locally. The remaining 5% is sold to neighboring countries, such as Laos, Myanmar, and Cambodia (USOAE, 2004). CPO refinery results in either **R**efined-**B**leached-**D**eodorized (RBD) oil as the main product, or in its derivatives RBD stearin & olein. The only byproduct of refining is **P**alm **F**atty **A**cid **D**istillate (PFAD), which results from filtering the fatty acids and amounts to less than 5% by weight of all processed CPO. PFAD is commonly used in producing soap, animal feed, plastics, and other intermediate products for the oleochemical industry (Chavalparit, 2006).

The problems in this sector are: 1) To protect the CPO industry in Thailand, the government imposed a high tariff wall and restricted import of palm oil products in 1982. When the Thai palm oil market has to open up to foreign competition, under the Asian Free Trade Agreement, the palm oil industries will be strongly affected due to it higher cost compared to that of Malaysia; 2) FFB production is about 4 M t/y, but the maximum production capacity of all 25 wet-process factories is about 740 t/hr or 5.3 M t/y (with 300 operating days/y and 24 hr/day). Thus average factories currently operate at 75% of their full design capacity; 3) The electricity and fuel costs of palm oil mills are less than 1% of the total cost, consequently there is no incentive to recover and reuse biogas from wastewater treatment systems. Only if they can sell excess power to the grid, the investment of anaerobic digestion tanks to recover biogas for power generation will be economically attractive for these factories; 4) There is a lot of solid waste that has to be treated before disposal. These wastes include 0.03 M t/y of decanter sludge and 0.05 M t/y of ash; 5) The problems of solid waste management in factories are improper storage and handling of solid waste material, and improper land application techniques or practices for solid waste. These wastes consequently case a bad smell and dust that affects the surrounding communities. Moreover, the overflow from wastewater treatment plants in the rainy season causes heavy surface water pollution.

2.2.3.4 Oil Palm Residues and their utilization in Thailand

The amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials, is on the average of 231.5 kg/y of dry weight. Fig. 2.9 shows types of biomass produced from oil palm tree and their utilizations. Oil palm fronds are available daily throughout the year when the palms are pruned during the harvesting of FFB. Oil palm trunk is obtained during the re-plantation of the oil palm trees. Fronds are a source of food for ruminants (cattle and goats). They are also left to rot in between the rows of oil palm trees at the planting site for following reasons: 1) soil conservation; 2) increase the fertility of the soil; 3) increase the amount of water retained in the soil; 4) erosion control; and 5) provide a source of nutrients to the growing oil palm trees (Nutrients are recycled, as a long term benefits) (Dixon, 2008). Some of the trunks are mixed with EFB and PPF to be combusted and produce energy. Oil palm lumber has been successfully utilized as core in the production of blackboard (Sumathi et al., 2007; Husin et al., 2005). Moreover, oil palm trunk has been used to produce particleboards (Husin et al., 2005; Gurmit et al, 1999)

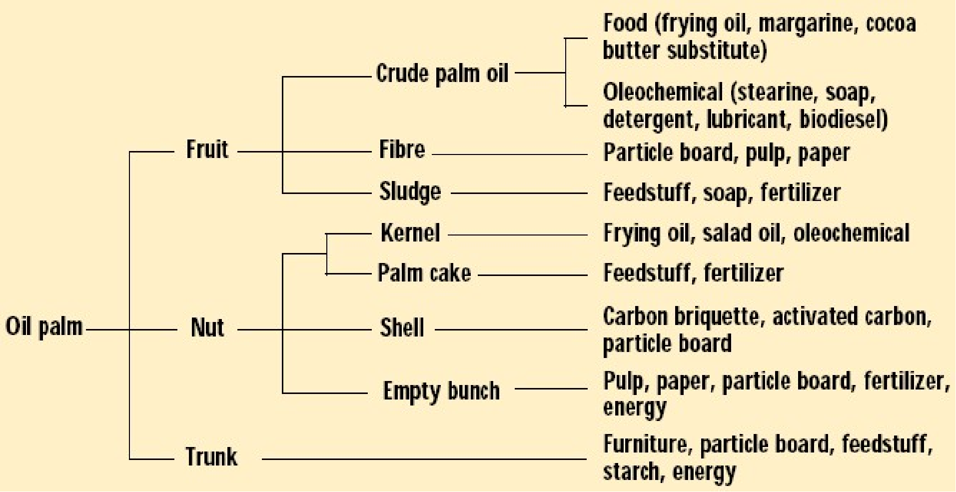

Fig. 2.9: Generated biomass from oil palm tree and their utilizations
Source: Fairhurst and Mutert (1999)

The entire crude palm oil process does not need any chemical as a processing aid. Therefore, all substances found in the products, byproducts and residues, originate from the FFB. However, there are still a number of pollution problems at the production facilities, such as high water consumption - generation of high organic loaded wastewater - generation of large quantities of soled waste and air pollution (Fig. 2.10). In a palm mill, only 23% of raw materials are produced as products, the rest are wastes/byproducts. Most of the byproducts can be reused in the production process or in other industries. PPF (14%) are used as fuel in boilers to generate steam and energy, required for the mill operation. In the past, EFB (24%) and PKS (6%) were disposed of by the land filling method, which is very costly. Recently, only 20% of shell is burnt together with fiber, the rest is sold as fuel in cement factories and brick production. EFB is return back to the field as media for growing straw mushrooms. After the mushroom harvest, EFB is available as palm fertilizer. EFB is also used as a soil cover material in the oil palm plantation, but it takes almost a year to decompose and its transport is costly owing to its bulky property. EFB can also be used to generate power. To make it more easily combustible, EFB should be chip before feed to boiler, however this option is not often practiced because palm mill has already enough energy from shell and fiber. From the viewpoint of logistics and cost, EFB offers the best choices as raw material in pulp and paper industry (Chavalparit, 2006).

Wastewater from palm oil mill commonly has an extremely high content of degradable organic matter, which is due in part to the presence of unrecovered palm oil. Therefore, it could be regarded as a source for the production of biogas, despite not having the biggest potential for producing it (Fig. 2.10). However, the major sources for biogas of the country are the wastewaters from cassava starch factories and pig farms.

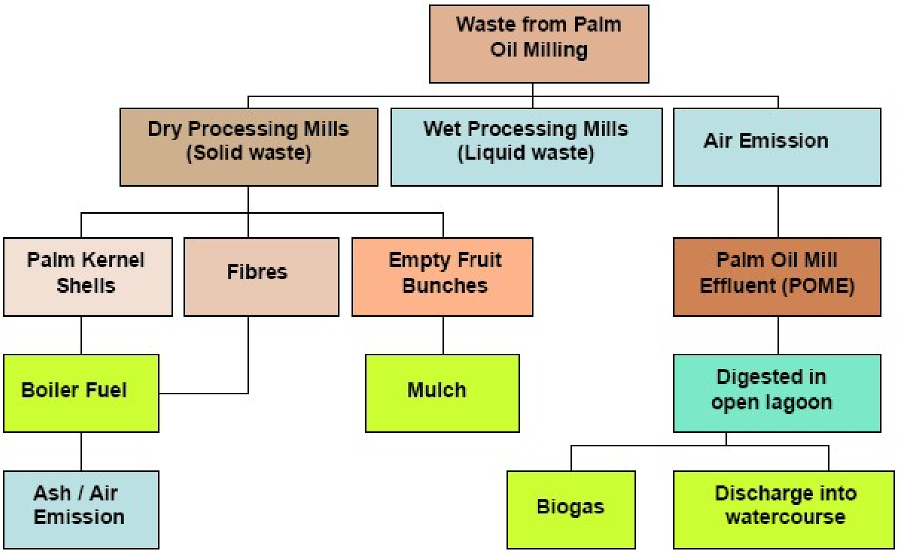

Fig. 2.10: Sources of waste from palm oil milling

Source: redrawn from ADB (2006) by Panapanaan et al. (2009)

The amount of CH_4 emitted during POME treatment at the mill is based on the case study of Prasertsan and Sajjakulnukit (2006) POME yield of 3 m^3 POME per t CPO, a biogas yield of 28 m^3 biogas/m^3 of POME and a 40% share of CH_4 in the biogas. The potential of biogas production in 2006 was approximately 105 M m^3 provided 60 M m^3 of CH_4. The equivalent energy content is approximately 84 KTOE, equal to 15 MW_e or 84 M L for fuel oil. Referred to the strategy of palm oil plan (2003 to 2029), potential trend of biogas production in 2029 could be estimated for 420 M m^3, equivalent energy content around 193 KTOE or 59 MW_e. However, all of the 71 palm oil mills, the existing systems produce only about 2 to 3 M m^3 of biogas or 1 to 3% of the overall potential - a little utilization because the mills have already excess energy sources from other palm oil residues as mention before -. The mill employs a decanter for the recovery of oil from the wastewater. The generated decanter cake can be utilized as fertilizer, but it has the potential to be used as animal feed thanks to the high protein content. If it (about 75% MC) is kept for more than 24 hr, it ferments and then produces a bad smell (Chavalparit, 2006; Pleanjai et al., 2004).

2.2.4 Cassava

2.2.4.1 General Data about Cassava

Botanical Specification: Also known as yuca, manioc, or mandioca, cassava (*Manihot esculenta* Crantz) is a woody shrub of the Euphorbiaceae (spurge family) native to South America (Velmerugu, 1992). It is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates. About 40% of cassava root is directly used for human consumption, particularly in processed form. Most of the remainder is destined for animal feed or processed for starch. Indeed, cassava is the third largest source of carbohydrates for humans in the world (JIC, 2010).

Cassava varieties are often categorized as either "sweet" or "bitter" varieties, signifying the absence or presence of toxic levels of cyanogenic glucosides. The so-called sweet types can produce as little as 20 mg of cyanide per kg of fresh roots, while "bitter" ones may produce more than 50 times as much (1 g/kg). Cassavas grown during periods of drought are significantly high in these toxins. One dose of pure cassava cyanide (40 mg) is sufficient to kill a healthy cow. Its root, however, is eaten raw wherever in Africa (Aregheore and Agunbiade, 1991; White et al., 1998).

Commercial cultivars can be 5 to 10 cm in diameter at the top, and 50 to 80 cm long. The large, palmate leaves ordinarily have 5 to 7 lobes borne on a long slender petiole. They grow only toward the end of the branches. As the plant grows, the main stem forks usually into three branches which then divide similarly. The roots or tubers radiate from the stem just below the surface of the ground. Feeder roots growing vertically from the stem and from the storage roots and penetrate the soil to a depth of 50 to 100 cm. This ability of the cassava plant to obtain nourishment from deep below the surface may help to explain its growth on inferior soils. The flesh can be chalk-white or yellowish. The cassava plant yields the highest food energy per cultivated area per day among crop plants, except possibly for sugarcane (Rosa et al., 2006; FAO, 1977).

Cultivation and Harvest: Just like a potato, the cassava root is long and tapered, with a firm homogeneous flesh encased in a detachable bark, about 1 mm thick, rough and brown on the outside (Rosa et al., 2006). Cassava can be harvested either manually or mechanically, although it is generally gathered by hand. The upper part of its stem with the leaves is plucked off before harvest, then the lower part of stem is raised and the roots are pulled out of the ground. Finally, the roots are removed from the base of the plant. Cassava is commonly propagated by cutting the stem after the root harvest into sections of approximately 30 cm (1 foot), these being planted prior to the next rainy season. Farmers cultivate cassava frequently on marginal soils. (FAO, 2004b; Dixon et al., 2002; Fresco, 1986). Average fresh yields in Africa vary from 9.1 to 14.4 t/ha (http://faostat.fao.org). However, it gives relative good yields when soil fertility is poor (Howeler, 2002; Fresco, 1986).

Although popular as a source of starch, the roots can be seen as a liability owing to their high degree of perish-ability and high water content (70% of fresh weight). As a result there is no margin for error in handling cassava (DNC, 2004). Also the high water content of roots introduces the added expense of transporting a large amount of water from field to factory with no useful purpose. This problem might be overcome by producing dry chips, but starch recovery and quality both from dry chips is poor (FAO/IFAD, 2004). This hardy tropical root seems unsuited to modern farming. First, it is usually propagated vegetatively from stem cuttings that do not store well and are costly to cut and handle. Vegetative reproduction also means the rate of multiplication of new, improved varieties is slow, retarding their adoption. Harvesting cassava is labor-intensive, and its roots are bulky and highly perishable. In fact, far less research and development have been devoted to cassava than to rice, maize and wheat (see http://www.fao.org/ag/AGP/agpc/gcds/index_en.html)

Utilization: Though a good source for protein, **cassava leaves** cannot be consumed raw, since they contain free and bound cyanogenic glucosides which are converted to cyanide in the presence of linamarase, a naturally occurring enzyme in cassava (O'Hair, 1998). The utilization of cassava root exists in three broad areas: 1) direct human food; 2) starch and flour industry; and 3) chip or pellet for animal feed. These will be discussed below (FAO/IFAD, 2004).

1) **Direct human food:** To express the consumption level in different terms, daily cassava consumption in Africa is 0.4 kg/person. This is greater than the daily consumption level of most staples in any part of the world. Because of higher population growth rates and higher levels of cassava consumption, the greatest growth potential for the use of cassava as a human food appears to exist in Africa. The major importers are North America with imports of nearly 38,000 t and Europe with imports of 5,000 t. The prime exporter is Costa Rica. This market exists because of the discovery of the paraffin coating process, or less frequently used CO_2 filled plastic bag process, that extends the shelf life of fresh cassava roots. The market is driven by ethnic communities in Europe, normally of African descent, and North America, normally Hispanics.

2) **Starch:** From past experience, manufacturers associated the name "cassava flour" with poor quality fermented products having a low pH, unpleasant taste, odor and colour. The renewed interest in cassava flour is owing to economic factors. Thailand is the dominant exporter accounting for about 85% of world cassava starch exports. In 1990, China and Japan accounted for about 80% of global starch imports partially reflect the fact that these countries do not have an abundant raw material source for starch manufacturing. In North America, the preferred starch is maize starch, but a variety of starches are preferred in Europe depending in part on the geographical region. The preferred starches are potato, wheat, and maize. When the price of maize starch is too high, the North American paper industry becomes a large importer of cassava starch .

3) **Chips:** by the continental trends in urban growth and expanding livestock numbers, Intensive livestock production will undoubtedly place greater reliance on the use of compound animal feeds. Research has led to the identification of several successful cassava-high protein mixes that can be used as substitutes for maize, broken rice, or sorghum (Table X). Cassava is still considered to have a potential in this sector because of large differences in price between cassava and maize. As an estimate of the opportunities for the use of cassava in animal feeds, it is assumed that cassava chips or pellets can replace 10% of maize at a ratio 2.5:1.

World Productions, trade and trend: From the 1980s to the present, the main influences on cassava production and commerce were: 1) rapid growth in many Asian economies, with accompanying changes in food consumption patterns; 2) increased demand from industry for starch; and 3) increasing implementation of trade policies that reduced cassava preferential treatment in European markets (Fig. 2.11) (FAO, 2000a). Cassava generally enters markets where other calorie or industrial starch sources may readily be substituted. Future growth, therefore, is largely linked to cost competitiveness. Alternatively there is growth potential in markets that require specific characteristics that only cassava provides. World production of cassava root was estimated to be 184 M t in 2002. Africa is the center of cassava production with turnout of 99.1 M t, as 51.5 M t were grown in Asia against 33.2 M t of Latin America and the Caribbean (table 2.20). The fact that cassava production in Africa has more than tripled in the last 4 decades, mainly due to an increase in area cultivated (Hillocks, 2002). However, based on the statistics from the FAO, Thailand is the largest exporting country of dried cassava with a total of 77% of world export in 2005. The second largest exporting country is Vietnam (13.6%), followed by Indonesia (5.8%) and Costa Rica (2.1%) (see table 2.21).

In largely rice-based food systems of Asia, cassava is emerging as a fully commercial crop and entering a diversified market. The capacity of cassava on adaptation to soils of marginal fertility and uncertain rainfall, as well as its capacity to provide income and thereby alleviate poverty, are the principal attributes allowing this crop to play a catalytic role for rural development in Asia. The factors that tend to further reinforce this key role are the domestic industry demand for starch and animal feed, the market opportunities for processed food products, the export potential for pellets and starch, and the competitive costs of production. In Southeast Asia, cassava is the third most important food crop after rice and maize and its growing industrial importance makes investment in agriculture research even more crucial (Ceballos, 2008).

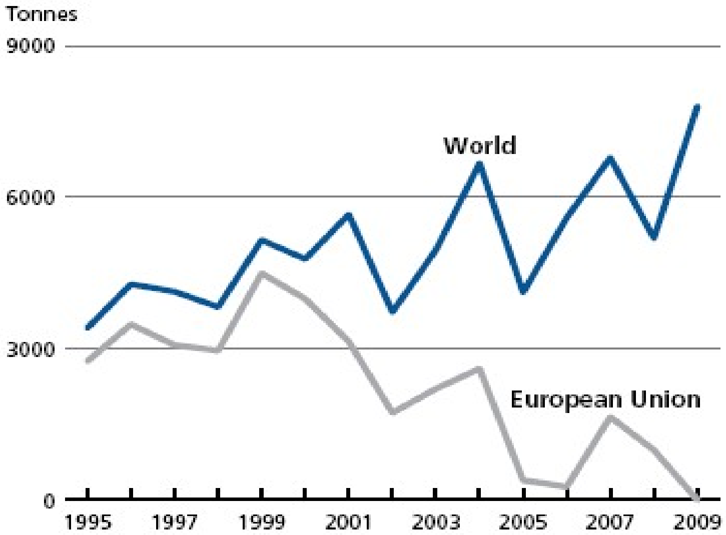

Fig. 2.11: World and EU trade in cassava chips and pellets
Source: FAO (2009c)

Table 2.20: Planted area, productivity, and yield rate of cassava by selected countries

Cassava	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	18.440	18.174	18.418	207.447	218.240	224.273	11.250	12.008	12.177
Nigeria	3.782	3.810	3.850	41.565	45.721	45.750	10.990	12.000	11.883
Brazil	1.902	1.896	1.945	25.872	26.639	27.313	13.605	14.047	14.044
Thailand	0.986	1.071	1.174	16.938	22.584	26.916	17.180	21.089	22.922
Indonesia	1.213	1.223	1.207	19.321	19.928	19.610	15.923	16.296	16.249
Congo	1.845	1.877	1.850	14.974	14.989	15.000	8.114	7.984	8.108
Ghana	0.750	0.790	0.800	9.567	9.638	9.650	12.755	12.199	12.063
Vietnam	0.433	0.475	0.560	6.646	7.714	8.900	15.356	16.244	15.893
Angola	0.749	0.757	0.760	8.606	8.810	8.800	11.496	11.639	11.579
India	0.229	0.242	0.242	5.855	7.620	7.600	25.519	31.436	31.395
Mozambique	1.105	1.010	0.990	6.500	7.500	7.350	5.883	7.425	7.424
Others	5.445	5.022	5.040	51.603	47.097	47.384	9.477	9.377	9.402

Source: OAE (2010); OAE (2007)

Indonesia has maintained a relatively stable production for over 30 years, with most used internally for human consumption. In India, cassava is concentrated in the southern states of Kerala and Tamil Nadu, which accomplish the world's highest national average yield levels through intensive cultivation. China and Vietnam are expanding production to meet rapidly growing internal demands for industrial starch and animal feed (FAO, 2000a). 2005 was an exceptional year for cassava prices, as quotations of both flour and chips reached historic highs. Lower production in Thailand – the dominant cassava-exporting country – coupled with steadfast demand for cassava products in the Far East, particularly in China and

Japan, contributed to higher prices in that year. International prices have since retreated following a recovery in exportable supplies in Thailand, but still remain firm.

Table 2.21: World export of cassava (product weight equivalent)

Total	World cassava trade (M t)			
	2006	2007	2008	2009
Flour and starch	**4.852**	**4.686**	**4.265**	**4.652**
Thailand	4.616	4.416	3.963	4.316
Others	0.236	0.269	0.302	0.335
Chips and pellets	**5.629**	**6.506**	**5.187**	**7.802**
Viet Nam	1.041	1.317	2.000	4.000
Thailand	4.348	4.824	2.848	3.450
Indonesia	0.132	0.210	0.170	0.160
Others	0.108	0.156	0.169	0.191

Source: FAO (2009c)

2.2.4.2 Cultivation Trend of Cassava in Thailand

In Thailand, cassava is the third most important crop and has developed a large and complex industrial system for processing and marketing of the crop. Table 2.22 shows the production trend of cassava during 2002 to 2008. Prior to 1970, Thailand was not a major cassava producing country (FAO/IFAD, 2004). Evolving from an early concentration of production in the Southeast, almost two-thirds of the cassava is now planted in the seasonally dry Northeast, especially in Nakhon Ratchasima province (table 2.23). Nearly all is grown on small farms of 0.5 to 2 ha. Manual planting is a common practice in Thailand. No organized large-scale plantations have been established in Thailand, as this is prohibited by the land reform act. However its indigenous direct consumption is very small, most of the roots are produced tapioca starch or animal feed. Chipping and drying is done on simple drying patios nearby, while processing for starch is generally done in large factories. The pellet export industry depends heavily on the middle-men, either trucks or drying patios owner, who consolidate products from these small farms into processing and marketing channels (FAO, 2000a).

Table 2.22: Planted area, productivity, and yield rate of cassava for Thailand

Cassava	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	0.996	1.030	1.081	1.044	1.109	1.220	1.240
Production (M ton)	16.868	19.718	21.44	16.938	22.584	26.916	25.566
Yield (t/ha)	16.938	19.151	19.831	16.227	20.359	22.068	20.618

Source: OAE (2010); OAE (2007)

The goal of cassava breeding in Thailand is to increase yields and root starch content, as well as the crop's adaptability to a wide range of growing conditions. By 1999, new hybrids from the national programme and Kasetsart University, Bangkok almost extended more than half of the total area. The research programme established by the Department of Agriculture, based at Rayong Station in the East, is among the most productive in the world (max. 37.5 t/ha). Breeding and agronomy are the main focus. Private industry, mainly starch factories, plays an important role in promotion and distribution of new technology. Mechanized land preparation, fertilizer application, and mechanical or chemical weed control are becoming more common (FAO, 2000a).

Production of cassava has steadily increased during the 1970s and 80s through expansion of the planted area, but has decreased again since the early 1990s. Despite the total planted area remained unchangeable, the production of cassava has increased by improving the national average yield which is approximately 17 t/ha (currently 18.75 t/ha). Since 1959, the products derived from cassava have been a major export commodity for Thailand, assisted by relatively easy market access to the EU and recently to China. Thailand and Indonesian exports account for 95% on European imports of cassava chips and pellets. Thailand exports of chips and then pellets increased yearly from nothing in the early 1960s to 6 M t in 1978. The exports then oscillated around the 6 M t level until 1988. From 1988 to 1992, the exports oscillated around 8 M t. Since that time there has been a steady decline of Thai cassava chips and pellets exports, but this has not been as great as the decline of the European import of cassava chips and pellets (Fig 2.11). Thailand has successfully found alternative importers, however the demand from these countries has not been reliable. The main alternative markets have been China and Republic of Korea. The motive is that Thailand financial crises in 1997 and resulting devaluation has made cassava more competitively priced. Secondly, Thailand has a lot of sunk cost in the capacity to produce cassava pellets, therefore Thailand may be able to export cassava pellets for as long as the export price covers the variable costs (FAO/IFAD, 2004).

Table 2.23: Planted area, productivity, and yield rate of cassava by regions for Thailand

Cassava		**Country**	**North**	**Northeast**	**Central + East**	**South**
Planted Area (M ha)	**2006**	1.109	0.155	0.610	0.344	n.s.
	2007	1.220	0.178	0.674	0.368	n.s.
	2008	1.240	0.185	0.679	0.376	n.s.
	2009	1.373	0.234	0.722	0.417	n.s.
Production (M ton)	**2006**	22.584	3.208	12.152	7.224	n.s.
	2007	26.916	3.894	14.578	8.443	n.s.
	2008	25.566	3.815	13.715	8.036	n.s.
	2009	30.088	5.287	15.571	9.230	n.s.
Yield Rate (t/ha)	**2006**	20.358	20.722	19.912	20.986	n.s.
	2007	22.068	21.869	21.638	22.951	n.s.
	2008	20.616	20.635	20.206	21.347	n.s.
	2009	21.908	22.592	21.559	22.129	n.s.

Source: OAE (2010); OAE (2007)

Production costs are mainly dependent on the time of planting and environmental conditions during growth. For example, the first planting period (Feb to Apr) and the second planting period (Nov to Jan), known as early and late rainy season plantings, respectively, need different levels of weed control and inputs. Variable costs account for about 80% of the total costs. Major components of production costs in descending order are labor, land rent, and materials. In 2000, the world economic crisis was reflected by a reduction in meat consumption and surplus of cereals, especially of maize, driven by reduced demand from the feed sector. This had depressed the current maize and maize starch prices, and as cassava products (pellets, starch) have to compete directly with maize, this had substantially reduced the price of these cassava products that subsequently reflected the lower root price, i.e. 630 Baht/t (12.6 Euro/t) (OAE, 2005). Recently the situation of cassava root price, however, has altered due to a shortage of root supply caused by the drought in 2004/2005 and the government approval of the national programme on fuel ethanol produced from cassava. This leads to an increase in root price, which is currently approximately 1,500 Baht/t (30 Euro/t) (Sriroth et al., 2005). The structure of the cassava market in Thailand is depicted in Fig. 2.12.

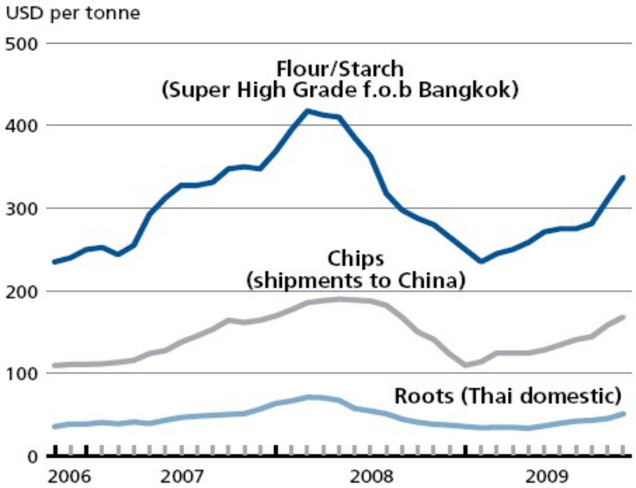

Fig. 2.12: International cassava and Thai domestic prices
Source: FAO (2009c)

Major production problems are declining soil productivity, soil erosion, and long drought period. ***Soil erosion control*** and ***fertility maintenance*** are now widely recognized as critical to sustainable income generation from cassava. Soil fertility is most commonly maintained by fertilizer inputs, although still at quite low levels in comparison to many crops. The technology for reducing erosion includes land preparation practices, fertilization, plant density and varietal canopy characteristics, vegetative erosion barriers, and intercropping or understory crops. Alleviating the constraints from these two components of soil management would increase yields by 33%. An unstable market is the problem too. As a result, some farmers earn nothing or even lose money after nearly a year's work for their farm produce (Nguyen et al., 2006).

The Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, is in charge for formulating national cassava policies with the cooperation of other organization; important are Ministry of Commerce, the **T**hai **T**apioca **D**evelopment **I**nstitute (TTDI), and non-profit private organization including the **T**hai **T**apioca **T**rade **A**ssociation (TTTA), the Thai Tapioca Flour Industries Trade Associations, the **T**hai **T**apioca **S**tarch **A**ssociation (TTSA), and North Eastern Tapioca Trade Association. The core of cassava roadmap (below) contains four important strategies (2008 to 2010) including improvement of root productivity, development of value added cassava-based products, cassava market expansion, and support of research & development for cassava industry (Sriroth et al., 2005).

Strategy I: Improvement of root productivity. The total cassava-planted area remains unchanged as it is reserved to be 1.056 M ha. An increase of root productivity can be achieved by implementing good cultural practice including dissemination of good stake of good varieties, soil fertility maintenance, intercropping system, crop rotation, weed control, good soil preparation, and good harvest practice. Currently, the root productivity is about 18.75 t/ha and by 2007, the root productivity should be increased to 31.25 t/ha for promoted area (7.5 M ha) and to 21.25 t/ha for the rest.

Strategy II: Value addition of cassava-based products. The establishment of fuel ethanol production from cassava is recognized, however the utilization of cassava as the raw material for this purpose should be well-managed so that it will not considerably interfere with other current industries. This will be performed by various approaches including contract farming, root and ethanol price guarantee, determined ethanol policy of government. Moreover, since cassava chip market has expanded substantially as they are used as the feedstock for producing many chemicals, the government has promoted the production of clean chips for this purpose. In addition, the government has supported the SMEs for downstream process of cassava either by technology transfer or technology import to rapidly promote cassava conversion.

Strategy III: Market expansion. It is very critical that Thai cassava industry has to improve and maintain the quality of cassava-based products. That will make Thailand the leader in producing and exporting cassava-derived products. Various means have to be implemented in order to increase cassava consumption, both onshore and offshore.

Strategy IV: Research and development. The R&D of cassava and the development of human resource in cassava area have to be continued in order to support and strengthen the competitiveness of Thai cassava industry. Many urgent tasks relating to cassava production such as new variety development, weed control technology evaluation, post harvest technology improvement, and on-farm machinery development have to be achieved rapidly.

2.2.4.3 Processing of Cassava in Thailand

Cassava roots are utilized for making dry chips, pellets, native starch, modified starch, MSG (monosodium glutamate), glucose, fructose, sorbitol, sago, citric acid which are used in the food, beverage, feed, paper, textile, and plywood industries (Sriroth et al., 2005). In addition, they are used as the major raw materials for the production of bioethanol, an alternative biofuel to be blended with petroleum gasoline. However, cassava product processing costs in Thailand are influenced by the size of the factory and the number of operating days per year (FAO/IFAD, 2004). Of the various cassava-based products mainly cassava starch and pellets are exported (table 2.21). In the future, the export of cassava starch will be more significant in both value and volume. Thailand exports not only native cassava starch but also the modified products, for example, chemically and physically modified starch, sago, seasoning powder, sorbitol and liquid glucose. Future exports of cassava starch are expected to increase due to the growth of global industrial sector and starch market expansion. The export of cassava starch and its derivatives, however, has to comply with the AFTA (Asean Free Trade Area) and FTA (Free Trade Area) agreements with other countries (Sriroth et al., 2005).

Cassava Chip Industry: Cassava chip producers are mostly small entrepreneurs and chip processing is rather simple. Most factories have no formal company registration and are located in close proximity to the growing area. The chipping factories are installed with simple equipment, consisting mainly of a chopper. Roots are loaded into the hopper of the chopping machine by tractor; after chopping into small pieces, the chips are sun-dried on a cement floor. The chips are spread out to a specific density, ensuring consistent final moisture contents of dried products. During drying, which typically requires 2 to 3 days, a vehicle with a special tool for turning over the chips is used to ensure uniform drying. Economic loss occurs as a result of weight loss of the chips, caused by wind that blows the dry particulate matter; this is also a major problem leading to air pollution. When it starts raining, chips must be quickly pushed into piles and covered with plastic. This prolongs the drying time and inevitably results in lower chip quality. The final moisture content should be below 14%. Normally it takes 2.00 to 2.50 kg of fresh roots (with 25% starch content) to produce 1 kg of chips (14% MC) (Sriroth et al., 2005).

Cassava Pellet Industry: The pellet industry began a few years after the start of cassava exports to the EU (around 1967). Development of this product was stimulated by a need to improve the uniformity in shape and size of cassava chips required by the compound feed producers/users. In addition, during transportation, loading and unloading of chips dust generation caused serious air pollution, placing pressure on the importers in Europe to improve the nature of cassava products handled by the port authorities. Production of pellets involves pressing chips, and extrusion through a large die. The heat and moisture in the chips helps in the formation of a pellet-like shaped product, known as a soft pellet. Later process developments involved grinding of chips followed by steam extrusion; this created strong pellets upon cooling, known as hard pellets. The raw material (cassava chips) for pellet manufacture is purchased from chip drying yards. The purchase price is directly dependent on the export price of pellets in Bangkok. Competition for raw material by the pellet factories favours those with a large capacity and these always occupy a large proportion of the export quota; these factories can offer a higher price for chips. There are approximately 200 pelleting factories in Thailand with a total capacity of about 10 M t/y. However, the EU importation quota is only 5 M t and this is the sole market for this product. The factories are therefore working only at 50% of their capacity (in only 3 to 4 months/y) (Sriroth et al., 2005).

Cassava Starch and Starch-based Industries: Conversion of fresh cassava roots, by grating, mixing with water followed by sedimentation and sun-drying (or conductive heating) produces a product traditionally called “cassava flour” but now called “cassava starch”. Demand for cassava starch increased dramatically and this led to the development of the modern starch manufacturing process in the 1970s. A survey conducted in 1996 indicated that at that time there were 41 modern factories registered to the Thai Tapioca Flour Industries Trade Association. These factories were working with modern separation and drying processes. The processing time (from the grating of fresh root to dried starch) is estimated to be less than 30 minutes. Presently, factories using the sedimentation process do no longer exist in Thailand. About 4.75 t of fresh roots produce one tonne of dry starch (Sriroth et al., 2005). About 40% of cassava starch, i.e. 0.6 to 0.8 M t, is used domestically and 60% i.e. 0.7 to 0.9 M t, for export (TTFITA, 1999). Distribution from factories is by three outlets; 1) direct sale for general consumption and local factories, 2) sale to intermediary dealers for domestic retail and export, and 3) direct export.

Cassava in biofuel industries: To produce ethanol from cassava, the starch is initially converted to fermentable sugars, mainly glucose by enzyme or acid process. The sugars are then fermented to ethanol by yeast. To produce 1 L of anhydrous ethanol, around 6 kg of fresh roots (25% starch content) or 2.5 kg of dried chips (65% starch content) are required; the conversion ratio, however, varies depending on processing efficiency. Cassava in the form of dried chip is considered suitable raw material for ethanol production. The great benefit of cassava over sugar cane is the material versatility as it can be processed in form of fresh roots during the harvest season or dried chip and extracted starch when fresh roots are out of season. Currently, there are 6 factories possessing licenses to produce fuel ethanol from cassava, the total operating capacity is estimated to be 2.120 M L/day, whereas the other 18 factories own the licenses to produce fuel ethanol from molasses with the total production of 2.565 M L/day. Recently, with a tremendous increase in gasohol (see Ch. 1.4.3) demand encouraged by price incentive of the national policy, there is a shortage of molasses and the price increases dramatically which affects the implementation of the national energy agenda. Consequently, the National Biomass Energy Committee, previously named as the National Ethanol Committee, has approved permission to the 9 molasses ethanol factories to use cassava as raw material during the molasses shortage, resulting in the maximum capacity of 3.350 M L/day of ethanol. This will cause an enormous demand of cassava up to 20,000 t/d or 7.2 M t/y of roots (Sriroth et al., 2005).

2.2.4.4 Cassava Residues and Their Utilization in Thailand

Generally, the production of tapioca starch culminates in wastes and polluted wastewater. On the average, a kilogram of fresh roots yields 0.2 kg of starch and between 0.4 and 0.9 kg of filter cake (Reungsang et al., 2004). Wastewater is also produced during the processing; later biogas is produced after a series of wastewater treatments (Chavalparit and Ongwandee, 2009). The cassava leaves can be used as animal feed or fermented to increase protein before feed, but currently most of them is left on the soil surface where they contribute some fertilizer value. However, various studies in Thailand conducted for use of these cassava foliages to partially substitute for soybean meal in the feeding of different types of animals, such as cows, pigs, and poultry, in order to reduce the import of soybean meal. If only 10% (0.14 M t) of soybean meal in animal feed is substituted by cassava leaf meal, the country would be able to save 900 M baht or 18 M Euro per year (Limsila et al., n.d.). For cassava stem and cassava rhizome, the good stems are selected for next plantation, while the rest is left in the field or use as the fuel source for household stoves (this is the same case for cassava rhizome too).

For ethanol production, treatment of distilled mash in anaerobic digester produces biogas. This biogas is collected and reserved for plant use, saving about 35% of bunker oil cost. Other potential byproducts associated with ethanol production are CO_2 and manure. For every kilogram of ethanol produced, approximately one kg of CO_2 can be captured. This CO_2 can be collected, purified, and transformed for use in the coolant, soft drink, soda, dry ice, and fire extinguisher industries. The solids contained in the digester effluent can be recovered to be used as manure in cassava farms. This sludge having value of good soil conditioner can be sold to cassava farmers with low price, but some heat is required for sludge dewatering (Nguyen et al., 2006). Manure: One tonne of cassava chips passing ethanol conversion process can produce about 84 to 89 kg sludge with 10% MC (Ronjnaridpiched et al., 2003). However, all of this was at pilot scale and sufficient markets for such products in Thailand have not yet been developed (Nguyen et al., 2007).

2.2.5 Other Potential Crops

Apart from sugarcane, paddy rice, oil palm, and cassava, Thailand also cultivates other crash crops. Some of them show declining trend, but some are focused on by state policy or agricultural market. These other crops include physics nut, maize, cotton, kenaf, and soybean respectively.

2.2.5.1 Physics nut

A native of northern Latin/Central America, there are three varieties of Jatropha: ***Nicaraguan***, ***Mexican*** (distinguished by its less- or non-toxic seed), and ***Cape Verde***. As an energy crop, *Jatropha curcas* (L.) is making a lot of headlines. This plant is drought-tolerant with pest-resistant, grows well on marginal land, needs only moderate rainfall of among 300 to 1,000 mm annually, can help reclaim eroded land, and grows quickly. It is easy to establish attaining a height of 3 to 4 m in 3 years, requires little water and fertilizer, and can survive on infertile soils. It is not browsed, for its leaves and stems are toxic to animals (Openshaw, 2000). It has a high-seed yield after 2 to 5 years of its plantation, and continues to be produced for 30 to 40 years. Of particular importance, the fruit of Jatropha contain 30 to 40%

by kernel weight of viscous oil being used for soap making, in the cosmetics industry and as a diesel/kerosene substitute or extender. The oil fraction consists of both saturated fatty acids (palmitic acid 14.1%, stearic acid 6.7%), and unsaturated fatty acids (oleic acid 47.0%, and linoleic acid 31.6%). These characteristics appeal to many developing countries that are concerned about diminishing tree cover and soil fertility and are looking for an energy crop that minimizes competition with food crops (FAO, 2008d). Jatropha oil is now also being promoted by a non governmental organization to power multifunctional platforms, a slow-speed diesel engine containing an oil expeller, a generator, a small battery charger, and a grinding mill (UNDP, 2004).

Jatropha can be established from seed, seedlings, and cuttings. The best time for planting is in the warm season before or at the onset of the rains. The number of trees per ha at planting may vary from 1,100 to 3,300. Seed production ranges from about 0.4 to over 12 t/ha/y after 5 years of growth, with an average whole nut moisture content of about 10% (wet basis). The seed contains 19.0% oil, 4.7% polyphenol, and 3.9% hydrocarbon. The calorific value and cetane number of Jatropha oil are comparable to diesel, but the density is high (Narayana Reddy and Ramesh, 2006). The high viscosity of the oil can be decreased by blending with diesel. By 40 to 50% of substitute, the blend can be used without preheating or any engine modification (Pramanik, 2003). However, Jatropha oil contains about 14% free fatty acid (FFA) being far beyond the limit of 1% FFA level that can be converted into biodiesel by transesterification using an alkaline catalyst. Net primary production (NPP), the production of all types of plant biomass, ranges an average from 1 t/ha/y of above ground oven dry matter with an annual rainfall of 200 mm, to 10 t/ha/y with a rainfall of 1,500 mm (Openshaw, 2000). If management favours fruit production through the application of fertilizers, about one-quarter each of the NPP may be in the form of woody biomass, and leaves, with the remaining half being fruit. Augustus et al. (2002) reported the energy value of the seed: the gross heat value of dry seed is 20.85 MJ/kg, higher than that of lignite coal, cattle manure, and comparable to that of corn cobs (10% MC). Seed cake, a by-product of oil extraction, contains curcin -a highly toxic protein - making it unsuitable for animal feed. Nevertheless, it has potential as a fertilizer or biogas production (Staubmann et al., 1997; Gubitz et al., 1999). It can also be used as a fuel for steam turbines to generate electricity, if available in large quantities.

The many positive attributes claimed for Jatropha have translated into numerous projects for large scale oil or biodiesel production as well as small scale rural development. The largest scale venture is the Indian Government’s “National Mission” to replace 20% of diesel consumption by 2011 to 12 with biodiesel produced from Jatropha, cultivated on around 10 M ha of wasteland and generating year-round employment for 5 M people (Gonsalves, 2006; Francis et al., 2005). In Mali, thousands of km of Jatropha hedges can be found in order to protect gardens from livestock and reduce damage and erosion from wind or water. Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of Jatropha are not available. The fear that the rush into Jatropha on the basis of unrealistic expectations will not only lead to financial losses, but also undermine confidence among local communities. Information on the relationship between yields and variables such as soil, climate, crop management and crop genetic material on which to base investment decisions is poorly documented and the many positive claims for the plant are not based on mature project experiences (FAO, 2008d). Jongschaap et al. (2007) argue that, on a modest scale, Jatropha cultivation can take more benefits. However, they conclude that claims of high oil yields in combination with low nutrient requirements (soil fertility), lower water use, low labour inputs, the non-existence of competition with food production and tolerance to pests and diseases are unsupported by scientific evidence.

Physic nut plants could thrive well in most soil types in Thailand. It attains a height of 3 to 4 m in 3 years, and grows quickly forming a thick bushy fence in 6 to 9 months, reaching its heights of 4 m with thick branches in 2 to 3 years. Its wood is a very light wood and is not popular as a fuel wood source, because it burns too rapidly. Currently, Thailand has 16,000 ha of Jatropha plantations, but only 3,200 ha is managed commercially (Siriwardhana et al., 2009) and growers are unable to achieve the optimum economic benefits from the plant, especially for its various uses. However, the planted area is expected to increase in the future (see also Ch. 4.2.5.6) in order to support community biodiesel programme by the state. Finally, Sampattagul et al. (2007) concluded that, Jatropha bio-diesel production in Thailand should be improved according to higher environmental impacts and total cost than that of conventional diesel fuel from life cycle aspects. The cultivation of Jatropha should be developed to increase the production yield per planed area and the proper cultivated technologies such as new irrigation system must be applied to maximize the efficiency of Jatropha production.

2.2.5.2 Maize

A major source of food for both humans and animals, Maize or Corn (*Zea Mays*) is grown in more countries than any other crop. The versatile plant can thrive in climates as diverse as the arid desert plains of the southwestern USA and the high Andean mountain plains of Ecuador and Peru. The temperate plains of the US provides some of the best growing conditions for corn in the world, making this country the world's top corn producer (table 2.24) (U.S. Grains Council). The role of biofuel policies in the food-price hikes has become particularly controversial. The rapid increase in demand for and production of biofuels, particularly bioethanol from maize and sugarcane, has had several effects on grain supply-and-demand systems. Expanded production of ethanol from maize, in particular, has increased total demand for maize and shifted land area away from production of maize for food and feed, stimulating increased prices for maize. Rising maize prices, in turn, have affected other grains. On the demand side, higher prices for maize have caused food consumers to shift from maize (which is still a significant staple food crop in much of the developing world) to rice and wheat. On the supply side, higher maize prices made maize more profitable to grow, causing some farmers to shift from rice and wheat (and other crop) cultivation to maize cultivation. These demand- and supply-side effects have tended to increase the price of rice and wheat and other crops.

Table 2.24: Planted area, productivity, and yield rate of maize by selected countries

Maize	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	147.759	146.750	157.836	715.814	699.262	784.689	4.844	4.765	4.972
U.S.A.	30.399	28.591	35.022	282.311	267.598	332.092	9.287	9.360	9.482
China	26.379	27.050	28.050	139.498	145.610	151.830	5.288	5.383	5.413
Brazil	11.549	12.613	13.828	35.113	42.662	51.590	3.040	3.382	3.731
Mexico	6.606	7.295	7.800	19.339	21.893	22.500	2.928	3.001	2.885
Argentina	2.783	2.447	2.838	20.483	14.446	21.755	7.359	5.903	7.665
India	7.588	7.856	7.770	14.710	14.979	16.780	1.939	1.907	2.160
France	1.658	1.503	1.481	13.688	12.902	13.107	8.254	8.586	8.850
Indonesia	3.626	3.346	3.451	12.524	11.611	12.382	3.454	3.470	3.588
Canada	1.085	1.061	1.361	9.332	8.990	10.555	8.604	8.473	7.755
Italy	1.113	1.108	1.082	10.428	9.671	9.891	9.368	8.728	9.143
Thailand	1.030	0.939	0.928	3.943	3.716	3.661	3.829	3.956	3.947
Others	53.942	52.941	54.226	154.445	145.184	138.546	2.863	2.742	2.555

Source: OAE (2010); OAE (2007)

In Thailand, maize is one of five major crops and occupies a major portion (about 33%) of Thai upland farmlands. Although Thailand was a major maize grain exporter in the 1980s, maize exports declined substantially in the 1990s as the domestic demand for grain increased along with the domestic livestock industry, which in turn processed its output into various exportable products. In 1984 to 85, planted area of maize was about 12.4 M Rais (nearly 2 M ha), ranking second only to rice (59 M Rais or 9.5 M ha), while Thailand exported 3.0 to 3.7 M t of maize and earned nearly 10,000 M Baht (US$ 400 M). But thereafter the maize area began to decline and occupied only 7.3 M Rais (about 1.2 M ha) by 2002 to 2003, with a production of around 4.5 M t (Ekasingh et al., 2004). Table 2.25 shows the production trend of maize in Thailand from 2002 to 2008. Low maize grain prices and high production costs are the major reasons for the decline. Over the past 10 years, the prices of maize production inputs have been increasing through the years, while output prices have either remained the same or decreased, resulting in lower farm profits. In recent years, Thailand's domestic maize production has not been adequate to meet domestic requirements, and small quantities of grain have been imported. The North is the largest maize-producing region, accounting for 49% of the national acreage, followed by the Northeast with 26% and the Central for 24%, leaving a tiny fraction to some of the southern provinces (Table 2.26).

Table 2.25: Planted area, productivity, and yield rate of maize for Thailand

Maize	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	1.171	1.111	1.126	1.060	0.966	0.954	1.025
Production (M ton)	4.23	4.178	4.216	3.943	3.716	3.661	4.178
Yield (t/ha)	3.613	3.761	3.743	3.719	3.845	3.838	4.077

Source: OAE (2010); OAE (2007)

Maize in Thailand is predominantly used for animal feed, with 80 to 100% of production being sold to commercial poultry and livestock feed mills. Its sale as animal feed is mainly used domestically, and only a small fraction is exported. Meanwhile, only about 5 to 20% is consumed as food, as either white corn or sweet corn. Using **G**eographic **I**nformation **S**ystem (GIS) tools to study land suitability for maize at the district and provincial levels, a study found that some 14.6 M ha (28.6%) of all areas in Thailand was suitable for growing maize. Farmer-respondents reported that maize was easy to grow and had low production risks compared to other crops. Maize was drought tolerant, had no insect or disease problems, and allowed double cropping. Maize was also the best crop for the rained uplands with good rainfall. In general, decisions of farmers to continue maize cultivation depend heavily on favourable maize grain prices compared to those of competing crops. While they favour growing maize, they might decide to quit planting the crop if better alternatives present themselves. The first maize crop was planted in the early rainy season, followed by second and third when there was sufficient water. In general, maize farmers prefer to buy and plant reasonably priced seed that produce early maturing, high yielding hybrids with large ears and good grain color. Farmers also look for good fresh weight in early maturing varieties and good dry weight for the late maturing ones (Ekasingh et al., 2004).

Land preparation consisted of land clearing, burning crop residues, and tillage by tractors. Land clearing and burning of crop residues were often done during February to March, and tillage was mostly done in April, just before sowing. If land preparation is not done in time, planting is delayed and this can adversely affect maize yields. Planting is done from mid-April to early May for the early rainy season, and in July for the late rainy season. They would irrigate three to four times per season having better yields but higher fuel costs with irrigation. Weed control was reportedly more important than insect and disease control by spraying pre-emergence herbicide after planting and mechanical weeding when the maize plants were about 30 to 40 days old. Mechanical weeding was sometimes done simultaneously with the second round of fertilizer application. Maize was harvested in one of two ways, depending on whether another maize crop would follow or not. Farmers who grew a second maize crop harvested the first in July right after maturity, when the fresh grains still had 20 to 30% MC ("wet"). Maize harvested this way had to be sold immediately even at low prices because fungi attacks the fresh grain and the loss of income due to the lower grain weight is not covered by the higher prices later when stored. Farmers also felt that storage requires additional grain handling and management. Maize grains were harvested "dry" (15 to 20% MC) by leaving the plants to dry in the field if only first maize crop was planted. The harvest is in September, October, or even November with about 0.4 to 0.8 t/Rai (2.5 to 5.0 t/ha) (Ekasingh et al., 2004).

Table 2.26: Planted area, productivity, and yield rate of maize by regions for Thailand

Maize		Country	North	Northeast	Central + East	South
Planted Area (M ha)	**2005**	1.060	0.615	0.246	0.199	n.s.
	2006	0.966	0.576	0.206	0.184	n.s.
	2007	0.954	0.572	0.202	0.180	n.s.
	2008					n.s.
Production (M ton)	**2005**	3.943	2.432	0.800	0.712	n.s.
	2006	3.716	2.346	0.683	0.687	n.s.
	2007	3.661	2.309	0.666	0.686	n.s.
	2008					n.s.
Yield Rate (t/ha)	**2005**	3.719	3.955	3.250	3.569	n.s.
	2006	3.845	4.069	3.313	3.743	n.s.
	2007	3.839	4.034	3.300	3.822	n.s.
	2008					n.s.

Source: OAE (2010); OAE (2007)

Although most farmers use single-cross hybrids, maize yields are still low because of poor soil fertility. Soil erosion and soil infertility are the main problems in highland areas and sloping land. Labour scarcity also causes problems of inadequate crop care. Of all inputs, harvest labour is the top expenditure, followed by fertilizers, tractor hire and seed. In 1999, the national average maize yield in Thailand was 2.74 t/ha, with early and late rainy season average yields of 2.72 t/ha and 2.88 t/ha, respectively. This national average yield was considered quite low, considering that 87% of farmers use private sector hybrid seed (mostly single-cross). In 2000, the national average maize yield increased to 3.49 t/ha, although actual yield levels varied by production. A comparison across seasons shows that the average dry season maize (irrigated) yield was the highest, at 4.97 t/ha, while the average early rainy season maize yield was 3.52 t/ha, and the late rainy season average was 3.75 t/ha (Ekasingh et al., 2004).

2.2.5.3 Cotton

More than 70 countries produce and export cotton, while many developed and developing countries depend on imports of cotton lint for their spinning and textile industries (ODI, 2004). Moreover, cotton is an important cash crop to a number of developing countries at both farm and national levels. The FAO estimated that about 100 M rural households were involved in cotton production worldwide in 2001. One-third of cotton production is traded internationally. The four East Asian textile producers - Indonesia, Thailand, Taiwan, and Korea - accounted for 22% of world cotton imports in 2002, compared to just 3% in 1960 (Baffes, 2004). Cotton is usually harvested with a machine that pulls the fiber from the plant. Seeds, parts of the bole, and pieces of stalk and leaves are also collected during harvest. Most cotton in the US, Europe, and Australia is harvested mechanically, either by a cotton picker (a machine that removes the cotton from the boll without damaging the cotton plant) or by a cotton stripper, which strips the entire boll off the plant. Cotton stalks contain about 46% of alpha cellulose and 26% lignin, and can be used as a raw material for preparation of various products. However, the main problem with cotton stalks lies in its high transportation and storage cost due to their low bulk density. Table 2.27 below shows the production trend of world cotton by selected countries.

Table 2.27: Planted area, productivity, and yield rate of cotton by selected countries

Cotton	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	34.840	34.841	35.014	44.452	43.430	44.170	1.276	1.247	1.261
China	5.693	5.062	5.416	12.650	11.403	13.460	2.222	2.253	2.485
India	8.787	8.900	8.900	5.586	6.664	7.128	0.636	0.749	0.801
U.S.A.	5.284	5.586	5.586	7.477	7.712	6.666	1.415	1.381	1.193
Pakistan	3.193	3.103	3.103	4.853	4.123	4.065	1.520	1.329	1.310
Uzbekistan	1.456	1.472	1.472	2.334	2.461	2.376	1.603	1.672	1.614
Brazil	1.157	1.263	1.263	2.466	1.785	1.785	2.131	1.413	1.413
Turkey	0.640	0.547	0.547	1.350	1.125	1.350	2.109	2.057	2.469
Australia	0.198	0.321	0.321	0.494	0.912	0.844	2.494	2.841	2.630
Syria	0.234	0.238	0.238	0.651	0.664	0.664	2.779	2.793	2.793
Greece	0.374	0.366	0.366	0.645	0.677	0.520	1.723	1.848	1.419
Thailand	0.010	0.012	0.005	0.014	0.015	0.006	1.367	1.234	1.250
Others	7.813	7.970	7.797	5.932	5.889	5.306	0.759	0.739	0.681

Source: OAE (2010); OAE (2007)

Thailand is one of the major cotton importing countries. During 2002 to 2008, cotton growing in the country decreased uninterruptedly from 11,200 ha to 1,490 ha., while cotton lint with seed production decreased from 14,000 to 2,060 t and the average yield range between 1.463 and 1.103 t/ha (table 2.28). Consequently, 398,840 M t of cotton fiber was imported for the textile industry. The main problem of cotton production was the continuous decrease in growing area due to a high cost of production (especially for insecticides), low seed cotton price, competitive crops, and extensive pest problem. In 2007, the number of cotton growers was 10,589, decreasing from 13,540 in 2005. The cotton production cost in 2007 was 468 US$/ha, slightly decreased from 496 US$/ha in 2005; while seed cotton price increased from 482 to 594 US$/t, resulting in higher profit to farmers. Farmers generally grew cotton (Gossypium hirsutum) in small areas of less than one ha/family for using in handicraft textile. Due to a serious problem with insect pest damage, growing cotton in a large area is impossible; thus, a small area of natural colour fiber production for local consumption or hand-made product will be appropriate. Over the last 3 years, although the requirement of cotton for textile industry increased, the policy contrarily encouraged farmers to grow the high-profit crops such as sugarcane and cassava. Therefore, more than 95% of total demand in cotton fiber was imported annually, especially from USA, China, Australia, and India. For cotton production by regions, it is illustrated in table 2.29.

Table 2.28: Planted area, productivity, and yield rate of cotton for Thailand

Cotton	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	0.01120	0.00752	0.01056	0.01248	0.00496	0.00272	0.00149
Production (M ton)	0.01400	0.01100	0.01400	0.01500	0.00600	0.00300	0.00206
Yield (t/ha)	1.250	1.463	1.326	1.202	1.210	1.103	1.383

Source: OAE (2010); OAE (2007)

Table 2.29: Planted area, productivity, and yield rate of cotton by regions for Thailand

Cotton		**Country**	**North**	**Northeast**	**Central + East**	**South**
Planted Area (M ha)	**2005**	0.012487	0.003855	0.000286	0.008346	n.s.
	2006	0.004942	0.002730	0.000183	0.002030	n.s.
	2007	0.002689	0.001675	0.000091	0.000923	n.s.
	2008	0.001488	0.000889	0.000048	0.000552	n.s.
Production (M ton)	**2005**	0.015097	0.004761	0.000229	0.010107	n.s.
	2006	0.006240	0.003581	0.000152	0.002507	n.s.
	2007	0.003374	0.001928	0.000102	0.001344	n.s.
	2008	0.002058	0.001115	0.000045	0.000898	n.s.
Yield Rate (t/ha)	**2005**	1.2090	1.2350	0.8009	1.2110	n.s.
	2006	1.2626	1.3119	0.8319	1.2350	n.s.
	2007	1.2548	1.1512	1.1224	1.4556	n.s.
	2008	1.3828	1.2543	0.9406	1.6282	n.s.

Source: OAE (2010); OAE (2007)

2.2.5.4 Kenaf

Kenaf (*Hibiscus cannabinus* L.) is a warm-season annual fiber crop of the Malvaceae family native to east central Africa. It has a high growth rate, reaching heights of 4 to 6 m in about 4 to 5 months and its yields of 6 to 10 t/ha/y of dry mass. Superior adaptation to poor soils than that of most of commercial crops, kenaf can be also planted on marginal land. The mean growing temperature ranges from 22.6 to 30.3 °C. During the growing season, a well-distributed rainfall of 100 to 125 mm/month is necessary for proper kenaf growth (Dempsey, 1975). Crane (1947) reported that 500 to 625 mm over a period of 5 to 6 months is essential for the successful production of kenaf fiber. Kenaf is generally harvested for its stalk from which the fiber is extracted. It consists of two distinct fiber types: the outer, bast fibers which comprise about 35% of the stalk dry weight, and the inner, core fibers that comprise about 65% of the stalk’s dry weight (Lin et al., 2004 cited by Liu, 2005). About 20% of the volume of kenaf seed is oil, very similar in composition to that of cotton. Grower interest in kenaf arises primarily from its potential as a commercial fiber crop. However, it can also be used for bean stakes, animal litter, also a fiber source for improving recycled paper quality, a bulking agent for composting sewage sludge, a cellulose fiber for composition panels and boards, and a potting-mix ingredient. Moreover, kenaf also makes excellent animal forage. The crude protein levels in kenaf leaves range from 15 to 35% (Preston Sullivan, 2003). After solving the problem of manual pollination, many hybrid cultivars have been released and utilized in production (Li, 2002). Kenaf hybrids are very popular in some countries, like China, Russia, and Thailand (IBFC, 2005 cited by Liu, 2005).

In 1985, global kenaf production reached an all time high of 2.8 M t. After that, kenaf production has shown a declining trend. Now its production is stable around 0.4 M t (Liu, 2003). Kenaf is commercially cultivated in more than 20 countries. 90% of the sown area and more than 95 % of total production are from China, India, and Thailand. Although kenaf originated from Africa, its production in Africa is very low. In 2002, total production of Africa was just 2.9% of the world production (FAO, 2003b). Currently, many countries pay more attention to kenaf research and promotion because of its high biological efficiency and wide ecological adaptability. Kenaf has been called “the future crop” (Mazumder, 2000; Cheng, 2001).

In Thailand, kenaf, a once dominant crop in the 1960s, has been almost replaced by sugarcane. It mostly planted in the north eastern part of Thailand and its fiber mostly used for fabricating sack. Kenaf farmings and sack fabricating industries in Thailand, however, tend to be declined due to the booming of plastic sack and cheaper imported kenaf sack from India and Pakistan. In addition, kenaf defiber process is accusing for deteriorating natural water resource, therefore it is no longer described and recommended as economy crop for Thailand and kenaf planting areas become less. Despite the decline of kenaf sack industry and small scale farming certain numbers of local kenaf sack industry are still existed. Kenaf is rated as low potential fibrous biomass to be used for producing composite construction material due to its insufficient quantity and non-environment friendly treatment process (Soontornrangson et al., n.d.).

Table 2.30: Planted area, productivity, and yield rate of kenaf for Thailand

Kenaf	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	0.0245	0.0212	0.0171	0.0031	0.0022	0.0014	0.0016
Production (M ton)	0.0414	0.0333	0.0254	0.0046	0.0032	0.0025	0.0029
Yield (t/ha)	1.690	1.567	1.485	1.503	1.430	1.796	1.880

Source: OAE (2010); OAE (2007)

Table 2.31: Planted area, productivity, and yield rate of kenaf by regions for Thailand

Kenaf		Country	North	Northeast	Central + East	South
Planted Area (ha)	**2006**	2,228	n.s.	1,935	294	n.s.
	2007	1,370	n.s.	1,178	192	n.s.
	2008	1,550	n.s.	1,546	4	n.s.
Production (ton)	**2006**	3,187	n.s.	2,637	550	n.s.
	2007	2,461	n.s.	2,071	390	n.s.
	2008	2,914	n.s.	2,905	9	n.s.
Yield Rate (t/ha)	**2006**	1.430	n.s.	1.363	1.873	n.s.
	2007	1.796	n.s.	1.757	2.031	n.s.
	2008	1.880	n.s.	1.880	2.009	n.s.

Source: OAE (2010); OAE (2007)

2.2.5.5 Soybean

Originated in China, soybean (*Glycine max* (L.) Merr.) is the world's most important grain legume as a source of protein and oil (Chotiyarnwong et al., 2007). The world soybean production quantity increased by 4.8% annually from 1960s and reached 217.6 million tons in 2005-07. By country, the top producer in the world was the USA., who produced 37.0% (80.6 M t) out of the world total soybeans, and the second largest producer was Brazil, who produced 53.9 M t of soybeans (24.8%). Argentina was the third producer and produced 41.4 M t (19.0%). Including China (15.8 M t, 7.3%) and India (8.9 M t, 4.1%), these top five countries produced more than 90% of the world total soybeans (table 2.32). World production of soybeans is predicted to increase by 2.1% annually to 359.7 M t by 2030, using an exponential smoothing model with a damped trend (Fig. 2.13) (Masuda and Goldsmith, 2008). A policy on renewable bioenergy has been strongly favored by many countries, particularly the USA, the EU members, and Brazil. Different forms of subsidy to promote and encourage the use of gasoline cum alcohol (gasohol) and biodiesel formulations also stimulated the demand for biofuel. This created an alternative use of food crops, particularly, corn and soybean in the USA and sugar cane in Brazil (Isvilanonda and Bunyasiri, 2009). As the soybean demand increases, the supply is challenged, the stocks reduce, and the market prices rise.

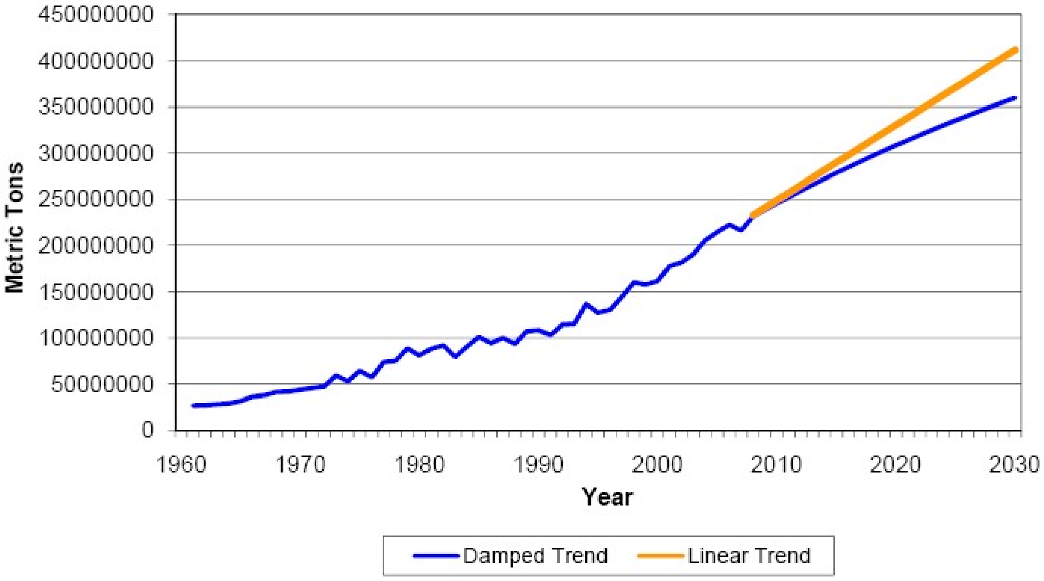

Fig. 2.13: World Soybean Production Quantity and its projection for the year 2030
Source: Masuda and Goldsmith (2008)

Table 2.32: Planted area, productivity, and yield rate of soybean by selected countries

Soybean	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
World Total	92.430	94.927	94.889	214.251	222.405	216.129	2.318	2.343	2.278
U.S.A.	28.835	30.191	30.562	83.368	87.670	70.707	2.891	2.904	2.314
Brazil	22.949	22.047	20.638	51.182	52.465	58.197	2.230	2.380	2.820
Argentina	14.037	15.097	16.100	38.300	40.467	45.500	2.729	2.680	2.826
China	9.594	9.100	8.900	16.350	15.500	15.600	1.704	1.703	1.753
India	7.708	8.334	8.550	8.274	8.857	9.433	1.073	1.063	1.103
Paraguay	1.970	2.200	2.300	3.988	3.800	3.900	2.024	1.727	1.696
Canada	1.165	1.201	1.169	3.156	3.466	2.785	2.708	2.885	2.382
Bolivia	0.934	0.950	0.960	1.690	1.619	1.900	1.810	1.704	1.979
Ukraine	0.422	0.715	0.665	0.613	0.890	0.836	1.453	1.245	1.257
Uruguay	0.278	0.309	0.366	0.478	0.632	0.800	1.719	2.045	2.185
Thailand	0.144	0.138	0.129	0.226	0.215	0.204	1.568	1.563	1.584
Others	4.396	4.644	4.550	6.626	6.824	6.267	1.507	1.469	1.377

Source: OAE (2010); OAE (2007)

Soybean is the most important grain legume crop in Thailand. It has been cultivated for a century in the upper north of the country after the major rice (rainy season crop) harvest (table 2.34). Subsequently, the planted area has expanded to the lower north, northeast and central plain. The planted area reached the maximum of 0.51 M ha in 1989. Later the planted area dramatically decreased to about 0.22 ha during 1998-2001 due to the increase in planted area of the second rice (irrigated crop) in dry season and sugarcane in rainy season. Moreover, during the past four years, soybean crinkle leaf virus has been the main problem of soybean production resulting in yield decrease (Srisombun, 2003). Currently, Thailand produced 0.18 to 0.22 M /y of soybeans (table 2.33). The domestic demand for soybean is for the food industry and the animal feed industry.

Table 2.33: Planted area, productivity, and yield rate of soybean for Thailand

Soybean	Crop Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Area (M ha)	0.181	0.154	0.151	0.149	0.142	0.133	0.121
Production (M ton)	0.260	0.231	0.218	0.226	0.215	0.204	0.187
Yield (t/ha)	1.438	1.502	1.442	1.520	1.517	1.534	1.550

Source: OAE (2010); OAE (2007)

At present, Thailand cannot produce enough soybean grain for domestic consumption. For example, in 2002 Thailand imported 1.3 M t of soybeans and 1.9 M t of soybean meal. Limiting factors responsible for low yield are poor environment and lack of resistance to insect pests and diseases (Chotiyarnwong et al., 2007). Consequently, Thailand is a net importer of soybean; it imports 1.5 M t annually (Isvilanonda and Bunyasiri, 2009). Demand for soybean meal in Thailand is growing because of growth of the poultry industry. Although the production area decreased, the national productivity of soybean increased from 0.981 t/ha in 1978 to 1.55 t/ha in 2008. This was probably associated with the release of high yielding varieties combined with appropriate management techniques (Srisombun, 2003).

Table 2.34: Planted area, productivity, and yield rate of soybean by regions for Thailand

Soybean		**Country**	**North**	**Northeast**	**Central + East**	**South**
Planted Area (M ha)	**2005**	0.1487	0.1000	0.0372	0.0115	n.s.
	2006	0.1418	0.0943	0.0364	0.0111	n.s.
	2007	0.1330	0.0895	0.0329	0.0107	n.s.
	2008	0.1207	0.0847	0.0344	0.0016	n.s.
Production (M ton)	**2005**	0.2257	0.1522	0.0514	0.0221	n.s.
	2006	0.2148	0.1440	0.0488	0.0220	n.s.
	2007	0.2040	0.1375	0.0448	0.0216	n.s.
	2008	0.1868	0.1367	0.0474	0.0027	n.s.
Yield Rate (t/ha)	**2005**	1.5179	1.5222	1.3818	1.9189	n.s.
	2006	1.5149	1.5270	1.3407	1.9843	n.s.
	2007	1.5337	1.5371	1.3649	2.0244	n.s.
	2008	1.5480	1.6137	1.3786	1.7190	n.s.

Source: OAE (2010); OAE (2007)

2.3 Wood Industries Sector

In 2005, our world had forest areas at around 3.87 billion ha, covering only about 30% of its land area, with varying distribution around the world (Fig. 2.14). Forests in temperate and boreal countries comprised 52% of the world's forests and covered 25% of the temperate land area. Approximately 95% of the total forest area was natural forest, the remaining 5% comprising plantations of various sorts (both softwood and hardwood). Roughly 34% was designated primarily for wood production, on a par with for multiple purposes, while the rest were assigned for conservation (11%), protection (9%), social services (4%), and none or unknown (8%). Logging, agricultural expansion, and other factors such as forest fires, insect pests, diseases, also weather-related damage have reduced forest area all over the world. From Global Forest Resources Assessment (FRA) 2005, for countries that were able to report on different aspects, an average of 1.4% of their forest area was adversely affected by insects in an average year; 1.4% was affected by diseases; and 0.9% by forest fires (FAO, 2007a).

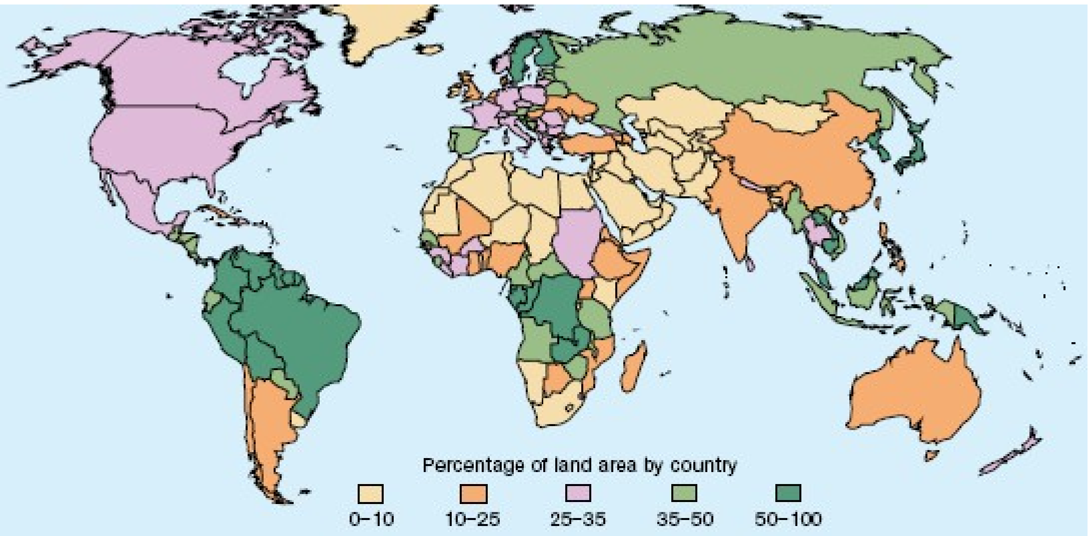

Fig. 2.14: World Forest Area, 2005
Source: FAO (2007a)

Responding to the diminishing capacity of their natural forests to produce timber, many countries have turned to forest plantations thanks to its highly productive and sustainable source of both wood and non-timber forest products. They can also provide social and environmental services, including storing carbon, combating desertification, and rehabilitating degraded lands. In 2000, while plantations shared only 5% of global forest, it was estimated that they supplied about 35% of the world's timber. The areas of forests planted for productive purposes and of those planted for protective functions are both steadily increasing, similar in all regions except Africa (Fig. 2.15). The survey in 2005 covered 38 selected countries representing 83% of the semi-natural forest area and 86% of the global forest plantation area. Asia led the world in planted forests, followed by Europe. Conifers dominated the productive planted forest category, accounting for 54% of area reported in 2005 (Fig. 2.16), while broadleaves accounted for 39%. In the protective forests category, coniferous species comprised 47% and broad-leaved species was 31% (FAO, 2007a; FAO, 2006a).

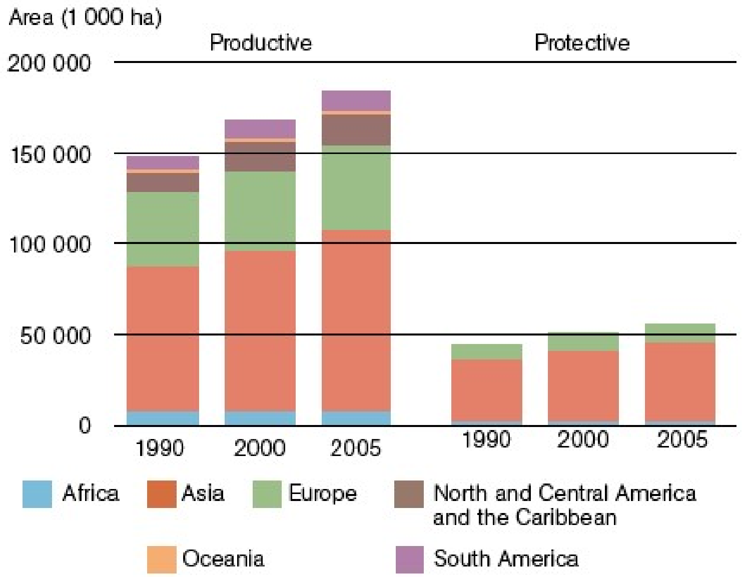

Fig. 2.15: Forest Management objectives (productive and protective)
Source: FAO (2007a)

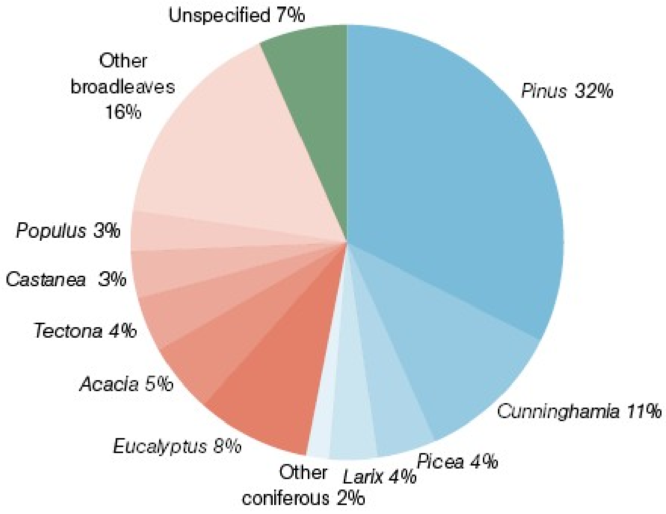

Fig. 2.16: Productive planted forests, 2005: area by genera
Source: FAO (2007a)

As reported to the FRA 2005, planted forests were about 140.8 M ha. Additionally, the area of productive forest plantations increased by 2.5 M ha between 2000 and 2005, therefore it was indicated that a larger portion of wood supply may come from forest plantations in the future (FAO, 2007a). It was also estimated that around 50 to 100 M ha of new forest plantations are needed to meet the world industrial wood demand by the year 2010 (Boyle, 1999). The vast areas of degraded forest land in the tropics provide much scope for further increasing planted area, with potential benefits for the wood-processing sector and opportunities for capturing funds from emerging GHG markets. However, it is important to ensure that payments for ecosystem services do not lead countries to convert natural forest to fast-growing plantations (ITTO, 2008). Clear and consistent policies, laws and best practice guidelines could help to balance the cultural, economic, and environmental trade-offs caused by increased investment in forest plantations (FAO, 2007b).

Trade of forest products, referred to forest and wood based production activities, including productions of wood fuel, roundwood, sawnwood, also fibreboard, etc., among countries was increasing (Fig. 2.17). A positive net trade balance indicated that the value of exports exceeded the value of imports. Throughout the period from 1990 to 2004, Asia & the Pacific continued to be the major net importer of forest products. North America was, for many years, a net exporter, but in recent years it has become a net importer as well. The trend for Europe was the opposite of that for North America; today Europe is the leading net exporter of forest products (FAO, 2007a). Latin America had the highest annual increase in the world in industrial roundwood production from 1997 to 2005. Uruguay is the leading exporter of the roundwood, mostly hardwood timber (Eucalyptus sp.), in Latin Amarica with about 1.5 M m^3/y, while Brazil is one of the major suppliers of hardwood chip to the USA (Gonzalez et al., 2008). Temperate timber and wood products are increasingly traded in globalized markets, although trade in tropical hardwood logs is declining. Production from tropical and temperate plantations will exceed 50% of total trade by 2050. Increasing timber demands in China, India, and other Asian countries will reduce roundwood availability for Europe.

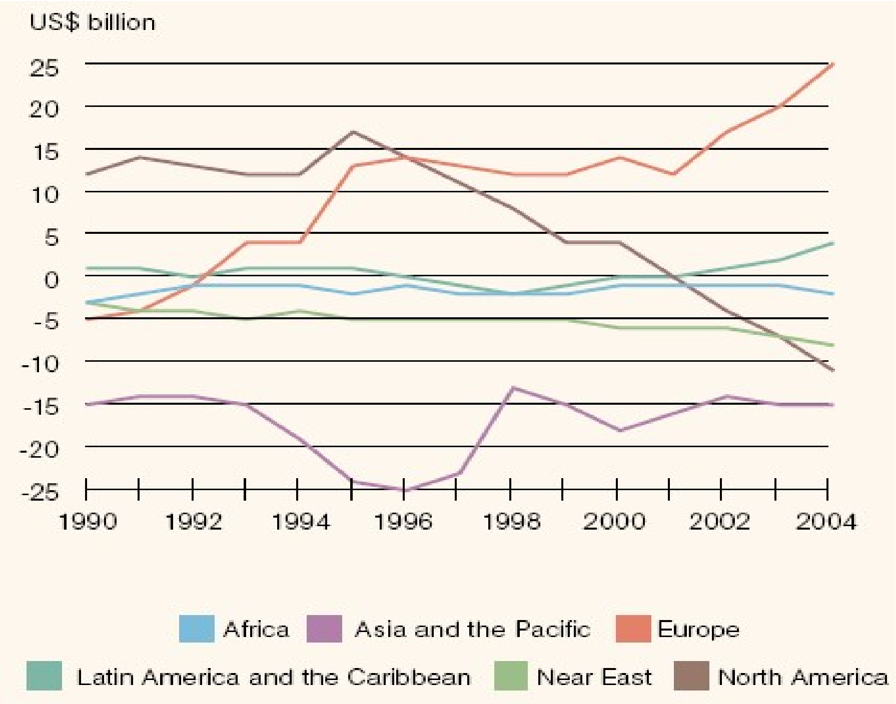

Fig. 2.17: Trends in net trade of forest products by region

Note: A positive value indicates net export. A negative value indicates net import.
Source: FAO (2007a)

The main factors affecting long-term global demand for wood products include ECORYS (2010): 1) ***Demographic Changes***: the world's population is projected to increase from 6.4 billion in 2005 to 7.5 billion in 2020 and 8.2 billion in 2030; 2) ***Continued Economic Growth***: global GDP increased from about US$16 trillion in 1970 to US$47 trillion in 2005 (at 2005 prices and exchange rates) and is projected to grow to almost US$100 trillion by 2030; 3) ***Regional Shifts***: The rapid growth of developing economies, especially in Asia, will swing the balance significantly in the next 25 years; 4) ***Environmental Policies and Regulations***: more forests will be excluded from wood production; and 5) ***Energy Policies***: the use of biomass, including wood, is increasingly encouraged. 6) ***Other important factors*** include a decline in harvesting from natural forests, the emergence of planted forests as the major source of wood supply, and technological developments in enlarged plantation output via tree improvement and reduced wood requirements thanks to expanded recycling, higher recovery, wider use of new composite products, and production of cellulosic biofuel (see Ch. 3.3.2).

Primary forest products (roundwood and fuelwood) represented a fairly big share on the forest sector's value in Africa, Asia and the Pacific, along with Latin America and the Caribbean. In contrast, wood-processing and pulp & paper industries accounted for the large portion of that value in more developed regions. However, wood processing industries have developed in the past decade, especially in China, Eastern Europe, South America, and some developing countries. Foreign investment has played a critical role of the development in rapidly growing regions, particularly in technology transfer, infrastructure development, and improved access to global markets. Recent expansion of processing capacity in developing regions has shifted production bases on a global scale. A consequence is intensified competition, reflected in the downward trends in trade prices for major wood products (FAO, 2007a). Eastern European countries have become major exporters of sawnwood, wood-based panels, and secondary processed wood products. Southeast Asia and Brazil have also developed their secondary wood processing industries. Asia and the Pacific are becoming the major producer and consumer of wood-based panels, along with paper & paperboard. This region's industrial roundwood production will be far short of consumption, increasing dependence on imports unless substantial efforts are made to boost wood production, but it will be difficult to expand wood production in Asia and the Pacific given the high population density and competing land uses (FAO, 2009a).

The process of felling trees and converting them into logs results in huge wastes, that is to say, branches, stumps, and leaves, etc. Log recovery rates vary from place to place depending considerably on the processing methods, but generally, a 50/50 ratio is reasonable. In natural forests, up to 70% of total volume may be available for energy generation. Accessibility to these residues may be a major reason why wood residues are left to rot in the logging sites. Moreover, in those places where the population is quite sparse, their demand of fuel wood is generally near to the ground/low. However, forest residues and stumps were not only seen as potential resources for energy production; biologists now pointed out that they were also a substantial substrate for many organisms adding to the biodiversity of the forest landscape (Björheden, 2002). Wood residue supply can therefore be expected to decrease in coming years, despite high rates of plantation establishments.

Wood residues from mills represent another, more easily accessible source of residues. At present, wood energy is most competitive when produced as a byproduct of the wood processing industry. The main byproducts of forest industries are used to produce fuelwood and charcoal, while black liquor (a byproduct of pulp mills) is a major fuel source for electricity generation in countries such as Brazil, Canada, Finland, Sweden, and the USA. With huge investments in wood-energy industries, there is a growing market for forest byproducts as raw materials for energy. Sawmills and pulp & paper industries benefit by becoming energy producers (FAO 2008c). Theoretical analyses of energy supply from wood residues in developing countries suggest that there is considerable potential for energy generation. Excess wood residues at mill sites at those countries are often left unused and may create environmental problems by affecting the water and air quality. Producing energy from these residues can solve both energy and waste disposal problems. Residue combustion technology includes simple steam machines for small scale power production and steam turbines for larger power plants (ITTO, 2005; Tomaselli, 2007).

High fossil fuel prices together with new energy & environmental policies are making woodfuel an essential ingredient of energy policy in both developed and developing countries. In developed countries, it is likely that the use of wood for energy will continue to increase, especially for electricity production, if fossil fuel prices continue to rise. For instance, around 1/5 of the final energy in Sweden is derived from forest biomass after 3 decades of development (FAO, 2007a). In developing countries where wood and it residues are generally utilized for domestic heating and household cooking. Unfortunately, the wood producing energy is also in desperately short supply, while controlled firewood cutting also occurs on public lands by local users (Hillring, 2006). The gap between energy wood demand and where they can be obtained easily is now large and grows larger everyday. Industrial plantations are broached to bring about wood thick and fast in a short period. A forest plantation established solely for the purpose of energy production, ***Dendrothermal*** plantation is then becoming more common in various countries. Energy crops are not a new innovation. Forest plantations dedicated to the energy purpose have existed in several countries for some time, though most of them are small, use poorly developed technology and generally focus on supplying fuelwood for local consumption (GreenFacts, 2009).

In temperate zones, there are a number of fast growing tree species suitable for energy plantations, including Acacia mangium, Gmelina arborea and several Eucalyptus, and Populus species (Perley, 2008). While forests managed for wood production commonly yield among 1 to 3 m^3/ha/y, plantations of fast-growing species commonly yield around 30 m^3/ha/y; a Grand Fir plantation at Craigvinean in Scotland has a growth rate of 34 m^3/ha/y (Aldhous and Low 1974), and Monterey Pine plantations in southern Australia can yield up to 40 m^3/ha/y (Everard and Fourt 1974). Nevertheless, short rotation forest crops demand higher nutrient status than other forests that occupy lands less in demand for agriculture. Furthermore, the emphasis on plantation for energy need not detract from the other vital forest functions. It is likely that plantations with multiple end uses may provide logs for wood fuels as well as logs for other purposes as markets demand. No real conflict is expected between the pulp production and energy use of wood in the foreseeable future. Integration of the procurement of fiber and fuel simplifies the transaction of residual forest biomass within the traditional timber trade (Hakkila, 2006).

In Thailand, forest cover declined by approximately 45% during the last 30 years, mainly due to the transformation of forest land into agricultural area and the shifting culture by hill-tribe people. The turning point in Thai forestry sector was the imposition of the logging ban of conservative forest in 1989 (see Ch. 1.1.2). Despite this ban, forest cover continues to shrink due to illegal logging and encroachment into national forests for farmland and firewood. Over the period 2000 to 2004, Thailand lost an average of 60,475 ha/y of natural forest (National Park, 2005) or at an annual rate of 0.4% (FAO, 2009b). The goal of the Thai government is to achieve a forest cover of 40%. However, national efforts for reforestation have not attained this goal (see Table 2.3.1). The 1985 National Forest Policy Directive promoted 15% of conservation and 25% of economic forest (Vandergeest, 1996). The 1992 to 97 **N**ational **E**conomic and **S**ocial **D**evelopment **B**oard (NESDB) plan outlined a forest policy, which would continue towards the goal of 40% forest cover, but reversed the proportion of conservation to be 25%. These figures have since been further adjusted towards conservation goals in the NESDB Plan (2002 to 2006) with the objectives now placed at 30% conservation and 10% economic (plantation) forest. The area of forest plantations is to be increased up to a total of 2.56 M ha on state land and 2.56 M ha on private lands (Mahannop, 2002), for a total of 5.12 M ha corresponding to 10% of Thai territory (Barney, 2005).

The Re-Afforestation Act of 1992 was firstly designed to encourage the private sector to widen forest plantations. Investments in planted forests, especially by the private sector, have increased in the past two decades. Government influences on plantation establishment generally fall in two categories: direct government planting programmes and the payment of incentives for plantation establishment, which accordingly triggered a surge in plantation development (Nalampoon, 2003). **Recently**, forest in Thailand cover totals 14.52 M ha (28.4%), with a plantation estate comprising 4.9 M ha or 33% of the total forest area. Its forest plantations can be classified into 3 types as follows: 1) Teak Plantation (?%); 2) Other Reserved Species Plantation such as eucalyptus and non-teak (?%); and 3) Rubber Tree Plantation (43%). Plantations (especially rubberwood, eucalyptus, and teak) and imports are now supplying the country's thriving downstream-processing timber industry. Following the ninth NESDB plan, the country calls for the promotion of 2.56 M ha of additional planted forests in Thailand by 2013. This would be accomplished through an addition of: 1) 0.8 M ha of commercial forest plantations; 2) 0.96 M ha of parks, wildlife sanctuaries and class 1(A) and 1(B) watershed zones reclaimed and rehabilitated through the Department of National Parks, Wildlife and Plants; and 3) 0.8 M ha of community forests of both non-commercial and commercial species, including eucalyptus and teak (Barney, 2005).

Table 2.35: Reservation of forest land in the NSEDP and the real existing forest for preservation in Thailand

NSEDP	**Period**	**Forest area (%)**	
		Planned (%)	**Existing**
I	1962-1966	50	52
II	1967-1971	50	48
III	1972-1976	50	42
IV	1977-1981	50	34
V	1982-1986	40	30
VI	1987-1991	40	28
VII	1992-1996	40	28
VIII	1997-2001	40	28
IX	2002-2006	36	28
X	2007-2011	33	29*

* 14.8 M ha or about 29%, reported in 2009 (FAO, 2009b)
Source: NSEDP and RDF of Thailand

Notification: the actual extent of plantation resources in Thailand is very difficult to establish for several reasons. These include a general lack of reliable data gathering; Thai government figures tend to include government-related tree planting activities only and competing authorities between government departments for jurisdiction over the management of different tree species (e.g. rubber or palm oil, under the Ministry of Agriculture, versus eucalyptus under the Forestry Department) (Barney, 2005). Mahannop (2002) states that data regarding plantation development by large-scale investors and small-scale farmers is not comprehensively available in Thailand and that data on eucalyptus in particular is "hard to come by, as no standard reporting procedure has been established". Besides, the FAO (2000) reports: Data of forest plantations available are only for those plantations that are on government budget. Finally, the main objective of Thailand's forest policy, as stated in the tenth National Economic and Social Development Plan (2007-2011), is to maintain and restore biodiversity, and conserve natural resources and to maintain the forest area at 33%, and protected area no less than 18% (FAO, 2009b).

2.3.1 Rubberwood

2.3.1.1 General Data about Rubberwood

Botanical specifications: Rubberwood is wood from the Para rubber tree (*Hevea brasiliensis*), often called the rubber tree or parawood in Thailand. It is the most important source of natural rubber in the world. As a tropical tree, rubberwood grows best under conditions of temperatures between 20 to 28 °C, well-balanced annual rainfall of 1,800 to 2,000 mm and protection from high winds. It develops reasonably well up to 600 m above sea level (but is capable of growing to at least 1000 m near the Equator), and will perform on most adequately drained soils. Its prime growing area is between 10° latitude on either side of the equator, although it is also found further North, as in China, and South (IRRDB, 2000). The most important utilization after stopping the harvest of latex, natural plastic, are in furniture and furniture parts, parquet, paneling, wood-based panels (particle board, cement- and gypsum-bonded panels, medium density fiberboard) and kitchen and novelty items, and as sawntimber for general utility and fuel (Killmann, 2001).

Mature trees on rubberwood plantations are commonly 20 to 30 m tall with a relatively slim trunk of up to 30 cm diameter at breast height, an average branch-free bole of 3 m and upwards-extending branches. Young trees have a smooth brown-green bark. Rubber trees flower once a year. Insect cross-pollination results in large fruits containing several thimble-sized seeds with hard outer coats (in some countries, such as Malaysia, a second round of seed production may occur). If satisfactorily germinated and planted within 2 to 3 weeks (at about 500 trees/ha, although some clones are planted at much higher densities), seeds grow to produce seedling plants. Depending on conditions, tapping of rubber trees starts in the fifth to seventh year after planting and then continues for 25 to 30 years. It is done by incising the bark with a special knife and wounding the resin canals, usually without damaging the cambium. In practice, this is when the trunk has about 500 mm circumference at 1 m above ground level (Balsiger and Bahdon, 2000; Killmann, 2001).

Cultivation and logging: Rubberwood becomes available from agricultural plantations, when replanting is carried out after 25 to 30 years due to declining latex yield making further tapping of the trees uneconomical. The trees are then removed and replaced with new seedlings. In the past, felled rubberwood were either burnt on the spot or used as fuel for locomotive engines, brick burning, or latex curing. The availability of rubberwood in large quantities is partly a result of the tree undemanding site requirements, but mainly of the fact that rubberwood is only a byproduct of a crop grown for latex production. An additional, a vital factor for the availability of rubberwood is, at least in Malaysia, strong governmental support and incentives to ensure the continuing supply of latex through replanting of rubber tree plantations (Killmann, 2001).

Rubberwood yields per tree vary according to clone, site conditions, and management. The global rubberwood study carried out under the auspices of the International Trade Centre estimated yield at 140 to 200 m^3/ha, with the higher ranges observed in countries where plantations are carefully managed, i.e. Malaysia, Thailand, India, and Sri Lanka (Indufor, 1993). A 1995 study on using Malaysian rubber tree plantations as timber resources used as the following (next page) as a basis for its calculations (Arshad and Othman, 1996):

Greenwood production up to 8 cm diameter	0.8 m^3/tree
Surviving tree stand – estate	240 trees/ha
Surviving tree stand – smallholding	228 trees/ha
Length of logs extracted	1.8 m
Replanting cycle	25 years
Sawnwood recovery – estates	32%
Sawnwood recovery – smallholders	20%

Accordingly, estates and smallholdings can yield 190 and 180 m^3/ha of greenwood, respectively. In the case of usable logs, estates recuperate about 57 m^3/ha and smallholdings about 54 m^3/ha. After sawing, the estates and smallholdings produce about 18.1 m^3 and 10.8 m^3 of sawnwood, respectively. In another study, gross yield in 1994 for estates in Peninsular Malaysia was quoted at 180 m^3/ha, which included branches greater than 5 cm diameter. In smallholdings, where trees are generally of poorer form, average yields were found as low as 100 m^3/ha (Khoo et al., (1987) quoted in Ismariah and Norini, 1994). Net volumes suitable for sawnwood processing were 20% and 15% of total harvested volumes for estates and smallholdings, respectively.

Utilizations: A member of the Euphorbiaceae family, rubberwood has a dense grain character that is easily controlled in the kiln drying process. Thanks to its low shrinkage, rubberwood is also a stable construction material available for furniture manufacturing. Rubberwood lumber has various different types of colours and wood finishes such that rubberwood used in furniture can mimic rosewood, oak, or other expensive lumbers creating confusion in the identification of the type of wood used in the furniture. It is also prized as an "environmentally friendly" wood, as it makes use of trees that have been cut down at the end of their latex-producing cycle. The old practice was to burn the "useless" tree. However, in the Buloh Kasap plantation of Makmurplus Industry, Malaysia, rubber trees are grown not necessarily for latex but for wood that would be used in the furniture industry.

Generally, wood from the rubber tree is either exploited as timber or fuelwood. Rubberwood has traditionally been used as a cheap source of fuelwood in most of the countries where rubber tree plantations are abundant. As fuel, huge amounts are generated on the field (in form of branches or chunks) after the trees are cut down for rotation, and in the processing factories (off-cuts and sawdust). The steady supply of wood from the replanting scheme of rubber makes the power plant fuelled by rubberwood a promising project. Most of the technical problems in processing and utilization of rubberwood have been overcome by the Southeast Asian countries over the past 20 years and the timber has been successfully marketed internationally. Rubberwood has thus become a Southeast Asian success story. It is even more important than teak as a plantation timber in Southeast Asia (Killmann, 2001).

Apart from the utilization in the sawmilling sector, the use of rubberwood logs in the wood based panel sector is rapidly expanding, although chipboard, cement board, MDF, and OSB rely primarily on small diameter logs or after thinning/clearing operations. When logs are delivered to sawmills, long transport distances have to be avoided because of the high potential for insect and fungal attacks. For this reason, Indufor in 1993 estimated that only 80% of total rubberwood are economically available in Thailand and in Malaysia, 45% in Indonesia, and 90% in India and Sri Lanka. Since rubberwood is readily attacked by fungi and insects, its chips are easily discoloured during storage. Therefore, in the MDF manufacture with urea formaldehyde resin, rubberwood chips must be used within 4 weeks, in order to maintain the expected strength properties of MDF (Razali and Diong, 1992). Additionally, MDF produced from rubberwood is still having problems with the dark colouration of panels and with latex in the waste water. Rubberwood could be also used for the production of semi-chemical pulp. In Japan, corrugated medium paper is produced by imported rubberwood chip. Rubberwood in the form of small logs, off-cuts, edges, slabs, and branches is used for particleboard manufacture. To boot, good quality charcoal and briquettes can be produced from rubberwood waste.

World production, trade and trend: In 2006, more than 9.5 M ha in about 40 countries were devoted to rubber tree cultivation with a production about 6.5 M t of dry rubber each year. Roughly 78% of the total plantations worldwide was in Southeast Asia with 70% mainly in Indonesia (35.2%), Thailand (21.6%), and Malaysia (14.07%) (table 2.36). Since 1991, Thailand has been the biggest producer of natural rubber of the world. Currently, it produces about one-third of the world's natural rubber, averaging 3 M t/y. Thailand is also the number one in terms of rubber output, but Indonesia has a larger area for planting rubber tree and hence a possibility to overtake Thailand in the future (Fig. 2.18) (GTZ, 2008). Rubber prices were on the increase in spite of rising supplies, which reached a record level in 2005. The 2005 average price of natural rubber in London was nearly 200% higher than its record low in 2001. This price increase largely reflects higher global consumption, especially in China, India, and Southeast Asia. It is expected that global demand for natural rubber will continue to increase steadily as global economic growth continues to stimulate demand, and as high oil prices continue to make natural rubber more attractive than synthetic rubber (FAO, 2006b).

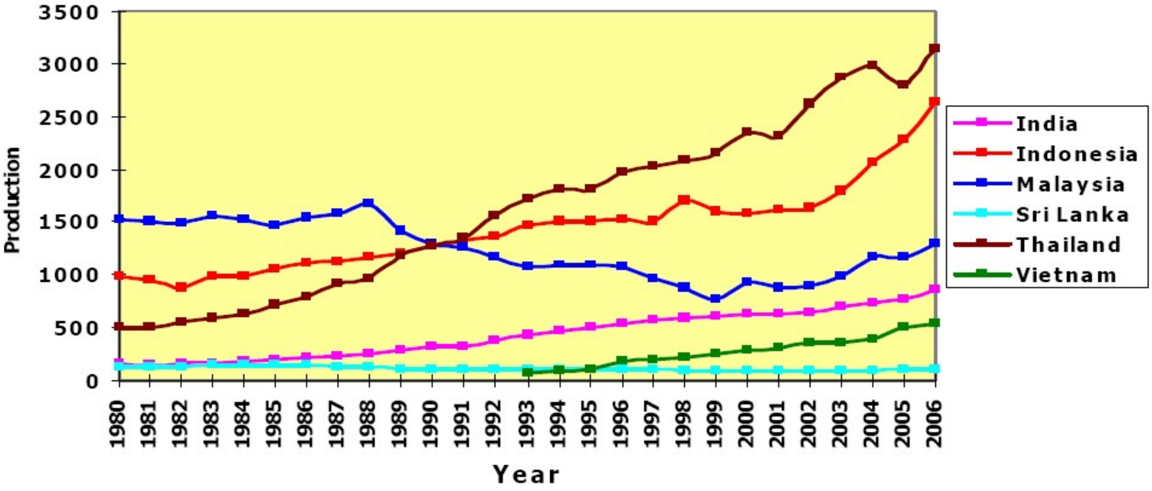

Fig. 2.18: Trends in Production of Natural Rubber from 1980-2006 (Thousand Tons)
Source: GTZ (2008)

Recently, the demand of rubberwood has increased as the wood material of rubber tree is found to be an attractive source of raw material in furniture, plywood, and composite board~~s~~ manufacturing – especially Thailand and Malaysia (Shigematsu et al., 2010). Rubberwood log prices are relatively low when compared to natural forest species, and rubberwood is used instead of not only wood from natural tropical forests, but also timber from other sources. The large-scale export of rubberwood sawn-timber and its finished products (mainly furniture and indoor building components such as flooring and parquet) started from Malaysia in the early 1980s. With increasing wages in Malaysia and decreasing rubber prices, labour-intensive production of natural rubber in larger estates is slowly shifting to lower-wage countries in the region, while in Malaysia plantations are increasingly replanted with oil palms.

Table 2.36: Planted area, productivity, and yield rate of natural rubber by selected countries

Rubberwood	Planted Area (M ha)			Productions (M ton)			Yield (t/ha)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
World Total	8.166	8.693	8.949	9.350	9.817	9.938	1.145	1.129	1.110
Thailand	1.691	1.743	1.768	2.980	3.071	3.024	1.762	1.762	1.710
Indonesia	2.660	2.940	3.175	2.271	2.350	2.540	0.854	0.799	0.800
Malaysia	1.237	1.400	1.400	1.126	1.284	1.270	0.910	0.917	0.907
India	0.450	0.450	0.450	0.803	0.831	0.803	1.784	1.846	1.784
Viet Nam	0.483	0.512	0.512	0.482	0.546	0.550	0.999	1.067	1.074
China	0.465	0.470	0.475	0.514	0.538	0.545	1.106	1.144	1.147
Philippines	0.082	0.094	0.095	0.316	0.352	0.360	3.857	3.729	3.788
Nigeria	0.340	0.340	0.340	0.142	0.143	0.143	0.418	0.421	0.421
Cote d'Ivoire	0.075	0.075	0.075	0.135	0.130	0.128	1.799	1.732	1.706
Sri Lanka	0.116	0.116	0.116	0.104	0.109	0.118	0.893	0.936	1.013
Others	0.567	0.553	0.542	0.477	0.463	0.457	0.841	0.837	0.843

Source: OAE (2010); OAE (2007)

2.3.1.2 Cultivation Trend of Rubberwood in Thailand

In 2006, about 2.297 M ha of rubber tree plantations were estimated to be in existence (see table 2.37). More than 77% of rubber tree plantation areas were in the South (table 2.38). The rest was in the Northeast (11%), while a small number existed in the Central & East (11%), and the North (1%). There were slightly over 1 M rubber tree growers with an average of 2.24 ha of land holdings. The production area has increased by 26% since 1997. An average growth rate for rubber production was 3.5% annually, whereas 95% of the country's production was from smallholdings, who planted different rubber clones. Important factors influencing an expansion of plantation areas include natural rubber price and government policy. The government promotes the spreading of rubberwood plantations all over the country in order to produce and supply more latex to a rubber industry. Nowadays, rubber is one of the most important export products of the country. The top three customers are China, USA, and India. An income from rubberwood tends to continuously increase, since the government has a policy to promote the planting of rubber tree plantation throughout the country (GTZ, 2008).

Table 2.37: Planted area, productivity, and yield rate of natural rubber for Thailand

Rubberwood (Parawood)	Crop Year						
	2002	2003	2004	2005	2006	2007	2008
Planted Area (M ha)	1.988	2.018	2.071	2.178	2.297	2.457	2.675
Harvested Area (M ha)	1.554	1.601	1.656	1.691	1.743	1.768	1.819
Production (M ton)	2.633	2.860	3.007	2.980	3.071	3.024	3.167
Yield Rate (t/ha)	1.695	1.787	1.816	1.762	1.762	1.710	1.741

Source: OAE (2010); OAE (2007)

In the last decade, the rubberwood becomes the most important raw material for sawmills and wood product factories, e.g., furniture, kitchen ware, and wooden toys. About 96.79% of a total sawn timber for export comes from rubberwood. Presently 80% of Thai sawn rubberwood is exported, mainly to China and Malaysia, the remaining of 20% is used for domestic furniture factories. Out of 2.72 M ha of the peninsular area in the South, more than 1.75 M ha were rubber tree plantations which therefore make Southern Thailand the single largest rubberwood plantation region in the world (table 2.38). As the economic lives of the trees are 25 to 30 years, about 3 to 4% of the rubberwood growing area is cut down for replanting annually. The supply of rubberwood residues is consequently quite secure in the long term. After rubberwood cutting, logs with diameter more than 15 cm and 1 to 3 m in length are sent to process factories by truck. Leaves and branches are destroyed by burning, while stumps are generally destroyed by a chemical method. The other one consists of felling the whole tree, including the root system, with a bulldozer and thereafter cutting the trunks with chainsaw. The root system is used as firewood or just burnt at the site. The rubberwood residues comprise small branches left in the plantation (54% of total biomass) and sawmill wastes (32%). They are "real" wastes where there is no competitive user (Krukanont and Prasertsan, 2003).

From another study, only 10% of the wood ends up as end products. In other words, 90% are residues, which comprise of 54% small branches (normally burnt down in the field, unless shipped to particleboard factories), 32% are wastes at sawmills and 4% in furniture factories. A study by the Forestry Department showed that approximately 180 t/ha of woody biomass is obtained. This leads to the availability of rubberwood residues of 97.2 t/ha at the plantation and 57.6 t/ha at the sawmill (Prasertsan and Sajjakulnukit, 2006). In general, rubberwood industrials utilize heat energy for drying and pressing lumber or wood products. The fuel in heat production is gas or fuel oil, but the factories also exploit their biomass residues such as wood chip, wood shavings, and sawdust. About 25 to 50% has been used for combustion in the boiler, while the rest is sold to other factories, such as cement or lime factory. However, the small power plants for electrical energy in factories encourage the increase of utility these waste woods.

Production capacity statistics: In Thailand, better management practices, effective smallholder organization, and higher utilization rates have consistently translated the country into higher rubberwood production figures, even if these have arguably not turned into as much value-added as in Malaysia. Table 2.38 shows planting area of rubberwood trees between 2002 and 2008 by regions.

Table 2.38: Planted area, productivity, and yield rate of natural rubber by regions for Thailand

Rubberwood (Parawood)		Country	North	Northeast	Central + East	South
Planted Area (M ha)	**2005**	2.178	0.018	0.161	0.251	1.748
	2006	2.297	0.034	0.246	0.263	1.753
	2007	2.457	0.064	0.343	0.272	1.778
	2008	2.675	0.096	0.448	0.316	1.814
Havested Area (M ha)	**2005**	1.691	0.001	0.061	0.176	1.453
	2006	1.743	0.001	0.073	0.183	1.486
	2007	1.768	0.003	0.084	0.192	1.489
	2008	1.819	0.002	0.091	0.204	1.522
Production (M ton)	**2005**	2.980	0.001	0.096	0.295	2.587
	2006	3.071	0.002	0.117	0.312	2.639
	2007	3.024	0.005	0.136	0.339	2.544
	2008	3.167	0.004	0.155	0.364	2.644
Yield Rate (t/ha)	**2005**	1.368	0.080	0.596	1.178	1.480
	2006	1.337	0.059	0.476	1.187	1.505
	2007	1.231	0.074	0.397	1.248	1.431
	2008	1.184	0.039	0.346	1.151	1.457

Source: OAE (2010); OAE (2007)

The clear cut of the rubber tree stand takes place when trees reach the age of 25 to 30 years. The time of harvesting depends on the site fertility and whether the owner is concentrating on latex or timber production (Kainulainen, 2007). Table 2.39 shows wood quantity exploited from old rubber trees in Thailand among 2000 to 2008. Around 30% of the wood is produced as sawn timber, and the processed outcome is further used as a raw material in the furniture industry, the wooden toy industry along with other related industries. About 10% is supplied for the country's timber consumption, while roughly 40% is used for the production of particle boards. The remainder can be used as fuel both in rubber drying and in biomass power generation. A study conducted by Kyoto University predicted that 8 power plants of burning rubberwood can provide a total capacity of 186.5 MW, which can be the future financial feasible based fuel availability. Up to today, only one plant with a capacity of 20 MW has been built (Krukanont and Prasertsan, 2003).

Fig. 2.39: Production of Rubber Wood in Thailand (Includes stem and branch)

Year	2001	2002	2003	2004	2005	2006
Production (M m^3)	3179	4620	5060	4840	6160	2445

* Estimated production of rubber wood from trees uprooted from a hectare of area: 137.5 m^3
Source: GTZ (2008)

The age at which rubber trees are felled in Thailand shows extreme variation. In the top 5 rubberwood producing provinces (accounting for 69% of total production), the share of trees harvested after more than 25 years ranges from 40 to 95%, while that of trees between 20 and 24 years old ranged from 5 to 53%. This variance indicates the flexibility rubber tree growers can apply in controlling rubber and rubberwood supply. Rubberwood is lacking for local consumption, because most of it is delivered to the export market. In 2005, there were 2,596 of furniture and furniture parts factories, consisting of 86 large entrepreneurs, 295 medium entrepreneurs, and 2,215 small entrepreneurs, with the total of around 148,000 labours. The higher numbers of factories creates many problems relating to a shortage of raw material as well as an increasing of its price (GTZ, 2008).

State policy and production trend: Thai government has come up with an interesting plan to overhaul the agricultural sector of the country, beginning with 6 "economically-viable" products, namely, rice, tapioca, rubber, bio-fuel plants, prawns, and chicken. According to the state plan, farmers will be given access to new technology, know-how, and credit, under the plan to add value to their farm products by processing. The government will also provide further assistance in research and development as well as in marketing the final products. Their target is to replant 32,000 ha/y of rubber tree and support the cost for the replantation about 1,125 Euro/ha for 5.5 years. Moreover, they have expanded plantation area to northeast of Thailand. It will add production quantity, income and green area in northeast of Thailand too. The government's project on the promotion of rubber in the new plantation areas with a target of 0.16 M ha is in the north and the northeast of Thailamd.

Problems and barriers: Since rubber trees are a long-rotation crop when compared with agricultural crop, the certainty of long-term plentiful supply of wood residues from both the rubberwood growing areas and the processing plants makes it very attractive to power plant developers. Nevertheless, it still needs careful study for power generation projects. This had led to a considerable competition between the brick industry (which used rubberwood as an energy source) and wood processing industries. Rubberwood industries (furniture, boards) are the main competitor, if rubber wood is going to be utilized for energy production. Moreover, an industry of wood-based panel composites has been expanding vastly. Many big factories such as Wanachai (public) Co., Ltd. have increased their productions while smaller companies are continuously founded which subsequently create higher demands of rubberwood. Rubberwood is also used as raw material to produce chips, which are burned to produce hot air for both rubber industries and rubber wood seasoning.

For other problems, including:

1) Latex production is the main objective for rubberwood cultivation in Thailand. When the price of rubber latex increases, the farmers don't have to cut their rubber trees. Therefore, there is not a sufficient supply of rubberwood for the entire sawmills and wood-based panel industry all time;

2) Rubberwood prices at the farm gate vary from plantation to plantation depending on many factors;

3) The number of processed rubber factories is increasing. A survey of Department of Factory in 2005 reveals that there are 500 processed rubber factories of which 388 factories locate in the south especially in Surat Thani and Nakhon Srithammarat Province. This results in a high purchasing demand of rubberwood;

4) The rubber wood sawing industry is still quite undeveloped in Thailand. Besides, small and medium sized sawmills control the market;

5) The market that accommodates the rubberwood from farmer is not yet available. If the plantation area is located near a saw mill, the farmers will often directly sell the rubberwood to the saw mill, but generally the farmers trade their rubberwood to the middleman in the form of log with a lower economic value. For the farmers who have no sawing machine, they sell the rubberwood to any middleman offering the best price;

6) Currently, Rubber tree cultivation is for agricultural purpose, and not for the economic forest purpose. When Rubber tree cultivation applies a silviculture system like that of teak or eucalyptus, it will result in a high quality and quantity of logs being sent to the saw mill;

7) Due to the higher energy price, it leads the state to seek a substitute/alternative energy, especially palm oil. The government supports an increase in palm oil plantations, thus farmers in turn increase palm oil plantation; and

8) Lack of organizations. In the past, a rubber research institute focused mainly on the development of rubber breeds, tapping methods, and farm maintenance, but not on the application of rubberwood. The department of forestry, on the other hand, has few of its researches relating to the application. Nevertheless, today, it is still unclear on the term of rubberwood between being an agricultural tree or a wild plant. This unclear term leads to an unclear responsibility, thus no specific government sector is obviously assigned to be in charge of the rubberwood issue as a whole.

2.3.2 Eucalyptus

2.3.2.1 General Data about Eucalyptus

Botanical specifications: widely promoted for the plantation, *Eucalyptus camaldulensis* is a plantation species of the genus Eucalyptus (over 600 species) in many parts of the world, but is native to Australia where it is widespread especially beside inland water courses. It usually grows up to 40 m tall (normally 25 to 35 m); its thick (30mm) spongy, bark is dappled with red, grey, green and white. It is a fast-growing tree (time of felling beginning with 5 years), so it is suitable for short-term purposes. *Eucalyptus camaldulensis* prefers deep moist subsoils with clay content. Wildly it grows in creek valleys and requires a certain length of flooding duration. With a good water supply it may reach a height of 12 to 15 m in few years. It is not physiologically adapted to either drought or salinity, although these stresses can be tolerated for short periods or at low levels. Compared to many other species, *Eucalyptus camaldulensis* performs high productivity on infertile soil and hot temperatures (CSIRO, 2004).This species has superior characteristics of coppicing, saline land and water logging tolerance, high calorific value; a market demand exists as fuel and posts/poles (Sangkul and Niyomdham, 1996). It is a light-demanding species, but very fire sensitive. Even low intensity fires may cause cambial injury lowering the value of the timber.

Eucalyptus camaldulensis is a diffuse-porous hardwood, with distinct sapwood and heartwood. The sapwood is white in colour, while the heartwood is reddish brown. The red heartwood contains a high extractive content, especially in its outer portions. The wood is even and fine textured. The arrangement of grain is interlocked and wavy. It is a medium dense timber with specific gravity of 0.59 in air dry condition. It is a moderately strong timber with MOR of 807 kg/cm^2. The strength properties of the species are lower than those of teak in most of the cases, except nail holding capacity where higher values are observed. It is a refractory timber and develops check and warp during drying. It is reported that drying defect can be minimized, if quarter sawn timber is used. For chemical components, *Eucalyptus camaldulensis* consists of holocellulose (73 to 77%), lignin (21 to 23%), and extractives (6 to 12%), based on its within-tree variations (Kabir et al., 1995).

Cultivation and logging: *Eucalyptus camaldulensis* is usually propagated from seed. There are about 700,000 viable seed/kg and 1 kg of eucalyptus seed is sufficient to provide plant for 100 ha of cultivating area at spacing of 3 x 2 m Seedling survival rate is low about 25% (Doran et al., 1990). *Eucalyptus camaldulensis* is one of the several eucalypt species suited also to mass vegetative propagation through stem cutting (Eldridge et al., 1993). Under nursery conditions seed germination should be completed after 7 days at optimum temperature of 32 °C (Ponynton, 1979; Doran, 1990).Thanks to its wide geographical range and the many positive characteristics, *Eucalyptus camaldulensis* has become a very successful fast-growing species. According to the Private Plantation Unit of Royal Forestry Department (1996), Thailand, the planting can take place at any time of the year as a mixed or monoculture stand with spacing of 1×1 or 2×2 m, however 3×1.5, 3×3, and 4×3 m also reported from Brazil and Australia. To boot, *Eucalyptus camaldulensis* does not demand thinning as it is a self pruning species.

After first 3 years, the use of fertilizers at form of mixed green tenure and NPK-fertilizer at proportion of 15-15-15 once a year is recommended in order to increase production. As with rubber tree also in case of eucalypt, the fire breaks are highly recommended. Eucalypt is harvested by clear cutting after 5 to 7 years and the strong coppicing provides 4 to 5 new generations of productive eucalypt (Private plantation unit, RFD, 1996). The application of NPK fertilizer at mid-rotation to *Eucalyptus camaldulensis* produced high net energy returns per ha but a low energy output:input ratio. These low energy balance ratios for the use of high rates of nitrogenous fertilizer confirmed results from various studies (Heller et al., 2003; Mead and Gadgil, 1978). The coppice eucalyptus plantation often had higher energy balance ratios than that of pine because of its faster growth rate and higher basic wood density, 651 kg/m^3 comparing to 410 kg/m^3 (Mead and Pimentel, 2006).

Utilizations: *Eucalyptus camaldulensis* could be utilized to produce fuelwood, charcoal, and woodchip. Fuelwood from *Eucalyptus camaldulensis* is suitable for industrial use in brick kilns, but is not preferred for domestic use because it is too smoky and burns too fast. However, it makes good-quality charcoal. It is used for pulp and paper production and also processed for hardboard, fibreboard, and particleboard. As timber, *Eucalyptus camaldulensis* is suitable due to its great strength and good durability for many structural applications, for example, railway sleepers, poles, posts, floorings, wharves, ship building, and heavy construction. The density of the wood is up to 900 kg/m^3 at 12% mc. Eucalypt leaves have a high potential for oil extraction for pharmaceutical purposes and in dying silk and cotton yarns (Orwa et al., 2009). *Eucalyptus camaldulensis* is also found to be suitable in supporting bees for honey production, or for *positive externalities* (carbon sequestration, phytoremediation via salinity control, phytoremediation via rhizofiltering, auxilliary design tools for agroforestry systems, etc) (Trabado and Wilstermann, 2008). Eucalypt plantations with correct mycorrhiza, will also produce edible mushrooms.

Eucalypts have been successful as exotics because of their capacity for fast growth and tolerance of harsh environments involving many effective adaptations: indeterminate growth, coppicing, lignotubers, drought, fire, insect resistance, and tolerance of soil acidity and low fertility. Many eucalypts have wood properties, such as high density, suitable for fuel and charcoal production, pulp and paper manufacturing, and sawn wood (Rockwood et al., 2008). Plantation-grown *Eucalyptus* has long had the reputation of being a difficult species to work with. However, significant advances in log handling, sawing, and drying technology, have greatly improved sawmill and veneer mill recoveries in the last 4 to 5 years. Proper harvesting and log handling techniques have proven essential to improving conversion yields. It is expected that new sawmills built in the next several years will benefit from the experience gained and will process higher quality sawlogs soon to become available. As with most hardwood lumber, however, drying *Eucalyptus* is considerably more expensive than with conifer lumber, due to the much longer times involved (Flynn, 2003).

World production, trade and trend: Eucalyptus cultivated forests have followed a spectacular growth trend since their first cultivation out of Australia 235 years ago. Of the 12.751 M ha of eucalypt plantations reported to FAO in 2005, almost 12 M ha classified as productive forest (Rockwood et al., 2008) was nearly all accounted for by 12 countries (table 2.40). Eucalypt planting has intensified in recent years and continues to do so, especially in tropical countries. In these regions of faster growth, rotations were as short as 5 years with yields as high as 70 m^3/ha/y. 4 species and their hybrids from this subgenus, *Eucalyptus grandis* , *E. urophylla* , *E. camaldulensis*, and *E. globulus*, account for about 80% of the eucalypt plantations worldwide. The expansion of eucalypt plantations throughout the world is largely attributable to eucalypts' superior fiber and pulping properties and the increased global demand for short-fiber pulp.

Today, the total area of *Eucalyptus* plantations is estimated at between 16 and 19 M ha. While the overwhelming majority of this resource has been managed to produce either pulpwood or fuelwood, a number of companies, including some large multi-national companies, are changing their focus. Brazil, followed by Chile, is now the largest plantation plywood producer in the world. Small-scale experiments indicate that plantation eucalypts have the potential to displace some of the tropical and non-tropical timber used for plywood production. Eucalypt veneer is also penetrating the market, although much of it is still low grade owing to knots and other defects (ITTO, 2006a). Eucalyptus began to be established in Brazil as early as the initally 1900s, but the major plantings occurred between 1966 and 1989 when government incentives were available (Wright, 2006). Although eucalyptus wood is converted to charcoal for the Pig iron and Steel industry, it is also a major pulp resource and makes beautiful furniture.

Table 2.40: Area of productive eucalypt plantations and semi-natural forests (*) in 2005 by country, species, and age class

Country	**Species**	**Area (1,000 ha) by Age Class (years)**					
		0-5	**5-10**	**10-20**	**20-30**	**30-40**	**>40**
RSA	nitens	109.7	99.3	19.4	0.7	1.8	
	grandis	144.1	140.7	44.9	3.7	1.7	
Sudan	spp	118.2	189.1	165.5	8.0		
China	spp	683.0	576.4	982.7	154.4		
India	spp	43.0	64.4	103.2			
	spp*	656.1	984.2	1,576			
Myanmar	camaldulensis	1.1	2.1	2.2	1.1	0.5	
Vietnam	spp	222.4	286.5	67.1	7.0	3.0	
Iran	spp	24.6	6.2				
Italy	spp	7.0	8.2	8.2			
Australia	regnans	5.2	0.2	2.8	3.7	4.7	1.1
	globulus	131.2	260.1	48.7	1.1	0.4	
	pilularis	5.2	5.5	0.5	1.4	4.6	0.4
	dunnii	5.3	12.2	0.2			
	grandis	5.2	5.5	0.5	1.4	4.6	0.4
Argentina	grandis	15.8	32.6	34.5	11.8	3.9	
Brazil	spp	2118.1	756.5	121.0	30.3		
Chile	spp	353.4	204.1	85.4	7.2	2.0	
subtotal		**4,648.6**	**3,633.8**	**3,262.8**	**231.8**	**27.2**	**1.9**
total		**11,806.1**					

Source: Rockwood et al. (2008)

Most of the *Eucalyptus* roundwood produced in the world from plantations today is in South America. Despite wide-spread planting in parts of Asia and Australia, South America is still expected to produce 55% of the world's *Eucalyptus* roundwood in 2010. Sawlogs make up only a small share of the *Eucalyptus* harvest today, approximately 6 M m^3 of sawlogs in total. Of this, just over half are logs from native *Eucalyptus* forests in Australia, while the balance is from plantations worldwide. Brazil produces just over a third of all the plantation-grown *Eucalyptus* sawlogs in the world. By 2015, the volume of sawlogs from native forests in Australia will be substantially smaller, but the total sawlog harvest will be nearly double the current amount. Of the total production in 2015, an estimated 1.4 M m^3 is expected to be pruned sawlogs (Flynn, 2003).

2.3.2.2 Cultivation Trend of Eucalyptus in Thailand

The boom of eucalyptus in Thailand happened almost 20 years ago, in 1989/1990, with the support of the government and with the push of foreign investors. Its purpose was to provide enough raw materials for the pulp & paper industry, and to sell seedlings. Since eucalyptus is a fast-growing tree, it can be accessed for pulp production within 4 to 5 years after plantation. The plantation area of eucalyptus has increased to more than 0.4 M ha in 2000 (ITTO, 2003b). Eucalyptus plantations cover now in Thailand about 0.48 M ha, of which 10% is on levee in paddy fields; logs production from these plantations is estimated to be about 7 M m^3/y. Most (70 to 80%) of the harvest is used by the paper and pulp industry, while 10 to 15% goes for charcoal and 5% for construction poles; eucalypts are also starting to be used in the manufacture of MDF, hardboard, and particleboard. The substantial potential of Eucalyptus for sawnwood and plywood still remains to be tapped (ITTO, 2006b).

The key conclusion from available data on the spatial distribution of eucalyptus plantations is that they are concentrated in the Northeast (almost 50%). About two-thirds of the total eucalyptus plantation base in Thailand managed by smallholders. Many of these farmers are growing trees outside of contract systems, although this is changing as companies become increasingly interested in securing their fiber supplies in the face of growing competition and reduced government assistance for eucalyptus growers (Barney, 2005). Large-scale plantation areas of eucalyptus for pulp industry in Thailand totaled about 54,500 ha, including: 1) Advance Agro Plc, with 32,000 ha rented from forest reserves of the RFD (farmers' common lands) for eucalyptus plantations in the East; 2) FIO, with 20,500 ha in the Northeast; 3) Asia Tech Co, with 1,600 ha in the upper Northeast along Songkhram River; 4) Phoenix Pulp & Paper Co, with 440 ha of irrigated eucalyptus plantations in Khon Kaen (Project Green). This figure does not include the planned Sino-Thai-Advance Agro pulp mill project, which would need 120,000 ha of plantations (either rented from RFD or through contract farming) in the East and the Northeast. This project has been halted due to strong local resistance. Small-scale plantations came altogether to 73,000 ha: 1) Contract eucalyptus farming for Advance Agro in the East: 57,000 ha; 2) Farmers selling eucalyptus and bamboo to Phoenix Pulp & Paper in the Northeast: 16,000 ha.

Production capacity statistics: Government feasibility studies on Eucalyptus plantations, most of which have sprouted in the Northeast, yielded the most promising results. There are a number of reasons for the choice of the eucalyptus: it is the most common fast growing species for pulp and wood fuel production, it is less susceptible to hazards and calamities, it is fire resistant, and its density and calorific value make the wood excellent to use in thermal power production. Once established, a eucalyptus plantation is easy to manage and it will sustain for a period of 3 to 4 rotations for 25 to 30 years.

In 1997, Thailand had 438,524 ha of eucalypt private plantations distributed 47.38% in the Northeast, 28.73% in the East, 12.77% in the North, 11.07% in the Central, and only 0.05% in the South (Thaiutsa, 2002). New technologies were introduced to private plantations. Most planting stocks were produced from cutting, followed by tissue culture and seeds with the percentages of 80, 12, and 8, respectively. The spacing of 2 m × 3 m was a common practice planted after intensively mechanized site preparation. Some plantations preferred early dry-season planting in order to minimize the first-year weeding problems. Chemical fertilizers were applied periodically. Clear cutting with coppice system was carried out at 5 years old, followed by thinning the new shoots and remaining 2 to 3 sprouts for the next rotation.

Demands of eucalypt log for wood-chip industry in the year 2002 for 3 main categories, i.e. pulp mills, chip mills, and MDF, are 3,700,000 (57.86%), 2,015,000 (31.51%), and 680,000 t (10.63%), respectively, leading to the total demands of 6,395,000 Green Metric Ton. Most private plantations set up rotation length at 5 years old with an average yield of about 75 t/ha under proper establishment and maintenances. Thus, total plantation areas required for wood chips are 426,335 ha in order to be harvested 85,267 ha/y (Thaiutsa, 2002).

State policy and production trend: Eucalyptus plantations became a business associated with the pulp & paper industry, whose main raw material was the eucalyptus tree species. During this period, domestic business groups, transnational corporations, and the government played an active role in promoting tree plantations as Thailand's principal national policy. The government officiously set a target for eucalyptus plantations at 6 M ha. As in other countries of the region today, the target area for eucalyptus plantations is "degraded forests" in National Forest Reserves. In short, this has become a major issue, particularly where fast-wood plantations are a significant land use. However, there are no studies done to show how many families or communities have really been affected by the plantations. Since plantations are scattered in large areas of East and Northeast Thailand, the number of affected communities could easily be several thousand, totaling hundreds of thousands of families.

Problems and barriers: In Thailand, the policy of commercial eucalyptus plantation faced strong and wide opposition from local people, environmental groups, and NGOs who pointed out the following 3 major adverse impacts: 1) destruction of nature, vast areas of eucalyptus plantations by business groups were obtained by destroying existing natural forests; 2) conflict over land, in order to have the area reforested, the local people would have to be evicted. This resulted in violent conflicts between the State and the business or private sector groups on one side and the village people on the other; 3) destruction of the ecosystems, large areas of monoculture eucalyptus plantations lead to the drying up of water sources, affect soil fertility, and decreased the agricultural yields of surrounding farmlands (Enters et al., 2004).

Environmentalists warned that, "commercial eucalyptus plantations are incompatible both with forest conservation and with village livelihood(s)" (Lohmann, 1990; Lang 2002). Although the discussion on the environmental impacts of plantations, especially related to catchment hydrology, is plagued by myths and misperceptions (Cossalter and Pye-Smith 2003), environmental campaigns against tree plantations have clearly affected investor behavior in some countries, including also Thailand. In addition, these campaigns have led to the condemnation of some "exotic species" such as *Eucalyptus camaldulensis* as an inherent evil, in many countries in Asia. The notoriety of eucalyptus: under certain soil and climatic conditions, it might be ecologically feasible and economically profitable to clear-cut a forest and replant it in a monoculture. While this might be profit-maximizing, it is unlikely to be social welfare maximizing because forest plantation monocultures are associated with notoriously low ecological services (Kahn, 2002).

2.3.3 Teak

2.3.3.1 General Data about Teak

Botanical specifications: Teak is commonly found as a component of monsoon forest vegetation. It belongs under a genus of tropical hardwood trees in the family Verbenaceae, native to the south and southeast of Asia. It is a large deciduous tree with a rounded crown, growing to 30 to 40 m tall and diameters of 2 m, deciduous in the dry season. There are only 3 species of Tectona worldwide: 1) *Tectona grandis* (Common Teak) is by far the most important, with a wide distribution in India and Indo-China; 2) *Tectona hamiltoniana* (Dahat Teak) is a local native species confined to Burma where it is endangered; 3) *Tectona philippinensis* (Philippine Teak) is endemic to the Philippines and it is also threatened (Singh, 2004; Schubert and Francis, n.d.). Tectona grandis tolerates a wide range of climates, but grows best in a warm, moist, and tropical climate (1,250 to 3,000 mm of mean annual precipitation) with a marked dry season of 3 to 6 months (Webb et al., 1984). The base of the tree is often buttressed (having outgrowths at the base caused by exaggerated root swelling) and sometimes fluted (having irregular involutions and swellings in the bole). Leaves are broadly elliptical or obovate, with usually 30 to 60 cm long. It also requires very good drainage and rich soil. Teak has probably been cultivated for centuries in Asia and has been planted for timber production in India and Burma since at least 1840 (Troup, 1921). Geographical races of teak have been distinguished by differences in stem form and rate of growth (Champion, 1936). An insect native to Southeast Asia, *Hyblaea puera* is a teak pest whose caterpillar feeds on teak and other species of trees common in the region.

Cultivation and logging: Teak, relative to other species, is easily established in plantations and because of the enduring global demand for products from teak it has good prospects as a plantation species. These prospects are boosted by the rapidly developing trend of replacing lumber with reconstituted panels (Loke, 1996). Sliced veneer of teak as a lay-on for reconstituted panels is assured of a demand for its value in enhancing the potential for panels to substitute for lumber in a widening variety of applications. Teak has borne viable seeds when only 3 years old (Schubert, 1974). Germination in nursery beds in various parts of the world has varied from 0 to 96% in periods varying from 10 days to 3 months. Seeds extracted from the fruits and treated with fungicide gave a germination of 54% in 12 days (Dabral, 1976). Because it is difficult to extract teak seeds from their fruits and untreated teak fruits give protracted, often low and unpredictable germination, some fruit pretreatment in usually applied. Teak fruits are usually broadcast in nursery beds and covered with 1.2 to 2.5 cm of sand, soil, or sawdust (Schubert, 1974; White and Cameron, n.d.).

Field planting is generally done with plants (seedlings with the tops removed) or potted plants grown in plastic nursery bags. The stump plants are grown in the nursery until they reach 1.2 to 2.5 cm in diameter at the root collar which have had the top cut back to about 2.5 cm and the taproot cut back to 18 or 20 cm in length (Schubert, 1974; White and Cameron, n.d.). Sowing of the nursery beds should be timed so that the proper size is reached in time for planting at the start of the rainy season. Direct seeding is also practiced. It requires prepared seed spots. Early growth is slow and often high mortality results (Weaver, 1993). It can also be reproduced by coppicing, because cut stumps produce very vigorous sprouts. Teak does not tolerate shade or suppression at any stage of its life and requires unimpeded overhead light for its proper development. It begins flowering and seeding at a young age, about 20 years from seedling and about 10 years from coppice. Mixed plantations of teak with other tree species are generally less susceptible than pure teak plantations to soil erosion and pest and disease risks. Pure teak plantations are susceptible to defoliating pests, particularly when under storey growth is suppressed and site conditions are suboptimal.

Because teak is planted and managed for timber production, its stem size plays a decisive role in determining harvesting, rather than the age of maximum volume production. The rotation age of plantation teak in its natural range has varied between 50 and 90 years, while outside its range the rotation age is between 40 and 60 years. Based on a weighed assessment of economic and silvicultural considerations, a rotation of 25 years to 40 years may at present be considered as the optimum cycle to achieve a viable balance between financial returns and the production of market quality timber. During this rotation period, thinning operations will provide returns at intermediate stages, easing the economic burden related to the long-term nature of the operation, and making the investment financially attractive. An initial thinning should be considered as soon as the branches start to make contact with those of surrounding trees; this may occur when the plantation is around 4 to 5 years old and the intensity of removals may be as high as 50% of the initial stocking. A production thinning may follow at about age 10 to 15, and a final production thinning at around 15 to 20 years (Pandey and Brown, 2000).

Utilizations: Teak wood is famous the world over for its strength, durability, dimensional stability, working qualities, and the fact that it does not cause corrosion when in contact with metal (Kukachka, 1970; Troup, 1921). Its heartwood is golden brown with a distinct grain, and has a specific gravity of 0.55. The untreated wood weathers well, resists rot, and is not attacked by termites; calling forth its competence for utilizing in exposed locations. Teak wood from natural forests is generally more durable and harder than that from plantations. Teak from plantations is more prone bringing about splitting problem and water damage, nevertheless kiln drying allows planted teak to perform nearly on par with old-growth teak. It is currently used for shipbuilding, exterior windows & doors, fine furniture, trim, decorative objects, veneer for decorative plywood, posts, poles, and fuel (Kukachka, 1970; Webb et al., 1984). Although relatively unimportant in terms of the volume of world timber production, because of its strength and aesthetic qualities, teak is the tropical hardwood most in demand for a specific market of "luxury" applications including furniture and decorative building components. It is thus of major importance in the forestry economies of its main producing countries.

World production, trade, and trend: During the past 20 years, most supplies of teak wood from natural forests have dwindled, but increased interest has developed in the establishment of teak forest plantations. Teak plantation, once mainly the domain of government forest departments, is nowadays also being attracted by the private sector. In tandem with the involvement of farmers in planting teak, a shift from large to small scale plantations and from long to shorter rotations can be observed. Teak is being grown in at least 36 countries across the 3 tropical regions and constitutes an estimated 75% of the world high-quality tropical hardwood plantations (Bhat and Ma, 2004). Global demand for plantation teak is expected to continue to increase as restrictions continue to be placed on the harvesting of native teak (now almost exclusively from Myanmar). In several countries, however, policies and legislation restricting harvest and transport of teak in order to protect natural forests but applying even to teak grown in plantations act as disincentives to private sector investment (Enters, 1999).

As the sustainable supply of teak from natural forests diminishes and the demand continues to increase, the general trend in the future of teak growing will be towards increasing production and utilization of plantation-grown teak. Logging in Myanmar is conducted according to the Myanmar Selection System: the Forest Department selects mature trees for harvest and Myanmar Timber Enterprises, a government corporation, is the sole agency responsible for extraction. As a result of Myanmar's long experience with harvesting under this system, teak management is generally well regarded in terms of environmental sustainability (Wint, 1998). Because of teak's durability much of this production is utilized as posts and poles, although a part also finds its way into higher-value end-uses. For example, Zamora (1998) reports that companies in Costa Rica produce furniture components and small flooring boards from six- to seven-year-old teak thinnings. Tropical timber imports of logs from ITTO members totalled 15.8 M m^3 in 2005. Two of the largest global importers of teak logs are China and Thailand, where the timber is manufactured into semi-finished and finished products, either for export or domestic consumption. India, a substantial producer of teak in its own right, also imports a large amount to meet the growing requirements of its domestic market.

Due to intense competition in suitable sites from a number of cash crops such as oil palm, fruit-trees and vegetables, teak is being planted on degraded land. Obtained from thinnings and final felling over the rotation, **M**ean **A**nnual **I**ncrement (MAI) range from 2 to 5 m^3/ha and are often below the potential yield of the site. The poor performance is mainly a result of low inputs and poor management, coupled with yield-reducing factors such as illicit removal, fire, pest infestation and disease outbreaks. Improvement in production could increase the MAI to 8 to 12 m^3/ha. Yields of 15 to 20 m^3/ha/y on a 20 years rotation should be viewed as the upper limit with present technologies. The available studies suggest that, if properly managed, teak plantations could generate attractive returns to investment. However, reliable financial appraisals are very limited. Profitability of small diameter wood obtained from thinning or short rotation is substantially influenced by the high proportion of sapwood, the variability in physical and mechanical properties, the appearance of the wood in comparison with that of large diameter wood from natural forests and long rotation plantations, and the feasibility of processing and marketing smaller dimensions (Enters, 1999).

2.3.3.2 Cultivation Trend of Teak in Thailand

In Thailand, pioneer plantations of teak were established from 1906 on an area of less than 1 ha, but teak plantations currently cover approximately 0.836 M ha. Thailand has a very heavy dependence on imports of plantation-grown teak for its rapidly growing export-oriented furniture manufacturing industry. This industry employs approximately 0.4 M people, is responsible for export earnings of approximately US$400 M. Since 1945, in conjunction with Scandinavian designs and manufacturing techniques, has done much to popularize teak furniture on a global basis. Cutting system prescribed for the deciduous teak forest, based on a 30-year felling cycle. Today, dominant planting methodology is industrial. Most of the tree plantations grown for saw timber require early, heavy, and repeated thinnings in order to sustain rapid diameter growth of the selected trees (Galloway et al., 2001). The moderate and heavy thinnings yielded the highest percentage of heartwood volume (25 to 30% of total stem volume). Increased yield and higher uniformity from shorter rotations are key incentives for developing intensively managed teak plantations. However, future development opportunity is limited.

Production capacity statistics: All industrial harvesting in the natural forests of Thailand has been banned since 1989, although logging of teak has reportedly continued illegally in some areas, notably along the Myanmar border (for example, in Salween National Park) (Bangkok Post, 1998 cite by Pandey and Brown, 2000). The area of natural teak forest in Thailand decreased. 2.3 M ha in 1954 to about 0.15 M ha in 2000. During the same period, the private and public sectors established 0.836 M ha of teak plantations and their thinnings are now being sold. Apart from genetic improvement, practically no research has been done regarding teak, even though the specie was the mainstay of the forestry sector for more than a hundred years (ITTO, 2006a). The FIO controls total area of teak plantation 80,000 ha. On the basis of the silvicultural system adopted by FIO, the teak rotation cycle lasts between 20 to 35 years. Above ground biomass of teak plantation at the ages of 6, 14, and 27 years were 17.635, 120.533 and 165.977 t/ha, while those of Acacia mangium (age 6 years) was 106.740 t/ha, and Eucalyptus camaldulensis ages 6 years were 50.005 t/ha and 117.129 t/ha, respectively. But when teak reached the age of 14 years, it generates above ground biomass a litter higher than Eucalyptus camaldulensis (Sumantakul and Viriyabuncha, 2007).

State policy and production trend: Teak is one of the most valuable kinds of timber of the country. It has long been one of Thailand's important exports of forestry sector. However, the yield is diminishing when the concession has been banned in 1989. Because of heavy loggings by big foreign companies last century, the government is now trying hard to restore the teak forests by planting new trees wherever possible. The FIO, a state enterprise for the utilization of forest resource, has many reforestation projects throughout the country. Current policies relating to tenure, royalties, taxes and rules and regulations covering the harvesting and transport of teak wood, and their impact on investment in teak plantations, should be reviewed at the national level. Existing systems for financing investments should be evaluated and funding mechanisms that encourage teak as a long term investment should be designed. Financial and tax incentives could have an important role in promoting investment in teak as a "green investment". Efforts in this direction could facilitate higher investment in establishing and managing teak on a long rotation basis. Several countries are interested in improving financial returns from teak plantations through utilization of thinnings and small roundwood. Many studies are being conducted on conversion techniques for small round-wood, techniques for reconstituting small sawnwood as larger material, and market opportunities for small-dimension timber or components (Pandey and Brown, 2000).

Problems and barriers: In Thailand, the large-scale expansion of the teak plantation estate is not foreseen; prevailing policies in Thailand even discourage harvesting in the existing teak plantations. One of the main hindrances to high-quality teak plantation development remains the insufficient production of seed. In Thailand, tissue-culture facilities have been used to produce and sell seedlings of plus-trees. For other problems including: 1) The use of such improved materials is expected when existing plantations are harvested and re-planted, or when new private plantations are established. 2) The mechanisms that link potential investors with growers remain underdeveloped, particularly in the case of small scale growers whose access to institutional financing is limited; 3) The linkage between public, private sector research, and teak growers is generally very weak and there is no effective mechanism to facilitate a two-way flow of information. The role of different players is ill defined and competing interests often lead to unnecessary secrecy and failure to share information for mutual benefit; 4) Areas that require more research efforts include the long term sustainability of teak plantations, management of mixed plantations and agroforestry systems; 5) Coordinated efforts are required to identify gaps in the conservation, sustainable management, breeding and enhancement of teak genetic resources and to avoid duplication of efforts.

During the past 20 years, most supplies of teak wood from natural forests have dwindled but increased interest has developed in the establishment of teak forest plantations. The transition towards greater utilization of plantation-grown teak is not, however, being made without difficulty or controversy. Until recently, misgivings over the environmental impacts of teak plantations - particularly controversies regarding possible soil deterioration and erosion in pure teak plantations - rivaled those often associated with eucalypt plantations. Nonetheless, with teak remaining one of the world's most valuable timbers, interest in growing and investing in the species will remain high. Legislation and vigilance in both the commercial and the environmental spheres will be necessary to ensure that the teak-growing industry develops in an orderly fashion (Pandey and Brown, 2000).

2.3.4 Dendrothermal Plantation in Thailand

2.3.4.1 General Data

As a source for bioenergy (see Ch. 2.1), trees offer an advantage over many agricultural crops, which usually have to be harvested annually, increasing the risk of oversupply and market volatility (Perley, 2008). The sole purpose of fast-wood plantations for energy is to produce large volumes of small-diameter logs at competitive prices as fast as possible. There have been a number of energy budget studies reported for growing and utilizing short-rotation woody energy crops such as willows and poplars. Output:input energy ratios vary from 5 to 55 depending on species, growing conditions, inputs and assumed boundaries to the system. Smith and Johnson (1977) discussed the silvicultural energy costs and returns for intensive silviculture plantations grown on a 30-year rotation. Treatments included mechanical site preparation, planting, some additional tending and the application of a modest dose of nitrogen fertilizer. They described an output:input ratio of 157:1 and 22:1 before and after harvesting, respectively. Another study, which included intensively managed plantations of Pinus taeda in Oklahoma grown on a 30-year rotation, found an output:input ratio of 9.4 after silviculture, logging and transport were accounted for.

Global industrial roundwood production was about 1.7 billion m^3 in 2005, compared with fuelwood production of around 1.8 billion m^3 (FAO, 2007c). Roughly 65% of global industrial roundwood was produced in industrialized countries, compared with only 13% of fuelwood. The last 15 years global consumption of woodfuel has remained relatively stable, at between 1.8 and 1.9 billion m^3. Fig. 2.19 shows woodfuel consumption for OECD and non-OECD country groups between 1990 and 2030. The global trend indicates increasing consumption of woodfuel, largely a reflection of increasing consumption in Africa. Non-OECD countries in Asia and Oceania are, in contrast, showing a downward trend as rapid increases in income occur and urbanization takes place. Future consumption in OECD European countries is expected to be greater than shown in Fig. 2.19 due to recent EU plans to increase the proportion of renewables in total energy use to 20% by 2020 (EU, 2007).

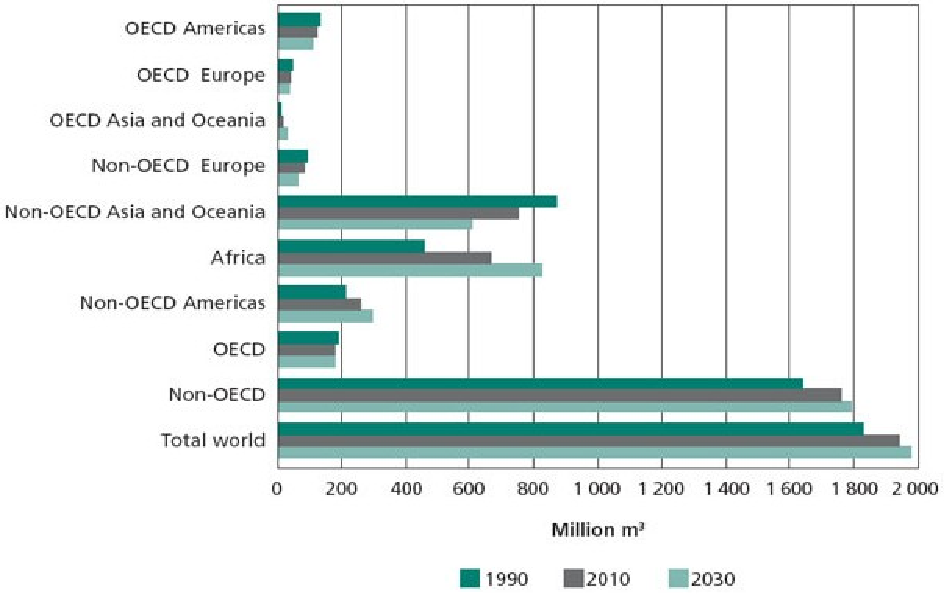

Fig. 2.19: Woodfuel consumption for OECD and non-OECD countries 1990, projections for 2010 and 2030

Source: FAO (2008c)

Mabee and Saddler (2007a) reviewed a number of regional and global outlook studies on forest fiber availability to determine the renewable global supply of forest biomass for wood energy production. They concluded that increased demand for wood energy in industrialized countries will have a significant impact on the amount of available excess forest biomass, taking between 10 and 25% of the estimated global surplus. The global availability of fiber may not, however, cover demand in some regions and increased demand from wood processing industries may also compete for supply. To boot, Pulp mills and panel manufacturers are in most direct competition with bioenergy applications for wood supplies, and in the short-term it is likely that consumers will face higher prices for some products (UNECE/FAO, 2007).

2.3.4.2 Cultivation Trend in Thailand

Despite growth in population (see Ch. 1.1.1), the consumption of fuelwood and charcoal both in Thailand has not appreciably increased in the last 10 years. Resulting from the impetuous economic development of the country (see Ch. 1.1.4), rapid development in infrastructure in the past decade has resulted in shift onto the pattern of energy utilization in the country. Modern forms of energy, mainly electricity and LPG, have been brought to the rural households (see Ch. 2.1 and Ch. 1.4.1). However, in remote villages and among the hill tribes, the households still lean totally on fuelwood, particularly for cooking. Moreover, small-scale rural industries normally utilize fuelwood for process heating or drying their final products. Generally, utilizing conventional technologies which are ineffective by nature, these industries include: 1) agricultural and food processing (rubber and coconut processing, fish and meat drying etc.); 2) metal processing and mineral based activities (brick making, lime burning, pottery, foundry, etc.); 3) forest products (Bamboo and cane, distilleries, timber drying, etc.); and 4) service sector (road tarring, catering services etc.) (RWEDP, 1999).

The household sector uses about 20 M t of wood annually in the form of fuelwood or charcoal, but wood supplies from around the dwelling (such as home gardens, woodlots, and public forests) are able to fulfill this demand. Overall, the rural people have been able to meet their fuelwood needs, but in many localities only by overexploiting the sources. On the other hand, there is a shortage of fuelwood in the industrial sector, which requires about 6.5 M t annually. Demand for electricity increases by 1,000 MW_e annually. This means that more energy supplies must be found to meet this demand. Unsurprisingly, when planning the new investments in power plant, the availability of energy resources is the main issue (Sutthisrisinn, 1998).

As for fuelwood supply, both indigenous and exotic tree species were chosen for planting in various parts of the country. The superior indigenous trees include *Acacia catechu*, *Combretum quadrangulare*, *Peltophorum pterocarpum (inerme)*, *Rhizophora mucronata*, etc., while *Acacia auriculiformis*, *A. Mangium*, *Casuarina equisetifolia*, *C. junghuhniana*, *Eucalyptus camaldulensis*, *E. saligna*, *E. tereticornis* and *Leucaena leucocephala* are promising exotic trees.

Production capacity statistics of Thailand: In Thailand, the development of unsuitable lands for agriculture to wood plantation areas was proposed in the first master plan of dendrothermal power programme. The unsuitable lands include marginal agricultural lands and degraded forests, but steep lands with high risks of erosion are excluded. During that time, about 0.6 M ha of marginal lands were identified to be a suitable area for fast-growing tree plantation of which logs are utilized as fuel for generating electricity around 1,200 MW

(NEA, 1987). In 1993, about 17.5 M ha of lands were classified as idle and unclassified lands (this includes degraded national forest reserves) (RFD, 1996). 34% (almost 6 M ha) of this is found in the Northeast where the wood fuel crisis is very severe and where there are extreme seasons of prolonged droughts and floods. However, the area of land available for energy cropping will depend largely on the extent to which it is competitive with alternative land uses. From the study by Suranaree University of Technology, it was recently estimated that a fast-growing tree from a planting area can be produce electricity 1400 to 12000 MW_e.

State policy and production trend: Under energy policies of Thailand, the strategy of the government on energy since 2003 has been established involving an ambitious target for both energy efficiency and renewable energy development. The national energy policy in Thailand promotes renewable sources as these address key issues on energy security, reduction on energy imports, and GHG reductions. In order to have alternative energy replacing non-renewable energy from fossil fuel, the Government aspires to increase the share of renewable energy from 0.5% of the commercial primary energy in 2002 to 8% by 2011 (see also Ch. 5.1.2). The promotion of biomass residues in particular is part of this policy, and favours the purchase of power from small power producers (SPP), with PPA of 21 years. Moreover, under the Thai Forest Sector Master Plan target area, Wood energy as a substation of fossil energy shall be promoted through energy plantations. Therefore, species of wood that are not suitable utilized by traditional wood-processing industries represent another opportunity to produce biomass for energy generation.

Problems and barriers in Thailand: Dendrothermal plantation for modern biomass energy utilization is even now infant industry in Thailand. Many problems are still challenge. These include:

1) The ban on domestic wood logging in 1989, however, may have an affect on the development of the dendrothermal power program, which to date has seen little progress. Moreover, the increasing interest in the use of wood for such other high value added products as furniture, pulp & paper, etc., brings less justification for the use of dendrothermal plantations solely for energy generation. In the short to medium terms, there is a need to attend to fuelwood problems in the North and in some specific localities in other regions, where the energy shortage is severe.

2) The analyses given under the agroforestry and forest plantation development programme show that forest plantations could not be profitable at low wood prices, and certainly along with fuelwood prices. In general, the value of wood for fuel should be low in comparison with other end uses. Pulp mills and panel manufacturers are in most direct competition with bioenergy applications for wood supplies. Changes, however, in energy prices may render woodfuel plantations for energy unviable, and consequently of no market value. The problem of forest fuels is that their use is beneficial to the national economy, but it has not necessarily been a profitable business (Hakkila, 2006).

3) As bioenergy opportunities are explored, increased competition for wood fiber should support the recent trend towards higher wood prices. As wood prices rise, development of bioenergy opportunities may slow down over the medium to long term. Higher transportation costs and incentives for bioenergy production were also cited as major reasons for these increases (GreenFacts, 2009).

4) Some developing countries, including Thailand, need to invest in technological research and development for several years in order to turn these plantations into an attractive business, also adapt it to other utilizations, for example, pulp and wood panels industries use the same raw materials, reducing the risk of investment in dendrothermal plantation.

5) More importantly, in accordance to the 1997 Constitution, the energy strategy will be affected by the decentralization policy of the government. This implies that powers as well as finance will be delegated to provincial and local authorities, which eventually will undertake and be responsible for the actual planning and implementation.

6) Government policies have a significant impact on dendrothermal prices. Subsidies for investments in renewable energy, tax incentives and tariffs all are having an impact attractiveness of this business. However, the future of these businesses is in doubt because the government cannot guarantee their long-term status (GreenFacts, 2009).

2.3.5 Others potential trees in Thailand

From point of view in indigenous wood utilization: rubberwood is used in furniture manufacturing; teak is processing to expensive cabinet wood; eucalyptus and acacia spp. is cheaper utility wood; *Pinus merkusii* is medium-quality timber. Apart from these plants, bamboo is the most important marketed non-wood forest products, while construction and demolition wood may have potential for the utilization as an energy source for the country.

2.3.5.1 Bamboo

General data: Although bamboo has a long history of utilization in Asia, it is increasingly becoming an important source of raw material for further downstream processing, as new uses for it have emerged. Traditionally, the culms were used as a wood substitute for construction and scaffolding, while the shoots of certain species were eaten. New processes use bamboo as raw material for particleboard, fiberboard, ply-bamboo, laminated boards, bamboo flooring, also pulp & paper (Ruiz-Perez et al., 2001). Bamboo is a naturally occurring composite material which abundantly grows in most of the tropical countries. The main advantages of bamboo are its fast growing nature, high productivity, quick maturity and better mechanical properties when compared to other wood species (Malanit, 2009). Lobovikov et al. (2007) reported that bamboo is mostly distributed in Asia, Africa, as well as Central and South American. It covers an area of over 36 M ha, while Asia is the richest continent with about 65% of total world bamboo resources.

In Thailand, bamboo is one of the most socio-economically important species. There are 13 genera and about 60 species of bamboo in Thailand, the main ones being Thyrsostachy siamensis, Bambusa blumeana, B. polymorpha, B. mana, B. tulda, B. arundinacea, Dendrocalamus hamiltonii, D. giganteus, and D. brandisi (Rao and Ramanatha Rao, 1998). Numerous articles of daily use, such as baskets, furniture, tool handles, beds, sticks, poles, brushes, pipes, fans, umbrellas, toys, musical instruments, water containers, and fishing rods & traps are made of bamboo of different species. These varied uses illustrate the versatility of bamboo as an economic commodity. Generally, bamboo is indigenously used extensively as a substitute of timber in construction (scaffolding, ladders, bridges, and fences) and in pulping. About 80% of the bamboo production goes to the various non-industrial utilizations, and only 20% to the pulp industry (mainly the pulp mill in Khon Kaen province, in the Northeast)

Resource base, production, and employment: Bamboos constitute the natural undergrowth in deciduous forests. In forest areas disturbed by fire or shifting cultivation, bamboos potentially become the dominant vegetation. The latest survey of bamboo (1988) showed that bamboo covers a total area of around 5.06 M Rais. On the basis of an average annual yield at 0.1 t/ha green weight, the potential annual production of bamboo from natural sources is about half a million tonne. In addition to the natural sources, bamboos are also grown in small plots along fences and around homesteads for domestic/local utilization. A bamboo plantation can yield average annual net revenue of 5,600 Baht/rai. Because of this attractive yield, commercial bamboo plantations for edible shoot production using D. asper have rapidly expanded, particularly in **Nakon Nayok** and **Prachin Buri** where soil and climatic conditions are favourable for bamboo growing. About 107,000 Rais of bamboo plantations have been established under the extension programme. Average bamboo production from 1980 to 1990 was 49.2 M culms, or around 147,600 t. About 4,400 t were exported and 143,200 t were used locally. No trend can be discerned in the annual harvest, but a collating between 1985 and 1990 shows a decrease of bamboo utilization in rural construction from 33% of total consumption to 21%. While the use of bamboo as pulping material increased from 8% to 20% during the same time (Sutthisrisinn, 1998).

The demand of bamboo for pulping has risen to reach about 0.4 M t/y, which is about 2.5 times the current bamboo production. It is approaching the estimated potential yield of the whole country, although it is harvested as a relatively small area. With the impasse in the promotion of fast-growing tree species in reforestation, this increase in demand threatens the natural bamboo resources. The importance of bamboo as a source of employment is mostly unrecognized. No systematic investigations have been made, but on the basis of a harvesting rate of 50 culms per day and the average annul production of 49.2 M culms, harvesting alone generates almost one million person-days of employment per year. Including other activities from plantation to marketing and processing, the generated employment could be about 3 to 4 M person-days per year (Sutthisrisinn, 1998).

Marketing, exports, and imports: There are many stages on bamboo marketing from the source of production or forest to its consumer. The most/main direct line is from the collector to the local consumers, while the longest line involves local traders, district traders, shippers, wholesalers, retailers, and finally the urban consumer. During the last decade, bamboo exports were at their highest in the mid-1980s, reaching 9,667 t in 1985, but steadily declined since then. Only 659 t was exported in 1990. The average annual export earnings among 1980 to 1990 were about 18.5 M Baht. The imports consisted mainly of edible dry bamboo shoots, averaging about 170 t/y with a value of around 13 M Baht (Sutthisrisinn, 1998).

Problems and recommendations: Because of uneven distribution, inaccessibility, population pressure, and localized industrial demand, areas of scarcity, and over-exploitation still exist in spite of the abundance of bamboo on a national scale. Because of inaccessibility and lack of management, the overall productivity of bamboo in Thailand is only about 8% that of Japan. Although Thailand has relied for centuries on bamboo to meet daily needs, there is surprisingly little known about many aspects of bamboo production. The following actions are therefore needed: 1) conduct of research over the entire spectrum of bamboo: propagation, management, and utilization; 2) nation-wide survey on both bamboo supply and demand to determine where new plantings should be concentrated and to find out what form of promotion or extension measures are needed; 3) proper management of natural areas by the formulation and implementation of working plans and stopping of over-exploitation. The problem of rapidly declining bamboo resources are due to excessive harvesting, including illegal harvesting of bamboo stands in the forests, was identified. Appropriate propagation and plantation management techniques for shoot and pole production were generally not widely known by farmers. Similarly, rural-based bamboo-using enterprises had limited access to information and technologies on the efficient use of bamboo; hence no opportunities to improve traditional products, let alone produce higher value ones (Soriano, 2008).

2.3.5.2 Construction and Demolition Wood

Most often disposed of in landfills, construction and demolition (C&D) waste is the waste produced during new construction, renovation, and demolition of buildings and structures. A lot of research has been carried out on its minimization, management, and potential utilization. In many countries including Thailand, the increasing unregulated dumping of construction waste and the scarcity of landfill space are becoming very serious issues. The management of construction waste is therefore a major priority, especially in Bangkok and the Northern provinces of Thailand where the population is much denser and the rate of building construction is higher than in other parts of the country (NSO, 2007). Usually, a material like wood is reused within the construction site as many times as possible to avoid the cost of collection and disposal and the extra cost of virgin material. Scrap dealers usually collect scrap metals (mostly off-cuts of metal sheets and bars), as well as other salvageable materials generated. These are resold to secondhand buyers or, if metals, to metal smelting companies (Kofoworola and Gheewala, 2009). Although the collection and sale of these materials by collectors is a positive application of reuse and recycling, it is not a system that functions at an efficient level (Esin and Cosgun, 2005).

In Thailand, construction waste is classified as part of municipal solid waste (MSW). It was estimated that 16 to 34% of collected MSW in 2000 had recyclable materials, but only 7% (or 2,360 t/d) was actually recycled (Padungsirikul, 2003). A National Integrated Waste Management Plan for Thailand included control of waste generation at sources, increase waste separation to facilitate recycling and enhancement of waste utilization efficiently prior to final disposal; and reduce by 30% of total waste generated by 2009 (Thongkaimook, 2005). The total MSW generation in Thailand increased from 11.2 M t in 1993 to 14.3 M t in 2002. Also, the average per capita generation rate increased from 0.53 kg/cap/day in 1993 to 0.62 kg/cap/day in 2002 (Chiemchaisri et al., 2006). With many assumptions, Kofoworola and Gheewala (2009) evaluated construction waste in Thailand about an average of 1.1 M t of construction waste per year from 2002 to 2005. The component of construction waste shows in the table 2.41 next page. This study estimated that about 7.7% of all wastes disposed of (whether in landfills or in open dumps) was construction wastes. This figure was expected to increase when wastes from the construction of infrastructure as well as maintenance and demolition activities was considered.

Chipped or shredded wood from construction waste is used as a composting bulking agent, sewage sludge bulking medium, and animal bedding. Recovered wood can be also used to manufacture value-added products such as particleboard or cement/gypsum based materials. However, these industries normally demand clean and consistent feedstock, which can be difficult to achieve with wood from the construction waste stream. Consequently, most wood waste usually ends up as input for products such as mulch, or used as fuel (Falk and McKeever, 2004). It was also assumed that the lower heating value of biomass pellets from wood waste is 16.9 MJ/kg (Rakos, 2004; Hikiert, 2007 cited by Kofoworola and Gheewala, 2009).

Table 2.41: Total construction waste amounts by material (in 10^3 t) 2002 to 2005.

Material	10^3 tons				Average (%)
	2002	2003	2004	2005	
Asbestos	0.0	0.0	0.0	0.0	0.0
Harzard waste	1.8	2.6	3.2	2.9	0.0
Concrete/bricks	354.8	517.2	634.1	586.7	46.0
Gypsum	48.4	70.6	86.5	80.1	6
Glass	3.6	5.3	6.5	6.0	0.0
Insulation/EPS	14.5	21.1	25.9	24.0	2.0
Metal	10.2	14.9	18.3	16.9	1.0
Paper/Cardboad/plastics	34.9	50.8	62.3	57.6	5.0
Wood	105.9	154.4	189.2	175.1	14.0
Unknow compostion	200.6	292.4	358.4	331.6	26.0

Source: Kofoworola and Gheewala (2009)

For demolition wood, actually model waste generation from demolition activity within Thailand's building stock is unavailable due to lack of its data. From the literature review, the sources of **D**emolition **W**ood (DW), also called **B Q**uality **W**ood (BQW), include timber yards, packaging and scrap furniture. In consequence, DW can include paints, wood preservatives and fire retardants with toxic elements and compounds. DW was contaminated with lead, which tended to get strongly enriched in the fine fly ash fraction (Kofoworola and Gheewala, 2009). Therefore, it must be utilized by higher technology.

2.3.6 Wood Based Industry in Thailand

The wood-based industry (WBI) has long been an important segment of Thai dynamic manufacturing sector, the main driver of economic growth for the country. The industry has also played a significant role as an export earner. The industry has undergone major changes over the years, with downstream activities becoming increasingly important (see Ch. 1.1.2 to 1.1.4). Thailand is no longer a major exporter of unprocessed wood. However, it has emerged as a major exporter of wood furniture, panels (plywood, fiberboard, and chipboard), flooring, etc. As both the population and the economy of the country continue to grow, and even allowing for substitution by other materials, the demand for wood products is still expected to grow even more. The domestic WBI is therefore trying to meet the country's demands, but it is faced with a shortage of raw material from logging ban since 1989. Necessary to protect the rapidly diminishing forests, the logging ban has drastically enfeebled wood supplies. Ergo, this industry has got to hinge copiously on imported wood, on plantation wood (especially rubberwood), and even on illicitly logging wood.

Increasing and large quantities of processed wood products are imported, placing a heavy burden on the trade balance, instead of the forestry sector bringing in foreign exchange as in the past. The insecure raw material base has stifled whatever to modernize the industry or make it competitive. Although China's imports of tropical sawnwood decreased by 11.5% from 2005 to 2006, it still remained the world largest importer. In 2006, accounting for a 39.5% share of ITTO consumer country imports. Malaysia and Thailand were the next largest importers, although they are also important tropical sawnwood producers. Thailand's imports decreased significantly (27.1%) from 2005 to 2006. Thailand's economy and construction activity slowed in 2006 following political uncertainties, resulting in a decline in demand for construction grade tropical sawnwood, principally supplied by Malaysia (UNECE/FAO, 2008). Tropical log production of Thailand is based almost entirely on its rubberwood and other plantation resources. In the first half of 2007, new housing starts, including condominiums, fell sharply, although they were expected to recover at the end of 2007. The real estate sector is expected to recover in 2008 in anticipation of economic growth and relative political stability after the general election at the end of 2007.

2.3.6.1 Wood based Industry types and their processing methods in Thailand

Sawmaills: Owing to the forest closing policy in 1989, the number of sawmills (also plywoodmills) has gradually retrogressed. Currently, the vast majority of Thailand's log production is from plantation timber, largely rubber wood, teak, and eucalyptus. Indeed, ITTO (2003a) reports that all new sawmilling licenses in Thailand are currently contingent on the use of plantation rubber wood as a raw material. Technology of sawing in the past solid wood loss into sawdust during using circular saw 50 to 60%. To solve this problem many sawmills have replaced circular saw by band saw. At present, only the large log was imported to saw. Small log of rubberwood and wood from government extension plantation play an important role in sawing which have the different qualification from the wood of natural forest such as growth stress of small wood due to twist and split of lumber. Therefore, technology of sawing should be developed for the quantity and quality of lumbering. However, lumbering of small log less than 5 to 7 ins. of diameter is possible, but providing little yield because of a lot of headsaw and lapwood.

Field survey on sawmaills by the RFD, both in eastern and southern part of Thailand, similar in sawing pattern generally some was mixed both patterns of through and through – Cant sawing and some of Half-cut. The combination of 2 to 3 saw machines with 5 to 6 ins. blade with and N-shape tooth profile. Saw pattern VS Log diameter from 3 difference tooth profiles by using Splite-plot test found that through and through, Cant and Half-cut patterns produced lumber with 39.32%, 38.39%, and 37.08% of recovery rate, mean of the recovery was 38.26%. The sawmill produces side products that cannot be used in the pulp industry. They can, however, be used as fuel in the mill or elsewhere. 34% ends up as wood chips, while 10.4% as sawdust. The rest is registered as waste products (Wisuttithepkul, 2003). Wood chips are used in the pulp industry, and sawdust is exploited by the board industry or as wood fuel, while the waste products are used as wood fuel in the sawmill or sold. Generated heat is applied in the drying kilns. Wood residues from mills could also produce a significant portion of the electricity consumed in Gabon, Nigeria, Malaysia, and Brazil. The potential contribution of wood residues to total electricity consumption in India, Thailand, Colombia, and Peru is relatively small by comparison (GreenFacts, 2009).

Plywoodmills and Composite Board: Manufacturing of plywood was started up in 1957 (Thaiplywood Co., Ltd., established by the **F**orest **I**ndustry **O**rganization, FIO), while exported veneer begun production in 1971 (Thaichipboard Co., Ltd.). Nowadays, number of veneer and plywood factories has 14 and 21, respectively. The majority of plywood factories produce veneer by themselves. Technology of processing of veneer and plywood in Thailand is normally of foreign import machinery. Today, due to the shortage of large logs, some factories have changed peeling machines from 8 to 4 ft lengths and slicing machines for the thinnest veneer, 0.1 mm thickness. Some factories import logs for veneer production, then re-export or overlay on wood products of the factory. However, there is a difference in plywood quality, in that high quality is for exterior, standard for interior, and low quality for non-permanent e.g. advertising board. Unfortunately, plywood production records are not available, because of the shortage of raw materials (Ma and Broadhead, 2002).

Raw material for composite boards in Thailand comes from imported logs, plantations, and lapwood from logging or sawmills. Flooring (parquet and mosaic parquet) and block board are common technologies. At present, the manufacturing of flooring is produced by the finger joint technique. The raw materials are rubberwood and wood from plantations. The diameter of the wood should be more than 6 ins. Wood from plantations are Teak and Eucalyptus, and the rejected wood in flooring production are 20 to 25 % and 50 to 60 %, respectively. Colour coating is necessary in the production, because the colour of sapwood (cream color) differences from that of heartwood (dark colour).

Fiberboard, Hardboard, MDF: Manufacturing of fiberboard in Thailand has two types: Hardboard and MDF. All of Hardboard produced in Thailand is by the wet process. Raw materials are eucalyptus, wood from plantations e.g. Acacia sp., and bagasse. Raw materials of MDF are rubberwood, eucalyptus, Acacia sp., and bagasse (MDF, which bagasse used the first factory of the world). 4 MDF factories of 7 factories used rubberwood as raw materials (more details Ch. 2.3.6.2). The export of particleboard and fiberboard from Thailand shows in Fig. 2.2 below.

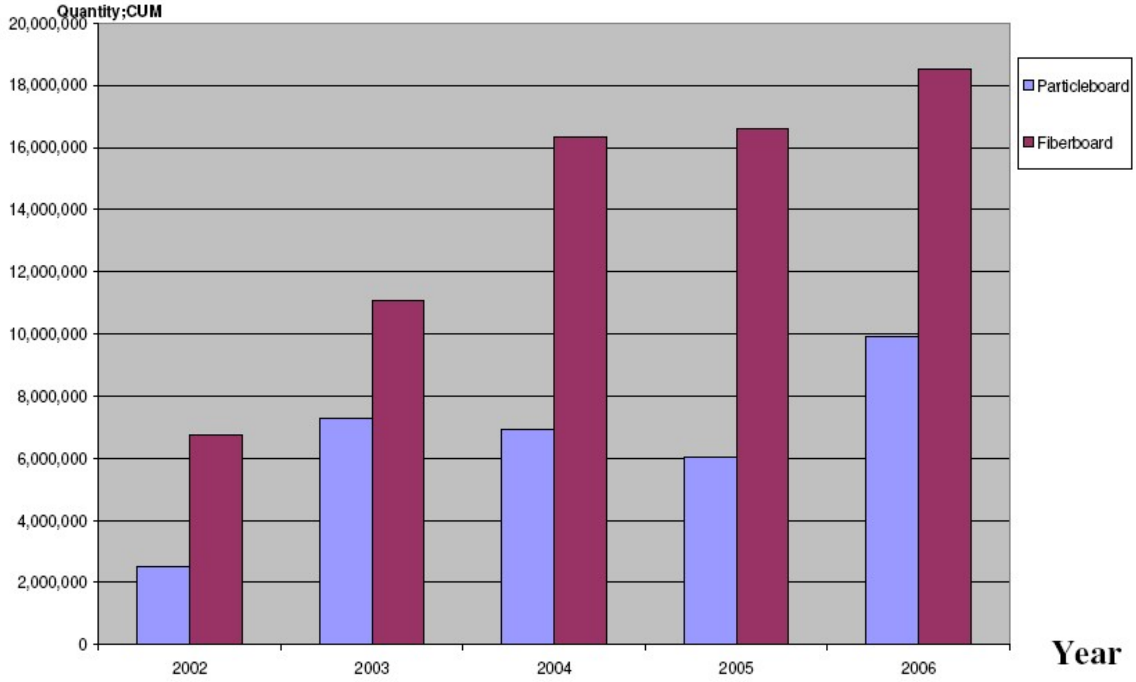

Fig. 2.20: Exports of Particleboard and Fiberboard of Thailand in 2002-2006
Source: GTZ (2008)

Softboard and Particleboard: Manufacturing of Particleboard in Thailand was started up in 1958, but when particleboard became more popular, another larger factory was established in 1986. Particleboard is used as a raw material for both construction and furniture production because of the decreasing availability of solid wood and the logging ban in 1989. Moreover, particleboard has been increasingly used in woodworking too. Nowadays, particleboard is produced by 19 factories, with a total capacity of 1.424 M m^3/y. The extruded pressed processing technique is only used by one factory (Thaichipboard Co., Ltd.). Another factory applies the platen pressed processing. The raw materials are rubberwood, eucalyptus, and bagasse. 16 particleboard factories of 19 factories utilize rubberwood as the main raw material. This consists of 3 sheet layers, 12 and 16 mm thickness, being characteristically the make up of particleboard in Thailand (more details in Ch. 2.3.6.2).

Manufacturing of Wood Wool Cement Board in Thailand was started up in 1956. Raw material is ***SomPhong*** (*Tetrameles nudiflora* R.Br.), import from Myanmar, today. The capacity of this factory is 1,000 t/y. Then, in 1989, Wood Cement Particleboard was produced from Eucalyptus. In 2000, Wood Cement Fiberboard, planks for the walls houses, is produced from cement approximately 90% and recovered paper approximately 10 % mixed with a small amount of asbestos.

Furniture and joinery industry: The Thai furniture industry has three segments: 1) export furniture production; 2) official production for the domestic market; and 3) non-recorded furniture production for the local and national markets. Expansion in this industry is export driven. In the 1980s, the exportation of furniture and its parts was one of the fastest growing export segments. Joinery and other wood converting industries comprise a wide array of businesses such as parquet, match, door, window frame, kitchen cabinets, wooden utensil, wooden frame, or even wooden toy manufacture. Almost all manufactured furniture is commonly produced by skilled labour. Although the large factories make export furniture with machinery (imported machinery), skilled labour is still important for assembling the parts together (Sutthisrisinn, 1998).

Furniture manufacturing can be divided into 3 productions as follows: 1) Higher usage of skilled labour, lower unskilled labour. This production must done by skilled labour for (difference or same style of furniture e.g. Thai style and Louis style, but difference of design, carving, jointing, and grain pattern) Thus, processing depend on capability of each factory. But the same is quality of wood, suitable moisture content from drying for stability of furniture; 2) Manufacture by machines more than skilled labour. All of the products are made by machines, without skilled labour finishing, except for sanding and coating. It is only produced by factory design. This manufacturing process produces mass products; 3) Manufacturing with machines. It is designed to produce mass products with the same standard for export.

Wood chip: Wood chips derived mainly from eucalyptus plantation are used for pulp and paper industry and for export to overseas. Japan is the main market of Thai wood chips. Japan accounts for 53% of global trade of hardwood chips and 15% of softwood chips. According to the Japan Paper Association, Japan's imports of hardwood chips were around 18 to 19 M m^3 per year over the period 2004 to 2008. This makes Japan the world's major market for wood chips. From the renewable energy policy by the state, nowadays, wood chip in Thailand is expected to use as a feedstock for generating electricity too. Currently, Thailand has a small number of key woodchip producers and exporters (more details in Ch. 2.3.6.2) (Barney, 2005).

Pulp and Paper Industry: There are 2 major processes of pulp production in Thailand, Kraft and Soda process. The Kraft process uses a sodium based alkaline pulping solution consisting of sodium sulfide (Na_2S) and sodium hydroxide ($NaOH$). The Soda process uses alkaline cooking liquors in a similar process to Kraft pulping but without the use of sulfur compounds. In Thailand, the Kraft pulp has a larger share (80%) in total pulp production than that of Soda pulp (20%) (ERIC and TPPIA, 2002). The Kraft process is also the dominating chemical pulping process worldwide (accounting for 80% of the world chemical pulp production and 60% of the total chemical and mechanical pulp production). This illustrates the high quality of the Kraft pulp compared to other types of pulp (EC, 2001).

Indonesia and Thailand are two key modernized pulp and paper producers in Southeast Asia. The core of the Thai pulp and plantation sector is comprised of a relatively small group of vertically integrated players that are also competitive in regional export markets. The broader sector also includes a larger number of smaller, domestically-oriented paper producers. According to a summary by Asiapapermarkets.com, a recent report by Credit Suisse First Boston suggests that Advance Agro is the only major pulp producer in Thailand that is globally cost competitive on a sustainable basis, primarily due to its status as an integrated producer, access to abundant supplies of high quality wood, advanced production technologies and alliances with world class players (Barney, 2005).

2.3.6.2 Production statistics of Wood based Industry in Thailand

Poles: About 1.9 M m^3 of poles are used year by year, for both structural and non-structural purposes, in the residential and industrial construction sector. In both of these end uses, they are being superseded by other materials such as concrete and steel. As a result, the use of poles for pilings and scaffolding has also declined. The substitution is expected to increase and continue. Absolute demand for wooden poles may remain at present levels, or even decline in the coming years.

Sawnwood: Recently, the increase in Thailand's tropical sawnwood imports is related to its growing furniture industry (Hashiramoto et al. 2004). Major tropical log producers still figure prominently in tropical sawnwood production. Brazil was by far the largest ITTO tropical sawnwood producer, at an estimated 15.8 M m^3 in 2006. Indonesia (7.6 M m^3), India (5.4 M m^3), Malaysia (5.4 M m^3), and Thailand (3.2 M m^3) were other major producers of tropical sawnwood in 2006 (Fig. 2.21). Together, they comprised more than three quarters of ITTO tropical sawnwood production. Brazil alone accounted for one third.

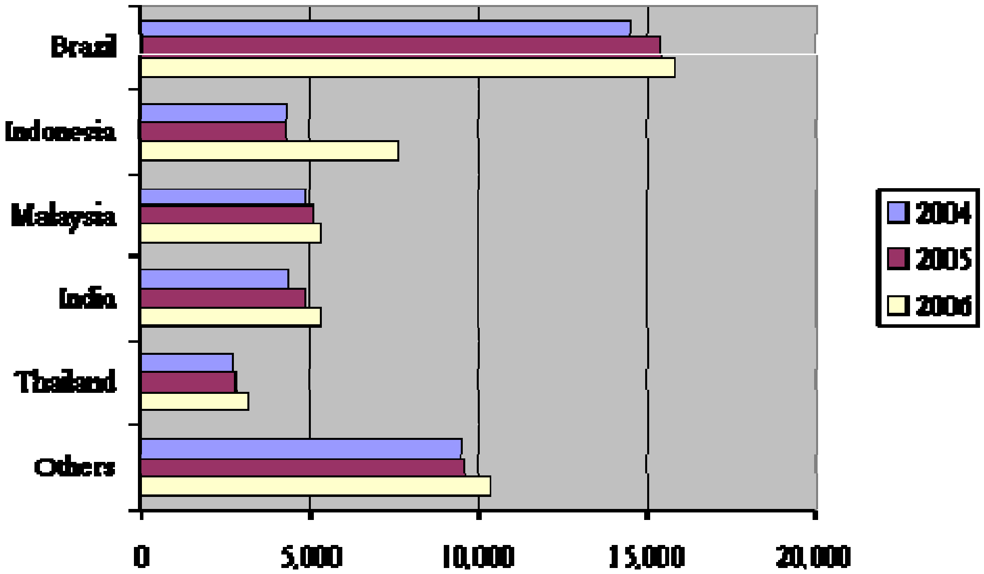

Fig. 2.21: Tropical sawnwood in major producers

Source: UNCTAD secretariat, based on data from the ITTO
see also <http://www.unctad.org/infocomm/anglais/timbertrop/market.htm>
Note: The category "Others" includes other ITTO member countries

Plywood and veneer: In this decade, plywood industry faces more challenges than it has encountered during its whole previous history. There is an increasing competition from other wood based panels, such as OSB. Besides, The plywood industry in Thailand is suffering from a shortage of suitable raw material and competition from China. Today, there are 14 veneer factories and 21 plywood factories, although the majority of plywood factories also produce veneer. Established by the FIO, the Thaiplywood Co. Ltd. is the main leader in this sector.

Other wood-based panels: Thailand's panel industry has experienced extraordinary growth in the past five years according to the ITTO, becoming the world's second largest tropical fiberboard exporter and its largest tropical particleboard exporter. For Thailand's important MDF, particleboard, and hardboard industries, Laemsak (2002) has published good quality baseline information (tables 2.42 to 2.44, next page). ITTO (2003a) also confirms that Thailand's Vanachai Group is Asia's largest producer of MDF and particleboard: "The Group currently has the capacity to produce 0.27 M m^3/y of MDF and 0.3 M m^3/y particleboard". The Thai MDF's production goes to both domestic and export markets. Initially it was nearly all exported, as MDF was little known in Thailand, but today around 80% of production is consumed on the domestic market, mainly going to furniture production. Currently, many companies had ambitious plans to improve margins by employing the economies of scale, planning on installing new capacity (mainly in Indonesia, Thailand, and Vietnam) and moving up or down the supply chain (Wood Based Panels International, 2005).

Furniture and joinery industry: Within the Asian region, China, Malaysia, Indonesia, Thailand, and the Philippines are the leading furniture exporting countries, although Vietnam has been fast emerging as an exporter in recent years. Evidences based on exit surveys conducted between the period 1998 and 2001 at the regional static furniture fairs held almost simultaneously in Malaysia, Thailand, Singapore, and Indonesia clearly shows the lack of product differentiation within the region. The productivity gains in the Asian furniture industry are relatively low and the industrial growth can be accounted for on the basis of incremental capital inputs. Despite the aggressive industrial development policies implemented by the various governments in the region, the growth of the furniture industry in the various Asian countries has been hampered by a different set of problems (Ratnasingam, 2003a,b). Without reliable and accurate information pertaining to industrial performance, the future growth of the regional furniture industry will be unstable (Stiglitz, 2002). Recently, much high quality furniture formerly made from solid rubber wood, has transferred to MDF and PB in particular for export to Japan, Europe, or North America (Higham, 2008).

Table 2.42: Thai Particleboard Factories: Capacities and Raw Materials Used

Company	Annual Capacity (m^3)	Raw Material Used
Thai Chipboard (extruded PB)	6,900	Sawmill waste
Dorospan	45,000	Rubber wood
Particle Planner	123,000	Rubber wood
Thai Particle Products	93,000	Rubber wood
MP Particleboard	70,000	Bagasse
Daiichi Particle	60,000	Rubber wood
Sahachai Particleboard	45,000	Rubber wood
Thainumsaeng	60,000	Rubber wood
SS Furnitech	15,000	Rubber wood
Molar Wood Products	75,000	Rubber wood
STA Particle Products	195,000	Rubber wood
Rayong Particleboard	54,000	Rubber wood
Pangnga Particleboard	60,000	Rubber wood
S. Kitchai	30,000	Rubber wood
Vanachai Panel Industries	300,000	Rubber wood
Siam Riso Wood Products	84,000	Rubber wood
Asia Planner	100,000	Rubber wood
Total	**1,364,900**	

Source: Lamesak (2002)

Table 2.43: Thai MDF Factories: Capacities and Raw Materials Used

Company	Annual Capacity (m^3)	Raw Material Used
Khon Kaen MDF	66,000	Bagasse
MDF Planner	217,800	Rubber wood
STA Group	115,500	Rubber wood
Metro MDF	113,900	Rubber wood
Metro Group	115,500	Rubber wood
Thai Plywood	99,000	Eucalyptus
AgroMats	113,900	Eucalyptus
Total	**841,600**	

Source: Lamesak (2002)

Table 2.44: Thai Hardboard Factories: Capacities and Raw Materials Used

Company	Annual Capacity (tons)	Raw Materials Used
Thai Plywood	66,000	Eucalyptus and Plywood waste
Thai Caneboard	50,000	Bagasse
Metro Fiber	27,000	Eucalyptus
Agro Lines	38,000	Eucalyptus
Total	**181,000**	

Source: Lamesak (2002)

Furniture factory in Thailand had 2,596 plants in 2005 (table 2.45, next page). The Majority of products are grouped into–sofa, table, chair, and shelf etc. Both natural and artificial colours are produce. Furniture can be divided into 2 sections as follows: 1) Stable furniture or Furnished furniture. Almost all of stable furniture is produced for domestic consumption; 2) Knock down furniture. Almost all of knock down furniture is exported.

Table 2.45: The Quantity of Furniture Factories Classified by Region (2005)

Region	Quantity	(%)
Bangkok and boundary	886	34.13
The Northeast	449	17.30
The North	436	16.80
The Central part	374	14.40
The South	260	10.02
The Eastern	191	7.35
Total	**2,596**	**100**

Source; Department of Industrial Works, Ministry of Industry (2006)

Wood chip: A conference presentation by Thaiutsa (2002) provides some further overview of the chipping sector in Thailand. Table 2.46 shows Thaiutsa's data for Thai woodchip supply, demand, growth rates and required plantation areas to support the industry at the current production level. Thailand has a small number of key woodchip producers and exporters (table 2.47).

Table 2.46: Thai Woodchip Log Supply and Demand

Rotation Length	5 years
Yields	75 t/ha/5 years
Log Demand from Woodchip Industry	6,395,000 GMT/y
Harvested Areas	85,267 ha
Total Plantation Areas Needed	**426,335 ha**

Source: Thaiutsa (2002)

Table 2.47: Thai Woodchip Supplier

Company	Province	Capacity (BDTs)	Export (tons)	CF.	Raw Materials	Sources
Rung Ruang Kitti	Chachoengsao				eucalyptus	
Siam Forestry	Kanchanaburi				eucalyptus	
Thai Wittawat	Surin	80,000	70,000	2.5	eucalyptus	buy
Kit Thawee	Surin	>60,000	Yes	2.5	eucalyptus	buy
Siam Tree Dev.	Chon Buri	130,000-136,000	100%	2.2-2.3	eucalyptus	
August Chip Woods	Chon Buri				eucalyptus	
K.M.I. Forest	Buriram	>150,000		2.5	eucalyptus	buy
Thai Martin Group	Prachuab.	80,000	Yes	2.5	acasia spp.	Self/buy
Total						

Source: Thaiutsa (2002)

Pulp and Paper Industry: In Thailand, paper is produced from domestic virgin pulp, as well as imported pulp and recycled paper. Most of the paper products are industrial and printing paper, for which imported recycled paper is used as raw material. Only 30% of the raw material is supplied by domestic pulp manufacturers as short fiber (Mongabay, 2006 cite by Jawjit, 2006). Only about 20% of the pulp produced in Thailand is allocated for exporting. To supply pulp mills in Thailand with fibrous raw material, approximately 0.48 M ha are currently used for fiber-tree plantations, mainly Eucalyptus, with more than 100,000 farmers involved (Jawjit, 2006). Nowadays, Thailand has 5 pulp factories, 44 paper factories and 1 full-cycled factory, which have about 300,000 employees. The major raw materials of paper industry consist of long fiber pulp, short fiber pulp, and waste paper pulp. The waste paper pulp comes from the collection inside the country, and import from abroad. It is used as a raw material for the production of paperboard and corrugated paper. Thailand can produce only the short pulp, made from eucalyptus, bamboo, and bagasse. Therefore the long fiber pulp must be imported from other countries.

In 2002, the pulp industry has 0.945 M t of production capacity and 98% of capacity utilization rate (see table 2.48). The main raw material used in this industry is eucalyptus with 82%. To provide eucalyptus, the manufacturers will prepare and give eucalyptus sprouts to farmers for cultivation and send the grown eucalyptus to the pulp factory for pulp production. The demand volume of pulp is expected to increase by 5% in line with the growth of paper industry. Moreover, there is a plan to settle a pulp factory producing pulp from bagasse, which has the production capacity of 0.1 M t/y. It is also expected that this factory would operate within the next 2 years, which will be able to produce more than 1 M t/y of short fiber pulp.

Table 2.48: Estimation of Pulp Industry Conditions in 2002

Products	Consumption Volume (M t)	Production Volume (M t)	Production Capacity (M t)	Capacity Utilization Rate
Virgin Pulp				
- Short pulp	741	927	945	98%
- Long pulp	216	-	-	-
Total	957	927	945	-
Waste paper	1,830	950 (Collection)	-	Recycle rate 52%
Paper and paperboard	2,169	2,575	3,734	69%

Source: the TPPIA (2003)

The domestic paper production capacity has slightly increased with the total of 3.7 M t owing to the improvement of modern machinery. Kraft paper has the highest production capacity by 60%, followed by printing and writing paper with 27%. The capacity utilization rate has slightly increased from 66% of last year to 69%, resulted from the increasing paper demand. For the paper industry, the demand volume of paper is expected to increase by 6% or 2.3 M t in 2003. This will be 0.11 M t of production capacity. Therefore, the entire production capacity will be 3.8 M t in 2003.

Table 2.49: Estimation of Paper Industry Conditions in 2002

Products	Consumption Volume (1,000 t)	Production Volume (1,000 t)	Production Capa. (1,000 t)	Capacity Utilization Rate
Kraft Paper	1,220 (56%)	1,447 (56%)	2,219 (60%)	65
Printing & Writing	429 (20%)	706 (27%)	1,008 (27%)	70
Paperboard	205 (10%)	205 (8%)	293 (8%)	100
Newsprint	245 (11%)	126 (5%)	126 (3%)	100
Sanitary Paper	70 (3%)	91 (4%)	88 (2%)	100
Total	2,169 (100%)	2,575 (100%)	3,734 (100%)	69

Source: the TPPIA (2003)

At present, the Thai production capacity of short-fiber pulp is ranked second among ASEAN (Association of Southeast Asian Nations) and is fifth overall in Asia after China, Japan, Indonesia, and India. The capacity of 1 M t comes from 5 main pulp producers. The existing five pulp mills in Thailand are as follows Advance Agro (Barney, 2005): 1) Advance Agro Public Company Limited, with installed capacity 0.175 M t/y. Eucalyptus is the main raw material; 2) Panjapol Pulp Industry Public Company Limited, with installed capacity 0.11 M t/y. Eucalyptus and bamboo are the main raw materials; 3) Phoenix Pulp and Paper Public Company Limited, with installed capacity 0.21 M t/y. Eucalyptus, bamboo, and kenaf are the main raw materials; 4) Siam Cellulose Co., Limited, with installed capacity 60,000 t/y. Eucalyptus is the main raw material; 5) The Siam Pulp and Paper Public Company Limited, with installed capacity 68,000 t/y. Eucalyptus and bagasse are the main raw materials; 6) Bang Pa-in paper plant, with installed capacity 3,000 t/y. Rice straw is the main raw material.

2.3.6.3 Residues and their utilization of Wood Based Industry in Thailand

Wood residue resulting from timber processing and wood based industry can be used by industries to produce energy for their activities and operations. The biomass wastes generated from wood processing industries has been traditionally used by local people for domestic heating purposes. Most of the sawdust and bark remain unutilized is also burned rto keep the immediate area clean from such wastes or for wood drying process. Many wood and paper processing plants already utilize their waste to generate both heat and electricity, but more could be exploited becuase existing plants are often not the most efficient available. Black liquor generates a great amount of energy, and its inclusion in the database is important for estimating the contribution of woodfuel to total energy. However, the FAOSTAT forest product statistics do not include it because, as it is a derivative of other wood products, its inclusion would lead to double counting. Black liquor deserves special mention for the amount of energy it generates. The pulp and paper industries have so improved their energy efficiency and productivity that they generate electricity surpluses which can be sold to the public grid.

2.3.6.4 State policy related to Wood Based Industry in Thailand

As a result of the logging ban, imports of logs, sawnwood, short/long-fibre pulp, and recovered paper are important constituents for Thai wood processing sector. Although Thailand is one of the world's leading importers of tropical sawnwood, the domestic wood industry is unable to meet the country's needs because of shortage of raw material. The household sector uses about 20 M t of wood annually for woodfuel, which is met by local supplies (from home gardens, woodlots and public forests). However, there is a shortage of woodfuel in the industrial sector, which requires about 6.5 M t annually (FAO, 2004c). Moreover, wood processing still uses low technology. Immature wood and the products fall short of international standards. The specialist recommended the training programmes to improve wood processing skills and productivity. These programmes need the supports from the Royal Thai Government and the universities. For the case of rubber wood (the main raw materials for wood based industry in Thailand, unfortunately, there is a conflict between the policy of strategically developing rubber industry and the policy of supporting rubber plantations to be a wood economic especially on the legal issue of processed rubber according to the royal act of forestry B.E 2484 which partly states the limitation of machines used in wood processing, timing for wood work, etc. Related wood operation group has been requesting for an amendment of the act, but there still has been no further change to it. For wood fuels, forests in several countries have been replaced by crops intended to produce biofuels and this trend could accelerate if there are large increases in the demand for biofuels and bioenergy in general. The dynamics could change dramatically, however, if woody biomass becomes the biofuel feedstock of choice, and a future in which forests threaten farmland, rather than the opposite may be possible. This should be applied to the case of Thailand, too.

2.3.6.5 Problems and barriers of Wood Based Industry in Thailand

Although wood based industry in Thailand is one of the leading industries that earn money income for the country. It still has many problems in this sector. These problems can be summarised here:

Roundwood Market: The demand for wood fiber in Asia (including Thailand) is significant, and can be attributed to two quite distinct sources. The first services household domestic needs-for fuelwood, building poles, furniture production and the like. The second derives from export markets; these are for raw wood (roundwood or unprocessed logs), a variety of processed lumber, and more finished products (e.g., teak garden furniture and paper products). Viewed from a macro perspective, most Asian countries demand a significant amount of wood for household needs. Thailand has major wood-processing economies with many companies involved in those operations, and often target export markets (Thomson and Kanaan, 2003), but this country must import wood and timber product from neighboring countries. For example, in 2009, Malaysia exported wood and timber products worth RM522.8 million to Thailand, with the major export articles being sawnwood, plywood, wooden furniture and particleboard (ITTO, 2010). Forest resources in Thailand have been under a variety of pressures including conversion to large-scale monoculture plantations (e.g., cash crops, para rubber), fuelwood collection, clearing driven by land speculation, forest fires, illegal logging, as well as infrastructure development. Therefore, market transparency is limited in the log trade. Small-scale producers often do not have a clear understanding of the value of their timber crops and have limited negotiating power with buyers. Wood measurement practices cannot be controlled effectively by sellers and therefore provide opportunities for misuse. The establishment of producer cooperatives or associations would help protect the interests of growers (ITTO, 2006c).

Furniture Industry: Without a concerted effort by government, the boom of Thai furniture industry as a significant source of export earnings is likely to become stagnant due to heavy competitive pressure. This industry has not taken a strategic approach to resource management, to sector-wide research and development, to marketing support, to standardization and quality control systems, or to specialist technical training. The key problem is a shortage of competent supervisors and middle managers who can improve operations on the mill floor and implement effective quality control systems. Besides, there is only a limited domestic capacity for furniture design. The Thai export industry has already taken some action to respond to increasing market demands for certified and legally produced products. However, the Thai furniture and wood-based panels industries cannot yet meet these demands due to obstacles in certifying rubber plantations for timber (ITTO, 2006c). In addition, due to low efficiency in this section, the concept of bench marking of the key performance index to analyze and assess the potential of manufacturing operation in each factory to find out the best practice of rubber wood processing s industry should be applied, for example, in the production aspect, energy using aspect, management aspect, etc.

Wood-based Industry: Thailand had long been a traditional exporter of raw logs and in more recent years had begun to develop a competitive furniture industry. Despite the ban on harvesting, Thailand's furniture industry has continued to climb in terms of total output and export value. Moreover, Thailand is active in the production of chips and particles. A majority of MDF and particleboard produced in Thailand is used as a substrate for thin overlay in cabinet and molded door skin production. Although Thailand has linked the development of the furniture industries to the rubberwood plantation resources, today MDF and particleboard are applied as feed stock for furniture making too. Capital-intensive pulp and paper industries have also developed. Thailand is also one of the major producers and exporters of pulp and paper. Even with rising wood value, the forest industry is experiencing lower returns today than in previous years and this is likely to act as a barrier for reinvestment or for entry into the arena by new companies. For other problems include: 1) Lack of information about wood based panel's type, property, and usage; 2) Lack of local supporting industry.

Environment: The wood industry involves the conversion of trees into lumber and wood products, such as finished plywood, veneer, and particleboard. Different types of pollution can occur at various points along the wood products supply chain. Environmental issues associated with sawmilling and wood products manufacturing primarily include the following: 1) Sustainable forestry practices, 2) Solid waste generation, 3) Emissions to air, 4) Wastewater, 5) Noise, and 6) Fire. Opportunities for recycling of wood waste may exist through use of waste as inputs for secondary products in other industries or as a source of fuel for heat and power generation. However, wood waste containing preservative chemicals should be treated as hazardous waste and disposed of in a landfill facility capable of handling wastes that may have chemical leaching properties or by high temperature incineration in an incinerator with effective air pollution control devices (IFC and WBG, 2007). The potential impacts of increasing biomass recovery could include nutrient scarcity, loss of biodiversity and changes to ecosystem function (GreenFacts, 2009). Wood residues are necessary for maintaining soil and ecosystem health, and certain amounts should therefore remain on the ground. Logging residues are an important source of forest nutrients and help reduce the risk of soil erosion (UN-Energy, 2007). Finally, pulp bleaching is a potential source of pollution that has generated interest with several stakeholders. The majority of paper manufacturers in the world have phased out the use of elemental chlorine as a bleaching agent, although it is still used in Thailand. The results from the study by Jawjit (2006) indicate that the environmental pressure is caused by the kraft pulp production subsystem rather than by the eucalyptus forestry one. Largely due to environmentalist pressures, recycled paper is today even more important as a raw material than formerly, being used increasingly in newsprint, writing papers, and toilet and tissue papers.

2.4 Conclusion

The agriculture and forestry is a significant part of Thailand's economy. They provide the important source of revenue for more than 35% of Thai labor forces. Moreover, they also generate the residues that can be transformed into modern energy forms; therefore this is a great opportunity to reduce energy import and environmental pressure, while increase the energy security of the country. With respect to the agriculture, although there are various cultivated crops in Thailand, only residues from sugarcane, paddy rice, cassava, oil palm, and some of minor crop have a high potential for energy utilization. Residues from forestry and wood-based industry can also contribute for producing energy, although the Thai forestry sector has announced the imposition of the logging ban from conservative forest since 1989. However, the use of biomass as an energy source is widely practiced throughout Thailand industries, particularly in rural and agricultural areas. Major industrial users of biomass energy include sugar cane milling, rice milling, palm oil production, and the wood. In this chapter, therefore, classification of biomass sources according to their quantities and supply sectors is revealed for estimating the potential for energy utilization in Chapter 4.2. The availabilities, distributions, production rates and forecasts, as well as the competitions of these residues were also assessed. This chapter provides the details of these investigations.

Chapter 3: Energy Production

Not only around the world but also in Thailand, ***bioenergy*** from biomass is promoted to be one of significant sources for their energy supply in the future. Biomass sources are, however, varied and disparate. Therefore, the three main technologies necessary to success for an economy of bioenergy are:

1) growth of the biomass feedstock;
2) biomass conversion into energy; and
3) energy utilization.

This chapter will focus on biomass conversion into energy and biofuel. Both efficient and reliable conversion technology of biomass energy is needed to overcome or relieve the crisis faced by commercial fuels, the production of which will decline to the point where it is considered uneconomical. The aim of this chapter is to provide a compilation of bioenergy technologies for analysis in the next chapter, by concentrate on their processes, facets of advantage and hindrance, socio-economic & environmental aspects, along with problem and barrier contexts.

3.1 Introduction

3.1.1 General Aspect

Although biomass can be converted into useful forms of energy using a number of different processes (Fig. 3.1), distinct categories of biomass necessitate unique technologies/processes to produce biomass feedstocks after having converted them to useful biofuels along with value-added products. Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock; the desired form of the energy, i.e. end-use requirements; environmental standards; economic conditions; and project specific factors (McKendry, 2002b). The raw unprocessed biomass can either be dried and pelletized, or combusted directly to produce power. It can also be converted to biomass-based motor fuels such as ethanol, methanol, or **Di**m**e**thyl **E**ther (DME). Conversion of biomass to energy is undertaken using two main process technologies: ***thermo-chemical*** and ***bio-chemical/biological***. Both sets of technologies remain unproven at the fully commercial scale, are under continual development and evaluation, and have significant technical and environmental barriers yet to be overcome. The potential advantage of the biochemical route is that cost reductions have proved reasonably successful to date, possibly providing cheaper biofuels. ***Mechanical extraction*** (with esterification) is the third technology for producing energy from biomass such as **R**apeseed **M**ethyl **E**ster (RME) bio-diesel (Nguyen et al., 2009). However, at present, generating energy from biomass is quite expensive due to both technological limits related to lower conversion efficiencies, and logistic constraints. A recent study on the effects of wood fuels on power plant availability also showed that use of wood fuels actually involved more problems than expected (Caputo et al., 2005).

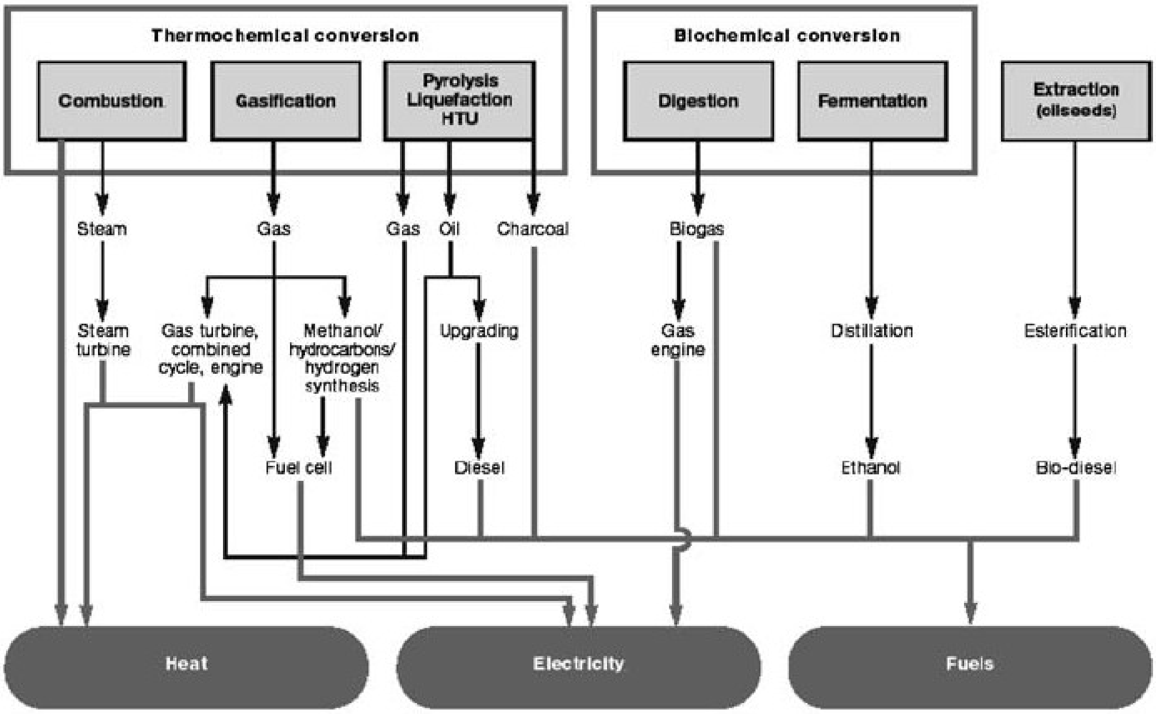

Fig. 3.1: Main conversion options for biomass to secondary energy carriers
Source: Turkenburg et al. (2000)

Thermo-chemical conversion of biomass offers a possible process to provide gaseous, liquid, and solid fuels. There are less technical hurdles to this route, since much of this technology is already proven. A drawback is that there is perhaps less opportunity for cost reduction. One problem concerns securing a large enough quantity of feedstock for a reasonable delivered cost to meet the big commercial-scale required. Within this option, 4 process options are available: combustion, pyrolysis, gasification, and liquefaction. All options include complex chemical and physical processes such as vaporization, devolatilization, volatile secondary reactions, and char oxidation, coupled with the transport phenomena. ***Combustion*** is used to convert biomass energy into heat, mechanical power, or electricity. Net conversion efficiencies range from 20 to 40%, even if higher values may be obtained when the biomass is co-combusted in coal-fired power plants (McKendry, 2002b). ***Pyrolysis*** of biomass generates 3 different energy products (coke, gas, and oils) in different quantities by heating the biomass in absence of oxygen/air. Pyrolysis can be used for the production of bio-oil, if flash pyrolysis processes are used. The bio-oil can be used in engines and turbines and its use as a feedstock for refineries is also being considered (DOE, 2010; McKendry, 2002a, 2001; Demirbas A., 2001). ***Gasification*** converts biomass into a combustible gas mixture of CO, H_2, and CH_4. Conversion efficiencies up to 50% may be reached, if biomass integrated gasification/combined gas-steam cycles are utilized commercially from 5 to 300 MW (Caputo et al., 2005). ***Direct Liquefaction*** is the conversion of complete plants into liquid fuels without gasification like pyrolysis, but in addition of H_2 generating upgraded-quality liquid fuels. The ***differences*** among the processes are determined by the operation conditions of feed properties, oxidizer (air, oxygen, or steam) amount, temperature, heating rate, and residence time. These conditions change the proportions of the gas, liquid and solid products (see table 3.1).

Table 3.1: Thermo-chemical conversion variant

Technology	Residence time	Heating rate	Temperature °C	Aim Products	Oxidizer amount
carbonation	very long (days)	low	low (~400)	charcoal	absence
fast pyrolysis	short (<2 sec)	high (>1000°C/s)	moderate (~500)	bio-oil, chemicals	limited
gasification	long	high	high (~800)	gas, chemicals	limited
combustion	long	high	high	heat	enough

Source: Wang and Yan (2008)

Bio-chemical systems, characterized by low energy consumption and non-pollution methods, are among the most promising, environmentally sustainable alternatives for reducing atmospheric CO_2 levels. They encompass 2 process options: anaerobic digestion (production of biogas) and fermentation (generating ethanol) (McKendry, 2002b). ***Biogas*** is generated by the anaerobic decomposition of wet organic feedstock using bacteria in a multistage process called biomethanization. The generated biogas is basically a two-component gas composed of CH_4 (60 to 75 %) and CO_2 (25 to 40 %), although minor amounts of other trace gases (2%) such as H_2S, N_2, O_2, H_2, and NH_3 may be formed. The biogas is very useful because it is combustible and can be used to provide power via the use of a motor and an electric generator. Moreover, biogas can be upgraded to higher quality i.e. natural gas quality, by the removal of CO_2. The anaerobic digestion process was developed many years and is well known and understood. It, however, has not been implemented in many countries because of the high initial cost and heavy maintenance issues (Caputo et al., 2005). ***Fermentation*** is used commercially on a large scale in various countries to produce ethanol (C_2H_5OH) from biomass materials which contain sugars, starch, or cellulose. Starch based biomass is usually cheaper than sugar based materials, but requires additional processing. The conversion of lignocellulosic[22] biomass (such as wood and grasses) is more complex, due to the presence of longer-chain polysaccharide molecules, then requires acid or enzymatic hydrolysis before the resulting sugars are fermented to ethanol by yeast (Wei et al., 2009). Ethanol can be used as a supplement or substitute for gasoline in vehicles. Even though purification of ethanol by distillation is an energy intensive step, the solid residue from the fermentation process can be used as cattle feed (McKendry, 2002b).

Mechanical extraction is a process to produced crude vegetable oil by dry extruding the seeds of various biomass crops, such as oilseed rape, cottonseed, and groundnuts. These oils usually contain **F**ree **F**atty **A**cids (FFA), phospholipids, sterols, water, odorants, and other impurities. Even refined oils contain small amounts of FFA and water. The process produces not only oil, but also a residual solid termed cake, which is suitable for animal fodder. The possibility of using vegetable oils as fuel has been recognized since the beginning of diesel engines. Besides, vegetable oils naturally fix the solar energy and do not contain sulphur. Transesterification is widely applied to produce biodiesel. Esters from vegetable oils are the best substitutes for diesel, because they do not need any modification in the diesel engine and have a high energetic yield. Most industrial processes employ alkaline catalysis and methanol. The main end use is the transport sector, including agricultural machinery. For instance, about 3 tons of rapeseed is required per ton of rape-seed oil produced. Rapeseed oil can be processed further by esterification to obtain RME (WSL, 1993). RME is used in some European countries as a supplementary transport fuel. Fig. 3.2 depicts a generalized flow

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[22] Lignocellulosic biomass typically has 40 to 45 wt % oxygen, and oxygen removal increases the heating value. Therefore, the production of liquid fuels from lignocellulosic biomass involves removal of some oxygen, as CO_2 or H_2O, and conversion into a higher-density liquid fuel (Huber et al., 2006).

sheet for the production of methyl ester biodiesel and its byproduct glycerine (McKendry, 2002b).

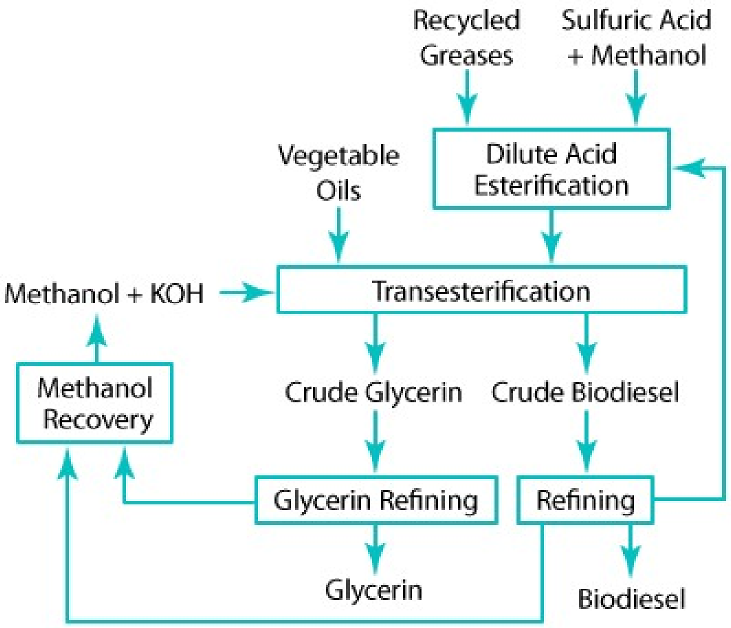

Fig. 3.2: Schematic process for biodiesel production
Source: US. DOE <http://www.afdc.energy.gov/afdc/fuels/biodiesel_production.html>

There are 3 different applications of biomass based energy: Electricity generation, Heating & Cooling, and Biofuels for transport. Due to the long life time of power plants (30 to 50 years), the decisions taken now will influence the socio-economic and ecological key factors of energy system by 2020 and beyond. The IEA study points out that fuel costs will be in the same order of magnitude as investment in infrastructure, increasing the scale of the challenge, especially for developing countries. To boot, about half of the costs are for new and refurbished power generation capacities, while the other half is for transmission and distribution costs. Therefore, distributed generation like renewables can help to reduce investment in transmission costs. With respect to transportation fuels, the market for biomass has been divided into (Feber and Gielen, 1999): 1) ***Diesel substitutes***: RME, DME, diesel from **H**ydro **T**hermal **U**pgrading (HTU), diesel from biomass pyrolysis oil, **F**ischer **T**ropsch (FT) diesel, and diesel from algae; 2) ***Gasoline alternates & additives***: methanol, ethanol (95%), dehydrated ethanol (99%), **M**ethyl **T**ertiary **B**utyl **E**ther (MTBE), **E**thyl **T**ertiary **B**utyl **E**ther (ETBE), and FT gasoline (Gielen et al., 2001).

3.1.2 Global Trend

The **E**uropean **U**nion (EU) has supported renewable energy through policy, legislation, funding, and research since the 1980s. With triple objective of reducing greenhouse gas (GHG) emissions, diversifying fuel supply, and developing long-term replacements for fossil fuels, The EU has therefore made a commitment to raise the share of renewable energy in the EU energy mix to 20% as well as to increase the level of biofuels in transport fuel to 10% by 2020 in each Member State (table 3.2). However, different renewable energies are at different stages of technological and commercial development. Sources such as wind, hydro, biomass, and solar thermal are already economically viable. But others, like photovoltaic, will depend on increased demand to improve economies of scale (RFA, 2008;

Trostle, 2008; EU, 2007). The status report shows that electricity from wind and photovoltaics is well on track to reaching the EU Commission's targets. However, electricity from biomass still faces multiple challenges and - in order to reach the EU 2010 target - must increase its current growth of 9% per year to ca. 27%. For electricity/heat, either the **L**arge **C**ombustion **P**lant (LCP, > 300 MW_{th}) directive or the **W**aste **I**ncineration **D**irective (WID) is applied, depending on the fuel. The European transport sector is 98% dependent on fossil fuels and accounts for around a quarter of all CO_2 emissions in the EU. A number of existing projects specifically target biodiesel, the most currently used biofuel in Europe, with comparative study on the best raw materials for mass production of biodiesel, including additives for improved fuel characteristics. Bioethanol projects are expected to kick off in the next few years. Second generation biofuels (see Ch. 3.3.2) will have an important role to play as soon as they are ready for the market. Whilst research continues on the development of second generation biofuels, a study is also working with the biofuels already available to create favourable market conditions (Khan et al., 2009; EUBIONET, 2003).

Table 3.2: Biomass development targets towards 2020 in MTOE

Target	2004	2010 (*BAP*)	2020 (*AEBIOM*)
Biomass for heat	48	75	120
Biomass for cogeneration / electricity	22	56	60
Biomass for liquid fuels	2	19	40
Total	72	150	220

Note: BAP – Biomass Action Plan of the European Commission 2006
AEBIOM - Association Européenne pour la biomasse – European Biomass Association).
Source: Biomass – a burning issue. refocus March/April 2007 see www.re-focus.net

Since its inception in the 1970s, the **U**nited **S**tates (U.S.) **D**epartment **o**f **E**nergy (DOE) has operated a substantial programme in the development and encouragement of renewable energy technologies. It developed the first set of Renewable Energy **T**echnology **C**haracterizations (TCs) in 1989. In the U.S., ***Biopower*** (biomass-to-electricity) is a proven electricity-generating option. With about 11 GW of installed capacity, biopower is the single largest source of non-hydro renewable electricity (Total net summer capacity in 2007 was 995 GW, non-hydro renewables accounted for 30 GW or 3.0%). According to the Biomass Producers Association 2008, over 100 biomass power plants are connected to the electrical grid, while the U.S. Energy Information Administration estimates that the total installed capacity of wood biomass power generation is 6 GW and predicts that this figure could double over the next 10 years. The majority of the capacity is produced in **C**ombined **H**eat and **P**ower (CHP) facilities in the industrial sector, primarily in pulp and paper mills and paperboard manufacturers. The stand-alone power production facilities largely use non-captive residues, including wood waste purchased from forest products industries and urban wood waste streams, and some agricultural residues from pruning, harvesting, and processing (OUT, 1997). The U.S. has one-third of the world’s automobiles (230 M) and uses 25% of the world’s oil for transportation. The U.S. economy depends largely on liquid fuels, principally derived from petroleum, to power their cars, buses, trucks, locomotives, barges, and airplanes. The government established a goal to reduce gasoline consumption by 20% in 2017 through efficiency and alternative fuels, and to displace 30% of gasoline consumption with biofuels by 2030. The targets are not technology specific nor based on detailed cost analyses of biomass supply chain and process plant operations. Whether they can be reached or not remains to be seen. Therefore, the Biomass Programme is focusing its R&D efforts to ensure that cellulosic ethanol (2nd generation biofuels) is cost competitive by 2012.

The internal offer of energy in **Brazil** in 2006 was 226 million **t**one of crude **o**il **e**quivalent (TOE) of which biomass energy was responsible for 30.2%. The total installed power is 96.63 GW from which 4.74 GW (4.9%) corresponds to biomass. Six thermal power plants using biomass are being built with installed power 80.35 MW. Also, the construction of 42 other units (total 673.6 MW) has already been authorized. The technical potential for the generation of electricity in the sugar/alcohol sector using high-parameter steam cycles is 3.85 GW using 40% of existing cane straw. However, other studies mention a total which varies from 6 to 8 GW. The highest values are attained by considering **B**iomass **I**ntegrated **G**asification-**G**as **T**urbine (BIG-GT) technology. Biopower could be one of the solutions for electric power supply in Amazonian region isolated communities and for development programmes in rural areas. The Brazilian programme for the utilization of automotive alcohol 'PROALCOOL' was considered to be the largest bioenergy programme in the world. Today, all the gasoline in Brazil is mixed with alcohol at a concentration of 23%. Dual-fuel automobiles, commercialized in 2003, must give a new incentive to this programme. The alcohol production in Brazil is expected to double and the exportation must jump from 1.9 to 10 billion liters within 2010. 89 new ethanol distilleries projects are being carried out. Biomass R&D activities in Brazil are funded mainly by the government. The demonstrative and commercial projects are being implemented. The ongoing projects at Universidade Federal de Itajuba´, Brazil, have embraced almost all the spectra of bioenergy potential applications with advanced technologies. Biomass gasification has a wide scope of application and must constitute the basis of the dissemination of 'modern biomass' use. Efforts and resources are necessary so that this technology can have its commercial phase initiated (FAO, 2008d).

In **Southeast Asia**, biomass provides 26% of total primary energy supply (87% of all renewable energy), mostly in the form of traditional utilization. Though more than 110 M t (about 41 GW) of biomass residues from agro-industrial-based industries is generated annually in this region, only a small portion is utilized. All countries in the region have policies supporting renewable energy except Singapore and Brunei, but only the Philippines, Malaysia, and Thailand have set installed capacity targets to increase the share of renewable energy. At this instant, the total capacity of the 165 projects analyzed (about half of which are still in development stage) would account for only 5% of the total potential for the regions (table 3.3 and table 3.4). Due to the dispersed nature of the resource, biomass power-generating facilities tend to be small (61% less than 10 MW). Only 18% are greater than 20 MW (table 3.5). 81% of projects using rice husk and 69% of projects in both palm oil waste and wood waste are less than 10 MW, since an environmental impact assessment is not required by law for power projects in this size. The projects are traditionally carried out to supply the agro-industry's own energy requirements and are considered as an integral part of their operation, therefore only 41% of the projects are **S**pecial **P**urpose **C**ompany (SPC). The most important barrier in Southeast Asia is the lack of an enabling institutional, policy, and regulatory environment to support the development and implementation of biomass energy projects. Moreover, successful operation is not widely demonstrated in the region. For Thailand, smaller SPC uses rice husk as primary fuel, while bigger SPC exploits bagasse (see Ch. 1.3) (Carlos and Khang, 2007).

Table 3.3: Geographical distribution of biomass energy projects in Southeast Asia

Country	No. of projects		Total capacity	
	Number	Percentage	Number	Percentage
Cambodia	1	0.6	2.0	0.1
Indonesia	11	6.7	128.4	6.5
Laos	8	4.8	17.0	0.9
Malaysia	25	15.2	163.2	8.3
Philippines	21	12.7	286.5	14.6
Singapore	3	1.8	4.0	0.2
Thailand	87	52.7	1,338.7	68.0
Vietnam	9	5.5	28.0	1.4
Total	**165**	**100.0**	**1,967.8**	**100.0**

Source: Carlos and Khang (2007).

Table 3.4: Ownership of biomass energy projects in Southeast Asia

Type of ownership	Phase of implementation	Number of projects								total number	%
		Cambodia	Indonesia	Laos	Malaysia	Philippines	Singapore	Thailand	Vietnam		
Internal	Conceptual		1	6	9	11	1	12	9	49	29.7
	Development				1					1	0.6
	Construction					3				3	1.8
	Operation		1		3	1	2	38		45	27.3
	Total		**2**	**6**	**13**	**15**	**3**	**50**	**9**	**98**	**59.4**
Special purpose company	Conceptual		9	2	10	5		11		37	22.4
	Development				1	1				2	1.2
	Construction	1								1	0.6
	Operation				1			26		27	16.4
	Total	**1**	**9**	**2**	**12**	**6**		**37**		**67**	**40.6**

Source: Carlos and Khang (2007).

Table 3.5: Fuel used in the different biomass energy plants in Southeast Asia

Fuel	Project size									
	<5 MW		5-10 MW		10-15 MW		15-20 MW		>20 MW	
	No. of projects	%	No. of projects	%	No. of projects	%	No. of projects	%	No. of projects	%
Rice husk	16	26.7	20	48.8	1	5.0	3	21.4	4	13.3
Bagasse	7	11.7	13	31.7	10	50.0	7	50.0	21	70.0
Palm oil residues	11	18.3	7	17.1	6	30.0	3	21.4	0	0.0
Wood waste	15	25.0	1	2.4	2	10.0	1	7.1	3	10.0
Biogas	7	11.7	0	0.0	0	0.0	0	0.0	0	0.0
Others	4	6.7	0	0.0	1	5.0	0	0.0	2	6.7
Total	**60**	**100.0**	**41**	**100.0**	**20**	**100.0**	**14**	**100.0**	**30**	**100.0**

Source: Carlos and Khang (2007).

3.2 Heat and Electricity Production

In recent years, interest in biomass as a modern energy source, especially for electricity generation has been growing worldwide. The bases for the conversion of biomass to electricity are direct combustion, gasification, and pyrolysis. The next generation of stand alone biopower production should substantially reduce the high costs and efficiency disadvantages of today’s industry. The industry is expected to dramatically improve process efficiency through the use of co-firing of biomass in existing coal-fired power stations, through the introduction of high-efficiency gasification-combined-cycle systems, and through efficiency improvements in direct-combustion systems where fuel drying is possibly added or higher performance steam cycles at larger scales of operation can be utilized. Therefore, biomass conversion technologies into heat/electricity production can be here classified into 3 categories: traditional, modern, and future technologies. ***Traditional technologies*** are conventional procedures having been used for a long time without any technical barriers. Most of the existing technologies employed in industry sector belong to this category. System (boiler) efficiencies may range from 50% to above 80%, but the systems may have none or minimal environmental features to meet existing environmental regulations (see also Ch. 3.2.2). ***Modern technologies*** are currently available in the market with minimal developmental barriers, although its uptake is still limited to a few industries. These types of technologies are generally considered more efficient and more environment-friendly than traditional technologies, but need more investment (see Ch. 3.2.3). ***Future technologies*** are long-term technologies requiring further research, before commercialization can be considered (see Ch. 3.2.4). Most of them are still on a pilot or demonstration scale.

3.2.1 Basic Fundamental of Heat and Electricity Production via Thermo-Chemical Conversion

Before discussion about biomass conversion technologies as mention in the last paragraph, it is necessary to understand the basic techniques and general problems that will be referred to throughout the heat and electricity production topic. These procedures include direct combustion, gasification, and pyrolysis. The major areas of current research focus on gasification and pyrolysis (see Ch. 3.3.3.1.1). However, direct combustion is simple and its dominant role among techniques currently in use would be mentioned.

3.2.1.1 Biomass handling and Preparation for Heat and Electricity Production

The handling and flow properties of biomass are usually poor because of high moisture content, particle size variation, bulk density, high fiber, and over sized particle content. Additionally, the bulk is adherent, corrosive, and even abrasive. The importance of pre-treatment is likely to increase with the tendency to utilize low-quality biomass (EUBIONET, 2003). Another interesting option, especially for herbaceous biomass might be a pre-treatment process combining torrefaction and pelletization. High shear strength and low energy density of biomass have lead to the design of receiving pits and pre-screens that are as open as possible, enabling sufficient unloading for the boiler capacity. Impact of combustion processes (especially of solid fuels) can be worsened by the heterogeneous composition of waste biomass leading to unacceptable consequences. For bulk material handling, various options such as hoppers or lock hoppers, screw feeders (Dai, 2007), conveyor belts (Abbas et al., 1994), and pneumatic feeding systems (Tmej and Haselbacher, 2000; Sami et al., 2001; Dai, 2007), have proved to be suitable for different kinds of biomass. The feeding system should be designed to handle the specific fuel flow properties. The most common feeding system for pellet stoves is a screw auger driven by a slow-moving high torque motor fed from a hopper. Screw feeders may cause fuel flow fluctuations and segregation of pellet and forest residues when fed by the same screw. Because of segregation during storage and different feeding behavior of pellet and forest residue, different chambers are needed in a hopper to obtain steady flow and to control mixing (Granada et al., 2006).

3.2.1.2 Direct Combustion of Biomass

Direct combustion is widely used on various scales to convert biomass energy to heat or electricity with the help of a steam cycle (stoves, boilers, and power plants) (Demirbas, 2000a), thus for electric generation allowing either centralized or decentralized applications. It involves the oxidation of biomass with excess air, producing hot flue gases (around 800 to 1000 °C) which generate steam in the heat exchange sections of boilers. The steam is utilized to produce electricity in the ***Rankine cycle***, a thermodynamic cycle which converts heat into work. In electricity-only process, all of the steam is condensed in the turbine cycle, while - in CHP operation - a portion of the steam is extracted to provide process heat. The two common boiler designs for steam generation by biomass are stationary or traveling-grate combustors (see

Ch. 3.2.2.1.2), and atmospheric fluid-bed combustors (see Ch. 3.2.3.1.2). A qualitative evaluation of biomass combustion technologies is presented in the table 3.6 below. It is possible to burn any type of biomass, but in practice combustion is feasible only for biomass with a moisture content less than 50%, unless the biomass is pre-dried (McKendry, 2002b). Then, all biomass combustion systems require feedstock storage[23] and handling systems. Because of the dispersed nature of the resource, biomass power-generating facilities tend to be small, so they cannot capture the economies of scale typical of fossil-fuel-fired generating facilities. All of today's capacity is based on mature, direct-combustion boiler/steam turbine technology. The average size of existing biopower plants in the U.S. is 20 MW (the largest approaches 75 MW) and the average biomass-to-electricity efficiency of the industry is 20% (generally ranging from 20 to 40%). The higher efficiencies are obtained with systems over 100 MW or when the biomass is co-combusted in coal-fired power plants.

Table 3.6: The thermo-chemical biomass conversion technologies and Parameters for the considered plant technologies

	Grate firing combustion	Fluid bed Combustion	Fluid bed gasification	Fast pyrolysis (FP/DE)
Pre-treatment	None	None	Dryer	Dryer
Power cycle	Steam cycle	Steam cycle	Gas engine	Diesel engine
Products	Electricity-Heat	Electricity-Heat	Electricity	Electricity
Thermal efficiency [%]	0.90	0.90	0.90	-
Electrical efficiency [%]	0.23	0.25	0.27	0.24
Fixed cost [€ MW_e/y]	210,000	287,000	355,000	450,000
Maintenance cost [€ MW_e/y]	0.02	0.03	0.04	0.05

Source: Frombo et al. (2009)

Slagging[24] can be defined as the deposition of fly ash on the heat transfer surface and refractory in the furnace volume primarily subjected to radiant heat transfer. ***Fouling*** is termed as deposition in the heat recovery section of the steam generator subject mainly to convective heat exchange by fly ash quenched to a temperature below its melting point. For the demolition wood, glue, coating, and shielding materials may cause bed agglomeration, slagging, fouling, and unexpectedly high flue gas emissions. The main factors that contribute to fouling are caused by inorganic materials in the fuel. Biomass ash, particularly in some agricultural residues and new tree growth, contains a larger amount of alkalines compared with coal ash. Alkaline metals that are usually responsible for fouling of heat transfer surfaces are abundant in wood fuel ashes and will be easily released in the gas phase during combustion. High alkaline metal content often means low ash melting temperature; in coal, a large proportion of inorganic substances are bound in silicates (EUBIONET, 2003). ***Phenol*** was the main constituent in the condensates. It is a heterocyclic aromatic and has high solubility in water. The concentration of phenol can be reduced by increasing the operating temperature, preferably to above 800 °C. This would lead to a decrease of phenol in condensates, but it would convert phenol and the heterocyclic aromatics into other components such as naphthalene and fluoranthene. However, these components do not have high solubility in water and would not pose a water hazard. The converted components would eventually be combusted in end-use applications and therefore does not present harmful emissions into the surroundings.

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[23] Parameters influencing the storage are (Rupar and Sanati, 2005): 1) Moisture content; 2) Type of material; 3) Age of the material; and 4) Size of the material.

[24] Ash in biomass melts around 1000 °C, and it is important to keep the operating temperature of gasification below this temperature to avoid ash sintering and slagging (Bauen, 2004).

3.2.1.2 Biomass Gasification

Gasification is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperatures, typically in the range 800 to 900 °C. The low **C**alorific **V**alue (**CV**) gas produced (about 4 to 6 MJ/N m^3) can be burnt directly, or used as a fuel for gas engines and gas turbines (LRZ, 1993; Natural Resources Institute,1996). The gas can be used as fuel in a combined cycle power generation plant that includes a gas turbine topping cycle or a steam turbine bottoming cycle. It can be also used as a feedstock (syngas[25]) in the chemical production (e.g. methanol). After adequate cleaning up and reforming, it can be directly fed to high temperature fuel cells (MCFC and SOFC) or to produce hydrogen. Moreover, biomass gasification systems are now gaining popularity with implementation of IGCC becoming more imminent, and will be appropriate to provide fuel to fuel cell or hybrid fuel-cell/gas-turbine systems, particularly in developing or rural areas without cheap fossil fuels or having a problematic transmission infrastructure (McKendry, 2002b). This conversion route is more attractive than direct combustion due to: 1) potentially higher thermal efficiency. The first generation of **B**iomass **G**asification **C**ombined **C**ycle (BGCC) systems had efficiencies nearly double that of direct-combustion systems (e.g., 37% vs. 20%). In cogeneration applications, total plant efficiencies could exceed 80%; 2) the ability to maintain high performance in systems over a wide range of sizes from about 5 MW to about 100 MW; and 3) increased fuel flexibility thanks to opportunities to reduce unwanted contaminants in raw material handling and preparation prior to the power generation stage.

There are several competing technologies for gasification which can be classified such as pressurized or atmospheric, oxygen-blown or air-blown, and fixed bed or fluidized bed (Wahlund et al., 2004). However, it is usually divided into two large categovnries: partial oxidation and steam gasification. The first process uses air as gasifying agent, while the second employs water steam: they differ also in the way of feeding the energy necessary to break down the organic molecules forming biomass: partial oxidation obtains energy from the biomass itself but has the drawback that, since air is used as the oxidizing agent, the syngas has a very low heating value due to the dilution with N_2 (see table 3.7); steam gasification allows for a much better (and H_2 rich) fuel gas, but requires an external heat source to allow the reaction to proceed. In the case of partial oxidation using O_2, heat is generated to effect the gasification; but the complexity, costs, and energy requirements of the process are usually increased by the need to supply pure O_2, or to remove N_2 from the gaseous product. However, there are very strong reasons why O_2 gasification should be considered for producing synfuels efficiently from biomass. The first reason is the supply of energy to the gasification process from partial oxidation: this removes the need for external heating and steam generation. The second is the generation of high temperatures, favourable to the formation of H_2 and CO.

Table 3.7: different calorific values (CV) of produced gas of various gasification categories

Low CV	4 to 6 MJ/Nm^3	Using air and steam/air
Medium CV	12 to 18 MJ/Nm^3	Using O_2 and steam
High CV	40 MJ/Nm^3	Using H_2 and hydrogenation

Source: Morf et al. (2002)

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[25] Syngas is produced industrially from coal and natural gas. The principle difference between producer gas and syngas is that air is used to make producer gas, which has higher levels of N_2 and lower concentrations of CO, H_2, CO_2, and CH_4 than those of syngas (Sadaka, FSA1051).

It is estimated by EPRI/DOE that a condensing biofuel-based power plant may reach 45% electrical efficiency (Wahlund et al., 2004). The reactor may be of different types (Fig. 3.3), such as circulated or bubble fluidized bed (CFB, BFB), multi-bed combustion (MBC) or grate-fired boiler. Different technologies are more suitable for different scales of operation as shown in Fig. 3.4. The most modern cycle is equipped with a CFB boiler, which can reach 30% of electrical efficiency and 90% of total efficiency (Wahlund et al., 2004). Although gasification technologies have recently been successfully demonstrated at large scale, several demonstration projects are under implementation. They are still relative expensive in comparison to fossil based energy and, therefore, face economic and other non-technical barriers when trying to penetrate the energy markets. An extensive review of gasifier manufacturers in Europe, USA, and Canada identified 50 manufacturers offering commercial gasification plants from which: 75% downdraft type, 20% fluidized bed systems, 2.5% updraft type and 2.5% other designs. The efficient and economic removal of tar (details see below) still presents the main technical barrier to be overcome. Producing a clean (low in tar) syngas is difficult and costly; subsequent conversion to fuels and alcohols tends to afford low yields (Maniatis, 2001).

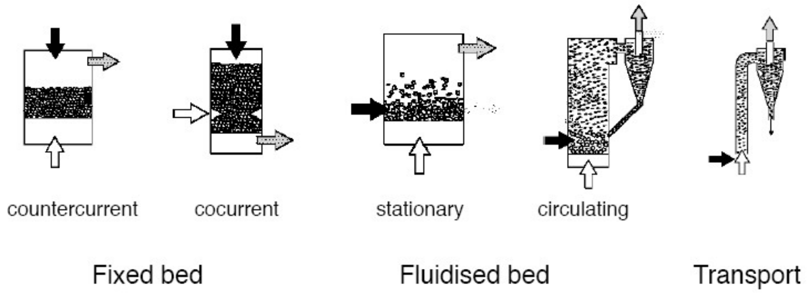

Fig. 3.3: Gasifier Concepts and Different Types of Operation
Source: Kaltschmitt (2001)

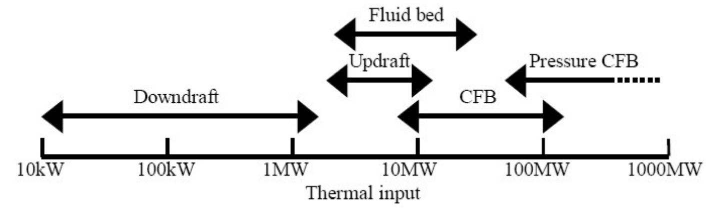

Fig. 3.4: Gasifier Concepts and Different Scales of Operation
Source: Bridgwater (2002)

When biomass is heated up above 400 °C, it first decomposes to charcoal and volatile oils (primary oils). At higher temperatures, these oils will crack to olefins, and then to aromatic compounds, often collectively referred to as ***tars***[26]. They are problematic because they condense in exit pipes and on particulate filters leading to blockages and clogged filters. Many times new biomass gasification projects end because the cost of removing the tars is greater than the cost of project. For this reason, Tar removal, conversion, or destruction has been reported to be one of the greatest technical challenges for the successful development of

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[26] Also defined as any material in the product stream that is condensable in the gasifier or in downstream processing equipment, the tar is a liquid product consisting mainly of condensed poly-aromatic hydrocarbons (PAH) and other organic molecules with high molecular weight, whose great viscosity and acidity make removal difficult. The amount of tars can be reduced by choosing the proper gasification conditions and reactor (Khan et al., 2009).

commercial gasification technologies. The main problem relates to efficient removal of tar, however, the engine manufacturers have not been able to design and construct more robust engines, which can tolerate some tar in the gas. Tars removal can be done on three approaches: ***scrubbing***, ***catalytic reforming*** followed by scrubbing, and ***hot gas clean up***[27]. In the later case, syngas is kept above 400 °C to avoid tar condensation, then burned in a gas turbine. This approach applies only to pressurized gasification IGCC systems. Between wet and catalytic cleaning methods, the latter is preferred because it actually destroys/modifies the tars instead of transferring them to a liquid phase, which needs further and expensive waste water treatment. The combination of catalytic reforming followed by scrubbing is currently the only way to effectively address the tar problem (table 3.8). Three main configurations are under development: reverse flow catalytic bed with dolomite, fluidized bed with dolomite, and catalytic bed with monolith based catalyst (Maniatis, 2001).

Table 3.8: Fuel gas contaminants, their problems, and the solutions

Contaminant	Examples	Problems	Solution
Tars	Refractive aromatics	Clogs filters Difficult to burn Deposits internally	Tar cracking thermally or catalytically, or tar removal by scrubbing
Particulates	Ash, char, fluidised bed material	Erosion	Filtration, scrubbing
Alkali metals	Sodium, potassium compounds	Hot corrosion	Cooling, condensation, filtration, adsorption
Fuel-bound nitrogen	Mainly ammonia and HCN	NO_x formation	Scrubbing, Selective catalytic removal (SCR)
Sulfur, chlorine	HCl, H_2S	Corrosion emissions	Lime or dolomite, scrubbing, absorption

Source: Bridgwater (1995)

3.2.2 Traditional Technologies

3.2.2.1 Processes and Concepts of Traditional Technologies

Biomass conversion plant for the production of electricity (also heat and process steam) is applied commercially worldwide. Many plant configurations have been developed and deployed over time. Conventional concepts include pile burning, various types of grate firing (stationary, moving, and vibrating), and fixed-bed concepts.

3.2.2.1.1 Pile Burners

The pile burner is the original, *circa.* 1700, industrial process-scale biomass burner and can be viewed as a sort of enclosed fire (Overend, 2002). It typically consists of a two-stage combustion chamber with a separate furnace, and a boiler located above the secondary combustion chamber. The combustion chamber is separated into a lower pile section for primary combustion and an upper secondary-combustion section. Wood is piled on a grate in the bottom section and combustion air is fed upwards through the grate and inwards from the walls; combustion is completed in a secondary combustion zone using overfire air. The wood or biomass is introduced either on top of the pile or through an underfeed arrangement using an auger. The underfeed arrangement gives better combustion control by introducing feed

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[27] Tars can be destroyed by thermal destruction, but this typically requires very high temperatures of greater than 1000 °C. This high temperature causes material and economical problems and also produces soot. Therefore, it is usually desirable to remove the tars at a lower temperature, which requires the addition of a catalyst and often steam or oxygen to the product gas (Huber et al., 2006).

underneath the active combustion zone , but it increases system complexity and lowers reliability. Ash is removed by isolating the combustion chamber from the furnace and manually dumping the ash from the grate after the ash is cooled. Pile burners typically have low efficiencies (50 to 60%), have cyclic operating characteristics because of the ash removal, and have combustion cycles that are erratic and difficult to control. Because of the slow response time of the system and the cyclic nature of operation, pile burners are not considered for load-following operations. The advantage of the pile burner is its simplicity and ability to handle wet, dirty fuels. Main disadvantages are the generally low boiler efficiency and relatively poor combustion control also lower heat capacity (Hollenbacher, 1992).

3.2.2.1.2 Combustion on Grate

In this combustion technology, a variety of grates are applied to support the combustible fuel bed including stationary sloping, travelling, and moving grates. Though each type of grate has different fuel distribution and dispersion, fuel is fed into the furnace and onto the grate where combustion takes place. Particulate problems associated with dropping fuel onto the fire are eliminated. The thin pile allows more uniform air distribution as compared to a heaped pile, and combustion rates can be increased more rapidly. Wet fuel can be used, but more size uniformity is required than with a gravity-fed Dutch Oven, an well known pile burner (Bulpitt 1984, Vasenda and Hassler 1993). In a ***stationary sloping-grate*** boiler, the grate does not move, but the fuel burns as it slides down the slope. Disadvantages of this boiler type are the difficult control and the risk of avalanching the fuel. In a ***travelling-grate*** boiler, the fuel is fed in at one side the grate and has to be burnt before it reaches the ash dumping site of the furnace. Combustion control is improved, because the layer of fuel on the grate is thinner. Carbon burnout efficiency is also better than the first type. With a ***vibrating-grate*** boiler, the fuel is fed evenly over the whole grate. The grate makes a shaking movement spreading the fuel evenly. This type of grate has fewer moving parts than a travelling grate and therefore has lower maintenance requirements (COGEN3, 2003).

Stokers, in combination with grate burners, improve on operation of the pile burners by providing a moving grate which permits continuous ash collection, thus eliminating the cyclic operation characteristic of traditional pile burners. In the basic stoker design, the bottom of the furnace is a moving grate, cooled by underfire air. The underfire air rate defines the maximum temperature of the grate and thus the allowable feed moisture content. More modern designs include the Kabliz grate, a sloping reciprocating water-cooled grate. Reciprocating grates are attractive because of simplicity and low fly ash carryover (EPA, 2007). It is not common to apply grate combustion in multifuel combustion. It is also more sensitive to changes in fuel quality and moisture, and automation of grate combustion is difficult. When temperatures in the combustion chamber reach 1,300 to 1,400 °C, ash melting problems may occur, but can be reduced by using mechanical & water-cooled grates and by avoiding the use of preheated combustion air in the final burning area (EPA 2007; EUBIONET, 2003). Plant efficiency of the stoker plant increases to 27.7% in the year 2000 through the use of fuel pre-dryer. The forecast for 2020 is that plant efficiency will increased to 33.9% due to larger scale plants which permit more severe steam turbine cycle conditions, e.g. higher pressure, higher temperature, and reheat (Bain et al., 1998).

3.2.2.1.3 Fixed-bed Gasification

The fixed bed gasifier has been the traditional process used for gasification (see also 3.2.1.2), operated at temperatures around 1000 °C. Depending on the direction of airflow, the gasifiers are classified as ***updraft***, ***downdraft***, or ***cross-flow***. In the **U**pdraft **G**asifier (UG), the feed is introduced at the top and the air at the bottom of the unit via a grate (Fig. 3.3). Immediately above the grate the solid char (the residual solid remaining after the release of volatiles) formed higher up; the gasifier is combusted and the temperature reaches about 1000 °C. Ash falls through the grate at the bottom and the hot gases pass upwards and are reduced. Higher up the gasifier again, the biomass is pyrolysed and in the top zone, the feed is dried, cooling the gases to around 200 to 300 °C. In the pyrolysis zone, where the volatile compounds are released, considerable quantities of tar are formed which condenses partly on the biomass higher up and partly leaves the gasifier with the product gas. The temperature in the gasification zone is controlled by adding steam to the air used for gasification, or by humidifying the air. Due to the low temperature of the gas leaving the gasifier, the overall energy efficiency of the process is high but so also is the tar content of the gas. The filtering effect of the feed helps to produce a gas with a low particulate content (McKendry, 2002a).

For **D**owndraft **G**asifier (DG), the feed and the air move in the same direction (Fig. 3.3). The product gases leave the gasifier after passing through the hot zone, enabling the partial cracking of the tars formed during gasification and giving a gas with low tar content. Because the gases leave the gasifier unit at temperatures about 900 to 1000 °C, the overall energy efficiency of a downdraft gasifier is low, due to the high heat content carried over by the hot gas. The tar content of the product gas is lower than for an updraft gasifier, but the particulates content of the gas is high. In a **C**ross-flow **G**asifier (CG), the feed moves downwards, while the air is introduced from the side, the gases being withdrawn from the opposite side of the unit at the same level. A hot combustion/gasification zone forms around the entrance of the air, with the pyrolysis and drying zones being formed higher up in the vessel. Ash is removed at the bottom and the temperature of the gas leaving the unit is about 800 to 900 °C: as a consequence this gives a low overall energy efficiency for the process and a gas with high tar content (McKendry, 2002a).

3.2.2.2 Advantages and Drawbacks of Traditional Technologies

Direct-fired biomass technology will provide base-loaded electricity and is operated in a way similar to fossil and nuclear plants. All of the assumed advantages in performance involve the incorporation of proven commercial technology. Therefore, there are no R&D issues involved in this technology. However, there is R&D required for boiler modifications to permit the combustion of high-alkali biomass, such as wheat straw, without fouling of boiler heat exchange surfaces (Bain et al., 1998). Typical capacities for stand-alone biomass combustion plants (typically using wood, such as forest residues, as fuel) range between 20 and 70 MW_e, with related electrical efficiencies in the 25 to 30% range. Such plants are only economically feasible when fuels are available at low costs, or when a carbon tax or feed-in tariff for renewable electricity is in place (EPA, 2007). Biomass-fired steam cycle plants typically use single-pass steam turbines. However, in the past decade, efficiencies and more complex design features, characteristic previously of only large scale steam turbine generators (> 200 MW), have been transferred to smaller capacity units. Today's biomass designs include reheat and regenerative steam cycles as well as supercritical steam turbines. The two common boiler configurations used for steam generation with biomass are stationary/traveling-grate combustors (stokers), and atmospheric fluid-bed combustors (EPA, 2007).

In general fixed-bed gasifiers have the advantage of a simple design, but the disadvantage of producing a low CV gas with a high tar content. The product gas composition is typically 40 to 50% N_2, 15 to 20% H_2, 10 to 15% CO, 10 to 15% CO_2, and 3 to 5% CH_4, with a net CV of 4 to 6 MJ/Nm^3. When using air as the gasifying medium, the resulting high N_2 content doubles the volume of the product gas and increases the size of the downstream gas cleaning equipment. Improvements to gas quality have been proposed by operating a two-stage, two-reactor process. Pyrolysis of the biomass takes place in the first stage using external heating at 600 °C. The gases formed in the first stage are then reacted with steam to crack the tars. In the second stage the gases react with the char from the first stage to produce the final product gas. After clean-up the gas quality is sufficient for use in a spark ignition gas engine (Warren et al., 1995).

3.2.2.3 Economics Aspect of Traditional Technologies

Biomass direct combustion and power generation technology is mature in technology, but it is only feasible for the power capacity of more than 10 MW, due to steam parameters of biomass boiler of small scale are difficult to be increased. Additionally, Grate combustors are less tolerant for fuel quality variations than fluidized bed boilers, however they have been able to compete with modern combustion technologies due to continuous research and development. The economics of power generation are dependent on the capital cost, the operating cost, and the fuel cost, in almost equal measure over the generating plant's life cycle. Scale and efficiency are linked and are illustrated in Fig. 3.5, which compares the levelized costs of electricity for biomass-fired systems based on stoker firing and gasification combined cycles, using data from the EPRI - NREL technology assessment (EPA, 2007; Overend, 2002; Bridgwater, 1995).

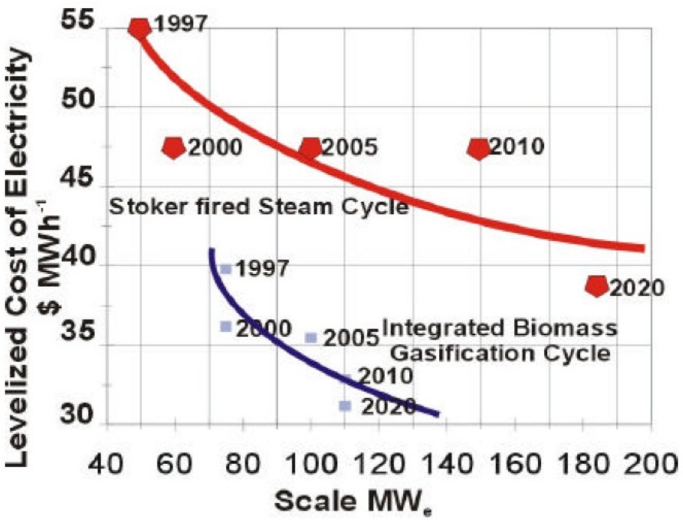

Fig. 3.5: Levelized cost of traditional direct-fired steam cycle power generation and biomass IGCC

Source: Overend (2002)

3.2.2.4 Environmental Aspect of Traditional Technologies

Biomass combustion is often related to significant pollutant formation and needs to be improved (NYSERDA, 2008). Generally, nitrogen, sulphur, and chlorine components in the biomass can lead to the production of NO_x, SO_2 and HCl, respectively, in the flue gas. In common direct biomass burners, "fuel NO_x" or "thermal NO_x" can be generated from N_2 and O_2 at high combustion temperatures (especially > 1400 °C). Caused by a difficulty to control, incomplete combustion also leads to (enhanced concentrations of) CO and hydrocarbons (C_xH_y), tar, Poly Aromatic Hydrocarbons (PAH), and incompletely burned char (in grate-fired boilers) (Yin et al., 2008). Some products of incomplete combustion are hazardous to health when breathed. A different set of these products are also strong direct or indirect greenhouse gases, potentially contributing to global warming[28]. Besides, poor combustion can contribute directly to low energy efficiency, with its attendant problems of onerous human labor requirements and pressure on biomass resources from harvesting. Besides, combustion of biomass fuels generates substantial amounts of fine particles (< 1 μm in aerodynamic diameter). If no effective flue gas cleaning systems are applied, most of these particles are released into surroundings, affecting air quality and the climate system. In addition, a fraction of the particles can deposit on boiler surfaces, causing operational problems such as reduced efficiency, plugging and corrosion (Sippula, 2010). Therefore, biomass direct combustion normally exhibits relatively high emissions of NO_x and particulates[29].

Noted for relatively simple design, low capital and operating costs, ability to deal with wide range of wood particles and moisture contents (up to 65%), pile burners are conversely considered poor in process control owing to the large mass of burning fuel and they slowly respond to changes in process conditions meaning that energy output cannot easily to meet the fluctuations of energy demand. Locally, high temperatures can lead to high emissions of NO_x. The pile burner is capable of handling wet and dirty fuels, but it is extremely inefficient. Boiler efficiencies are typically 50-60% and Power generation in a pile-burner based power station will usually involve a single pass steam turbine generator operating at a relatively low steam temperature and pressure with an overall efficiency as low as 20% (UNEP-DTIE, 2007; Badger, 2002; Dinkelbach, 2000). Minimum particle sizes of biomass for pile burner hinge on the grate openings, while the maximum particle size depends on the fuel feed opening into the combustion chamber (Badger, 2002).

Grate-fired boilers are often labeled ''high carbon-in-ash, low efficiency, and high emissions'' (Yin et al., 2008). Due to the comparatively poor mixing, incomplete combustion is, most likely, a big problem or challenge for grate-fired boilers, particularly old units, compared to Fluidized bed combustors (see Ch. 3.2.3.1.2 and Ch. 3.2.4.1.1) or suspension-fired boilers (see Ch. 3.2.3.1.1) (Yin et al., 2008). The relatively high contents of specific elements (e.g., Cl, S, and heavy metals) in some biomass fuels may aggravate the pollutant emissions by emitting HCl, SO_x, Polychlorinated Dibenzo-dioxins (PCDD), Polychlorinated Dibenzofurans (PCDF), and heavy metals. The important NO_x precursors (e.g., NH_3, HCN, and NO) released from the fuel bed on the grate, which are directly related to the atmosphere and the propagation speed of the ignition front in the fuel bed, play a vital role in NO_x

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[28] Fine particle emissions from combustion sources directly affect the climate by absorbing and scattering sunlight. The highest emissions in relation to energy produced are usually generated in residential scale combustion (< 100 kW) (Sippula, 2010).

[29] Particulate air pollution is an important health concern worldwide. Several studies have shown that increased particle concentrations in the ambient air correlate with adverse health effects in the exposed population, including respiratory and cardiovascular illnesses as well as increased mortality (Samet et al., 2000).

emissions from grate-fired boilers. Therefore, the pollutant emissions due to incomplete combustion tend to be a more prominent topic associated with grate-fired boilers. The pollutant emissions from incomplete combustion can be controlled by improved burning system. In grate-fired boilers, better mixing in the freeboard, increased residence time in the combustion zones, low total excess air, and the appropriate choice of grate assembly is normally mentioned. For the pollutant emissions caused by fuel properties (e.g., ash, heavy metals, Cl, and S), they can be reduced by pre-treatment of the biomass, well-controlled burning process, or post-combustion systems (Yin et al., 2008).

In fixed-bed gasifier and other gasifier types, producer gas (the mixture of carbon monoxide, hydrogen, methane and other gases) is hazardous, if it is not handled and used properly. Carbon monoxide (CO) is a major constituent of producer gas and is by far the most common cause of gas poisoning because of its colorless or odorless. All operating personnel should be aware of the vulnerabilities presented by this gas (Turare, 2002; Bridgwater et al., 1999). During the gasification of biomass, ashes and condensate (mainly water) are produced. Although ashes do not contribute to any environmental hazards and can be safely disposed, the disposal methods of tars containing condensate can have adversely environmental effects. No specific information is available about the bio-degradation of the phenolic and tarry constituents of the condensates. However, properties of exhaust emission from engines running on producer gas are generally acceptable (Turare, 2002). For other problems, there may also be additional specific requirements such as the following: dust from feed handling, dust explosions, gas explosions, solids disposal, and noise. All of these factors can be adequately managed through good design and operation practice. Finally, some surfaces of the gasifier parts, the cyclones, the gas lines, the engines, and the exhaust parts may get hot during operation and thus create a hazard to personnel for skin burns (Bridgwater et al., 1999).

3.2.2.5 Problems and Barriers of Traditional Technologies

Main barriers to widespread use of biomass for power generation are cost, low conversion efficiency, and feedstock availability. In general, combustion efficiency of biomass can be 10 percentage points lower than for coal at the same installation, but co-firing (see Ch. 3.2.3.1.4) efficiency in large-scale coal plants (35 to 45%) is higher than the efficiency of biomass-dedicated plants. For direct-fired biomass technology, the increase in efficiency comes from an improvement in boiler capability that occurs when dry feed substitutes for wet feed. Boiler efficiency is a function of the amount of moisture in the fuel, the amount of excess air used in the combustion process, and the amount of heat lost in the heat transfer process, which is largely a function of boiler design. Moreover, straw-fired boilers have had major operational problems due to rapid deposit accumulation and corrosion rates. By several examples on straw firing in a stoker, pulverized, and fluidized bed boilers - the lowest levels of slagging, fouling, and corrosion have been achieved with pulverized combustion - whereas experiences with fluidized bed boilers are more complex (EUBIONET, 2003; Maniatis, 2001). Most important are the lack of internalization of external costs in power generation and effective policies to improve energy security and reduce CO_2 emissions. In the long term, bio-power potential will depend on technology advances and on competition for feedstock utilization. Competition may not be an issue until 2020 if industrial-scale production and international standards facilitate biomass international trade. Risks associated with widespread use of biomass relate to intensive farming, fertilizers, and chemicals use as well as biodiversity conservation. Certifications that biomass feedstock is produced in a sustainable way are needed to improve acceptance of public forest and lands management.

3.2.3 Modern Technologies

3.2.3.1 Processes and Concepts of Modern Technologies

Modern technologies are state-of-the-art processes, which can be utilized at the present time with minimal developmental barriers. The major technologies in this category are suspension burning, atmospheric fluidized bed combustion, atmospheric fluidized bed gasification, and biomass co-combustion/co-firing.

3.2.3.1.1 Suspension Burning

Suspension burning technology provides high efficiency in combustion, resulting in economy of fuel consumption and better control of ash quality. Generally, this boiler furnace is designed for use with solid fuel, but employing the principle of liquid fuel combustion. Combustion of liquid fuel occurs when the fuel flows upwards into the air by the force of a fuel pump. This pump will atomize the liquid fuel from a burner in the form of mist or spray. When the atomized liquid fuel comes in contact with the heat in the furnace, it will be burned in the air. Transport air is used as a means to transport pulverized coal and at the same time is utilized as combustion air. Two basic types of suspension burners are cyclonic burners and solid-fuel burners (ANL, 1990). Cyclonic burners are design to mix fuel and air in the correct proportion and to complete combustion before swirling particles of fuel reach the end of the refractory chamber. Solid-fuel burners mix the air and fuel together in the correct proportion and ignite the combustible mixture. Burnout of fuel particles is completed in a vertical cylindrical furnace. Successful suspension firing requires a feed moisture content of less than 15% and a particle size less than 0.15 cm. These requirements give higher boiler efficiencies (up to 80%) than stoker grate (27.7%) or fluid bed systems (65% efficiency), which fire wet biomass chips (50 to 55% moisture). A disadvantage is that the fuel requires a considerable amount of pretreatment. The presence of dry fine fuel particles creates a potential hazard. Thus, handling systems of suspension burning fuel require more careful design than those of conventional biomass. The higher efficiency of suspension burners results in smaller furnace size. Offsetting the higher efficiency is the cost and power consumption of drying and comminution by feedstock (Swezey et al., 1994). In addition, special burners (i.e. scroll cyclonic burners and vertical-cylindrical burners) are required.

3.2.3.1.2 Atmospheric Fluidized Bed Combustion

The best current combustion systems due to their ability to burn a wide assortment of fuels and still keep emissions low, a fluidized bed is solid material inside the furnace suspended or fluidized by forcing air through the bed. When the air velocity is increased above the minimum fluidization velocity (the velocity that solid particle behave themselves like a fluid), air flows through the bed as bubbles. This type of bed is called **B**ubbling **F**luidized **B**ed (BFB), the first version of FBC. When the air velocity is increased, the particles are carried higher up in a **C**irculating **F**luidized **B**ed (CFB) reactor. With CFB, it is no longer possible to distinguish between the bed and freeboard area. A large fraction of the particles rise up from the bed and are circulated with the help of a cyclone back to the bed. The circulating bed material can be used for temperature control in the boiler. Fluidization velocity of a BFB boiler is typically between 1 and 3.5 m/s, whereas in a CFB boiler it is among 3 to 6 m/s (Koornneef et al., 2007; EUBIONET, 2003). CFBs generally have higher efficiencies than BFBs due to higher fluidization velocities. Fluidized bed boilers can be designed to combust almost any solid, semi-solid, or liquid fuel as long as the calorific value is sufficient to heat the fuel, drive off the moisture and preheat the combustion air. They achieve high fuel-to-steam efficiency, typically over 90%. For high moisture content fuels, a support fuel can be used. More than 90% of the bed is sand or ash, while the rest is fuel. In some cases, special bed materials can be used in order to avoid agglomeration of bed matters. The choice between BFB and CFB technology has been largely linked to the choice of fuels. As a simpler and cheaper technology, BFB has been favoured in plants fuelled exclusively with biomass or similar low-grade fuels containing highly volatile substances. The new enhanced CFB designs can be a competitive alternative even in smaller biomass-fired plants (Khan et al., 2009; EUBIONET, 2003).

The main advantage of fluidized bed operation is its ease of both scale-up and control. The heat is stored in fluidized sand, then thorough circulation and mixing of the sand results in a uniform temperature throughout the bed. This helps prevent undesirable occurrences such as bridging or deposition. Another advantage is the flexibility with respect to feedstock. However, the uniform temperature also militates against the production of a hydrocarbon-free gas. Intimate contact between char, fresh biomass, pyrolysis oils, oxygen, and reducing gas, all means that pyrolysis and combustion are occurring at the same time and place as the gasification itself. This would result in the persistence of tars and light hydrocarbons, a situation also enhanced by a temperature that is lower than the maximum temperature achieved in the devices previously considered. Possible solutions would include operation at higher temperature, and longer residence times, but there is a lack of raw data on this. The risk, particularly with higher temperature, is that the ashes can melt and coalesce (ashes from biomass may melt at temperatures as low as 800 °C in the case of straw) and are corrosive to refractory materials (Higman and van der Burgt, 2003). Fluidized bed boilers are more suitable for direct co-firing of waste due to their ability to tolerate variations in fuel quality and moisture. However, the use of recycled fuels often has a negative effect on power plant availability. High steam temperature increases the risk of hot corrosion. Because of this, the chlorine concentration of recycled fuel should be less than 0.5 % or even 0.1 % by weight, hinging on the share of the recycled fuel and other fuels. No dioxin is formed when the atmosphere of gasifiers is reduced.

3.2.3.1.3 Atmospheric Fluidized Bed Gasification

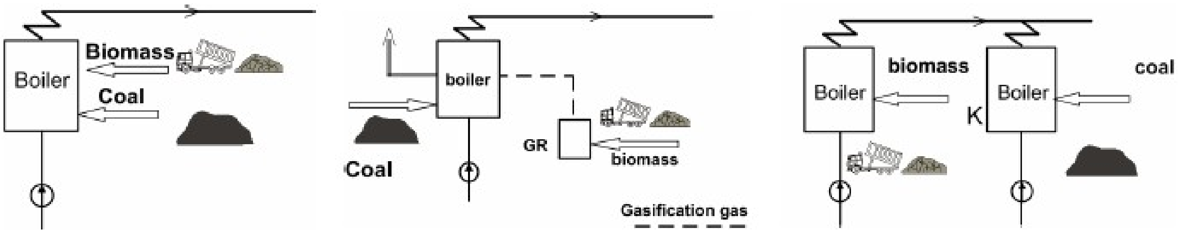
The Fluidized Bed Gasifier (FBG) is able to cope with such varying fuels because of the presence of inert bed material, which bubbles and mixes turbulently under buoyancy force from a fluidizing agent (see also Ch. 3.2.1.2 and Ch. 3.2.3.1.2). Under such violent bed conditions biomass particles are able to react fully to release volatiles as a result from high solids contact rate. Gases are released from the biomass particles and have generally an energy content of 3.5 to 5.0 MJ/m^3. These gases can then be used for firing up furnaces or in diesel generators for producing electricity (Lim and Alimuddin, 2008). **A**tmospheric **C**irculating **F**luidized **B**ed **G**asifiers (ACFBG) have proven very reliable with a variety of feedstocks and are relative easy to scale up from few up to 100 MW$_{th}$, while **A**tmospheric **B**ubbling **F**luidized **B**ed **G**asifiers (ABFBG) are limited in their capacity size range, up to about 25 MW$_{th}$, as they have not been scaled up significantly and their diameter is significantly larger than that of ACFBG for the same feedstock capacity (see Fig. 3.3). However, ABFBG are more economic for small to medium range capacities. Recently test for biomass feedstock only, **A**tmospheric **C**yclonic **G**asifiers (ACG) have medium market attractiveness due to their simplicity, but they are still unproven and not promoting by well known company. **A**tmospheric **E**ntrained **B**ed **G**asifiers (AEBG) are still at the early developing stage and require very small particle size of feedstock, thus their market attractiveness is very low (Maniatis, 2001). As a whole, the yield of solid carbon is both a decreasing function of the temperature and an increasing function of the process pressure and, correspondingly, the gaseous product (CO) is favoured by high temperatures and low pressures (Boudouard equilibrium).

3.2.3.1.4 Biomass Co-combustion/Co-firing

Defined as simultaneous combustion of different fuels in the same boiler, co-firing refers here to the practice of introducing biomass as a supplementary energy source in high efficiency boilers (Rosendahl et al., 2007; OUT, 1997). Extensive demonstrations and trials have shown that effective substitutions of biomass energy can be made in the range of 10 to 15% of the total energy input with little burner and feed intake system modifications to existing stations. Besides, biomass is a well-suited resource for co-firing with coal as an acid rain and GHG emission control strategy, since it in general has much less sulphur than coal and early test results suggest that there is also a NO_X reduction potential of up to 30% with woody biomass co-fired in the 10 to 15% range. However, Co-firing biomass in an existing pulverized coal boiler will generally require modifications or additions to fuel handling, storage, and feed systems. An automated system capable of processing and storing sufficient biomass fuel in one shift for 24-hour use is needed to allow continuous co-firing while minimizing equipment operator expenses. Preparation of biomass for co-firing involves well known and commercial available technologies. Investment levels are very site-specific and are affected by the available space for yarding and storing biomass, installation of size reduction and drying facilities, and the nature of the boiler burner modifications. In general, capital costs for blended feed systems are lower than that for separate feed systems. At low co-firing levels in a pulverized-coal unit (< 2%), or at mid-level (5 to 10%) in a cyclone, blended feed can be used (Hollingdale, 2006; EUBIONET, 2003).

There are basically 3 choices for co-combustion: direct, indirect, and parallel co-combustion (Fig. 3.6). ***Direct*** co-combustion is the combustion of biomass together with fossil fuel in a single combustion chamber. ***Indirect*** co-combustion means combustion of fossil fuel with previously gasified biofuel, and ***parallel*** combustion requires at least two boilers as biomass is burned in one and fossil fuel in another (EUBIONET, 2003). The last two choices have the advantage over the first one in coal co-combustion when biomass residual ash is not mixed with coal ash, which has an existing market as a component of construction material. In a pulverized fuel boiler, there are basically 4 options for co-combustion. ***The first option***, when the proportion of biofuel is rather low, biomass can be fed together with coal to coal mills and then be burned together with coal through coal burners. This is the simplest option, the smallest investments, but the highest malfunction risk of fuel feeding systems. ***The second option*** involves separate handling, metering, and comminution of the biofuel and injection into the pulverized fuel upstream of the burners or at the burners. This option requires the installation of a number of biofuel transport pipes across the boiler front, which may already be congested. It may also prove to be more difficult to control and to maintain the burner operating characteristics over the normal boiler load curve. ***The third option*** involves the separate handling and comminution of the biofuel with combustion through a number of dedicated burners. This approach represents the highest capital cost option, but involves the least risk to normal boiler operation. ***The forth option*** involves the use of biofuel as a reburn fuel for NO_x emissions control at a specially-designed reburn system located in the upper furnace. The problem with all these is that the loss in power output is almost inevitable and that the proportion of biofuel in fuel blend is limited (van Loo and Koppejan, 2002).

Gasification is also a route towards large co-firing shares of existing (coal-fired) power plants, avoiding the need for additional solid fuel feeding lines and allowing for better control of the combustion process. Successful deployment of (A)CFB gasifiers is recently shown in co-firing schemes (e.g. Lahti in Finland and Amer in the Netherlands) (van Loo and Koppejan, 2002). An interesting alternative application for producer gas from biomass gasification is to use it for co-firing in existing (or new) natural gas fired combined cycles. In this way, economies of scale are utilized resulting at in low cost and (very) high overall efficiencies (currently up to 60% for NG fired combined cycles), combined with a secure fuel supply since one can vary the share of fuel gas and natural gas fired (Rodrigues et al., 2003). So far, this option has not been demonstrated anywhere in the world, but research efforts are increasing and it could prove to be of major importance on short term given that co-firing opportunities at existing coal-fired power plants are increasingly utilised already.



(1) **(2)** **(3)**

Fig. 3.6: Three options of biomass co-firing: 1) direct co-firing; 2) Indirect co-firing; and 3) Parallel co-firing.
Source: Leckner (2007) Zuwała (2007)

3.2.3.2 Advantages and Drawbacks of Modern Technologies

Suspension-fired boilers have high combustion efficiencies, but require considerable fuel pretreatment (drying and pulverizing) to meet their strict fuel conditions, whereas fluidized bed systems have relatively high efficiencies and are also flexible with regards to fuel. An obvious advantage of fluidized bed systems over other systems is that they form less thermal NO_x, which will often mean that further NO_x removal is superfluous. In gasification state, the particle size and shape of the biomass feedstock affects the rate of gasification as it is related to volatile matter release. The irregular shape of wood chips would increase the retention time required to fully convert it into gas (Lim and Alimuddin, 2008). From literature reduced biomass particle size would increase the gasification rate, however, the output particle from the grinding mill and the fluidized bed material should have similar properties especially particle size to avoid elutriation (air classification) before reaction to the biomass particle even begins.

The major operational difficulty experienced with FB gasifiers is the potential for the slagging of the bed material due to the ash content of the biomass. Of particular importance is the alkali metal content of the biomass, which is a problem with biomass derived from herbaceous annual plants. To avoid slagging, the bed temperature can be lowered, but these results in an increased loss of char with the ash removed (McKendry, 2002a). Table 3.9 shows the comparison between gasifiers, while table 3.10 shows the variables of these gasifiers. For biomass co-combustion/co-firing, the magnitude of these implications depends on the quality and percentage of biomass in the fuel blend. The overall result is that operating and maintenance costs may increase, but this can be reduced or even avoided with appropriate fuel blend control: 1) the possibility for increased slagging and fouling on boiler surfaces when firing high-alkali herbaceous biomass fuels such as switchgrass, and 2) the potential for reduced fly ash marketability due to concerns that commingled biomass and coal ash will not meet existing ASTM fly ash standards for concrete admixtures, a valuable fly ash market.

Table 3.9: Comparison of selected gasifiers

Gasifier types	**Gasifier characteristics**	**Demands on fuels**
Co-current gasifier	High pure gas Low tar contents	Demand a great deal of burning fuel of humidity and grain size
Counter current gasifier	High in tar and dust at burning gas High efficiency Easy to regulate	High humidity No demands on homogeneity of inputs
Circulating Fluidized bed	Increased mass transfer and heat exchange High investment costs High in tar and dust at burning gas Problems with part load	Humid burning fuels applicable Input can be high in ash Grain size high limited No demands on homogeneity of input
Fixed Fluidized bed	Increased mass transfer and heat exchange High investment costs High in tar and dust at burning gas Problems with part load Very high investment costs	Humid burning fuels usable High ash value at inputs possible Grain size high limited No demands on homogeneity of input

Source: Osowski et al. (2003b)

Table 3.10: Variables of selected gasifiers

	Co-current	**Counter current**	**CFB**	**Stationary FB**
η Plant,el (%)	Approx. 25	15–30	20–30	25–28
η tot (%)	<90	<75	75–80	Approx. 85
Capacity (MW_{th})	0.05–0.5	0.5–10	5–100	0.5–20
Scale-up	Meanly	Moderate	Very well	Well
Particle size	5–50 mm	Dispensable	Up to 20 mm	Up to 40 mm
Humidity	<25%	<50%	<50%	<50%
Homogeneity	Essential	Dispensable	Dispensable	Dispensable
Purity of gas	Well	Meanly	Moderate	Moderate
Tar content	Very low	Very high	Low	Moderate
Dust content	Moderate	Moderate	High	Very high
Development status	Commercial use	Commercial use	Pilot stage	Pilot stage
Profitable	<5 MW_{th}	<10 MW_{th}	>1 MW_{el}	>2.5 MW_{el}

Source: Osowski et al. (2003b).

3.2.3.3 Economics Aspect of Modern Technologies

Power generation from biomass by advanced combustion technology and co-firing schemes is at present the real growth market worldwide. Mature, efficient, and reliable technology is available to turn biomass into power. In various markets the average scale of biomass combustion schemes rapidly increases due to improved availability of biomass resources and the economic of scale. It is also in this field that competitive performance compared to fossil fuels is possible where lower cost residues are available. This is in particular true for co-firing schemes, where investment costs can be minimal. Specific (national) policies (such as carbon taxes, renewable energy support, e.g. by direct investment subsidies or feed-in tariffs) accelerate this development. Gasification technology (integrated with gas turbines/combined cycles) offers even better perspectives for power generation from biomass on medium term, and can make power generation from energy crops competitive in many areas in the world once this technology has been proven on commercial scale.

Gasification (in particular larger scale CFB concepts) also offers excellent possibilities for co-firing schemes. The FBC technology can be considered as a mature technology for cogeneration and industrial sized applications. The most important areas (in order of importance) for FBC used in industrial applications are materials' handling, environmental control technology, and boiler reliability. BFB technology is well suited to smaller industrial applications as well as to the combustion of waste materials. The CFB variant is derived from the BFB technology and surpasses its predecessor in terms of sulphur removal, efficiency, and scale. The application of CFB has changed over time, as the capacity of the installation steadily increased. The result is that it has developed from industrial applications to utility applications (Koornneef et al., 2007).

3.2.3.4 Environment Aspect of Modern Technologies

Initially, co-firing was seen as a means for reducing GHG emissions from fossil energy generation, when power plants voluntarily combusted some biomass fuel as an environment friendly gesture. Today, co-combustion is an industrial practice. It is now an accepted fact that these savings come not only from displacement of coal, but also from displacement of materials being sent to landfill that ultimately decompose and form both CO_2 and another, more powerful GHG gas, CH_4 (Hughes and Benemann, 1997). Additionally, it also reduces problems that occur in biomass gasification associated with the production of tar. Therefore, governments in different developed countries are taking increasing interests and regulations and incentives have been put together to increase the biomass share in co-firing. Co-firing residue biomass at 15% by heat input reduces the greenhouse gas emissions and net energy consumption of the average coal system by 18% and 12%, respectively (Khan et al., 2009). Thermal NO_x increases with rising temperature, N_2 concentration in the flame, O_2 concentration, and gas residence time. CFB and BFB operate at relative low temperatures resulting in virtually no formation of thermal NO_x.

3.2.3.5 Problems and Barriers of Modern Technologies

As for FBs, ash contents of alkali metals in biomass are especially detrimental as agglomeration leads to abrupt shutdowns. Although different remedies including extracting these problematic elements from fuel to different bed additives and use of different bed material (agglomeration) have been suggested and successfully implemented at few units, however, methods need to be improved and new additives need to be found to handle harmful and hazardous compounds out of biomass. Especially extensive research needs to be carried out to find additives/other bed materials to avoid bed agglomeration problems for FBs (Khan et al., 2009; EUBIONET, 2003). Future technology development of BFB is likely to be limited to ensuring fuel flexibility on existing designs for the increasing use of biomass or waste as feedstock with, or instead of, coal. Ensuring a firm market share in the niche market of small and cogeneration units seems to be the most viable option for BFB technology. Contrary to CFB, there are no major industrially focused international R&D projects under way for BFB (Koornneef et al., 2007). The main problems in co-firing are the feeding and control of the boiler. Although combustion technology works properly, mixing homogeneity is difficult to attain. Mixing is a problem because biomass physical properties vary within a great range. Feeding stability is difficult to achieve because of bulk density heterogeneity, amongst other reasons. Waste with high alkaline metals content (straw for example) that promotes high metal corrosion constitutes a further difficulty in co-firing. Greater boiler control is required to maintain efficiency and emissions when different fuel mixes are used (Granada et al., 2006).

3.2.4 Future Technologies

3.2.4.1 Processes and Concepts of Future Technologies

In this category of technologies for heat/electricity production, the technologies feature prominently in the solutions of process efficient and environmental problems, along with offer high-energy conversion. They include advance technology (PFBC, PFBG, EF Gasifiers, and Fuel Cell), cogeneration (STIG & ISTIG), and combined cycle (IGCC). However, these technologies are generally immature, unavailable, or only in demonstrated stage.

3.2.4.1.1 Pressurized Fluidized Bed Combustion (PFBC)

In contrast to AFBC (see Ch. 3.2.3.1.2), PFBC operates at elevated pressures, therefore are typically more compact than similar capacity AFBC. The PFBC design allows for potentially greater efficiency, reduced operating cost, and less waste than the AFBC design. PFBC plants use the same process as AFBC plants to fluidize or float the fuel/sorbent mixtures. In both AFBC and PFBC plants, the reacted sorbent forms a dry and granular material that is easily disposed of or used as a commercial byproduct. The reacted sorbent is removed with the bed ash through the bottom of the boiler and with the fly ash that has been gathered in the dust collectors at the top of the boiler stacks. In PFBC plants, additional energy is captured when the combustion gases that leave the fluidized bed are cleaned in a gas cleanup system and then re-burned in a gas turbine. The gas turbine is connected to an electrical generator thereby improving the plant's efficiency. The use of a steam turbine and a gas turbine improves performance by creating a highly efficient combined cycle system (Wong, 2006).

PFBC is normally operated at a pressure of 6 to 16 atmospheres. Due to the pressurized conditions and the more efficient steam production, the combustion chamber of a PFBC is generally one third the size of a conventional furnace. The pressurized gases existing the combustor are then expended in a gas turbine to generate electricity and passed through an economizer to preheat the feedwater for the steam turbine cycle before being discharged to the ambiance. The steam that is generated by the tubes immersed in the FFBC is expanded in a conventional steam turbine to produced additional electric power (NETL, 2000). The 1st-generation PFBC system also uses a sorbent and jets of air to suspend the mixture of sorbent and burning fuel during combustion, but these systems operate at elevated pressures and produce a high-pressure gas stream at temperatures that can drive a gas turbine. Generated steam is sent to a steam turbine, creating a highly efficient combined cycle system.

3.2.4.1.2 Pressurized Fluidized Bed Gasification (PFBG)

For power production in relatively large-scale application (> 5 MW_e), gas turbines are the preferred prime movers since. When used in a gas turbine, the producer gas has to be fed into the combustor at high pressures (10 to 25 bar, depending on the gas turbine design) (Quaak et al., 1999). As a consequence, the hot producer gas from an atmospheric gasifier has to be cooled and compressed resulting in a high level of internal power consumption in such concepts. The cooling of the gas is necessary because: 1) the temperature of the gas increases during compression; 2) the temperature resistance of compressors is limited; and 3) hot gases take large volumes and addition work is needed for compression. Both pressurized and atmospheric gasifiers are currently used in designs of advanced biomass gasification shemes.

The alternative is to gasify under pressurized conditions (see Fig. 3.3), delivering producer gas at the pressure of the gas turbine combustor. The advantages of this approach are: 1) low level of internal power consumption; 2) higher methane content of producer gas; 3) compact design implying low specific investment costs; and 4) decrease of sintering behaviour of the ash. The drawbacks are: 1) fuel feeding into the gasifier is complex; 2) the need for high temperature producer gas cleaning devices. This technology is still under development; 3) due to the complexity of the installation, the specific investments will be high for low capacity installations (Quaak et al., 1999).

3.2.4.1.3 Entrained Flow Gasifiers (EF)

Entrained Flow Gasifiers are commonly used for coal because they can be slurry fed in direct gasification mode, which makes solid fuel feeding at high-pressures inexpensive. Recently, EF gasifiers are taken more serious to be used for biomass fuels as well. In EF gassifers, small fuel particles (< 100 μm) are pneumatically fed at the top of the gasifier and injected in a burner for optimum mixing with steam/oxygen. EF gasifiers are further characterized with short residence time (about 1 s), high temperatures (1,300 to 1,600 °C), high pressures (25 to 60 bar), and large capacities (> 100 MW). There are several commercial designs available for coal (Shell, Destec, Kellogg, Lurgi, Texaco, Krupp-Uhde, and Noell), but these will not work with more than 10 to 15% biomass in a coal blend. This principal slurry feeding benefit can not be afforded to biomass due to its high porosity (lower energy density) and moisture holding capacity in slurry phase. Since 2000, experiments of solid biomass with coal EF gasifiers have been condected at Buggenum, the Netherlands and Puertollano, Spain, while liquid bio-oil has been used at oil-fired EF gasifiers at Future Energy and Choren, Germany. For feeding solid fuels at high pressures relative expensive lock hoppers have to be used, while for liquid fuel simple pumps can be used (Higman and van der Burgt, 2003).

3.2.4.1.4 Steam-injected gas turbine (STIG)

Industrial cogeneration is gaining popularity as an energy and money saving alternative to separate steam and electricity generation. Among cogeneration technologies, gas-turbine systems are attractive largely because of their lower capital cost and high thermodynamic efficiency. However, at industrial plants where steam and electricity loads vary daily, seasonally, or unpredictably, the economics of conventional gas turbines are often unfavourable due to low capacity utilization. STIG cogeneration overcomes the part-load problem by providing for excess steam to be injected back into the turbine (Fig. 3.7) to raise electrical output and generating efficiency (Weston, 1992). Water injection has been used for many years for brief augmentation of the thrust of jet engines. More recently, liquid water injection and steam injection have been used to control the formation of NO_x in gas turbine. Injection of water or stream into the combustion chamber reduces the combustion temperature. Power output is maintained or extended, because the injection increases both the turbine mass flow and the energy extraction by the turbine. The latter is possible because the heat capacity of steam is almost twice that of normal combustion products. Thus the enthalpy change of steam for a given temperature drop is about double that of air or combustion gas. If water is injected as a liquid, additional energy must be extracted from the combustion gas to vapourize the water (Bouam et al., 2008; Ansari, 1998).

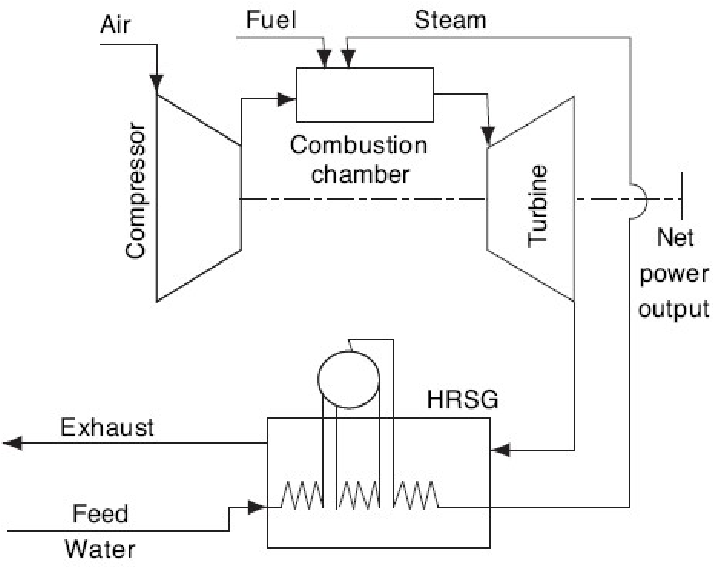


Fig. 3.7: Steam injected gas turbine.
Source: Bouam et al. (2008)

The STIG systems operate as an enhancement to the Brayton cycle. High quality steam is used to increase the power output and improve operating efficiency of the basic Brayton cycle. Typically produced by an auxiliary steam boiler, external steam source, or external process source, steam is then injected into the combustion chamber of the gas turbine. The place where this steam is injected differs according to the design of the particular gas turbine, but basically high pressure steam is injected into the high-pressure sections of the gas turbine via the combustor fuel nozzles and compressor discharge plenum. In its most basic form, steam injection works by increasing general mass flow through the gas turbine. The increased mass flow generates an increase in the rotational torque and power output. The amount of steam injected into the combustor can vary at a rate of 2 to 10%. The main benefits of STIG are an increase in power output, a decrease in NO_x emissions from the gas turbine, and a reduction in base fuel consumption. The major components of STIG (Fig. 3.7) are: 1) the gas turbine and generator set, 2) water treatment plant, and 3) steam source. Each component must be engineered to best match the application and its particular needs (Koivu, 2007; Fagbenle et al., 2007).

3.2.4.1.5 Intercooled steam-injected gas turbine (ISTIG)

A modification of the steam-injected gas turbine is ISTIG, in which steam is injected into compressor bleed air for turbine cooling, together with steam injection into the combustor and into one or more turbine stages (Fig. 3.8). The enhanced blade cooling allows increased turbine inlet temperature and further power and efficiency increases. The reference predicts efficiencies for ISTIG turbines better than for existing combined cycles and comparable to advanced combined cycles. The STIG technology has been investigated for the cane sugar industry, with the residues of sugar cane production and processing to be used as fuel. The study highlighted the plant as having good prospects for cogeneration in the cane sugar industry. Thus STIG and ISTIG show great promise for cogeneration applications and are likely to find their way into future power generation plans (Fagbenle et al., 2007; Weston, 1992; Willams, 1992).

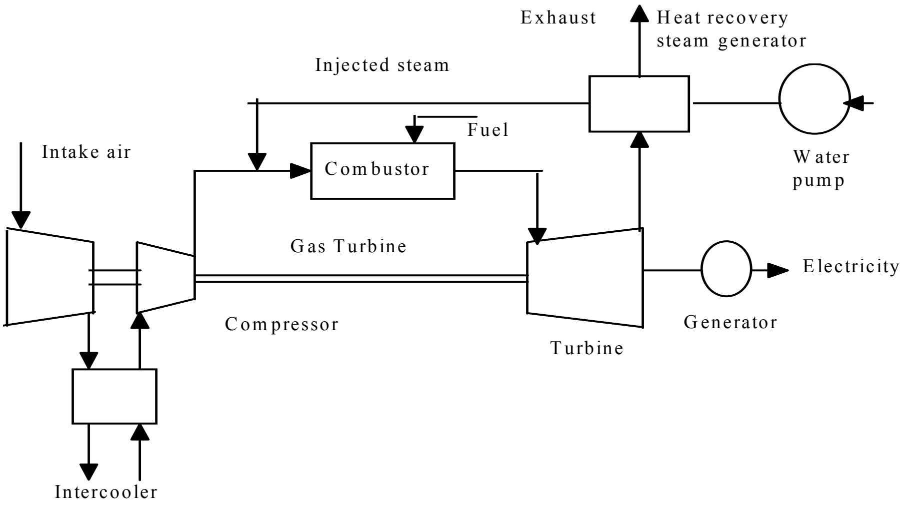


Fig. 3.8: Intercooled steam-injected gas turbine
Source: modified from Williams and Larson (1996)

3.2.4.1.6 Integrated gasification combine cycle (IGCC)

An advanced cycle, the IGCC process is a two-stage combustion with cleanup between the stages. The first stage employs the gasifier where partial oxidation of the solid/liquid fuel occurs by limiting the oxidant supply. The second stage utilizes the gas turbine combustor to complete the combustion of the syngas from the first stage (Fig. 3.9). This process optimizes the gas turbine/combined cycle (GT/CC) technology with various gasification systems. The syngas produced by the gasifiers, however, needs to be cleaned to remove the particulate, as well as wash away sulphur compounds and NO_x compounds before it is combusted in the Gas Turbine. ***It is the Integration of the entire system components which is extremely important in an IGCC Plant.*** Recent advances in the Gas Turbine technologies have presented great potential towards much higher gas turbine efficiencies. Increasing the firing temperatures and utilizing materials that withstand higher temperatures can increase the efficiency of gas turbine. Continuous developments have been taking place in the newer materials of construction thus consequent higher gas turbine performance. At present the efficiency of gas turbines is in the range of 45 to 50% which is projected to go upto 60% with the development of H-technology by GE. The advances in gas turbines would improve the overall efficiency of IGCC plant. The first integrated gasification combined cycle (IGCC) running on 100% biomass (straw) has been successfully operated in Sweden (Jalkote, EA-0366)

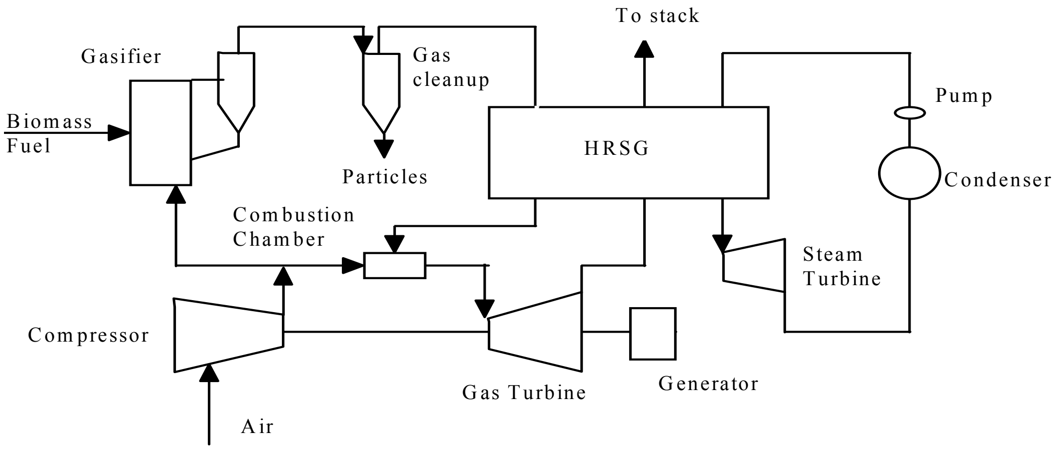


Fig. 3.9: Integrated gasification combined cycle
Source: modified from Krigmont (1999)

3.2.4.1.7 Fuel Cell

Hydrogen (H_2) is not a primary fuel, but it can be burned to produce heat or passed through a fuel cell to generate electricity. Fuel cells have no moving parts, produce only clean water as emissions, and are about 70% efficient (compared with only 45% of the highest efficient internal combustion engine) (Demirbas, 2008). H_2 is currently most economically produced from natural gas, about half of the world's production (Carere et al., 2008). Apart from biological production (Levin et al., 2004), H_2 can be also produced from biomass via two thermo-chemical processes: 1) gasification followed by reforming of the syngas, and 2) fast pyrolysis followed by catalytic steam reforming of the carbohydrate fraction of the bio-oil. In each process, **W**ater–**G**as **S**hift (WGS) is used to convert the reformed gas into H_2, and pressure swing adsorption is used to purify the product. The yield of H_2 from ***Supercritical Fluid Extraction*** was considerably high (49%) at lower temperatures. The pyrolysis was carried out at the moderate temperatures and steam gasification at the highest temperatures. Compared with other biomass thermo-chemical gasification such as air or steam gasification, the supercritical water gasification can directly deal with the wet biomass without drying, and have high gasification efficiency in lower temperature. There are two types of steam reformers for small-scale H_2 production: conventional reduced-scale reformers and specially designed reformers for fuel cells. For the production of high purity H_2, the reforming of fuels is followed by two water gas-shift reaction steps, a final CO purification and CO_2 removal. The yield of H_2 from biomass is relatively low, 16 to 18% based on dry weight. At present, the amount of bio-oil available for reforming is rather limited, but a viable way to increase the production of H_2 in a biomass-based plant could be co-reforming of bio-oil with natural gas (Czernik et al., 2001).

3.2.4.2 Advantages and Drawbacks of Future Technologies

Biomass gasification technologies have reached the point where the first simple applications with minimal technical risks are becoming commercial. STIG technology offers a clear improvement over the Brayton cycle while providing a fully flexible operating cycle by introducing steam injection in a gas turbine an efficiency gain of about 10 points and a power augmentation of about 50-70% are possible. Thermal potential of exhaust gas can be used for steam production by a waste heat recovery boiler, however contrary to cogeneration units steam is used not as heat-transfer agent but is supplied to gas turbine as additional working media for mechanical power augmentation of the gas turbine (De Paepe and Dick, 2001). Moreover, most gas turbine vendors offer a standard kit that is suitable to convert their turbines to accept steam injection from an external source. This variation of the STIG can raise both thermal efficiency (from 47% to 50%) and shaft power output. An advanced form of the STIG is the ISTIG. In BIG-ISTIG (Biomass Integrated Gasifier-Steam Injected Gas turbine), steam is recovered from exhaust heat and injected back into the gas turbine. In this way, more power can be generated from the turbine at higher electrical efficiency. IGCC systems are extremely clean, and are much more efficient than traditional combustion systems.

3.2.4.3 Economics Aspect of Future Technologies

No company is presently developing pressurized systems for downdraft, updraft, cyclonic, and entrained bed gasifiers using biomass feedstock due to the inherent problems of scale, tar removal, and cost. PFBG systems, either PCFBG or PBFBG, have medium market attractiveness due both to the complex installation and to higher costs of all pressurized vessels. However, PFBG systems have the advantage in integrated combined cycle applications as the need to compress the fuel gas prior its utilization in the combustion chamber of the gas turbine is avoided (Maniatis, 2001). Pressurized Bed systems are often used with oxygen as the oxidant to improve the gas quality. There is, however, a significant energy and financial cost associated with the use and supply of oxygen, from both its procurement and the additional measures needed to mitigate hazards in handling and use. An economic advantages study of STIG turbines for utility use relative to the combined-cycle power plant has shown combined cycles to be superior in unit sizes above 50 MW. However, utilities are becoming increasingly interested in plants of 50 MW or less because of their small size and quick availability. Fuel Cell technology is not commercially proven as yet. The latest efforts are being made to decrease costs in order to compete with the proven technologies like gas turbines and reciprocating engines. Some of these technologies are expected to be commercialized before 2010 (COGEN3, 2003).

3.2.4.4 Environmental Aspect of Future Technologies

A major disadvantage of steam injection is that the cycle consumes water. The injected steam is lost to the atmosphere through the stack. The water used for the production of the injected steam has to be of high quality, to protect the steam generator and the turbine blades. The loss of this water results in an extra exploitation cost which, according to Tuzson (1991) is about 5% of the total fuel cost of the installation. For fuel cells, hydrogen has the potential to solve two major energy problems: reducing dependence on petroleum and reducing pollution and greenhouse gas emissions (Demirbas, 2008).

3.2.4.5 Problems and Barriers

Gasification of biomass offers some important potential advantages over gasification of fossil fuels, such as a high concentration of H_2 in the gas produced, but there are many problems associated with the complex chemistry and wide range of properties of the feedstock. The currently achievable quality of raw gas is below the requirements for H_2 supply, although it is adequate for electricity generation. Even with the best-controlled and most favourable feedstock, a gas cleaning/conditioning system is essential for H_2 production. The technical complexity of the gas cleaning means that larger-scale operation is needed for H_2 production that for power generation. Only biomass gasification for H_2 production on a large scale is at present conceivable. ***The problem*** with fuel cells is that realistic, cost-efficient mass production of H_2 is years away. IGCC plants are already economically competitive in CHP mode using black-liquor from the pulp and paper industry as a feedstock, but Integrated Gasification Fuel Cell (IGFC) plants still need significantly more R&D.

3.3 Biofuel Production

Predominantly conversed from biomass, ***biofuel***[30] is denoted here fuels for transport sector which shares about 18% of the primary energy consumption worldwide. The introduction of biofuels into the energy market would be chiefly key for the transportation sector. Biofuels have been lumped into first, second, and third generational categories. The key challenge for developing biofuels is acquiring economical feedstock, when feedstock cost contributes 80 to 90% of the final fuel price for most processes. Currently crops generating starch, sugar, or oil are the basis for transport biofuel production. ***The first generation*** biofuels are in our fuel tanks today. As being the culprit behind rising food prices, they are created largely from feedstocks that have traditionally been used as nourishment such as corn for ethanol and soybeans for biodiesel. Caused by limited quantities of low-cost feedstocks, the first generation biofuels have nearly reached their maximum market share in the fuels market (Gomez et al., 2008). For ***the second generation***, feedstocks consist of the residues or left-overs from crop and forest harvests. They show much promise for near-term adoption with advanced technical processes, but market accessibility and acceptance are hurdles that need to be addressed. Cellulosic ethanol is the most developed second-generation biofuel (Gomez et al., 2008). ***The third generation*** biofuels, like the second ones, are conversed from nonfood feedstocks, but the resulting fuel is indistinguishable from its petroleum counterparts. These fuels are also known as advanced biofuels or green hydrocarbons. Feedstocks are crops which require further R&D to commercialize, such as perennial grasses, fast growing trees, and algae. Several technological and economic challenges exist to bring them to the market. All together, biofuels currently provide over 1.5% of the world total transport fuels (34 MTOE in 2007) (see also Fig. 3.10). The cost of biomass varies according to type and region. Caused by its environmental merits, the share of biofuel in the automotive fuel market will grow fast in the next decade. Electric vehicles are being developed by several automobile manufacturers and hydrogen fuel cells have been demonstrated, but it will be many years before either of these technologies could surpass the classical **I**nternal **C**ombustion **E**ngines (ICEs).

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[30] In practice, it is impossible to convert all the energy in the biomass into a fuel just as it is impossible to convert all the energy in crude oil into gasoline and diesel fuels. Furthermore, although a number of other renewable options for sustainable electricity and heat production are available such as solar, wind, and hydroelectric, plant biomass is the only current renewable source of carbon that can be used directly for liquid fuels and chemicals. However, some current biomass technologies have been criticized because they have low overall thermal conversion efficiencies, in which only a small part of the energy in the plant is converted into the final fuel product (Huber et al., 2006).

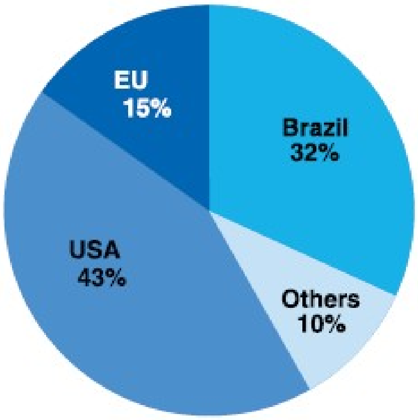

Fig. 3.10: Proportion of global production of liquid biofuels in 2007
Source: SCOPE policy brief 2009 cited by Bringezu et al. (2009)

Liquid biofuels being considered world over fall into the following categories: 1) bioalcohols (see Ch. 3.3.1.3, Ch. 3.3.2.4); 2) vegetable oils and biodiesels (see Ch. 3.3.1.2, Ch. 3.3.2.2); and 3) biocrude and bio-synthetic oils (see Ch. 3.3.2.3, Ch. 3.3.3.1) . They may be pure (100%) biofuels for dedicated vehicles or blend fuels in such a proportion that they can substitute conventional motor fuels without affecting car performance. Two of the alcohols (***biomethanol*** and ***bioethanol***) are technically and economically suitable as fuels for the ICEs. Pure ***vegetable oil***, however, cannot be used in direct-injection diesel engines, such as those regularly used in standard tractors, since the vegetable oil cooking occurs after several hours of use. ***Bio-oils*** are liquid or condensable gaseous fuels made from biomass via biochemical or thermo-chemical processes. They can substitute conventional fuels in vehicle engines, either totally or partially in a blend. Pyrolysis can be used for the production of bio-oil, if flash pyrolysis processes - currently at pilot stage - are used (Demirbas A., 2008).

3.3.1 The First Generation of Biofuels

The first generation biofuels refer to the fuels that have been derived from sources like starch, sugar, animal fats, or vegetable oil. This oil is normally obtained by using the conventional techniques of production. Some of the most popular types of first generation biofuels are discussed in this topic, including Pure Vegetable Oil, FAME/Biodiesel, and Bioethanol.

3.3.1.1 Pure Vegetable Oil

These kinds of oil can be either used for cooking purpose or even as fuel. The main fact that determines the usage of this oil is the quality. The oil with good quality is generally used for cooking purpose. It can be also utilized as for lubricants and raw materials for soap, detergents, cosmetics, and chemicals. From the more than 350 known oil-bearing crops, those with the greatest potential for fuel production, according to Peterson, are sunflower, safflower, soybean, cottonseed, rapeseed, canola, corn, and peanut oil. Additionally, the oil can be also produced from aquatic biomass such as algae (see Ch. 3.3.3.2) too. Pure vegetable oils are chemically ***triglycerides***[31] molecules in which three fatty acids groups are esters attached to one glycerol molecule (see also table 3.11). Vegetable oils have a higher heating

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[31] Triglycerides are found in the plant and animal kingdom and consist of water insoluble, hydrophobic substances that are made up of one mole of glycerol and three moles of fatty acids (Sonntag, 1979).

value of approximately 40 MJ/kg. Several attempts have been made to apply vegetable oils directly in diesel engine since the World War II. They can be used as fuels for diesel engines somehow necessity on engine modifications, because their viscosities are much higher than that of usual diesel fuel. It has been observed that the straight vegetable oils when used for long hours tend to choke the fuel filter because of high viscosity and insoluble present in the straight vegetable oils. Although vegetable oils from renewable oil seeds can be exploited when mixed with diesel fuels, in many countries vegetable oil is mainly used for the production of biodiesel (Demirbas, 2008).

Table 3.11: Chemical composition of Fatty Acids in Vegetable oils

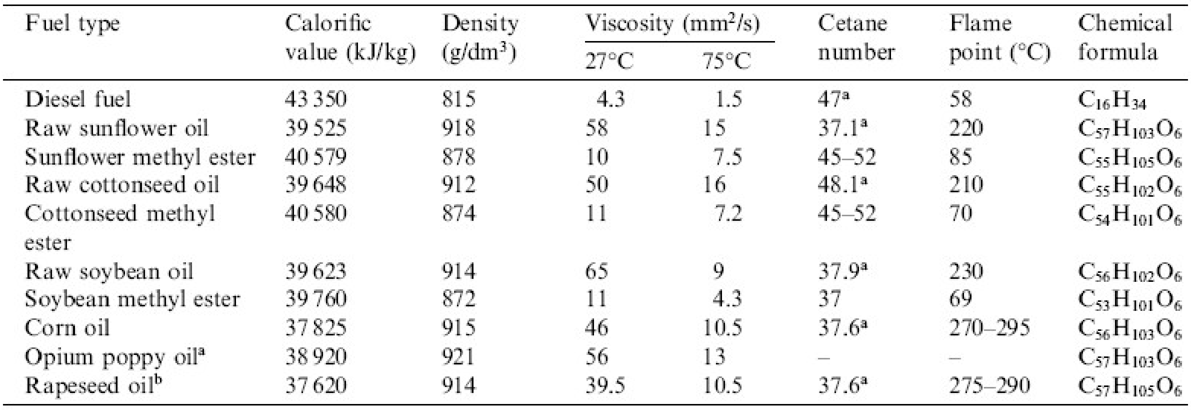
Vegetable oil	Fatty acid composition (wt%) (no. of carbons: C=C bonds)										Iodine value	Sapon value
	8:0	**10:0**	**12:0**	**14:0**	**16:0**	**18:0**	**18:1**	**18:2**	**18:3**	**22:1**		
canola					1.2-6	1-2.5	52-66.9	16.1-31	6.4-14.1	1-2	110-126	188-193
coconut	4.6-9.5	4.5-9.7	44-51	13-20.6	7.5-10.5	1-3.5	5-8.2	1.0-2.6	0-0.2		6-12	248-265
corn				0-0.3	7-16.5	1-3.3	20-43	39-62.5	0.5-13.5		103-140	187-198
cottonseed				0.6-1.5	21.4-26.4	2.1-5	14.7-21.7	46.7-58.2			90-119	189-198
olive			0-1.3	7-20	0.5-5.0	55-84.5	3.5-21				75-94	184-196
palm		0-0.4	0.5-2.4	32-47.5	3.5-6.3	36-53	6-12				35-61	186-209
peanut				0-0.5	6-14	1.9-6	36.4-67.1	13-43		0-0.3	80-106	187-196
rapeseed				0-1.5	1-6	0.5-3.5	8-60	9.5-23	1-13	5-56	94-120	168-187
soybean					2.3-13.3	2.4-6	17.7-30.8	49-57.1	2-10.5	0-0.3	117-143	189-195
sunflower					3.5-7.6	1.3-6.5	14-43	44-74			110-143	186-194
tallow (beef)				2.1-6.9	25-37	9.5-34.2	14-50	26-50			35-48	218-235

Source: Adapted from Knothe et al. by Huber et al. (2006)

3.3.1.1.1 Process and Technology of Pure Vegetable Oil

The first step in the production of vegetable oils is extraction of the oils from the plant. A pretreatment step that involves cleaning, drying, and dehulling must be done prior to extraction. The oils are then extracted by one of these three methods: hydraulic pressing; expeller pressing; or solvent extraction (Mwithiga and Moriasi, 2007). Two main products are produced in this process: vegetable oil and the dry solid residue known as meal. The meal has a high amount of protein and is used as a protein supplement for animal feeds. In general, the viscosity of vegetable oil is higher than that of diesel oil by many folds. Its high viscosity made it more difficult to be exploited in diesel engine dilrectly, especially in a cool season. It resulted in the difficulty to ignite and unable to run at low speed (see table 3.12 for comparison between various vegetable oils with diesel). In additional, it was found to have incomplete combustion and emissions with substantial amount of burned hydrocarbon, CO, and particulate matter. Besides vegetable oils normally are unstable and tend to be oxidized and hydrolysed. Thus, vegetable oils are hardly used directly as alternative fuel for conventional diesel engine. Caterpillar Brazil, in 1980, used pre-combustion chamber engines with a mixture of 10% vegetable oil to maintain total power without any alterations or adjustments to the engine. At that point, it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% diesel fuel was successful. Some short-term experiments used up to a 50/50 ratio. Different ways have been also considered to reduce the viscosity of vegetable oils such as dilution, microemulsification, pyrolysis, catalytic cracking, and transesterification (Ramadhas et al., 2004; Demirbas, 2008).

Table 3.12: Physical and chemical specifications of the vegetable oil fuels used



Fuel type	Calorific value (kJ/kg)	Density (g/dm^3)	Viscosity (mm^2/s)		Cetane number	Flame point (°C)	Chemical formula
			27°C	75°C			
Diesel fuel	43 350	815	4.3	1.5	47[a]	58	$C_{16}H_{34}$
Raw sunflower oil	39 525	918	58	15	37.1[a]	220	$C_{57}H_{103}O_6$
Sunflower methyl ester	40 579	878	10	7.5	45–52	85	$C_{55}H_{105}O_6$
Raw cottonseed oil	39 648	912	50	16	48.1[a]	210	$C_{55}H_{102}O_6$
Cottonseed methyl ester	40 580	874	11	7.2	45–52	70	$C_{54}H_{101}O_6$
Raw soybean oil	39 623	914	65	9	37.9[a]	230	$C_{56}H_{102}O_6$
Soybean methyl ester	39 760	872	11	4.3	37	69	$C_{53}H_{101}O_6$
Corn oil	37 825	915	46	10.5	37.6[a]	270–295	$C_{56}H_{103}O_6$
Opium poppy oil[a]	38 920	921	56	13	–	–	$C_{57}H_{103}O_6$
Rapeseed oil[b]	37 620	914	39.5	10.5	37.6[a]	275–290	$C_{57}H_{105}O_6$

Source: Altın et al. (2001)

3.3.1.1.2 Advantages and Drawbacks of Pure Vegetable Oil

Two severe problems associated with the use of vegetable oils as fuels were oil deterioration and incomplete combustion (Peterson et al., 1983). Polyunsaturated fatty acids were very susceptible to polymerization and gum formation caused by oxidation during storage or by complex oxidative, or thermal polymerization at the higher temperature and pressure of combustion. The gum did not combust completely, resulting in carbon deposits and lubricating oil thickening. For ICEs, problems appear only after the engine has been operating on vegetable oils for longer periods, especially with direct-injection engines. The problems include (Wang et al., 2006; Ramadhas, 2004; Karaosmanoglu F., 1999): 1) coking and trumpet formation on the injectors to such an extent that fuel atomization does not occur properly or is even prevented as a result of plugged orifices; 2) carbon deposits; 3) oil ring sticking; and 4) thickening and gelling of the lubricating oil as a result of contamination by the vegetable oils. Additionally, Agarwal et al. (2007) argued that problems associated with vegetable oils during engine tests can be classified into two broad groups, namely, operational and durability problems. The first ones are related to starting ability, ignition, combustion, and performance. The rests are related to deposit formation, carbonization of injector tip, ring sticking, and lubricating oil dilution.

Table 3.13: Advantages and disadvantages of vegetable oil

Advantage	Disadvantages
1) liquid nature-portability	1) higher viscosity
2) heat content (80% of diesel fuel)	2) lower volatility
3) ready availability	3) the reactivity of unsaturated hydrocarbon
4) renewability	

Source: Pryde (1983)

3.3.1.1.3 Economic Aspect of Pure Vegetable Oil

Although oil seeds can be efficiently converted into liquid fuel, the problems with vegetable oils as feedstock are that they are more expensive than cellulosic biomass and normal diesel, and there are limited quantities. The cost of vegetable oils is slightly higher than that of diesel because of the fragmented nature of vegetable oil market. Additionally, there are several middle-men involved which increase the cost of vegetable oils. For biodiesel production, the cost of raw vegetable oils accounts about 70 to 80% of the total production cost. Therefore, the cost of vegetable oil or its derivatives is generally much more than that of diesel. When cultivation programme of vegetable oil crop is implemented under a cooperative structure, the use of vegetable oils to partially substitute mineral diesel will make economic sense by various researchers (Agarwal, 2007). Comparative study of cost for different vegetable oils, biodiesel, and mineral diesel shows that cost per unit energy produced is almost similar for all fuels. However, the data presented in the early studies clearly indicate that there are many other non-edible oils that can be the alternative feedstock for biodiesel production (Gui et al., 2008). Although the yield of oil from these non-edible oil plants is lower than oil palm, they are still comparable with rapeseed and soybean, two of the main biodiesel feedstock at the moment.

3.3.1.1.4 Environment Aspect of Pure Vegetable Oil

Apart from the comparable performance of engine running by vegetable oil, its blends, and pure diesel, the engine power output and the fuel consumption are almost the same as well. The emissions of nitrogen oxides (NO_x) from vegetable oil and its blends, at the range of tests, are lower than that of pure diesel fuel. This is the most important gaseous emission characteristic of vegetable oil and its blends. The carbon monoxide (CO) emissions from the vegetable oil and its blends are also lower than that of the diesel fuel at the engine full load; but in the cases of lower engine loads, the CO emissions are all slightly higher. The hydrocarbon (HC) emissions of vegetable oil and its blends are lower than that of diesel fuel, except in the case of 50% of vegetable blend, which is a little higher than that of diesel fuel. The results from the experiments prove that vegetable oil and its blends are potentially good substitute fuels for diesel engine in the near future when petroleum deposits become scarcer (Wang et al., 2005).

3.3.1.1.5 Problems and Barriers of Pure Vegetable Oil

To apply vegetable oils as energy source especially for automotives, the concern about food supplies is actually more realized. It is believed that large-scale production of biodiesel from edible oils may bring global imbalance in the food supply and demand market both. There is continuous increase in the production of edible oils; however, the ending stocks of edible oils are constantly decreasing due to increasing production of biodiesel. Clearly, the demand of biodiesel in the future is still increasing considerably, therefore competition of edible oil sources as food vs. fuel makes edible oil not an ideal feedstock for biodiesel production. Although edible oils (mainly palm oil) might be the cheapest feedstock for biodiesel production, it may not be a sustainable source. This arrangement ensures that biodiesel should be produced from a variety of feedstocks. With the increase in global human population, more land may be needed to produce food for human consumption (indirectly via animal feed). The problem already exists in Asia. Vegetable oil prices are relatively high there. The same trend will eventually happen in the rest of the world (Ma and Hanna, 1999).

The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation and polymerization during storage and combustion, carbon deposits and lubricating oil thickening are obvious problems. Heating and blending of vegetable oils can reduce the viscosity and improve volatility of vegetable oils, but its molecular structure still remains unchanged hence polyunsaturated character remains (Agarwal et al, 2006). Apart from blend with diesel fuel, the oil can be upgraded by other methods including zeolite upgrading and pyrolysis, but the most common way of upgrading vegetable oils to a fuel is transesterification of triglycerides into alkyl-fatty esters (biodiesel). For other problems, it can be mentioned here: 1) The price of vegetable oil is usually dependent on the feed stock price; 2) Feed stock homogeneity, consistency and reliability are questionable; 3) Homogeneity of the product depends on the supplier, feed stocks, and production methods; 4) Storage and handling is difficult (particularly stability in long term storage); 5) Continuous availability of the vegetable oils needs to be assured before embarking on the major use of it in I.C. engines.

3.3.1.2 FAME/Biodiesel

Commonly known as biodiesel, a **F**atty **A**cid **M**ethyl **E**ster (FAME) is a mixture of mono-alkyl esters of fatty acids, most often obtained from extracted plant oils or collected animal fats. Biodiesel is the most common type of biofuel used in the European countries. Now in many countries, the manufacturers of the diesel engine ensure that the engine works well even with the biodiesel.

3.3.1.2.1 Process and Technology of FAME/Biodiesel

Biodiesel is commonly produced via transesterification process in the presence of catalyst (Fig. 3.11). The purpose of this process is to lower the viscosity of the oil. Ideally, transesterification is potentially a less expensive way of transforming the large, branched molecular structure of the oils into smaller, straight-chain molecules of the type required in regular diesel combustion engines (Demirbas, 2008). Biodiesel is better than diesel fuel in terms of sulphur content, flash point, aromatic content, and biodegradability. However, it also produced slightly lower power and torque, but higher fuel consumption (Bala, 2005). Nearly all biodiesel that is currently made uses edible oil, methanol, and an alkaline catalyst[32]. The high value of edible oil as a food product makes production of a cost-effective fuel very challenging. However, there are large amounts of low-cost oils and fats such as restaurant waste (yellow greases), animal fats and trap grease[33] that could be converted to biodiesel. The problem with processing them is that they often contain large amounts of **F**ree **F**atty **A**cids (FFA), which cannot be converted to biodiesel using an alkaline catalyst (Demirbas, 2003; Canakci and Van Gerpen, 2001). The most important variables affecting the yield of methyl ester during the transesterification reaction are molar ratio of alcohol to vegetable oil and reaction temperature. Apart from reduced capital investment costs by having the crushing or esterification facility added onto an existing grain or tallow facility, the viability of a continuous transesterification process (Fig. 3.12) and the recovery of high-quality glycerol as a biodiesel by-product are primary options to be considered to lower the cost of biodiesel.

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[32] Both acid and base catalysts can be used for transesterification; however, base catalysts are 4000 times more active and cause fewer corrosion problems than do acid catalysts (Gondra, 2010).

[33] Trap grease has a zero or negative feedstock cost, but is normally contaminated with sewage components.

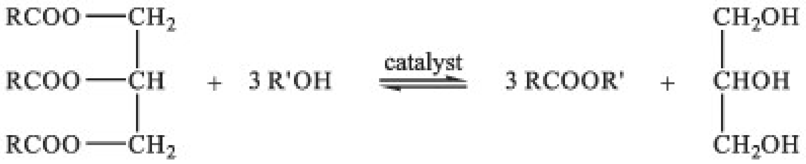

Fig. 3.11: Transesterification reaction of triglyceride.
Source: Gerpen (2005)

One parameter, which is necessary when defining general standards for biodiesel, is iodine value. It is the standard to describe and measure the degree or content of unsaturated fatty acid in vegetable oil. Iodine value is dependent only on the origin of the vegetable oil (Mittelbach, 1996; Knothe and Dunn, 2001; Lang et al., 2001). It also correlates with ***Cetane Number*** (CN), which is used to measure the fuel ignition characteristics, like the octane number on gasoline. Biodiesel from vegetable oils with low iodine value will have a higher CN while the low-temperature properties are poor (Knothe and Dunn, 2001). Mittelbach (1996) also stated the necessary of a limitation of unsaturated fatty acids due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides (esters). This can lead to the formation of deposits or to deterioration of the lubricating oil. A two-step transesterification process is reported by several researchers as the best method to produce biodiesel from non-edible oil. At the initial step, the FFA content of oil is reduced by acid-catalyzed esterification process; meanwhile, at the second step, an alkaline-catalyzed process is used to convert oil and methanol into methyl esters and glycerol. Overall process can reach up to above 90% of conversion. A novel process of biodiesel fuel production without using any catalyst has been conducted via ***Supercritical Methanol*** (SCM). In comparison to the catalytic processes under barometric pressure, purification of products from SCM is much simpler, shorter reaction time, more environmentally friendly and lower energy demand. However, the reaction requires temperatures among 252 to 402 °C and pressures with 350 to 600 bar.

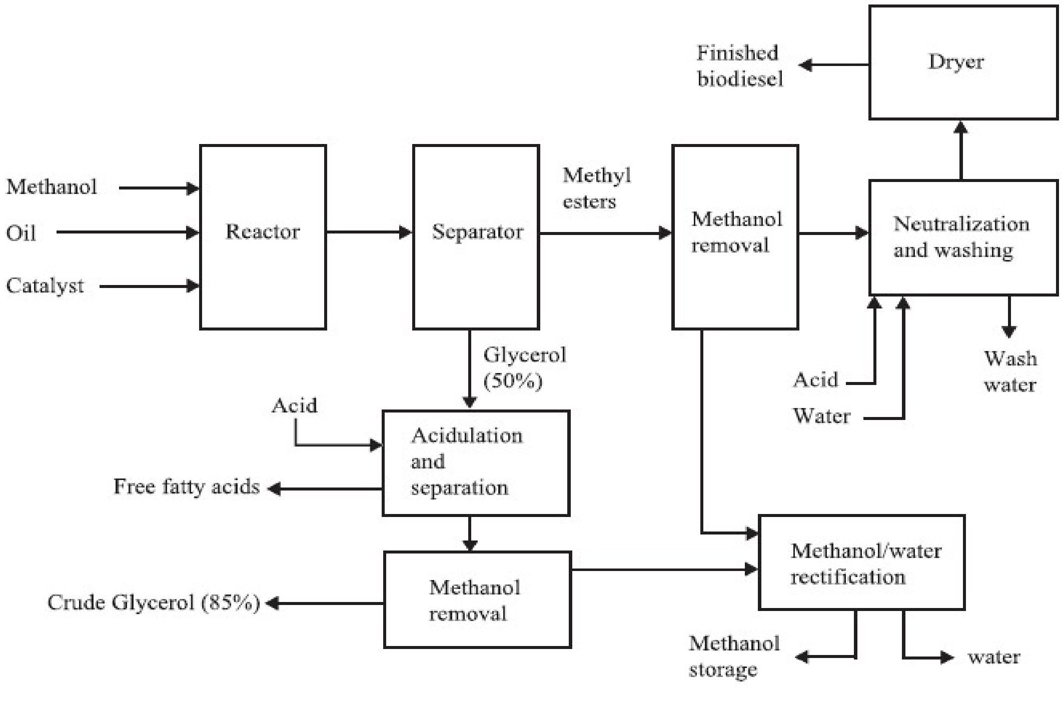

Fig. 3.12: Process flow schematic for biodiesel production
Source: Gerpen (2005)

3.3.1.2.2 Advantages and Drawbacks of FAME/Biodiesel

Biodiesel from oil seeds are produced from classic agricultural food crops that usually require high-quality agricultural land for growth. The technology for converting edible oil to biodiesel has been well established, however, the main concern for converting non-edible oil into biodiesel is always associated with the high free fatty acid (FFA) content. The properties of biodiesel can be fluctuated accordingly to the fatty acid composition in the feedstock oil which is used to produce biodiesel. In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification purposes. In those remote areas, different types of vegetable oils are available locally, but it may not be possible to chemically process them due to logistics problems (Acharya et al., 2009).

For other advantages of biodiesel production can be outlined as following: 1) It provides a market for excess production of vegetable oils and animal fats; 2) It decreases, although will not eliminate, the country's dependence on imported petroleum; 3) Biodiesel is renewable and does not contribute to global warming due to its closed carbon cycle; 4) The exhaust emissions of CO, unburned hydrocarbons, and particulate emissions from biodiesel are lower than with regular diesel fuel. Unfortunately, most emissions tests have shown a slight increase in oxides of NO_x; 5) When added to regular diesel fuel in an amount equal to 1 to 2%, it can convert fuel with poor lubricating properties, such as modern ultra-low-sulphur diesel fuel, into an acceptable fuel (Gerpen, 2005).

It is widely reported in EU and US that biodiesel is nontoxic, biodegradable, free of sulphur, and carcinogenic benzene. Its higher flash point makes it safer to handle, transport, and store, when compared to diesel oil. On top of that, it can be used in a conventional diesel engine without/less modification. The only barrier in its utilization as an alternative fuel is the cost. Transesterification process is relatively simple at either small or large scales and is well understood. It was believed that some general parameters, like density, CN and content of sulphur, mainly depend on the choice of vegetable oil and cannot be influenced by different production methods or purification steps (Mittelbach, 1996). Nevertheless, Lang et al. (2001) found that the density of the biodiesel is influenced by the original crude oil and the refining steps to make the product. However, recently, the results of many researches reported on some improvement in CN of original vegetable oils after transesterified to biodiesel (Knothe and Dunn, 2001; IEM, 2001; Altin et al., 2001; Crabbe et al., 2001).

3.3.1.2.3 Economic Aspect of FAME/Biodiesel

Biodiesel production costs are made up of three major components: feedstock costs; capital costs and byproduct credits. Biodiesel feedstock (soybean oil, methanol and catalyst) is the single largest cost for biodiesel production representing over 70% of the biodiesel cost. Currently, most biodiesel fuels can only compete without subsidies, when crude oil prices are high and vegetable oil commodity prices are low. Indeed, increases in the price of vegetable oils (91% between 2004 and 2007) have seriously undermined biodiesel profitability. Since there is limited opportunity to further reduce costs - subsidies or tax exemptions, etc. are therefore currently imperative at this stage - although a progressive phasing out could be envisaged in the future. A high efficient and flexible biodiesel production process technology should be selected. Profitable markets with secured take-off conditions need to be identified. A supportive national legal framework should be established to secure long term production and industrial profitability. The co-product, glycerol, needs to be recovered because of its value as an industrial chemical such as CP glycerol, USP glycerol, and dynamite glycerol. Glycerol is separated by gravitational settling or centrifuging. Although biodiesel cannot entirely replace diesel fuel, there are at least five reasons that justify its development (Meyer, 2008).

3.3.1.2.4 Environment Aspect of FAME/Biodiesel

When blends of biodiesel and diesel are used in diesel engines, a significant reduction in hydrocarbons (HC) and particulate matter (PM) are observed, but NO_x emissions are found to have increased. For GHGs emission, relatively few studies exist for palm oil, with much depending on the land used to grow plantation, and the land-use change implications. Significant GHG savings can occur if the plantation is grown on already cultivated land, but if forest has to be cleared before planting or peatland destroyed, then there can be very significant increases in emissions (Sims et al., 2008). For biodiesel from rapeseed oil, if the IPCC reference values for nitrogen release are used and the energy allocation method applied, a GHG improvement of between 40 to 55% under European conditions seems a reliable and robust result (see Fig. 3.15). A life cycle analysis of biodiesel is shows in Fig. 3.13.

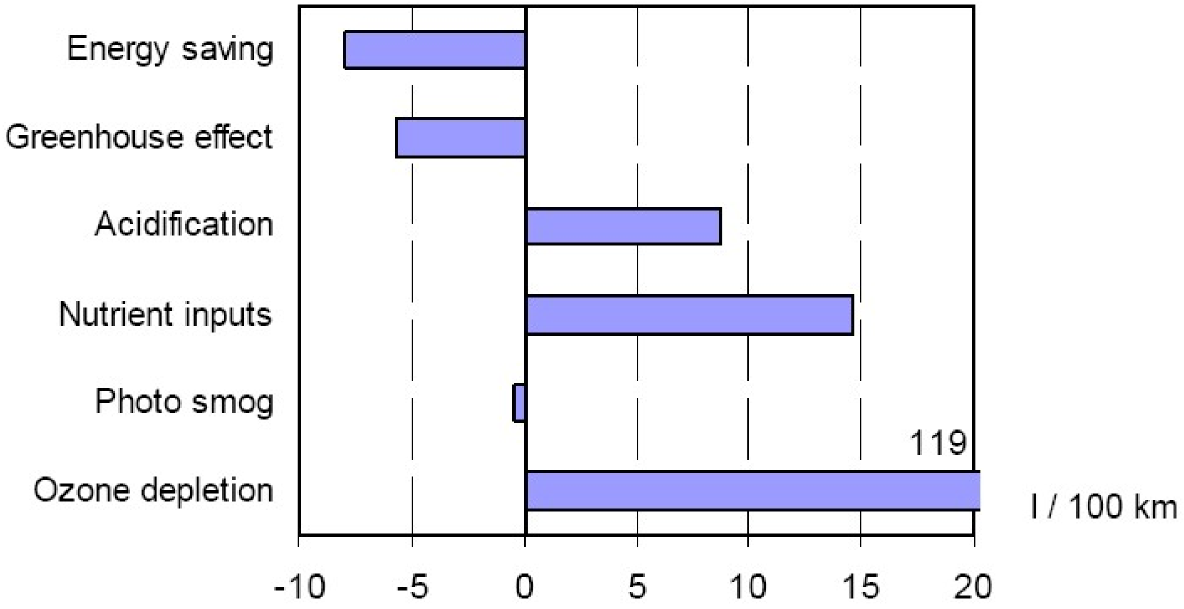

Fig. 3.13: Environmental impacts for the life-cycle assessment of biodiesel from rapeseed vs. diesel fuel, standard utilization options. Negative values are advantages for biodiesel.

Source: Braschkat et al. (2003)

From the life cycle analysis of biodiesel, it can be seen that future work on biodiesel production should focus first on developing high-yield crops that have small amounts of energy inputs and improving the refining process efficiencies. Research is ongoing to develop ***heterogeneous*** and ***enzymatic catalysts*** for esterification and transesterification, because removal of homogeneous catalysts requires further downstream processing, increasing biodiesel production cost. Heterogeneous catalysts have the advantage that they can be easily removed from the product and recycled, and current research indicates a number of promising heterogeneous catalysts for biodiesel production. Problems with current heterogeneous catalysts are that they are not as active as homogeneous catalysts, and they require higher reaction temperatures (200 to 250 °C) and pressures. For another method, at high pressure (120 atm) and temperature (350 °C) transesterification of triglycerides occurs without any catalyst. Some production plants in Europe use this technology; however, this requires high pressure leading to an increased capital cost. Advantages of this method are that the esterification reaction can occur rapidly (less than 5 min), and no catalyst is required decreasing downstream processing costs.

3.3.1.2.5 Problems and Barriers of FAME/Biodiesel

For biodiesel, more studies are needed to reduce the production cost, develop low cost feed stocks, and identify potential markets in order to balance cost and availability. During the process of converting a vegetable oil or animal fat into biodiesel many unwanted reactions and chemical substances can develop and contaminate the fuel. Under such conditions, the transesterification reaction is an equilibrium process, in which the yield of ester is only about 75% of theoretical. Typically, the glycerol layer, which contains unreacted alcohol and catalyst, is removed, fresh methanol and catalyst are added, and transesterification repeated. However, the two-step tranesterification typically gives high degrees of transesterification (>98%).

The difference in biodiesel is that it can be manufactured and sold by numerous small producers so that maintaining quality by frequent testing of batches is difficult to achieve. The basic inter-etherification process for biodiesel production at normal pressure and ambient temperature can easily be reproduced although the quality of the resulting fuel can vary and international standards are now in place to ensure stringent fuel specifications are met. This led to biodiesel becoming accepted as a reliable fuel by diesel engine and fuel injection equipment manufacturing industries. Apart from the developments of additives for improving cold flow properties, material compatibility, and prevention of oxidation in storage, the emergence of a number of improved processes in order to reduce the production costs is on going, however such modified technologies often have weaknesses in terms of reaching the desired quality and high yield levels –the aim being to convert above 99% of all available triglycerides and FFA in a raw oil feedstock into FAME. A 10% drop in yield can result in a 25% drop in profitability (Körbitz, 2007).

3.3.1.3 Bioethanol from sugar

Bioalcohols produced by the use of enzymes and micro organisms through the fermented process of starches and sugar. Ethanol is the most common type of bioalcohol, whereas butanol and propanol are some of the lesser known ones. ***Ethanol*** produced from biomass is called as bioethanol. It can be fermented from sugars, starches, or cellulosic biomass. Presently, the production of ethanol by fermentation of carbohydrates is the primary technology for the generation of liquid fuels from renewable biomass resources. Most commercial production of ethanol is from sugarcane or sugar beet, as starches and cellulosic biomass usually require expensive pretreatment (Demirbas, 2001).

3.3.1.3.1 Process and Technology of Bioethanol from sugar

Bioethanol from ***sugar***: Generally, sugar is extracted through a crushing process; then it is mixed with water and yeast[34], and kept warm in a fermentator. The yeast breaks down the sugar, converting it to ethanol (Caputo et al., 2005). Although almost half of the mass of sugar is released as CO_2, almost all of the sugar energy is captured in the ethanol. Sugar solution from sugar cane or grain crops is fermented to produce about 12% ethanol by yeast. Subsequently, the alcohol can be concentrated by distillation to produce up to 95% ethanol. Ethanol concentration and purification is an expensive step in industrial alcohol production, since its distillation is energy consume process. When produced ethanol contains about 5% water by volume, this mixture may also not be purified by simple distillation, as it forms an ***azeotropic mixture*** called hydrated/azeotropic ethanol. Removal of the remaining 5% water requires special treatment. Ethanol contains more than 2% by volume of water is not completely miscible with petrol (Demirbas, 2008). Bioethanol is already being produced in several African and South American countries based on the Brazilian model, the world successful sugarcane bioethanol producer. Sugarcane ethanol will go on to improve and therefore they will play a continuing role in future biofuel demand (FAO, 2008d).

Bioethanol from ***starch***: As the most potential starch-based feedstock, corn and cassava have hitherto been used for ethanol production. Ethanol production from corn-starch has been developed by DOE and NREL in USA, whereas cassava-based ethanol production has been reported in Thailand. To produce ethanol, starch is initially converted to fermentable sugars, namely, glucose by the enzymatic process. The sugars are then fermented to ethanol by suitable ethanologens, similar to fermentation of cane sugar or molasses. Pretreatment consists of milling the grains of corn, wheat or barley followed by liquefaction and fractionation. Acidic or enzymatic hydrolysis then occurs prior to fermentation of the resulting hexoses. Two technologies are available for the conversion of corn or cassava chips to fermentable sugars: Wet-milling process, Dry-grinding process.

Bioethanol from ***molasses***: bioethanol can be conversed from molasses by 3 steps: 1) Hydrolysis, this step can be classified to (a) enzymatic hydrolysis of lignocellulosic waste. Microbial degradation of lignocellulosic waste and the downstream products resulting from it is accomplished by a concerted action of several enzymes, the most prominent of which are the cellulases. (b) Concentrated acid hydrolysis process. This process is based on concentrated acid de-crystallization of cellulose followed by dilute acid hydrolysis to sugars at near 85 to 90% theoretical yields. Separation of acid from sugars, acid recovery and acid re-concentration are critical unit operations. (c) Dilute acid hydrolysis. The dilute acid hydrolysis process is one of the oldest, simplest and most efficient methods of producing ethanol from biomass. The first stage uses 0.7% sulphuric acid at 190 °C to hydrolyze the hemicelluloses present in the biomass. The second stage is optimized to yield the more resistant cellulose fraction by using 0.4% sulphuric acid at 215 °C. The liquid hydrolates are then neutralized and toxic compounds are removed before fermentation; 2) Fermentation, fermentation is an anaerobic biological process in which sugars are converted to alcohol by the action of microorganisms, usually yeast. The resulting alcohol is ethanol. Different fermentation processes are batch processes, semi-continuous processes and continuous processes; 3) Ethanol recovery, this process is similar to bioethanol from sugar.

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[34] Sugars are converted to ethanol by fermentation usually with the yeast *Saccharomyces cerevisiae* as shown in this equation ($C_6O_6H_{12} \rightarrow 2C_2H_5OH + 2CO_2$)

3.3.1.3.2 Advantages and Drawbacks of Bioethanol from sugar

Since the mid-1990s, there has been a growing worldwide interest in alternative transport fuels, of which ethanol is among the most promising options. The introduction of fuel ethanol offers good possibilities for greater fuel diversification, lower prices, cleaner environment, and better social benefits. Today, ethanol for fuel accounts for roughly two-thirds of world ethyl alcohol production. Growth in world ethanol production crucially depends on the development of the fuel-alcohol market. It is a comparative cleaner burning fuel with high octane and fuel-extending properties. However, minor problems still remain, particularly in colder climates, such as cold start caused by lower vaporization pressures of blends. Although blending of ethanol with petrol enhances the volatility of the mixture, the use of petrol blended with 20 to 24% ethanol is a standard practice in Brazil. Ethanol can be also produced diesohol, a blended mixture between diesel fuels (84.5%) and hydrated ethanol (15%), using a chemical emulsifier (0.5%). For non-sugar based ethanol, the most critical element for the success of bio-ethanol technology is the availability of celluloses at a nominal cost, thermo-tolerant high activity liquefying and saccharifying enzymes (a-amylase and glucoamylase) would be required for the development of cost-effective starch-based ethanol production (Saxena et al., 2009).

Table 3.14: Advantages and Problems of ethanol derived from food crops

	Advantages	**Problems**
Food to ethanol (C_2H_5OH)	Popularly perceived to be a 'green' and 'clean' option, which in reality it isn't	Very low net energy yield; competition with food crops; air and water pollution; low yield per unit area

Source: Adapted from Karp and Shield (2008) by Abbasi and Abbasi (2010)

3.3.1.3.3 Economic Aspect of Bioethanol from sugar

The world market of ethanol can be classified according to its end-use, namely, beverage, solvent, and fuel ethanol (Berg, 2004). Over 60% of world ethanol production (all uses) comes from sugar crops, including sugar beet. Of the various fuel alternatives under consideration in the transportation sector, ethanol and biodiesel are the most promising in both the short and medium terms. Globally, substituting 10%, or even 20%, of petrol (gasoline) with ethanol in 2020 is a feasible option. The US has become the largest producer, having recently overtaken Brazil. Europe is the third, remaining well above China. However, the international market in fuel ethanol is still in the initial stage and the full development will require the diversification of production, in terms of both feedstocks and number of producing countries. The low-cost production of sugarcane ethanol in Brazil may not be easy to replicate in Africa and other Latin American countries where sugarcane grows, due to higher costs and lower productivity in factors such as land, labour, and conversion facilities. Production costs of ethanol, therefore, will be highly dependent on the regional cost of producing biomass. Typical ethanol production costs from sugarcane, corn grain, and lignocellulose[35] (see Ch. 3.3.2.4) are shown in Fig. 3.14. However, the ethanol production cost decreases depending on the feedstock as sugarcane > corn grain > lignocellulose. Lignocellulose has the lowest feedstock cost, and research is in progress to reduce the cost of cellulosic ethanol. In future designs of large scale of sugarcane, corn, small cereal grains etc could possibly be better

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[35] The combination of these polymers - cellulose, hemicelluloses, and ligninall - is called 'lignocellulose'. It comprises around half of the plant matter produced by photosynthesis and represents the most abundant renewable organic resource on earth. Cellulose, hemicellulose and lignin are strongly intermeshed in lignocelluloses and are chemically bonded by non-covalent forces or by covalent crosslinkages (Perez-Garcia et al, 2005).

utilized on-site as feedstock to produce additional ethanol. Focuses on the optimization of energy integration and finding value-added solutions for co-products deemed as wastes in existing production facilities.

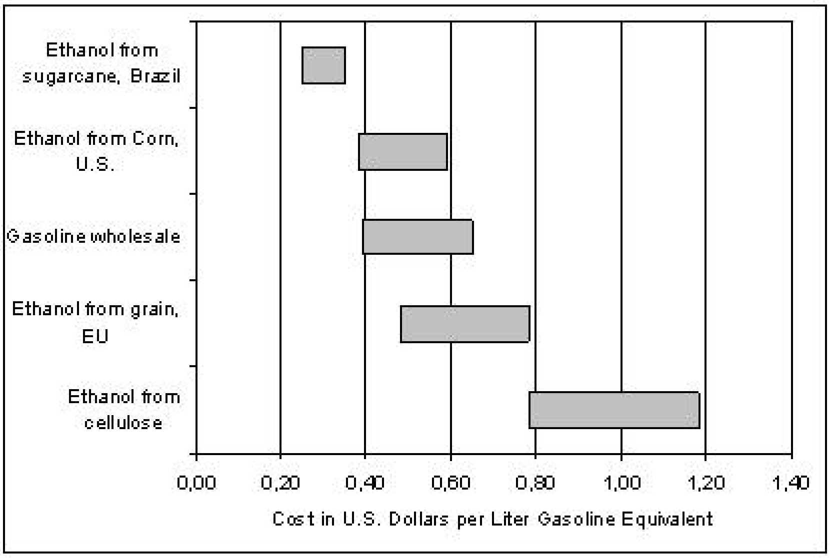

Fig.3.14: Production costs of various biomass feedstocks.
Source: Worldwatch Institute, GTZ, and FNR (2006).

3.3.1.3.4 Environment Aspect of Bioethanol from sugar

Ethanol from sugarcane can produce significant net savings in GHGs (see Fig. 3.15), particularly when the bagasse is used to provide heat/power at the processing plant. Where co-products are allocated, the total savings can be more than 100% of those produced using gasoline as a vehicle fuel. By contrast, ethanol from cereals can, under some circumstances (even excluding land-used change) be negative. For the production of ethanol from sugar cane under Brazilian conditions, a study by Macedo et al. (2004) has shown that the ratio of energy output to fossil energy input varies from 8.3 to 10.2, while the avoided GHG emissions for anhydrous ethanol utilization are 2.7 kg CO_2 equivalent/l of ethanol. In the case of the USA, according to a study of the US Department of Agriculture the energy output/input ratio of ethanol production from corn is 2.7 (RFA, 2005). Farrell et al. (2006) have evaluated six studies on fuel ethanol. They show that studies which reported negative net energy have incorrectly ignored co-products and used some obsolete data. All studies indicated that current corn ethanol technologies are less petroleum-intensive than petrol, but have GHG emissions similar to those of petrol. The protection of soil and water streams can be a major issue in large-scale ethanol production. It is well accepted that sugarcane has little impact on soil erosion, but prevention in fact, because of the nature of its roots. Avoidance of wind and rain run-off effects can be also considered (Nastari et al., 2005). Most sugarcane plantations do not require irrigation. However, water consumption in industrial processes is high (partly due precisely to abundance of water). Although water consumption has decreased significantly in recent years, this can still be an important issue in some parts of Brazil (Macedo, 2005).

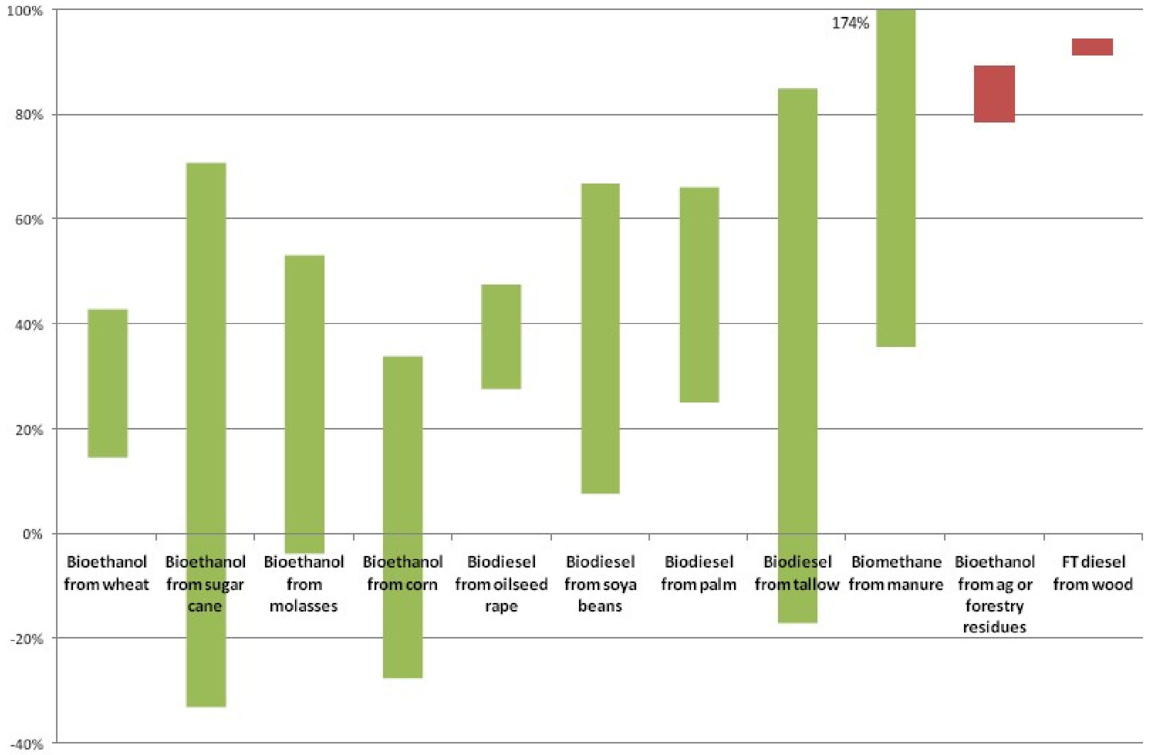

Fig. 3.15: Range of GHG saving from biofuels, by feedstock
Source: E4tech (2008)

3.3.1.3.5 Problems and Barriers of Bioethanol from sugar

The economic viability bioethanol from sugar is certainly more controversial and must take into account all externalities. Currently, more than 30 countries are in the process of introducing ethanol as a substitute for petrol. The use of bioethanol as a liquid fuel has been questioned on the basis of that the energy required for distillation is equal to the total combustion energy of the alcohol product. Additionally, one of the concerns of ethanol as a gasoline blending agent is the high volatility of the ethanol-gasoline blend. Ethanol can be further converted into other fuels. For example, **E**thyl-**T**ertiary-**B**utyl-**E**ther (ETBE) is produced by the reaction of ethanol with isobutylene. An advantage of ETBE is that it is less volatile than ethanol and can be blended with gasoline (up to 15 wt %); however, ETBE may leak from gasoline stations causing groundwater contamination similar to MTBE. Since so many countries are considering the ethanol fuel option, it is time to get serious with ethanol fuel and act accordingly [see, e.g., Koonin, 2006]. The drivers and policies are expected to continue to play an important role in the future development of fuel ethanol, although technological developments in the automotive industry are expected to play a much greater role together with emerging alternatives, e.g., hybrid vehicles or large-scale utilization of hydrogen. The chosen methods in support of alternative transport fuels (ATFs), ranging from fiscal incentives to legislative measures, vary widely from country to country.

3.3.2 The Second Generation of Biofuel

The second generation biofuel technologies have been developed because the manufacture of the first one has important limitations, which it cannot produce enough biofuels without threatening food supplies and biodiversity. Plant biomass represents one of the most abundant and underutilized biological resources on the planet, and is seen as a promising source for biofuel production (DOE, 2006). In these technologies, either via enzymatic hydrolysis or via gasification, it can be classified to Biomethane, Vegetable Oil Hydrogenation, ***Biomass To Liquid*** (BtL) via Gasification & Synthesis, and Bioethanol from lignocellulose[36].

3.3.2.1 Biomethane

Biogas is mainly generated after the Anaerobic Digestion (AD) of the organic or organic waste materials. The biogas produced is very rich in methane, which can be easily recovered through the use of mechanical biological treatment systems. The residue or the byproduct is easily used as manure or fertilizers for agricultural use. However, methane from this rout can also be classified to be the first generation of biofuels. A less clean form of biogas is the ***landfill gas***, which is produced by the use of naturally occurring anaerobic digesters, but the main threat is that these gases can be a severe threat if escapes into the atmosphere. Nevertheless, the landfill gas can be extracted from existing landfill sites by inserting perforated pipes into the landfill. In this way, the gas will travel through the pipes under natural pressure for use as an energy source, rather than simply escaping into the atmosphere to contribute to greenhouse gas emissions (Demirbas, 2001; Gavrilescu and Macoveanu, 1999). The gas composition is 65 to 70% CH_4, 35 to 30% CO_2 and negligible traces of other gases (e.g. H_2S and H_2) and is saturated with water. The gas has an approximate heating value of about 26 MJ/m^3 (Demirbas, 2000b). For another route, biogas can be generated by gasification of biomass and then synthesis. This path will be discussed in next topic.

3.3.2.1.1 Process and Technology of Biomethane

For Biomethan from AD, the process consists of gathering organic compounds (any organic material or waste) and hydrolyzing these compounds. In the hydrolysis step, insoluble materials become soluble. The hydrolyzed compounds then pass through acid bacteria, which create an organic acid. Finally the organic acid is converted into biogas with the aid of the methanogens, or bacteria that create methane. The biogas is then sent to a storage tank and is later passed through an energy generator. Process temperature affects the rate of digestion and should be maintained in the mesophillic range (35 to 41 °C) with an optimum of 37 °C. It is possible to operate in the thermophillic range (57 to 63 °C), but the digestion process is subject to upset if not closely monitored. This is a commercially proven technology widely used for treating high moisture content biomass such as MSW. Typically 30 to 60% of the wet biomass input is converted to methane by digestion. The raw gases can be scrubbed to produce a high quality methane-rich gas fuel, similar to commercial natural gas, **C**ompressed **N**atural **G**as (CNG) (Demirbas, 2008).

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[36] Lignocellulosic material can be converted into liquid fuels by three primary routes: 1) syngas production by gasification (3.3.2.3); 2) biooil production by pyrolysis or liquefaction (3.3.3.1); and 3) hydrolysis of biomass to produce sugar monomer units (3.3.2.4).

Bio-SNG, Synthetic Natural Gas, can be produced either from wet biomass streams through anaerobic digestion or supercritical water gasification, or from relatively dry biomass through gasification then requiring a methanation process to form SNG from the CO and H_2 (see reaction below). Different components can be converted into methane by changing the catalyst of the process. The process is strongly exothermic, therefore part of the energy from the gaseous components is lost in the form of heat which has to be removed from the reactor and cooled of the SNG before storage. Efficient recovery of the reaction heat, which amounts to about 20% of the heating value of the synthesis gas, is essential for any industrial methanation technology. Conversion routes include stand-alone SNG, SNG co-produced with FT synthetic diesel, and biomass gasification in super-critical water (though due to the syngas composition, this is more suited to H_2 production than SNG). In the combined route with FT diesel production, the off-gas from the FT reactor is taken to a methanation reactor and, using a Ni-based catalyst, converted to SNG. The catalysts are sensitive to impurities, so a gas clean-up process is required, though this remains technologically challenging.

$$CO + 3\,H_2 \rightarrow CH_4 + H_2O$$

3.3.2.1.2 Advantages and Drawbacks of Biomethane

The science and technology of biomethane generation are already developed and commercialized. AD is generally used worldwide for the treatment of industrial, agricultural, and municipal waste-water and sludge, as well as for treatment of municipal solid wastes (Kiely, 1998). The benefits of AD include: 1) Odor reduction; 2) Decrease in the biological oxygen demand of treated effluent by up to 90%, reducing the risk for water contamination; 3) Improved nutrient application control, because up to 70% of the nitrogen in the waste is converted to ammonia, the primary nitrogen constituent of fertilizer; 4) Reduced pathogens, viruses, protozoa and other disease-causing organisms in lagoon water, resulting in improved herd health and possible reduced water requirements; and 5) Potential to generate electricity and process heat.

Biomethane can be produced cost efficiently at low-medium scales today (20 to 100MW), whereas liquid second generation alternatives (ethanol and methanol and FT diesel) all require large-scale production - due to the synthesis step - in order to meet cost criteria. In comparison to other alternative fuels like biodiesel or bioethanol, the fuel yield of biomethane out of one field hectare is significantly higher. Moreover, biomethane distribution can be integrated into the existing natural gas distribution network. Bio-SNG has similar qualities to natural gas, so a benefit is the possibility to distribute it via natural gas pipeline grids. Due to a lack of compatible vehicles and infrastructrue, gaseous biofuels are far less popular than liquid biofuels. As a vehicle fuel, SNG is similar to CNG or LNG. Hence it must be compressed or liquefied to reduce its volume for on-board storage, which both have energy and cost penalty. It is a clean burning fuel with relative low CO, NO_x, and particulate emissions. However a feasibility study showed that the plant could not currently compete with methane produced as biogas from animal wastes and sewage due to the high feedstock cost resulting from the labour intensive in forest industry.

3.3.2.1.3 Economic Aspect of Biomethane

Biogas is widely used for heating purposes or electricity generation, and may be upgraded by the separation of CO_2, resulting in biomethane which usually has a higher methane concentration than natural gas. The upgrading of biogas into biomethane as a renewable resource for future automotive strategies is a promising and trendsetting concept. In some countries (e.g., Finland, Sweden, and France), a few city-buses or vehicles owned by farmers are powered by biomethane (Hilkiah et al., 2007). Sweden and Switzerland are the top countries in biomethane operated vehicles with 10,000 respectively 3,500 gas vehicles; 50% resp. 37% of the gas fuel comes from biogas. Besides, biomethane and biogas can be co-produced with ethanol from grains, Second generation liquid fuels such as FT diesel and methanol and electricity. Co-production increases the overall primary energy efficiency and increases the economic viability and market flexibility.

The development of biogas has been driven largely by feed-in tariffs (e.g. Germany) and Renewables Obligation Certificates (e.g. UK) that both have spawned a market for electricity production from land-fill gas and farm-based methanization plans. Especially in German has farm production systems based on crops and manure grown substantially the last years and now accounts for up to 70% of the biogas production in the country (Biogas barometer, 2005 - 2008). As a whole however, the biogas production from land-fill gas and sewage sludge still dominates within the EU.

As can be seen in Europe from Fig. 3.16, the costs of potential large-scale production for second generation biofuels, including methane, need not be substantially more costly compared to current that of petrol excluding taxes. Also be noted, all the cost projections are very dependent on the emergence of an efficient market for low-cost woody biomass. The cost of woody biomass constitute more than a third of the potential costs of biofuels. In the short- and medium-term, costs for biofuels are substantially higher compared to that of petrol. As an example, current farm-based production of biomethane (biogas and upgrading facilities) is estimated to range between 20 and 28 Euros/GJ depending on the size of the digester (Concawe et al.,2007; SGC, 2008). This is close to twice the cost of petrol today. At the same time, current production of ethanol (from wheat) and biodiesel is estimated to cost around 21 Euros/GJ in the EU.

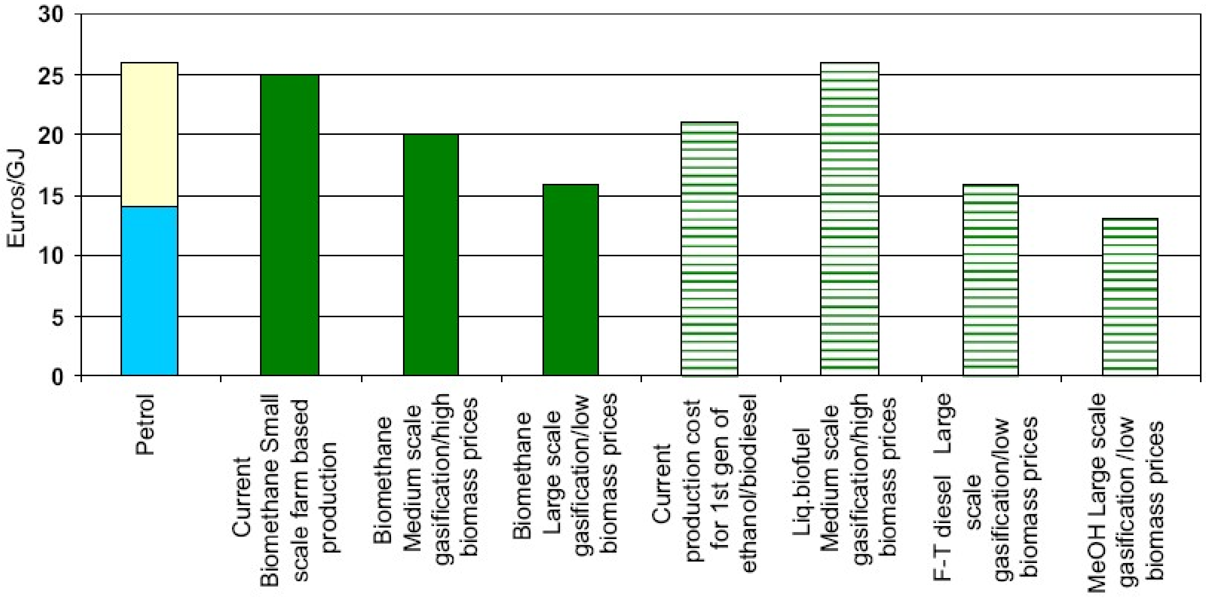


Fig. 3.16: Current and potential production, distribution and dispensing costs for biofuels and petrol
Source: Åhman (2010)

3.3.2.1.4 Environment Aspect of Biomethane

AD is more than energy production. It serves time like to stabilize sewage sludge and MSW, upgrades industrial waste water and improves fertilizer quality of animal waste. Hence it helps fulfilling a number of environmental laws. A benefit of biomethane combustion is that it produces low amounts of greenhouse gases due to the relatively low portion of carbon in the gas (Balat, 2005). Although biogas is a high quality energy carrier that can be used in a number of applications with high efficiency, the market for biogas (both supply and demand) has so far been policy driven. The production of biogas relates to several policy objectives such as environmentally friendly waste management, rural development, security of supply and mitigating climate change. However, where to use the biogas is predominately motivated by the ability to replace fossil fuels and thus mitigating climate change. Anaerobic digestion is increasingly used in small-size, rural, and off-grid applications at the domestic or farm-scale. Slow anaerobic fermentation converts only a fraction (50 to 60%) of feedstock but produces soil conditioners as a byproduct. In modern landfills, methane production ranges between 50 and 100 kg per tonne of MSW. Large-size plants using MSW, agricultural wastes and industrial organic wastes (large-scale co-digestion) need some 8000 to 9000 tonne MSW/yr/MW of installed capacity.

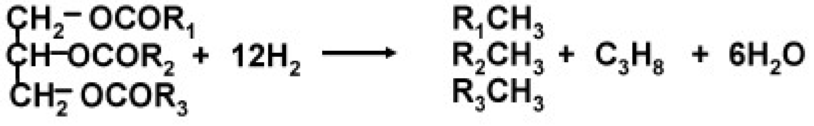
3.3.2.1.5 Problems and Barriers of Biomethane

Currently, biomethane is a local and small-scale option mostly produced by upgrading biogas from locally collected wet biowaste. It is also produced from dedicated agricultural crops (grasses and maize) which has a larger potential, but is still limited by competition for land suitable for other purposes such as food. In order to become a large-scale option, biomethane produced from woody biomass via gasification and methanisation needs to be developed. To boots, advanced digesters are still in its infancy and further research can increase yields and cut cost substantially the coming years. The obvious disadvantage of biomethane compared to second generation of liquid biofuels is that it in gaseous form at normal temperature and pressure, thus require a new infrastructure and adopted vehicle technologies, especially a more costly fuel tank. The problems with more complicated vehicle technologies are not insurmountable with 8.7 millions of CNG vehicles globally already in place and the possibility to take advantage of the already existing distribution systems for natural gas. However, policy incentives will be needed for the private car market to overcome up-front costs and low availability of fuelling stations in the short- and medium-term (Åhman, 2010).

The currently most common production of biologically derived methane is land-fill gas, which is a result from the natural process of decomposing organic waste. However, as dumping of organic waste in landfills is being phased out in the EU. This resource is set to decrease in the long-term. Furthermore, landfill gas contains nitrogen from the air that is difficult to separate from the methane. This makes land-fill gas less favorable to upgrade for vehicle use. Therefore, land-fill gas is today typically used for heating purposes and electricity production (Åhman, 2010).

3.3.2.2 Vegetable Oil Hydrogenation

Catalytic hydrogenation and cracking of oils and fats is not strictly a new process and is already entering the market. So in this sense, especially where edible oil and fats are used, it would be classified as a 1st-generation biofuel with similar issues of sustainability of feedstocks. With this route, triglycerides are converted into high-quality synthetic biodiesel (Fig. 3.17). Since the process involves the application of H_2, it is well suited to be integrated into an oil refinery in which H_2 is generated as a part of the process.



$$\begin{array}{l} CH_2-OCOR_1 \\ CH-OCOR_2 \\ CH_2-OCOR_3 \end{array} + 12H_2 \longrightarrow \begin{array}{l} R_1CH_3 \\ R_2CH_3 \\ R_3CH_3 \end{array} + C_3H_8 + 6H_2O$$

Fig. 3.17: Hydrogenation of triglyceride.
Source: Casanave et al. (2007)

3.3.2.2.1 Process and Technology of Vegetable Oil Hydrogenation

A well known chemical process, ***hydrogenation*** is applied in many different products across a variety of industries; petrochemical, pharmaceutical, and food industries amongst others. The normal process conditions involve elevated pressure and temperature in the presence of a precious metal catalyst. For biodiesel production, triglycerides can also be hydrogenated into linear alkanes in a refinery hydrotreating unit over conventional sulfided hydrodesulfurization catalysts (Bjørn et al., 2009). Direct hydrogenation of vegetable oils was proposed several years ago, using processes and catalysts similar to those used for middle distillate hydrotreatment, for example, $NiMo/Al_2O_3$ catalyst. Such processes were considered as non-economical (not astonishingly with low oil prices) and, more recently, not competitive with the esterification route (with further hydrogenation in the case of unsaturated fatty chains R) produces straight-chain hydrocarbons and propane, with significant hydrogen consumption (of the order of 3 wt%). However, there is renewed interest for this route for several reasons. Straight-chain paraffins as in FT synthesis (see Ch. 3.3.2.3), the primary product of the hydrogenation process is then hydrocracked to obtain very high quality diesel (and kerosene) under mild conditions. Additionally, the propane byproduct can be fed into important markets as a (motor) fuel, or as a petrochemical feedstock.

There are several examples of this approach including the ***H-Bio*** process of Petrobras, the Canadian Super-Cetane process, and the commercial ***NExBTL*** process of the Finnish company Neste Oil. In addition, two 800 kt plants are envisaged in Rotterdam and Singapore. ***UOP*** has developed a hydroprocessing technology, called Ecofining process, which will be incorporated into a plant to be built by ENI. It is expected to come online in 2009 and will produce 650 bpd biodiesel. In the NexBTL process the oils are hydrogenated by a direct process in dedicated plants, whereas ***Conoco Phillips*** and others are employing an indirect process where the oils are added downstream in the oil refinery. Since the process is refinery-based, it benefits from the existing infrastructure including energy supply, blending facilities, transport logistics, and laboratories. The resulting fuel can be mixed with mineral oil diesel at any blend without any problems as they have similar properties but have a superior quality that helps lower exhaust emissions. It is also more stable than biodiesel during longer-term storage. The first commercial-scale plant was commissioned in summer 2007 and the second plant is under construction at Neste Oil's oil refinery in Porvoo, Findland (Sims et al., 2008).

3.3.2.2.2 Advantages and Drawbacks of Vegetable Oil Hydrogenation

To produce higher quality biodiesel than that of first generation, a large variety of vegetable oils and animal fats can be processed by this route to yield the same final product with high quality. The final products from the simple hydro-processing (simple alkanes) are the same components as those present in normal fossil diesel, whereby the problematic and limiting filter plugging and cold flow properties (which generally occur with FAME biodiesel in the temperate part of the world) are minimized. Therefore, some of these can be used as diesel fuel additives. The FFAs are also removed in the hydro-treater, therefore the corrosion problem is localized to the hydro-treating unit. Furthermore, co-processing with crude oil derived middle distillates is possible and even favourable. There are very valuable properties that enable refiners to optimize the amount of lower value refinery streams that can be blended into the refinery diesel pool. Cold flow properties can be controlled by adjusting process severity, thus making the process more flexible than biodiesel with respect to feedstock selection and plant location.

With this route, several problems must still be addressed. H-Bio process, for example, has been started in Brazil by Petrobras. The presence of a large amount of water in the hydrotreatment reactor could have adverse effects on the sulphided catalyst performance. For stand-alone processing, since vegetable oils do not have high sulphur content, new nonsulphided hydrotreating catalysts could be used. For co-processing, carbon monoxide (CO) which can be formed by hydrogenolysis of vegetable oils, has an inhibiting effect on hydrodesulphurization activity. In the hydrotreatment conditions, unsaturated fatty chains are hydrogenated. The resulting straight chains, mainly C12 to C18, are completely paraffinic. Such fully saturated compounds have excellent cetane index but generally bad cold flow properties compared to corresponding esters, which may require an additional hydroisomerization step. This type of process opens the way to improving the yield per hectare as there are no longer any constraints on the chemical composition of the vegetable oils or fat (length of the fatty chains, degree of unsaturation).

3.3.2.2.3 Economic Aspect of Vegetable Oil Hydrogenation

Although this process is in the early commercial stage of development, there are several companies with various technologies that focus on this process. The hydrogenation process would normally be integrated within an oil refinery to avoid having to construct a dedicated hydrogenation production unit. The process can be integrated with hydrotreaters, and make use of hydrogen, already used in a refinery to remove sulphur. With respect to feed, it will be possible to hydrotreat other materials than edible seed oils with high contents of oxygen compounds into fuels. These materials could be simple alternatives like tall oil as well as more diverse materials like fast pyrolysis oils or shale oils. With respect to product, the hydrotreating processes, which are controlled by catalyst properties and process conditions, furthermore offer a tool to be used in future biorefineries to make a large variety of chemicals. With demand for biodiesel set to continue, processes which produce a superior diesel product and which can be blended at higher levels and at similar cost are likely to be attractive. However, this product is still dependent on vegetable oils as feedstock, therefore is not as attractive as those second generation biofuels which can be produced from wastes or residues.

3.3.2.2.4 Environment Aspect of Vegetable Oil Hydrogenation

The GHG emissions savings from this route are similar to the emissions savings from conventional biodiesel production. However, this technology is at very early stages of development and production is a number of years away, but progress should be monitored to assess competitive effects.

3.3.2.2.5 Problems and Barriers of Vegetable Oil Hydrogenation

One of the most important issues in this process is the same that of the first generation biodiesel; that is to say, the production of this fuel is currently limited by the need for food based feedstocks (vegetable oils) which are becoming increasingly expensive with concerns about global food shortages. To be more economically, viable hydrogenation needs to be closely coupled to a refinery operation. One of the components leading to high costs is the additional hydrogen stream needed, especially if not coupled to a refinery. If it is integrated with a refinery, the volume of conventional fuels that can be processed through the hydrotreater is also reduced. Another challenge to hydrotreated biodiesel routes is that they do not have any greater GHG savings than conventional biofuels. Thus they would not be favoured by a policy which moved to linking biofuel support to the GHG intensity of the fuel.

3.3.2.3 Biomass to Liquid (BtL) via Gasification and Synthesis

Biomass fo Liquid (BtL) is a multi step process to produce liquid biofuels from biomass. In this rout (BtL via gasification), biomass is used to produced syngas by gasifier, then the syngas is converted into longer-chain hydrocarbons such as gasoline or diesel fuel (see Fig. 3.18). Syngas is usually applied for production of fuels or chemicals, and many industrial routes for utilization of syngas exist such as production of H_2 by the water gas shift reaction, diesel fuel by FTS[37], methanol by methanol[38] synthesis, methanol-derived fuels, isobutane by isosynthesis, and ethanol by fermentation[39] or with homogeneous catalysts.

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[37] The Fischer-Tropsch synthesis (FTS) is an industrial process to produce alkanes from syn-gas using Co-, Fe-, or Ru-based catalysts. This technology was first developed in the early 1900s and used by Germany during the 1930s and 1940s to produce liquid fuels from syn-gas-derived coal. The products from FTS are a range of mostly straight chain alkanes ranging from C1 to C50 governed by the Anderson-Schulz-Flory (ASF) polymerization model.

[38] Methanol is a platform chemical used to produce a range of other chemicals and fuels including olefins, gasoline, dimethyl ether, methyl *tert*-butyl ether, acetic acid, and formaldehyde.

[39] Fermentation of syngas with the anaerobic bacterium, *Clostridium ljungdahlii* can generate ethanol. The fermentation performance is not adversely affected by a specific CO/H_2 ratio, and both CO and H_2/CO_2 mixtures can be used simultaneously even though the bacteria generally prefer CO to H_2.

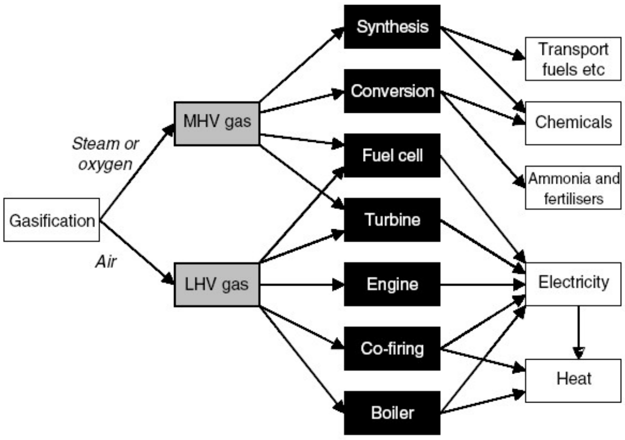

Fig. 3.18: Aplication for biomass gasification systems (MHV = Medium Heating Value typically 15 MJ/Nm^3; LHV = Low Heating Value typically 5 MJ/Nm^3).
Source: Bridgwater (2006)

3.3.2.3.1 Process and Technology of BtL via Gasification

The Fischer-Tropsch Synthesis (FTS) can produce hydrocarbons of different length from a syngas, then the large hydrocarbons can be hydrocracked to form mainly diesel with excellent quality. The products from FTS are mainly aliphatic straight-chain hydrocarbons (C_xH_y). Besides the C_xH_y, branched hydrocarbons, unsaturated hydrocarbons, and primary alcohols are also formed in minor quantities depending on the catalyst and the process parameters. High-temperature FTS lead to the production of synthetic gasoline and chemicals, whereas Low-temperature FTS lead to the generation of waxy products that can be cracked to synthetic naphtha, kerosene or diesel fuel. Cobalt catalysts are in general more reactive for hydrogenation and produce therefore less unsaturated hydrocarbons and alcohols both compared to iron catalysts. Iron catalysts have a higher tolerance for sulphur, are cheaper, and produce more olefin products and alcohols. However, its lifetime is short and in commercial installations generally limited to 8 weeks. The Al_2O_3/SiO_2 ratio has signifcant influences on iron-based catalyst activity and selectivity in the process of FTS. With increasing Al_2O_3/SiO_2 ratio, the selectivity of low molecular weight hydrocarbons increases, while the olefin to paraffin ratio in the products shows a monotonic decrease. The FTS-based Gas to liquids (GtL) technology includes 3 processing steps namely syngas generation, syngas conversion, and hydroprocessing. The syngas consists mainly of H_2, CO, CO_2 and CH_4. Although it is unsuitable for direct using in the FTS, it can be tailored by CH_4 reforming, WGS reaction, and CO_2 removal. To maximize the utilization of C sources, the steam reforming of syngas with additional natural gas feedstock can be considered (Demirbas, 2008).

For the gasifier, it is important to avoid CH_4 formation as much as possible, and convert all carbon in the biomass to mainly CO and CO_2, while a main characteristic regarding the performance of the FTS is the liquid selectivity of the process. Typical operation conditions for the FTS are a temperature range from 202 to 352 °C and pressures among 15 to 40 bar, depending on the process. ***Biomethanol*** can also be produced via methanol synthesis from the syngas obtained from steam reforming process of biomass. It is considerably easier to recover than bioethanol, because it is expensive to purify ethanol during recovery due to azeotropic property of ethanol (see Ch. 3.3.1.3). Prior to the methanol synthesis, the syngas must generally undergo cleaning, shift reaction and compression (Wahlund et al., 2004). The synthesis takes place over a catalyst at increased temperature and pressure. The methanol synthesis step is well known and commercially available. Studies of methanol production reported efficiencies in the range of 50 to 60% (Ahlvik and Brandberg, 2001). Except for the synthesis step, **Dim**ethyl **E**ther (DME) production is identical to that of methanol. The catalyst is modified for immediate dehydration of the methanol formed. The conversion of methanol to DME is more kinetically favourable, therefore giving a 5% higher yield than that of methanol. Winell and Svedberg (1997) indicate that the production cost per energy unit might be up to as much as 20% lower than for methanol, thanks to both higher yield and lower requirements of distillation equipment (Wahlund et al., 2004). With a conversion efficiency of 57%, DME from woody gasification appears to be a promising wood-based fuel for heavy-duty vehicles (Ahlvik and Brandberg, 2001; JRC, 2006). On the other hand, a similar study in Sweden (Maniatis, 2001) resulted in DME as the most promising liquid biofuel.

3.3.2.3.2 Advantages and Drawbacks of BtL via Gasification

In principle, if a clean synthesis gas can be produced, there should not be any serious technical barrier for its subsequent conversion to methanol or FT liquid products as these processes have been demonstrated by the novel **M**ethanol **t**o **G**asoline (MtG) process by *ExxonMobil* in New Zealand or by *SASOL* in South Africa (Maniatis, 2001). Synthetic FTS diesel fuels can have excellent auto-ignition characteristics. It is composed of only straight chain hydrocarbons and has no aromatics or sulphur. Methanol can also used as stand alone fuel, in blends with gasoline, or as a potential hydrogen source, because it has a favourable 4:1 of H:C ratio. In methanol synthesis, high concentrations of CO_2 can deactivate the catalyst. Methanol synthesis reactions (whether from CO_2 or from CO) are exothermic, and if too high a temperature is reached within the catalyst bed, this may lead to undesirable effects such as: a lowering of the conversion per pass; byproduct formation (e.g. methane and oxygenates other than methanol); and even catalyst sintering with subsequent loss of activity as a result of a decrease of the surface area. With copper-based catalysts, temperatures of up to 280 °C are reportedly used in methanol synthesis reactors. For DME, it could be mixed with LPG or be a useful substitute. As well as a vehicle fuel in converted spark ignition engines, DME is used widely for heating and cooking, and hence could be an option in developing countries to replace dung and fuelwood at the domestic and village scale. Existing LPG storage and distribution facilities can be utilized for DME, but where these are not available, costly infrastructure is required since it is gaseous under normal temperature and pressure.

3.3.2.3.3 Economic Aspect of BtL via Gasification

A **key** exception under ‘conventional’ biofuels is production of ethanol from sugarcane in tropical regions where good soils are available, which proves currently a competitive system in the Brazilian context and some other countries. For countries where sugarcane production is feasible, commercially available technology allows for production of relatively lowcost ethanol. Brazilian experience shows that ethanol production competitive with gasoline is possible at current oil prices (Rosillo-Calle and Cortez, 1998; Goldemberg et al. 2004). But it is production of methanol (and DME), hydrogen, Fischer-Tropsch liquids, and ethanol produced from ligno-cellulosic biomass that offer much better perspectives and competitive fuel prices in the longer term (e.g. around 2020). Partly, this is because of the inherent lower feedstock prices and versatility of producing ligno-cellulosic biomass under varying circumstances. **To** make the BtL technology more cost-effective, the focus must be on reducing both the capital and the operating costs of such a plant (Vosloo, 2001). The most expensive section of an FT complex is the production of purified syngas and so its composition should match the overall usage ratio of the FT reactions, which in turn depends on the product selectivity (Dry ME, 2002). The cost of the syngas production can be more than 50% of the total process cost (Spath & Dayton, 2003). Most economic studies have indicated that deployment of large scale commercial plants is required to gain the necessary cost reductions from both economies of scale and learning experience for these processes. However, the volatile tar component has been exploited as a feedstock for value-added chemicals by companies such as Choren (Germany), Ensyn (the USA) and Enerkem (Canada) (Branca & Di Blasi, 2006).

Spath and Dayton (2003) analyzed the PTE and economics of syn-gas-derived fuels with a feedstock cost of $33/dry metric ton, and the results of their analysis are shown in table 3.15. In their economic analysis, they concluded that syn-gas production accounts for at least 50% and up to 75% of the final product cost. As can be seen from table 3.15, the cost of syn-gas-derived fuels on an energy basis increases in the order H_2 < methanol & ethanol < FTS liquids. This conclusion consistent with the results of Hamelinck et al. who have also studied the economics of production of FT transportation fuels, methanol, and hydrogen from biomass and concluded that FTS diesel is 40 to 50% more expensive than methanol or hydrogen.

Table 3.15: Base Case Minimum Product Selling Price of biofuels from Spath and Dayton Analysis

Product	$/Gj (HHV)	$/Gj (LHV)	$/gallon or $/kg
H_2	8-14	9-17	1.1-2.0/kg
MeOH	12-13	13-14	1.1-2.0/kg
FTL	19-25	20-27	0.80-0.91/gal
Ethanol via syngas fermentation	14	16	2.7-3.6/gal

Source: Spath and Dayton (2003)

3.3.2.3.4 Environment Aspect of BtL via Gasification

FT diesel from wood can produce significant net savings in GHGs (see Fig. 3.15). DME is non-toxic; it can be used in gas turbines or fuel cells for power generation, and as a good quality vehicle fuel in compression ignition engines. It emits lower NO_x and SO_x emissions than diesel, has zero particulates and has lower life cycle GHG emissions than most other biofuels.

3.3.2.3.5 Problems and Barriers of BtL via Gasification

In spite of many years of research and commercial endeavors, cost effective and reliable methods of gasification at the business scale remain elusive. Various gasification technologies have been developed and commercialized, but have been focused mainly on gasification for power generation, where high calorific value gas is the target and impurities are less in an issue than FTS. Gasification technologies need to meet a number of criterias for BtL production, including the ratio of CO to H_2, ability to scale up to large commercial plant sizes (above 100 MW), and clean gas produce (Maniatis, 2001). Given the constraints on scalability and the level of impurities in the desired syngas, *pressurized oxygen-blow direct entrained flow* gasifiers would appear to be the most suitable concept for BtL. If the particle size is reduced to less than 1 mm, tar-free syngas can be obtained with a relatively high CO and H_2 content compared to other designs of gassifiers. If feedstocks can be successively comminuted into small particles, entrained flow gasifiers are able to successfully convert a wide range do to the extreme process conditions involved. Another potential option is the preliminary gasification of biomass in a PCFDB reactor. The gas formed is then fed to the second gasification stage in an entrained flow gasifier. The advantage of this approach is similar to pyrolysis, in that relatively little comminution of the biomass is required of the biomass and a wide range of feedstocks can be processed. A potential drawback trough is maintaining a stable feed flow due to variability in the output of the CFDB processes being common. The ealiest catalyst used for FTS were iron and cobalt. These catalysts degrade when exposed to toxic impurities in the syngas that reduce their effectiveness which has implications for the gasification process. Today, the catalysts come from Group VIII transition metal oxides. For large-scale commercial FTS reactors, heat removal and temperature control are the most important design features in order to optimize products selection and maximize catalyst lifetimes.

3.3.2.4 Bioethanol from Lignocellulose

When bioethanol is produced from lignocellulose, biomass must be broken down into fermentable C5/C6 sugars, and then converted into bioethanol. The advantage: almost every solid biomass can be used for this suitable process, and consequently the range of plants which can be cultivated increases enormously. At the same time, the areas needed for cultivation are reduced, because the entire plant is used for this production process.

3.3.2.4.1 Process and Technology of Bioethanol from Lignocellulose

To achieve high yields of glucose, lignocellulose must first be pretreated. The goal of pretreatment[40] is to decrease the crystallinity of cellulose, increase biomass surface area, remove hemicellulose, and break the lignin seal. Pretreatment methods include physical, chemical, and thermal (or combination of these three). According to Mosier et al. (2005), the most cost-effective and promising pretreatment methods are dilute acid, uncatalyzed steam explosion, pH controlled hot water, treatment with lime, and treatment with ammonia. Uncatalyzed steam explosion is used commercially in the manufacture of fiberboard by the Masonite process. This process increases the surface area without decrystalizing the cellulose, and cellulose downstream digestibility is significantly improved. Water treatments at elevated temperatures (200 to 230 °C) and pressures can increase the biomass surface area and remove hemicellulose. Three types of reactors are used for hot water pretreatment including co-current, countercurrent, and flow through[41]. The advantage of hot water treatment is that acid addition and size reduction are not needed, but its disadvantage is that hot water treatment forms sugar degradation products. Dilute sulphuric acid treatments can be used to hydrolyze hemicellulose to sugars with high yields, change the structure of the lignin, and increase the cellulosic surface area. The disadvantage of this process is that it requires corrosive acid, with corresponding downstream neutralization, and special materials for reactor construction. Ammonia fiber/freeze explosion (AFEX)[42] where anhydrous ammonia is contacted with lignocellulose can increase the surface area of the biomass, decrease crystallinity of cellulose, dissolve part of the hemicellulose, and remove lignin.

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[40] Pretreatment is one of the least understood processing but also one of the most expensive steps for sugar production from biomass. The costs have been estimated to be as high as $0.08/l of ethanol.

[41] Flow through is the process that hot water passes over a stationary bed of lignocellulose.

[42] Treatment of the biomass with a less concentrated ammonia solution is known as ammonia recycled percolation (ARP).

A major processing step in an ethanol plant is enzymatic saccharification of cellulose to fermentable sugars; this step requires lengthy processing and normally follows a short-term pretreatment step (Ouellette et al., 1997). The value of any particular type of biomass as feedstock for fermentation depends on the ease with which it can be converted to sugars. The technologies for producing ethanol from woody biomass are still at the research stage. At present, a pilot plant based on the diluted acid process is being constructed in Sweden. IIT Delhi, India, studied two different cases of ethanol production. One is the diluted acid process (EtOH, DA), whose energy yield is expected to consist of up to 27% ethanol and with 44% lignin as a by-product. The lignin can either be used as fuel in the process itself or pelletised for exporting as fuel pellets for use elsewhere. The other process is enzymatic hydrolysis, combined with simultaneous saccharication and co-fermentation of both pentoses and hexoses, which gives a 41% ethanol yield (EtOH, Enz). In self-supplying units, 8% lignin or 4% electricity is also generated. Acid disruption and transgenic microorganism fermentation (Quadrex process) were developed. Bioenergy International, L.C., a subsidiary of Quadrex Corporation, possesses the exclusive worldwide license for a constructed set of genes that when inserted into a microorganism has the ability to ferment both pentose (5-carbon sugars) and hexose (6-carbon sugars). The detail of this process is shown in Figure below.

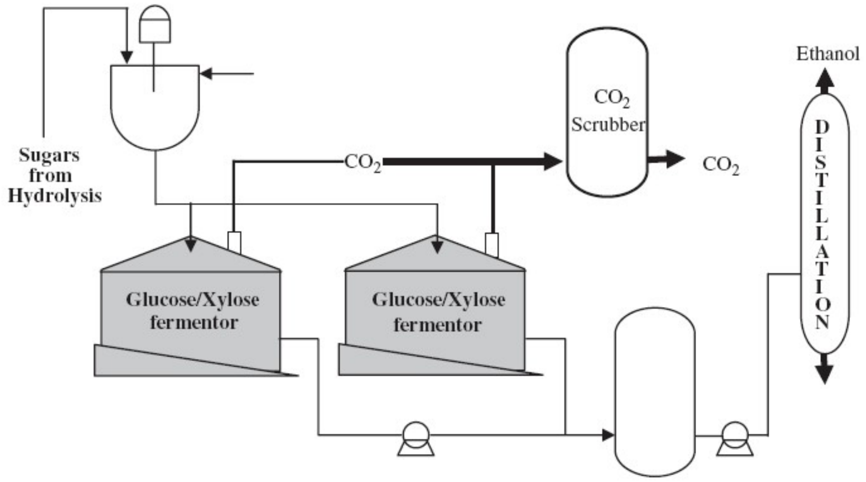

Fig. 3.19: Acid disruption and GM ethanologens (Quadrex process)
Source: Saxena et al. (2007)

Hydrolysis breaks down H_2 bonds in cellulose and hemicellulose fractions into their sugar components, pentoses and hexoses. At present, it is only possible to ferment hexoses, although research is ongoing on pentose fermentation. The most commonly applied methods can be classified into two groups: chemical hydrolysis and enzymatic hydrolysis. In chemical hydrolysis, the pretreatment and the hydrolysis may be carried out in a single step and two basic processes are used: dilute acid and concentrated acid. The biggest advantage of dilute acid processes is their fast rate of reaction, facilitating continuous processing. Since 5-carbon sugars degrade more rapidly than 6-carbon sugars, one way to alleviate this is to set a two-stage process. The first stage is conducted under mild process conditions to recover the 5-carbon sugars, while the second one is conducted under harsher conditions to recover the 6-carbon sugars. The concentrated acid process uses relatively mild temperatures, and the only pressures involved are those created by pumping materials from vessel to vessel. Its reaction times are typically much longer than that of dilute acid, but little sugar degradation. The critical factors are to optimize sugar recovery and cost effectively recovers the acid. The solid residue from the first stage is dewatered and soaked in a 30 to 40% concentration of sulphuric acid for 1 to 4 hr as pre-cellulose hydrolysis step. The solution is again dewatered and dried, increasing the acid concentration to about 70%. After reacting in another vessel for 1 to 4 hr at low temperatures, the contents are separated to recover the sugar and acid via ion exchange, then acid is re-concentrated via multiple effect evaporators. The sugar/acid solution from the second stage is recycled to the first stage to provide the acid for the first stage hydrolysis (Wahlund et al., 2004).

The hydrolysis can also take place ***simultaneously***[43] with the fermentation, as in the ***Simultaneous Saccharification*** and ***Fermentation*** (SSF) or ***Simultaneous Saccharification*** and ***Co-fermentation*** (SSCF) process (Lynd et al., 2005; 2002). Both SSF and SSCF require extensive pre-treatment of the cellulosic feedstock by steam-explosion or acid treatment, followed by addition of exogenously produced cocktails of cellulolytic enzymes to hydrolyse cellulose chains and release the glucose monomers required for fermentation (Carere et al., 2008). The SSF process (Fig. 3.20) consists of 4 major steps that may be combined in a variety of ways: pre-treatment, enzyme production, hydrolysis, and fermentation. The key to increasing the digestibility of lignocelluloses lies in increasing the cellulose surface area which becomes accessible to enzymes. By carrying out a pre-hydrolysis (dilute 1.1% sulphuric acid at 160 °C for 10 min), the hemicellulose fraction is removed (93% of the xylan is hydrolyzed resulting in fully digestible cellulose pulp) enlarging pore size and thus opening the structure to attack by enzymes. In the SSF process, enzymes that break down cellulose are produced separately by the fungus. Yeast and the enzymes are added to the remaining material where the enzymes digest the cellulose to produce glucose. Glucose is then fermented by yeast or other microorganisms to produce ethanol. IIT Delhi developed a process involving SSF followed by removal of ethanol using vacuum distillation. The SSF reactor is coupled to a settler and a flash vessel operated in conjunction with a vapour recompression system. The operation was programmed to work between two discrete steps, namely, 1) vacuum to remove the bulk of the ethanol produced and 2) feeding of fresh lots of cellulose equivalent to the ethanol removed. The average concentration of ethanol obtained in the fermented product is 12.4 wt% and ethanol productivity of 4.4 g/L/h.

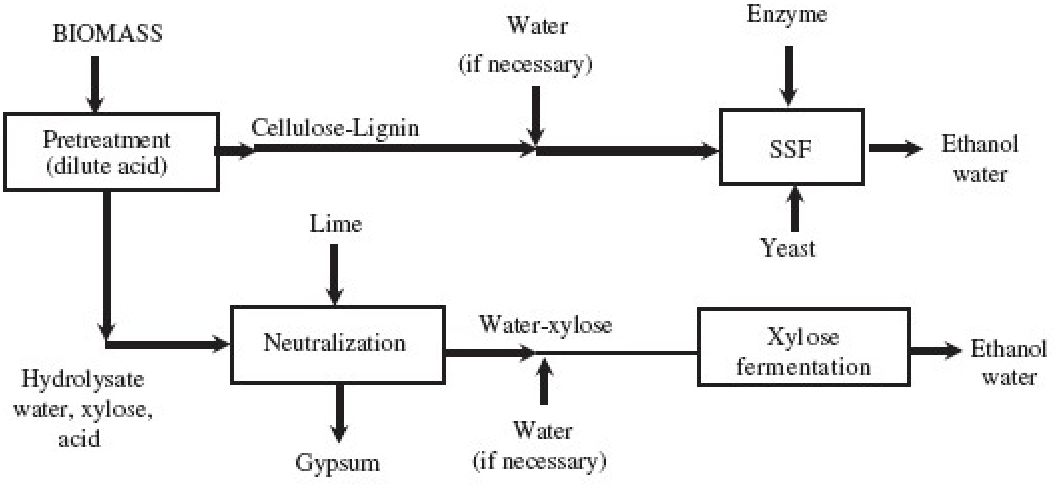

Fig 3.20: SSF process by NREL

Source: Saxena et al. (2007)

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[43] By combining the hydrolysis and glucose fermentation units, not only would the number of reaction vessels be reduced, but also it would reduce the potential problem of inhibitors reducing the effectiveness of the hydrolysis reaction, since any glucose sugars would be removed by the fermenting microbes. But it requires microorganisms that will ferment sugars at temperatures required for hydrolysis conditions.

3.3.2.4.2 Advantages and Drawbacks of Bioethanol from Lignocellulose

It is estimated that ethanol yields from the bio-conversion of lingo-cellulosic feedstocks range between 110 and 300 liter/t dry matter (Mabee et al., 2006; ORNL, 2006). Given the energy content of lingo-cellulose is around 20 GJ/dry t, the process conversion efficiency of 1 tonne of feedstock to give an energy yield of 2.3 to 2.6 GJ of liquid biofuels at the low end of the range is only around 12 to 15%. At the high end of the range, 5.7 to 6.3 GJ of biofuels is obtained, being closer to 35% efficiency (comparing with a 51% efficiency of complete conversion of carbohydrate-to-ethanol of lingo-cellulosic material containing 70% carbohydrates). The overall energy efficiency could be improved by combusting the lignin to provide heat or possibly by using some of the carbohydrate component for purposes other than for ethanol production. In sugar/starch-based processes, pretreatment can be as simple as pressing sugarcane to extract sucrose, or shucking corn cobs to separate the starch-rich kernels for further processing. When dealing with lignocellulosic feedstocks, however, the pretreatment step uses techniques analogous to traditional mechanical pulp processing where the lignin is either softened to release individual cellulosic fibers and/or removed to create a low-lignin pulp. But this leaves much of the intact ligning present in the resulting pulp. Steam explosion under mildly acidic conditions is currently the state-of-the-art pretreatment technology (not suitable for softwood and requires after- wash to remove degraded components, leading to loss of solulibized sugar).

3.3.2.4.3 Economic Aspect of Bioethanol from Lignocellulose

For bioethanol production, lignocellulosic biomass is the most promising feedstock considering from its great availability and low cost. Besides, this bioethanol may open new employment opportunities in rural areas, and thus make a positive socio-economic impact (Wyman, 2003; Bevan and Franssen, 2006 cite by Chandel et al., 2007). However, the large-scale commercial production of bioethanol from it has still not been implemented. Both raw material and capital cost contribute most to the total production cost. The cost of raw material (Approximately 60% of the production cost) varies considerably between different studies (22 to 61 US$/t dry matter), while the capital costs makes the total cost dependent on plant capacity. Pretreatment has been viewed as one of the most expensive processing steps in cellulosic biomass-to-fermentable sugars conversion with costs as high as 0.3 US$/gallon of bioethanol produced. Although the cost of commercial cellulose preparations has been reduced by up to 20-fold in recent years, enzyme costs are still an obstacle to full-scale process commercialization. Enzymes can be utilized at lower costs if they are recycled by treating multiple batches of feedstock using the same batch of enzymes. This can be achieved by the immobilization of enzymes on an inert carrier. Successful separation facilitates the generation of heat and power from using the lignin fraction, allowing sugars to be converted to ethanol or other co-products. The value of lignin as a fuel substitute for heat and power generation on-site can be significant with gas and electricity prices having doubled in the past 10 years, on-site generation of heat and power for in-mill use may be economic, particularly where government support exists.

3.3.2.4.4 Environment Aspect of Bioethanol from Lignocellulose

Generally, the biggest environmental advantage of bioethanol is that burning them does not result in extra CO_2, because during the reproduction of the plant it is consumed. By the utilization of bioethanol, the global CO_2 emission can be reduced by 50% compared to the use of fossil fuels. Moreover, the toxicity of the exhaust emissions from ethanol is lower than that of petroleum sources (Wyman and Hinman, 1990). Ethanol contains 35% oxygen that helps complete combustion of fuel and thus reduces particulate emission that pose health hazard to living beings. A study conducted by Bang-Quan et al. (2003) on the ethanol blended diesel (E10 and E30) combustion at different loads found that addition of ethanol to diesel fuel simultaneously decreases cetane number, high heating value, aromatics fractions, and kinematic viscosity of ethanol blended diesel fuels and changes distillation temperatures. With its ability to reduce ozone precursors by 20 to 30%, bioethanol can play a significant role in reducing the harmful gasses in metro cities worldwide. Ethanol blended diesel (E15) causes the 41% reduction in particulate matter and 5% NO_x emission (Subramanian et al., 2005).

The reduction of GHG pollution is the main advantage of utilizing biomass conversion into ethanol (Demirbas, 2007). GHG emissions from lignocellulosic ethanol chains will vary depending on the feedstock and the particular technology used to produce the fuel. The well-to-tank GHG emissions from lignocellulosic ethanol projected for 2020 are estimated to be in the range of 15.9 to 19.9 kg CO_2e/GJ (depending on whether energy crops or residues are used), resulting in a 76 to 81% reduction in GHG emissions compared with gasoline. Besides, A review of energy balance studies carried out by the US National Resources Defence Council (NRDC, 2006) indicated that, under current production methods, corn (starch-based) bioethanol gave only a slight improvement in energy efficiency over petroleum fuels, while cellulosic ethanol can improve this by up to 4 times. One of the disadvantage in using ethanol as fuel is that aldehyde predominantly acetaldehydes emissions are higher than those of gasoline. However, acetaldehydes emissions generate less adverse health effects in comparison to formaldehydes emitted from gasoline engines (Gonsalves, 2006 cite by Chandel et al., 2007).

Table 3.16: Emission levels from four different fuel types used in the transport sector in 2025.

Technology	CO_2 Kg/GJ	SO_2 Kg/GJ	NO_x Kg/GJ	Particles Kg/GJ
Diesel	333	0.01	0.62	0.02
Petrol	414	0.01	0.15	0.00
Second-generation bioethanol, E85	330	0.06	0.44	0.00
Methanol based on biomass	63	0.02	0.14	0.00

Source: The report "Alternative fuels in the transport sector" – The Danish Energy Agency, June 2007.

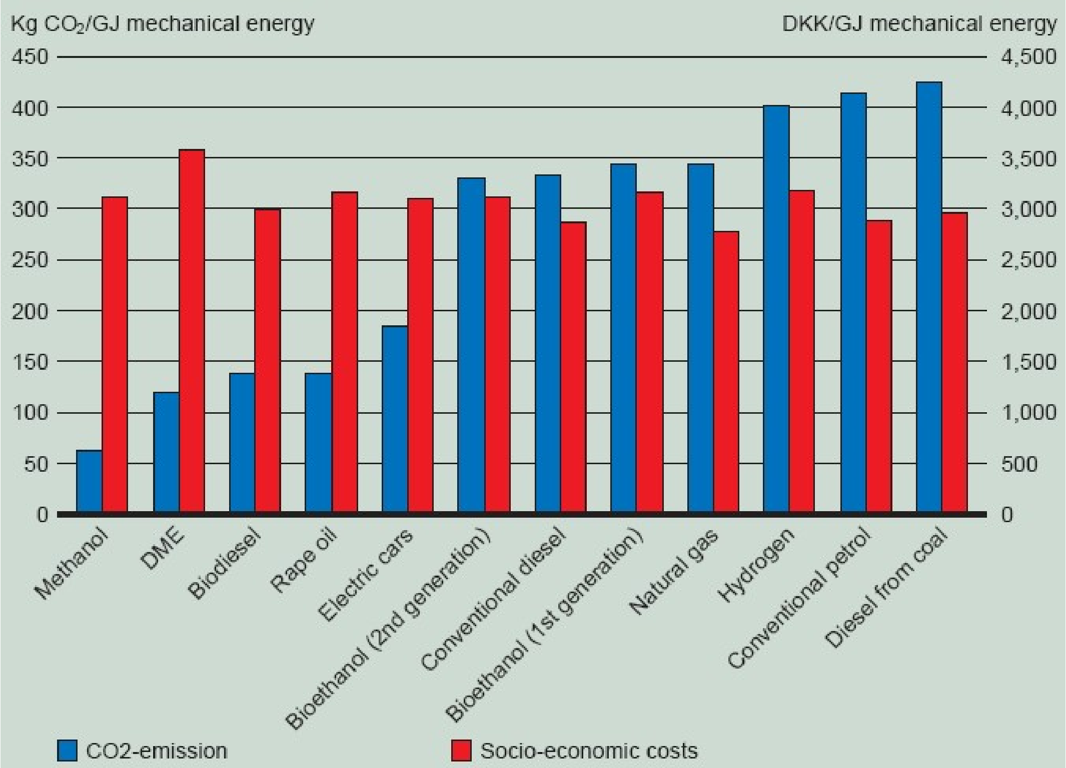

Fig. 3.21: CO2-emission and socio-economic costs related to various fuel types in 2025
Source: "Alternative fuels in the transport sector", the Danish Energy Agency (2007)

3.3.2.4.5 Problems and Barriers of Bioethanol from Lignocellulose

The key challenge of bioethanol from lignocellolose is to find more energy efficient and low cost processes in its production, and possibly to produce other fuels and fuel additives. Recent technological improvements have considerably reduced the cost of enzymes and the cost of pretreating biomass (Houghton et al., 2006; Wyman et al.,2005). Additionally, new approaches, such as the genetic modification of the biomass lignin structure (Chapple, et al., 2007; Chen and Dixon, 2007), have the potential to reduce the need for pretreatment. Acid hydrolysis is still relative the expensive option. One of the most promising technologies is considered to be enzymatic hydrolysis. This technology is currently more expensive than the other hydrolysis technologies, but is thought to have the greatest potential for cost reduction, to a level competitive with ethanol from other sources. Pan et al. (2006) showed that removal of between 35.5% and 43.2% of lignin from a steam-pretreated substrate was effective in enhancing the enzymatic hydrolysis yield from 50 to 85%. Currently, there are no known natural organisms that have the ability to convert both C5 and C6 sugars at high yields, although major progress has been made in engineering microorganisms for the co-fermentation of pentose and glucose sugars.

Co-fermentation of glucose and pentose sugars can be done, but their sensitivity to inhibitors and the production of unwanted byproducts remain serious problems. From literature, physiological effects of inhibitors on ethanol from lignocellulosic materials and fermentation strategies were comprehensively investigated. Laboratory testing has shown that the recovery from softwood after steam explosion pretreatment can be significantly lower than agricultural residues or hardwoods. Re-deposition and condensation of lignin on the surface of fibers can be a problem in fermentation process, especially for softwood. The key to commercially viable processes is low cost cellulase production, an area which is believed to have significant potential for cost reduction. The key areas of focus for research going forward are microbe development, scale up, process control, and plant design. In terms of making the process work, a number of demonstration plants have been able to demonstrate the science. The imminent construction of the first commercial plants, will demonstrate whether these routes suitably perform at scale. However, a high capital costs coupled with the high cost of capital increase the risk of a first of a kind technology and therefore hinders commercialization (Wyman, 2007; Wooley et al., 1999).

3.3.3 Third Generation of Biofuel

While global continue to spend vast amounts of money on developing the second generation biofuels, proposals heading directly for third generation technologies are being put forward. An example of such third-generation biofuels are those based on tree crops whose lignin-content has been artificially weakened and reduced, and disintegrates easy under dedicated processing techniques. Plant breeding, biotechnology, and genetic engineering promise to develop more efficient plant materials with faster growth rates, which require less energy inputs. However, second and third generation biofuels are also called ***advanced biofuels***. These technologies being discussed in this topic include BtL via direct route (to produce Bio-oils) and Algal Feedstocks.

3.3.3.1 Biomass To Liquid (BtL) via Direct Rout

For BtL via direct rout, these processes can be produce crude oil with properties similar to that of petroleum crude oil. They can be classified into two processes: ***Pyrolysis*** and ***Liquefaction***. Pyrolysis is thermal decomposition occurring in the absence of O_2. It is always the first step in combustion and gasification, but in these processes it is followed by total or partial oxidation of the primary products. With pyrolysis, lower process temperatures and longer vapour residence times favour the production of charcoal. High temperatures and longer residence times increase biomass conversion to gas, and moderate temperatures and short vapour residence time are optimum for producing liquids. Table 3.17 indicates the product distribution obtained from different modes of pyrolysis. ***Fast pyrolysis*** for liquids production is currently of particular interest because liquids can be stored and transported more easily and at lower cost than solid biomass.

Table 3.17: Biomass Pyrolysis Technologies, Reaction Conditions, and Products

Process	Residence time	Temp (°C)	Heating rate	Major products
conventional carbonization	hours-days	300-500	very low	charcoal
pressurized carbonization	15 min-2 h	450	medium	charcoal
conventional pyrolysis	hours	400-600	low	charcoal, liquids, gases
conventional pyrolysis	5-30 min	700-900	medium	charcoal, gases
flash pyrolysis	0.1-2 s	400-650	high	liquids
flash pyrolysis	<1 s	650-900	high	liquids, gases
flash pyrolysis	<1 s	1000-3000	very high	gases
vacuum pyrolysis	2-30 s	350-450	medium	liquids
pressurized hydropyrolysis	<10 s	<500	high	liquids

Adapted from Klass (1998) by Huber et al. (2006)

Liquefaction is the conversion of biomass into a stable liquid hydrocarbon using low temperatures and high H_2 pressures (WSL, 1993). The process produces a marketable liquid product. The interest in liquefaction is low, because the reactors and fuel feeding systems are more complex and more expensive than for pyrolysis processes (McKendry, 2002b).

A generalized conceptual flow sheet for liquefaction is shown in Fig. 3.22. Concerning the catalytic effect of alkali hydroxides and carbonates, there has been little description about that a catalyst plays in liquefaction with some exceptions (Demirbas, 2001). Pyrolysis oils are water soluble and have a higher oxygen content than that of a water-insoluble oils from liquefaction.

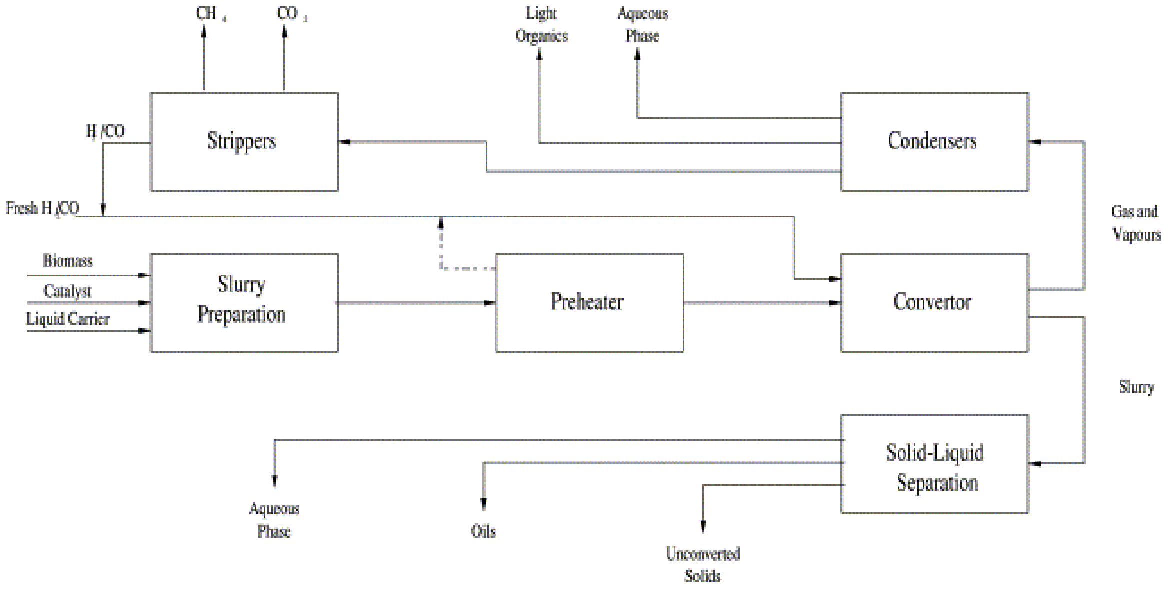

Fig. 3.22: Flow sheet example of liquefaction process
Source: McKendry P. (2002b)

3.3.3.1.1 Process and Technology of BtL via Direct Route

Pyrolysis[44] is the conversion of biomass to liquid (termed ***bio-oil*** or ***biocrudeoil***), solid, and gaseous fractions, by heating the biomass in the absence of air to around 500 °C. First, the biomass needs to be dried, which can be done by low-grade process heat such as the outlet flue gas. The biomass particles must then be ground so that they have the optimal heat transfer properties. The cost of grinding, however, increases when smaller particles are desired. Unfortunately, there is quite a bit of confusion in the literature, and many so-called pyrolysis systems are actually gasification systems. Both pyrolysis and gasification systems are used to convert solid waste into gaseous, liquid, and solid fuels. The principal difference between the two systems is that pyrolysis systems use an external source of heat to drive the endothermic pyrolysis reactions in an oxygen-absence environment, whereas gasification systems are generally self-sustaining and use air or oxygen for the partial combustion of solid waste. Pyrolysis can be used to produce predominantly bio-oil if flash pyrolysis is used, enabling the conversion of biomass to biocrude with an efficiency of up to 80%. Nonthermodynamically controlled products, bio-oil can be used as fuel in internal combustion engines or turbines, however its utilization as a feedstock for biorefineries is also being considered (McKendry, 2002b).

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[44] Vacuum pyrolysis has the advantage of short residence time for volatiles, with longer residence time for the solids. The disadvantages of vacuum pyrolysis are that poor heat and mass transfer rates occur.

Under controlled process conditions, **fast pyrolysis** can result in a greater proportion of liquid products. The residual solid char can be used to provide heat for the process or for drying the biomass. To maximize the yield of liquid products resulting from biomass pyrolysis, a low temperature, high heating rate, and short gas residence time process would be required. If the purpose were to maximize the yield of fuel gas resulting from biomass pyrolysis, a high temperature, low heating rate, long gas residence time process would be preferred. Fast pyrolysis occurs in a time of a few seconds or less. Therefore, heat and mass transfer processes, phase transition phenomena, as well as chemical reaction kinetics play important roles. The critical issue is to bring the reacting biomass particles to the optimum process temperature and minimize their exposure to the intermediate (lower) temperatures that favour formation of charcoal. One way this objective can be achieved is by using small particles, for example in the fluidized bed processes that are described later. Another possibility is to transfer heat very fast only to the particle surface that contacts the heat source as applied in ablative pyrolysis. A critical technical challenge in every case is heat transfer to the reactor in commercial systems.

Direct hydrothermal liquefaction involves converting biomass to an oily liquid by contacting the biomass with water at elevated temperatures (300 to 350°C) with sufficient pressure to maintain the water primarily in the liquid phase (120 to 200 bar) for residence times up to 30 min. Alkali may be added to promote organic conversion[45]. The primary product is an organic liquid with reduced oxygen content (about 10%) and the primary byproduct is water containing soluble organic compounds. A well known process, ***hydrothermal treatment*** is based on early work performed by the Bureau of Mines Albany Laboratory in the 1970s. Developers include Changing World Technologies (West Hampstead, NY), EnerTech Environmental Inc (Atlanta, GA), and Biofuel B.V. (Heemskerk, Netherlands). Celeghini and Lancas (1998) studied the experimental variable effects on direct liquefaction. This study provides information on how bagassse lignin was submitted to a liquefaction process to obtain light oil. In another study (Jongwon, 1999) the effect of the addition of lignin to coal during liquefaction, by utilizing the black liquor waste stream from pulping process, is investigated. The HTU® Process offers excellent opportunities for conversion of biomass to a transportable form of energy with a heating value approaching that of fossil fuels. It converts biomass in liquid water at temperatures of about 300 °C to a '*biocrude*' which resembles the atmosferic distillate of crude oil. On the basis of research carried out in 1981 to 1989 by the Shell Laboratory in Amsterdam, while technical/economic feasibility studies were carried out in 1995/1997. They concluded that the process is potentially well placed in comparison with the main alternatives for biomass conversion. Main strengths are the (prospective) economics, processability of a wide variety of (wet) feedstocks, product quality/flexibility, and the potential for upscaling and rapid rate of commercial development.

3.3.3.1.2 Advantages and Drawbacks of BtL via Direct Route

Pyrolysis oil is not only easier to store and transport than solid biomass material, but is burned like petroleum to generate electricity. The fast pyrolysis of solid biomass feedstock into a bio-oil allow larger particle sizes (up to 5 mm) to be used than for some other gasification technology, thereby reducing the comminution costs and energy inputs. Bio-oil, containing a wide range of chemicals, can be produced by thermal decomposition of biomass

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[45] For other systems, the reactor feeds consist of slurry containing the solid biomass feed in a solvent, reducing gases such as H_2 or CO, or a catalyst. A number of different solvents have been used for liquefaction including water (the most common solvent), creosote oil, ethylene glycol, methanol, or recycled bio-oil.

in the near absence of oxygen. The twin-screw pyrolysis reactor, for example, is a mature technology. It is similar to entrained flow gasification, but the temperature is lower (about 500 °C) and it operates at atmospheric pressure. The chopped biomass is not heated directly, but with a hot sand medium (similar to FDB gasification). The pyrolysis gases are cooled down as quickly as possible (in a few seconds) to temperatures below 100 °C and a liquid condensate (pyrolysis oil) is obtained. The char from the pyrolysis process is separated from the sand in a cyclone, then milled and the char powder mixed with the pyrolysis oil, form bio-oil/char slurry, thereby increasing the overall carbon conversion efficiency. This mix could then be fed into a direct entrained flow gasifier without too many concerns. However, the drawback of the technology is that pyrolysis oil is a strong acid and thus necessitates expensive storage and handling equipment constructed of corrosive resistant materials. In addition, its low flashpoint raises safety issues. Some problems in the conversion process and use of the oil need to be overcome; these include poor thermal stability and corrosivity of the oil. Upgrading by lowering the oxygen content and removing alkalis by means of hydrogenation and catalytic cracking of the oil may be required for certain applications (Demirbas and Gullu, 1998).

Although pyrolysis has a lower capital cost than liquefaction and many pyrolysis technologies are currently being used commercially, the advantages of liquefaction process are the high thermal efficiencies for conversion of wet feedstocks, good product quality/flexibility, the potential for up scaling, and rapid rate of commercial development. The high-pressure processing that occurs with liquefaction causes technical difficulties and an increased capital cost. Moreover, the HTU bio-oils do have a high viscosity, and it is questionable if this technology could indeed be rapidly commercialized. ***Research*** in bio-oil production has shifted to focus on production of less costly fast pyrolysis oils mainly due to the high capital cost involved for high-pressure liquefaction processes. According to Elliott et al., upgrading of the high-pressure liquefaction-derived bio-oils does not appear to have any significant advantage in the upgrading area. However, in the long term liquefaction-derived bio-oils may prove to be more beneficial, since they have properties more similar to transportation fuels.

3.3.3.1.3 Economic Aspect of BtL via Direct Route

The advantage of bio-oil production is that it requires only a single reactor, a large fraction of the biomass energy (50 to 90%) can be converted into a liquid, and a wide range of feedstocks can be used for bio-oil production - including wood, black liquor, agricultural wastes, and forest wastes -. Pyrolysis produces energy fuels with high fuel-to-feed ratios, making it the most efficient process for biofuel conversion of up to about 70% for flash pyrolysis processes, and the most capable method competing and eventually replacing non-renewable fossil fuel resources (Demirbas, 2008). However, the major challenges for producing bio-oils are: 1) Cost of bio-oil is 10 to 100% more than fossil fuel (based on the cost of fossil fuels in 2004); 2) Availability: there are limited supplies for testing and development of applications; 3) There are a lack of standards and inconsistent quality; 4) Bio-oils are incompatible with conventional fuels; 5) Users are unfamiliar with this material; 6) Dedicated fuel handling systems are needed; 7) Pyrolysis as a technology does not enjoy a good image. Commercially, bio-oils are used as boiler fuel for stationary power and heat production, and for chemical production. Bio-oils must be upgraded, if they are to be used as transportation fuels. They can be upgraded into a liquid transportation fuel by three different routes: 1) hydrodeoxygenation with typical hydrotreating catalysts (sulphided CoMo or NiMo); 2) zeolite upgrading; or 3) forming emulsions with the diesel fuel. Alternatively, bio-oils and chars can be converted into H_2 or syngas by steam-reforming process.

3.3.3.1.4 Environment Aspect of BtL via Direct Route

A relatively cheap energy carrier that enables easy transport of the stored and has high density energy prior to its application, bio-oil can be burned for direct heat production in a combustion process; used as feedstock in a bio-refinery for extraction of chemicals; or gasified to syngas. During bio-oil production, chars are produced, which can be converted into H_2 or syngas by steam reforming. Alternatively, the chars can be burned as a solid fuel. Selecting the technology with the most promising environmental and economic attributes from the optional routes available for the thermo-chemical conversion of biomass continues to be under review. However, as the process is still at an early stage of development and there is no agreed upon process by which transport fuels would be produced using a pyrolysis process, it is not possible to estimate the GHG savings from this route. Conversely, the carbon intensity of the fuel will depend on the carbon intensity of the feedstock production and of hydrogen production and consumption, if a hydrotreating process is used.

3.3.3.1.5 Problems and Barriers of BtL via Direct Route

Biomass pyrolysis itself is at the early commercial stage, with few relatively small scale plants operating. The key areas for improvement of this technology are: different reactor designs are being pursued by different developers; optimization of process relative to feedstock used should be considered. The most significant problems of bio-oils as a fuel are poor volatility, high viscosity, coking, corrosiveness, and cold flow problems. These problems have limited the applications of bio-oils. Additionally, bio-oils polymerize and condense with time, and this process is accelerated by increasing temperature, oxygen exposure, and UV light exposure. During bio-oil storage, the inorganic compounds of biomass also catalyze polymerization and other reactions in the bio-oil leading to a viscosity increase. Leaching of processing and storage equipment by the acidic bio-oils can also cause inorganic contaminants in the bio-oils. Therefore, care must be taken to properly design equipment. No quality standards have yet been made for bio-oil production. The main concerns for burning bio-oils in diesel engines have to do with difficult ignition (due to low heating value and high water content), corrosiveness (acids), and coking (thermally unstable components). Inorganic impurities of the biomass play a key role in terms of the bio-oil product selectivity (Badger, 2002).

The presence of catalyst seemed to substantially influence the behaviour of raw material towards liquids. A catalyst, especially an acidic one like FCC, affected the type and number of secondary reactions of pyrolysis, increasing the quality of liquids. Besides the type of pyrolysis, the yield and composition of the hydrogen-rich gas products were also related to the chemical composition of the biomass. Residues having more cellulose and hemicellulose content produced more hydrogen-rich gas than those characterized by a higher lignin content. Problems with the conversion process and subsequent use of the oil, such as its poor thermal stability and its corrosivity, both still need to be overcome (McKendry, 2002b). Bio-oil aging[46] should not be a problem since storing longer than 12 months is very unlikely and it should not be forgotten that fossil fuels also age. Phase separation is still seen as the major problem, usually caused by high feed moisture or mixed feed such as forestry residues with a high bark content. Because bio-oil is so much different from petroleum fuels for example, low flash-point, but a high ignition temperature, it requires new standards that have to be developed. Upgrading bio-oils by lowering the oxygen content and removing alkalis by

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[46] Aging is characterized by an increase in bio-oil viscosity, decrease in volatility, and ultimately phase separation into a heavy non-aqueous phase and light aqueous phase (Diebold, 2002).

means of hydrogenation and catalytic cracking of the oil may be required for certain applications. Possible treatment and upgrading options for bio-oil are shown in Fig. 3.23 below (McKendry, 2002b). The bio-oil can be refined into an acceptable diesel fuel substitute by: 1) hydro-deoxgenation (using high pressure hydrogen); 2) using a zeolite catalyst which is cheaper but produces lower yields; 3) steam reforming into syngas which can be converted into a range of liquid fuel; or 4) blending with diesel using surfactants to reduce the high viscosity characteristics. Several pyrolysis pilot plants have been constructed in Germany, US, Australia and Brazil but scaling up for commercial liquid transport fuel production is expensive (Henrich, 2007).

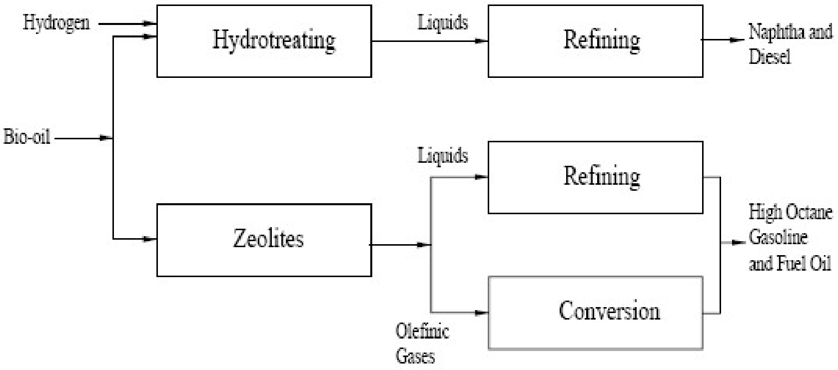

Fig. 3.23: Treatment and upgrading options for bio-oil
Source: McKendry (2002b)

3.3.3.2 Algal feedstocks

Aquatic algae are other sources of triglycerides, as well as carbohydrates and lignin. They are the fastest-growers in the plant kingdom, utilize a large fraction of the solar energy (up to 10% of the solar energy), and can grow in unsuitable conditions for terrestrial biomass. When photosynthesizing, certain species can produce and store inside the cell, large amounts of carbohydrates and up to 50% by weight of oil as triglycerides (Campbell, 2008). Algae have triglyceride production rates of 45 to 220 times higher than that of terrestrial biomass.The conversion of algae oil into biodiesel is a similar process to that of vegetable oils. This conversion bases on inter-esterification of the triglycerides after oil extraction. The potential of algae has been understood for many years and research was widely undertaken in the 1970s, for example by the U.S. DOE, before abandoning it in the mid-1990s. More recently, worldwide interest has been renewed, since seawater and coastal land can be used for production, there will be no competition for agricultural land and water resources (Sims et al., 2008).

3.3.3.2.1 Process and Technology to produce Algal

Algae can be produced continuously in closed photo-bioreactors, but oil concentration is relatively low, then capital costs are high. To collect cheaply oil would need high volumes of algae to be cultivated in large facilities at low cost, hence the interest in growing the algae in open ponds, including sewage ponds where nutrients are abundant and the sewage is partly treated as a result. In practice, a problem is contamination of the desired culture by other organisms that limit algal growth. A combination of closed and open systems is, therefore, a proper option (Huntley & Redalje, 2007). The microbes are initially grown in closed reactors under controlled conditions that favour continuous cell division and prevent contamination. A portion of the culture is transferred daily to an open pond where it is subjected to stress and nutrient deprivation. This stimulates cell concentration and oil production within a short residence time before contamination can occur. Oil production costs of around USD 84/bbl were claimed with cost reductions thought possible due to improved technology and experience. Currently researchers at University of Minnesota and elsewhere are evaluating the optimum strains of algae and determining how to extract the oil most efficiently. Increased funding has been received from governments, oil companies, utilities, and venture capital firms over the past two years. Although no valuable arable land is needed, the cost of production and processing is thought to be around a relatively high USD 5/L. In New Zealand, where a Range Rover was powered by an algae biodiesel blend in 2006, researchers say uncertainty remains about when algal biofuels will become commercially viable. The US Defence Advanced Research Projects Agency is funding research into producing jet fuel from plants, including algae. Honeywell, General Electric Inc. and the University of North Dakota are involved (Sims et al., 2008).

AlgoDyne Ethanol Energy Corp., Washington, has conducted a series of biofuels initiatives in Brazil including planned bio-kerosene projects and the development of a pilot plant for ethanol production from algae. In September 2006, the Brazilian biofuel company Tecbio, Fortaleza, Brazil announced that it was working with NASA and Boeing to develop a bio-kerosene aviation fuel. A flight test was carried out in 1984 with 100% bio-kerosene in a twin-prop Bandeirante aircraft manufactured by Brazilian company “Embraer” that also developed a small ethanol-powered plane. A new version of the fuel claimed to overcome several technical hurdles is to be patented in 2008. If algae by Tecbio could provide 80,000 l/ha/y as some claim, about 320 billion liters/y of "bio-jet" fuel could be produced on a landmass and be sufficient to supply the present world's aircraft fleet with 100% of its fuel needs. In Hawaii, Royal Dutch Shell has established a company, Cellana, to work with the small local company HR Biopetroleum and build a demonstration plant on the island of Kona to commercially harvest algae and demonstrate that it can be technically viable to convert it into biodiesel. A 2.5 ha site has been built close to seawater ponds where the algae have been growing for 2 years. The construction of a separate 1,000 ha site is also planned to evaluate whether algae can become economic when scaled up to a commercial level. If the results are encouraging, the next step would be to build a 20,000 ha site[47].

3.3.3.2.2 Advantages and Drawbacks about Algal Feedstocks

The main advantages of second generation microalgal systems are that they: 1) have a higher photon conversion efficiency; 2) can be harvested batch-wise nearly all-year-round, providing a reliable and continuous supply of oil; 3) can utilize salt and waste water streams, thereby greatly reducing freshwater use; 4) can couple CO_2-neutral fuel production with CO_2 sequestration; 5) Produce non-toxic and highly biodegradable biofuels. The micro-algae oil yield per hectare is claimed to be 16 times higher than palm oil and up to 100 times higher than for traditional vegetable oil. Algae also consume 99% less water. But to produce large oil volumes, large surface areas of ponds are involved, requiring high capital investment. In addition, since algae can absorb CO_2, they are also being studied to clean flue gas from coal-fired power plants. The injection of CO_2 collected from fossil-fuelled thermal power plants could be used to enhance growth. The current limitation of microalgae is the high production cost. The total biomass algae cost was \$273 and \$185/t, which is considerably higher than the cost of lignocellulosic biomass (less than \$40/t).

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[47] Other companies with an interest in algae for biofuel production include www.solixbiofuels.com and www.greenfuelonline.com

3.3.3.2.3 Economic Aspect about Algal Feedstocks

Microalgae commonly double their biomass within 24 h. Oil content in microalgae can exceed 80% by weight of dry biomass (Metting, 1996; Spolaore et al., 2006). Depending on the algal growth rate and the oil content of the biomass, microalgae with high oil productivities are desired for producing biodiesel. Producing microalgal biomass is generally more expensive than growing crops. To minimize expense, biodiesel production must rely on freely available sunlight, despite daily and seasonal variations in light levels. World experts were invited to collaborate and apply for significant funding opportunities in 2008 and beyond. The main aim was to develop a highly-efficient system for lowcost algal oil production and to optimize conversion to JP-8. The economic targets were given as algae hydrocarbon costs of US $0.48 per litre ($2 per gallon) with a minimum order of 210 M litres (50 M gallons). At this price, algae by-products would have to factor into the economics to make it viable. However, the cost of producing microalgal biodiesel can be reduced substantially by using a biorefinery[48] based production strategy, improving capabilities of microalgae through genetic engineering, and advances in engineering of photobioreactors.

3.3.3.2.4 Environment Aspect about Algal Feedstocks

Microalgal biofuels are also likely to have much lower impacts on the environment and the world's food supply than conventional biofuel-producing crops. The main reasons for this are high yields, a near-continuous harvest stream, and the potential to site the algal bioreactors on non-arable land. Therefore, there are a large number of companies starting up in this area which quote high yields for algal oil production and who release press statements saying that they will be producing large quantities of algal biodiesel in the coming months or years. However, none of these companies have yet produced algal biofuels at scale and none have produced evidence of the GHG intensity of their fuel. It is believed that whilst this is potentially a promising technology, there is still much to be done in terms of basic R&D and also understanding and improving the GHG intensity of the process.

3.3.3.2.5 Problems and Barriers about Algal Feedstocks

The biggest challenge over the next few years in the biodiesel field of algal feedstocks will be to reduce costs for cultivation and to further improve the biology of oil production. New materials and designs for cultivation in closed bioreactors and the use of cutting-edge metabolic engineering and screening/selection techniques are thought to provide the biggest promises. The only practicable methods of large-scale production of microalgae are raceway ponds (Terry and Raymond, 1985; Molina Grima, 1999 cited by Chisti, 2007) and tubular photobioreactors (Molina Grima et al., 1999; Tredici, 1999; Sánchez Mirón et al., 1999 cited by Chisti, 2007). Microalgae cultivation issues are limited by the availability of water, CO_2, sunlights, and flat land. The development of low-cost harvesting processes could also reduce the cost of algae. A recent overview of algae potential for transport fuels conducted for the IEA Advanced Motor Fuels Implementing Agreement (McGill, 2008), concluded that even if the technical barriers can be overcome, the practical barriers such as location, land use etc. will take many years to be removed and that commercialization will be evolutionary, not revolutionary.

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[48] biorefinery is a processing plant for converting waste and virgin biomass feedstocks to energy, fuels, and other products (Klass, 2004) (see Ch. 3.4.3).

3.4 Outlook

There are still various biomass energy technologies/concepts that can be applied to produce a variety of energy forms. However, they are still in development or demonstrating stage. In this out look, all of them will be monitored carefully.

3.4.1 Refuse Derived Fuel (RDF)/Refuse Liquefaction

3.4.1.1 Introduction

Refuse-derived fuel (RDF) or **S**olid **R**ecovered **F**uel/ **S**pecified **R**ecovered **F**uel (SRF[49]) is a fuel produced by shredding **M**unicipal **S**olid **W**aste (MSW) or steam pressure treating in an autoclave. RDF consists largely of organic components of municipal waste such as plastics and biodegradable waste. There are two technologies which have been developed and produce high calorific fraction to be used as RDF in Europe as follows; 1) Mechanical Biological Treatment plant. In this technology, after metals and inerts are separated out, organic fractions are screened out for further stabilization using composting processes, either with or without a digestion phase. It also produces a residual fraction which has a high-calorific value as it is composed mainly of dry residues of paper, plastics, and textiles; 2) Dry Stabilization Process, where residual waste (excludes inerts and metals) are effectively dried (and stabilized) through a composting process, produces the residual mass with higher calorific value and suitable for combustion. The high calorific output of this process developed in Germany has the trade name of ‘Trockenstabilat’ (Gendebien et al., 2003).

RDF processing facilities are normally located near a source of MSW, while an optional combustion facility is normally close to the processing facility or may also be located at a remote location. The thermal treatment processing of municipal solid waste, used both for volume reduction and energy recovery, is an important element in many integrated solid waste management systems. Liquefaction is one of the proper energy conversion processes (see Ch. 3.3.3.1). Solid biomass is converted into liquid fuel by thermo-chemical treatment. The generation of tar, oil, and chars from plant material and it various components has been a subject of study for over a century. Research is aimed at improving the conversion of biomass into fuel (oil and biogas). Much research has been undertaken, worldwide; development of technologies from the experimental results is underway and, in addition to the investigation of a pilot system, large-scale systems have been established. Appell et al. (1975) have entensively studied the conversion of cellulosic wastes into liquid fuel in aqueous alkaline media. Some liquefaction experiments have been applied to various lignocellulosic waste materials in aqueous solutions of acetic acid and sodium hydroxide in the laboratory (Taner 1986a; 1986b; 1988; Taner et al., 1989 cite by Taner et al., 2004).

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[49] SRF can be distinguished from RDF in the fact that it is produced to reach a standard such as CEN/343.

3.4.1.2 Process and Technology

Over the years, different waste management, treatment, and disposal methods have been adopted apart from the traditional options of landfill and incineration. Emphasis is now shifting to technologies that will be acceptable to the end users. RDF production is designed to divert combustible fractions from municipal solid wastes (MSW) to produce fuel and then to be used as substitution or supplementary energy. In terms of applications, RDF has been used in industrialized countries as a fuel supplement for coal-fired utility boilers and as the sole fuel for firing in dedicated boilers (i.e., boilers that use RDF exclusively). When fired as a supplemental fuel in coal-fired boilers (i.e., co-fired), experience has shown that RDF with heating values in the range of 12,000 to 16,000 J/g (wet wt basis) can successfully contribute up to about 30% of the input energy.

It is argued that RDF co-incineration in industrial processes has several advantages such as saving non-renewable resources by substituting fossil fuels in high-demand energy processes. However, there are concerns over the discrepancies between the controls applied on dedicated incineration and co-incineration plants and argument that it encourages their removal from the material recovery/re-use cycle, thereby going against the waste hierarchy which rates waste prevention/minimisation and recycling as being preferable to energy recovery and disposal. On the other hand, some argue that using RDF in industrial processes compared with bulk incineration has a flexibility advantage as to optimise economic performance; incinerators must be fed with a constant through put of waste which could in certain cases hinder the development of prevention or recycling initiatives. In the USA, there are a number of factors which would seem to be favouring an increased use of RDF in co-incineration facilities. Whilst the economic drivers may be increasingly strong, they are somewhat complex and coupled with local conditions and policies such as the strategy chosen by Member States to implement the Landfill Directive and its obligation to divert large quantities of biodegradable material away from landfill within the next few years.

Apart from co-incineration and combustion, pyrolysis and liquefaction are also focused on. Coarsely-shredded waste is converted in an enclosed reactor which is normally operated at or below atmospheric pressure with the absence of oxygen. Waste within the pyrolysis chamber is transformed by a cracking process into hydrocarbons (combustible gases and oils/tar) at temperatures of 500 to 800 ^{o}C. A solid residue containing carbon, ash, glass and metals (up to 40% by weight) is all that remains of the waste and this may be burned separately after it is screened for metals, mineral parts etc. Pyrolysis of waste is not a stand-alone process, but is generally followed by a gasification or combustion step and in some cases extraction of pyrolytic oil when it may be referred to as liquefaction. The 3 major component fractions resulting from the pyrolysis process are the following: 1) A gas stream, containing primarily H_2, CH_4, CO, CO_2, and various other gases, depending on the organic characteristics of the material being pyrolyzed; 2) A liquid fraction, consisting of a tar or oil stream containing acetic acid, acetone, methanol and complex oxygenated hydrocarbons. With additional processing, the liquid fraction can be used as a synthetic fuel oil, a substitute for conventional fuel oil; 3) A char, consisting of almost pure carbon plus any inert material originally present in the solid waste.

3.4.1.3 Economic Aspect

RDF can be used in a variety of ways to produce electricity. It can be used alongside traditional sources of fuel in coal power plants. RDF can also be fed into plasma arc gasification modules, pyrolysis plants, and where the RDF is capable of being combusted cleanly or in compliance with the Kyoto Protocol. Therefore, RDF can provide a funding source where unused carbon credits are sold on the open market via a carbon exchange. The most common methods used for MSW are landfilling, composting, recycling, mechanical-biological treatment and waste-to energy (WTE). According to actual operating data collected by the US WTE industry, on the average, combusting 1 metric tonne of MSW in a modern WTE power plant generates a net of 600 kWh of electricity, thus avoiding mining a 1/4 tonne of high quality US coal or importing one barrel of oil. WTE is the only alternative to landfilling of non-recyclable wastes, where the decomposing trash generates carbon dioxide and methane, a potent greenhouse gas, at least 25% of which escapes to the atmosphere even in the modern sanitary landfills that are provided with a gas collection network and biogas utilization engines or turbines. The non-captured methane that escapes before a landfill is ‘‘capped” so that the landfill biogas can be collected, has a greenhouse gas (GHG) potential 21 times that of the same volume of carbon dioxide (IPCC, www.ipcc.ch). However, use of RDF in industrial processes offers more flexibility than incineration. It leaves more opportunity for future recycling programmes, it does not need to be fed with a constant amount of waste and it does not require investment in capital intensive dedicated incineration facilities.

3.4.1.4 Environment Aspect

RDF becomes one of the interesting alternatives to solve both global warming and problems of municipal solid waste management. Its benefits are not only to improve world environmental quality, but also reduce local economical loss. However, due to high moisture content, low calorific value and high ash content of raw MSW, it is needed to segregate the raw MSW and produce RDF. The advantage of RDF over raw MSW is that RDF has higher calorific value and more consistency in quality. The assessment of the environmental impacts of the production and use of RDF has been undertaken using a multiple approach including: 1) An LCA type system analysis that considers general benefits or disadvantages of the total recovery system of RDF; 2) An EIA type estimation of local impacts of the production and use of RDF; and 3) An assessment of impacts on the products from industries co-incinerating RDF.

The use of wastes and residues can be very economical and environmentally beneficial. If left to decay, CO_2 (and possibly methane) is released to the atmosphere. When wastes and residues displace fossil fuels, CO_2 emissions are still produced but the fossil carbon stays in the ground. Drawbacks include the potential for undesirable contaminants in the wastes and excessive removal of crop residues from the fields. The environmental impact of MSW management was reduced (lower GHG emissions, energy production, land savings, materials recovery, etc.). Furthermore, the emissions of toxic and dangerous substances like mercury and dioxins have been significantly reduced, thus protecting public health. Evaluating further these results, it can be seen that the WTE facilities have quite lower emissions compared to electricity production facilities from fossil fuels (except natural gas), reducing further the GHG emissions from landfills while at the same time decreasing the dependency for power production on fossil fuels.

3.4.1.5 Problems and Barriers

Visvanathan et al. (2005) pointed out that MSW stream in most Asian countries contains high biodegradable fraction and moisture. Direct landfill without pretreatment is not environmental friendly approach. Also incineration is not suitable. Therefore, pretreatment of MSW by MBT will bring sustainable SWM in Asia. Pyrolytic technology among other methods is a way of harnessing the energy in these wastes, providing a good method of disposing the wastes without affecting the ecological system (John et al., 1980; Robert, 1998). However, liquid hydrocarbon oil and water have been produced from the liquefaction of cellulosic matter present in municipal solid waste. The resulting oil and water fraction seemed to be contaminated with considerable amounts of oxygen compounds as compared with fuels derived from a petroleum origin (Gharieb et al., 1988).

3.4.2 Whole Tree Energy (WTE) Concept

3.4.2.1 General Concept

Whole Tree Energy (WTE) Concept was developed and patented by David Ostlie, University of Wisconsin (the U.S.) to produce biopower on a large scale. To recap the concept, trees are severed at ground level using a feller-buncher and stacked butt-end forward on truck-trailers with stake-sides (Fig. 3.34). The trucks transport the trees to a specially designed power plant where the trees are unloaded and stored in an air-inflated dome. During the 30 days in storage, waste heat from the power plant’s condensers are used to dry the trees, still in whole tree form, from 50 down to 25% MC. After drying, batches of trees are lifted onto ratcheted drag conveyors that carry them to the burner where a cut-off saw cuts them into 6 m long batches, then they were dumped into the combustion chamber. Depending on the load, the furnace is charged every 5 to 20 min by opening a gate allowing a ram to push a batch into the combustion chamber. Inside the furnace, the tree segments burn as very large particles, allowing excellent air flow through the burning material and minimizing the need for excess air. Minimizing excess air in turn minimizes the formation of atmospheric NO_x and greatly improves combustion efficiency due to reducing stack losses. Combustion occurs in three stages. In the first stage, the tree segments are supported on a stationary/water-cooled grate that allows the volatiles to be readily released under substoichmetric conditions at approximately 1,093 ºC. In the second stage these volatiles are mixed with overfire air above the pile and combusted at 1,482 ºC. In the last stage, the char remaining after devolatilization falls through the grate openings and burns below the pile. Heat from the burning char is captured in the water-cooled grate (Bain et al., 1998; Ragland et al., n.d.).

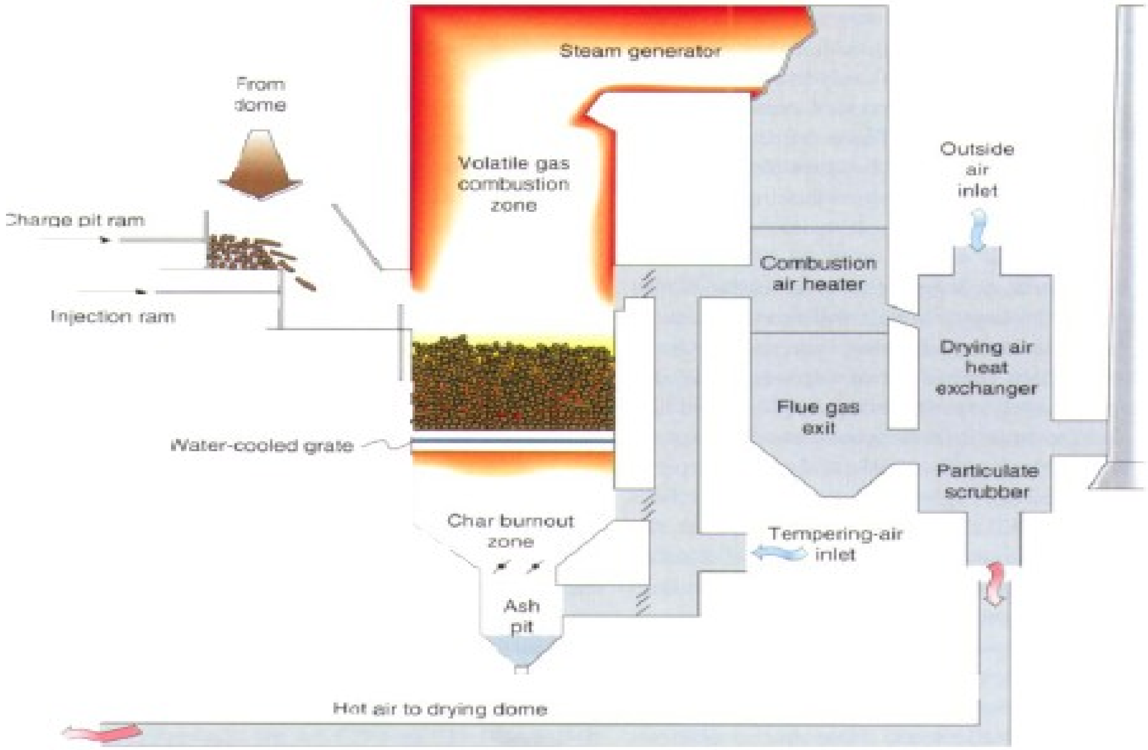

Fig. 3.34: Process of WTE concept.
Source: Lamarre (1994)

3.4.2.2 Advantages and Drawbacks

WTE concept show the highest electrical efficiency, namely 44 and 39% respectively. However, the capacity that will be needed to achieve these efficiencies is much larger (250 MW_e and 100 MW_e respectively) than that of the existing biomass combustion plant. Another advantage of the WTE concept is the low investment costs. It has become clear that efficiencies ranging from 38 to 44% are obtainable with biomass combustion systems only if large-scale plants are used (capacity ranging from 100 MW_e up to 250 MW_e). At these capacities, high investment in material that can resist high steam pressures, corrosion, and temperature are economic. However, Bain et al. (1998) argued that, although elements of the process have been tested, the system has not been run as an integrated process.

3.4.2.3 Economic Aspect

One obvious advantage of the system is both the minimization of field processing & handling, and the elimination of the need for chipping. An EPRI study has shown that eliminating the chipping process can save about 35% of the cost of harvesting and handling the fuel before it arrives at the power plant. Moreover, the method of "large particle" combustion is highly efficient, producing minimal particulates, NO_x formation, and sensible heat loss. Tests conducted by Northern States Power Company (NSP), Minnesota found that uncontrolled emissions from a pilot WTE combustion unit had lower SO_2, NO_x, and particulate emissions than those resulting from pulverized-coal plants that utilized expensive emissions control systems.

3.4.2.4 Environment Aspect

Energy crops utilized here provide vegetative cover throughout the year, reducing soil erosion and improving wildlife cover, unlike annual row crops. Much lowered applications of agricultural chemicals and reduced tillage benefit water quality. Conversion of agricultural land from row crops to woody crops improves soil structure, organic matter content, and water quality. Woody crops develop an extensive root structure that adds organic matter to the soil, slows wind and water erosion, and helps to reduce soil compaction. Soil nitrogen and inorganic nutrients are maintained by means of a controlled combination of fertilizer, leaf litter, and fly ash pellets from the power plant. In regions with high levels of nitrate pollution in the ground water, planting hybrid poplar trees has been shown to reduce the nitrate levels by a factor of ten or more when the water table is 1.5 m or less below the surface 10. Woody crop cover in agricultural areas benefits a wide variety of birds, small mammals, and deer. Woody crops provide edge effects and corridors with native habitats thereby improving wildlife diversity. Plots averaging about 32 hectares are envisioned so that landscape diversity is preserved. The Whole Tree Energy power plant is clean burning, and should meet all emission standards. The power plant is carbon dioxide neutral since the carbon emitted by the power plant is balanced by the carbon previously sequestered by the trees and roots (Ragland et al., n.d.).

3.4.2.5 Problems and Barriers

According to a study by the NREL, maximum steam turbine efficiency is 43% without reheating and with single feedwater heating, and 45% with reheating and two feedwater heaters. These figures are for steam temperature of 540 °C and steam pressure of 69 bars. Efficiencies may become even higher if these parameters can be raised further. As can be seen from the 45% turbine efficiency of the 100 MW_e of WTE concept, turbine efficiencies of about 41% will probably require large scale-up of the plants (above 100 MW_e) so that the additional investments can be paid for. If the turbine efficiencies of the selected plants are compared with theoretical maxima, it can be concluded that efficiency improvement in turbines is still possible from a technical point of view.

3.4.3 Biorefinery

3.4.3.1 General Concept

The concept of a bio-refinery that produces biofuels together with multiple co-products such as materials, chemicals, heat and power is explored (Fig. 3.25). It is analogous to that of a petroleum refinery processing a range of crude oils. Oil refineries have been in existence for over a century. During that time, the process has become increasingly more sophisticated, with the number of products growing from a handful of oils and lubricants to a full suite of over 2000 materials, chemical products and fuels. Some of the lessons learned by chemical and process engineers from oil refinery developments could be applied to bio-refineries, so the time required for this industry to develop naturally may be shortened. Biochemical and thermo-chemical processes for producing biofuels are capable of delivering a number of chemical or material co-products. A biorefinery can either deriver final, marketable products directly or create intermediate products that can be processed into new end-products in facilities elsewhere (DOE, 2010; Sims et al., 2008). Older pulp & paper mills are examples of the bio-refinery concept at work (albeit relatively inefficient ones), as they were often used to produce chemical co-products and burned waste biomass in a recovery boiler to generate power for internal use. An alternative approach to build new plants could be to retrofit existing pulp mills in order to add new process stages that liberate wood chemicals or to more efficiently generate heat and power (Mabee and Saddler, 2007b). As the biorefinery concept is developed, it can be anticipated that integrated food and industrial processing will begin to occur within the same facility. Producing high-value co-products form the corn feedstock would increase the robustness of the ethanol industry and help to protect it against risks associated with fluctuations in grain prices (Sims et al., 2008).

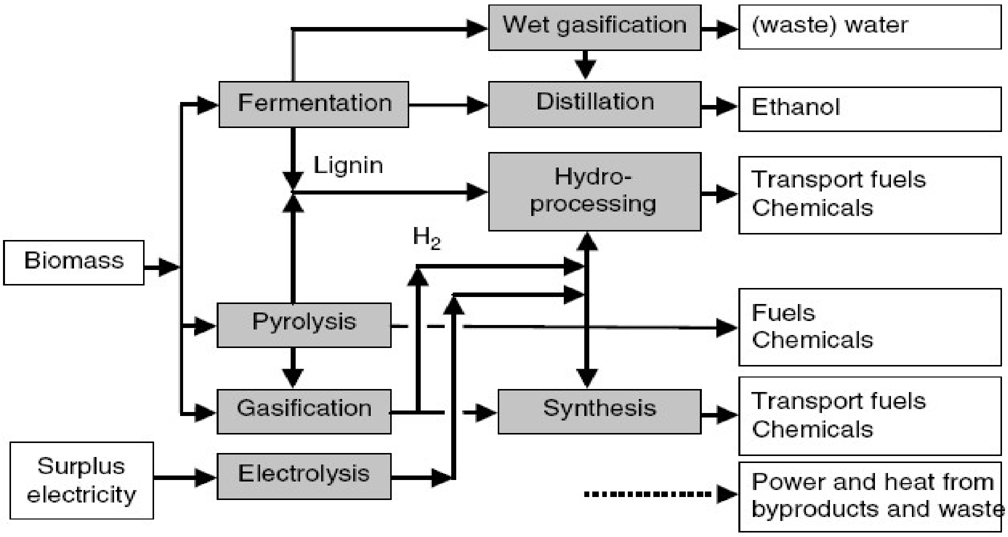

Fig. 3.25: A biorefinery system with processing options for fuels and chemicals.
Source: Royal Society (2008)

Older sulphite pulping technology for paper manufacturing have good potential to be adapted to produced a variety of chemical co-products, including ethanol, without major changes to the pulping process. However greater efficiency in the pulp & paper industry, and development of the Kraft pulping process so that almost all chemicals and waste are fully utilized, have reduced the potential for these mills to be modified as biorefineries. One option could be for gasification technology to replace the less efficient recovery boiler in order to produce more power from the same amount of biomass and, at high pressures, also provide syngas for the production of high-value co-products (Sims et al., 2008). Forest biomass also has unique chemical properties that may be exploited in the development of specific chemical co-products. Currently at the pilot/demonstate scales, these include lignin-derived composite, furfural, acetic acid and cell matter (McAloon et al., 2000). Other co-products specific to ligno-cellulosic include levulinic acid used as a building block in the manufacture of industrial products, including the fuel additive Methyltetrahydrofuran (MTHF) and the herbicide/pesticide, delta-amino levulinic acid (Sims et al., 2008). For the enzymatic hydrolysis of wood residues, the species variation in basic chemistry is even more significant than in agricultural residues, particularly when comparing softwood and hardwood species. Softwoods also have only two principal phenyl propane units (coumaryl and guaiacyl) that form the basic building blocks of lignin, while hardwoods and herbaceous plants have additional syringyl units (Sjöström, 1993). This lignin chemistry increases the difficulty of delignification due to the enhanced stability of the lignin in condensed form when exposed to acidic conditions (Shimada et al., 1997) making lingo-cellulosic materials from woody biomass a challenge for biochemical conversions.

3.4.3.2 Advantages and Drawbacks

A biorefinery is characterized by it ability to create high value co-products from residual biomass for supplying niche markets while reserving the bulk of the material for low-value commodities. Chemical co-products have higher economic potential and hence are currently the subject of increasing interest. **Horizontal bio-refining** is a single facility that is capable of generating a selection of fuels, heat/ power, chemicals, and material products from a single feedstock. Bio-refining as **a vertical concept**, enforces recycling into every stage of the biomass production and processing system. A vertical bio-refinery makes it possible to extend the utility of a single tree over several hundred years and would greatly enhance the ability of the world's forest resource to meet multiple demand for materials, chemical, fuel and energy (Sims et al., 2008). Various Dutch research centers have proposed a once through configuration for methanol combined with an IGCC fuelled by the lignin by-product of an ethanol facility in order to improve the overall economics and process efficiency while simultaneously producing ethanol. However, such schemes are only potentially viable at large scale and require a concerted approach by several stakeholders. Others have looked into the methanol route specifically, but these studies are still in the laboratory scale and a significant amount of work is required before industrial scale processes could be developed. On the other hand the results are promising.

3.4.3.3 Economic Aspect

The concept of producing small quantities of high value products (e.g. chemicals) and larger quantities of low value products (e.g. biofuels) theoretically maximizes returns from the biomass feedstock by improving economic performance of the same way that oil refineries do for crude oil today. Biorefineries can theoretically produce a variety of products such as biopolymers, liquid bio-fuels, biogas, electricity or hydrogen. Using proper feedstock and exploiting production synergies, bio-refineries could gain worldwide economic appeal. The most economical way to produce biofuels is in an integrated biorefinery, where the biomass can be used to produce multiple outputs - fuels, high-value bioproducts and power. Key challenges are to effectively integrate complex feedstock, conversion systems and develop new/value-added co-products together (U.S. DOE, 2007). Performance in a single/integrated system depends upon upstream and downstream processes. The processing facilities required to convert biomass into value-added products create direct and indirect jobs (more than in an oil refinery of similar output especially when the supply chain is included), provide regional economic development, and can increase resource-dependent incomes in rural areas. In general terms, biochemical conversion systems can be cost-effective at relatively small scales, while thermo-chemical conversion requires larger facilities. In a future carbon-constrained global economy, the use of fossil fuels will be restricted and there will be increased demand for renewable products arising from biomass resources. Consequently, bio-refineries and bio-products will play an increasingly important economic role. However, the transition to a biorefinery economy would require huge investment in new infrastructure to produce, store, and deliver biorefinery products to end users (Demirbas, 2010).

3.4.3.4 Environment Aspect

It is difficult to make accurate assumptions about the role that biorefineries could play in terms of employment, health, sustainable development, cohesion of rural communities etc. however, most commentators believe that the development of a bioenergy industry in a region will provide jobs, and that bioenergy and biofuels enterprises can become important opportunies for improving rural economies in both developed and developing countries. Biorefineries have the potential to provide significant environmental benefits measured as net GHG emission reduction through a life cycle assessment approach. A key issue under consideration is how best to allocate emission reduction to a biofuel when a range of co-products are involved. Biorefinery products usually have significantly lower GHG emissions when substituted for equivalent petroleum-base products. In most studies, biofuel products from biorefinery are characterized by a positive energy balance (NRDC, 2006). Biorefineries can also provide the benefit of encouraging carbon sequestration. Demand for biomass provides an impetus to increase carbon stocks in agricultural soils and forests, both of which play an important role in the global carbon cycle. An effective biorefinery industry would give a strong incentive to further increase the carbon stocks of agricultural soils and forests. A ligno-cellulose-based biorefinery can offer many environmental, economic and security-related benefits (GBEP, 2007).

3.4.3.5 Problems and Barriers

Development of biorefineries usually requires a supportive policy framework by government, as well as research and development support in order to overcome the existing technological barriers. The strong bonds in lingo-cellulosic feedstock require pre-treatment so that the polysaccharides can be accessed for conversion. Cellulose, unlike starch, is not hydrolyzed by conventional enzymes and requires the application of sophisticated (hitherto expensive) cellulase enzymes. Novel micro-organisms are required to ferment the xylose sugars extracted from hemicelluloses, since common yeasts will not work. For example, the US Energy Independence and Security Act (December 2007) includes a limit of 1st-generation biofuels of less than 47% of the require production of 136 billion liters of renewable fuels by 2007. It is recognized that 1st-generation biofuels other than sugarcane ethanol are often an expensive way to meet environmental goals in particular, but also to provide grater energy security. In addition feedstock cost account for 55 to 70% of total production costs and these are unlikely to fall sufficiently to make 1st-generation biofuels more competitive. The USA is then focusing on biorefineries: small scale configurations were kept to support the demonstration of cellulosic biorefneries at one-tenth of commercial scale. Subsequently, Range Fuels, Inc. broke ground on 2007, for a biorefnery that will become the first to make commercial levels of cellulosic ethanol. It will initially make 76 million liter/y of ethanol from sawdust, pine trees and wood bits left over from cutting down lumber (DOE, 2010).

3.4.4 Combined Gasification plus Electrolysis (GPE) Process

Biomass is a promising CO_2-neutral carbon source for fuel products, but it is deficient in H_2 for that purpose. On the other hand, H_2 is the fuel that is most readily made from another renewable power (wind, wave, solar, etc.) by the electrolysis of water, but it is also a challenge to store, transport, or distribute. By augmenting biofuel synthesis gas with H_2 from electrolysis, the processes can be designed to enhance both the ability to derive liquid fuels from renewable electricity, and also the ability to convert biomass to fuels efficiently. Generally, solar energy is also used to dry wet biomass prior to the gasification process. Concentrated solar energy can also supply the energy to drive the gasification process. Solar gasification decreases the amount of biomass that needs to be burned in the gasification process, thus improving the PTE (Mignard and Pritchard, 2008).

In the GPE process (Fig. 3.26), the avoidance of a shift step and of CO_2 elimination can contribute to more effective utilization of the biomass, increasing conversion to methanol by up to 130%. This is a natural choice; because the O_2 produced as a by-product from electrolysis - 50% of the H_2 amount - is more than sufficient for gasification. Comparison of the benefit of these schemes is made with the conventional technology that relies on shift and CO_2 extraction to adjust the C to H ratio. In the traditional process, the C to H ratio that is required for fuel synthesis is adjusted by rejecting a great amount of C. Steam is added before a shift step to convert CO to CO_2 and H_2, and the excess CO_2 is extracted and rejected. By contrast, the process advocates the addition of electrolytic H_2 using renewable electrical energy to avoid the rejection of C and increase the conversion of the biomass to fuel. This unshifted gas may have a some what different composition from the traditional gaseous product. The overall result of applying the GPE process is a considerable increase of the C efficiency of these processes; or put another way, a greater conversion of the biomass to fuels (Mignard and Pritchard, 2008).

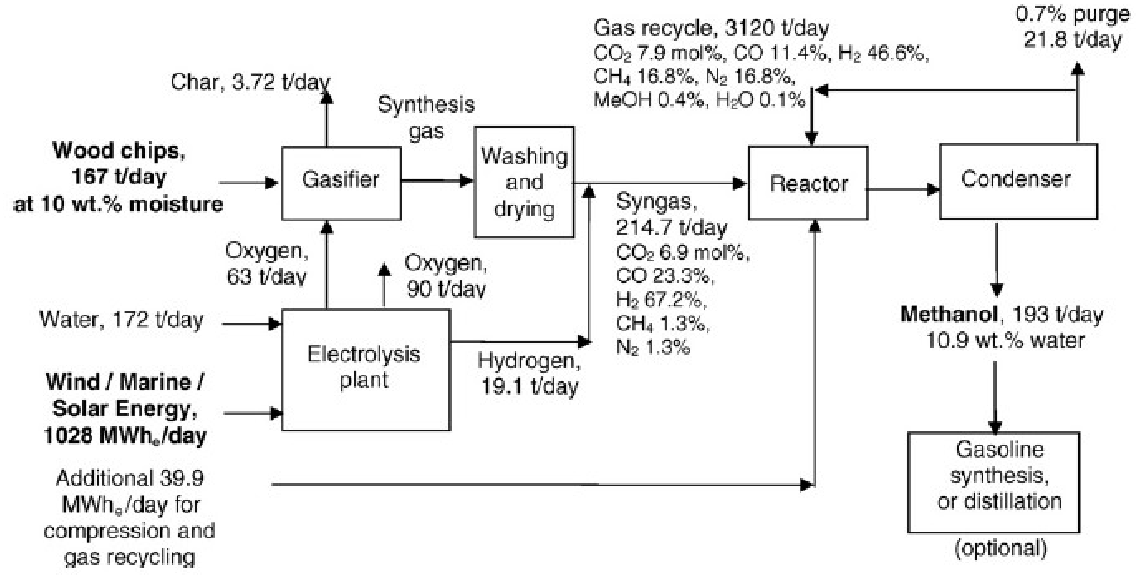

Fig. 3.26: Example of hybrid process for fuel synthesis that combines biomass and renewable energy

Source: Mignard and Pritchard (2008)

3.4 Conclusion

Biomass can be burned to produce electricity or CHP via a steam turbine in dedicated power plants. The typical size of these plants is ten times smaller (from 1 to100 MW) than coal-fired plants because of the scarce availability of local feedstock, low energy density, and the high transportation cost. The small size roughly doubles the investment cost per generated kW and results in lower electrical efficiency, around 30% depending on plant size, compared to coal plants. At present, biomass co-firing in modern coal power plants with efficiencies up to 45% is the most cost-effective biomass use for power generation. In cogeneration mode, however, the total efficiency may reach 85 to 90%. If biomass exceeds 10% or biomass/coal are burned separately, then changes in mills, burners and dryers, are needed. Biomass integrated gasification in gas-turbine plants (BIG/GT) is not yet commercial, but IGCCs using black liquor are already in use in pulping plant. Due to their small size, dedicated biomass power plants are more expensive than coal plants. Cheap/high-quality biomass (e.g., wood waste) for power generation may become scarce as it is also used for heat production and in the pulp & paper industry. Using low-cost local biomass, the incremental investment may have a short payback period, but low-quality biomass such as herbaceous crops and wet wood may produce tar and cause slagging and fouling that affects plant equipment reliability and raises costs. When using MSW, corrosion problems limit the steam temperature and reduce electrical efficiency to around 22%. CHP plant designs using MSW are expected to reach 28 to 30% electrical efficiency, and above 85 to 90% overall efficiency in CHP mode if good matching is achieved between heat production and demand. Incineration of MSW is a mature technology. Emissions of pollutants and dioxin can be effectively controlled, but in many countries, incinerators face public acceptance issues and are seen as competing with waste recycling. In the short term, co-firing remains the most cost-effective use of biomass for power generation, along with small-scale, off-grid use. In the mid-long term, BIG/GT plants and biorefineries could expand significantly.

Densification of biomass improves its handling characteristics, reduces transportation cost, enhances its volumetric calorific value, and produces a uniform, clean, stable fuel, or an input for further refining processes (Granada et al., 2002). Densifying biomass feedstocks improves the process of feeding the fuel into co-fired power plants (e.g. coal) (Li and Liu, 2000). Also, the combustion of dense granulated and uniformly sized biomass can be controlled more precisely than loose, low bulk density biomass and thus reduce emissions (Sokhansanj et al., 2005). There are numerous methods available to accomplish densification of biomass; conventional processes for biomass densification can be classified into three types: extrusion, roll briquetting, and pelletizing (Li and Liu, 2000). However, not all biomass is readily to used desification. Although **pile** and **grate burner** is one of the oldest combustion technology, they still have some problems and need to improve. For fluidized bed combustors, despite the relatively low temperature of combustion, the three T rule (temperature, time, and turbulence) of high quality combustion is well met, with 99% to 100% carbon burnout. In fluidized beds, the uniform, low combustion temperature gives low NO_x emissions. It is easy to introduce a sorbent solid, such as limestone or dolomite, to control SO_x. Gaseous biofuels include biogas from anaerobic digestion (AD), and low and medium heating value gases from thermal processes. While thermal gasification is in the early stages of commercial deployment, anaerobic digestion processes are already commercial and widely deployed, either in designed processes for specific environmental problems or in landfills, which are managed to capture the methane that is naturally produced (Overend, 2002).

For gasification, CFBG is the preferred and most reliable system for large scale applications, while downdraft gasifiers are the most extensively studied for small scale and BFBG can be competitive in medium ones. Large scale FBG have become commercial due to its success in co-firing projects, while moving bed gasifiers are still trying to achieve marketable. In heat generation, there is no need to eliminate the tar from the fuel gas, thus any reliable gasifier systems can be used successfully. Although heat applications are relative easy than others, there are very few examples in the market. The most commercial successful is the BIONEER, updraft gasifier in Finland. It was originally commercialized for lime kiln applications using peat and was later applied to co-utilization of locally available residues and wastes. Woody biomass has the highest reliability in feeding into a gasifier, whereas grasses have low bulk density resulting both in solids flow problems and local hot spots in the gasifier. For straw, severe problems of ash sintering and bed agglomeration are known to exist in FBG, and it is impossible to use straw in moving bed gasifiers due to low bulk density unless palletization, an expensive operation. However successful operation of the Värnamo plant was achieved with 100% straw feeding. RTF has sufficient experience in gasification. but, the feeding systems for fluff RDF need to be developed further to ensure reliable operation and more experimental results at large scale applications are needed to prove efficient operation for industrial application. Final sludge can also be utilized in gasification applications, but there exists little experience. The most reliable gasification applications are co-firing and direct firing. Nevertheless commercial IGCC, medium scale gasification and hot air gas turbines are expected to become commercially available in the short to medium term of about 4 to 6 years. Future market opportunities exist for liquid biofuels production via syngas, however a significant amount of work has still to be done before such plants could be considered by the financial community.

Biomass costs from cheapest to most expensive are typically lignocellulose < starches < vegetable oils < terpenes < algaes. Therefore, lignocellulose is the cheapest and most abundant form of biomass, and on an energy basis is significantly cheaper than crude oil. The three basic technologies for lignocellulosic conversion into liquid fuels, include gasification of lignocellulose to syn-gas followed by syn-gas conversion, production of bio-oils by pyrolysis or liquefaction followed by upgrading of bio-oils, and acid hydrolysis of biomass to monomer units, which can then be converted into fuels. A large fraction of biomass is lignin, and in an ideal biorefinery the lignin should be used for biofuels and biochemicals production. Processes exist to convert lignin into liquid fuels including the production of alkyl benzenes and paraffins (by hydrodeoxygenation) or aromatics and coke (by zeolite upgrading). Algae have a tremendous potential as a feedstock because they have very high growth rates and can be grown on non-agricultural land. However, algae are currently too expensive to be grown on energy farms, and future work should focus on the development of cheaper algae crops.

New technology development is needed for liquid biofuels, which can be utilized directly in existing modern energy structures, especially as transport fuels. A petrol additive/substitute, bioethanol can be produced from plentiful, domestic, cellulosic biomass resources such as herbaceous and woody plants, agricultural and forestry residues, and a large portion of municipal solid waste and industrial waste streams. Biodiesel is better than diesel fuel in terms of sulphur content, flash point, aromatic content and biodegradability. Biomethanol can be produced from biomass using bio-sythetic gas (bio-syngas) obtained from steam reforming process of biomass. Although bio-ethanol and biodiesel from grain and seed respectively are supposed to be more competitive, various studies indicate that Fischer-Tropsch diesel and DME can be competitive in the medium to long term of about 5 to 10 years. H_2 will always remain the cleanest fuel of all and any process that can produce H_2 from biofuels under economically competitive conditions will be an immediate market success. Even with present high oil prices, biofuels cost is still more than that of conventional fuel. The biofuel economy, and its associated biorefineries, will be shaped by many of the same forces that outlined the development of the hydrocarbon economy and its refineries over the past century. A multi-feedstock plant could take the advantage of obtaining the cheapest feedstocks on the market at a specific point of time throughout the year, including biomass imports. However, such plants are more difficult to design at the front-end and also more costly to operate (Demirbas, 2008; Maniatis, 2001). Support systems/financial from state designed to encourage demand for biofuel play a larger role. The main approaches are biofuel obligations and tax reductions/exemptions.

Concerns about the recent rapid growth in oil and food prices, security of future energy supplies particularly oil for transport, and the need for climate change mitigation have brought renewed focus on the cost and benefits of biofuels. But limited returns on sometimes risky investments, and other potential resource and environmental impacts including competition for water supplies where not properly managed and fertilizer run-off, are still on controversial. Cost data for thermo-chemical technology options is not readily available. VTT (Helsinky) the Finnish technical research organization, has yet estimated investment requirements for thermo-chemical plants of capacity in the range of EUR 220 to 250 M. the costs increase slightly where biofuels are produced in a stand-alone plant rather than in a plant integrated with an existing one but still appear to be optimistic compared with other assessments. The investment costs of a new 2nd-generation biofuel plant, at least in the early stage of development for a medium scale plant producing around 50 to 150 M liter/y, will be in the range of USD 125 to 250 M. The logistics and transport costs of delivering feedstock to a 1st-generation biofuel processing facility, then distributing the biofuel to the customers, possibly as a blend with petroleum products, is a key factor for profitability. Producing and delivering biomass feedstocks in large volumes will require significant investment throughout the supply chain - from feedstock production and transport trough conversion processing and product delivery. Their transport by water has a clear cost advantage and so sites selected for 1st-generation process plants on waterways and harbours would have clear benefits. This is also the case for many 2nd-generation feedstocks.

A common concern relates to the removal of too many agricultural or forest residues from the soil which might increase soil erosion or reduce the soil nutrient status over time. The appropriate amount that can be removed varies with soil type and site conditions as it prescribed by IEA bioerergy Task 31 that has studies this issue. Returning the ash to land after some processes where it is produced (e.g. gasification) is an option being already practiced by some biomass combustion plant operators. With high production cost and small net GHG reductions often possible, the marginal abatement cost from using some 1st-generation biofuels has been quoted to be relatively high around USD 200 to 300 / t CO_2 avoided, or even up to USD 1700 /t (OECD, 2008) or above. The possibility exists that continue development of 1st generation biofuels might lead to net deforestation as more land is changed from permanent forest cover to agriculture. In addition the increased use of scarce fresh water for irrigating energy crops is under question. Increasing the irrigated area of food crop production will result in increased yields but competition for the water often exists with other users. From Sustainable Biofuels Consensus document in March 2008 by the Rockefeller Foundation Bellagio Center, Italy, it became clear that some 1st-generation biofuels have significant potential for greater global deployment since their benefits clearly outweigh their disbenefits. However other biofuels can result in net negative impacts and therefore require more careful consideration by policy makers and investors.

One advantage of many lingo-cellulosic feedstocks makes them easier to store (cereal straw for example requires no drying or chilling) and hence they can be made available all-year round (forest residues for example). The value of pretreatment in reducing fixed capital costs per liter of capacity is apparent, but there was no significant difference in capital cost between systems. Primary drivers in choosing a pretreatment technology will therefore be the feedstock characteristics, the operating costs, and the necessary expertise available. The genetic modification of lingo-cellulosic feedstocks is an important research topic. If feedstocks can be modified to make their pretreatment or conversion easier or less costly, then important reductions in the production cost of 2nd-generation biofuels could be achieved. More recent analysis indicates that the overall cost of delignification associated with pretreatment remains a larger cost hurdle to overcome for softwood lingo-cellulosic substrates (Mabee et al., 2006). Misunderstanding of environmental/energy tradeoffs is occurring because the adoption and development of 2nd-generation biofuels is still at an early stage. High costs of production of 2nd-generation biofuels are a fundamental barrier to deployment. A global system that incentivized the reduction of GHG by placing a value on carbon emissions (such as a carbon tax) would help put 2nd-generation biofuels on a more level-playing field with fossil fuels, but would probably not be enough in itself to lead to commercialization. Reductions in the costs of biomass feedstocks, transport logistics and conversion processes will be required to overcome this barrier. Feedstock costs and availability for 1st-generation will determine the rate of growth of 2nd-generation industry. If 1st-generation growth continues to be supported by policies of some governments, then a delay in bringing 2nd-generation on stream could result, especially if government funding sues towards supporting 1st-generation by means of subsidies and grants rather looking forward to the longer term.

The dissenting Pimentel and Patzek (2005) study used higher energy input figures than the standards used by most researchers. Overall, the results of this study indicate that development of 2nd-generation biofuels utilizing forest residues has the potential to improve energy efficiency and the overall energy balance in the biochemical route. In the thermo-chemical route, the lignin is converted to syngas, so it is not more available to provide process heat by process such as combustion. However, the process demands fewer energy inputs than biochemical ethanol, so importing energy in not too critical to overall costs. The IEA analyzed 60 LCA studies of biofuels (OECD, 2008). Only 18 included non GHG environmental impacts and less than a third included 2nd-generation biofuels. All of those that did however showed a net improvement of GHG emissions of around 60 to 120% compared with petroleum fuels. Land use GHG emissions were not included but co-products were. Hence the ability to achieve >100% reductions when co-products are also able to substitute for fossil fuels to generate heat and power for example. Both the ethanol and synthetic diesel routes from ligno-cellulose produced GHG emission reduction ranges similar to displacing gasoline with sugarcane ethanol. The few LCA studies that have considered non-GHG environmental impacts of 2nd-generation biofuels showed for both bio- and thermo-chemical routes, reduced acidification, lower summer smog levels and less eco-toxicity compared with petroleum use. However, due to their agricultural origins and fertilizer use during feedstock production from energy crops, eutrophication increased. The amount of water and processing chemicals used for 2nd-generation biofuel production can also be an issue needing consideration. In addition the treatment of the stillage resulting from distillation can involve additional costs to minimize the environmental impacts.

Considerable investment in pilot and demonstration plants has been made worldwide but how and when commercial scale-up can be realized is the key question. 2nd-generation biofuels are expected to be superior to many of 1st-generation in terms of energy balances, GHG emission reductions, land use requirements and competition for land, food, fiber and water. However, they do not produce co-products such as animal feed which should also be considered in comparison (RFA, 2008). For 3rd-generation biofuels, some are already reasonably close to market, however there is no accepted definition for this group. Typical commercial BtL plant capacites could vary from 200 to 300 MW_{feed} using an integrated approach of biofuel production with existing industrial complexes, or even be considerably larger. While BtL technologies are not yet commercially proven, several pulp & paper concerns have begun installing gasification technologies which might be able to take advantage of future developments. When a biofuel process is integrated in pulp & paper mill or municipal CHP plant, the main consideration would be the logistics of delivering the biomass supply and efficient integration with the existing production process. This concept of a biorefinery is seen as a means of reducing the total additional capital cost per unit of biofuel capacity and hence decreasing the overall cost of the end products Typical commercial BtL plant capacites could vary from 200 to 300 MW_{feed} using an integrated approach of biofuel production with existing industrial complexes, or even be considerably larger.

Chapter 4: Analysis of Bioenergy Potential and its suitable conversion technologies for Thailand

For this chapter, it is divided into 4 main parts including the following:

4.1) ***Methodology for suitable technology selection*** - In this part, all mathematical methods for selecting the best technology, suitable for current situation of Thailand, will be carefully reviewed in order to find the best technique to deal with section 4.3 - ;
4.2) ***Raw material Analysis*** - For this part, each biomass from agriculture and forestry will be estimated to determine their potential energy purpose in the year 2010, 2015, and 2020, respectively - ;
4.3) ***Example of suitable technology selection for Thailand*** - The appropriate method from 4.1 and the chosen biomass data from 4.2 will represent the best energy conversion technology for Thailand - ;
4.4) ***Discussion*** - in this part, some interested issues from section 4.2 and 4.3 will be discussed in order to spot the vigour and hidden problems of bioenergy in Thailand; and
4.5) ***Summary***.

4.1 Methodology for suitable technology selection

One of the leading issues in bioenergy technology selection is how to derive promising related technology alternatives from ambiguities and various types of them (Shen et al., 2010). It is becoming more and more difficult to identify the right technologies, because the number of technologies is always increasing and they tend to become more complex (Torkkeli and Tuominen, 2002). The actual technology ranking step of investment is, therefore, typically too complex. It always involves, like many decision situations, multiple criteria that have been treated either implicitly or explicitly (Tuzkaya et al., 2010). Besides, there is generally no sole decision maker; instead the ranking consideration requires a consensus from a group of decision makers. The purpose of this methodology section is specifically to present the related theoretical concepts in multiple criteria analysis for application in section 4.3. A series of decision techniques must be carried out in order to carefully identify the advantages and disadvantages in this sector.

4.1.1 The Analytic Hierarchy Process (AHP) method

One of the most powerful tools for solving complex ***M**ulti **C**riteria **D**ecision **M**aking* (MCDM[50]) issues, the AHP has been applied in this study, because it is easily to understand and it can be plainly adapted for almost project decisions. It not only assists the analysts to arrive at the best decision by providing a clear rationale for the choice-making, but also can be integrated with other techniques[51] easily (Chin et al. 1999). Since the AHP was introduced by Thomas L. Saaty (1977, 1980, 1986, and 1994) at the Wharton School of Business, Philadelphia (the USA), many applications in real-world decision-making have been reported. By the AHP, the analysts must organize the critical aspects of a decision subject into a hierarchic structure similar to a family tree. This enables the evaluation team to visualize the selection systematically in terms of relevant criteria and sub-criteria. In short, the AHP

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[50] MCDA methods generally apply a decision matrix to provide a systematic analytical approach for integrating risk levels, uncertainty, and valuation, which enables evaluation and ranking of many alternatives.

[51] such as mathematical programming: Linear Programming, Quality Function Deployment, or Fuzzy Logic, etc. (Fong et al., 2007; Ho, 2008).

structures the decision topic in hierarchic levels (objective, criterion, sub-criterion, and alternatives) for comparing and ranking the priorities of each alternative, then synthesizing the overall results. Each level of the hierarchy can be analysed independently, to calculate the ***weights*** for (sub-) criterion or the ***scores*** for alternatives. The ***pair-wise method*** (Ch. 4.1.2) is a common tool for weighting calculation thanks to its allowance in the judgment of some small inconsistency, reflected by the attitude of the decision makers. These ratio scales are based on the principal ***eigenvectors***, while the ***Consistency Index*** ($C.I.$) is derived from the principal ***eigenvalue***. The input for the pair-wise method can be obtained from actual measurements such as price, weight etc., or from subjective opinion such as satisfaction feelings or preference. Consequently, the AHP approach can handle both qualitative (intangible) and quantitative (tangible) aspects applied in selective situation (Barzilai and Golany, 1994).

The concept of AHP has gradually evolved through many applications as diverse as energy allocation, marketing decisions, project selection & evaluation, technology selection, new product screening, and conflict resolution. In the technology management area, there have been several studies applying the AHP approach to evaluate the most appropriate choice of technologies: "Technological Choice in the Less Developed Countries: An Analytical Hierarchy Approach" (Ramanujam and Saaty, 1981); "The Analytical Hierarchy Process for Choice of technologies" (Prasad and Somasekhara, 1990); "The Prioritisation of Technologies in a Research Laboratory" (Melachrinoudis and Rice, 1991); "Prioritising Telecommunications Technologies for Long-Range R&D Planning to the Year 2006" (Suh et al., 1994); and "Justification of New Manufacturing Technology: A Strategic Approach Using the AHP" (Albayrakoglu, 1996). In those studies, the hierarchical model for the assessment of technologies is generally constructed with either 3 levels (objective, criteria, and alternatives) or 4 levels (objective, criteria, sub-criteria, and alternatives). The series of comparative judgments is analysed to determine the relative impact of technologies on the objectives. The results are represented as a relative value indicating how many times one technology is better than the other alternatives (Gerdsri and Kocaoglu, 2007).

To make a decision in an organised way for generating priorities of the alternatives, the AHP approach could be illustrated by the following steps.

4.1.1.1) The first step is to define the subject and determine the kind of knowledge sought.

4.1.1.2) For the next step, the decision situation is hierarchically structured at different levels, in each of which a finite number of decision elements adhere. The top level of the hierarchy represents the decision goal, while the lowest level consists of all possible alternatives. In the intermediate levels, the criteria could be further broken down into sub-criteria, sub-sub-criteria, and so on, in as many levels as the problem requires (Partovi, 1994).

4.1.1.3) The general techniques for estimating the relative weights of each element in (sub-) criteria level is the originally proposed eigenvector method. Therefore, this step is to construct a set of pair-wise comparison matrix at every intermediate levels, after that all matrixes is proved to be consistent (also see Ch. 4.1.2). The weights of the (sub-) criteria, called local weights, are considered as decision factors in the next step of the decision process.

4.1.1.4) By its local weight, each element in an upper intermediate level is then utilised to compare the elements in the level directly below with respect to it. Do these for every upper element, so each element in the level below add its weighed values and obtain its global weight. Continue this process of weighing and adding until the global weights (γ_i) of the (sub-) criteria in the lowest intermediate level are obtained.

4.1.1.5) The scores (r_{ij}) of the alternative can be elicited by various methods - such as the simple additive weighting (SAW) method (see Ch. 4.1.3), weighted product model (WPM) method, or pair-wise method (see Ch. 4.1.2) -, correspondingly to (sub-) criteria in the lowest intermediate level.

4.1.1.6) The last step is to calculate the global priority (R_j) of each alternative by summation all local priorities as show in the equation below:

$$R_j = \sum_i \gamma_i \cdot r_{ij} \tag{1}$$

The obtained global priorities are finally used to rank the alternatives, then the last process is to select the best alternative for the decided upon goal.

4.1.2 The Pair-wise Method

With the pair-wise comparison method, local weights or priorities are derived from a set of judgments, based on the fact that **humans are more capable of making relative rather than absolute judgments**. The decision-makers or specialists are generally entailed to provide their preferences by pair-wise comparisons. This method assumes that the decision-maker can compare any two elements (e_i, e_j) of total k elements on principle α at the same level of the hierarchy and provide a numerical value (a_{ij}) of their relative important ratio. Judgments are provided by means of a nine-point ratio scale (table 4.1) which ranges each of the two elements from being equally important to one another or being that one is more important than the other. If e_i prefers to e_j then $a_{ij} > 1$. Correspondingly, the reciprocal property $a_{ji} = 1/a_{ij}$ for $j = 1$ to k and $i = 1$ to k always holds. After construction of a pair-wise comparison matrix, the members of pair-wise matrix under the diagonals are reciprocal and usually omitted. The referenced priority local weights are usually obtained by the eigenvector approach (Sevkli et al., 2007). The pair-wise comparison, in contrast of ranking and rating, has a solid theoretical foundation based on ratio-scale judgments about pairs of criteria and the properties of reciprocal matrix of pair-wise comparisons. The advantage of this technique is that it is applied from handbooks, regression output, or decision-maker/experts who can be asked to compare individual factors. The disadvantage is that the larger the number of criteria, the more the number of judgments that must be made. Each set of comparisons for a level with k elements requires $[k(k-1)]/2$ judgments. Moreover, there exists a problem that pair-wise comparisons might be uncertain or inconsistent with each other, because they are based on human attitude.

Table 4.1: Saaty's scale of relative judgments

Saaty's scale	The relative importance of the two sub-elements
1	Equally important
3	Moderately important with one over another
5	Strongly important
7	Very strongly important
9	Extremely important
2, 4, 6, and 8	Intermediate scale between adjacent scale values

Source: Saaty (2008)

To get the referenced priority local weights, the eigenvector approach can be outlined as follows:

4.1.2.1) Initially, a decision matrix $(k \times k)$ for the ranking as explained before has been established. The structure of the matrix can be expressed as follows (next page):

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ a_{k1} & a_{k2} & \cdots & a_{kk} \end{bmatrix} = A(a_{ij}) \tag{2}$$

Where: a_{ij} could be integer from 1 to 9 by table 4.1, or reciprocals of these integers ($a_{ji} = 1/a_{ij}$).

4.1.2.2) After that, the normalised decision matrix $B(b_{ij})$ is found. The normalised value b_{ij} is then calculated by:

$$b_{ij} = \frac{a_{ij}}{\sum_{l=1}^{k} a_{lj}} \tag{3}$$

4.1.2.3) The next step is to compute the eigenvector $c = (c_1, c_2, ..., c_k)^T$ of the judgment matrix via:

$$c_i = \sum_{j=1}^{n} b_{ij} \tag{4}$$

4.1.2.4) Afterwards, the normalise eigenvector $w = (w_1, w_2, ..., w_k)^T$ of judgment matrix can be obtained by:

$$w_i = c_i \Big/ \sum_{j=1}^{k} c_j \tag{5}$$

4.1.2.5) Finally, to avoid inappropriate assessments of judgment, the $C.I.$ must be computed to ensure that pair-wise comparisons by expert are reliable. Assuming maximum eigenvalue of matrix $A(a_{ij})$ is $\lambda_{\max}$, according to characteristic equation of A:

$$A \cdot w = \lambda_{\max} \cdot w \tag{6}$$

$\lambda_{\max}$ can be worked out via:

$$\lambda_{\max} = \frac{1}{k} \sum_{i=1}^{k} \frac{\sum_{j=1}^{k} a_{ij} w_j}{w_i} \tag{7}$$

Meanwhile, the $C.I.$ is defined as:

$$C.I. = \frac{\lambda_{\max} - k}{k - 1} \tag{8}$$

When matrix $A(a_{ij})$ is consistent, $\lambda_{\max} = k$ and $C.I. = 0$. Finally, the consistency ratio ($C.R.$), usage of which enables someone to conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the $C.I.$ and the random index ($R.I.$) (see table 4.2), as indicated below.

$$C.R. = \frac{C.I.}{R.I.} \quad < \quad 0.1 \tag{9}$$

The judgment matrix is considered consistent and satisfying, and the eigenvector $w = (w_1, w_2, ..., w_k)^T$ can be applied as the relative weight. If the final consistency ratio exceeds 0.1, the judgments should be revised. The measurement of consistency can be used to evaluate the consistency of decision-makers as well as the consistency of overall hierarchy (Wang and Yang, 2007)

Table 4.2: Random Index ($R.I.$) by different sizes of matrix

Size of Matrix	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (2008)

4.1.3 The Simple Additive Weighting (SAW) Method

The best known and the most widely used method for scoring the alternatives in a classical MCDM problem is the SAW or the weighted sum method which is applied to aggregate the scores into one score based on the criteria weights (Hwang and Yoon, 1981; Zavadskas and Kaklauskas, 1996; Balcomb and Curtner, 2000; Triantaphyllou, 2000). It uses all m attribute values of an alternative and uses the regular arithmetical operations of multiplication and addition. The attribute values could be both numerical and comparable. At first, the construction of a decision matrix for m alternatives over n criteria is necessary, then the elements in this matrix are usually normalised by converting raw measures (z_{ij}) into standardised measures (r_{ij}) via equation 10 or 11 below. Formula (10) is applied in maximum case (higher score, more preference), while formula (11) is proposed for minimum case (lower score, more proper). This normalization process converts all the ratings in a linear (proportional) way, so that the relative order of magnitude of the ratings remains equal. Finally, these scores will be used for equation (1) in step 4.1.1.6.

$$r_{ij} = z_{ij} \big/ z_j^{\max} \tag{10}$$

$$r_{ij} = z_j^{\min} \big/ z_{ij} \tag{11}$$

Where: $r_{ij}\left(0 \le r_{ij} \le 1\right)$ is defined as the normalised performance rating of alternative n_i on attribute m_j;

z_{ij} is the raw measure of the criterion n_i by alternative m_j.

4.1.4 The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

The TOPSIS method, one of a variety of multiple criteria techniques, was developed in 1981 by Hwang and Yoon. The basic concept of this method is that the best selected alternative should simultaneously minimize the distance from an ideal point and maximise the space from a nadir point in a geometrical sense (Olson, 2004). The solution will be ideal, when the best scores in all attributes are collected. TOPSIS assumes that each attribute has a tendency toward monotonically increasing or decreasing utility. Therefore, it is easy to locate the ideal and negative ideal solution. The Euclidean distance is used to evaluate the relative closeness of alternatives to the ideal solution. Thus, the preference order of alternatives is derived by comparing these relative distances. The TOPSIS method evaluates the following decision matrix, which refers to m alternatives that are evaluated in term of n criteria. The idea of TOPSIS can be expressed in a series of steps (next page):

4.1.4.1) First of all, it is necessary to obtain performance data of scores or raw measurements for m alternatives over n criteria. After the construction of a decision matrix with dimension $m \times n$, the members in this matrix are usually standardised by converting raw measures (z_{ij}) into standardised measures (r_{ij}) via:

$$r_{ij} = \frac{z_{ij}}{\sqrt{\sum_{k=1}^{m} z_{kj}^2}} \tag{12}$$

4.1.4.2) The next step is to develop a set of important weights $w = (w_1, w_2, ..., w_n)^T$. There are a number of specific procedures that can be used for developing weights such as pair-wise approach (see Ch. 4.1.2).

4.1.4.3) Subsequently, the weighted standardised decision matrix will be set up by multiplying the standardised decision matrix with its associated weights. For each member, the weighted standardised value (v_{ij}) can be computed by:

$$v_{ij} = w_j \times r_{ij} \quad i = 1 \quad to \quad n; \quad j = 1 \quad to \quad n. \tag{13}$$

After that, both sets of ideal and nadir alternative must be found following the next two steps;

4.1.4.4) Extreme performance on each criterion, the ideal alternative (v^+) must be identified by:

$$A^- = \left\{(\min_j v_{ij} \middle| i \in I), (\max_j v_{ij} \middle| i \in I'), j = 1,2,3,...,m\right\} = \left\{v_1^-, v_2^-, ..., v_n^-\right\} \tag{14}$$

4.1.4.5) The nadir alternative (v^-), reverse extreme performance on each criterion, is also recognised via:

$$A^+ = \left\{(\max_j v_{ij} \middle| i \in I), (\min_j v_{ij} \middle| i \in I'), j = 1,2,3,...,m\right\} = \left\{v_1^+, v_2^+, ..., v_n^+\right\} \tag{15}$$

4.1.4.6) Afterwards, the distances measure over each criterion to both ideal (s^+) and nadir (s^-) by the equations below is developed:

$$s_i^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \tag{16}$$

$$s_i^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2} \tag{17}$$

4.1.4.7) Before the last step, for each alternative, a ratio (c^+) equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal must be determined. This ratio can be expressed as:

$$c_j^+ = \frac{s_j^+}{s_j^+ + s_j^-} \tag{18}$$

4.1.4.8) Finally, all alternatives must be ranked by maximising the ratio (c^+) from Step 4.1.4.7.

4.1.5 The Fuzzy Analytic Hierarchy Process (FAHP) Method

Although the classical AHP is one of the most popular approaches for solving conventional MCDM issues or nearly crisp decision applications, the selection and preference of decision-makers have great influence on the success of this method. It is no longer practical if the raw input data is dubious, because analysts or experts show that it is difficult to map qualitative preferences to point estimates since the AHP should be dealt with a very unbalanced scale of judgment. Besides, a degree of uncertainty will be associated with some or all pair-wise comparison values in an AHP analysis[52]. The difficulty of generating such a priority vector in the uncertain pair-to-pair comparison environment is generally referred to the fuzzy AHP subject (Cheng et al., 1999). Furthermore, in complex systems, the experiences and judgments of individuals are normally represented by vague patterns or linguistic variables[53]. A much better representation of this linguistics can be developed as quantitative data. This hitch can be refined by the evaluation methods of fuzzy set theory. After Zadeh (1965)[54] introduced the fuzzy set theory to deal with the vagueness of human thought, many studies have continually applied his concept to improve MCDM and solve linguistic and cognitive fuzziness problems. The first fuzzy AHP, originated by Laarhoven and Pedrycz in 1983, was described by triangular membership functions[55] to compare fuzzy ratios. From then till now, the fuzzy AHP has been affected in more than 30 diverse areas to rank, select, evaluate, and benchmark decision alternatives (see Appendix B). Even if the fuzzy AHP method claimed it's superiority over the existing AHP methods, the mathematical complexity involved may restrict its practicability.

A tilde '~' will be placed above a symbol, if that symbol represents a fuzzy set such as $\tilde{S}$ characterized a triangular fuzzy number (TFN). To calculate a priority vector of the triangular fuzzy comparison matrix, Chang (1992) suggested an extent analysis method, which is generally employed in quite a number of applications (see Appendix B) thanks to its computational simplicity. Consider a triangular fuzzy comparison matrix expressed by:

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix},$$

Where: l is the lower limit value, m is the most promising value, and u is the upper limit value.

If $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, then $\tilde{a}_{ji} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$ for i, j = 1 to n and $i \neq j$.

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[52] The AHP approach has been also criticised in the literature on account of weaknesses in its theoretical foundation. The three most important issues are the rank reversal problem (Johnson et al., 1979), the priorities derivation method (Barzilai et al., 1987; Barzilai, 2001b), and the comparison scale (Barzilai, 2002, 2001a, 2001b, 1997; Salo and Hämäläinen, 1997).

[53] A linguistic variable is a variable whose values are not numbers, but words or sentences from a natural or artificial language. For example, ''***quality***'' is a linguistic variable; its values possibly are very low, low, medium, or high, etc. These linguistic values can also be represented by fuzzy numbers (Sun et al., 2009).

[54] According to Zadeh (1965), it is very difficult for conventional quantification methods such as a scale from 1 to 10 to express reasonably those situations that are overtly complex or hard to define. This is why a linguistic variable is necessary in these situations.

[55] The reason for using a triangular fuzzy number is that it is intuitively easy for the decision-makers to use and calculate. In addition, modeling using triangular fuzzy numbers has proven to be an effective way for formulating decision problems where the information available is subjective and imprecise (Chang and Yeh, 2002; Chang et al., 2007; Kahraman et al., 2004; Zimmerman, 1996).

The steps of Chang’s analysis can be given as in the following (Chang, 1996):

4.1.5.1) Firstly, sum up each row of the fuzzy comparison matrix $\widetilde{A}$ by fuzzy arithmetic operations;

$$RS_i = \sum_{j=1}^{n} \widetilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right), \qquad i = 1 \text{ to } n. \tag{19}$$

4.1.5.2) Secondly, normalise the above row sums by;

$$\widetilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}} \right), \qquad i = 1 \text{ to } n. \tag{20}$$

4.1.5.3) Next, compute the degree of possibility of $\widetilde{S}_i \geq \widetilde{S}_j$ by the following equation;

$$V\left(\widetilde{S}_i \geq \widetilde{S}_j\right) = \begin{cases} 1 & if \quad m_i \geq m_j, \\ 0 & if \quad l_j \geq u_i, \quad i, j = 1, \ldots, n; \quad i \neq j \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & otherwise \end{cases} \tag{21}$$

where: $\widetilde{S}_i = (l_i, m_i, u_i)$ and $\widetilde{S}_j = (l_j, m_j, u_j)$. The definition of possibility degree is shown in Fig. 4.1.

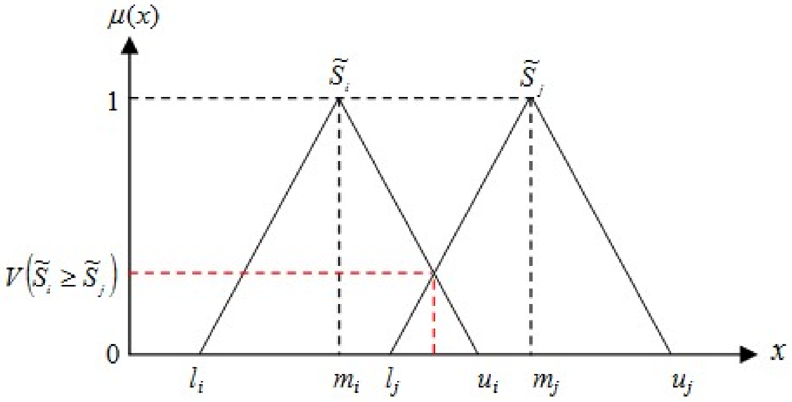

Fig. 4.1: Definition for the degree of possibility $V\left(\widetilde{S}_i \geq \widetilde{S}_j\right)$

Source: Chang (1996); Kahraman et al. (2004)

4.1.5.4) Afterwards, the degree of possibility of $\widetilde{S}_i$ is calculated over all the other $(n-1)$ fuzzy numbers by;

$$V\left(\widetilde{S}_i \geq \widetilde{S}_j \middle| j = 1, \ldots, n; j \neq i\right) = \min_{j \in \{1, \ldots, n\}, j \neq i} V\left(\widetilde{S}_i \geq \widetilde{S}_j\right), \quad i = 1, \ldots, n. \tag{22}$$

4.1.5.5) For the last step, the priority vector $W = (w_1, \ldots, w_n)^T$ is defined for the fuzzy comparison matrix $\widetilde{A}$ as;

$$w_i = \frac{V\left(\widetilde{S}_i \geq \widetilde{S}_j \middle| j = 1, \ldots, n; j \neq i\right)}{\sum_{k=1}^{n} V\left(\widetilde{S}_i \geq \widetilde{S}_j \middle| j = 1, \ldots, n; j \neq i\right)}, \quad i = 1, \ldots, n. \tag{23}$$

4.1.6 The Fuzzy TOPSIS Method

To run the full application of the AHP or fuzzy AHP is only practical, if the amount of pair-wise comparisons is sufficiently low. This means that all of pair-wise comparisons in one decision-making must remain below a reasonable threshold (Önüt et al., 2008). Also applied to achieve the final ranking results under the uncertainty environment of the decision making, the fuzzy TOPSIS is the extension of classical TOPSIS that is able to handle an unreasonably number of criteria and alternatives efficiently. The two main differences between the fuzzy AHP and fuzzy TOPSIS are: 1) pair-wise comparisons are applied to evaluate weights and scores only in the AHP; 2) the fuzzy AHP uses generally a hierarchy of attributes and alternatives, while TOPSIS does not (Dağdeviren et al., 2009). To deal with the fuzzy TOPSIS, triangular fuzzy numbers are still normally applied like in the fuzzy AHP. Let $\tilde{a}$ and $\tilde{b}$ be two triangular fuzzy numbers parameterised by the triplet (a_l, a_m, a_u) and (b_l, b_m, b_u), respectively, then the operational laws of these two triangular fuzzy numbers are as follows:

$$\tilde{a}(+)\tilde{b} = (a_l, a_m, a_u)(+)(b_l, b_m, b_u) = (a_l + b_l, a_m + b_m, a_u + b_u) \tag{24}$$

$$\tilde{a}(-)\tilde{b} = (a_l, a_m, a_u)(-)(b_l, b_m, b_u) = (a_l - b_l, a_m - b_m, a_u - b_u) \tag{25}$$

$$\tilde{a}(\times)\tilde{b} = (a_l, a_m, a_u)(\times)(b_l, b_m, b_u) = (a_l \cdot b_l, a_m \cdot b_m, a_u \cdot b_u) \tag{26}$$

$$\tilde{a}(\div)\tilde{b} = (a_l, a_m, a_u)(\div)(b_l, b_m, b_u) = (a_l / b_u, a_m / b_m, a_u / b_l) \tag{27}$$

and,

$$k\tilde{a} = (ka_l, ka_m, ka_u) \tag{28}$$

The vertex method (Chen, 2000) is defined to calculate the distance between them.

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a_l - b_l)^2 + (a_m - b_m)^2 + (a_u - b_u)^2\right]} \tag{29}$$

According to the briefly summarised fuzzy theory above, the following steps are designed to obtain the desirability of projects, using a TOPSIS method (Önüt and Soner, 2007):

4.1.6.1) For the first step, the linguistic values ($\tilde{x}_{ij}$; $i = 1$ to n and $j = 1$ to n) for alternatives with respect to criteria are chosen. The fuzzy linguistic rating ($\tilde{x}_{ij}$) preserves the property that the ranges of normalised triangular fuzzy numbers that belong to $[0,1]$; thus, there is no need for normalisation.

4.1.6.2) The next step is to calculate the weighted normalised fuzzy decision matrix. The weighted normalised value $(\tilde{v}_{ij})$ can be calculated by eq. (30).

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times J}, \quad i = 1 \text{ to } n \text{ and } j = 1 \text{ to } J \tag{30}$$

4.1.6.3) Afterwards, a positive-ideal (A^+) and negative ideal (A^-) solutions must be identified. The fuzzy positive-ideal solution (FPIS, A^+) and the fuzzy negative-ideal solution (FNIS, A^-) are shown in the following equations:

$$A^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, \ldots, \tilde{v}_n^+\} = \{(\max_j v_{ij} \mid i \in I'), \times (\min_j v_{ij} \mid i \in I'')\}, \; i = 1, 2, 3, \ldots, n \mid j = 1, 2, 3, \ldots, J \tag{31}$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\} = \{(\min_j v_{ij} \mid i \in I'), \times (\max_j v_{ij} \mid i \in I'')\}, \; i = 1, 2, 3, \ldots, n \mid j = 1, 2, 3, \ldots, J \tag{32}$$

Where: I' is associated with benefit criteria and I'' is associated with cost criteria.

4.1.6.4) Next, the distances of each alternative from A^+ and A^- are computed by the following equations (next page):

$$D_j^+ = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij},\ \ \widetilde{v}_i^+\right) \quad j = 1 \text{ to } J \tag{33}$$

$$D_j^- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij},\ \ \widetilde{v}_i^-\right) \quad j = 1 \text{ to } J \tag{34}$$

4.1.6.5) Later, similarities to the ideal solution are calculated by the equation below.

$$CC_j = \frac{D_j^-}{D_j^+ - D_j^-} \qquad j = 1 \text{ to } J \tag{35}$$

4.1.6.6) The final step is to rank the preference order. Choose an alternative with maximum CC_j or rank alternatives according to CC_j in descending order.

4.1.7 A consistency improving method in the AHP

Due to the influence of the limited ability of human thinking which has been explained in 4.1.5 and the shortcomings of 1-9 scale on paired comparison judgments, a high order constructed matrix in the AHP is generally not accepted, only if its *C.R.* is less than 0.1 (see also Ch. 4.11 and Ch. 4.12). Because the consistency in preference relations has a direct impact on the ranking results of the final decision, how to alleviate inconsistencies has been addressed by many studies (Raharjo et al., 2001; Zeshui and Cuiping, 1999). If a pair-wise matrix is inconsistent, there are normally two procedures that could be realised to deal with: firstly, the revision of the matrix by returning the matrix to the same expert before in order to restructure it until a satisfactory level has been reached; or improvement of the consistency matrix by adopting some techniques to adjust the comparison matrix properly. The first choice is reliable and accurate, but impracticable because of the large amount and the long period of work needed. For the second option, a given reciprocal judgment matrix can be transformed to a near consistent matrix by applying mathematical iterating algorithm. Based on the eigenvector method (EM), Saaty (1994) also proposed a way for improving the consistency of judgments in the AHP. These methods compare each judgment (a_{ij}) of the pair-wise comparison matrix with the ratio ω_i / ω_j. Then, the reasonable priority vector of the original one by the EM can be derived.

To deal with above problem, let $A = \left(a_{ij}\right)$ be an inconsistent comparison matrix and A^k be the matrix sequence generated the maximal eigenvalue of A^k. Then for each *k*, $\lambda_{\max}\left(A^{(k+1)}\right) < \lambda_{\max}\left(A^{(k)}\right)$ and $\lim\limits_{k \to \infty} \ \lambda_{\max}\left(A^{(k)}\right) = n$. Moreover, two criteria of modificatory effectiveness are proposed as follows:

$$\delta = \max_{ij}\left\{\left|a_{ij}^m - a_{ij}^0\right|\right\}, \qquad i, j \ = 1 \text{ to } n. \tag{36}$$

and

$$\sigma = \sqrt{\sum_{j=1}^{n}\sum_{i=1}^{n}\left(a_{ij}^m - a_{ij}^0\right)^2} \Big/ n \tag{37}$$

The underlying presumption here is that the projected weights should be accepted, if the comparison matrix is sufficiently consistent and rejected otherwise. If the weights are rejected, the matrix is to be revised through an iterative procedure which converges to a consistent matrix. Therefore, almost all the elements in the preference matrix will be modified. However, if $\delta < 2$ and $\sigma < 1$, the modification can be regarded as acceptable.

From the above theory, with $A = (a_{ij})$ being an $n \times n$ comparison matrix, k being the number of iterative times, and $0 < \lambda < 1$. Following step by step of iterative procedure to modify the comparison matrix will be made clearly.

4.1.7.1) Let $A^{(0)} = (a_{ij}^{0}) = (a_{ij})$, $C.R.^{*} = 0.1$ and $k = 0$.

4.1.7.2) Calculate the maximal eigenvalue $\lambda_{\max}(A^{(k)})$ of $A^{(k)}$ and the normalised principal right eigenvetor $\omega^{(k)} = (\omega_1^{(k)}, \omega_2^{(k)}, \ldots, \omega_n^{(k)})^T$.

4.1.7.3) Calculate the consistency index, $C.I.^{(k)} = (\lambda_{\max}(A^{(k)}) - n)/(n-1)$ and the consistency ratio $C.R.^{(k)} = C.R.^{(k)}/R.I.$, where $R.I.$ is given by Saaty in table 4.2.

4.1.7.4) If $C.R.^{(k)} < C.R.^{*}$, then go step 4.1.7.6; otherwise, continue the next step.

4.1.7.5) Let $A^{k+1} = (a_{ij}^{(k+1)})$, where $(a_{ij}^{(k+1)}) = (a_{ij}^{(k)})^{\lambda} (\omega_i^{(k)} / \omega_j^{(k)})^{1-\lambda}$ (38)

Let $k = k + 1$, then return to step 4.1.7.2.

4.1.7.6) Calculate δ and σ, if $C.R.^{(k)} < 0.1$, $\delta < 2$, and $\sigma < 1$ then

4.1.7.7) Output k, $A^{(k)}$, $\lambda_{\max}(A^{(k)})$, $C.R.^{(k)}$, $\omega^{(k)}$, and $A^{(k)}$ is the modified positive reciprocal matrix and $\omega^{(k)}$ is the vector of priorities.

4.1.7.8) End.

4.1.8 Numerical Evaluative Example

The purpose of this section is to demonstrate the calculation methods of the multi-criteria decision techniques previously explained in 4.1.1 to 4.1.7 step by step.

4.1.8.1 The AHP method with the Pair-wise approach example

In this example, a numerical analysis of AHP-based simulation to evaluate a set of conceptual design alternatives will be exemplified. The aim of the work in this example was to choose the best provider for machinery parts. With this purpose, six main criteria were developed for appraising by specialists. There are ***Price*** (C1), ***Quality*** (C2), ***Delivery Day*** (C3), ***Service*** (C4), ***Capacity of spare parts*** (C5), and ***Preferred Technology*** (C6). The four acceptable suppliers have been also identified (company A, B, C, and D). Therefore, the hierarchical model of this example can be divided into 3 levels (Fig. 4.2) (step 4.1.1.1-2): Goal (the top level); Criteria (the middle level); and Alternatives (the lowest level). The lines connecting the goal to each criterion mean that the criteria must be pair-wise compared for their important weight with respect to the goal. Similarly, the lines connecting each criterion to all alternatives imply that the alternatives are normally pair-wise compared as to which is more preferred for that criterion. Thus, in the hierarchy that is shown below, there should be 7 sets of pair-wise comparisons, one for the criteria with respect to the goal and 6 for the alternatives with respect to the 6 criteria. However, other methods can be also applied to find the local weight for the both criteria and alternative as explained in Ch. 4.1.1 earlier.

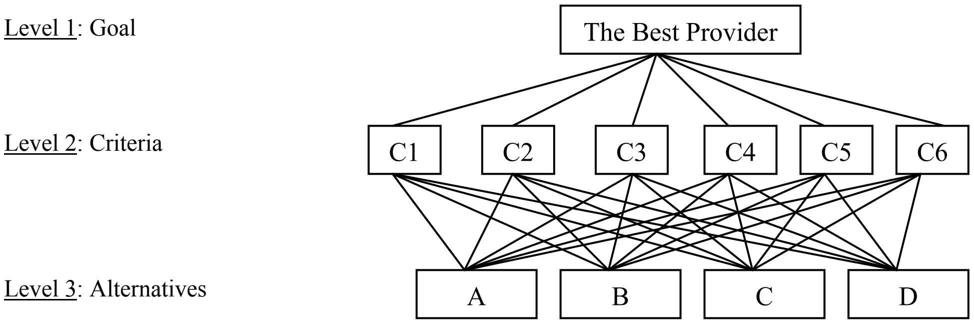

Fig. 4.2: Abstract representation of a decision hierarchy for the best provider example

Following the hierarchical construction of this situation, the criteria pair-wise matrix by using the saaty's scale (table 4.1) is built up as show in table 4.3.1, then completed all members via reciprocal property like in table 4.3.2 (step 4.1.1.3). Although the relative weights of the criteria can be calculated by using the AHP or fuzzy AHP method, the AHP will initially be focused on. Therefore, summations of each column in table 4.3.2 are represented.

Table 4.3.1: constructing matrix of pair-wise comparison

	C1	C2	C3	C4	C5	C6
C1	1	3	3	3	3	5
C2		1	3	1	1	3
C3			1	1/3	1	1/3
C4				1	1	1
C5					1	1
C6						1

Table 4.3.2: complete reciprocal matrix of pair-wise comparison

	C1	C2	C3	C4	C5	C6
C1	1	3	3	3	3	5
C2	1/3	1	3	1	1	3
C3	1/3	1/3	1	1/3	1	1/3
C4	1/3	1	3	1	1	1
C5	1/3	1	1	1	1	1
C6	1/5	1/3	3	1	1	1
	2.533	**6.667**	**14**	**7.333**	**8**	**11.333**

To achieve table 4.4.1, all elements in each column in table 4.3.2 must be divided by the respective column sum. For example, $b_{2,4} = a_{2,4} \Big/ \sum_{l=1}^{6} a_{l,4} = 1/7.33 = 0.1364$ (step 4.1.2.2). After that, by summation of each row in table 4.4.1, judgment matrix (table 4.4.2) is obtained. For example, $c_{2,1} = \sum_{j=1}^{6} b_{2,j} = 0.1316 + 0.15 + 0.2143 + 0.1364 + 0.1250 + 0.2647 \quad = 1.0219$ (step 4.1.2.3). Finally, the relative weights of the criteria (table 4.4.3) are derived by normalising the members of matrix in table 4.4.2 such member as $w_{2,1} = c_{2,1} \Big/ \sum_{i=1}^{6} c_{i,1} = 1.0219/6 = 0.1703$ (step 4.1.2.4).

Table 4.4.1: the normalised matrix of table 4.3.2

	C1	C2	C3	C4	C5	C6
C1	0.3947	0.4500	0.2143	0.4091	0.3750	0.4412
C2	0.1316	0.1500	0.2143	**0.1364**	0.1250	0.2647
C3	0.1316	0.0500	0.0714	0.0455	0.1250	0.0294
C4	0.1316	0.1500	0.2143	0.1364	0.1250	0.0882
C5	0.1316	0.1500	0.0714	0.1364	0.1250	0.0882
C6	0.0789	0.0500	0.2143	0.1364	0.1250	0.0882
	1	**1**	**1**	**1**	**1**	**1**

Table 4.4.2[*]

Eigenvector
2.2843
1.0219
0.4529
0.8455
0.7026
0.6928
6

Table 4.4.3[**]

N. Weight
0.3807
0.1703
0.0755
0.1409
0.1171
0.1155
1

[*] Table 4.4.2: derived eigenvetor matrix from table 4.4.1

[**] Table 4.4.3: normalised eigenvector matrix which is developed from table 4.4.2

Therefore, the relative weights of each criterion are: C1 = 0.3807, C2 = 0.1703, C3 = 0.0755, C4 = 0.1409, C5 = 0.1171, and C6 = 0.1155, respectively. The next step is to check the consistency of judgment following step 4.1.2.5. Initially, the matrix of table 4.3.2 must be multiplied (matrix operation) by the normalised matrix of table 4.4.3 to obtain table 4.5.1. For the numerical example, the value **1.1281** in table 4.5.1 can be calculated by: ($C_{2,1}$ x W_1 + $C_{2,2}$ x W_2 + $C_{2,3}$ x W_3 + $C_{2,4}$ x W_4 + $C_{2,5}$ x W_5 + $C_{2,6}$ x W_6 = (1/3)·0.3807 + (1)·0.1703 +(3)·0.0755 + (1)·0.1409 + (1)·0.1171 + (3)·0.1155 = 1.1281. Where upon, each member of table 4.5.1 will be divided by the element of table 4.4.2 at the same position in order to set the member of table 4.5.2. For instance, 6.6233 in table 4.5.2 is computed with 0.1703 from table 4.4.2 and 1.1281 from table 4.5.1 by: 6.6233 = 1.1281/0.1703.

Table 4.3.2′

A	C1	C2	C3	C4	C5	C6
C1	1	3	3	3	3	5
C2	1/3	1	3	1	1	3
C3	1/3	1/3	1	1/3	1	1/3
C4	1/3	1	3	1	1	1
C5	1/3	1	1	1	1	1
C6	1/5	1/3	3	1	1	1

Table 4.4.2′′

W
0.3807
0.1703
0.0755
0.1409
0.1171
0.1155

Table 4.5.1*

A x *W*
2.4695
1.1281
0.4617
0.8971
0.7462
0.7328

Table 4.5.2**

6.4865
6.6233
6.1172
6.3668
6.3722
6.3465
38.3124

′Table 4.3.2: complete reciprocal matrix of pair-wise comparison
′′Table 4.4.2: derived eigenvetor matrix from table 4.4.1
*Table 4.5.1: multiplied matrix which is developed from table 4.3.2 and table 4.4.2
**Table 4.5.2: derived matrix which is achieved from table 4.5.1 and 4.4.2

By dividing the summation of table 4.5.2 by the number of criteria, $\lambda_{\max}$ is lastly created. In this case, the summation of all members in table 4.5.2 is 38.3124 and the number of criteria is 6, hence $\lambda_{\max} = 38.3124/6 = 6.3854$. The next step is to calculate $C.I.$ by applying eq. 8, as a result $C.I. = (6.3854 - 6)/(6-1) = 0.0771$. Finally, with $R.I.(n=6)$ = 1.24 (table 4.2), $C.R. = C.I./R.I. =$ 0.0771/1.24 = 0.0622. Because this $C.R.$ is less than 0.1, the judgment is satisfying and the calculated relative weight can be used for reference in the next step of the decision-making.

4.1.8.2 The AHP method with the SAW approach example

The next phase of the calculation example is to exemplify how to score alternatives by using the SAW and TOPSIS method. In both methods, the matrix of raw measures with dimension m alternatives by n criteria is constructed (see Ch. 4.1.3 and step 4.1.4.1) as show in table 4.6.1 by using the collected data of the past. With the SAW method, it must standardise the raw matrix by eq. 10 or 11 first, therefore $z_j^{\min}$ or $z_j^{\max}$ in each column (blue numbers in table 4.6.1) must be identified hinge on its nature of minimum or maximum case. For this example, Price (C1) and Delivery Day (C3) are based on minimum case, while Quality (C2), Service (C4), Capacity of spare parts (C5), and Preferred Technology (C6) are in the maximum case. Table 4.6.1 is then converted to table 4.6.2. For a numerical example, for C3 criterion the most preference value is $z_j^{\min} = 4$, therefore $r_{2,3}$ of table 4.6.2 can be calculated by: with $z_{2,3} = 5$ from table 4.6.1, consequently $r_{2,3} = z_3^{\min} / z_{2,3} = 4/5 = 0.8$ in table 4.6.2.

Table 4.6.1: the matrix of raw measures for alternatives

	C1	C2	C3	C4	C5	C6
A	325	0.75	5	0.7	0.6	**0.8**
B	275	0.89	5	**0.8**	0.7	0.5
C	301	**0.97**	**4**	**0.8**	0.7	0.7
D	**257**	0.94	7	0.7	**0.85**	0.6

Table 4.6.2: standardised matrix derived from table 4.6.1

	C1	C2	C3	C4	C5	C6
A	0.791	0.773	0.800	0.875	0.706	**1.000**
B	0.935	0.918	**0.800**	**1.000**	0.824	0.625
C	0.854	**1.000**	**1.000**	**1.000**	0.824	0.875
D	**1.000**	0.969	0.571	0.875	**1.000**	0.750

All standardised scores in each column of table 4.6.2 will be multiplied by their calculated relative weight from 4.1.7.1 (C1 = 0.3807, C2 = 0.1703, C3 = 0.0755, C4 = 0.1409, C5 = 0.1171, and C6 = 0.1155) as show in table 4.7, then the results are presented in table 4.8.1. For the numerical example, 0.3011 ($C_{1,1}$) in table 4.8.1 is obtained by multiplying C1 weight of 0.3807 with the standardised score of $C_{1,1}$ = 0.791 from table 4.6.2: therefore, 0.3807 x 0.791 = 0.3011.

Table 4.7: standardised matrix from table 4.6.2 with the relative weights respect to each criterion for all alternatives

	C1		C2		C3		C4		C5		C6	
A	**0.3807**	0.791	**0.1703**	0.773	**0.0755**	0.800	**0.1409**	0.875	**0.1171**	0.706	**0.1155**	1.000
B		0.935		0.918		0.800		1.000		0.824		0.625
C		0.854		1.000		1.000		1.000		0.824		0.875
D		1.000		0.969		0.571		0.875		1.000		0.750

The summations in each row of table 4.8.1 are then shown in table 4.8.2 (step 4.1.1.6) to reach the global priority (R_j) of all the alternatives. Finally, these R_j are used for rank the alternatives, so alterative D confirms the best provider of this decision-making problem due to its highest R_j of 0.9159.

Table 4.8.1: the result matrix from table 4.7

	C1	C2	C3	C4	C5	C6
A	**0.3011**	0.1317	0.0604	0.1233	0.0827	0.1155
B	0.3558	0.1563	0.0604	0.1409	0.0964	0.0722
C	0.3251	0.1703	0.0755	0.1409	0.0964	0.1010
D	0.3807	0.1651	0.0431	0.1233	0.1171	0.0866

Table 4.8.2*

0.8146
0.8820
0.9092
0.9159

Table 4.8.3**

Rank
4
3
2
1

*Table 4.8.2: the matrix of global priority vector which is obtained from summation by row of table 4.8.1

**Table 4.8.3: rank priority of all alternative with the SAW approach by the points from table 4.8.2

4.1.8.3 The AHP with the TOPSIS method example

The TOPSIS method can be applied in the last two step of the AHP like the SAW approach. This method also starts with the construction of the raw measured matrix (table 4.6.1). All elements of table 4.6.1 are then standardised by equation (12) to attain the table 4.9.2 (step 4.1.4.1). For a numerical example, the standardised number of 581.3 in C1 column of table 4.9.1 can be calculated from all members of the column as $\sqrt{335^2 + 275^2 + 301^2 + 257^2} = 581.3$. Subsequently, the value of $C_{2,1}$ for table 4.9.2 is computed with $C_{2,1}$ = 275 of table 4.9.1 by: $275/581.3 = 0.473$.

Table 4.9.1: the matrix of raw measures for alternatives

	C1	C2	C3	C4	C5	C6
A	**325**	0.75	5	0.7	0.6	0.8
B	**275**	0.89	5	0.8	0.7	0.5
C	**301**	0.97	4	0.8	0.7	0.7
D	**257**	0.94	7	0.7	0.85	0.6
	581.3	**1.78**	**10.72**	**1.50**	**1.44**	**1.32**

Table 4.9.2: the standardised matrix from table 4.9.1

	C1	C2	C3	C4	C5	C6
A	0.559	0.421	0.466	0.466	0.418	0.606
B	**0.473**	0.499	0.466	0.532	0.487	0.379
C	0.518	0.544	0.373	0.532	0.487	0.531
D	0.442	0.527	0.653	0.466	0.592	0.455

After standardisation, all members in each column of table 4.9.2 will be multiplied by their calculated relative weight from 4.1.7.1 (C1 = 0.3807, C2 = 0.1703, C3 = 0.0755, C4 = 0.1409, C5 = 0.1171, and C6 = 0.1155) as show in table 4.10 (step 4.1.4.3), then the results are displayed in table 4.11. For the numerical example, 0.1801 ($C_{2,1}$) in table 4.11 is obtained by multiplying C1 weight of 0.3807 with the standardised score of $C_{2,1}$ = 0.437 from table 4.10: therefore, 0.3807 x 0.437 = 0.1801.

Table 4.10: standardised matrix from table 4.9.2 with the relative weights respect to each criterion for all alternatives

	C1		C2		C3		C4		C5		C6	
A	**0.3807**	0.559	**0.1703**	0.421	**0.0755**	0.466	**0.1409**	0.466	**0.1171**	0.418	**0.1155**	0.606
B		0.473		0.499		0.466		0.532		0.487		0.379
C		0.518		0.544		0.373		0.532		0.487		0.531
D		0.442		0.527		0.653		0.466		0.592		0.455

From 4.1.4.4 and 4.1.4.5 step, v_i^- (red numbers in table 4.11) and v_i^+ (blue numbers in the same table) in each column must be identified hinge on their nature of minimum or maximum case. For the numerical example within table 4.11, $v_2^- = 0.0716$ (lowest value) and $v_2^+ = 0.0927$ (highest value) in C2 column, because C2 (Quality) is based on the maximum case. The next example, $v_3^- = 0.0493$ (highest value) and $v_3^+ = 0.0282$ (lowest value) in C3 column, since C3 (Delivery Day) is the minimum case.

Table 4.11: the result matrix from table 4.10

	C1	C2	C3	C4	C5	C6
A	0.2129	0.0716	0.0352	0.0656	0.0489	0.0700
B	**0.1801**	0.0850	0.0352	0.0750	0.0571	0.0438
C	0.1971	0.0927	0.0282	0.0750	0.0571	0.0613
D	0.1683	0.0898	0.0493	0.0656	0.0693	0.0525

To achieve s_i^- of each alternative in the following step 4.1.4.6, all members in each column of table 4.11 must be subtracted by their v_i^-, then obtained values are to the power two. The results are shown in table 4.12.1. For a numerical example, the value 0.00042 in column C5 of table 4.12.1 can be calculated from both 0.0693 of the same position and column of table 4.11, and v_{C5}^- = 0.0489; therefore, $(0.0693 - 0.0489)^2$ = 0.00042. The summations of each row in table 4.12.1 will be displayed in table 4.12.2. Finally, each s_i^- is reckoned by square root the member of table 4.12.2 at the same position such as $\sqrt{0.00160} = 0.04005$ (in table 4.12.3). All calculated results are presented in table 4.12.3. Do the same procedures for the s_i^+ calculation, but utilise v_i^+ instead of v_i^- to reach the table 4.13.3.

Table 4.12.1: matrix for s_i^- calculation derived from table 4.11

	C1	C2	C3	C4	C5	C6
A	0.00000	0.00000	0.00020	0.00000	0.00000	0.00069
B	0.00107	0.00018	0.00020	0.00009	0.00007	0.00000
C	0.00025	0.00044	0.00045	0.00009	0.00007	0.00031
D	0.00198	0.00033	0.00000	0.00000	**0.00042**	0.00008

Table 4.12.2*

Sum
0.00089
0.00160
0.00160
0.00281

Table 4.12.3**

s_i^-
0.02980
0.04005
0.03994
0.05296

*Table 4.12.2: vector matrix which is derived from summation of each row in table 4.12.1

**Table 4.12.3: vector matrix which is derived from square root each member in table 4.12.2

Table 4.13.1: matrix for s_i^+ calculation derived from table 4.11

	C1	C2	C3	C4	C5	C6
A	0.00198	0.00044	0.00005	0.00009	0.00042	0.00000
B	0.00014	0.00006	0.00005	0.00000	0.00015	0.00069
C	0.00083	0.00000	0.00000	0.00000	0.00015	0.00008
D	0.00000	0.00001	0.00045	0.00009	0.00000	0.00031

Table 4.13.2*

Sum
0.00298
0.00109
0.00106
0.00085

Table 4.13.3**

s_i^+
0.05457
0.03296
0.03251
0.02913

*Table 4.13.2: vector matrix which is derived from summation of each row in table 4.13.1

**Table 4.13.3: vector matrix which is derived from square root each member in table 4.13.2

The last step of the AHP with the TOPSIS method example is to calculate c_i^+ by using eq. 18, then rank order alternatives by maximising c_i^+ (step 4.1.4.7 – 8). For example by considering alternative ***A***, with $s_i^- = 0.0298$ and $s_i^+ = 0.05457$ as well as $c_j^+ = s_j^- / \left(s_j^+ + s_j^-\right)$; therefore, $c_i^+ = 0.0298/\left(0.0298 + 0.05457\right) = 0.3532$ in table 4.14.2.

As show in table 4.14.3, the company D is the most compromising alternative in this analysis. This result is the same as the ranking method by the SAW approach in 4.1.7.2, but the numerical values by the TOPSIS method are easier for identification than those of the SAW approach (for instance the difference between rank order 1 and 2 is 0.6453 >> 0.5513 in the TOPSIS method; while 0.9159 > 0.9092 in the SAW approach). Therefore, the TOPSIS method is suggested to rank the **alternatives** of the real analysis in this research.

Table 4.14.1: summary of s_i^- and s_i^+

Alternatives	s_i^-	s_i^+
A	**0.02980**	**0.05457**
B	0.04005	0.03296
C	0.03994	0.03251
D	0.05296	0.02913

Table 4.14.2*

c_i^+
0.3532
0.5486
0.5513
0.6452

Table 4.14.3**

Rank
4
3
2
1

*Table 4.14.2: vector matrix of c_i^+ which are derived from table 4.14.1

**Table 4.14.3: rank priority of all alternative with the TOPSIS method by the points from table 4.14.2

4.1.8.4 The fuzzy AHP method example

Under the fuzzy environment, instead of only a single crisp value, the fuzzy AHP applied a range of values to incorporate decision maker's uncertainty, because they feel more confident to give interval judgments rather than fixed value ones (Dağdeviren et al., 2009). The outlines of the extent analysis method on fuzzy AHP example can be summarised as follows: First, the crisp set must be fuzzified by using triangular fuzzy number $f = (l, m, u)$ as indicated in table 4.15 below for instance. The parameters l, m, and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value describing a fuzzy event, respectively. The spread between the lower (l) bound and upper bound (u) illustrates the uncertain range that might exist in the preferences expressed by the decision maker or experts. For numerical example, the comparison between C1 and C6 in the table 4.3.2 provided a crisp value "5" of their relative important ratio. This crisp value will be converted into triangular fuzzy number via table 4.15, therefore $a_{1,6} = 5$ is transformed to $\tilde{a}_{1,6} = (3,5,7)$. Let table 4.16 represent a fuzzified-reciprocal judgment matrix converted from the criteria pair-wise matrix of table 4.3.2.

Table 4.15: Example of conversion from Crisp PCM to triangular Fuzzy PCM

Crisp PCM Value	**Fuzzy PCM Value** (l,m,u)	**Crisp PCM Value**	**Fuzzy PCM Value** (l,m,u)
1	(1,1,3)		
3	(1,3,5)	1/3	(1/5,1/3,1)
5	(3,5,7)	1/5	(1/7,1/5,1/3)
7	(5,7,9)	1/7	(1/9,1/7,1/5)
9	(7,9,9)	1/9	(1/9,1/9,1/7)

Table 4.3.2 complete reciprocal matrix of pair-wise comparison

	C1	C2	C3	C4	C5	C6
C1	1	3	3	3	3	5
C2	1/3	1	3	1	1	3
C3	1/3	1/3	1	1/3	1	1/3
C4	1/3	1	3	1	1	1
C5	1/3	1	1	1	1	1
C6	1/5	1/3	3	1	1	1

Table 4.16: the fuzzified-reciprocal judgment matrix converted from the criteria pair-wise matrix of table 4.3.2

	C1			C2			C3			C4			C5			C6		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
C1	1	1	3	1	3	5	1	3	5	1	3	5	1	3	5	3	5	7
C2	1/5	1/3	1	1	1	3	1	3	5	1	1	3	1	1	3	1	3	5
C3	1/5	1/3	1	1/5	1/3	1	1	1	3	1/5	1/3	1	1	1	3	1/5	1/3	1
C4	1/5	1/3	1	1	1	3	1	3	5	1	1	3	1	1	3	1	1	3
C5	1/5	1/3	1	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
C6	1/7	1/5	1/3	1/5	1/3	1	1	3	5	1	1	3	1	1	3	1	1	3

After forming a fuzzy pair-wise comparison matrix, relative weights of all criteria or sub-criteria can be determined by using the extent analysis method (Chang, 1992, 1996; Zhu et al., 1999). As explication in 4.1.5, this technique begins with the summations of l,m,u in each row of table 4.16 to obtain $RS_i = \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right)$ of eq. 19. The results can be represented in table 4.17.1. For the numerical example, the l,m,u value of C1 in table 4.17.1 can be obtained by summation of each l,m,u in C1's row of table 4.16:

$$L_{C1,\text{table 4.17.1}} = \sum_{j=1}^{n} l_{ij} = (l_{C1/C1} + l_{C1/C2} + l_{C1/C3} + l_{C1/C4} + l_{C1/C5} + l_{C1/C6})_{C1\text{'s row, table 4.16}}$$

$$= (1+1+1+1+1+3)_{C1\text{'s row,table 4.16}}$$
$$= 8$$

$$M_{C1,\text{ table 4.17.1}} = \sum_{j=1}^{n} m_{ij} = (m_{C1/C1} + m_{C1/C2} + m_{C1/C3} + m_{C1/C4} + m_{C1/C5} + m_{C1/C6})_{C1\text{'s row, table 4.16}}$$

$$= (1+3+3+3+3+5)_{C1\text{'s row, table 4.16}}$$
$$= 18$$

$$U_{C1,\text{ table 4.17.1}} = \sum_{j=1}^{n} u_{ij} = (u_{C1/C1} + u_{C1/C2} + u_{C1/C3} + u_{C1/C4} + u_{C1/C5} + u_{C1/C6})_{C1\text{'s row, table 4.16}}$$

$$= (3+5+5+5+5+7)_{C1\text{'s row, table 4.16}}$$
$$= 30$$

Table 4.17.1: summation of l, m, u from table 4.16

Criteria	Fuzzy Number		
	l	m	u
C1	**8.000**	**18.000**	**30.000**
C2	5.200	9.333	20.000
C3	2.800	3.333	10.000
C4	5.200	7.333	18.000
C5	5.200	5.333	16.000
C6	4.343	6.533	15.333
	30.743	**49.867**	**109.333**

Table 4.17.2: $\tilde{S}_i$ derived from table 4.17.1

$\tilde{S}_i$	Fuzzy Number		
	l	m	u
$\tilde{S}c1$	0.073	0.361	0.976
$\tilde{S}c2$	0.048	0.187	0.651
$\tilde{S}c3$	**0.026**	**0.067**	**0.325**
$\tilde{S}c4$	0.048	0.147	0.586
$\tilde{S}c5$	0.048	0.107	0.520
$\tilde{S}c6$	0.040	0.131	0.499
	0.281	**1.000**	**3.556**

The next step is the sum of $l, m,$ and u in each column of table 4.17.1 to obtain $\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}$, $\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}$, and $\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}$ using in eq. 20. For numerical example, $\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj} = (u_{C1} + u_{C2} + u_{C3} + u_{C4} + u_{C5} + u_{C6}) = (30+20+10+18+16+15.333) = 109.333$. After that, the fuzzy synthetic extent values $\tilde{S}_i$ are calculated via of eq. 20, and the results are showed in table 4.17.2. For the numerical example, by $\tilde{S}_i = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}} \right)$ of eq. 20, the l, m, u value of C3 in table 4.17.2 will be achieved by:

$$\tilde{S}_{C1,l} = l_{C3,\text{ table 4.17.1}} / \sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj} = 2.8/109.333 = 0.026$$

$$\tilde{S}_{C1,m} = m_{C3,\text{ table 4.17.1}} / \sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj} = 3.333/49.867 = 0.067$$

$$\tilde{S}_{C1,u} = u_{C3,\text{ table 4.17.1}} / \sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj} = 10/30.743 = 0.325$$

The next step of the extent analysis method is to calculate the degrees of possibility $V(\tilde{S}_i \geq \tilde{S}_j)$ by eq. 21 (step 4.1.5.3) and then to compare them (step 4.1.5.4). As mention in eq. 22, the comparisons require both $V(\tilde{S}_i \geq \tilde{S}_j)$ and $V(\tilde{S}_j \geq \tilde{S}_i)$. All comparisons are showed in table 4.17.3. For the numerical example, $\tilde{S}_{C1} = (l_{C1}, m_{C1}, u_{C1}) = (0.073, 0.361, 0.976)$ and $\tilde{S}_{C2} = (l_{C2}, m_{C2}, u_{C2}) = (0.048, 0.187, 0.651)$ in table 4.17.2, $V(\tilde{S}_{C1} \geq \tilde{S}_{C2})$ and $V(\tilde{S}_{C2} \geq \tilde{S}_{C1})$ can be illustrate following eq. 21 here:

$V(\tilde{S}_{C1} \geq \tilde{S}_{C2}) \rightarrow V((l_{C1}, m_{C1}, u_{C1}) \geq (l_{C2}, m_{C2}, u_{C2}))$
$\rightarrow V((0.073, 0.361, 0.976) \geq (0.048, 0.187, 0.651))$
$\rightarrow$ Step 1 of eq. 21: $m_{C1} = 0.361 > m_{C2} = 0.187$,
therefore $V(\tilde{S}_{C1} \geq \tilde{S}_{C2}) = 1$

$V(\tilde{S}_{C2} \geq \tilde{S}_{C1}) \rightarrow V((l_{C2}, m_{C2}, u_{C2}) \geq (l_{C1}, m_{C1}, u_{C1}))$
$\rightarrow V((0.048, 0.187, 0.651) \geq (0.073, 0.361, 0.976))$
$\rightarrow$ Step 1 of eq. 26: $m_{C2} = 0.187 < m_{C1} = 0.361$,
therefore go to step 2
$\rightarrow$ Step 2: $l_{C2} = 0.048 < u_{C1} = 0.976$, therefore go to step 3

$$\rightarrow \text{Step 3: } V\left(M_{C2} \geq M_{C1}\right) = \frac{l_{C1} - u_{C2}}{\left(m_{C2} - u_{C2}\right) - \left(m_{C1} - l_{C1}\right)}$$

$$= \frac{0.073 - 0.651}{\left(0.187 - 0.651\right) - \left(0.361 - 0.073\right)} = 0.769$$

Table 4.17.3: Calculation and comparison of $V\left(\tilde{S}_i \geq \tilde{S}_j\right)$ derived from table 4.17.2

V	$\tilde{S}c1$	$\tilde{S}c2$	$\tilde{S}c3$	$\tilde{S}c4$	$\tilde{S}c5$	$\tilde{S}c6$	min	Normalisation
$\tilde{S}c1$	-	**1**	1	1	1	1	1.000	0.237
$\tilde{S}c2$	**0.769**	-	1	1	1	1	0.769	0.182
$\tilde{S}c3$	0.462	0.698	-	0.776	0.874	0.817	**0.462**	**0.109**
$\tilde{S}c4$	0.705	0.931	1	-	1	1	0.705	0.167
$\tilde{S}c5$	0.638	0.855	1	0.922	-	0.952	0.638	0.151
$\tilde{S}c6$	0.649	0.889	1	0.966	1	-	0.649	0.154
							4.223	**1.000**

The following step is to $\min_{j \in \{1,\ldots,n\}, j \neq i} V\left(\tilde{S}_i \geq \tilde{S}_j\right)$ following eq. 22 as description in 4.1.5.4. The results are showed in "**min**" column of table 4.17.3. These minimised values are considered as the nominal weights of the criteria that must be normalised to get the final relative weights as in the last column of table 4.17.3 (step 4.1.5.5). For the numerical example, $\min V\left(\tilde{S}_{C3} \geq \tilde{S}_{Ci}\right)$ = min (0.462, 0.698, 0.776, 0.874, 0.817) = 0.462. For normalisation, each element in "min" column must be divided by the column's summation such as 0.462/4.223 = 0.109 for $\tilde{S}_{C3}$ in the last column. Therefore, the comparison of the relative weights for each criteria between the fuzzy AHP method and the eigenvector method (in Ch. 4.1.8.1) are:

Method	C1	C2	C3	C4	C5	C6
The Fuzzy AHP	0.237	0.182	0.109	0.167	0.151	0.154
Eigenvector	0.381	0.170	0.076	0.141	0.117	0.116

Because the results from the eigenvector method are easier for recognition than those of the fuzzy AHP and the calculation process of the eigenvector method is not complicate like that of the fuzzy AHP, the eigenvector method is recommended to apply for computation the relative weights of main criteria in this study.

4.1.8.5 The fuzzy AHP with the fuzzy TOPSIS method example

As picture in 4.1.6, a large number of pair-wise comparisons - especially in decision making with sub-criteria - can cause impractical usage in both the AHP and the fuzzy AHP method. To deal with this problem, a two step of fuzzy AHP and fuzzy TOPSIS methodology can be applied to reduce the number of pair-wise comparisons and to rank the alternatives. The main concept of this technique is that the fuzzy TOPSIS will utilise the fuzzy AHP result weights as its input weights (for example, relative normalised weights from 4.1.8.4). Therefore, in the next example, only C1 branch in level 2 and 3 will be focused on with assigned weight of C1 = 0.237, which is obtained from previous method, (Fig. 4.3 next page).

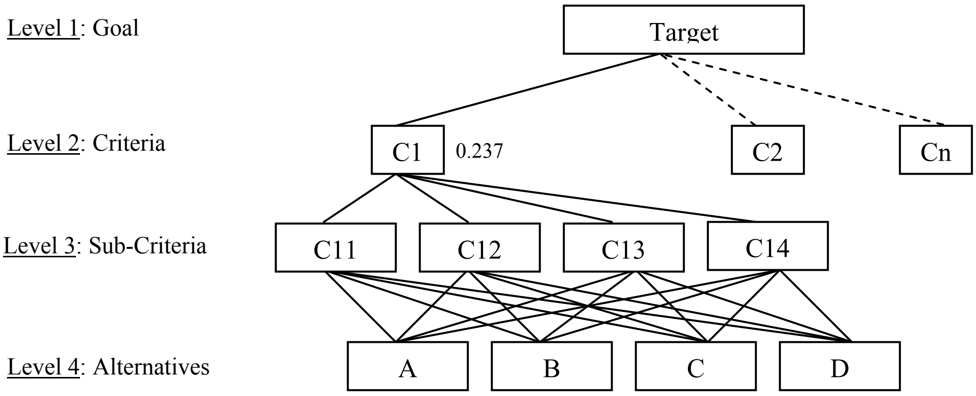

Fig. 4.3: Abstract representation of a decision hierarchy with Sub-Criteria for topic 4.1.8.5

At level 3 of the decision procedure in this example, the decision makers who have experience in this field will be also introduced to establish the fuzzy TOPSIS matrix like in the fuzzy AHP method. The fuzzy matrix of C1 sub-criteria, found by evaluating linguistic variables (table 4.19) with the fuzzy numbers (table 4.18), can be presented in table 4.20. The next step is to obtain the global weights of C1 sub-criteria, therefore the main criteria weight calculated by the fuzzy AHP must be applied in this step (in this example = 0.237 for C1). A numerical example is presented to show applicability and performance of the methodology.

Table 4.18: Example of conversion from linguistic value to triangular Fuzzy number

Linguistic values	**Fuzzy numbers** (l,m,u)
Very Low (VL)	(0,0,0.2)
Low (L)	(0.1,0.2,0.3)
Medium Low (ML)	(0.2,0.35,0.5)
Medium (M)	(0.4,0.5,0.6)
Medium High (MH)	(0.5,0.65,0.7)
High (H)	(0.7,0.8,0.9)
Very High (VH)	(0.8,1,1)

Table 4.19: Example of linguistic approval by specialists for sub-criteria in Fig 4.3
(For all abbreviations in this table, please see table 4.18)

Sub Criteria	**linguistic** variables			
	Specialist 1	**Specialist 2**	**Specialist 3**	**Specialist 4**
C11	L	VH	H	ML
C12	M	H	MH	H
C13	M	**MH**	VH	MH
C14	MH	L	M	VH
C15	VH	H	VH	L

For the conversion example, the linguistic value from the opinion by the specialist 2 on C13 sub-criteria is Medium High (MH) (table 4.19). This linguistic value will be converted into triangular fuzzy number by table 4.18; therefore the fuzzy number of C13 by specialist 2 is $(0.5,0.65,0.7)$ as show in table 4.20, which represents a fuzzified matrix converted from the judgment linguistic matrix of table 4.19.

Table 4.20: Fuzzy mumber matrix which is converted from table 4.19 by table 4.18

Step 1	**Fuzzy Numbers** (l,m,u)											
	Specialist 1 (sp1)			**Specialist 2** (sp2)			**Specialist 3** (sp3)			**Specialist 4** (sp4)		
C11	0.10	0.20	0.30	0.80	1.00	1.00	0.70	0.80	0.90	0.20	0.35	0.50
C12	0.40	0.50	0.60	0.70	0.80	0.90	0.50	0.65	0.70	0.70	0.80	0.90
C13	0.40	0.50	0.60	**0.50**	**0.65**	**0.70**	0.80	1.00	1.00	0.50	0.65	0.70
C14	0.50	0.65	0.70	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.00
C15	0.80	1.00	1.00	0.70	0.80	0.90	0.80	1.00	1.00	0.10	0.20	0.30
	2.20	**2.85**	**3.20**	**2.80**	**3.45**	**3.80**	***3.20***	**3.95**	**4.20**	**2.30**	**3.00**	**3.40**

After acquisition of table 4.20, the next step is to sum all members in each column for starting fuzzy operation of normalisation. For $\sum_{j=1}^{m} l_j$ example by specialist 3, $\sum_{j=1}^{m} l_j$ = (l_{C11} + l_{C12} + l_{C13} + l_{C14} + l_{C15}) = (0.7+0.5+0.8+0.4+0.8) = 3.2. Following this, the normalised fuzzy numbers are calculated, and the resulting matrix is shown in table 4.21. However, to normalise the fuzzy numbers in l, m, u column under the same specialist, the elements in m column must be divided by the sum of its respective columns, while the members in l column are assigned by the sum of u column and the components in u column are distributed by the sum of l column, according to eq. 27. With specialist 3 in table 4.20, the calculation example can be illustrated here:

$$l_{C12,\ Table\ 4.21} = l_{C12,table4.20} \Big/ \sum_{j=1}^{5} u_j = 0.50/4.3 = 0.116.$$

$$m_{C12,\ Table\ 4.21} = m_{C12,table4.20} \Big/ \sum_{j=1}^{5} m_j = 0.65/3.95 = 0.165.$$

$$u_{C12,\ Table\ 4.21} = u_{C12,table4.20} \Big/ \sum_{j=1}^{5} l_j = 0.8/3.2 = 0.25$$

Table 4.21: Fuzzy operation Matrix which is derived from table 4.20

Step 2	**Fuzzy Numbers** (l,m,u)											
	Specialist 1 (sp1)			**Specialist 2** (sp2)			**Specialist 3** (sp3)			**Specialist 4** (sp4)		
C11	0.031	0.070	0.136	0.211	0.290	0.357	0.167	0.203	0.281	0.059	0.117	0.217
C12	0.125	0.175	0.273	0.184	0.232	0.321	**0.119**	**0.165**	**0.219**	0.206	0.267	0.391
C13	0.125	0.175	0.273	0.132	0.188	0.250	0.190	0.253	0.313	0.147	0.217	0.304
C14	0.156	0.228	0.318	0.026	0.058	0.107	0.095	0.127	0.188	0.235	0.333	0.435
C15	0.250	0.351	0.455	0.184	0.232	0.321	0.190	0.253	0.313	0.029	0.067	0.130
$\tilde{\upsilon}_i^-$	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
$\tilde{\upsilon}_i^+$	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

According to the fuzzy TOPSIS method, the next step is to define the fuzzy positive-ideal solution (FPIS, A$^+$) and the fuzzy negative-ideal solution (FPIS, A$^-$) as $\tilde{\upsilon}_i^+$ = (1, 1, 1) and $\tilde{\upsilon}_i^-$ = (0, 0, 0), respectively, as figure in table 4.21. After that, the geometric distance of each sub-criteria from $\tilde{\upsilon}_i^-$ and $\tilde{\upsilon}_i^+$ can be therefore calculated via eq. 29. The last step is to solve the similarities to an ideal solution by eq. 35, then to normalise them before multiply with main criteria weight to get global weights of all sub-criteria in the same branch. In order to exemplify these steps, the C15 calculation is used as an example as follows (input data from table 4.21 and the results in table 4.22):

$$D_{C15}^{-}=\sqrt{\frac{1}{3}\left[(l_{v^-}-l_{C15})^2+(m_{v^-}-m_{C15})^2+(u_{v^-}-u_{C15})^2\right]_{sp1}}+\ldots+\sqrt{\frac{1}{3}\left[(l_{v^-}-l_{C15})^2+(m_{v^-}-m_{C15})^2+(u_{v^-}-u_{C15})^2\right]_{sp4}}$$

$$\begin{aligned}D_{C15}^{-}&=\sqrt{\frac{1}{3}\left[(0-0.250)^2+(0-0.351)^2+(0-0.455)^2\right]}+\sqrt{\frac{1}{3}\left[(0-0.184)^2+(0-0.232)^2+(0-0.321)^2\right]}\\&+\sqrt{\frac{1}{3}\left[(0-0.190)^2+(0-0.253)^2+(0-0.313)^2\right]}+\sqrt{\frac{1}{3}\left[(1-0.029)^2+(1-0.067)^2+(1-0.130)^2\right]}\\&=0.957\end{aligned}$$

$$D_{C15}^{+}=\sqrt{\frac{1}{3}\left[(l_{v^+}-l_{C15})^2+(m_{v^+}-m_{C15})^2+(u_{v^+}-u_{C15})^2\right]_{sp1}}+\ldots+\sqrt{\frac{1}{3}\left[(l_{v^+}-l_{C15})^2+(m_{v^+}-m_{C15})^2+(u_{v^+}-u_{C15})^2\right]_{sp4}}$$

$$\begin{aligned}D_{C15}^{+}&=\sqrt{\frac{1}{3}\left[(1-0.250)^2+(1-0.351)^2+(1-0.455)^2\right]}+\sqrt{\frac{1}{3}\left[(1-0.184)^2+(1-0.232)^2+(1-0.321)^2\right]}\\&+\sqrt{\frac{1}{3}\left[(1-0.190)^2+(1-0.253)^2+(1-0.313)^2\right]}+\sqrt{\frac{1}{3}\left[(1-0.029)^2+(1-0.067)^2+(1-0.130)^2\right]}\\&=3.085\end{aligned}$$

$$CC_{C15}=\frac{D_{C15}^{-}}{D_{C15}^{-}+D_{C15}^{+}}=\frac{0.957}{0.957+3.085}=0.237$$

Table 4.22: Summary of the fuzzy AHP with the fuzzy TOPSIS calculation

Sub-criteria	**D^-**	**D^+**	**CC_j**	**Normalization**
C11	0.751	3.295	0.186	0.174
C12	0.923	3.117	0.229	0.214
C13	0.885	3.152	0.219	0.205
C14	0.801	3.240	0.198	0.186
C15	**0.957**	**3.085**	**0.237**	0.222

Via normalisation, the relative *local* weights of each criteria are: C11 = 0.174, C12 = 0.214, C13 = 0.205, C14 = 0.186, and C15 = 0.222 (last column of table 4.22), respectively. After multiply by C1 criteria weight of 0.237, the global weights for sub-criteria are then: C11 = 0.171 x 0.237 = 0.0412, C12 = 0.214 x 0.237 = 0.0507, C13 = 0.210 x 0.237 = 0.0486, C14 = 0.187 x 0.237 = 0.0440, and C15 = 0.218 x 0.237 = 0.0525. These weights will be applied in the next step of decision procedure (more details briefly like in 4.1.1.4 to 4.1.1.6).

4.1.8.6 Group Decision Making and the Geometric Mean example

As stated in the beginning of the methodology section in this chapter, a decision making issue normally requires a consensus from a group of decision makers. On the other hand, decision makers from different backgrounds may define very different weight vectors (Naghadehi et al., 2009). They usually not only cause imprecise evaluation, but also serious trouble (to deal with their extremely deferent opinions) during the decision process. To cope with this case, the technique for achieving the group's judgment, proposed by Saaty (1989), using the Geometric Mean Method (GMM) as shown in eq. 39 has been generally applied (Davis, 1994). The key advantage of this method is that it can aggregate various judgments from several experts (see calculation example). Moreover, the isolated runaway values will not affect the results dramatically, unlike min-max operations.

$$a_{ij}^{gp} = \left(a_{ij}^{1} \times a_{ij}^{2} \times \ldots \times a_{ij}^{h} \times \ldots \times a_{ij}^{H}\right)^{1/H} = \left(\prod_{h=1}^{H} a_{ij}^{h}\right)^{1/H} \qquad (39)$$

Where; $a_{ij}^{h} = \left(w_i / w_j\right)$ is an element of the square matrix of a decision maker h;

a_{ij}^{gp} is the geometric mean of the paired comparisons conducted by each expert;

and H is the total number of human experts.

The ***Reason*** for applying GMM will be demonstrated below. Assume that the recommendation for weighting the criteria by three experts on the same position $\left(a_{ij}\right)$ of judgment according to the Pair-wise Method (see Ch. 4.1.2) are 4, 3, and 2, respectively. When Arithmetic Mean is applied, 4 + 3 + 2 = 9 then the reciprocal should be 1/9. However, if the reciprocal is computed directly, the result is 1/4 + 1/3 + 1/2 = 13/12. This value 13/12 is not equal 1/9, therefore Arithmetic Mean is inappropriate. Following GMM by eq. 39, the group's judgment is $\sqrt[3]{4 \times 3 \times 2} = \sqrt[3]{24}$, therefore the reciprocal is $1/\sqrt[3]{24}$. This resulting reciprocal is the same as the outcome from direct calculation: $\sqrt[3]{1/4} \times \sqrt[3]{1/3} \times \sqrt[3]{1/2} = 1/\sqrt[3]{4 \times 3 \times 2} = 1/\sqrt[3]{24}$. This example shows that the GMM is the unique way to combine group judgments in a theorem of mathematics. However, it could be noted from many literatures (Lee et al., 2009) that only consistent judgments by experts should be included in GMM. Prior to aggregating the single pair-wise comparisons, the main point is therefore to evaluate consistency for each respondent. Test of consistency is a critical step in the AHP methodology. If the test shows that the result is inconsistency, a specialist is needed to make revisions until reaching the acceptance or a mathematical procedure is required to derive a consistent matrix from the inconsistent original (see Ch. 4.1.8.7).

In this instance, modified from Z. Xu (2000), the following four judgment matrices (A_1, A_2, A_3, and A_4) are derived from the comments by also four experts. These matrices are then checked for their consistency (see Ch. 4.1.8.1) as be shown below. After consistent test's pass with C.R. < 0.1, the group's judgment can be calculated via GMM and then the assigning matrix $\left(\overline{A}\right)$ will be constructed. For a calculation example, $\overline{a}_{1,2}$ of matrix $\overline{A}$ can be determined by: $\overline{a}_{1,2} = \sqrt[4]{\left(a_{1,2}\right)_{A1} \times \left(a_{1,2}\right)_{A2} \times \left(a_{1,2}\right)_{A3} \times \left(a_{1,2}\right)_{A4}} = \sqrt[4]{4 \times 5 \times 3 \times 4} = 3.963$. Hereafter, the matrix $\overline{A}$ can apply to the next step of calculation for decision-making procedure.

$$A_1 = \begin{bmatrix} 1 & 4 & 6 & 7 \\ 1/4 & 1 & 3 & 4 \\ 1/6 & 1/3 & 1 & 2 \\ 1/7 & 1/4 & 1/2 & 1 \end{bmatrix},\ A_2 = \begin{bmatrix} 1 & 5 & 7 & 9 \\ 1/5 & 1 & 4 & 6 \\ 1/7 & 1/4 & 1 & 2 \\ 1/9 & 1/6 & 1/2 & 1 \end{bmatrix},\ A_3 = \begin{bmatrix} 1 & 3 & 5 & 8 \\ 1/3 & 1 & 4 & 5 \\ 1/5 & 1/4 & 1 & 2 \\ 1/8 & 1/5 & 1/2 & 1 \end{bmatrix},\ A_4 = \begin{bmatrix} 1 & 4 & 5 & 6 \\ 1/4 & 1 & 3 & 3 \\ 1/5 & 1/3 & 1 & 2 \\ 1/8 & 1/3 & 1/2 & 1 \end{bmatrix}$$

$$\begin{aligned}
w_{A1} &= (0.617, 0.224, 0.097, 0.062)^{\mathrm{T}},\ \lambda_{\max} = 4.102,\ \text{C.R.} = 0.038 < 0.1, \\
w_{A2} &= (0.653, 0.225, 0.076, 0.047)^{\mathrm{T}},\ \lambda_{\max} = 4.181,\ \text{C.R.} = 0.067 < 0.1, \\
w_{A3} &= (0.570, 0.277, 0.096, 0.057)^{\mathrm{T}},\ \lambda_{\max} = 4.091,\ \text{C.R.} = 0.034 < 0.1, \\
w_{A4} &= (0.597, 0.222, 0.109, 0.073)^{\mathrm{T}},\ \lambda_{\max} = 4.126,\ \text{C.R.} = 0.047 < 0.1,
\end{aligned}$$

$$\overline{A} = \begin{bmatrix} 1 & 3.936 & 5.692 & 7.417 \\ 0.254 & 1 & 3.464 & 4.356 \\ 0.176 & 0.289 & 1 & 2 \\ 0.135 & 0.230 & 1/2 & 1 \end{bmatrix}$$

$$w_{\overline{A}} = (0.610, 0.237, 0.094, 0.059)^{\mathrm{T}},\ \lambda_{\max} = 4.119,\ \mathrm{C.R.} = 0.044 < 0.1.$$

4.1.8.7 Example of a consistency improving method in the AHP

To retrieve the idea of the algorithm represented in 4.1.7, in this section, a 4×4 inconsistent pair-wise matrix with $C.R. = 0.1098$ and the original priority vector $\omega = [0.631 \quad 0.219 \quad 0.098 \quad 0.052]^T$ will be considered carefully. A step by step process to eliminate the inconsistencies applying this algorithm with a $\lambda = 0.925$ will be demonstrated here. In this case, the example matrix must be revised iteratively the preference ratios to improve inconsistencies until $C.R.$ is valid.

Step 4.1.7.1 to 4.1.7.3: at first, matrix $A^{(0)}$ was found $(k = 0)$, then $\omega^{(0)}$, $\lambda_{\max}^{(0)}$, and $C.R.^{(0)}$ were calculated respectively as the same scheme that is illustrated in 4.1.8.1. The results are shown below:

$$A^{(0)} = \begin{bmatrix} 1 & 6 & 6 & 8 \\ 1/6 & 1 & 2 & 8 \\ 1/6 & 1/2 & 1 & 2 \\ 1/8 & 1/8 & 1/2 & 1 \end{bmatrix},\quad \omega^{(0)} = [0.631 \quad 0.219 \quad 0.098 \quad 0.052]^T,\quad \lambda_{\max}^{(0)} = 4.296,\quad \text{and } C.R.^{(0)} = 0.1098$$

Step 4.1.7.4: Because $C.R.^{(0)} = 0.1098 > 0.1,$ matrix $A^{(0)}$ must be modified following Step 4.1.7.5 to obtain the revised matrix $A^{(1)}$. For the numerical example via eq. 44 - with these data $a_{1,3}$ of $A^{(0)}$ = 6, $\lambda = 0.925$, $\omega_1^0 = 0.631$, and $\omega_3^0 = 0.098$ - $a_{1,3}$ of $A^{(1)}$ can be calculated by: $a_{1,3}^1 = (a_{1,3}^0)^{\lambda} [\omega_1^0 / \omega_3^0]^{1-\lambda} = (6)^{0.925} [0.631/0.098]^{1-0.925} = 6.034$. After all members of matrix $A^{(1)}$ was computed, the matrix $A^{(1)}$ was formed as display below. The next step will turn back to 4.1.7.2 with $k = 1$, therefore $\omega^{(1)}$, $\lambda_{\max}^{(1)}$, and $C.R.^{(1)}$ must be reckoned in the same way before (see details in Ch. 4.1.8.1).

$$A^{(1)} = \begin{bmatrix} 1 & 5.679 & 6.034 & 8.256 \\ 1/5.679 & 1 & 2.018 & 7.627 \\ 1/6.034 & 1/2.018 & 1 & 1.991 \\ 1/8.256 & 1/7.627 & 1/1.991 & 1 \end{bmatrix},\quad \omega^{(1)} = \begin{bmatrix} 0.653 \\ 0.192 \\ 0.097 \\ 0.058 \end{bmatrix},\quad \lambda_{\max}^{(1)} = 4.285,\quad \text{and } C.R.^{(1)} = 0.105$$

Owing to $C.R.^{(1)} = 0.105$, the attempt to improve the matrix $A^{(1)}$ by step 4.1.7.4 - 5 again must be carried on. Correspondingly calculation step of matrix $A^{(1)}$, the adjusted matrix $A^{(2)}$ will be obtained $(k = 2)$, also for $\omega^{(2)}$, $\lambda_{\max}^{(2)}$, and $C.R.^{(2)}$. For the numerical example - with this data $a_{1,3}$ of $A^{(1)}$ = 6.034, $\lambda = 0.925$, $\omega_1^1 = 0.653$, and $\omega_3^1 = 0.097$ - $a_{1,3}$ of $A^{(2)}$ can be calculated by: $a_{1,3}^2 = (a_{1,3}^1)^{\lambda} [\omega_1^1 / \omega_3^1]^{1-\lambda} = (6.034)^{0.925} [0.653/0.097]^{1-0.925} = 6.083$.

$$A^{(2)}=\begin{bmatrix}1 & 5.465 & 6.083 & 8.453\\ 1/5.465 & 1 & 2.014 & 7.165\\ 1/6.083 & 1/2.014 & 1 & 1.966\\ 1/8.453 & 1/7.165 & 1/1.966 & 1\end{bmatrix},\quad \omega^{(2)}=\begin{bmatrix}0.655\\0.189\\0.098\\0.058\end{bmatrix},\quad \lambda_{\max}^{(2)}=4.245,\ \text{ and } CR^{(2)}=0.091$$

Step 4.1.7.6: From the last improvement, $C.R.^{(2)}=0.091$ was less than 0.1, then the revised matrix $A^{(2)}$ is considered consistent and satisfying. The next step is to check this revised matrix with the rest conditions of the algorithm. Following calculation of δ and σ, $\delta<2$ and $\sigma<1$ must be tested. For δ calculation via eq. 42, $\delta=\max_{ij}\left\{\left|a_{ij}^{m}-a_{ij}^{0}\right|\right\}$, can be explain below:

$$A^{(2)}-A^{(0)}=\begin{bmatrix}\left|a_{1,1}^{(2)}-a_{1,1}^{(0)}\right| & \left|a_{1,2}^{(2)}-a_{1,2}^{(0)}\right| & \left|a_{1,3}^{(2)}-a_{1,3}^{(0)}\right| & \left|a_{1,4}^{(2)}-a_{1,4}^{(0)}\right|\\ \left|a_{2,1}^{(2)}-a_{2,1}^{(0)}\right| & \left|a_{2,2}^{(2)}-a_{2,2}^{(0)}\right| & \left|a_{2,3}^{(2)}-a_{2,3}^{(0)}\right| & \left|a_{2,4}^{(2)}-a_{2,4}^{(0)}\right|\\ \left|a_{3,1}^{(2)}-a_{3,1}^{(0)}\right| & \left|a_{3,2}^{(2)}-a_{3,2}^{(0)}\right| & \left|a_{3,3}^{(2)}-a_{3,3}^{(0)}\right| & \left|a_{3,4}^{(2)}-a_{3,4}^{(0)}\right|\\ \left|a_{4,1}^{(2)}-a_{4,1}^{(0)}\right| & \left|a_{4,2}^{(2)}-a_{4,2}^{(0)}\right| & \left|a_{4,3}^{(2)}-a_{4,3}^{(0)}\right| & \left|a_{4,4}^{(2)}-a_{4,4}^{(0)}\right|\end{bmatrix}$$

$$=\begin{bmatrix}|1-1| & |5.465-6| & |6.083-6| & |8.453-8|\\ |1/5.465-1/6| & |1-1| & |2.014-2| & |7.165-8|\\ |1/6.083-1/6| & |1/2.014-1/2| & |1-1| & |1.966-2|\\ |1/8.453-1/8| & |1/7.165-1/8| & |1/1.966-1/2| & |1-1|\end{bmatrix}$$

$$=\begin{bmatrix}0 & 0.535 & 0.083 & 0.453\\ 0.016 & 0 & 0.014 & 0.835\\ 0.002 & 0.004 & 0 & 0.034\\ 0.007 & 0.015 & 0.009 & 0\end{bmatrix}$$

Therefore: $\delta=\max_{ij}\left\{\left|a_{ij}^{2}-a_{ij}^{0}\right|\right\}=0.835<2$ **OK**

For σ calculation via eq. 43, $\sigma=\sqrt{\sum_{j=1}^{n}\sum_{i=1}^{n}\left(a_{ij}^{m}-a_{ij}^{0}\right)^{2}}\Big/n$ can be explained below:

$$\left(A^{(2)}-A^{(0)}\right)^{2}=\begin{bmatrix}\left(a_{1,1}^{(2)}-a_{1,1}^{(0)}\right)^{2} & \left(a_{1,2}^{(2)}-a_{1,2}^{(0)}\right)^{2} & \left(a_{1,3}^{(2)}-a_{1,3}^{(0)}\right)^{2} & \left(a_{1,4}^{(2)}-a_{1,4}^{(0)}\right)^{2}\\ \left(a_{2,1}^{(2)}-a_{2,1}^{(0)}\right)^{2} & \left(a_{2,2}^{(2)}-a_{2,2}^{(0)}\right)^{2} & \left(a_{2,3}^{(2)}-a_{2,3}^{(0)}\right)^{2} & \left(a_{2,4}^{(2)}-a_{2,4}^{(0)}\right)^{2}\\ \left(a_{3,1}^{(2)}-a_{3,1}^{(0)}\right)^{2} & \left(a_{3,2}^{(2)}-a_{3,2}^{(0)}\right)^{2} & \left(a_{3,3}^{(2)}-a_{3,3}^{(0)}\right)^{2} & \left(a_{3,4}^{(2)}-a_{3,4}^{(0)}\right)^{2}\\ \left(a_{4,1}^{(2)}-a_{4,1}^{(0)}\right)^{2} & \left(a_{4,2}^{(2)}-a_{4,2}^{(0)}\right)^{2} & \left(a_{4,3}^{(2)}-a_{4,3}^{(0)}\right)^{2} & \left(a_{4,4}^{(2)}-a_{4,4}^{(0)}\right)^{2}\end{bmatrix}$$

$$=\begin{bmatrix}(1-1)^{2} & (5.465-6)^{2} & (6.083-6)^{2} & (8.453-8)^{2}\\ (1/5.465-1/6)^{2} & (1-1)^{2} & (2.014-2)^{2} & (7.165-8)^{2}\\ (1/6.083-1/6)^{2} & (1/2.014-1/2)^{2} & (1-1)^{2} & (1.966-2)^{2}\\ (1/8.453-1/8)^{2} & (1/7.165-1/8)^{2} & (1/1.966-1/2)^{2} & (1-1)^{2}\end{bmatrix}$$

$$=\begin{bmatrix}0 & 0.28637 & 0.00683 & 0.20534\\ 0.00027 & 0 & 0.0002 & 0.69644\\ 5.1\times10^{-6} & 1.2\times10^{-5} & 0 & 0.00115\\ 4.5\times10^{-5} & 0.00021 & 7.5\times10^{-5} & 0\end{bmatrix}$$

$\therefore$ Sum by row of $\left(A^{(2)} - A^{(0)}\right)^2$ to get $\sum_{i=1}^{n}\left(a_{ij}^{m} - a_{ij}^{0}\right)^2 = \begin{bmatrix} 0.49854 \\ 0.69691 \\ 0.00117 \\ 0.00033 \end{bmatrix}$

$\therefore$ Sum by column of $\sum_{i=1}^{n}\left(a_{ij}^{m} - a_{ij}^{0}\right)^2$ to obtain $\sum_{j=1}^{n}\sum_{i=1}^{n}\left(a_{ij}^{m} - a_{ij}^{0}\right)^2 = 1.19695$

Therefore: $\sigma = \sqrt{\sum_{j=1}^{n}\sum_{i=1}^{n}\left(a_{ij}^{m} - a_{ij}^{0}\right)^2 \Big/ n} = \sqrt{1.19695/4} = 0.2735 < 1$ OK

Step 4.1.7.7 - 8: From the above consistency improving step - with $k = 2$, $\delta = 0.835 < 2$, and $\sigma = 0.2735 < 1$ - the synthesized matrix $A^{(2)}$ passed all conditions of the procedure and can be utilised as the reference matrix. The final priority weight vector with acceptable consistency $\left(CR^{(2)} = 0.091\right)$ are: $\omega^{(2)} = \begin{bmatrix}0.655 & 0.189 & 0.098 & 0.058\end{bmatrix}^T$. The result of improvement can be summarised in table 4.23 below.

Table 4.23: Summary of a consistency improving method in the AHP

Criteria	**Original Relative Weight**	**Rank**	**Revised Relative Weight**	**Rank**
C-1	0.631	1	0.655	1
C-2	0.219	2	0.189	2
C-3	0.098	3	0.098	3
C-4	0.052	4	0.058	4

From the above example, it has been made clear that the original inconsistent pair-wise matrix with $C.R. = 0.1098$ was improved to be the acceptable matrix with $C.R. = 0.091$, while the core judgment by the specialist is still the same. Therefore, this method is suggested to be one of the appropriate methods for improving consistency in the AHP.

4.2 Raw Material Analysis

As an agricultural based country, Thailand has a high ability for the energy production from various biomass sources. Agricultural and forestry residues, bio-waste (waste water and manure), and dedicated bioenergy crops could potentially be gathered and processed into an energy form (heat, fuel, or power). On an annual basis, around 60-90 M t of agricultural residues is generated. Of these, about 65-70% is untouched, then the energy from these surplus residues can range from 5,000 to 8,000 KTOE or 2,000 to 3,000 MW_e (PDTI, 2007). However, these biomass sources may not be a viable option, energetically or economically, according to several recent reviews of bioenergy production. In the past, several bioenergy projects faced difficulties (Junginger et al., 2001) such as limited accessibility (USAID et al., 1991), and logistical problems (FAO-RWDP, 1998), seasonal availability, increasing residue prices and increased utilization for other applications such as animal fodder, fibre, or compost uses (Koopmans and Koppejan, 1998).

The bioenergy potential in the country is also limited by various factors, such as the demand for food, industrial round wood processing, traditional wood fuel, soil degradation from excessive residue removal and intensive agriculture, and the need to maintain existing forests for the protection of biodiversity. Special attention has been devoted to the technical aptitude for further food security by increasing the efficiency of agricultural technology including: efficient management and mechanisation, optimal applications of fertilizer, irrigation and pesticides, and regionally tailored crop from biotechnology or breeding programs. To properly manage all biomass resources, it is essential to identify the spatial distribution of agricultural residues for the whole country. Therefore, in this section, the distribution of corresponding potential energy for each residue will be intently evaluated.

4.2.1 Availability of biomass for Thailand with current situation

Because large quantities of agricultural residues are generated annually and typically under utilized, biomass programmes for energy purpose in Thailand are currently focusing chiefly on these residues as the main source of feedstock supplies for the country's growing bioenergy industries. Furthermore, the agro-industry is an important source of biomass due to a large scale production and expedience collection of biomass from its facilities such as rice mills, sugar mills, and oil palm mills (Papong et al., 2004). If all process-based agricultural residues alone were to be utilized, they could contribute between 25 to 40% of the total primary commercial energy production in the country. In this part, the issue of feedstock availability for each biomass source will be discussed to predict their potential for energy utilization. Understanding for the availability of these biomass and providence of their useful information are necessary for pointing bioenergy development, also allowing a useful upper-level benchmark in approximating their potential future supplies. Thus, the biomass budget in this section should be developed systematically.

Crop residue supply estimations have been developed for six crops: **paddy rice, sugarcane, cassava, oil palm, maize,** and **physic nut**. Specifically, the aspects of the agricultural residue supply were revised with updated data from national statistics. Although a large amount of soybeans and cotton are produced in Thailand, the field residues from both crops are comparatively modest and readily decompose in the field, making collection of these plant residues unattractive. The cultivated area of soybean was only 0.128 M ha in 2009 and expected lower in the future, while that of cotton was less than 0.048 M ha with the same trend. The data on annual production and yield of each crop are obtained with high accuracy from the official statistics, although this data may be affected by the weather or drought such that the values may vary by 10% from the average in any particular year. Other factors that impact on historic cultivated trends were also analysed from statistics and literatures. In discussing a future vision based on forecasting and scenario studies, rough estimation will conversely suffice.

The basic material for each crop consisting of grain (paddy rice and maize), stalk (sugarcane), root (cassava), nut (physic nut), and **Fresh Fruit Bunch** (FFB) (oil palm) is utilized for the residue evaluation. Therefore, identification of viable sources for these basic materials is a high priority. The **Crop-to-Residue Ratio** (CRR) is generally applied to estimate the quantity of agricultural residuals. This ratio, derived through field experiments, is the ratio of interested residue to the total cumulative biomass at harvesting or processing period. For example, the CRR of rice straw (above ground) is approximately 0.49; this means that the weight of rice straw is around 49% of the total plant weight (including paddy). Generated specific agricultural residue is directly related to the corresponding crop production and its CRR ratio, which varies from crop to crop. Variation in the moisture percentage of the residue should also be considered, because this variable is one of the main relevant influences on the useful energy available in the conversion process, i.e., the higher the degree of moisture, the less the final obtained energy.

Prior to the estimation of biomass availability by this scenario for the years 2010, 2015 and 2020 (see Ch. 4.4.5), the production of key biomass in Thailand is assessed following these assumptions:

1) The trend of changes in cultivated areas and potential yields over the last decade is assumed to continue;
2) The future available biomass will come from this trend only; and
3) For other affecting conditions, there will be analysed in the next scenarios/sections.

Based on present situation, the data for all main crops will be adduced in Ch. 4.4.5, while several limitations, primarily due to record unavailability, are also highlighted.

4.2.2 Cultivated Area and Yield Increase

Since biomass production is a beginning of the supply chain for modern bioenergy industries, to satisfy the growing demand of the feedstock two broad options are generally meditative: 1) An enlargement of the cultivated area; or 2) More production improvement for food, round wood for industrial application, and traditional wood fuel. Of the two options, increasing productivity from both existing irrigated and non-irrigated farmlands is preferable as it avoids greenhouse gas (GHG) emissions and the large-scale disruption of existing ecosystems associated with bringing a new land into cultivation (Edgerton, 2009). For Thailand, rising the production of surplus agricultural products (including food) for export in the past does not bring about through improvements in productivity, but mainly through expansion of farmland (see Ch. 1.2). However, the availability of arable land is currently decreasing because of non-sustainable farming, soil erosion, and soil degradation. Besides, the availability of water for agriculture may also decline (Takeda and Matsuoka, 2008).

To boost the yield potential, several major national programmes that were initiated in the last decade began to develop crop cultivars with not only a higher yield potential and stability, but also better production efficiency. The agricultural research system in Thailand is dominated by government agencies under the Ministry of Agriculture and Cooperatives (MOAC), mainly funded from the annual government budget (around 95%) (Poapongsakorn, 2006). Changes in plant architecture, improved the CRR and photoperiod insensitivity, will result in new varieties with higher yield potential. Superior plant types with elevated nutrient content and resistance to pests/diseases should be also developed. Additionally, for the future of new species, planting material requiring fewer inputs and extending in less favourable zones is more focused. Improved drought tolerance will be one of the next transgenic technologies brought to the marketplace (Nelson et al., 2007; Castiglioni et al., 2008). Drought tolerance has the potential to: 1) increase yields in arid areas; 2) raise average yields in rain-fed systems by reducing the effects of sporadic drought; and 3) decrease water requirements in irrigated systems (Edgerton, 2009).

Farming improvement is not considered in more details, since there are fewer studies in this topic and they are beyond the scope of this research although better yields are obtained under good agricultural practices including the use of good plant nutrition, irrigation when necessary, and skillful farmers. With the last option, it has complications, since farmers vary and the practices may not be widely adopted because farmers do not accept these practical or appropriate schemes when taking prudent account of economics and risk (Fischer and Edmeades, 2010; Dalton et al., 2005). Improvement of site specific management practices with regards to choice of appropriate species and management practices to optimise biomass production on specifically identified soils is also another proper option (Blanco-Canqui and Lal, 2009; Lal, 2009). The full yield potential is not realized because of the toll taken by the attack of diseases and insects, causing drop in yield of cereal crop up to 25 % annually for instance (Khush, 2001). Nitrogen fertilisation is essential to increasing the yield, but it also promotes leaf and stem elongation. This results in an overall increase in plant height (Sakamoto, 2006). Although the CRR shows large differences among crops, the reduction in plant height will improve the CRR and enhance biomass production (Khush, 1999).

To assess the potential biomass contribution from agriculture and forestry in Thailand, three sub-scenarios were evaluated. These sub-scenarios include various combinations of changes in the following: 1) harvested area; 2) product yield; and 3) harvested area and production yield. The change in harvested area is thanks mainly to the national strategies. Planting areas of cassava and oil palm are expected to increase obviously due primarily to the demand of biofuel production[56], and science providing new techniques to use these crops for materials. Crop yields are of particular importance, because they affect the amount of residue generated and the amount of land needed to meet food, feed and fiber demands. The assumption that modern farms could achieve the extra yield by 1 to 2% of national farms today is likely optimistic. This approach offers an upper bound on how future yield advances could be met. Therefore, the estimation on the future crop yield is presumed with an average increase of about 1%[57] yearly in this study for major crops that their new data are unavailable, because agriculture is expected to continue to change and adapt to new technologies and widespread use of new farming applications such as new hybrid, synthetic fertilizers, and farm machinery (Edgerton, 2009). Other parameters, for instance, CRR ratio is assume to have two possibilities: 1) the same CRR ratio as present situation; and 2) the lower CRR ratio by maintain similar residual quantity as previous, resulting from the success of higher yield improvement. However, the CRR can be changed if new data available.

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[56] Recently in Thailand, ethanol for gasohol generally uses molasses mainly as feedstock, while the production of biodiesel is largely relied on deficient oil palm seeds.

[57] Because this number is in line with the growth rate in the past, for agricultural sector, an average annual growth rate of Total Factor Productivity (TFP) in Thailand over the period 1970 to 2006 was 0.68%. Also, it has been estimated that on average an increase of about 1% per year has occurred in the yield potential of major crops (Khush, 2001).

4.2.3 Environmental Protection Purpose

Many significant efforts in literatures have gone into estimating the available quantities of agricultural and forestry residues, however the amount of residues that can be sustainably removed from their fields is still unfortunately questioned. Environmental issue is even now one of their eminent handicaps. Biomass utilization for energy needs to be developed with an understanding of the environmental management that may be necessary to create a truly sustainable and renewable energy supply. It is, therefore, important to recognise the short-term and long-term implications of harvesting biomass residues on crop yields, sustainability of production, soil quality, and environment quality specifically with regard to water resources and non-point source pollution (NSP)[58]. Residue retention has short-term impact on crop yields, and long-term impact on agronomic productivity and sustainability. Short-term impacts on crop yields vary among seasons depending on soil temperature & moisture regimes, rainfall amount & distribution, and incidence of pests & diseases. In the long-term, residue retention improves agronomic productivity and enhances sustainability because of improvements in soil quality (Lal, 2009).

Retention of crop residues on agricultural soils has numerous direct and indirect/ancillary benefits with strong impacts on soil quality by increasing soil organic matter and nutrient content in several cropping systems (Lal, 2009; Basanta et al., 2003; Promsakha Na Sakonnakhon et al., 2005), thus their removal must be considered carefully (Andrews, 2006). Excessive removal of crop residue would adversely impact soil quality in all climates. The rate and magnitude of the adverse impact is much higher in the tropics than temperate climates (Lal, 2009), especially the need to leave residues to limit rain and wind erosion to tolerable losses and to maintain soil moisture in rain-limited regions. At the farm level, soil erosion can cause crop yield losses reducing agricultural incomes. At the national level, soil erosion produces sediment and silt that can clog irrigation channels and lower the water storage capacity of dams (Dalton et al., 2005). Therefore, sediment loss from farm fields eventually affects crop productivity, and sediment transport has significant negative offsite effects (Baker and Wilhelm, 2006). Sustainable **Residue Removal Rates** for biofuel production vary by factors such as farm management, crop yield, climate, topography, soil type, and existing soil quality, especially in arid regions where the generated residue is inadequate even for basic soil protection (Parr and Papendick, 1978), therefore site-specific guidelines for residue harvest need to be developed until general recommendations for safe removal rates is terminated (Andrews, 2006).

To secure the environment, only excess crop residues should be potentially used as an energy source. For lignocellulosic residues of cereals (e.g., corn, wheat, barley, oats, and rice), excessive (>25%) and continuous (>10 years) removal can risk soil quality, reduce agronomic productivity, accentuate soil erosion, increase the NSP, and exacerbate the problem of hypoxia[59] in coastal ecosystems (Lal, 2008). Approximately 20% of cane residues must be left in the field so that it can be reincorporated and thereby increasing its contents of

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[58] Unlike pollution from industrial and sewage treatment plants, The NPS comes from many diffuse sources. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters (http://www.epa.gov/nps).

[59] ***Hypoxia*** is a condition in which dissolved oxygen levels are too low to sustain most marine life. The zone of hypoxic water can also block the migration of marine organisms. Even under conditions where dissolved oxygen levels are not low enough to kill marine organisms, stress due to insufficient amounts of dissolved oxygen can disrupt their life cycles and increase their susceptibility to predation (IATP's work on hypoxia, see www.agobservatory.org).

organic matter (Delgado, 1985). Although there is still no clear scientific basis for other crops recently, the low and high scenarios could be applied to represent a bandwidth within which their residual possibility to removal might develop. Therefore, 20% and 40% is chosen in this study for low and high scenario, respectively. The reason is that residue remaining on the soil surface can stabilise the soil and a minimum of 20% residue cover is necessary to reduce soil erosion (Beyaert et al., 2002; Moldenhauer et al., 1983). Nevertheless, other high residue crops, such as rice and sugarcane, might contribute to biofuel production as a solution to their residue disposal issues (DiPardo, 2000; Wilhelm et al., 2004).

4.2.4 Harvest and Collection

Because agricultural and forest residues are of low value, are of low demand, but has high extraction cost, they are generally left on their cultivated land. Besides, these residues are usually produced in different forms, so their supply has been constrained with equipment harvest efficiency (75% of gross) making them uneconomical. The **harvest and collection**[60] operations associated with these residual resources are, therefore, technical memorandum as one of the most potential options for increasing bioenergy feedstock resources and their utilization. Minimising biomass costs (including harvest, handling, transport, storage, and processing costs) delivered to the conversion plant is also required (Banowetz et al., 2008). To achieve this goal, a fresh look at conventional post-harvesting-system is required to identify efficient ways for integrating biomass collection and developing cost-effective technologies to handle these biomass feedstocks. A new technique is a unique way to not only improve biomass harvest performance and then increase profitability, but also enhance efficiently residues collection. An initial component of the design process is to gain an understanding of the spatial distribution of biomass production. In the case of poor crop residue sizing and distribution, alternative harvesting technologies are needed to improve the successful management of all biomass residue types.

The process of harvesting and separation has also a strong impact on the available energy, as it can influence the moisture degree of biomass. Lower the moisture content increases the energy density and makes biomass more friable, lowering the energy cost of grinding. Transporting and handling methods are highly dependent on the format and bulk density of the material, which makes them tightly coupled to each other and all other operations in the feedstock supply chain (Wilkerson et al., 2008). Since transportation can account for as much as 30% of the total collection costs (Andersson et al, 2002), size reduction can occur at any point in the supply chain. Although additional specialized equipment for size reduction increases fixed costs, the significant increase in material bulk density typically offsets these costs compared to hauling loose residues. The ground material can be transported via chip vans, or possibly large roll on/off containers, to the user facility (Wilkerson et al., 2008). Densification to pellets or cubes could increase the bulk density of biomass to as high as 448-640 dry kg/m^3 in the case of agricultural residues (Sokhansanj and Turhollow, 2004). A primary drawback of densification is that it increases the cost of biomass in comparison with conventional approaches such as baling. The approach and equipment used for harvesting, handling, storing, and transporting biomass will also have an impact on the amount of dry matter losses that can occur (Haq and Easterly, 2006). For example, one evaluation of bunker storage options for agricultural materials found that storage losses could range from 10 to 16% (Miller and Rotz, 1995). In an unbalanced state due to seasonal

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[60] ***Harvest and Collection*** encompasses all operations associated with getting biomass from its source to the storage or queuing location. In addition to logging and hauling, this often includes some form of densification, such as bundling or chipping, to facilitate handling and storage (Wilkerson et al., 2008).

variations, storage for a one to six month supply of biomass, however, may be required. Unfortunately, there are few of the studies took storage and storage loss into consideration (Wang et al., 2009; Wilkerson et al., 2008).

New technology adoption may require centralising biomass energy production, a process that is limited by the diffuse nature of biomass and the high cost of transportation. To be a realistic fuel, the supply chain that gets the residues to a centralised facility must be efficiently designed (Elmore et al., 2008). An agro-based biomass generation facility would require annual inventories of available biomass to help the strategize energy production, the proper mix of fuels, and transportation networks (Shi et al., 2008). Rather than storing bales at the "farm gate," an alternative is to store them at one or more central storage sites. Round bales can be stored in the open or in covered storage (round bales shed rainfall and can tolerate exposure to the weather), or square bales can be produced that are easier to stack, but are more susceptible to weather damage and thus need to be in covered storage (Haq and Easterly, 2006). In the case of forest residue, its availability is more diffuse than it is in forests, yet it is regenerated annually (Elmore et al., 2008). Residue bundlers and balers can improve transportation and handling efficiency of forest residues by densifying and packaging them, so they can be coped with conventional equipment. Limitations of the new technologies are their large capital costs and complexity, leading to high maintenance costs and the need for highly trained operators. The challenge is then to design equipment and systems that facilitate this integration within an operational framework robust enough to deal the variations associated with forest resources, while satisfying economic, efficiency, and capacity requirements (Wilkerson et al., 2008).

Summarily, the present ability to collect biomass residues from their growing fields varies between 20-50% of what is produced. In the near future it can be assumed that 70% of the residues were recoverable in the case of rice straw and corn stove, which was in line with the recovery rates suggested by Wall and Nurmi (2002) and Stokes (2004). This trend is also envisaged for Thailand, because agricultural machinery standards from various countries have been studied and then adapted until suitable with Thai agricultural machines and their corresponding working conditions. For other crops, it should be estimated with a **Collection Efficiency** (CE) of 40% and 60%, respectively. Future residue collection technology with the potential of collection up to 75% is envisioned, but it is not for the case of Thailand at the present. More details in each crop will be discussed in Ch. 4.2.5 below.

4.2.5 Biomass Potential from Agricultural & Forestry for Thailand

Before recognition for other competitive purposes (see Ch. 4.2.6), the total generated biomass for energy route following 4.2.1-4.2.4 scenarios will be digested and calculated in this section. Table 4.24, table 4.25a, table 4.25b and table 4.26 represent the summary of average annual production of agricultural and forest residues in Thailand for the year 2006-2009, 2011, and 2016 from different scenarios. According to the table, expanding agricultural and forest production has naturally resulted in increased quantities of crop and forest residues, as well as agro-industrial and wood-based industries by-products. The biomass quantities from the study ranged from 102.090 to 134.016 M t for 2006-2009, 137.882 to 217.649 M t for 2011 (Policy), 110.210 to 152.620 for 2011 (Projection), and 142.755 to 199.737 for 2016 (Projection). The successive replacement of traditional varieties of the main crops by improved ones, together with the associated development in farm management practices, has had a dramatic effect on the growth of crop yields and its residues, particularly in sugarcane, cassava, and oil palm (table 4.25a,b and table 4.26). Advantages of biomass generation from yield improvement are comparable and significant. The study showed that biomass availability can be greater than 35.1-62.4%, 8-13.9%, and 39.8-49% for the case of both yield improvement and extension of cultivated area compared to current situation trend for the year 2011 (Projection), 2011 (Policy), and 2016 (Projection), respectively.

Remark: Because residue removal takes away more nutrients from the agro/forest-system than main material harvest alone (Andrews, 2006), optimising the amount of biomass that can be gathered, with and without a minimum level of crop residue left in the field, is considered and discussed in 4.2.3 scenario. However, the harvesting and collection efficient should be also involved with the proper amount of removable biomass residues. To deal with the earlier notice, therefore, the combined result of two limitations (environmental and harvest/collection constraints) will be discussed and analysed to get the actual potential quantity of biomass in Thailand for both current situation and changes in cultivated area/yield scenarios. The effect of scenario 4.2.3 and 4.2.4 combination will be calculated in the last column to estimate the energy potential of biomass residues for the year 2011 to 2016.

Table 4.24: The potential of agricultural and forestry residues for Thailand between 2006 and 2009

Year	**Residues types**	**Scenario**			
		4.2.1	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	Sugarcane Bagasse	19.102	19.102	19.102	19.102
	Top & Trash	11.597	9.278	6.624	6.624
	Rice Straw	14.210	3.553	9.947	9.947
	Rice Husk	6.670	6.670	6.670	6.670
	Cassava Stalk	2.477	1.858	1.982	1.858
	Rhizome	13.487	11.733	10.789	10.789
	Leave	6.936	5.202	5.549	5.202
	Peel	1.651	1.437	1.321	1.321
	Oil Palm Empty bunches	2.371	2.371	2.371	2.371
	Fiber	1.581	1.581	1.581	1.581
	Shell	0.499	0.499	0.499	0.499
	POME	5.824	5.824	5.824	5.824
	Frond	21.665	12.999	17.332	12.999
	Male bunches	1.939	1.163	1.551	1.163
	Corn Cob	0.984	0.984	0.984	0.984
	Corn Stove	3.363	0.841	2.186	2.186
	Jatropha SCR	0.025	0.025	0.025	0.025
	Cotton Stalk, Leaves	0.028	0.022	0.017	0.017
	Kenaf Stalk, Leaves	0.009	0.007	0.006	0.006
	Soybean Stalk, Leaves, Shell	0.557	0.445	0.334	0.334
	Sorghum Stalk, Leaves	0.078	0.062	0.047	0.047
	Coconut Coir	0.684	0.684	0.684	0.684
	Shell	0.302	0.302	0.302	0.302
	Bunch	0.093	0.093	0.093	0.093
	Frond	0.425	0.340	0.255	0.255
	Groundnut Shell	0.020	0.020	0.020	0.020
	Parawood Small Branches	5.825	4.660	3.495	3.495
	Stumps	1.630	1.304	0.978	0.978
	Tops	0.583	0.466	0.350	0.350
	Sawdusks	1.438	1.438	0.863	0.863
	Slaps	2.397	2.397	1.438	1.438
	Eucalyptus Small Branches & leaves	0.387	0.310	0.232	0.232
	Barks	3.000	3.000	3.000	3.000
	Fast-Growing Trees Leaves	0.058	0.046	0.035	0.035
	Stem	2.015	1.289	1.289	1.289
	Small branches	0.106	0.085	0.063	0.063
	Total	**134.016**	**102.090**	**107.838**	**102.646**

Table 4.25a: The potential of agricultural and forestry residues for Thailand in the year 2011 by Policy

Year	Residues types	Scenario			
		4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2011 (Policy)	Sugarcane				
	Bagasse	20.966-22.579	20.966-22.579	20.966-22.579	20.966-22.579
	Top & Trash	12.902-13.709	10.322-10.967	7.370-7.830	7.370-7.830
	Rice Straw	15.893-17.306	3.973-4.326	11.125-12.114	11.125-12.114
	Rice Husk	7.417-8.123	7.417-8.123	7.417-8.123	7.417-8.123
	Cassava				
	Stalk	2.786-3.135	2.090-2.351	2.229-2.508	2.090-2.351
	Rhizome	16.022-17.067	13.939-14.848	12.817-13.653	12.817-13.653
	Leave	8.499-7.314	6.374-5.486	6.799-5.851	6.374-5.486
	Peel	1.742-2.090	1.515-1.818	1.393-1.672	1.393-1.672
	Oil Palm				
	Empty bunches	4.723-7.085	4.723-7.085	4.723-7.085	4.723-7.085
	Fiber	3.679-4.723	3.679-4.723	3.679-4.723	3.679-4.723
	Shell	1.144-1.492	1.144-1.492	1.144-1.492	1.144-1.492
	POME	14.170-17.402	14.170-17.402	14.170-17.402	14.170-17.402
	Frond	42.734-64.735	25.641-38.841	34.187-51.788	25.641-38.841
	Male bunches	3.828-5.792	2.297-3.475	3.063-4.634	2.297-3.475
	Corn Cob	1.026-1.071	1.026-1.071	1.026-1.071	1.026-1.071
	Corn Stove	3.614-3.659	0.904-0.915	2.349-2.378	2.349-2.378
	Jatropha SCR	0.715	0.715	0.715	0.715
	Cotton Stalk, Leaves	0.031	0.025	0.019	0.019
	Kenaf Stalk, Leaves	0.009	0.007	0.006	0.006
	Soybean				
	Stalk, Leaves, Shell	0.562	0.450	0.337	0.337
	Sorghum Stalk, Leaves	0.080	0.064	0.048	0.048
	Coconut Coir	0.687	0.687	0.687	0.687
	Shell	0.304	0.304	0.304	0.304
	Bunch	0.093	0.093	0.093	0.093
	Frond	0.427	0.342	0.256	0.256
	Groundnut Shell	0.020	0.020	0.020	0.020
	Parawood				
	Small Branches	5.825	4.660	3.495	3.495
	Stumps	1.630	1.304	0.978	0.978
	Tops	0.583	0.466	0.350	0.350
	Sawdusks	1.438	1.438	0.863	0.863
	Slaps	2.397	2.397	1.438	1.438
	Eucalyptus				
	Small Branches & leaves	0.387	0.310	0.232	0.232
	Barks	3.000	3.000	3.000	3.000
	Fast-Growing Trees				
	Leaves	0.058	0.046	0.035	0.035
	Stem	2.015	1.289	1.289	1.289
	Small branches	0.106	0.085	0.063	0.063
	Total	**181.512 to 217.649**	**137.882 to 163.204**	**148.685 to 179.131**	**138.809 to 164.503**

Table 4.25b: The potential of agricultural and forestry residues for Thailand in the year 2011 by Projection

Year	**Residues types**	**Scenario**			
		4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2011 (Project-ion)	Sugarcane				
	Bagasse	20.062-21.605	20.062-21.605	20.062-21.605	20.062-21.605
	Top & Trash	12.346-13.117	9.876-10.494	7.052-7.493	7.052-7.493
	Rice Straw	14.437-15.721	3.609-3.930	10.106-11.004	10.106-11.004
	Rice Husk	6.737-7.379	6.737-7.379	6.737-7.379	6.737-7.379
	Cassava				
	Stalk	2.688-3.023	2.016-2.268	2.150-2.419	2.016-2.268
	Rhizome	15.453-16.461	13.444-14.321	12.363-13.169	12.363-13.169
	Leave	8.600-7.424	6.450-5.568	6.880-5.939	6.450-5.568
	Peel	1.680-2.016	1.461-1.754	1.344-1.613	1.344-1.613
	Oil Palm				
	Empty bunches	2.120-2.877	2.120-2.877	2.120-2.877	2.120-2.877
	Fiber	1.514-1.918	1.514-1.918	1.514-1.918	1.514-1.918
	Shell	0.495-0.606	0.495-0.606	0.495-0.606	0.495-0.606
	POME	5.956-7.067	5.956-7.067	5.956-7.067	5.956-7.067
	Frond	25.974-26.287	15.585-15.772	20.780-21.030	15.585-15.772
	Male bunches	2.312-2.352	1.387-1.411	1.849-1.882	1.387-1.411
	Corn Cob	0.955-0.996	0.955-0.996	0.955-0.996	0.955-0.996
	Corn Stove	3.362-3.404	0.841-0.851	2.186-2.212	2.186-2.212
	Jatropha SCR	0.715	0.715	0.715	0.715
	Cotton Stalk, Leaves	0.031	0.025	0.019	0.019
	Kenaf Stalk, Leaves	0.009	0.007	0.006	0.006
	Soybean				
	Stalk, Leaves, Shell	0.562	0.450	0.337	0.337
	Sorghum Stalk, Leaves	0.080	0.064	0.048	0.048
	Coconut Coir	0.687	0.687	0.687	0.687
	Shell	0.304	0.304	0.304	0.304
	Bunch	0.093	0.093	0.093	0.093
	Frond	0.427	0.342	0.256	0.256
	Groundnut Shell	0.020	0.020	0.020	0.020
	Parawood				
	Small Branches	5.825	4.660	3.495	3.495
	Stumps	1.630	1.304	0.978	0.978
	Tops	0.583	0.466	0.350	0.350
	Sawdusks	1.438	1.438	0.863	0.863
	Slaps	2.397	2.397	1.438	1.438
	Eucalyptus				
	Small Branches & leaves	0.387	0.310	0.232	0.232
	Barks	3.000	3.000	3.000	3.000
	Fast-Growing Trees				
	Leaves	0.058	0.046	0.035	0.035
	Stem	2.015	1.289	1.289	1.289
	Small branches	0.106	0.085	0.063	0.063
	Total	**145.058 to 152.620**	**110.210 to 116.519**	**116.777 to 123.437**	**110.556 to 117.186**

Table 4.26: The potential of agricultural and forestry residues for Thailand in the year 2016 by Projection

Year	Residues types	Scenario			
		4.2.2	4.2.3	4.2.4	4.2.3&4.2.4
2016 (Project-ion)	Sugarcane				
	Bagasse	25.334-27.283	25.334-27.283	25.334-27.283	25.334-27.283
	Top & Trash	15.590-16.565	12.472-13.252	8.905-9.462	8.905-9.462
	Rice Straw	17.073-18.591	4.268-4.648	11.951-13.013	11.951-13.013
	Rice Husk	7.967-8.726	7.967-8.726	7.967-8.726	7.967-8.726
	Cassava				
	Stalk	3.670-4.129	2.753-3.097	2.936-3.303	2.753-3.097
	Rhizome	21.105-22.481	18.361-19.559	16.884-17.985	16.884-17.985
	Leave	7.754-6.698	5.815-5.024	6.203-5.359	5.815-5.024
	Peel	2.294-2.753	1.996-2.395	1.835-2.202	1.835-2.202
	Oil Palm				
	Empty bunches	3.327-4.516	3.327-4.516	3.327-4.516	3.327-4.516
	Fiber	2.377-3.011	2.377-3.011	2.377-3.011	2.377-3.011
	Shell	0.776-0.951	0.776-0.951	0.776-0.951	0.776-0.951
	POME	9.349-11.092	9.349-11.092	9.349-11.092	9.349-11.092
	Frond	39.628-41.260	23.777-24.756	31.703-33.008	23.777-24.756
	Male bunches	3.549-3.692	2.130-2.215	2.839-2.954	2.130-2.215
	Corn Cob	1.053-1.204	1.053-1.204	1.053-1.204	1.053-1.204
	Corn Stove	4.012-4.112	1.003-1.028	2.808-2.879	2.808-2.879
	Jatropha SCR	2.936	2.936	2.936	2.936
	Cotton Stalk, Leaves	0.033	0.026	0.020	0.020
	Kenaf Stalk, Leaves	0.010	0.008	0.006	0.006
	Soybean				
	Stalk, Leaves, Shell	0.590	0.472	0.354	0.354
	Sorghum Stalk, Leaves	0.087	0.070	0.052	0.052
	Coconut Coir	0.708	0.708	0.708	0.708
	Shell	0.313	0.313	0.313	0.313
	Bunch	0.096	0.096	0.096	0.096
	Frond	0.440	0.352	0.264	0.264
	Groundnut Shell	0.021	0.021	0.021	0.021
	Parawood				
	Small Branches	5.825	4.660	3.495	3.495
	Stumps	1.630	1.304	0.978	0.978
	Tops	0.583	0.466	0.350	0.350
	Sawdusks	1.438	1.438	0.863	0.863
	Slaps	2.397	2.397	1.438	1.438
	Eucalyptus				
	Small Branches & leaves	0.387	0.310	0.232	0.232
	Barks	3.000	3.000	3.000	3.000
	Fast-Growing Trees				
	Leaves	0.058	0.046	0.035	0.035
	Stem	2.015	1.289	1.289	1.289
	Small branches	0.106	0.085	0.063	0.063
	Total	**187.531 to 199.737**	**142.755 to 152.754**	**152.76 to 163.461**	**143.554 to 153.929**

The details of biomass potential for each crop in all scenarios were elucidated below. The potential of available biomass for Thailand - with current situation (Ch. 4.2.1); with Cultivated Area and Yield Changes (Ch. 4.2.2); with Environmental Protection Purpose (Ch. 4.2.3); and with Harvest & Collection Method Development (Ch. 4.2.4) - is estimated for the years 2006-2009, 2015, and 2020 based on these following calculations:

Remark: The national biofuel programme (bioethanol and biodiesel) involves with sugarcane, cassava, and oil palm cultivation, therefore firstly it is necessary to forecast the demand of the feedstocks for these biofuel productions. Currently, the agricultural raw materials for ethanol production in Thailand may be categorized into two following groups: Sugar Based Raw Materials - mainly sugarcane and molasses, and Starch Based Raw Materials – chiefly cassava roots. According to the 15-year renewable energy (RE) plan, the growing demand of ethanol is projected as following:

- The year 2008-2011 = 3 M liters/d
- The year 2012-2016 = 6.2 M liters/d
- The year 2017-2022 = 9.0 M liters/d

Therefore, table 4.27 shows the projection of sugarcane, molasses, and cassava production to meet the ethanol demand of the plan.

Table 4.27: Demand and supply forecasts for ethanol production to meet the Thai biofuel goal

Molasses feedstock	**2009**	**2010**	**2011**	**2016**
Supply				
Sugarcane Production (M t/y)	75.40	82.50	80.64	97.44
Molasses production (M t/y)	**3.39**	**3.71**	**3.63**	**4.38**
Demand of molasses				
Liquor Production (M t/y)	1.00	1.00	1.00	1.10
Animal Feed / MSG (M t/y)	0.40	0.40	0.41	0.51
Export (M t/y)	0.50	0.50	0.51	0.59
Total (M t/y)	**1.90**	**1.90**	**1.92**	**2.20**
Balance Available for Ethanol (M t/y)	**1.49**	**1.81**	**1.71**	**2.19**
Molasses Based Ethanol (M liters/d)	**1.02**	**1.24**	**1.17**	**1.50**

Cassava feedstock	**2009**	**2010**	**2011**	**2016**
Production (M t/y)	**33.53**	**33.67**	**34.83**	**45.88**
Demand				
Domestic Demand (M t/y)	**8.22**	**8.23**	**8.40**	**9.46**
Pellet / Chip (M t/y)	2.63	2.64	2.65	2.85
Starch (M t/y)	5.59	5.59	5.75	6.61
Export Demand (M t/y)	**21.36**	**21.45**	**22.25**	**25.70**
Pellet (M t/y)	2.1	2.1	2.00	1.85
Chip (M t/y)	8.61	8.64	9.07	10.43
Starch (M t/y)	10.65	10.71	11.18	13.42
Balance Available for Ethanol (M t/y)	**3.95**	**3.99**	**4.18**	**10.72**
Tapioca Based Ethanol (M liters/d)	**1.732**	**1.749**	**1.832**	**4.700**
Total Ethanol Availability (M liters/d)	**1.752**	**1.989**	**3.002**	**6.2**

Remark: 1) 45 kg of molasses is derived from 1 tone of sugarcane
2) 250 liters of ethanol is generated from 1 tone of molasses
3) 160 liters of ethanol is derived from 1 tone of cassava

In 2005, Thailand began a campaign to promote biodiesel. Initial production of biodiesel was insignificant until February of 2008, when the state adopted a policy requiring compulsory production of B2 biodiesel (98% high-speed diesel + 2% of pure biodiesel, called B100). In June 2010, the Government is presently scheduled to replace the compulsory production of B2 with B3 and by 2011, under the current biodiesel policy, all diesel sold in Thailand must be B5. Finally, after 2011, B10 will begin to implement as an optional diesel (Meyer, 2010). To meet this goal, the government has encouraged oil palm cultivation. Table 4.28 below forecasts biodiesel sales from 2009-2016, and this projection has been translated to estimate the demand for B100 biodiesel and palm oil feedstock (table 4.29).

Table 4.28: Projection of biodiesel demand for Thailand (M liters/y)

Year	Demand for all biodiesel*	Estimated market shares for biodiesel				B100 demand	Crude Palm Oil demand
		B2	B3	B5	B10		
2009	18,214	0.6		0.4		582.85	0.6178
2010	18,400	0.25	0.35	0.4		653.20	0.6924
2011	18,700		0.6	0.4		710.60	0.7532
2012	19,200			1.0		960.00	1.0176
2013	19,500			0.9	0.1	1,072.50	1.1369
2014	20,000			0.8	0.2	1,200.00	1.2720
2015	20,600			0.7	0.3	1,339.00	1.4193
2016	20,900			0.6	0.4	1,463.00	1.5508

Remark:1.0 liter of B100 production is derived from 1.06 kgs of Crude Palm Oil (CPO)*
*Source: Meyer (2010)

Biodiesel production in Thailand relies on two key industries: palm oil production for feedstock and B100 processing industry for blending material. Based on statistics of oil palm in the past, the OAE figures and projections, and the biodiesel programme, the following assessment on production, supply, and demand table for palm oil from 2009-2016 have been developed (see table 4.29).

Table 4.29: Supply, production, and demand for crude palm oil in Thailand (2009-2016)

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Planted Area[a]	0.632	0.696	0.76	0.824	0.888	0.952	1.024	1.072
Harvested Area[a]	0.512	0.5648	0.616	0.680	0.744	0.808	0.872	0.936
Beginning Stock	107,947	40,000	62,000	70,000	57,000	40,000	50,000	62,000
Production[a]	1,414,400	1,573,375	1,727,625	1,919,675	2,111,725	2,328,525	2,545,325	2,762,125
Imports	100,409	151,967	53,601	155,925	119,062	114,425	102,985	36,635
Total Supply	**1,622,756**	**1,765,342**	**1,843,226**	**2,145,600**	**2,287,787**	**2,482,950**	**2,698,310**	**2,860,760**
Exports	50,000	28,000	38,000	49,000	39,000	40,000	40,000	42,000
Biodiesel Production[b]	617,819	692,392	753,236	1,017,600	1,136,850	1,272,000	1,419,340	1,550,780
Domestic Consumption	914,937	942,950	981,990	1,022,000	1,071,937	1,120,950	1,176,970	1,227,980
Total Consumption	**1,582,756**	**1,663,342**	**1,773,226**	**2,088,600**	**2,247,787**	**2,432,950**	**2,636,310**	**2,820,760**
Ending Stocks	40,000	62,000	70,000	57,000	40,000	50,000	62,000	40,000
Total Distribution	**1,622,756**	**1,725,342**	**1,843,226**	**2,145,600**	**2,287,787**	**2,482,950**	**2,698,310**	**2,860,760**

Remark: [a] Planted area, harvested area, and crude palm oil production are projected.
[b] Estimated Biodiesel Production is derived from table 4.28.
The unit of planted and harvested area is reported in M ha, while the unit for the rest is liter.

Under the current government plans to enforce compulsory full B5 production in 2012 and B10 as optional biodiesel later, the domestic supply is still insufficient to meet the government's requirements, while the excess requirement of feedstock (CPO or stearin) must be imported as picture in table 4.29.

4.2.5.1 Sugarcane (see also Ch. 2.2.1)

Based on assumptions below, the potential of sugarcane production can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.30.

Table 4.30: The potential of sugarcane production for the year 2006-2009, 2011, and 2016

Year	**Planted Area** (M ha)		**Yield Rate** (t/ha)		**Production** (M t)	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
2006-2009	0.963-1.054	1.013	63.76-69.71	67.355	64.37-73.5	68.22
2011 (Policy)	0.96		84		80.64	
2011 (Projection)	1.01		76.4		77.16	
2016 (Projection)	1.12		87		97.44	

Assumption

i) Although sugarcane cultivated area generally varies between 0.877 and 1.139 M ha in the crop year, it has showed a downward trend since 2005 with the rate of -1.24% annually. Moreover, only 20% of the area can access the irrigative water. Reported on the mass of the stalks delivered to the processing mill, statistic sugarcane yield varies between 47 and 74 M t, nevertheless this yield can be increased with the proper management. Ranging from 46.45 to 69.71 t/ha, the yield per area has been speedily improved at an average annual growth rate of 12.23%. Production of sugarcane has been, therefore, projected to increase at a rate of 10.83% per annum. The based yield of 65.18 t/ha will be referenced for the future forecast in the case of sugarcane.

ii) Since sugarcane is mostly used as a raw material for the sugar industry, the conversion of sugarcane into sugar products ranged from 98 to 105 kg raw sugar per t sugarcane. Therefore, the production capacity of 50-65 M t Thai cane a year stabilises an output of 5-6.5 M t sugar of which export market takes up 65-70% while domestic market consumes the rest (Nguyen et al., 2009).

iii) Sugarcane is a protected crop for area expansion since farmers have to register their planted area with the sugar millers, therefore its cultivated area will not be above present condition. However, following Thai Cane Strategies 2007 to 2011 by the Office of the Cane and Sugar Board (OCSB), the growing area should be maintained at 0.96 M ha, including area for energy purpose of 0.088 M ha (Sriroth et al., 2010).

iv) To fulfill the maximum requirement of 80 M t sugarcane by indigenous 46 sugar mill plants and 15 ethanol plants, the yield per area of sugarcane should be at least 84 t/ha with the maintained area of 0.96 M ha.

v) Thai sugarcane yield is projected to reach 87 t/ha taking into account clone improvements in rain fed areas, comparing to the commercial maximum yield for three leading sugarcane production countries (Australia, Colombia, and South Africa) averaged 148 t/ha or normal farm yield of 98 t/ha (Waclawovsky et al., 2010). From the next strategies (after 2016), the average yield per area should be increased to 93.75 t/ha. Breeding programmes have been successfully increasing yield at around 1% a year. If the originators have biotechnological tools available, such as genes that could be used as markers in the selection of genotypes, conventional breeding can be improved considerably. Sugarcane yield is, therefore, set to reach a target of 106 M t/ha by 2021.

Based on assumptions below, the potential of sugarcane residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.31.

Table 4.31: The potential of sugarcane residues for the year 2006-2009, 2011, and 2016

Year	Sugarcane Production	Residues types	CRR	Scenario			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	68.22	Bagasse	0.28	19.102			
		Top & trash	0.17	11.597	9.278	6.624	6.624
2011	80.64	Bagasse	0.28	22.579			
(Policy)			0.26	20.966			
		Top & trash	0.17	13.709	10.967	7.830	7.830
			0.16	12.902	10.322	7.370	7.370
2011	77.16	Bagasse	0.28	21.605			
(Projection)			0.26	20.062			
		Top & trash	0.17	13.117	10.494	7.493	7.493
			0.16	12.346	9.876	7.052	7.052
2016	97.44	Bagasse	0.28	27.283			
(Projection)			0.26	25.334			
		Top & trash	0.17	16.565	13.252	9.462	9.462
			0.16	15.590	12.472	8.905	8.905

Remark: Bagasse is a byproduct from agro-industry, therefore its collection is assumed 100%

Assumption

i) Sugarcane residues are basically of two types: the cane residues made up of leaves and its tops (also known as cane trash), these residues commonly remain in the field after the harvest; and bagasse which is the generated fibrous residue after the extraction of the juice from the cane stalk in the sugar mill. The precise amount of biomass available from sugarcane residues (on field) is differed from plant varieties, climate, and soil conditions, etc. For most countries, sugarcane stalk 1 t can generate bagasse at average of 0.26 t with moisture content of 50% (Ripoli *et al*., 2000). However, for Thailand, about 0.29 t of bagasse comes from 1 t of sugarcane stalk.

ii) In Thailand, the sugarcane harvest residue deposited on the soil surface is usually burnt, because it is the cheapest way to prepare the cultivated area for the next growth. Besides, many researches have documented significant reductions in yield for ratoon crops (Rozeff, 1995; Richard, 2001; Viator et al., 2008b), if the residue is left on the soil surface by reducing new sugarcane emergence. The yield was 9.8% greater for the residue-burned treatment, a similar finding to industry observations and other research results. Research clearly shows that sugarcane crop residue should be removed from the row top to maximize yield of the ratoon crop. However, mechanical removal of the residue would cost considerably more than burning, although there would be some cost associated with burning (Judice et al., 2007).

iii) To separate and collect what is left in the cane filed by automatic posterior and mechanical bailing equipment, this method presented an efficiency of 68% in the separation of residue and 84% in the collection and baling of cane residue. For another method, it is harvesting without detaching the cane residue in the field but performing its separation later at the mill, prior to the industrial processing. This method produced an efficiency of 55-70% in separating the residue (Hassuani et al., 2005).

4.2.5.2 Paddy Rice (see also Ch. 2.2.2)

Based on assumptions below, the potential of paddy rice production can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.32.

Table 4.32: The potential of paddy rice production for the year 2006-2009, 2011, and 2016

Year		**Planted Area** (M ha)		**Yield Rate** (t/ha)		**Production** (M t)	
		Range	**Average**	**Range**	**Average**	**Range**	**Average**
2006-2009	**1st Rice**	8.96-9.28	10.304-10.8	2.481	2.744	22.23-23.03	28-30
	2nd Rice	1.344-1.52		4.269		5.74-6.49	
2011 (Policy)	**1st Rice**	9.2	10.64	3.106	3.319	28.578	35.318
	2nd Rice	1.44		4.681		6.741	
2011 (Projection)	**1st Rice**	9.2	11.12	2.594	2.885	23.863	32.083
	2nd Rice	1.92		4.281		8.220	
2016 (Projection)	**1st Rice**	9.2	11.2	3.106	3.388	28.578	37.94
	2nd Rice	2		4.681		9.363	

Assumption

i) Currently, rice cultivated area in Thailand fluctuates from year to year ranging between 8.96 and 9.28 M ha, while the paddy is produced among 28 to 30 M t annually. From the most update data, its total growing area has steadily increased at the rate of 1.33% per year since 2005; however this flowing rate came mainly from the off-season planted area with the rate of 9.61%. For future forecast in this study, the based paddy yield of 2.744 t/ha following Thai Rice Strategies for Sustainable Development 2007-2011 will be mentioned.

ii) Although rice is the major staple food in Southeast Asia and implicitly in Thailand, the FAO (1996) data showed that among Asian countries *per capita* cereal consumption has declined substantially in Japan, Taiwan, South Korea, Malaysia, and Thailand because welfare enhancement and food variation. This trend may lead to more excess rice for export, or to decrease in cultivated area. Between 1990 and 2005, the average per capita milled rice consumption of Thai households decreased from 119 to 101 kg (Isvilanonda and Kongrith, 2008). Using this data, the milled rice consumption is calculated with the requirement of 6.4 M t. With this condition and the improvement in yield, Chaiyachet and Polprasert (2009) stated that percentage of available safety land from rice cultivated area has been increasing annually of about 2.5%. This excess land may be available for other crops. From Thai Rice Strategies for Sustainable Development 2007-2011, however, planted area of paddy rice should be maintained at total 10.64 M ha annually including the in-season planting area 9.2 M ha and the off-season planted area 1.44 M ha in order to increase the milled rice export from 7.3 to 8.5-9.5 M t in this period.

iii) Improved grain yield has been a main focus of rice breeding programs in Thailand, since its yield has grown only slowly. From 1971-1975 to 2001-2007, paddy rice production steadily increased at an average annual rate of 3.06%. A declining price in the past caused the government putting less on venture in rice research (Isvilanonda and Kongrith, 2008). Another reason for slow growth in yield was increased attention paid mainly to better rice quality (Fischer and Edmeades, 2010). With the increased living standard, quality of the rice grain has become a priority (Zhang, 2007). The paddy yield should be improved to rise from

2.744 to 3.319 t/ha in the year 2011 according to the strategies. To get this target, a new hybrid is conceptualised. It should possess resistances to multiple insects and diseases, high nutrient efficiency, and drought resistance, promising to greatly reduce the consumption of pesticides, chemical fertilizers, and water.

Based on assumptions below, the potential of paddy rice residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.33.

Table 4.33: The potential of paddy rice residues for the year 2006-2009, 2011, and 2016

Year	**Paddy Production**	**Residues types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	29	Rice Straw	0.49	14.210	3.553	9.947	9.947
		Rice Husk	0.23	6.670			
2011 (Policy)	35.318	Rice Straw	0.49	17.306	4.326	12.114	12.114
			0.45	15.893	3.973	11.125	11.125
		Rice Husk	0.23	8.123			
			0.21	7.417			
2011 (Projection)	32.083	Rice Straw	0.49	15.721	3.930	11.004	11.004
			0.45	14.437	3.609	10.106	10.106
		Rice Husk	0.23	7.379			
			0.21	6.737			
2016 (Projection)	37.94	Rice Straw	0.49	18.591	4.648	13.013	13.013
			0.45	17.073	4.268	11.951	11.951
		Rice Husk	0.23	8.726			
			0.21	7.967			

Remark: Rice husk is a byproduct from agro-industry, therefore its collection is assumed 100%

Assumption

i) Straw makes up about 50% of the dry weight of a rice plant, with a significant variation from 40-60% according to the cultivar and cultivation method. The proportion of recoverable straw depends on the technique of reaping and harvesting (manual or mechanical) and on the condition of the field (wet or dry) and crop (lodged or not) (Hong, 2007).

ii) Rice husk is a co-product of rice products generated in the rice milling process. This husk accounts for about 23% of the total paddy weight (rice crop weight). This number is considered as a fair average for general rice husk production in Thailand. Although rice husk been used as an energy source in the rice mills themselves, there is still some surplus rice husk remaining unused in the mills (Prasara-A, 2009).

iii) Modern rice varieties have a harvest index (grain/straw) of 0.4 to 0.5. The new hybrid type was conceptualised to raise the harvest index to 0.6 (Khush, 2001).

iv) The mechanical method commonly applied to harvest and handle rice straw is baling, and even this has been done only on a limited basis owing to the lack of demand for the rice straw. Without viable alternatives, growers will continue to burn until a management practice(s) is identified that utilizes the residue reduce runoff, enhance soil fertility, while minimise the impact of remain residue on the subsequent crops (Hong, 2007; Viator et al., 2008a).

v) Three modern technology developments to potentially reduce collection and handling costs are: i) specialized containers; ii) combined harvester/grinder; and iii) bundling/baling. The major pieces of equipment needed consist of a collector device, a stationary or modified combine, straw drying equipment, and a large baler. The grain collected can be separated from the straw outside the field with the unthreshed rice unloaded to form long, high piles. A combination with a modified feeding device would process these piles, threshing the rice and dropping the straw in an adjacent pile (Hong, 2007).

vi) For another example of new concept about baling, it should be considered the case of switch grass. Wang et at. (2009) reasoned that rectangular bales minimise cost, if switch grass is processed immediately after harvest. However, round bales minimise cost, when switch grass must be stored under cover for 200 days before transporting to the biorefinery.

4.2.5.3 Cassava (see also Ch. 2.2.4)

Based on assumptions below, the potential of cassava production can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.34.

Table 4.34: the potential of cassava production for the year 2006-2009, 2011, and 2016

Year	**Planted Area** (M ha)		**Yield Rate** (t/ha)		**Production** (M t)	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
2006-2009	1.109-1.326	1.224	20.36-22.69	22.49	22.58-30.09	27.524
2011 (Policy)	1.296		26.875		34.83	
2011 (Projection)	1.311		25.625		33.594	
2016 (Projection)	1.184		38.75		45.88	

Assumption

i) During 2002 to 2008, the cassava production in Thailand was quite unstable. Although high yield varieties of cassava roots were widely planted, there were some important factors which affect cassava supply, the farm price and weather variation. As a result, the harvested areas were fluctuated between 0.996 and 1.24 M ha, whereas the production yields varied from 16.868 to 26.916 M t (see table 2.22). Since then, however, harvested area of cassava has been increased at an average annual rate of 2.6%, this has resulted from a number of factors: attractive prices, government policy to promote ethanol production from cassava, favourable weather, and high yield seed varieties. All these have contributed to area expansion and hence, production increases.

ii) All produced roots were consumed by two main large-scale industries, i.e. chips and starch (table 4.27). Around 45% of fresh roots were processed to chips (5 M t of chips or 11.25 M t of fresh roots), while the rests to starch (3.5 M t of starch or 14.75 M t of fresh roots). A large portion of chips (80%) were supplied to the export market as primary goods (Sriroth et al., 2010). Therefore, the domestic consumption of cassava in forms of chips and starch was about 8.75 M t and has been steadily increasing. On the other hand, it was forecasted that the cassava export demand will grow at the rate of 5% per year.

iii) In the past, cassava & maize plantations had to frequently compete with other high profit crops such as sugarcane. Since cassava is now promoted as the local feedstock for bioethanol industry, the supportive national policy for increasing cassava production is then in action. Recently (2009), there is an about 1.326 M ha of the total land devoted for the cassava production and productive yield is about 33.53 M t (or 25.279 t/ha). The product yielded of an enhancement with an average annual rate of 16.16% during 2006 and 2009. To maintain the recent export level and diminish the conflict in food security, it was estimated that the annual production growth rate from 2009 at about 1.94% of fresh cassava tuber will be required to meet the target of bioethanol programme in 2011.

iv) In Thailand, cassava is considered a cash crop, because it is a major raw material for many downstream industries, widely recognized as one of the most competent agri-business. The core competencies of Thai cassava manufacturing include improved varieties, increased root productivity, cost-effective production technology to various products, continuously expanding markets both locally and internationally, and strong collaborative programs/policies among all stakeholders (Sriroth et al., 2010).

v) Given that the current demand for cassava has been at least 33 M t. The increased quantity will continue to grow in the future. Such increases will be as a result of expansion from: 1) cassava derides demand industry, expected to increase for livestock feed as higher growth for meat petition by Asian incomes (Fuglie, 2004); and 2) the global growing trends of demand for energy-substitute agricultural products, such as, ethanol production from corn in the US. Hence, the demand will increase to 33.67 M t in the year 2010. For the ethanol industry, fermentation process is still mainly applied in Thailand. The feedstocks used for this process are sugarcane, cane molasses, and cassava, which are also considered as food crops. This is one of the reasons for companies facing the problems with sustainable supply of raw materials, and a consistent raw materials price. Besides, when all 40 plants of ethanol producer run their full installed capacity, it is expected that more fresh cassava tubers at about 8 M t will be required annually.

vi) As mentioned above, it is necessary to improve cassava yield from 20.359 t/ha in 2006 to 26.875 t/ha in 2011, by maintaining the cultivated area at about 1.296 M ha.

vii) Although cassava can be grown in infertile and arid lands, effective plantation technology can considerably improve the root productivity. Yield stagnation in the past has resulted from soil losses due to erosion and inappropriate fertilizer application (Roonnaphai, 2006). However, it can be demonstrated an increased root productivity of Thai cassava from 14.01 t/ha in 1995 to 20.618 t/ha in 2008. For breaking the current yield ceiling, the productivity of cassava roots can be significantly increased from 22 to 60 t/ha simply by applying yield improved varieties and good cultivation practices; important ones are soil plowing, high stake quality, weed control, good planting and harvesting period, land conservation with organic fertilizers and water irrigation (Sriroth et al., 2010). Therefore, Thailand is investing in research to increase cassava yield from 23 to 50 t/ha by 2020.

Based on assumptions below, the potential of cassava residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.35.

Table 4.35: the potential of cassava residues for the year 2006-2009, 2011, and 2016

Year	**Cassava Production**	**Residues types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	27.524	Stalk	0.09	2.477	1.858	1.982	1.858
		Rhizome	0.49	13.487	11.733	10.789	10.789
		Leave	0.252	6.936	5.202	5.549	5.202
		Peel	0.06	1.651	1.437	1.321	1.321
2011 (Policy)	34.83	Stalk	0.09	3.135	2.351	2.508	2.351
			0.08	2.786	2.090	2.229	2.090
		Rhizome	0.49	17.067	14.848	13.653	13.653
			0.46	16.022	13.939	12.817	12.817
		Leave	0.21	7.314	5.486	5.851	5.486
			0.244	8.499	6.374	6.799	6.374
		Peel	0.06	2.090	1.818	1.672	1.672
			0.05	1.742	1.515	1.393	1.393
2011 (Projection)	33.594	Stalk	0.09	3.023	2.268	2.419	2.268
			0.08	2.688	2.016	2.150	2.016
		Rhizome	0.49	16.461	14.321	13.169	13.169
			0.46	15.453	13.444	12.363	12.363
		Leave	0.221	7.424	5.568	5.939	5.568
			0.256	8.600	6.450	6.880	6.450
		Peel	0.14	2.016	1.754	1.613	1.613
			0.12	1.680	1.461	1.344	1.344
2016 (Projection)	45.88	Stalk	0.09	4.129	3.097	3.303	3.097
			0.08	3.670	2.753	2.936	2.753
		Rhizome	0.49	22.481	19.559	17.985	17.985
			0.46	21.105	18.361	16.884	16.884
		Leave	0.146	6.698	5.024	5.359	5.024
			0.169	7.754	5.815	6.203	5.815
		Peel	0.06	2.753	2.395	2.202	2.202
			0.05	2.294	1.996	1.835	1.835

Assumption

i) Cassava plant could yield 5.656-6.563 t of dry leaves per ha (4-5 times of harvesting per year), with an additional valuable protein 19.7-26.8%. These leaves can be fed for animals. For this purpose, the yield of cassava leaves will be targeted at about 8.75 t of leaves per ha. Cassava Starch Residues (CSR) are the fibrous wastes left behind after the extraction of starch from mechanically rasped cassava tubers in the processing factories. Very low protein but high fibre level, CSR is generally discarded to the environment without any treatment, causes serious concern to environmental pollution. A little amount of CSR is still utilized as feed or combustible, therefore it is interesting for the production of glutamic acid (Aro et al., 2008).

ii) Before the mature roots are harvested, good stems are generally collected for planting in the next crop season. The stems are cut and gathered manually and kept in standing stacks. While tractor-drawn trailers may be used in transporting the cut and gathered stems, no fully mechanised means have been found for the cassava stem harvesting operation.

iii) Harvesting cassava roots is usually done by hand, therefore its harvesting usually requires digging around the roots to free them and lifting the plant. Mechanical harvesting of cassava is difficult because of the non-uniform geometry of the roots in the ground. Nevertheless a few cassava harvesters have been designed and some are in operation, mostly by large-scale farmers. Typically, cassava plantation is achieved at a small-scale (about 0.5-2 ha) and the roots are collected from a large number of small farmers and transported to convertors in processing areas (Sriroth et al., 2010). The field efficiency of 80-92% and 85-92.51 was report in Malaysia (Sukra, 1986) and Thailand, respectively.

4.2.5.4 Oil palm (see also Ch. 2.2.3)

Based on assumptions below, the potential of oil palm production can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.36.

Table 4.36: the potential of oil palm production for the year 2006-2009, 2011, and 2016

Year	**Area** (M ha)		**Yield Rate** (t/ha)	**Production** (M t) (FFB)
	Planted	**Harvested**		
2006-2009	0.632	0.512	16.25	8.32
2011 (Policy)	1.23	1.13	22	24.86
2011 (Projection)	0.76	0.616	16.388	10.095
2016 (Projection)	1.072	0.936	16.928	15.845

Remark: 1) Fresh Fruit Bunch (FFB) is the main product from oil palm cultivation.
2) The planted and harvested area between 2006 and 2009 is based on the year 2009.
3) Because the biodiesel programme is the most unclear renewable energy plan, the target in 2011 is hardly to succeed with current progress.

Assumption

i) In the past, palm oil was served chiefly for indigenous food industry. However, both cultivated area and its yield has been noticeably increased since 2006, because Thai government has set its policy to produce biodiesel based mainly on palm oil as a feedstock (Pichalai, 2007). In response to this programme, a major initiative by the Government is to boost palm oil plantation and its yield by setting the National Palm Oil Development Plan of 2008-2012 (see ***iii*** below and ***iv*** next page). However, limitation by the raw materials is still seen as a major barrier that can prevent immediate increase in biodiesel production. Table 4.28 forecasts for the demand of biodiesel from 2009-2016 from the current point of view. This projection has been translated to estimate the demand for B100 biodiesel and the feedstock (table 4.29).

ii) The total oil palm harvesting area in 2007 was 0.426 M ha and production yield of Fresh Fruit Bunches (FFB) was around 16.25 t/ha (5 year average; 2003-2007). By comparison with those of Malaysia (3.79 M ha and 20.8 t/ha) (Papong et al., 2010), it still has a room for yield improvement. Owing to most of oil palm planting consists of small holding areas that are unsuited to modern management practice in Thailand, however, it results in both lower harvesting yield and higher production cost. At present, the oil palm plantations in Thailand are cultivated with a density of 128-148 trees per ha, while palm oil extraction rate in Thailand is around 16-17% and production yield of FFB is about 16.25-19 t/ha.

iii) The oil palm industry in Thailand will certainly continue to expand, regardless of the food debate, driven by the increasing demand for biofuel feedstock. According to the National Palm Oil Development Plan (2008-2012), an additional growing area of 0.806 M ha is needed for palm oil cultivation between 2008 and 2012, totalling 1.28 M ha of the palm cultivation. This added area includes the cultivated area for bioenergy purpose only at about 0.264 M ha. To fulfill the government’s ambition of biodiesel programme, however, a daily production of 8.5 M litres of pure biodiesel should be met by 2012, therefore the plantation areas of palm oil will reach 1.6[61] M ha.

iv) From the plan, although it can not be met with current situation, these objectives should be also mentioned: productive enhancement of oil palm from 19 to 22 t/ha, as well as augment of crushing rate from 17 to 18.5% by 2012. Future production has therefore been predicted by using a productivity increase rate of 5.2% per annum, but in the past five years Thailand has had only 1.4% average annual production growth. However, oil palm breeders must continue to improve the yields of this crop. The gap yields between Thai and Malaysia/Indonesia are widening, with record yields currently over 20% Thai national average. This not only shows that there is plenty of scope for future yield improvement, but also suggests that plantation managers may be failing to take full advantage of the genetic yield potential of their planting material.

Based on assumptions in the next page, the potential of oil palm residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.37.

Table 4.37: the potential of oil palm residues for the year 2006-2009, 2011, and 2016

Year	**FFB Production**	**Residues types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	8.32	Empty bunches	0.285	2.371			
		Fiber	0.190	1.581			
		Shell	0.060	0.499			
		POME	0.700	5.824			
		Frond	2.604	21.665	12.999	17.332	12.999
		Male bunches	0.233	1.939	1.163	1.551	1.163
2011 (Policy)	24.86	Empty bunches	0.285	7.085			
			0.190	4.723			
		Fiber	0.190	4.723			
			0.148	3.679			
		Shell	0.060	1.492			
			0.046	1.144			
		POME	0.700	17.402			
			0.570	14.170			
		Frond	2.604	64.735	38.841	51.788	38.841
			1.719	42.734	25.641	34.187	25.641
		Male bunches	0.233	5.792	3.475	4.634	3.475
			0.154	3.828	2.297	3.063	2.297
2011 (Projection)	10.095	Empty bunches	0.285	2.877			
			0.210	2.120			
		Fiber	0.190	1.918			
			0.150	1.514			
		Shell	0.060	0.606			
			0.049	0.495			
		POME	0.700	7.067			
			0.590	5.956			

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[61] For another option, the Department of Alternative Energy Development and Efficiency of Thailand indicated that another 0.161 ha can be leased or subcontracted from the neighboring countries: Cambodia, Lao, and Myanmar.

Table 4.37 (continue): the potential of oil palm residues for the year 2006-2009, 2011, and 2016

Year	**FFB Production**	**Residues types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2011 (Projection)		Frond	2.604	26.287	15.772	21.030	15.772
			2.573	25.974	15.585	20.780	15.585
		Male bunches	0.233	2.352	1.411	1.882	1.411
			0.229	2.312	1.387	1.849	1.387
2016 (Projection)	10.095	Empty bunches	0.285	4.516			
			0.210	3.327			
		Fiber	0.190	3.011			
			0.150	2.377			
		Shell	0.060	0.951			
			0.049	0.776			
		POME	0.700	11.092			
			0.590	9.349			
		Frond	2.604	41.260	24.756	33.008	24.756
			2.501	39.628	23.777	31.703	23.777
		Male bunches	0.233	3.692	2.215	2.954	2.215
			0.224	3.549	2.130	2.839	2.130

Remark: 1) Palm Oil Mill Effluent (POME) is the liquid waste combined of the wastes from sterilizer condensate and cooling water

2) Empty bunches, Fiber, Shell, and POME are the byproducts from palm oil mills, therefore their collection is assumed 100%

Assumption

i) For oil palm harvesting, it is still relied primarily on human labour, but mechanical tools and improved harvesting techniques has been developed to increase worker's productivity including: 1) stability of equipment enables harvester to move rapidly; 2) harvesting equipment can positioned with accuracy, ease, and speed; 3) shape and design of harvesting equipment gives well access to the base of the palm oil bunch; and 4) good visibility of the cutting target area. Therefore, a small fraction of the available biomass (10%) is assumed lost during the harvesting and collecting operations.

ii) For oil palm's residue, the products per t of FFB were as follows: 0.066-0.005 t of shell and 0.054-0.005 t of kernel. The calorific values of these were obtained from many sources as follows: Palm Mill Effluent (PME) 38.07 MJ/kg, glycerol 19 MJ/kg, palm kernel 17 MJ/kg, and shell 18.46 MJ/kg.

iii) Based on the study by Wicke et al. (2008), the future CRR of oil palm in Thailand can be projected following current palm oil production in Malaysia.

4.2.5.5 Maize (see also Ch. 2.2.5.2)

Based on assumptions below, the potential of maize production can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.38.

Table 4.38: the potential of maize production for the year 2006-2009, 2011, and 2016

Year	**Area** (M ha)		**Yield Rate** (t/ha)		**Production** (M t)	
	Planted	**Average**	**Range**	**Average**	**Range**	**Average**
2006-2009	1.018-1.164	1.076	3.706-3.969	3.811	3.89-4.341	4.101
2011 (Policy)	1.076		4.147		4.462	
2011 (Projection)	1.001		4.147		4.151	
2016 (Projection)	1.076		4.661		5.015	

Assumption

i) Maize, cassava and soybean are not main staples for Thais, therefore they are only food supplements and ingredients. Currently, maize is mostly utilized for domestic demand. It is generally used for starch production and animal feed, especially required in larger and larger quantities to make the feed for broilers, a type of chicken for meat production (Roonnaphai, 2006). During the past 5 years, although the planted area was more or less constant between 1.018 and 1.164 M ha, it faced moderately decline with the rate of -1.994% owing to competition from some other crops giving better returns. The annual production of maize was, therefore, reduced at about -0.94%, despite the yield per ha having improved at an average rate of 1.56% per year. This rate has been used to predict maize production for the future. To be referenced in the prediction, cultivated area about 1.076 M ha and yield about 3.678 t/ha will be mentioned.

ii) It is estimated that the maize harvested area and output would still decrease slightly despite of significant increasing price trend presently. This is because some maize growers have switched to higher profit plants such as cassava, sugarcane, or rubber wood (the perennial crops which can not be changed to upland crops in the short run). Moreover, water stress is unpredictable in rainfed agriculture, and regularly affects maize production in Thailand. Significant yield reductions occur, when maize encounters drought conditions during critical growth periods (Jampatong and Balla, 2005).

iii) As mention above, maize is principally required for animal feed. The feed includes: 64% for poultry, 34% for swine, and 2% for others. This demand has an average annual growth rate about 3.73%. Because its demand is about 4.25 M t annually, maize is therefore net import for Thailand. If the global demand of maize for biofuel production is still continually expanding, this will affect the maize supply for Thailand.

iv) Because a nation plan about maize is still not declared at the moment, the assumption in this study is that cultivated area about 1.076 M ha is still preserved. To meet the indigenous demand, however, maize productivity (t/ha) should been increasing by about 1.25% annually on average. If this trend continues into the future, it is possible that corn stover quantities will possibly growing or steady over time, up to the CRR improvement.

v) If maize production in the country does not meet the indigenous demand, the shortage will be imported from neighbouring countries. This plan is recently (2010) being considered by the Thai government.

Based on assumptions below, the potential of maize residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.39.

Table 4.39: The potential of maize residues for the year 2006-2009, 2011, and 2016

Year	**Maize Production**	**Residues types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009	4.101	Corn cob	0.24	0.984			
		Stove	0.82	3.363	0.841	2.186	2.186
2011 (Policy)	4.462	Corn cob	0.24	1.071			
			0.23	1.026			
		Stove	0.82	3.659	0.915	2.378	2.378
			0.81	3.614	0.904	2.349	2.349
2011 (Projection)	4.151	Corn cob	0.24	0.996			
			0.23	0.955			
		Stove	0.82	3.404	0.851	2.212	2.212
			0.81	3.362	0.841	2.186	2.186
2016 (Projection)	5.015	Corn cob	0.24	1.204			
			0.21	1.053			
		Stove	0.82	4.112	1.028	2.879	2.879
			0.80	4.012	1.003	2.808	2.808

Remark: Corn cob is a byproduct from agro-industry, therefore its collection is assumed 100%

Assumption

i) More evaluation is needed concerning whether the current ratio of about 1 kg of stove produced per kg of corn grain produced is likely to stay the same or change if corn productivity continues to increase in the future. As in the USA, maize varieties are assumed to transition from an average residue-to-grain ratio of 1.5 to a ratio of 2.0, because the residues are targeted to utilize for the 2^{nd} generation biofuel production (Haq and Easterly, 2006).

ii) Because the harvest and compilation of corn stover was further developed in the USA, this study will cite the research from this country. In the USA, it is possible under some conditions to remove as much as 60 to 70% of corn stover with currently available equipment. However, this level of residue collection is economically or environmentally viable only where land is under no-till cultivation and crop fields are very high. The analysis assumes that the harvest technology and the percentage of cropland under no-till management are increased simultaneously.

4.2.5.6 Other Potential Crops (see also Ch. 2.2.5)

Based on assumptions below, the potential of production from selected minor crops can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.40.

Table 4.40: The potential of production from selected minor crops for the year 2006-2009, 2011, and 2016

Year		**Planted Area** (M ha)		**Yield Rate** (t/ha)		**Production** (M t)	
		Range	**Average**	**Range**	**Average**	**Range**	**Average**
2006-2009	**Jatropha**	0.016		2.5-5.0	3.0	0.048	
	Cotton	0.0015-0.0125	0.007	1.25-1.469	1.364	0.0021-0.0151	0.0086
	Kenaf	0.0014-0.0031	0.002	1.669-2.031	1.819	0.0025-0.0046	0.0037
	Soybean	0.125-0.150	0.136	1.431-1.619	1.536	0.202-0.220	0.209
	Sorghum	0.033-0-041	0.036	1.644-1.888	1.728	0.053-0.077	0.062
	Coconut	0.247-0.285	0.266	6.038-7.863	7.097	1.484-2.126	1.889
	Ground nut	0.034-0-041	0.038	1.606-1.688	1.648	0.051-0.067	0.063
2011 (Projection)	**Jatropha**	0.185		7.5		1.388	
	Cotton	0.007		1.378		0.0096	
	Kenaf	0.002		1.837		0.0037	
	Soybean	0.136		1.551		0.2110	
	Sorghum	0.036		1.763		0.0635	
	Coconut	0.266		7.140		1.8991	
	Ground nut	0.038		1.663		0.0632	
2016 (Projection)	**Jatropha**	0.608		9.375		5.7	
	Cotton	0.007		1.446		0.0101	
	Kenaf	0.002		1.928		0.0039	
	Soybean	0.136		1.628		0.2214	
	Sorghum	0.036		1.935		0.0697	
	Coconut	0.266		7.352		1.9558	
	Ground nut	0.038		1.740		0.0661	

Assumption

i) **Jatropha oil** (see also Ch. 2.2.5.1) can be potentially a substitute for palm oil. According to the study of MTEC, its net energy ratio is 3.74 (Suppapitnarm, 2006). Thailand has 16,000 ha of jatropha plantations, but only 3,200 ha is managed commercially (Siriwardhana et al., 2009). For the production yield, jatropha can generate 2.5 to 3.125 t/ha of the nut containing 48.5% raw oil, up to farm managements. The extraction rate of the oil with current technology in Thailand is about 55%.

ii) For other products such as **coconut, cotton** (see also Ch. 2.2.5.3)**, kenaf** (see also Ch. 2.2.5.4) **and soybean** (see also Ch. 2.2.5.5), there was no significant change in harvested area and product yield during 2000-2010. Although for **groundnut and sorghum** there was no change in harvested area, production yield did increase at average annual rates of 0.93% and 2.0%, respectively. For coconut, because it is a perennial crop, its yield per area will be assumed to increased at an average 0.6% per annual.

iii) Jatropha plantation, according to its strategy 2009-2013, is expected to increase at 0.608 M ha with the yield of 9.375 t/ha. The main target of this plan is to utilize jatropha oil for local biodiesel production. This biodiesel will be fueled mainly for low speed farm machine in the rural community. For other crops, their situations are assumed to follow the assumption in 4.2.2.

Based on assumptions that all crops in 4.2.5.6 is guessed to be in line with 4.2.3 and 4.2.4 for environmental protection purpose and in harvest and collection topics, the potential of minor crop residues can be clearly projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table below.

Table 4.41: The potential of minor crop residues for the year 2006-2009, 2011, and 2016

Year	**Produc-tion**	**Residue types**	**CRR**	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2006-2009							
Jatropha	0.048	SCR	0.515	0.025			
Cotton	0.0086	Stalk, Leaves	3.232	0.028	0.022	0.017	0.017
Kenaf	0.0037	Stalk, Leaves	2.5	0.009	0.007	0.006	0.006
Soybean	0.209	Stalk, Leaves, Shell	2.663	0.557	0.445	0.334	0.334
Sorghum	0.062	Stalk, Leaves	1.252	0.078	0.062	0.047	0.047
Coconut	1.889	Coir	0.362	0.684			
		Shell	0.160	0.302			
		Bunch	0.049	0.093			
		Frond	0.225	0.425	0.340	0.255	0.255
Groundnut	0.063	Shell	0.323	0.020			
2011							
Jatropha	1.388	SCR	0.515	0.715			
Cotton	0.0096	Stalk, Leaves	3.232	0.031	0.025	0.019	0.019
Kenaf	0.0037	Stalk, Leaves	2.5	0.009	0.007	0.006	0.006
Soybean	0.2110	Stalk, Leaves, Shell	2.663	0.562	0.450	0.337	0.337
Sorghum	0.0635	Stalk, Leaves	1.252	0.080	0.064	0.048	0.048
Coconut	1.8991	Coir	0.362	0.687			
		Shell	0.160	0.304			
		Bunch	0.049	0.093			
		Frond	0.225	0.427	0.342	0.256	0.256
Groundnut	0.0632	Shell	0.323	0.020			
2016							
Jatropha	5.7	SCR	0.515	2.936			
Cotton	0.0101	Stalk, Leaves	3.232	0.033	0.026	0.020	0.020
Kenaf	0.0039	Stalk, Leaves	2.5	0.010	0.008	0.006	0.006
Soybean	0.2214	Stalk, Leaves, Shell	2.663	0.590	0.472	0.354	0.354
Sorghum	0.0697	Stalk, Leaves	1.252	0.087	0.070	0.052	0.052
Coconut	1.9558	Coir	0.362	0.708			
		Shell	0.160	0.313			
		Bunch	0.049	0.096			
		Frond	0.225	0.440	0.352	0.264	0.264
Groundnut	0.0661	Shell	0.323	0.021			

Remark: SCR = Seed Cake Residues

SCR, Coconut Coir, Coconut Shell, Coconut Bunch, and Groundnut Shell are byproducts from agro-industry, therefore their collection is assumed 100%.

4.2.5.7 Forest Products and Wood-based Industries:

Based on assumptions below, the potential of forest products and wood-based industries residues can be projected for the year 2006-2009, 2011, and 2016. These projections were summarised in table 4.42.

Table 4.42: The potential of forest products and wood-based industries residues for the year 2006-2009, 2011, and 2016

Year	**Replanted/ Harvested Area** (M ha)	**Residue types**	**CRR** (t/ha)	**Scenario**			
				4.2.2	**4.2.3**	**4.2.4**	**4.2.3&4.2.4**
2009-2016							
Rubberwood	**0.0767**	Small branches	75.95	5.825	4.660	3.495	3.495
		Stumps	21.25	1.630	1.304	0.978	0.978
		Tops	7.6	0.583	0.466	0.350	0.350
		Sawdusks	18.75	1.438	1.438	0.863	0.863
		Slaps	31.25	2.397	2.397	1.438	1.438
Eucalyptus	**0.8**	Small branches and leaves	2.42	0.387	0.310	0.232	0.232
		Barks	18.75	3.000	3.000	3.000	3.000
Fast-growing trees	**0.148**[a] (For Multi purposes)	Small branches	1.03	0.051	0.041	0.030	0.030
		Leaves	0.562	0.028	0.022	0.017	0.017
		Stem	19.625	0.968	0.242	0.242	0.242
	0.16 (For Energy purposes)	Small branches	1.03	0.055	0.044	0.033	0.033
		Leaves	0.562	0.030	0.024	0.018	0.018
		Stem	19.625	1.047	1.047	1.047	1.047

Remark: [a] available data on 2003 (see also Ch. 2.3.4)

Assumption

i) The biomass from forest plantation in Thailand includes stumps, tops, limbs and unutilized cull trees in defining the logging residues types. The volumes of logging residues are available mainly from the Royal Forest Department of Thailand (RFDT). Residue data estimates are based on a mill survey conducted by the RFDT and the Forest Industry Organisation (FIO) of Thailand, and a wood utilization study published by Faculty of Forestry, Kasetsart University, Thailand.

ii) The residues from thinning operations also offer the most potential for increasing biomass feedstock resources, as they are under utilized due to the cost and difficulty of their recovery.

iii) Apart from specifying above, the biomass available from the stump-root system is suggested to gain an additional 20% beyond that obtainable from the stem (Richardson et al., 2002). Stump chip has a higher calorific value (Eriksson and Gustavsson, 2008) and is more homogeneous than other sources of forest chip (Ala-fossi *et al.*, 2007). However, stump harvesting represents an increase in the intensity of forest management activities and is highly likely to intensify the negative environmental effects of existing forestry practices, such as mechanical site preparation (Walmsley and Godbold, 2010).

iv) Presently, a major source of domestic wood in Thailand is rubber wood, a leftover from latex production of cut down 20-25 year old rubber trees for replantation. Rubber wood has become the significant wood for the country in terms of economics. It is exported not only in form of raw material, but also value-added wooden furniture. In 2008, planting area of rubber tree was totalling 2.702 M ha, but latex harvesting area was only 1.778 M ha with the latex yield of 1.738 t/ha (about 3.09 M t).

v) From the National Rubber Development Strategy (2008-2013), latex yield of rubber tree should be improved from 1.738 t/ha (2008) to 1.912 t/ha (2013), therefore latex production of the country will be boosted from 3.09 to 3.4 M t. According to this plan, highest potential latex yield from the research of 2.056 t/ha, and unproductive area starting to give its output, the added area in the future will be not necessary, but thanks to higher profit return than agriculture crops growing area of rubber tree in this study is therefore projected to reach 2.88 M ha for the year 2020. For replanting area after 2011, it is forecasted to be about 0.0766 M ha following the suggestion of the Office of the Rubber Replanting Aid Fund and the Rubber Research Institute of Thailand.

vi) Processing of rubber wood, saw logs, and processed wood occurs at sawmills and production plants and is accompanied by residue production of 30 to 60% (average 53%). Based on a residue percentage of 53% and a collectively of 60%, the annual availability of this resource can be estimated.

vii) In the case of eucalyptus, its plantation is devoted mainly for pulp & paper production, however construction pole, furniture and wood chip industries are other quite significant consumers. Besides, to take more profit for farmers, the Thai government has also promoted eucalyptus to replace some agricultural crops. At present, the planting area of eucalyptus is projected to reach about 0.8 M ha.

viii) The eucalyptus expansion is now already redundant and enters a decreasing phase, although domestic pulp demand is still low when compared with Japan, China, and Korea (pulp consumption for Thailand is only 31.5, while for developed countries is about 200 kg/capita/year). Moreover, the present figure does not include small pulpwood plantations elsewhere in Thailand, since there are no proper statistics available. According to another estimate, the total area of eucalyptus plantations in Thailand now could be up to 1.44 M ha. Therefore, the future cultivated area is projected to not exceed this existing growing area. To prevent the shortage of wood chip, the additional pulp demand will be met by new hybrid such as "H4", giving an average of 75-150 t/ha for 5 years rotation with pulp yield 49%.

ix) For fast-growing trees (mainly Acacia mangium, Leucaena leucocephala, and Acacia auriculiformis), the cultivated area for energy purpose is recently around 0.148 M ha. It can be assumed, however, that 75% of these woods go to fibre and 25% is available for energy.

x) For energy purposes, the RFDT is now running a plan to plant the fast-growing trees about 0.16 M ha by the year 2012 with average yield rate at 19.625 t/ha.

xi) Current logging technologies are designed for felling, extracting and transporting high-quality saw logs or pulpwood from forests. If convenient, logging residues (limbs and small diameter tree tops) and small, non-merchantable trees are occasionally recovered for use as energy wood by paper mills or power plants. More often than not, logging residues are left in the woods, as the costs of removal have traditionally exceeded market value of the material. Besides, as a low-value product relative to round wood, their harvest and handling costs must be minimised as much as possible in order to reach an economically feasible level (Wilkerson et al., 2008).

4.2.6 Other competition for the biomass raw materials

Not counting economic consideration, environmental protection, and limitation from harvesting & collecting, an increase in the use of biomass for energy is also restricted by its utilization for other purposes such as animal fodder, poultry bedding, fibrous materials, and traditional fuel. The competition for energy route from these factors is considered unsustainable and should be avoided in this study. The demand for food, industrial round wood, and traditional wood fuel must be given priority. In the areas where biomass are extensively used, however, energy efficiency enhancements of output from the biomass could be taken up (especially in rural households and small and medium scale industries) by simply improving the current technology and auditing the prevailing equipments.

With rising living standards, consumption of animal fats may increase, this result will affect directly to some residues, utilized as an animal feed. During 2005-2007, at constant price, bread and cereal expenditures grew by 1% whereas meat expenditures grew by 10% (Isvilanonda and Bunyasiri, 2009). Livestock and fisheries production are among the major protein source for Thailand. The development of large scale poultry production in the recent past has significantly provided surplus in the domestic supply, while the animal products is also in the same case. The competing demand for residues for livestock will be forecasted by estimating from future population projections and per capita consumption. Most of the additional flesh may be palm oil, which has the lowest production cost of the major ones, but soya bean oil production will probably also increase. There are two possible scenarios (see detail table 4.43 below) that will be assumed in this study including: 1) **present consumption** with a ceiling of current situation; and 2) **high consumption** compared to the present western level.

Table 4.43: Projection of meat consumption for Thailand

	Thailand	**EU**
Chicken (kg/person/year)	14.8	15.9
Duck (kg/person/year)	1.20	2.0 [a]
Egg (eggs/person/year)	171	251
Milk (liter/person/year)	13.67	70
Pork (kg/person/year)	13.8	39.3
Beef (kg/person/year)	2.6	16.9

Source: Laurujisawat (2009)

In Thailand, food and beverages are the major biomass energy using industry. The types of factory that use biomass energy consist of sugar mills, rice mills, palm oil, noodle factories, food cans, beer brewing and tobacco curing. The major sources of biomass are bagasse, fuel wood, paddy husk, and palm fibre & kernel shell. It indicated that the trend of biomass demand has increased at the moderate rate of 2% per annum. Demand of bagasse has dramatically increased over double in the past decade, while paddy husk has slightly risen with a growth rate of 1% per annum in the same period. For the ethanol programme, over the past several years, Thai molasses stayed at more or less 3 M t a year, of which the surplus 1 M t was exported. About half of this surplus has been shifted to the production of 0.4 M litre of ethanol a day (Nguyen et al., 2009). Not only does domestic ethanol production result in a decline in molasses exports, but also tends to divert sugarcane commodity away from sugar production for export. However, Thai Roong Ruang Group, a sugar producer and exporter, very recently announced its plan to convert bagasse into ethanol (Nguyen et al., 2009).

Based on assumptions below, the competitions of biomass residues from agriculture, forest products, and wood-based industry can be can be projected for the year 2006-2009, 2011, and 2016, respectively. These projections were summarised in table 4.44a, table 4.44b, and table 4.44c.

i) The current practice of utilizing sugarcane residues in Thailand are as follows: cane residues (mainly tops and leaves) are left in the field or disposed of by open burning. These residues serve as soil enrichments by improving its physical, chemical and biological properties. Molasses is mainly used for ethyl alcohol (ethanol) production. Bagasse is mainly used for cogeneration and for paper, particleboard and MDF production.

ii) Currently, rice straw is mainly disposed by field burning in steps to prepare field for next crop, and the ash is then returned to the soil as an organic fertilizer. To some extent, it is used as field cover to retain soil moisture, as protection from heat, for weed control and to provide humus to the soil. Only 50-52% of rice straw is removed from fields for use as cattle feed and for purposes such as livestock bedding, thatching material for houses or for fuel, leaving little for fibre in the paper industry. Buangsuwon (1990) reports that 50% of straw produced in Thailand is used as animal feed, 30% for the paper industry (as raw material), 10% for other uses, 10% as field wastes, but data for energy route are still not available. However, from the study of DEDE (2003b) 48% of the rice straw that is generated is being burnt in the field. About 30% is unused, 15% is being used as animal feed, 5% is used as organic fertilizer, 1.5% is being traded (sold), 0.18% as fuel, and 0.27% for other activities (Gadde et al., 2007a, 2007b). At this time there is no spatially specific information on the multiple uses of rice straw and therefore, with present information, any estimate of true rice straw availability (accounting for competing uses) would be performed uniformly across the entire country. At current straw yields, over 6.54 M t of straw in excess of that required for conservation purposes are available in the country. With appropriate conversion technologies, this straw could serve as feedstock for energy production.

iii) As solid fuel for combustion process, many countries including Thailand use rice husk to produce electricity through direct combustion in their large rice mills. Koopmans et al. (2000) cite that about 50-70% of the husk is exploited by the rice mills themselves. Apparently, the remaining 30-50 % is not used. Using rice husk as a fuel for paddy drying process within rice mills was given first priority in most rice mills, then the left over husk will then be sold to other users (including filler in the brick industry, domestic fuel for cooking, a bedding material for animals, and fuel in the charcoal production and ethanol production). The actual quantity of the husk distributed into different sectors is barely examined, as there were no available records (Prasara-A, 2009). Due to the biomass energy policy by the state, power generation plants from rice husk increased to 35 plants in 2006 with total capacity about 574 MW, requiring rice husk about 6 M t/y (9,800 t/MW/y). Number of power plant is rapidly increasing, but amount of rice husk is limited (Ngaemngam and Tezuka, 2006). Therefore, excess rice husk at the national level is rather low, however it still has a potential at the local level for small-scale or decentralized power systems. Recently, the cost of rice husk is gradually increasing, so this makes the investment in energy production from rice husk higher than before (Wannapeera et al., 2008; Chungsangunsit et al., 2009).

iv) The use of cassava and its by-products has enjoyed widespread patronage in the nutrition of many livestock species. The production of roots at 20 t/ha implies the production of 40 t of total biomass/ha. Some stems with good stake quality are reserved for new crop propagation and the rest including other biomass is used for fuel and infield fertilizer. However, the present demand of these stems at 31,250 stem/ha can be reduced to 10,000 stem/ha with new farm technology. Major animals were cattle, buffalo, swine and chicken.

v) The high points in favour of cassava leaves as a potential feed resource for man and livestock are its relatively high crude proteins, minerals, and vitamins (Bokanga, 1994). Devendra (1977) had earlier concluded that this cassava byproduct is of low feed value that could probably be included in ration for cattle as it contains about 24% crude fibre and 55-70% nitrogen free extractives (NFE).

vi) For palm oil mills, they use about 90% of generated oil palm fibre producing steam and electricity for utilization in their process, while almost of oil palm shell is sold to other local industries such as the cement industry and the brick industry.

vii) About 40% of generated slaps from rubberwood production is used for rubber wood drying with the simple technology.

viii) Almost of eucalyptus dusk and bark is applied as energy source for pulp and paper industries.

Table 4.44a: The competitions of biomass residues from agriculture, forest products, and wood-based industry for the year 2006-2009

Residues types	**Competitions for Biomass**		
	Quantity	**Other Competitons**	**Remain**
Sugarcane Bagasse	19.102	19.1	0.002
Sugarcane Top & Trash	6.624	1.5	5.124
Rice Straw	9.947	2.188	7.759
Rice Husk	6.670	5.76	0.910
Cassava Stalk	1.858	0.743	1.115
Cassava Rhizome	10.789	-	10.789
Cassava Leave	5.202	5.202	-
Cassava Peel	1.321	-	1.321
Oil Palm Empty bunches	2.371	1.385	0.986
Oil Palm Fiber	1.581	1.423	0.158
Oil Palm Shell	0.499	0.499	-
Oil Palm POME	5.824	5.824	-
Oil Palm Frond	12.999	-	12.999
Oil Palm Male bunches	1.163	-	1.163
Corn Cob	0.984	0.189	0.795
Corn Stove	2.186	0.1	2.086
Jatropha SCR	0.025	-	0.025
Cotton Stalk, Leaves	0.017	-	0.017
Kenaf Stalk, Leaves	0.006	-	0.006
Soybean Stalk, Leaves, Shell	0.334	-	0.334
Sorghum Stalk, Leaves	0.047	-	0.047
Coconut Coir	0.684	0.198	0.486
Coconut Shell	0.302	0.125	0.177
Coconut Bunch	0.093	0.013	0.080
Coconut Frond	0.255	0.041	0.214
Groundnut Shell	0.020	-	0.020

Table 4.44a (continue): The competitions of biomass residues from agriculture, forest products, and wood-based industry for the year 2006-2009

Residues types	**Competitions for Biomass**		
	Quantity	**Other Competitons**	**Remain**
Rubberwood Small Branches	3.495	-	3.495
Rubberwood Stumps	0.978	-	0.978
Rubberwood Tops	0.350	-	0.350
Rubberwood Sawdusks	0.863	-	0.863
Rubberwood Slaps	1.438	0.576	0.862
Eucalyptus Small Branches & leaves	0.232	-	0.232
Eucalyptus Barks	3.000	3.000	-
Fast-Growing Trees Leaves	0.035	-	0.035
Fast-Growing Trees Stem	1.289	-	1.289
Fast-Growing Trees Small branches	0.063	-	0.063
Total	**102.646**	**47.866**	**54.78**

Table 4.44b: The competitions of biomass residues from agriculture, forest products, and wood-based industry for the year 2011

Residues types	**Competitions for Biomass** (policy)			**Competitions for Biomass** (projection)		
	Quantity	**Compet.**	**Remain**	**Quantity**	**Compet.**	**Remain**
Sugarcane Bagasse	20.966	20.591	0.375	20.062	19.868	0.194
Sugarcane Top & Trash	7.370	1.575	5.795	7.052	1.543	5.509
Rice Straw	11.125	2.447	8.678	10.106	2.223	7.883
Rice Husk	7.417	6.059	1.358	6.737	5.787	0.950
Cassava Stalk	2.090	0.836	1.254	2.016	0.806	1.210
Cassava Rhizome	12.817	-	12.817	12.363	-	12.363
Cassava Leave	6.374	6.374	-	6.450	6.450	-
Cassava Peel	1.393	-	1.393	1.344	-	1.344
Oil Palm Empty bunches	4.723	2.749	1.974	2.120	1.239	0.881
Oil Palm Fiber	3.679	3.311	0.368	1.514	1.363	0.151
Oil Palm Shell	1.144	1.144	-	0.495	0.495	-
Oil Palm POME	14.170	14.170	-	5.956	5.956	-
Oil Palm Frond	25.641	-	25.641	15.585	-	15.585
Oil Palm Male bunches	2.297	-	2.297	1.387	-	1.387
Corn Cob	1.026	0.197	0.829	0.955	0.183	0.772
Corn Stove	2.349	0.116	2.233	2.186	0.100	2.086
Jatropha SCR	0.715	-	0.715	0.715	-	0.715
Cotton Stalk, Leaves	0.019	-	0.019	0.019	-	0.019
Kenaf Stalk, Leaves	0.006	-	0.006	0.006	-	0.006
Soybean Stalk, Leaves, Shell	0.337	-	0.337	0.337	-	0.337
Sorghum Stalk, Leaves	0.048	-	0.048	0.048	-	0.048
Coconut Coir	0.687	0.199	0.488	0.687	0.199	0.488
Coconut Shell	0.304	0.126	0.178	0.304	0.126	0.178
Coconut Bunch	0.093	0.013	0.080	0.093	0.013	0.080
Coconut Frond	0.256	0.041	0.215	0.256	0.041	0.215
Groundnut Shell	0.020	-	0.020	0.020	-	0.020
Rubberwood Small Branches	3.495	-	3.495	3.495	-	3.495
Rubberwood Stumps	0.978	-	0.978	0.978	-	0.978
Rubberwood Tops	0.350	-	0.350	0.350	-	0.350
Rubberwood Sawdusks	0.863	-	0.863	0.863	-	0.863
Rubberwood Slaps	1.438	0.576	0.862	1.438	0.576	0.862

Table 4.44b (continue): The competitions of biomass residues from agriculture, forest products, and wood-based industry for the year 2011

Residues types	Competitions for Biomass (policy)			Competitions for Biomass (projection)		
	Quantity	**Compet.**	**Remain**	**Quantity**	**Compet.**	**Remain**
Eucalyptus						
Small Branches & leaves	0.232	-	0.232	0.232	-	0.232
Bark	3.000	3.000	-	3.000	3.000	-
Fast-Growing Trees						
Leaves	0.035	-	0.035	0.035	-	0.035
Stem	1.289	-	1.289	1.289	-	1.289
Small branches	0.063	-	0.063	0.063	-	0.063
Total	**138.809**	**63.524**	**75.285**	**110.556**	**49.968**	**60.588**

Table 4.44c: The competitions of biomass residues from agriculture, forest products, and wood-based industry for the year 2016

Residues types	Competitions for Biomass		
	Quantity	**Other Competitons**	**Remain**
Sugarcane Bagasse	25.334	24.086	1.248
Sugarcane Top & Trash	8.905	1.728	7.177
Rice Straw	11.951	2.629	9.322
Rice Husk	7.967	6.279	1.688
Cassava Stalk	2.753	1.101	1.652
Cassava Rhizome	16.884	-	16.884
Cassava Leave	5.815	5.815	-
Cassava Peel	1.835	-	1.835
Oil Palm Empty bunches	3.327	1.939	1.388
Oil Palm Fiber	2.377	2.139	0.238
Oil Palm Shell	0.776	0.776	-
Oil Palm POME	9.349	9.349	-
Oil Palm Frond	23.777	-	23.777
Oil Palm Male bunches	2.130	-	2.130
Corn Cob	1.053	0.202	0.851
Corn Stove	2.808	0.162	2.646
Jatropha SCR	2.936	-	2.936
Cotton Stalk, Leaves	0.020	-	0.020
Kenaf Stalk, Leaves	0.006	-	0.006
Soybean Stalk, Leaves, Shell	0.354	-	0.354
Sorghum Stalk, Leaves	0.052	-	0.052
Coconut Coir	0.708	0.205	0.503
Coconut Shell	0.313	0.130	0.183
Coconut Bunch	0.096	0.013	0.083
Coconut Frond	0.264	0.042	0.222
Groundnut Shell	0.021	-	0.021
Rubberwood Small Branches	3.495	-	3.495
Rubberwood Stumps	0.978	-	0.978
Rubberwood Tops	0.350	-	0.350
Rubberwood Sawdusks	0.863	-	0.863
Rubberwood Slaps	1.438	0.576	0.862
Eucalyptus Small Branches & leaves	0.232	-	0.232
Eucalyptus Barks	3.000	3.000	-
Fast-Growing Trees Leaves	0.035	-	0.035
Fast-Growing Trees Stem	1.289	-	1.289
Fast-Growing Trees Small branches	0.063	-	0.063
Totoal	**143.554**	**60.172**	**83.382**

4.2.7 Other Problems

In order to use biomass as energy resource, some issues must also be recognized and sought to deal with. In this section, these keystones will be discussed briefly:

4.2.7.1 ***Food Security:*** It is important to mention that developing countries are generally facing both food and fuel problems. The food security has three dimensions, namely: 1) endemic hunger caused by poverty-induced under- and malnutrition; 2) hidden hunger caused by the deficiency of micronutrients like iron, iodine, zinc and vitamin A in the diet; and 3) transient hunger caused by natural calamities or civilian conflicts. Adoption of agricultural practices should, therefore, take into account this reality and evolve efficient methods of utilizing available land and other resources to meet both food and fuel needs (besides other products), e.g., from agro-forestry systems. However, even today the food security challenge is not just increasing production, but providing jobs or livelihoods which can lead to economic access to food, and in achieving needed production increases without further environmental pollution (Swaminathan, 2007).

4.2.7.2 ***Biomass Production Cost:*** To become an important feedstock for energy purposes, all biomass related systems must demonstrate themselves with practical costs. In the case of new crop varieties, seeds amount to 5 to 10% of the plantation cost for an agro-industrialist, but 15 to 20% for a smallholder, who usually invests less in fertilizers, infrastructures, etc, casing lower yield than the potential. Additionally, all agrochemicals required are quantified as materials entering the systems with an associated energy and carbon cost (Thornley et al., 2009). Rising energy costs means that fertilizers are now commonly the highest input cost for farmers. Over-fertilization has not only greatly reduced the economic return and placed a heavy economic burden on the farmers, but it has also resulted in widespread water eutrophication[62] (Zhang, 2007; Blanco-Canqui and Lal, 2009). This problem can be optimised by best management practices (e.g., crop rotations and cover crops) that apply nutrients at the right rate, time, and place (Roberts, 2008; Viator et al., 2008a; Blanco-Canqui and Lal, 2009). Economic efficiency occurs when farm income is maximized from proper use of nutrient inputs, but it is not easily predicted or always achieved because future yield increases, nutrient costs, and crop prices are not known in advance of the growing season (Roberts, 2008). Hauling distance is one of the major barriers to use biomass as an energy source on a commercial scale. The larger the plant and the more diffuse the resource, the greater the impact on cost and embodied energy of transportation (Hong, 2007; Haq and Easterly, 2006).

4.2.7.3 ***Water Competition:*** Water is currently the most limiting resource for crop production, and is recognized as the most critical resource for future agricultural development (Khush, 2001). Efficient management of water resources and investment in their improvement, with regard to both availability and quality, must be realized. A shift towards biomass energy, as promoted to decrease the impact of fossil energy on the climate system, will bring with it a need for substantially more water, which will raise a conflict between ‘water for food’ and ‘water for energy’. Nowadays, the production of biomass for food and fibre in agriculture requires about 86% of the worldwide freshwater use (Hoekstra and

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[62] ***Eutrophication*** is a syndrome of ecosystem responses to human activities that fertilize water bodies with nitrogen (N) and phosphorus (P), often leading to changes in animal and plant populations and degradation of water and habitat quality. Eutrophication generally promotes excessive plant growth and decay, favours simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality (youngester, 2010; Thiyagarajan et al., 2007)

Chapagain, 2007). An increase in demand for food in combination with a shift from fossil energy towards energy from biomass puts additional pressure on freshwater resources (Gerbens-Leenes et al., 2009). Navigating the murky waters between current decisions and future technologies is a major challenge.

4.2.7.4 ***Environmental Degradation:*** biomass residue is needed on site to replenish nutrients and maintain soil productivity. Although crop rotation is more common, residue incorporation significantly increased Soil Organic Carbon (SOC)[63], nitrogen concentrations, and increased crop yields. Lal (2009) concluded that nutrients contained in residues produced in 2001 were about 83% of the global fertilizer consumption. Therefore, residues are still the important sources for plant nourishment. The removal of crop residues for alternative uses accelerates the already fast decline of soil organic matter content in dry land farming (Swaminathan, 2007). For other problems, if additional unit operations that include harvest of biomass increase the number of trips across a field, soil compaction might become a consideration. Besides, food consumption patterns are changing (Gerbens-Leenes and Nonhebel, 2002): globally, a transition is taking place towards more affluent consumption. Especially as the consumption of meat, dairy and beverages increases. This will not only require more land, but also more fresh water. Estimates for 2015 show that total worldwide water needs for food will double, causing further degradation of ecosystems (Rockström et al., 2007). Therefore, biomass production for energy has several unanswered environmental questions that will need to be addressed before full-scale implementation.

4.2.8 Summary

Based on the county's historical yields and different literatures, biomass availability in Thailand is one of the most potential options to fulfil the growing energy demand throughout the country. In this study, changes in future productions were also estimated for the year 2011 and 2016 by applying historical trends and two essential parameters, namely, harvested area and productive yield. The changes in land use are mostly from the state strategy, especially biofuel policies relating to bioethanol and biodiesel, because biofuel requires large volumes of the biomass input. Yield has been the major driver for almost all breeding programmes. The ability to produce more products on the same land area with less input has promoted the success of modern agriculture. Therefore, the plan to increase feedstock supply and effective management can support both emerging and existing downstream industries and diminish the conflict between food/feed vs. fuel security. In the case of yield modifications, there are two possible opportunities considered in this study: recent trend yield enhancement and high yield targets following the nation guidelines, respectively. As the steps toward that direction, moreover, biomass quantity is examined at the county level with the regard to better environment, problem of collection & harvesting, and the conflict for the use of those biomasses. New and more efficient material handling systems would need to be developed to have harvesting capacities comparable to that of a conventional system. Allowing carefully for the retention of the residue to minimize surface runoff and increase the soil fertility status, additionally, good farming practice is chosen in this research. The following five scenarios are summarised and reported in the table 4.45 next page.

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[63] SOC refers to the amount of carbon stored in the soil. It is expressed as a percentage by weight (g C/kg soil). SOC is closely related to the amount of organic matter in the soil (Soil Organic Matter (SOM)), according to the approximation: SOC × 1.72 = SOM (USDA NRCS, 2009)

Table 4.45: Summary of the potential of biomass residues from agriculture and forestry of Thailand for the year 2006-2009, 2011, and 2016

Residues types	**Residue Production (M t/y)**				**HHV (MJ/kg)**	**Energy from Residues (PJ/y)**			
	2006-2009	**2011a**	**2011b**	**2016**		**2006-2009**	**2011a**	**2011b**	**2016**
Sugarcane									
Bagasse	0.002	0.375	0.194	1.248	14.4	0.029	5.400	2.794	17.971
Top & Trash	5.124	5.795	5.509	7.177	17.39	89.106	100.775	95.802	124.808
Rice Straw	7.759	8.678	7.883	9.322	10.24	79.452	88.863	80.722	95.457
Rice Husk	0.910	1.358	0.950	1.688	14.27	12.986	19.379	13.557	24.088
Cassava Stalk	1.115	1.254	1.210	1.652	18.42	20.538	23.099	22.288	30.430
Rhizome	10.789	12.817	12.363	16.884	7.541	81.360	96.653	93.229	127.322
Leave	-	-	-	-	**n.a.**	-	-	-	-
Peel	1.321	1.393	1.344	1.835	1.49	1.968	2.076	2.003	2.734
Oil Palm									
Empty bunches	0.986	1.974	0.881	1.388	17.86	17.610	35.256	15.735	24.790
Fiber	0.158	0.368	0.151	0.238	17.62	2.784	6.484	2.661	4.194
Shell	-	-	-	-	18.46	-	-	-	-
POME	-	-	-	-	**n.a.**	-	-	-	-
Frond	12.999	25.641	15.585	23.777	9.83	127.780	252.051	153.201	233.728
Male bunches	1.163	2.297	1.387	2.130	16.33	18.992	37.510	22.650	34.783
Corn Cob	0.795	0.829	0.772	0.851	11.298	8.982	9.366	8.722	9.615
Corn Stove	2.086	2.233	2.086	2.646	11.704	24.415	26.135	24.415	30.969
Jatropha SCR	0.025	0.715	0.715	2.936	**n.a.**	-	-	-	-
Cotton Stalk, Leaves	0.017	0.019	0.019	0.020	14.49	0.246	0.275	0.275	0.290
Kenaf Stalk, Leaves	0.006	0.006	0.006	0.006	**n.a.**	-	-	-	-
Soybean									
Stalk, Leaves, Shell	0.334	0.337	0.337	0.354	19.44	6.493	6.551	6.551	6.882
Sorghum									
Stalk, Leaves	0.047	0.048	0.048	0.052	19.23	0.904	0.923	0.923	1.000
Coconut Coir	0.486	0.488	0.488	0.503	16.23	7.888	7.920	7.920	8.164
Shell	0.177	0.178	0.178	0.183	17.93	3.174	3.192	3.192	3.281
Bunch	0.080	0.080	0.080	0.083	15.40	1.232	1.232	1.232	1.278
Frond	0.214	0.215	0.215	0.222	16.00	3.424	3.440	3.440	3.552
Groundnut Shell	0.020	0.020	0.020	0.021	12.66	0.253	0.253	0.253	0.266
Rubberwood									
Small Branches	3.495	3.495	3.495	3.495	7.92	27.673	27.673	27.673	27.673
Stumps	0.978	0.978	0.978	0.978	10.365	10.137	10.137	10.137	10.137
Tops	0.350	0.350	0.350	0.350	7.92	2.771	2.771	2.771	2.771
Sawdusks	0.863	0.863	0.863	0.863	10.365	8.945	8.945	8.945	8.945
Slaps	0.862	0.862	0.862	0.862	10.365	8.935	8.935	8.935	8.935
Eucalyptus									
Small Branches & Leaves	0.232	0.232	0.232	0.232	15.56	3.610	3.610	3.610	3.610
Barks	-	-	-	-	6.811	0.000	0.000	0.000	0.000
Fast-Growing Trees									
Leaves	0.035	0.035	0.035	0.035	**n.a.**	-	-	-	-
Stem	1.289	1.289	1.289	1.289	17.99	23.189	23.189	23.189	23.189
Small branches	0.063	0.063	0.063	0.063	14.39	0.907	0.907	0.907	0.907
Total	**54.78**	**75.285**	**60.588**	**83.382**		**595.782**	**812.999**	**647.729**	**871.767**

Remark: 2011a = 2011 (Policy), 2011b = 2011 (Projection)
n.a. = no data available
HHV = High Heating Value
PJ = Peta Joule = 10^{15} J

From table 4.45, the final available biomass is 54.78, 75.285, 60.588, and 83.382 M t for the year 2006-2009, 2011 (Policy), 2011 (Projection), and 2016, respectively, with the regard to the low recovery amount due to a combination of collection equipment limitations, conservation requirement, and non-energy competition. With these biomass quantities, the available energy is equivalent 595.782, 812.999, 647.729, and 871.767 PJ for the year 2006-2009, 2011 (Policy), 2011 (Projection), and 2016, respectively. Therefore, the energy from these biomass residues could be exploited as energy resource to reduce the dependency on fossil fuels of the country. For example, if this excess biomass with the total energy of 595.782 PJ were applied for generating electricity at an efficiency of 25% (achievable at small scales today), the resulting electricity would be equivalent to about 4,723 MW_e or 16.2% the total currently installed power plant in Thailand (about 29,191 MW_e in 2009). The energy from biomass resource should be, therefore, considered as one of priority choices for the ongoing research and developments in alternative energy programmes for Thailand.

4.3 Suitable Technology Selection for Thailand

In this section, an integrated analysis from 4.1 has been done to examine the required technology for power generation in Thailand principally, because the biofuel industry of the country is still at an infant business stage. The commercial technology is also in a development phase, especially for 2nd generation biofuels (see Ch. 3.3.2). Although the application of biomass as a single fuel supply for large power plants (> 50 MW) is currently uncommon or costly, biopower is still striking since it is sustainable with greater potential for environmental (particularly reduction in GHG emissions), economic, and social impacts than most other renewable energy technologies (Thornley et al., 2009). Besides, it is expected that in the future biopower could be possibly generated with more reasonable cost by using advanced technologies and improved feedstock supplies (Hong, 2007). The new technologies should much have better heat rates than that of conventional biomass-fired boilers. It was difficult, however, to precisely choose a power generation system then sequentially to calculate its initial investments and input requirements for operations and maintenance. Therefore, the suitable technology selection is one of the greatest challenges for the successive bioenergy utilisation.

The purpose of the study in this section was to investigate the appropriate technology for generating power from selected agricultural residues in the Central and Northeast Areas of Thailand, respectively. Although electricity can be produced from a variety of biomass resources in those areas, - such as agricultural and forestry residues, dedicated bioenergy crops, biowastes, or other bio-processed gases and liquids -, the use of rice straw and cassava rhizome are primarily considered as an example of alternative feedstock for electricity generation in this research thanks mainly to their highly potential and under utilisation. Because development of biopower projects is not easy task, this example tries to facilitate the better guidelines/practices during the complex planning and consultative process for other bioenergy projects to guarantee that the forthcoming bioenergy industry would continue its feasible potential to minimise the environmental impacts, to bring about a well community, and to ensure an energy security for the country as a whole.

4.3.1 Biopower Technology Selection Criteria analysis

A development of the biopower project is in some ways more of an “art” than a science. In several specific sites, a few days of expert study is enough to determine whether or not the site has the potential to implement a biopower project. In cases where the investment options are immediately attractive, a feasibility study can be conducted straight away, whereas in complex cases for which the feasibility is doubtful, a pre-feasibility study is usually needed. Although technology selection is one of the most complicated steps in biopower project development, it greatly colours the success or failure of the project. As a result, in this section, all criteria for technology selection are calculated according to the analysis technique suggested in 4.1, the Fuzzy TOPSIS method (see Ch. 4.1.6). These criteria will be applied in the technology selection for devoted biomass in the next topic (Ch. 4.3.2 and 4.3.3).

The first step of the Fuzzy TOPSIS Method is to justify what the criteria in technology selection are, then calculate their global weight for employment in the next steps of the procedure. Therefore, the criteria for set up biomass power plant were initially reviewed from various literatures to investigate the past successes and failures of biomass power plant in both local and abroad context. The related criteria was classified and monitored by project experts to inform the direction and detail of project selection. The elected criteria are prepared for making a questionnaire, the most widely used data collection technique, when the opinions from research participants are requested with the same set of questions depending on the aim and objectives of the research. De Vaus (1995) suggested that it is important to get the understanding of the analysis schemes before developing a questionnaire because generated data can not be analysed in the last step.

To start the criteria analysis, the questionnaires were distributed to the preferred biomass power plant (both VSPPs and SPPs, see Ch. 1.3) in September 2009 providing the desirable data. The next step is to collect the data from the returned questionnaires. The final stage is to examine data collated from the second stages. Table 4.46 below shows the main criteria and their sub-criteria for set up the biomass power plant project in Thailand comprehensively. Their global weight was also calculated following the Fuzzy TOPSIS method.

Table 4.46: Main Criteria and Sub-Criteria for biopower plant set up in Thailand

Main Criteria	Sub Criteria	Remark
Monetary Criteria (M)	Investment Costs (M1) Operation Costs (M2) Maintenance Costs (M3) Project Life Time (M4) Process Efficiency (M5) Fuel Costs (M6) Savage Value (M7)	
Technical Related Criteria (T)	Technology Strength/ Reliability (T1) Availability of Needed Technology (T2) Feedstock Supply & Technology Reliability (T3) Flexibility of Feedstock (T4) Flexibility of Production (T5) Flexibility of Scale Up (T6) Plant Site Requirement (T7) Visibility of Project (T8)	

Table 4.46 (continue): Main Criteria and Sub-Criteria for biopower plant set up in Thailand

Main Criteria	Sub Criteria	Remark
Environmental Impact Criteria (E)	Airborne Emission (E1) Fresh Water & Waste Water Treatment (E2) Noise (E3) Ash & Solid Discharge (E4)	
Community Impact Criteria (C)	Public Perception (C1) Labor Availability/Training (C2) Strengthen Rural Development (C3)	
Risk Related Criteria (R)	Management Risk (R1) Policy/Legislation Risk (R2) Feedstock Supply Risk (R3) Financial Risk (R4)	
Policy Related Criteria (P)	Contribution to Nation’s goals (P1) Improve Technology Know-how (P2) Social Educational Impact (P3) National Equipment Supply (P4)	

Discussion of the survey results: Based on the information from the replied questionnaires including relevant literature reviews, the criteria analysis for biomass power plant project in table 4.47 shows that the environmental impact- and community impact-criteria are the most important factors rather than monetary or technical criteria like in other technology selections. This is a result from the recently distorted situation of power plant practices in Thailand. The highly concern about environmental problems comes not only from the project cognisance and state regulation (see also Ch. 4.3.4.3), but also indirectly from local intensive audit (see the beginning of Ch. 4.4). However, public acceptance has also played an important component in power plant development in other countries. Thus, public opinion, perception and satisfaction are often the key motivating factor for successful acceptance of the set up of a new power plant (Choi and Lee, 1995; Bureekul, 2000; Huang et al., 2009).

Table 4.47: Local weight of main criteria for biopower plant set up in Thailand from Thai and European point of view

Main Criteria	Local weight for the Multi Criteria Decision Making	
	Thailand	EU
Monetary Criteria (M)	0.077	0.240
Technical Related Criteria (T)	0.134	0.164
Environmental Impact Criteria (E)	0.237	0.136
Community Impact Criteria (C)	0.270	0.112
Policy Related Criteria (P)	0.219	0.197
Risk Related Criteria (R)	0.062	0.151

4.3.2 Biopower from Rice Straw

From the previous data (see Ch. 4.2.8), if rice straw in the year 2016 (see table 4.45) is applied through the direct combustion route, the theoretical electricity generation potential annually would be about 757 MW_e (assuming that the overall conversion efficiency is around 25%). Therefore, rice straw can provide 3-4% of total power demand about 18,200 MW_e according to the Nation Power Development Plan 2007 (see Ch. 1.3), and reduce the CO_2 emission by 0.58% when compared to the total CO_2 emissions of 192.6 M t for Thailand in the year 2002 (APEC, 2006) following the study of Siemers (2008)[64]. Due to its bulkiness, rice straw is normally costly to harvest, store, and transport, therefore this limit restricts its amount that can be collected in any one place. Rice straw can be, however, stored for 1 year without any severe deterioration (Matsumura et al., 2005), but the large area is required to stock up. Because the central part of Thailand (see Ch. 1.1.2 and Ch. 2.2.2.2) is known as the nation's "rice bowl", this region is selected to evaluate and examine biopower generation by utilising rice straw. Another reason, why it must be this region, could be the projected economic and population growth in the central part which will substantially increase the future electricity and energy demand in this area. Development of an economic approach to convert this straw to energy will require an assessment of the regional distribution of available straw to identify an appropriate scale of conversion technology that optimally reduces straw collection and transportation costs.

The energy content of rice straw (see Ch. 4.2.5.2) is relatively low, around 14 MJ/kg, and the MC of rice straw is available at around 10% (EEF, 2007). Rice straw is not specifically grown for energy usage, therefore its challenges for power generation are: 1) high ash content (10-17%) compared with that of wheat straw (around 3%) (Zevenhoven, 2000); 2) troublesome inorganic elements (K, Cl), though it has a lower total alkali content (Na_2O and K_2O typically comprise <15% of total ash) relating to that (>25%) of wheat straw (see also Ch. 4.3.4.1) (Baxter et al., 1996); and 3) need to densify the balls for optimal logistics. Although six different energy conversion technologies (see Ch. 3) seem to be applicable for rice straw in principle including - direct combustion heating/power generation (Ch. 3.2.1.2), co-firing (Ch. 3.2.3.1.4), gasification and power generation (gas engine, steam turbine, fuel cell) (Ch. 3.2.1.3), gasification and methanol production (Ch. 3.3.2.3), flash pyrolysis (Ch. 3.3.3.1), and acid hydrolysis then ethanol fermentation (Ch. 3.3.2.4) -, only direct combustion and co-firing power generation are now commercialised while the other technologies are at different stages of development (Matsumura et al., 2005). In turn, MC should be <10% for combustion technology (Grade et al., 2008). Rice straw can be fed to the burners in bulk when a fluidised bed (FB) is used, but it has to be pulverized or gasified before feeding to the boilers (Ch. 3.2.3.1.2, Ch. 3.2.3.1.3, Ch. 3.2.4.1.1, and Ch. 3.2.4.1.2) (Matsumura et al., 2005). Co-firing in existing ones is far less expensive than building a new biomass power plant (Hong, 2007). For gasification, it had an operational problem and limited durability due to corrosive constituents found in the reactor (Banowetz et al., 2008).

For combustion technology, a grate stoker has been widely used for a long time due to lower cost for investment and operation, especially for capacity 5-15 MW_e, with local manufacturers and maintenance companies available in Thailand (Grade et al., 2008). Suspension fired stoker (Ch. 3.2.3.1.1) provides better efficiencies of 80-90%, can possible

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[64] Siemers (2010) stated that if rice straw is used for electricity generation, a net GHG emission saving could be 180 kg of CO_2-eq per MWh.

partial load operation[65], and has a lower cost for capacity over 20 MW_e. The FB offers higher heat transfer, but a lower combustion temperature compared to those of stoker boilers, contributing lower NO_x formation and boiler slagging. Besides, the FB is suitable for larger capacity (>100 MW_e) thanks to higher flexibility towards feedstock types, fuel sizes, and MCs, but it is difficult to control with partial load operation (Foster Wheeler, 2004). Biomass gasification has higher thermal efficiency than that of direct combustion. It could be implemented for small capacity power plant, but requires a gas engine for power generation. It accepts MC up to 40% for fixed bed updraft, 30% for fixed bed downdraft, and 50% for FB gasifier (Ch. 3.2.1.3), but it requires tar and ash removal for maintenance. Although the gasification technology shows more promise than combustion technology, it is still at early stages in the market and has not been fully implemented at large scale. For anaerobic digestion (Ch. 3.3.2), it is a well-proven technology for producing biogas from various agricultural wastes with low maintenance and not so complicated. By this process, straw is digested together with other biomass types, commonly animal manure as substrate. This technology is suitable for rice straw in small-scale (about 2 MW_e) with short transportation distance.

Because the power plant scale has an effect on both technology selection and projects successful, 4-6 MW_e is the optimum choice for rice straw case study since it captures various additional benefits:

1) With this range, there are about 19 provinces (totally 262-364 MW_e) from total 26 provinces where the density of rice straw output is high enough for set up a standalone power plant (Suramaythangkoor and Gheewala, 2008).

2) Although in some regions (6 provinces, totally 163-225 MW_e) their sole power plant capacity can up to 20 MW_e, collecting and transporting rice straw will be an issue (Suramaythangkoor and Gheewala, 2008);

3) By a decentralised policy[66], this capacity range is generally a better solution than adding larger power plants in. Electricity demand in Thailand is also seasonal, with a 20% higher in summertime than average all the year due to more air condition use in this season. To combat with that peak demand, a number of decentralised power plants with moderate capacity are the most benign option;

4) For power plants with capacity <10 MW_e in Thailand, they do not need conducting an Environment Impact Assessment (EIA) and a Health Impact Assessment (HIA) by law;

5) The by-products (fly and bottom ash with highly silica), which have an economic value and could be used in cement or brick manufacturing, construction of roads, and embankments, is easier and has more potential for collecting than that of a smaller capacity (Grade et al., 2008); and

6) Finally, there are various conversion technologies in this range, therefore it is proper to explain how to choose the suitable one and to boost a new knowledge learning of the country.

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[65] Partial load operation is the operation of systems and components under conditions below full load. Due to the complexity of such an optimisation task, conventional optimisation methods consider only one operation point that is usually the full-load case. However, the frequent changes in demand lead to operation in several partial-load conditions (Jüdes et al., 2007).

[66] In short, the advantages of decentralised power plant are increasing both with reliability and stability of the national electrical system, reducing the amount of energy lost in transmitting lines because the electricity is generated very near to where it is used, and motivating/growing the local and state economy (Patterson, 1997).

The selected technologies to deal with rice straw in this example are: 1) travelling grate stoker (Ch. 3.2.2.1.2); 2) vibrating stoker (Ch. 3.2.2.1.2); 3) suspension fired stoker (Ch. 3.2.3.1.1); 4) pressurised FB (PFB) (Ch. 3.2.4.1.1); 5) a low temperature circulating FB (LT-CFB) (Ch. 3.2.3.1.2); and 6) the Biomass Integrated Gasification Combined Cycle (BIGCC) (Ch. 3.2.4.1.6), which is still in its development stage, but it promises high efficiency (exceeding 40%) for 6-8 MW_e. Owing to the nature of the technology (especially in developing stage ones), unavailability of sufficient pertinent data must be estimated the current uses by several analytical tools and techniques, thus these selected technologies can be compared with each other by the suggested method from 4.1.

The results from selected technology analysis for rice straw power plant using the Fuzzy TOPSIS method are shown in table 4.48 below. The evaluation of the suitable technology for rice straw is realized and according to the C^+ values (see also Ch. 4.1.8.3) the ranking of the selected technologies are LT-CFB combustor > Suspension fired stoker > Pressurised FB combustor > Vibrating stoker > Travelling grate stoker from most preferable to least. If the best one is needed to be selected, then the LT-CFB combustor must be chosen because of having the highest C^+ value.

Table 4.48: Final evaluation of the selected technologies for power production from rice straw

Technology	S^+	**Rank**	S^-	**Rank**	C^+	**Rank**
travelling grate stoker	0.4317	5	0.0136	5	0.031	5
vibrating stoker	0.4079	4	0.1089	4	0.211	4
suspension fired stoker	0.3667	2	0.2025	2	0.356	2
pressurised FB combustor	0.3676	3	0.1421	3	0.279	3
LT-CFB combustor	0.1109	1	0.4156	1	0.789	1
BIGCC	0.4402	6	0.0124	6	0.027	6

4.3.3 Biopower from Cassava Rhizome

Cassava (see also Ch. 4.2.6.3 and Ch. 2.2.4) is considered one of the best raw materials for ethanol production thanks to it’s low production cost resulting from small energy and effort requirements for its growing and harvesting. In the past, the cassava business in Thailand is typically driven by export, but the nation bioethanol programme may push enormously the future demand of cassava fresh tubers. The field residues, cassava stem and cassava rhizome, are currently interesting as one of the promising feedstocks for power generation, since they are available in large quantity throughout the Northeast region (Ch. 2.2.4.2) and are effective sources of feedstock for a gasifier, a reactor for producing syngas from gasification process (see Ch. 3.2.1.2). This syngas can be fuelled to drive an Internal Combustion Engine (ICE) or a gas turbine to generate electricity (it is usually considered that the gasification power unit under 500kW_e belongs to the small-scale, above 5MW_e is for the large-scale, and between 500kW_e to 5MW_e fits in the middle-scale (GOC/WB/GEF, 2008). Burning or left in the field are, however, commonly practices for cassava rhizome in many parts of the country, therefore power generation from cassava rhizome can reduce pollution from burning and facilitate energy for the local community.

From many references, cassava rhizome offers a tremendous potential for power generation, but its optimal conversion technology is still under investigation. Since sources of cassava rhizome are normally scattered, longer feedstock supply distances to facilitate a larger capacity power plant (> 1 MW_e) could lead to drastically higher supply cost making its developing project approval unattractive. Therefore, using cassava rhizome in local area with small power generation capacity (about 500 kW_e) is more appropriate. With this size, it is also regarded as a one choice promoting the decentralised power programme of the country to reduce unequal access into grid-quality electricity services, especially in remote area. When the capacity of power plant is less than 1 MW_e, gasification is a highly efficient technology whereas the other technologies are not available due to requirement of steam turbine generators. Thus, gasification is the only choice among the observed technologies. Furthermore, small-scale gasifier can be modified to provide an inexpensive source of energy for household cooking purposes, syngas, displacing the traditional fuel wood. To utilise generated syngas from crop residues, it will reduce firewood gathering time (normally done by woman in the rural areas) and improve family living conditions and health through sanitation and cleaner air.

Because cassava rhizomes are tolerably resistant to burning and their shapes are far from uniform, the size reduction process is necessary before it can be used as a fuel source for any thermo-chemical conversion process. Cassava rhizome must be chopped to a suitable size, then is fed to a stoker-fired or fluidised combustor. If heat is the only product required, combustion seems to be preferable. The main thermo-chemical characteristics of cassava stalk and rhizome are summarised in table 4.49. The MC of cassava rhizome in Thailand is about 60%. The volatile matter and fixed carbon contents of cassava rhizome are similar to those of wood, while the ash contents are comparable to that of straw (4-6%), but higher than that of wood (approximately 1%). The high ash contents imply the high alkali metal contents in the biomass like rice straw (see Ch. 4.3.2). Gasification produces a higher yield than combustion with respect to electricity production for low power plants (50 kW_e to 1 MW_e) with internal combustion engines. The vast majorities of small biomass gasifiers considered in this study are: 1) updraft fixed bed gasfier (UFB) (Ch. 3.2.2.1.3); 2) downdraft fixed bed gasfier (DFB) (Ch. 3.2.2.1.3); and 3) atmospheric circulating fluidised bed (ACFB) (Ch. 3.2.3.1.3).

Table 4.49: The thermo-chemical characteristics of cassava stalk and cassava rhizome

	Cassava stalk	**Cassava rhizome**
Proximate Analysis (wt %, dry basis)		
Volatile matter	79.90	77.75
Fixed carbon	14.09	18.20
Ash	6.01	4.05
Moisture	15.54	8.31
Ultimate Analysis (wt %, dry-ash free basis)		
Carbon	51.12	51.59
Hydrogen	6.87	6.69
Nitrogen	0.67	1.27
Oxygen	41.34	40.45
Sulphur	< 0.1	< 0.1
Molecular Formula	$CH_{1.6}O_{0.61}$	$CH_{1.54}O_{0.59}$
Heating Value (MJ/kg, dry basis)		
HHV	17.58	23.67
LHV	17.99	18.47

Source: Pattiya et al. (2009)

The results from selected technology analysis of small power plant from cassava rhizome using the Fuzzy TOPSIS method are shown in table 4.50 next page. According to table 4.50, the ranking order of the selected technologies for cassava rhizome are DFB gasifier > UFB gasifier > ACFB gasifier, thus the best technology for small power plant from cassava rhizome is the DFB gasifier.

Table 4.50: Final evaluation of the selected technologies for power production from cassava rhizome

Technology	S^+	Rank	S^-	Rank	C^+	Rank
UFB gasifier	0.2282	2	0.1985	2	0.465	2
DFB gasifier	0.2108	1	0.2385	1	0.531	1
ACFB gasifier	0.2380	3	0.1875	3	0.441	3

4.3.4 Other Problems

In order to successfully develop power plant projects by using biomass as an energy resource, some barriers that slow down or halt the task progress must also be identified. In this topic, their problems will be discussed briefly:

4.3.4.1 ***Technical Problems***: remove troublesome components in feedstock prior feeding to conversion systems can be met by ***leaching*** method. For rice straw, slagging and fouling could be reduced by keeping the operating temperature under 760 °C, whereas grate sintering could be controlled by mixing with other low alkali fuels (to dilute them). Temperatures higher than 760 °C could also result in the formation of chlorinated organic compounds and NO_x. Besides, the tar content can be minimised by separating pyrolysis and gasification zones as in two-stage gasifier.

Although this problem cannot be avoided completely, its adverse effects can be mitigated through controlled boiler temperature and special coating on the super-heater surface. In addition, as mentioned earlier, alkali and alkaline compounds are leached when straw is exposed to precipitation in the field. This improves feedstock quality by increasing the melting temperature of ash (Jenkins et al., 1998).

4.3.4.2 ***Project Problems***: Although a majority of the new retrofit for biomass power plants has been comprehended, the integration of these systems into new construction projects should be carefully considered in these topics:

- Construction contractor; Although several suppliers claim to be the best in the market, in fact only few have mastered the technology and it remains a great challenge for customers to identify the right suppliers.
- Operation costs; costs of electricity generation from biomass vary widely because of the variety of biomass sources, conversion technologies and logistics associated with different biomass fuel chains. Nevertheless, some indication of costs, relative importance of different stages of the fuel chain and cost reduction potentials can be provided for different fuel chain types.
- Investment cost overruns; even if project feasible is carefully studies, for the successful operation of power plants throughout their lifetime, enough attention and finance should be given over for their maintenance too.
- Interest rate risk; this difficulty occurs from the earnings or market value of a portfolio due to uncertain future interest rates.

- Cash flow risk; if available bills are not suddenly sufficient to meet its financial obligations, it will severely affect credit rating of the company.
- Management performance; to ensure that all activities of biomass power plant is consistently being met in an effective manner and a defined solution have a full understanding of the root causing of their current problems. The performance of all stakeholders should be monitored and evaluated.

4.3.4.3 ***Environmental Constraints***: With the increase of biomass utilisation for generating heat and power, the ash (10% of dry mass) from the conversion facility is becoming more significant in land disposal topics to minimise any negative impacts and applications to receive more special benefits. Fly ash from co-firing of biomass/coal is acceptable to be used as cement additive; however, fly ash from mixing of many types of biomass could negatively impact concrete properties (Loo and Koppejan, 2002). Ash quality from conversion processes should be recycled back to the fields being key step of nutrient management. In industrialised countries, where the biomass may contain significant levels of inorganic pollutants (heavy metals), there may be restrictions on the quantities of ash that can be utilised in this way. There are a number of other potential beneficial usages (Pels et al., 2005):

- The utilisation of bottom ashes from grate-fired and FB combustors as road construction or landscaping materials;
- The use of fly ashes as a component of cement blends and mortars; and
- The application of fly ashes as a component of lightweight aggregates.

Apart from the ash restraints, the biomass power plant commonly consumes the huge amount of water from a river or an irrigate source by the mechanic cooling system. This water is also used for agriculture. Besides, micro-organisms, young plants, fish larvae and juveniles are not strong enough to maintain in the water flow occurring at cooling water intakes as well as heated water effluents. Therefore, local inhabitants are concerned about the destruction to aquatic life and the ecosystem caused by the power plant cooling systems that could directly affect to their livelihoods (Chesoh et al., 2004).

4.3.4.4 ***Business competitiveness***: Because the biopower market is a subset of the power market, competition in this business is also a critical factor. Most of existing biomass power plants presently can not compete with fossil fuelled options, if its economic benefits from decentralised nature and environmental benefits are not taken into account. In Thailand, the tariff of biopower is also in the same situation. However, an efficient input/fuel procurement stage is suggested for the biopower industry to become more competitive. Choosing a proper location for a power plant will minimise the feedstock hauling costs (Hong, 2007). Modern pretreatment technology now available can also substantially improve the technical and financial performances of a bioenergy option. In any case, a well designed biomass storage is required. Biomass will absorb moisture from surrounding in the case of poor storage condition. It may naturally biodegrade in storage through a number of mechanisms, particularly if not absolutely dry. This will lead to loss of energy content and potentially the formation of moulds. However, growing experience with modern biomass technologies suggests that technology push policies need to be substituted or augmented by market pull policies.

4.3.5 Summary

This main section evaluates the appropriate technology for sustainable power production from biomass and its contribution to the potential of generated bioelectricity for Thailand. Although the combustion technology using biomass is well established in most Asian countries, modern technology with high efficiency and commercial potential is being viewed with interest to boost their renewable energy programme raising energy self-reliance of the country. At present, biomass conversion technologies for energy in Thailand are ranked from indigenous-tradition to imported-modern technology, but old technology with low efficiency are still extensively utilised, especially in rural areas and some factories. Hence, there are enormous gaps for promoting the efficient and most promising biomass technology, particularly Combined Heat and Power (CHP) process, to replace the old one (Suwannakhanthi, 2004). Wide demonstration of new technologies and their system coalitions with intensive research should be encouraged. To achieve this goal, two possible kinds of under utilised residues for technology selecting demonstration, namely cassava rhizome and rice straw, are chosen for the investigation of small- and middle-scale standalone power plant set up, respectively.

***Via** the Fuzzy TOPSIS Method* (see Ch. 4.1.7), The LT-CFB combustor is the best option for 4-6 MW_e rice straw power plant and the DFB gasifier is the compromising technology for <1 MW_e local cassava rhizome power plant. Both technologies and their systems are yet improved to deal with various types to biomass feedstock. Although the utilisation of rice straw in stand-alone power plant seems presently inapt, the electricity from rice straw would also result in a savings of about 1-1.8 billion m^3 of natural gas, which is about 4-7% of the total amount required for the 18,200 MW_e in the Power Development Plan 2007. Since straw collecting cost is the major portion of total power generation cost (~60%), complete mechanisation of the harvesting process must be attained. For instance, the harvesting machines of wheat straw have been developed maturely and its bundle machine can finish collecting, compressing, binding, and stowing sequentially. The feasibility study to utilise rice straw for generating electricity, the high efficient balers should be developed locally to reduce the baling cost below 11 Euro/t instead of importing machines (Jirakhakul et al., 2009).

The use of cassava rhizome as a source of energy is very interesting too, since the greatness of national ethanol programme from cassava is adopted. Furthermore, small-scale biomass power plant system is decidedly expected to fulfill the great market potential for distributed electricity policy. The gasification is chosen because it is suitable for small-scale power plant and has a lower temperature process than that of direct combustion technology. Moreover, gasifiers can have longer lifetimes and lower maintenance costs than combustion appliances, such as wood-fired boilers. Likewise, air emissions are generally lower with gasification, since nitrogen and sulphur oxides are generally created at higher temperatures. The selection and application of gasifiers, feedstock preparation and handling equipment, gas clean up technologies, and other ancillary equipment were investigated for power generation from cassava rhizome in Thailand.

4.4 Discussion

To reduce dependency on commercial energy imports (currently accounting for more than 10% of GDP) and strengthen its energy security, Thailand is currently in the process of shifting gradually to sustainable energy sources. The renewable energy utilisation is set at 8% of total energy demand in the 10th National Economic and Social Development Board (NESDB) plan (2007-2011). Therefore, the Thai government has ambitiously endeavoured to promote power generation from alternative energy. Comparing to all varieties of renewable energy, biomass offers the best near term opportunity for supplying a significant portion of the need for electricity since the excess amount of agricultural residues about 41 M t, equivalent to around 426 PJ, was unused. The development of biopower is, therefore, one of the top agendas under the current National Energy Policy and Strategy and the Power Development Plant of the country combating with the future peak power demand. Besides, biomass conversion efficiencies greater than 35% can be achieved with current state-of-the-art bioelectricity technology. However, as technology-importing nation with only 0.26% of GDP in research investment, technology availability and the know how for Thailand is also one of the business weak points (Wonglimpiyarat, 2010).

Apart from technology challenge, a lack of community support has also been a terrific barrier existing in Thailand (Wüstenhagen et al., 2007). The experience from power projects in the past is a factor influencing socio-political and community acceptance for a new project increasingly. The local publics close to project sites have generally believed that the power plant, especially coal-fired type, creating many severe environmental and health hazards in their settlement. These misperceptions about power plants for most Thai communities have caused a big hindrance against biopower projects. Many of them faced anticipated disapproval, if the locals believed that they avoided conducting the EIA and the HIA by declaring the production output under the legal limit of 10 MW_e, or the public hearing with an open invitation was not applied in their project proposal. These arguments advocate the main criteria analysis in 4.3.1, why the environmental criteria has the top score for selecting technology analysis.

The measures supporting biopower framework is, therefore, required to deal with above problems aiming to succeed the promoting renewable energy utilisation of the country. These measures can be summarised below (Bauen et al., 2004):

1) Promote the development and demonstration of advanced conversion technologies and sustainable energy plantations;

2) Stimulate the market uptake of technically proven and commercial bioelectricity chains, as well as the development of a feedstock supply infrastructure;

3) Encourage the development of industry wide good practice guidelines and standards for different stages of the fuel chain, as well as their implementation; and

4) Raise public awareness about bioelectricity.

4.4.1 Feasible conversion technology survey for biopower generation in Thailand

The development and commercialisation of biopower projects generally face many challenges due to the complex link between technology adoption and economies of scale (Uddin et al., 2010; Gan, 2007). However, it is expected that the unit investment cost could be lower for the new technologies when they are mature and their market broadly implement, therefore the electricity bill can consequently be lowered. Though commercial use of under utilised biomass, such as rice straw and sugarcane trash, for generating electricity is still not found in Thailand, preliminary technology evaluation could be conducted based on current biomass technology researches or demonstrations in the country or other high potential countries. The new scientific knowledge and technical innovations have been seeking for an economical option to handle the difficulties of existing bioenergy conversion with environmental benign. Table 4.51 next page shows the new various conversion technologies under demonstration for such feedstock types in Thailand from several countries.

Table 4.51: Examples of current demonstrating technologies for producing energy from biomass

Conversion Technology	Feedstock	Product(s)
gasification/existing boiler	energy cane	electricity sugar
gasification/co-firing	switchgrass, wood residues	electricity
fast pyrolysis/combustion turbine	sorghum, switchgrass, block locust, silver maple, cottonwood	electricity biocrude charcoal
direct combustion/steam cycle	sugarcane, energy cane, napier grass	electricity sugar
co-firing	willow	electricity
co-firing/gasification combined cycle	alfalfa	electricity animal feed
gasification combined cycle/ co-gen/ ethanol process	pine	electricity ethanol
combustion/fermentation / SSF ethanol process	elephant grass, sugarcane, eucalyptus, leucaena	ethanol electricity
SSF ethanol process/ gasification/ existing boiler	sugarcane, bagasse, eucalyptus, alfalfa, corn, and sorghum	ethanol electricity animal feed sugar
existing boiler	sorghum, kenaf, poplar, willow, eucalyptus	ethanol, electricity, compost
BIGCC – based technologies	bagasse	electricity and heat
large combustion furnaces, boilers, and superheat concepts	rice straw	electricity
CHP technology	cereal straw	electricity and heat
twin gasification facilities	MSW, sawage sludge, or waste (plastic)	electricity and heat
biochemical process	corn cob, corn fiber	biofuel
biochemical-concentrated acid hydrolysis	sorted MSW	biofuel

Although the modern research have speeded up the generation of knowledge and led to the creation of new scientific areas and disciplines, several technologies still need the break-through solutions, such as technologies for:

1) suitable pretreatment of biomass;
2) control ash-slagging and anti-corroding in biomass;
3) combustible biogas and coal in co-combustion;
4) new boiler with anti-alkaline-corroding; and
5) equipment with efficient and stable operation with minimum cost.

Apart from power generation, however, biomass utilisation in industrial boilers is more competitive and flexible with two alternatives: 1) installing new biomass boiler instead of heavy oil fired- or natural gas- boiler in case of the new ones; and 2) fuel switching from coal to biomass for existing boilers, but they need some modifications before handle with the selected biomass.

4.4.2 New technology set up

An adoption of advanced bioenergy technologies should be assured with financial and technical assistance during the penetration step into energy business to confirm their success and to create the reliability from all stakeholders. A target-oriented investment subsidy scheme should be effectively established for this purpose. For other challenges, availability of human resources with appropriate knowledge is also waiting to resolve. Currently, there is almost no research results available in the topics of skilled labour development and management for bioenergy production with new technologies. However, biomass-based electricity production, because of relatively high initial investment and the use of locally produced feedstocks, tends to have a greater ripple impact on local income than power generation using fossil fuels (Gan and Smith, 2007).

To investigate perception, satisfaction and participation of nearby communities toward the power plant developing site in Thailand, participation model is required for the clear guidelines in all stages based on (Chesoh, 2010):

1) freedom, ability, and willingness;
2) two-way communication;
3) transparency; and
4) co-management practice.

Although biofuel production has no technology selecting example in this chapter since its business is still in an infant stage, the first generation biofuel (bioethanol and biodiesel) is already in the market. Bioethanol has successfully penetrated through the market before biodiesel thanks to its feedstock supply readiness. Conversion of under utilised fibrous biomass to biofuel via the second generation technology is a more sustainable system because human food or animal feed is not needed, therefore the competition between energy and food/feed production is absolutely alleviated. If excess agricultural residues are used, adding value to the crop production system takes/ensures more profit for the grower.

4.4.3 Under utilised biomass management

Some power plant developers in Thailand have tried to exploit untouched biomass such as the use of rice straw for electricity generation in the past, but they gave up because these biomass types generally have higher price than that of agro-industrial residues that are easily available (Suramaythangkoor and Gheewala, 2010). With soaring utilising rate as present, the agro-industrial residues will be scarce in the future, then under utilised agricultural leftovers will be more economical choices. Apart from seasonal constrains, however, these biomass sources quite have a relatively high alkaline metal content, and are also rich in chlorine/silica (Nelson, 2001). This nature of biomass brings other severe problems to power generation such as slagging and fouling, which make this biomass only a less attractive investment alternative (Hong, 2007). The operating cost of biomass power plant will depend chiefly on the year-round biomass supply and cost, size and type of fuel handling, storage techniques (if necessary), chosen process (etc. traditional combustion, selected gasifier, or anaerobic digestion), equipment sources (indigenous or import duties), and waste disposal costs. The local availability and cost of biomass sources are, therefore, principal factors in determining the feasibility of biopower project at a specific site.

Avoiding untouched residues from improper open burning or land dumping is also the major motivation for the effort to use them in power plant, whereas energy is the secondary objective. To arouse the growers away from burning the crop residues in their field, some effective policies and regulations are needed to expedite the transition of these residues into bioenergy feedstock. From political point of view, when these measures in place, governments should enforce environmental regulations on open-field residue burning and convince the post harvesting mechanisations in both number and efficiency of machinery. For instance, since the central region of Thailand can produce 2-3 crops annually and the ready-to-use baling machines are already applied, this area has the highest potential and readiness for development of post harvesting management.

The most noticeable impact on untouched residues is probably the job creation (see also Ch. 5.6.2). Biomass can be used as a decentralised energy source where conversion plants are located close to their source. This would lead to stabilisation of employment in rural areas and regional development. Procurement of these residues logging would directly add the new jobs to the cultivated are throughout the country. For instance, the energy business from logging residues add the new 260 jobs to the logging industry in the 43 counties, with an additional 300 jobs created in other sectors due to the indirect and induced impacts (see also Ch. 5.6.2) (Gan and Smith, 2007). In the EU, one report claims that 4,900 jobs are created for each GW of biomass power (Ghani-Eneland, 2009). Further, the study by Heintz et al. (2009) showed that 17.36 jobs can be created per $1 M of investment, compared to 5.3 jobs for fossil fuels. The most affected other sectors would include agriculture and forestry supporting activities, industrial truck manufacturing and services, wholesale trade, and food services, among others (Gan and Smith, 2007).

4.5 Conclusion

The amount of biomass that can be sustainably removed from agricultural and forest lands for energy purpose in Thailand is currently about 54.78 M t annually. This quantity can be increased to 1.1-fold and 1.5-fold or nearly 60.59 and 83.38 M t in 2011 to 2016 through a combination of technology changes (e.g., higher crop yields and improved residue collection technology) and increase in harvested area. The effect of crop technology investment responding to the need of food and energy would result in improved productivity over time. Higher yield agriculture can provide larger quantities of biomass that can be used for energy and lower the demand for land. In the case of Thailand, yield of some crops still lag well behind world averages, therefore there is still room for improvements and are presently in an investigation phase. As both environmentally sound and producer friendly, soil and water conservation benefits must be included in biomass assessments to prevent long-term environmental damage, since the nation addresses short-term energy problems. Regardless of the specific residue removal practice chosen, fields should be monitored for visual signs of erosion or crusting, driven by a need to reduce erosion, to maintain soil structure and nutrients, to build soil carbon levels, and to get agriculture adopted sounder environmental and conservation practices.

Under mature first generation biofuel technology, bioethanol and biodiesel industries have expected to grow significantly and their supply could increase substantially in the future under the state mandate in order to reduce petroleum import and enhance energy security. The potential of power generation from biomass is also remarkable, especially the crop residues from state biofuel programme. Thailand has normally had numerous biomass from not only agricultural leftover and agro-industry residues, but also forest management and wood-based industry. Rice husks and bagasse have been the main feedstock; however potential of other biomass (e.g., rice straw, sugarcane trash, cassava rhizomes, or emptied palm bunches) still exists. The technologies to generate power from wood are generally mature because many boiler suppliers have mastered it, but most of those for agricultural residues still face the challenges. To deal with Thai eagerness in biomass for energy programme, therefore, **what efforts should be invested to ensure that technology innovative also response to both social expectations and the challenges posed by the socio-economic and cultural developments.**

Two examples of suitable technology selection for selected biomass are conducted to this study by applying a ***M**ulti **C**riteria **D**ecision **M**aking* procedure, *the Fuzzy TOPSIS Method*. Cassava rhizome and rice straw are chosen as the alternative feedstocks for two scale biopower plants, <1 MW_e and 4-6 MW_e, for this research thanks mainly to their highly potential and under utilisation. From six technologies for 4-6 MW_e biomass power plant (travelling grate stoker, vibrating stoker, suspension fired stoker, PFB combustor, LT-CFB combustor, and BIGCC), the LT-CFB combustor is the best option for rice straw feedstock. For cassava rhizome, the various types of gasifier are investigated since below 1 MW_e only gasification with the ICEs is only one conversion technology of choice. The results showed that among three gasifier alternatives (UFB, DFB, and ACFB), the DFB gasifier is the compromising technology. These examples can be applied to other untouched crop residues such as sugarcane trash, corn cob, corn stove, or cassava stalk, etc.

Though there is a huge potential for biopower generation in Thailand, some hindrances must be considered carefully, such as higher generation cost and some of the technology limitation due to biomass nature. This is in line with a suggestion by McCarl et al. (2000) that biopower are not very competitive without research innovations or subsidies. At present, for example, electricity production cost of biomass are relatively high compared to that of coal, however the feed-in tariff applied as in Thailand could compensate the higher biomass cost in the case of power projects. Besides, an environmental study conducted in Thailand shows that the generation of electric power causes more pollutions than any other single industry in the country, accounting for more than 60% of the CO_2 emitted into the atmosphere each year. At a national level, a reduction of CO_2 emissions by about 4.5% and 2.3% compared to that of the year 2002 is also a main target of the state according to the Tokyo Protocol (see also Ch. 5.3.1). Despite the high fuel prices ~~as~~ presently, if this plan is endowed with an income from a significant potential to reduce GHGs emission by biomass energy following the Clean Development Mechanism (CDM) (see Ch. 5.3.1) and a possibility of decentralised power plant benefits, - typically in the long term -, the biomass power plant will be more competitive with the other commercial power plants.

Chapter 5: The prospect for biomass energy generation in Thailand

Because of its limitation in indigenous energy resources and its fast growing energy-intensive economy, ensuring the security[67] of energy supply is, therefore, one of the major challenges for Thailand. As a heavily energy imports country (see Ch. 1.2), the future economic prosperity is dependent on the provision of adequate energy. Since 1932, the main focus of Thai energy policies has been to reduce the country's dependence on energy imports (Chaivongvilan et al., 2007). However, wide price fluctuations and the threat of inevitable exhaustion of fossil fuels currently stimulate Thailand to seek other alternative energy sources urgently in order to sustain its economic growth. Despite a long-term effort, unfortunately, renewable energy sources and more energy efficiency improvements are not yet utilized nearly to their potential (see table 5.1). Widespread diffusion of renewables has been usually hampered by the cost competitiveness of renewables with other energy sources, high initial capital costs, and the limitation of available renewable resources. In the case of bioenergy, moreover, many questions about its utilization are still suspicious such as:

- Does Thailand have a comparative advantage in biomass-based energy development?
- What are the various constraints likely to impede translating potential benefits into reality?
- What are the main concerns from a policy framework viewpoint to regulate bioenergy?

Most of these questions will be further focused on to find the answers in this chapter.

Table 5.1: Potential and utilization - Biomass in Asian.

Country	**Biomass**	
	Potential	**Utilization**
Brunei	-	-
Cambodia	Technical ~700MW	-
Indonesia	Technical ~49,810MW	312MW
Lao PDR	-	-
Malaysia	Technical ~29,000MW	211MW
Philippines	Commercial ~20MW	-
Singapore	Wood waste	220MW
Thailand	Technical ~7000MW	560MW
Vietnam	Technical ~400MW	50MW

Source: Lidula et al. (2007)

5.1 Situation of energy market in Thailand

Nowadays, energy is a very interested issue in the Thai society, because it is a one of factors that play central role in the life and welfare of human beings. Developing the energy market is quite a relatively new energy policy goal in Thailand. After the liberalization of energy markets, new investment decisions have been made by energy companies based on the market situation. In this first section, therefore, energy market in the country will be

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[67] Energy security is defined as: 1) a reliable supply and economic stability where the countries could reduce dependence on fossil energy sources; 2) an uninterrupted supply of energy sufficient to meet the needs of the economy at the same time, coming at a reasonable price; and 3) the availability of a regular supply of energy at an affordable price (IEA, 2007c; WEF, 2006; EC, 2000).

monitored its circumstance, competition between sources of energy, future supply/demand balance, environmental impact, and the necessary energy infrastructures.

5.1.1 Trends of energy market in Thailand

For Thailand, the energy demands are expected to increase by approximately 4.5% per year over the next decade. According to NEPO (1999), if Thailand's current energy trends do not change (in the business-as-usual scenario) in the years to come, the primary energy demand in the year 2025 would be 186,659 KTOE, as compared to 85,189 KTOE in 2005 (Chaivongvilan et al., 2007). Because the population growth rate in Thailand decreased from 0.93% in the year 2000 to 0.66% in the year 2007, it is assessed that the future energy demand will increase mainly due to the expansion of intensive energy manufacturing, road transport, and urban development. Therefore, it still has a large room for energy market in Thailand. The energy system in Thailand can be categorized into two major industries, namely, electricity and petroleum. These two industries will be discussed in their details respectively below:

Electricity; for the past decade, rapid economic development in Thailand has resulted in the exponential growth of electricity demand, especially in load center regions (urban areas and Industrial estates). Owing to the resulting levels of urbanization, increased income, and improved standards of living, large amount of electricity utilizations are found mainly in manufacturing and commerce sector (see Ch. 1.x), Moreover, electricity may be more consumed increasingly in the future, because larger parts of different services are provided electronically via Internet and mobile technologies. At present, about 70% of the total electricity generation in Thailand comes from natural gas, followed by lignite (20%), hydropower (7%), fuel oil (3%), and biomass, respectively (Watcharejyothin and Shrestha, 2009). Due to high reliance on natural gas, this makes Thailand's energy security position very weak and dependent on others, because about 30% of total natural gas consumption is met by imports from neighboring economies, like Myanmar (see Ch. 1.2.1). Therefore, security of energy supply and diversification of energy resources are the prime strategies of Thai electricity plan. IPPs, SPPs, and VPSSs[68] power purchase schemes represent a part of effort of drawing the involvement of private participants in power generation (see Ch. 1.3) (Chompoo-inwai et al., 2009). Investment requirements in electricity generation are considerable, because capacity is expected increasingly to about 950 GW in 2030. The expansion of electricity generation capacity, transmission, including oil and natural gas import infrastructure would require total investment of US$168-211 billion by 2030 (Chaivongvilan et al., 2007). Thanks to efficiency gains derived from technological progress, fuel switching, and completion of the internal market, electricity prices are also forecasted to decrease (Capros and Mantzos, 2006).

It would not be an overstatement to say that Thailand's plans and programs in sustainable energy development are probably more advanced than those of many other Asian countries, particularly in the areas of energy efficiency and green electricity production from new renewable energy sources (including solar, wind, small and mini-hydro, and biomass) (Todoc, 2004; Yan and Lin 2009). The government targets to increase the share of renewable energy in the generation mix from 19.8% in 2001 to 20.81% in 2006 and 21.21% in 2010 (Todoc, 2004). Moreover, in 2006 under the Thai Ministry of Energy, Energy Planning and

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[68] The VSPP program was amended to include cogeneration facilities and sale from a facility of up to 10 MW while sale of 10-90 MW would come under the SPP program (see also Ch. 1.3).

Policy Office (EPPO) commissioned a study to estimate the quantity of commercially viable new Combined Heat and Power (CHP) in 817 existing factories and 966 existing commercial buildings located in areas that will be served by planned Thai natural gas pipeline expansion. The study concluded that commercially viable CHP new potential capacity is about 3300 MW. Another trend that affects electricity production is repowering, which means the replacement of older, smaller turbines with fewer, larger turbines representing the state of the art in power production.

Petroleum for transportation: Petroleum products account for half of the total final energy consumption in Thailand. Almost all energy used by the transport sector derives from petroleum products which represent 72% of the total petroleum product consumption. 76% of transport energy is consumed by the road sector only. With little fuel diversification, the security of Thai energy supplies is highly vulnerable by possible future supply constraints or rapid price increases of fossil fuels (World Band and NESDB, 2009). The Thai government has introduced several strategies to reduce energy consumption in transportation sector and to make use of maximum available indigenous resources in energy supply, including alternative fuels (Pichalai, 2005). Several alternatives available such as natural gas, ethanol, palm diesel, or Liquefied Petroleum Gas (LPG) are appraised their capability for the market. Natural gas vehicles[69] (NGVs) are less energy efficient, but - thanks to the low price of natural gas in Thailand - the overall operation cost is much lower and compensates for the higher initial equipment cost. NGVs could reduce the vapor money for the imported fuel in the transportation sector, even if the gas has to be imported. LPG is commonly used as a fuel for cooking in most Thai households, therefore its shortage or soaring price has a large impact on Thai society. Subsidies have been in place for years for household’s LPG. The demand for LPG in Thailand has sharply risen recently; however, especially in the transportation and industrial sectors due to soaring prices of other forms of energy. At present, to prevent a shortage of LPG nationwide, The Ministry of Energy has decided to maintain retail price of LPG for household use, but float the price as fuel for transportation and industrial sectors (see also Ch. 1.2.1).

Biofuels can be produced at both the large scale (limited by local feedstock resource availability) and small scale (limited by maintaining fuel quality standards and higher costs) businesses. It would be a huge benefit for Thailand to introduce biofuel to the public, especially in transportation sector. As the first generation biofuels, gasohol and biodiesel industries are carefully monitored. Initially subsidized by the government, the ethanol industry for gasohol blending is now able to stand on its own feet. It is expected that in the near future the biodiesel industry will also become competitive with the classical diesel fuel. Because diesel accounts for more than 50% of transport fuel in Thailand, the road map is to develop raw materials and replace 5% of the total diesel consumption in the transport sector with bio-diesel by 2011 and increase it up to 10% by 2012. The plan is, therefore, to increase the use of bio-diesel from 365 million liters in 2007 to 3100 million liters by 2012 (Gonsalves, 2006). It is anticipated that by 2020 the substitution of gasoline and diesel by biofuels, natural gas, and LPG would increase from 8.1% during the first half of 2008 (equivalent to 5.8 million litres of crude oil) to 29% (equivalent to 34 million litres of crude oil) by 2020. The second generation biofuel is not yet established in Thailand, but in International Energy Outlook 2006, the US Energy Information Administration predicted the share of nonconventional oil in world oil consumption as 9.7 % in 2030, including synthetic fuels from natural gas (GtL), coal (CtL) and biomass (BtL), whereas the IEA predicts a share

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[69] To utilize natural gas as fuel in transport section, auto engines must be modified. The cost for a modified NGV vehicle is about 7000 US$ (In the case of a modified LPG about 5000 US$ less) (Gonsalves, 2006).

of 8.9 % in 2030 of nonconventional oil in its World Energy Outlook 2005, with synthetic fuels providing 22.5 % of nonconventional oil.

For sustainable energy development in transport section, as a policy option, pricing fuels on the basis of their long-run marginal costs is expected to have a significant and sustained effect on the improvement in transport energy efficiency in Thailand. However, recognizing the political difficulties in implementing a comprehensive fuel pricing policy in the short to medium term, the study also examined 16 other policy and technology options. These are grouped into the following five categories (World Band and NESDB, 2009):

1) **Fuel efficiency and fuel switching:** upgrade engine technologies for buses and trucks, and use natural gas selectively in vehicle fleets, especially for commercial vehicles;

2) **Better vehicle standards:** establish and (progressively) tighten fuel economy standards of passenger vehicles to match European standards, and improve logistics practices in the road-based freight transport sector to better match truck sizes to the task and operating environment; and

3) **Rail investment and reform:** reform and modernize the rail sector, expand the role of rail in freight transport and long-distance passenger services; and in the Bangkok Metropolitan Region (BMR), expand Mass Rail Transit (MRT) as well as improve its integration with bus services, also improve accessibility and walk ability to bus stops or mass rapid transit stations.

5.1.2 Evaluation of biomass energy market in Thailand

Thailand's longer-term ambitious target in the National Alternative Energy Development Plan adopted in March 2009 was to increase the share of renewable energy, including biomass energy, in final energy consumption from 8% by 2011 to 20% by 2022, comparing with 0.5% in 2002 (PRET, 2006a, b). In Thailand, biomass represents a significant energy generating potential, in particular in co-generation (CHP). As of January 2003, the total installed CHP-based electric generating capacity in Thailand was 3.6 GW, which accounted for 7.8% of the total installed power capacity in the country. 15% of installed CHP-based electric generating capacity was based on biomass (Bhattacharya and Salam, 2006). Currently under development and implementation, biopower projects are mostly in sugar mills, palm oil mills, rice mills, and wood-processing factories. There are also SPPs using renewable energy sources for their primary business to sell either electricity to the national grid, or heat/power to other off-takers (Carlos and Khang, 2007). However, there are still limitations, especially in terms of reliable sources, efficiency, and cost of investment. Biomass might not be commercially viable yet due to unreliable sources of fuel (e.g. rice husks), and other associated impacts (e.g. local opposition to set up new power plant nearby, long distance for transporting fuel to the plant). When a power plant is not adequate placement, it leads to more environmental and social impacts, e.g. higher traffic risks from carrying biomass for long distance, more use of energy in transportation, etc (Probe international, 2005). Social problems and local conflicts are becoming significant in future power plant development. New policies from the government should be enhanced giving serious consideration to the social problems and local involvement in the planning process (Probe international, 2005).

Thailand, with its abundant agricultural and forest resources, is well positioned to effectively deploy biofuels – ethanol and biodiesel – to meet its energy needs. The Thai Government has formulated a two-phase gasohol (gasoline-ethanol blend) programme :

- In Phase 1 (2004-2006), in addition to the three ethanol plants currently operating, three others are scheduled to come on-stream by the end of 2006, and this will increase the production capacity to 1.155 million litres/day.
- For Phase 2 (2007-2012), the Government awarded licences to 18 new biodiesel plants, and this will bring the total installed capacity to 3 million litres/day by 2012. Of the 18 new plants in Phase 2, 14 will use molasses as feedstock and the remaining four will be cassava-based.

Thailand's gasoline demand is estimated to be 30 million litres/day by 2012, and so there will be sufficient ethanol for blending in E10 gasohol (10% ethanol in gasoline) to meet the entire national daily demand (27 million litres of regular gasoline plus 3 million litres of ethanol). By 2012, the 91 octane regular gasoline will be replaced by E10 gasohol, which has an octane rating of 95. The Government is providing the necessary infrastructure for ethanol blending and gasohol distribution (Gonsalves, 2006).

The biodiesel industry is in its infancy in Thailand but is poised for rapid growth. Diesel consumption is currently (based on reference year 2006) at 50 million litres/day and is expected to rise to 85 million litres/day by 2012. The Government plans to have an installed biodiesel production capacity of 8.5 million litres/day by 2012 so that B10 blend (10% biodiesel in diesel) can meet the national diesel requirements. A key element of the Government’s strategic plan for biodiesel is plantation development for the vegetable oil crops to be used as feedstock – palm oil and Jatropha (see Ch. 1.4.4, 2.2.3, and 2.2.5.1). The Government plans to develop palm plantations totally 4 million Rai (0.64 million hectares), which will yield 4.8 million litres/day of biodiesel by actual refining technology. In addition, palm plantations covering 1 million Rai (0.16 million ha) in area will be developed in a neighbouring country, most likely Malaysia, and this will lead to an additional biodiesel production capacity of 1.2 million litres/day. Finally, the Government plans to cultivate more palm and Jatropha on other marginal lands for the rest of 2.5 million litres/day, as a result of which the total daily biodiesel production will be as already mentioned before 8.5 million litres by 2012 (Gonsalves, 2006).

Since Thai energy plan sets out targets for industry and transport, as well as equipment and appliance standards, these new targets stipulate biomass energy market in the country in both the production of biofuel (ethanol/biodiesel) and bioelectricity.Thailand has devised specific biomass resource base initiatives, such as for example, Thailand’s aggressive targets for biomass-based energy systems and its bio-fuels strategy for the transportation sector. As of November 2010, there are 17 bioethanol (2.73 million litres/day) and 14 biodiesel operational plants (5.95 million litres/day) in Thailand. Bioethanol industry faces a different set of challenges, while gasohol consumption is expected to increase with greater public acceptance of gasohol compatible vehicles, many ethanol plants have been forced to suspend operations due to surplus supply and rising input costs. On the other hand, biodiesel from oil palm confronts a problem of lacking raw material and high input cost (Morgera et al., 2009). For bioelectricity, policy measures are biased towards energy systems with relatively large-scale but suitably low electricity generating costs (Prasertsan and Sajjakulnukit, 2006). Electricity generation from biomass is not competitive with other fossil fuel generated electricity due to its high capital cost (Abraham, 2009; Santisirisonboon et al., 2001), although biomass has been set as a prime target for renewable electricity among the different renewable energy sources for electricity generation.

5.1.3 The business opportunities of biomass in Thai energy sector

The cumulative investments in energy supply infrastructure will be mainly carried out in developing countries and the largest investments will be in power sector (production, transmission and distribution) (IEA, 2008). Prior to the 2006 state coup and 2008-2010 financial recession, Thailand's electricity demand was expected to quadruple in the next two decades, driven by the manufacturing and service sectors. It is difficult to gauge how much these two events will impact this prediction, but it is reasonable to expect significant growth in electricity demand in Thailand's near future (Somboonpakron, 2009). If the country will continue to import more coal and gas[70] to serve that further energy demand, it is expected that the country will expend more money for this due to higher fuel cost in the future. As it is conceivable that the situation of high oil prices will continue in the foreseeable future, Gonsalves (2006) argue that the vulnerabilities for Thailand from gas dependence and fuel import reliance increase considerably. Moreover, the concentration of gas wealth naturally raises questions of security of supply, of transit, of the potential implementation by an organization of gas exporting countries (OGEC), and of assets nationalization strategies. To address these issues, consuming countries will increasingly respond by diversifying supplies (WEC, 2007). Power generation from natural gas is competitive with today's prices in many areas of the world, but total generation costs are more sensitive to increases in fuel prices in the case of natural gas combined cycle (NGCC) (see Ch. 3.2.4.1.6), than in plants using other generation technologies, because fuel costs account for 60–75 % of total generation costs. This means that, comparable increases in different fuel prices for electricity generation would have a greater impact on the economics of NGCC than on other technologies, such as gas turbine power plant.

Although addition of coal and nuclear power plants tends to offer the lower cost of power generation and a number of additional capacities based on these technologies would be able to reduce vulnerability issues, these choices must be considered carefully. Due to social contest by environmental problem with coal power plant in the past, when Thailand is planning to increase electricity generation from coal-fired power plants, it would have to rely on coal import (see also Ch. 1.3). For coal import option, it must consider the coal market in the future worldwide. Coal demand is expected to grow intensively by 2030, mainly due to the increase in electricity production and consumption in China and India. Coal share of the energy supply is projected to grow globally from 25 to 28% (IEA, 2007d). Moreover, promoting coal candidate seriously increases the environmental emission in the country, which adds to the nation concern of global warming[71]. Nuclear power plants could be one of the possible solutions to reduce environmental emission while offering least cost of electricity. Therefore, nuclear option should be considered in the long-term planning of electric capacity expansion in Thailand, but the development of nuclear power project requires extensive and thorough analyses on various relevant issues, including nuclear safety, radioactive waste management, legislation governing use of atomic energy in the country, high project costs, etc. In Thailand, nuclear plant can also face similar public opposition, thereby reducing the diversification options for supplying electricity.

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[70] Currently all natural gas utilized in the economy is met by domestic production, however, production is projected to decline from a peak of 26.6 M toe in 2010 to 16.5 M toe in 2030 (USAID, 2007).

[71] Global warming is one of the most serious challenges facing us today. Warnings from the scientific community are becoming louder, as an increasing body of science points to rising dangers from the ongoing buildup of human-related GHGs, produced mainly by the burning of fossil fuels and forests.

For other alternative energy options, although solar energy is the most prominent renewable energy source due to the appropriated geographic of Thailand, it is still considered as a low-density energy source which requires a large area of installation, permanent maintenance and very high investment cost but relatively low efficiency (Adhikari et al., 2008). In addition, the study from many literatures indicates that for the low-medium wind speed profile, at the studied-time, 1 MW or bigger turbine unit is preferable because it gives a better Capacitor Factor (CF). Therefore, a large wind farm[72] will give a better return of investment for the case of Thailand (Chompoo-inwai et al., 2009). However, this situation also requires higher initial investment cost and almost all stakeholders in energy market agreed upon a fact that Thailand has a very low wind potential as the wind speed is very low and not permanent. Summarily, the problems with wind and solar based technologies are as follows (Adhikari et al., 2008): 1) high investment cost of the technologies; 2) lack of energy subsidies; 3) administrative bureaucracy; 4) lack of transparent decision-making process; 5) state ownership of enterprises; 6) regulatory regime; and 7) quality control problems. In case of hydro-power, most of the resources (dams) have already been harnessed and there is not much room for further expansion except small hydro (see Ch. 1.X.X), so it is ranks as low potential technology. Therefore, the most current compromise choice for Thailand is energy from biomass. Moreover, this conclusion is agreed with the study from Mulugetta et al. (2007) that - by 2022 - the share of natural gas drops to about 66%, while coal increases its share to just under 23%, and biomass entering the picture as an important contributor to overall electricity generation in the BAU scenario. Besides, if social and environmental costs (externalities) associated with the use of fossil fuels are included in the final cost of electricity, then biomass in the GF scenario instantly becomes competitive (more details in Ch. 5.3.1).

Alternatives for transport fuel: Rapid expansion of natural gas infrastructures is required to support natural gas based engines of vehicles. In the medium term the problem will be how to divert the supply of natural gas from the power generation sector to the transport sector as other more economical fuels exist for the power generation. Moreover, natural gas for vehicles still remains a problem as long as the market is unable to raise domestic retail price to reflect the true cost. For gasohol and biodiesel, their retail prices are still not competitive with petroleum fuels without subsidies by the state. For the consumer, using E10 gasohol is a little cheaper than the baseline gasoline vehicle, but this very small price advantage repays with the lower energy content of gasohol. When the risk of higher maintenance costs is included, the calculation indicates that the gasohol option is not attractive for the gasohol consumer. In the case of biodiesel, the price of raw materials is not controllable[73]. A major factor in the push to increase production of biofuels is to contribute to domestic consumption as a substitute for imported petroleum. However, if there is a growing expectation that Thailand may emerge as a regional exporter of biofuels within Asia. The major challenge of using dedicated energy crops, especially in Thailand, is the competition of land use for food. The other important concern is the loss of biodiversity. Concerning about

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[72] Denmark and Germany are known for harnessing the wind power to produce electricity on a large scale. In Denmark, a political agreement settled in February 2008 states the goal to reduce the dependence on fossil fuels and the overall energy consumption, but increase the share of renewable energy. In a normal wind year, Danish wind turbines generate the equivalent of around 20% of the Danish electricity demand. In the report “Wind energy - The case of Denmark” September 2009, the Danish think tank CEPOS claims 1) that most of the Danish wind power has been exported in recent years, and 2) that wind turbines in Denmark are very costly to Danish taxpayers and electricity consumers (Lund et al., 2010).

[73] Some dry land crops such as *Jatropha* or *Euphorbia* (see Ch. 2.2.5.1) could be suitable for arid conditions, but energy yields per hectare are likely to be relatively low, thereby requiring strong subvention and variable harvesting costs (IEA, 2007b).

food security[74], land availability depends on the size of the population, diet, and in particular on the productivity and intensification of the agricultural sector (IEA, 2010). If no agricultural land can be made available for a supplementary biomass production for the energy purpose, then agricultural and forestry residues still continue the main source for bioenergy production. If these residues will be by far not enough for the proposed program, the second generation of biofuel should be more focused on how to use these residues for the biofuel production (IEA, 2010; Morgera et al., 2009).

5.2 Thai energy policy overview

Currently, a global paradigm shift has occurred from renewable energy technologies to a renewable energy market (Martinot et al., 2002). This must be supported by the promotion of policy frameworks and the enhancement of institutional settings. In industrialized nations, the penetration of renewable energy has received momentum from policy measures and support mechanisms through governmental intervention and subsidies (Sims, 2004). Thailand has also adopted the support policies for bioenergy to meet the nation’s future energy demand, therefore in this main section the policy and institutional settings relevant to bioenergy in Thailand will be discussed.

5.2.1 General energy policy of renewable energy in Thailand

Energy Policy: Thai energy sector is governed by several legislative arrangements, policy measures and programmes, based on the Energy Conservation and Promotion Act of 1992. The Act promotes energy conservation, the use of renewables and related activities, and established the Energy Conservation and Promotion Programme (ENCON). Subsequently implemented in 1994, The ENCON programme has been instrumental in promoting renewable energy including bioenergy in Thailand, emphasizing voluntary activities for renewable energy, and rural industries such as biogas for power generation from livestock wastes in small and medium firms, biogas digesters, and landfill gas pilot projects (CEERD, 2000). Besides, this programme also mandated guidelines, criteria, conditions, and priorities set for allocations to the Energy Conservation Fund. Other policy measures in favor of renewables include: the scheme of independent and small power producers[75] (IPPs and SPPs) mentioned above; pricing policy; tax reduction; support for renewables; and environmental requirements (Sajjakulnuki et al., 2002).The EPPO provides financial incentives - in the form of tax exemption, financial subsidies, low interest rate and guaranteed power price - to those who adopt or implement renewable projects. Additionally, the Thai Government also promoted special investment privileges through the Board of Investment, such as favorable tax and duty exemptions and loans, and land ownership rights for foreign investors (Morgera et al., 2009). Latest, the 2003 Energy Strategy for Thailand’s Competitiveness outlined the specific targets for the share of renewable energy in final energy consumption of 8% in 2011 and 10% by 2020 moving from 0.5% in 2002 (PRET, 2006a, b). Unfortunately, there is a lack of focus on policy measures towards small-scale and higher cost renewable electricity generation technologies (Uddin et al., 2010).

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[74] Food security means ensuring that all people at all times have access to the food they need for a healthy, active life (see also Ch. 4.2.6) (Hicks A., 2007).

[75] The Thai Government also plans to increase electricity generation from renewables by 2011 to about 2,400 MW (including both stand-alone and grid connected plants) (see also Ch. 1.3) by enforcing a new policy, the Renewable Portfolio Standard (RPS) (TEENET, 2004).

Environmental policy: In a broader environmental context, the Thai Government has stepped up emphasis on environmental regulation and enforcement. This was particularly a focus of the 7th National Economic and Social Development Plan (1992-1996) (Uddin et al., 2006). Other environmental regulations that support clean energy include: the National Ambient Air Quality Standard 1995; the National Environmental Quality Act 1992; the Factory Act 1992; and the Hazardous Substances Act 1992 (CEERD, 2000; MNRE, 2000). In order to oversee the National Environmental Quality Act of 1992, the Government established the National Environmental Board and the Environment Fund. Aside from these environmental mechanisms, EGAT has also committed to a number of environmental responsibilities, including increasing the environmental performance of power projects and renewable sources for rural electrification (CEERD, 2000; TEENET, 2004). During the 4 year period (2000–2004), however, Thailand's CO_2 emissions increased by about 27% to 146 million tonnes of CO_2 emitted in 2000 (MOE, 2004). This was mainly due to increased emissions from the transportation sector and rapid industrialization. According to recent projections, this upward trend of CO_2 emissions could lead to a four-fold increase by 2020 (Karki et al., 2005). For another study, Thailand's total CO_2 emissions from the energy sector are projected to increase from 193 million tonnes of CO_2 in 2002 to 734 million tonnes of CO_2 in 2030. The electricity sector will be the major contributor accounting for 40% of total CO_2 emissions in 2030, or 294 million tonnes CO_2.

Institutional setting: Thailand's energy sector is currently undergoing restructuring and privatization following a privatization master plan, approved in 1998. The plan calls for the introduction of wholesale and retail competition, establishment of a power pool, and privatization of utilities in order to lower government debt and increase efficiency. The National Energy Policy Council (NEPC), established in 1992 under the Cabinet, manages the energy sector in Thailand. Before recent bureaucratic reorganization, energy was handled in the Thai Government by some 20 agencies across 9 ministries. Because this dispersion hindered overall performance, the Ministry of Energy was finally formed in 2002 (MOE, 2005). The EPPO and Department of Alternative Energy Development and Efficiency (DEDE) under the Ministry of Energy became the sole government agencies responsible for renewable energy. The EPPO performs planning, analysis and strategy development, including broader socio-economic analysis and evaluation of the implementation of the national energy policy. The DEDE oversees the national policy on energy efficiency, water and renewables. Renewable energy centres (RECs) under the DEDE demonstrate and promote renewables in rural communities (DEDE, 2003a). The EGAT, a state enterprise, is responsible for electricity generation, transmission, and distribution, including power from renewables. The Ministry of Natural Resources and Environment (MONRE), through its Office of Natural Resources and Environment Policy and Planning (ONEP), acts as designated national authority (DNA) to the United Nations Framework Convention on Climate Change (UNFCCC), and is responsible for the approval of projects to reduce the greenhouse gas emission (GHG), including renewables under the Clean Development Mechanism (CDM) of the Kyoto Protocol (Uddin et al., 2006) (see also Ch. 5.3.1).

5.2.2 Outline of biomass energy policy in Thailand

The Thai Government has defined short- and medium-term strategies for the energy sector. For electricity, Power development in the country is currently becoming an important issue for three reasons (Watcharejyothin and Shrestha, 2009):

1) an opposition to fossil fuels for power generation has stemmed from environmental concerns;

2) requirement to diversify the fuel used in power generation; and

3) nuclear energy usage is further away but comprehensive plans could soon be announced.

According to the Power Development Plan (PDP 2007), during the year 2007-2021, the Thai Government plans to have the most economic power generation resources yet reliable and low environmental impact. To achieve those goals, there are three strategic plans which are (Chompoo-inwai et al., 2009):

- to import power from neighboring country[76],
- to promote the renewable power generation from the public power companies, and
- to have a variety on power generations resources.

The projected energy capacity expansion is expected to increase by more than 25,000 MW within approximately a decade, leading to an installed capacity of 52,829 MW in 2019 - up from 27,788 MW in 2007 (EGAT, 2007). In the PDP, this capacity expansion is, however, expected to be covered by domestic and imported natural gas, nuclear power, and coal imports. According to this plan, the share of renewable energy is also expected to increase in coming years, but still play an ineffective role. For a nuclear choice, Thailand has set goals of a functioning nuclear energy program by 2020. It is planning a 2,000 MW power plant (2 reactors of 1,000 MW each) for operation in 2020 and one more a 2,000 MW power plant by 2021. With its present political situation, this goal may not be achievable in the timeline prescribed (Somboonpakron, 2009).

To provide proper incentives for developers in renewable energy projects, the Thai Government policies on renewable energy including biomass energy should focus on promoting (Carlos and Khang, 2007):

1) accessibility to the grid and distributed generation;
2) off-grid options and increased electricity access in remote areas; and
3) general activities that include financial incentives, industry standards, education and information dissemination, and stakeholder involvement.

With the right policy mix and more effort on all types of alternative energy, the worst case is that Thailand should achieve the targets stipulated in the latest PDP: to raise the share of alternative energy in electricity generation from 6.5% in 2008 to 16.6% in 2015 and eventually 37.3% by 2021. This will also reduce the GHG from the power generation sector from 2018 then. In addition, energy efficiency obtained by means of the ENCON-Fund is expected to assist in lowering the total energy demand (Holm, 2009). This is therefore opening for biomass, because a lot of incentives, especially in terms of price, have been provided to biomass developers or investors.

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[76] The ASEAN 2020 Vision, adopted in 1997 by the heads of state at the 2nd ASEAN Informal summit, envisioned an energy-interconnected South-east Asia through the ASEAN Power Grid and the Trans-ASEAN Gas Pipeline Projects. These ventures call for regional cooperation in power pooling and maximizing efficient use of energy resources. Thailand is a strong supporter of the Power Grid project in ASEAN, especially the construction of hydro-electric dams in Myanmar and Laos (Chaivongvilan et al., 2007).

Some analyses estimate that biomass for energy purposes has a potential of 7,000 MW in Thailand (EPPO, 2003); this can cover more than 25% of the exiting installed power capacity. These estimations are primarily made based on the biomass wastes coming from the surplus agricultural residues left behind harvesting process, and from large scale of industrial crop processing etc., as for instance rice, sugar, and palm oil mills. These do not include biomass wastes from other types of Thai manufactures, nor cogeneration facilities by SPP who are allowed to sell power to the grid under long term contracts again. To date, SPPs still not meet their cost effective, but many investors plan to set up their business because of the policy from the Government to promote SPPs. To make more profit, some SPPs can sale the process steam to other industries nearby, therefore those industries should be encouraged to utilize both electricity and process steam from these SPPs when appropriate (Probe international, 2005). Although renewable energy being proposed in the new VSPPs is more diverse, future potential of other biomass still exists, such as corn cob, rice straw, sugarcane leaves, cassava rhizome and emptied palm bunches. A study is now being undertaken on the effective collection system and management of these types of biomass scattered in the fields. In addition, biogas generation from industrial wastewater is becoming very popular as industrial operators have realized that it is better than the former wastewater treatment system, both in terms of environmental impact and economic effectiveness as the energy is obtained as a very valuable by-product.

To support biofuel policies, the Thai Government is promoting the production of both liquid (bioethanol and biodiesel) and solid biofuel (from biomass). Currently, cassava and molasses feedstock are the main feedstock for bioethanol industry, (see Ch. 1.4.2), but palm oil is the only crop used as raw material for biodiesel production (see Ch. 1.4.4). The rapid rise in both gasohol and biodiesel consumption during the past years is just the beginning. It still requires consistent and comprehensive policy strategies. Various constraints must also be acknowledged, taken into account and resolved, such as: technical capability of old cars in using gasohol, the possibility to introduce E85 (blend of 15% gasoline and 85% ethanol) to the market, the speed of expansion of palm oil production. The ambitious to succeed in E85 like Brazil will take more than a decade, because it require not only a significant increase in crop yield or a development in second generation ethanol, but also the ability to manufacture indigenous vehicles equipped with E85 compatible engines. Government will provide higher tax incentives to automobile manufacturers for E85 vehicles. It could charge at lower taxes than that for E20 vehicles (currently 25%) and regular vehicles (30-50%). The Government also plans to push compulsory biodiesel production up from B2 to B5 across the country by 2011. A mandate of B5 is expected to reach a goal by 2011, but for B10 it still require a substantial increase in both palm yield and planted area. To achieve the plan, the Government should provide low interest loans for the participation of oil palm farmers. The Government is now adjusting its campaign by promoting palm plantation on non-rubber areas in the North and Northeast of Thailand.

5.3 Key drivers in biomass energy production in Thailand

Wonglimpiyarat (2010) concluded that bio-based energy is seen as the next new wave for future businesses and one of the solutions to the problem of high oil prices to improve the world’s economic security and sustainable development. However, to promote biomass as one of alternative energy sources for Thai society, there are many vital activities driving biomass to penetrate through energy market such as the climate change mitigation, the reduction of the dependency on energy imports, achievement of greater social & economic cohesion at community level, or new market & trade opportunity of modern bioenergy in the future.

Moreover, developments of modern biofuels imply new technologies for processing biomass and using biofuels; and increasing oil prices opens the way for a potential for new industries in developing countries (Peskett et al., 2007), like Thailand. Therefore, this main section wills analysis all key factors that can affect bioenergy growth in the country.

5.3.1 Environment impact

Thailand has been actively participating in the international climate change debates and agreements since the 1992. The Convention on Climate Change was signed at United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in the same year. Following this signing, Thailand established the National Committee on the Convention on Climate Change in June 1993. From data analysis from the past, more than two-third of the GHG emissions in Thailand come from emissions of CO_2 and the remaining one-third from methane (CH_4). Above half of the CO_2 emissions come from the energy sector, which steadily increase both in relative and absolute terms, therefore these trends only indicate that huge opportunities for the GHG mitigation are found in the energy sector (Todoc, 2004). The remaining GHG emissions come from the following sectors: agricultural, land use change & forestry, industrial, and wastes (Todoc, 2004; TGO, 2008). Therefore, energy from biomass has a highly potential to reduce these CO_2 emissions (see also Ch. 5.2.1: Environmental policy), because it is generally considered as CO_2 neutral. In the long term and in theory, biomass-based energy could offer the prospect not just of reducing emissions, but of reducing atmospheric CO_2 levels. Furthermore, with the Kyoto Protocol[77] entering into force on 16 February 2005, the country is well positioned to be benefited from Clean Development Mechanism (CDM) projects[78], especially in the areas of renewable energy and energy efficiency.

Energy is an essential factor in overall efforts to achieve sustainable development, because environmental degradation from improper energy use inhibits sustainable development (Vera and Langlois, 2007). Besides, uncertain international prices of fossil fuels currently motivates environmental and energy security interventions. The National CDM Strategy Study also point to the following resources, as appropriate for CDM project development: Biomass (biogas & biofuels); Solar; Waste to energy (ERM, 2002). To drive the use of energy conversion from biomass rapidly, carbon tax is one way to do that by increasing fossil-fuel costs until encourage energy conservation by reducing demand for fossil-fuel intensive goods and services, or by substitution towards more environmentally friendly technologies and processes. This can also to be a way of reducing CO_2 emissions efficiently. Beside, carbon tax can achieve the same emission reduction target at a lower cost than conventional command-and-control regulations. With the study of sustainable development in energy section of Thailand by using official state-level forecasts and plans., three long-term scenarios consisting of different ‘storylines’ which show the different ways in which the energy market could develop are assessed. The scenarios include Business-As-

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[77] The Kyoto Protocol, which was adopted by consensus, sets legally binding limits on the GHG emissions from industrialized countries and envisages innovative market-based implementation mechanisms aimed at keeping the cost of curbing emissions low. The Kyoto Protocol envisages three market-based mechanisms: 1) Emissions Trading allow industrialized countries to meet their targets through trading emission allowances between themselves and gaining credits for emission-curbing projects abroad; 2) Joint Implementation (JI) refers to projects in countries that have emission targets; and 3) the Clean Development Mechanism (CDM) denotes the projects in developing countries with no targets (Europa, 2006).

[78] Criteria for CDM are: 1) Environment Indicators; 2) Social indicators; 3) Development and/or technology transfer indicators; and 4) Economic indicators (Morgera et al., 2009).

Usual (BAU)[79], No-New-Coal (NNC)[80] and Green Futures (GF)[81] options. The period of study begins in 2002 and end in 2022, with 2002 taken as the reference year. The study show that the avoided emissions over the study period amount to 325 and 692 million tonnes of CO_2 equivalent for the NNC and GF scenarios, respectively, which represents reductions of about 17% and 36% relative to the BAU path (Mulugetta et al., 2007).

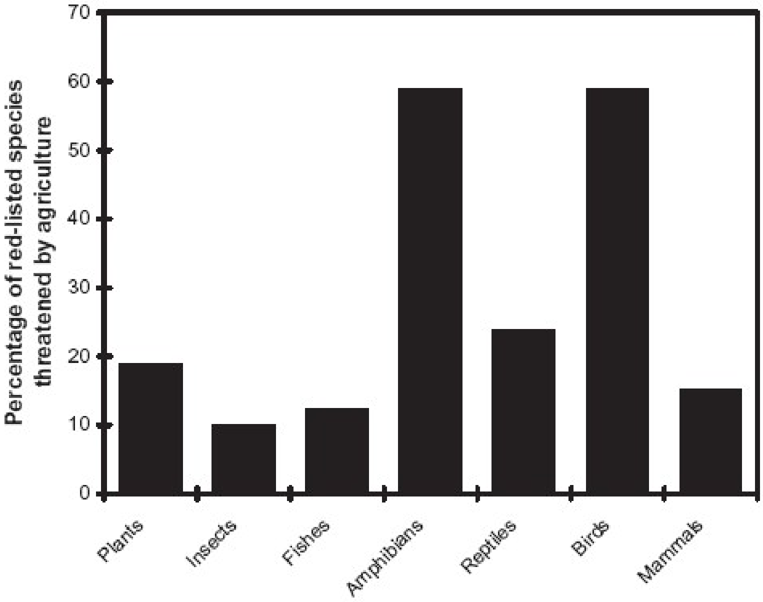

Fig. 5.1: The percentage of red-listed species threatened by agriculture in a range of biodiversity groups.
Source: Norris (2008)

If forest destruction is prevented, environmental benefits from bioenergy are met when high intensity agricultural techniques shift towards soil conservation and the production of native perennial grasses. The soil benefits in terms of erosion reduction, chemical leaching, and water quality can be significant (McLaughlin et al., 2002). Development with biomass in local value chains would be required to ensure environmental, economical, and social sustainability. To cultivate energy crops, land-use change is a key consideration, because in global level the expansion and intensification of agriculture have been the major driver of past biodiversity loss (Norris, 2008). According to International Union for Conservation of Nature (IUCN) data, agriculture is a major cause of global endangerment. Additionally, biomass convestion plants are expected to have less environmental impact, which is not really true in the case of long carry distance farther than 200 km to the plant location. Expressed as the amount of water consumed to produce a unit of energy (m^3/GJ), the Water Footprint (WF)[82] of biomass depends on crop type, agricultural production system, and climate. The WF of biomass is 70 to 400 times larger than that of the other primary energy carriers (e.g. coal,

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[79] The BAU scenario is focused on continuous trends in existing technologies and policies of Thailand

[80] The NNC scenario is inspired by clean technology principles and increasing resistance to by local residents

[81] The GF scenario is inspired by the Greenpeace study entitled ‘Positive Energy Choices’ (Greenpeace SEA, 2002) that argued 35% of Thailand’s electricity capacity could be derived from renewable energy sources.

[82] Calculations of a WF are made by summing daily crop evapotranspiration (mm/day) over the growing period of a crop. The WF consists of three components: green, blue, and gray virtual-water. The green virtual-water content of a product refers to the rainwater that evaporated during the production process, mainly during crop growth. The blue virtual water content refers to surface and groundwater applied for irrigation that evaporated during crop growth. The gray virtual-water content of a product is the volume of water that becomes polluted during production (Gerbens-Leenes et al., 2009).

crude oil, natural gas, excluding hydropower) (Gerbens-Leenes et al., 2009). According to Hargrove (2007), water requirements for lignocellulosic ethanol, are expected to lie between 4-8 litre water per litre biofuel. This is slightly more than for first-generation ethanol production (2-4 litre water per litre ethanol), mainly due to additional conversion steps in the production process. However, this is a small amount compared to the total water demand for feedstock cultivation. The sustainability of second-generation biofuels is high, but the new technologies represent industrial processes for which no experience with commercial production yet exists. Besides, developing countries will face a challenge to balance a large-scale biofuel industry (IEA, 2010).

5.3.2 Energy security

Securing[83] energy supply is the main energy policy goal in Thailand. The target is to preserve a diverse energy mix in the market in order to secure the availability and sufficiency of fuels, electricity, and heat. Diversification of energy supplies is the cornerstone to protect against supply disruptions and price hike (Thavasi and Ramakrishna, 2009). Security of energy supply is a major challenge facing both developed and developing economies since prolonged disruptions would cause major economic upheaval. In Thailand, research and development in alternative energy has also been intensified, particularly with the development of energy crop and biofuels. Moreover, Thailand has been working on the issue of energy security with like-minded countries within ASEAN, ASEAN+l, ASEAN+3, EAS, APEC, the Asia Cooperation Dialogue (ACO), and the Forum of East Asia & Latin American Cooperation (FEALAC) to share experiences and clean energy technologies as well as to promote sustainable energy development and utilization (ARF, 2007). Expenditures for oil imports put a particular strain on budgets of developing countries like Thailand. Locally produced biofuels, therefore, have a great potential to reduce dependency and oil bills and substantially strengthen access to energy. Factors such as high yields and low energy consumption are important to consider in promoting the future competitiveness of the modern biofuels vs. classical fossil fuels in the market. Depending on the feedstocks used and the final fuel output produced, biofuel conversion can be done through various routes using a range of biological, chemical, and thermal conversion processes (see Ch. 3). Feedstocks for biofuels production can be categorized into three main groups namely plant oils, sugars / starches, and lignocelluloses (Yan and Lin 2009).

On the global level, enlarging the group of countries producing biofuels for the liquid fuel market and international trade will diversify supply and thereby reduce the risk of disruption of the supply. Many nations have the ability to produce their own efficient and sustainable bioenergy from agriculture, forestry, and urban wastes. In addition, a number of government and companies are heavily investing in R&D for so called 2nd generation technologies. These investments will lead to an increase in the share of bioenergy to overall energy supply. Biomass resources can be used most efficiently if they are grown and used for a primary purpose, such as food or fibre, but its energy route is subsequently focused on agricultural field and manufacturing residues. With oil prices continuing to raise, materials derived from fossil fuels, such as plastic textiles, will become more expensive and create higher value opportunities for products based on biomass, leading to more residues for energy production. Converting residues and other organic waste streams into biogas or other fuels is

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[83] The International Energy Agency (IEA) defines energy supply to be “secure” if it is adequate, affordable and reliable (OECD/IEA, 2007).

already underway in several countries. Identifying and reaching a sustainable potential of bioenergy depends on several factors, including (UNEP: Energy Security & Bioenergy):

1) The resolution of environmental and social concerns about food security, vulnerable communities, water resources, and deforestation;
2) Increased production from technical innovation in agriculture and forestry;
3) The overall dynamics of the food, feed and fiber markets; and
4) Regional measures that address climate change impacts.

In the context of energy versus food security, there is growing international consensus that the increased demand of food crop feedstocks for the development of liquid biofuels for transport has contributed to recent commodity price hikes putting a further strain on food security. The impacts of biofuel production on nation level vary according to feedstock, technology and country characteristics. Food availability could be hampered by biofuel production since large scale use of land for the production of feedstock could pose a threat to the use of that same land and water resources for food production. Effective land-use planning can help to limit the negative effects of direct and indirect land-use change, therefore possible large negative impacts in terms of land dispossession, food prices, GHG emissions, and biodiversity loss could be avoided. Beyond that, however, some form of regulation is required to ensure that social and environmental standards are met by biofuel feedstock producers. Besides, this pressure on food availability could be lower if food and energy production systems were better integrated or second generation biofuels produced from lignocellulosic biomass are developed with competitive cost. This cellulose-rich biomass could be grown on marginal and degraded lands that do not compete with food crops, but it remains to be seen whether this will be economically viable. Further, seemingly "abandoned" land often provides important subsistence functions in times of stress to vulnerable households.

Rising food prices are good news for farmers selling their commodity. However, only a small minority of poor rural households, including farming households, have surplus to sell and hence rising prices are an immediate threat to food security. If in the medium term the continuous growth in biofuel demand will help reverse the trend of falling commodity prices experienced over the last few decades, this could help revitalize the agricultural sector. New demand can bring new income opportunities for poor farmers, and provide incentives for intensification, leading to increased food production and improved their livelihoods as long as production methods still sustainable. Therefore, demand of energy crops has the potential to create employment and value added being one of the keys for Thai economy. The risks that bioenergy may effect the food security including: 1) increased competition with current food production and natural resources; 2) price surges and increased price volatility; 3) other impacts on livelihoods such as hindered access to land or water. However, bioenergy can bring opportunities which: 1) drive forward rural development through increased energy access, fossil fuel substitution, employment and income; 2) increase harvests for both food and fuel crops through bioenergy investment.

5.3.3 Economics

A starting point is that bioenergy is currently the most compromising choices among alternative energy sources in Thailand thanks to its potential to replace fossil energy. From an economic point of view, the future use of different energy sources will be determined by their relative prices. Since inputs of bio-energy production (land, crops, and forest) are also used in other production sectors, the effects on other markets should be discussed. Bioenergy markets are heavily dependent on different kinds of political interventions, therefore government interventions in the bio-energy markets and their effects will also be investigated. Issues such as food security (see Ch. 5.3.2), effects on the production of forest products, and effects of changing oil prices should be analyzed too. However, bioenergy can create new economic opportunities for forestry, agriculture, municipalities supplier of bioenergy resources, as well as technologies and services. Switch or utilization to cleaner fuels are also least-cost options and offer higher mitigation potential, since bioenergy feedstock production based on perennial crops requires less labor than most agricultural activities. Extra employment opportunities will arise only to the extent that bioenergy feedstock production augments – rather than supplants – other agricultural activities (Larson and Kartha, 2000). Moreover, the technology developed and expertise gained from renewable energy projects can be exported to the neighbors, thus creating an additional source of income or supplementary bioenergy feedstock for Thailand.

For the biopower investment in Thailand, the size of the project is dependent on the available biomass resources and intended application. The difficulty of collecting and transporting residues from many sources necessitates that a new biomass energy project should be implemented at the vicinity of the agro-processing mill. Because of the dispersed nature of the resource, biomass power-generating facilities tend to be small, so they generally cannot capture the economies of scale typical of fossil-fuel-fired[84] generating facilities (Carlos and Khang, 2007; Gan, 2007). However, bigger projects are now implemented to sell electricity to the national grid. Projects attached to a host mill provide heat and power to the mill in exchange for the residues that the mill produces, while projects developed outside of a host agro-industry procure fuel from different sources usually through intermediaries. Financial incentives through soft loans and investment subsidies should be sufficient for selected types of renewable energy projects, particularly biogas in pig farms and factories producing tapioca starch, palm oil, rubber sheet, ethanol and other types of agro-industry, municipal wastes, and micro-hydro. Moreover, international finance institutions such as World Bank and the Asian Development Bank (ADB) have been encouraging the Asian countries, including Thailand, for developing clean energy and other necessary infrastructure projects (Thavasi and Ramakrishna, 2009).

From the financial point of view, project developers and equity sponsors in Thailand look at CDM (see Ch. 5.3.1) as a bonus as it does not significantly improve the financial performance of the project. Because of the remaining uncertainties of CDM, project developers add the CDM component in their projects only for a strategic reason: to learn from early CDM experience. Project developers don’t expect financial benefit from CDM owing to the uncertainty surrounding its implementation and the relatively low price of CERs. A higher tariff is granted to SPPs and VSPPs using renewable energy, including biomass, by providing an “adder” on top of the normal tariff guarantied for 7-10 years from the Commercial

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[84] In gas-fired combined cycle plants, fuel cost accounts for about 80% of the total project cost (including capital, operating, and maintenance). Capital costs for plants with capacity of 100 MW are typically between US$800 to US$1000 per installed kW (Probe International Briefing, 2005).

Operation Date (COD) for proposals submitted before the end of 2008. The "adder" depends on the type of renewable energy being. SPPs are commonly a product of government policy, not necessarily customer needs or market demand (USAID, 2007). This makes them quite insecure given their dependence on EGAT and vulnerability to government policy changes that affect their commercial viability. SPPs would not be able to attract private capital. In addition - in the case of combined cycle SPPs - some of them have unused capacity or not enough customers for electricity or steam, although cogeneration in industrial sector is one the mitigation options finding to have a net economic benefits in short-term (until 2005) policy of Thailand (Probe international, 2005).

At current costs, it is estimated that the prices of biodiesel can break even, only if the crude oil barrel price remain in the range of US$100 to $120. It is always debatable how long the government can subsidize bio-diesel in order to make it more attractive (Siriwardhana et al., 2009). The share of palm oil cost is 80% of the total production cost while the share of methanol cost is only 15%. Therefore, by reducing the cost of raw material or using low-cost raw materials will drastically reduce the cost of bio-diesel (Kapilakarn and Peugtong, 2007). Further research is needed to find new sources of bio-raw materials, to increase palm yield, to boost extraction rate, and to decrease methanol production cost. Rather than assisting farmers to reconstruct their lives and livelihoods after displacement to make way for large-scale growers, it will often be preferable to involve them in biofuel feedstock production on their own land. Besides, foreign investment in land for feedstock production could offer an option for developing countries to profit from the growing biomass market for second generation biofuel production outside their borders, provided that transport infrastructure is suitably developed. Profits could be invested in the rural sector to improve infrastructure and the overall economic situation, and at the same time to develop skills for feedstock cultivation and handling (IEA, 2010).

5.3.4 Renewable quotas and Bio-waste disposal & management

The development of a strong bioenergy sector would open in many countries the prospect of exporting Environmental Goods and Services (EGS) with favorable trade potentials. The gains from trading bioenergy services would not only result from the direct benefits of these services, but also from the compounding benefits of the better environment resulting from a more sustainable use of the natural resources in the production of the feedstock, and from the utilization of the fuels themselves as substitutes for fossil fuels (De La Torre Ugarte, 2005). Moreover, there is a great gap between countries at the forefront of advancement of their biofuels industries, such as Brazil, the Philippines, and the US, and countries where bioenergy utilization still increase incessantly, despite large biomass quantity is required to cover their bioenergy production (De La Torre Ugarte, 2005). However, the whole biomass trade issue is complex and is under evaluation by the OECD, Global BioEnergy Partnership (www.globalbioenergy.org), IEA Bioenergy's Task 40 (IEA BioenergyTrade, 2007). Importing biomass could prove to be a cheaper option than producing their own, but partly depending on any trade tariffs imposed. Furthermore, a joint workshop between IEA Bioenergy Task 40 and the World Bank however concluded that a combination of producing bioenergy carriers for export as well as for local use would generate revenue for development from the export earnings as well as support local industry (IEA BioenergyTrade, 2007; IEA, 2007b). Based on FAO's Unified Bioenergy Terminology (FAO, 2004), the conceptual view of bioenergy systems is shown in Fig. 5.2, describing the flow of bioenergy production from biomass as a source of energy.

Fig. 5.2: The flow of bioenergy production
Source: Gumartini (2009)

Ongoing negotiations with the World Trade Organization (WTO), the aim of liberal trade in agricultural commodities, are expected to address the potential for reducing biofuel trade barriers, offering an opportunity for countries to generate new agricultural revenue streams to offset loss of trade-distorting subsidies. From a macroeconomic perspective, bioenergy contribute to all important elements of country development: 1) economic growth through business expansion (earnings) or employment; 2) import substitution (direct and indirect economic effects on GDP); 3) efficiency improvement; and 4) security of energy supply and diversification (Domac et al., 2005). Since there are very limited volumes of solid biomass and liquid biofuels available for sale on the world market at present, and the energy and economic costs for transporting the biomass would need to be included in any comparison with local production, given the anticipated increases in demand, therefore the future price of biofuels is likely to increase significantly (IEA, 2007b). Administrative and economic consequences should be acceptable and should not decrease the competitiveness of biofuels (for statistics of bioethanol and biodiesel trade, please see Fig 5.3 and 5.4). The food and feed production should also be sustainable. Policy instruments of energy efficiency promotion set up on national level (such as energy efficiency contracts, energy audits, energy recommendations for public purchases and energy efficiency requirement of electric appliances as well as energy labels) have been focused mainly on energy end-use.

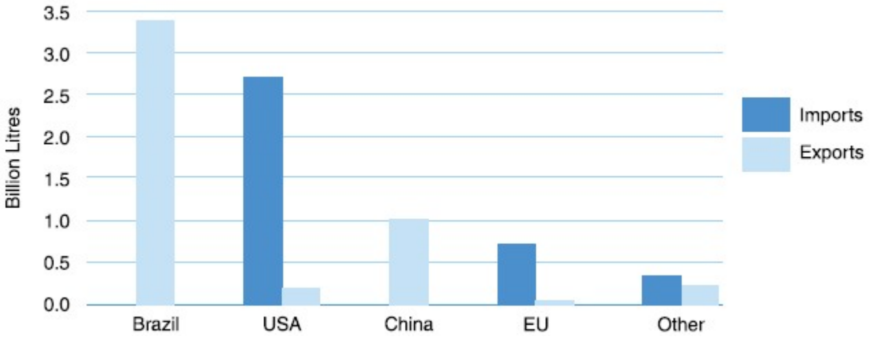

Fig. 5.3: International trade in ethanol in 2006
Source: OECD 2008 – data compiled from F.O. Licht's (2009) cited by Gumartini (2009)

Trade is good because it generates a global culture of competition and innovation, and thereby brings about improvements in goods and services that have an intrinsic monetary value far beyond the monies earned (Jha, 2009). Trading via an internet-based market has begun in several countries, leading to increased foreign investment. Trade renewable energy certificates, generated from specified types and scales of generation plant, is also under evaluation. Certification system should be set while taking into account the existing certification schemes which are applied for various biomass sources (FSC for forest, RSPO for palm oil, RTSS for soybean, etc), so to be set only for those missing parts that are not covered by existing reliable certification scheme. Redundancy with the existing cross-compliance certification scheme should be avoided (IEA, 2007b). At present, these certificates appear to play a relatively minor role in consumer decisions in most developing countries, but they already have considerable more effect on export markets as they are for people in other parts of the world who more awake to environmental impact at global level, especially in developed countries. AEBIOM (European Biomass Association) suggests that the concept of sustainability should not only be applied to biofuels, but also to the production of all energy crops as well as all conversion routes. Most trade in renewable energy technologies recently is only between developed countries. However, trade in renewable energy technologies also requires transmitting the knowledge component of those technologies, which is often embedded in the assembly and in project execution (Jha, 2009).

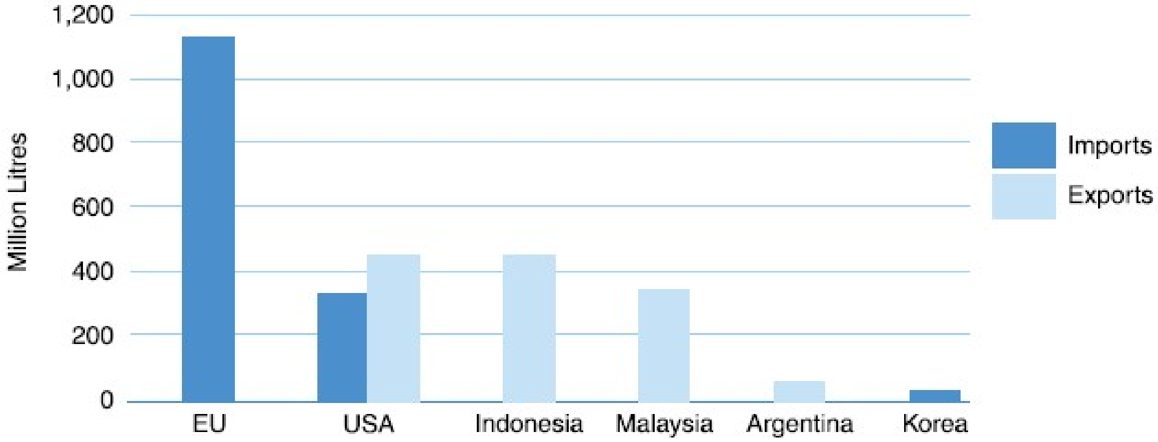

Fig. 5.4: International trade in biodiesel in 2007

Source: data compiled from LMC (2007) by Gumartini (2009)

Bio-waste disposal is also one of driving factors concerning to utilize biomass as energy source. A large amount of municipal waste which must be managed is generated everyday, therefore turning municipal waste into green energy offers endless potential. In the past, the main route for municipal waste disposal has traditionally been landfill, but currently in some regions such as in the EU this method is forbidden[85]. One question about this is “Will using waste for energy purposes reduce the desirable incentives to minimize and recycle waste materials if it is cheaper to burn it?” (IEA, 2007b). Apart from alternatives that create less waste and recycle more in a safe and environmentally friendly way, it must urgently find affordable ways of managing municipal waste that cannot be recycled and maximize its use such as a resource for energy generation. Moreover, recovering energy from waste can contribute to a balanced energy policy. Energy from waste (EfW) or incineration is where waste is burnt at high temperatures to reduce its volume and to produce heat or electricity. Like all other combustion plants burning solid and liquid fuels, the incineration process produces the following emissions: acid gases, particulates, dioxins, and heavy metals to air; ash residues (these arise from the non-combustible materials present in the incoming waste) (Environment Agency, n.d.).

There is significant public concern about the possible health risks of energy from EfW’s plant emissions (Environment Agency, n.d.). The U.S. Environmental Protection Agency enforces strict rules and regulations for waste-to-energy plants to follow an effort of protection that harmful GHGs and particles are not released into the environment. Initially, waste-to-energy facilities produced large amounts of emissions that were harmful to the

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[85] Waste management inside the EU is almost totally regulated by EU directives. The main target in view of sustainability is the prevention of direct disposal of reactive waste on a landfill, because biogenic constituents which cause problems on a landfill considering the formation of climate active methane and the risk of groundwater contamination by leachates. The targets are a reduction of biogenic waste compared to the situation in 1995 by 25 % in 2006, 50 % in 2009, and 75 % in 2016 (Vehlow, 2006).

environment (Beatty et al., 2010). If solid ash residues are handled and disposed correctly, air emissions are the main way affecting both public health and the environment. The literature research from England argues that the majority of published studies concentrate on the health effects from the older generation of incinerators. But, modern or well-managed EfW plants must now meet much tighter emission standards under the European Waste Incineration Directive. They release far less chemicals than the old incinerators and, therefore, only make a small contribution to background levels of air pollution. Indeed, dioxin emissions have been reduced by 99.8% since 1990. Finally, it may be appropriate for local authorities to include energy from waste in their strategies and plans provided that: 1) it does not undermine preventing or minimizing waste, re-use, recycling or composting; 2) it forms part of a properly considered and appraised regional or local strategy; and 3) it is consistent with the statutory aim to establish an integrated and adequate network of waste disposal installations and enable waste to be disposed of in one of the nearest appropriate installations (Environment Agency, n.d.).

5.4 Major challenges for biomass based energy in Thailand

Although bioenergy is seen, more and more, as a promising and largely untapped renewable energy resource, and its potential environmental and economic benefits are becoming more apparent as technological improvements continue to emerge (Msangi et al., 2007). There are many underlying issues and barriers that have constrained its deployment, particularly in developing nations. For obvious example, it still requires highly capital-intensive investment. Several studies on the success factors for renewable energy and biomass energy project implementation classify the drivers of renewable energy development into common elements: social, political, institutional, technical and economical (Jorb, 2002; ERCL and AMEEA, 2001; Uyterlinde et al., 2002; ESDGLL, 2004). Other studies categorize success factors by markets (ETSU, 1995; Roos et al., 1999) and the fuel chain (E4tech, 2003). The challenge is to recognize the many linkages among them. In this main part, all challenges will be discussed in order to finally compromise them for the Thai society.

5.4.1 Technology suitability

Technologies of biomass to energy are thermo-chemical and bio-chemical/biological (see also Ch. 3). It might also be more energy-efficient to use biomass to fuel power plants rather than convert it to liquid biofuels. The promise of biofuels seems not to be that they will replace fossil fuel use to any great degree in most countries, but they can only help to diversify supply and make a small contribution to reduce oil import dependence. Bioenergy projects can range from a small (~40kW) local on-farm heating plant to a large (~400MW) commercial cogeneration plant. In Thailand, the currently used technology to convert agricultural residues such as bagasse and rice husks into energy. Since they are difficult to be fermented, a proper technology is a thermochemical one (direct combustion, gasification, or pyrolysis) with or without cogeneration. It could be observed that the barriers like affordability, lack of knowledge to operate and manage new technologies, limited availability of spare parts and maintenance expertise, and lack of energy subsidies are common to all technologies (Adhikari et al., 2008), however; few other barriers are specific to some technologies only. The capacity of people in the governmental sector, especially those in the Customs Department, has to be increased. They need to understand some of the technical aspects and specifications of the engines or machines used in the power plant business. Some machines, engines, or maintenance parts need to be imported and are subject to high tax, which is a financial and economic burden for the private operators (Probe international, 2005). In global overview, lack of policy frameworks, institutional settings, markets, financing, technological development, human resources and slow diffusion rates of new technologies are among many of the underlying issues and barriers (Painuly, 2001; Yu, 2003).

The main barriers to widespread use of biomass for power generation in Thailand are cost, low conversion efficiency, and feedstock availability. Most important are the lack of internalization of external costs in power generation and effective policies to improve energy security and reduce CO_2 emissions. In the long term, biopower potential will depend on technology advances, on competition for feedstock use, and on efficiency of crop cuptiavation. To set-up a commercial second-generation biofuel plant with a capacity around 100 million liters per year, large investment volumes in the range of USD 125-250 million are currently required. Most of the selected countries (Brazil, China, India, South Africa, Mexico, and Thailand) have already set up bioenergy projects of this scale, financed from domestic resources and considerable amounts of foreign direct investment (IEA, 2010). While long distance transportation reduces economic and environmental attractiveness of biomass, conversion into “biooil” (e.g. by pyrolysis) could benefit by international trade. Associated with widespread use of biomass, the risks relating to intensive farming are more fertilizers/chemicals use and biodiversity conservation. The possibility of storing biomass, however, such as straw bales or wood chips can help to offset other variable power production systems. Using a bioenergy system as back-up to a solar thermal power plant is one example for household energy, although mainly for the nights as the bioenergy plant response time is not fast (IEA, 2007a).

5.4.2 Obstacles by biomass infrastructure and the long-run supply issues

The primary production of biomass has been classified into five categories, namely energy crops, agricultural residues, forestry, aquatic biomass, and wastes. There is a limit to the amount available depending on the area of crop grown for its primary products and the amount of residue products from a process. Many businesses are attempting to minimize their wastes by either improving the process or utilizing the material for co-products other than energy. So over time the volumes available of a waste resource could decline. Therefore, an energy crop is needed where waste materials are not available in sufficient quantities or with the suitable characteristics (IEA, 2007b). For biomass (both residues and wastes) that has multiple markets by nature, the suppliers will sell it to the highest bidder. Long-term contracts and agreements are often discussed as a strategy to develop a guaranteed biomass supply from producers. Guaranteeing biomass supply at competitive costs requires highly efficient biomass production system. In Thailand, biomass energy projects are traditionally implemented to supply the agro-industry’s own energy requirements and are considered as an integral part of their operation. The implementation of various policy instruments, ratification of the Kyoto Protocol and consequent implementation of the CDM, however, resulted in the establishment of SPC to operate biomass power generation or cogeneration facilities outside of a host agro-industry (Carlos and Khang, 2007).

This situation changes considerably with increased investments in bioenergy conversion and crop productivity improvements. However, lack of certainty of biomass supply availability at an acceptable cost over a long term can be a significant barrier for achieving increased development of many bioenergy projects. Project financiers want to reduce the risks of investment by having heat or power purchase agreements, along with fuel supply contracts, and perhaps green pricing options. The developers of a large plant may therefore take overall responsibility for obtaining the required biomass, either by securing long-term contracts well in advance or producing their own biomass supplies. Fuel supply risks from competing markets for the biomass can be overcome by negotiation of appropriate contracts and forward sales agreements. However, many biomass fuel suppliers are farmers who are not used to have the experience of long-term contracts (IEA, 2007b). The developers should think a good fuel has to meet the **CLAW** requirements: C - COST at reasonable price L - low to no additional LAND use (benefits for using degraded land to restore biodiversity and organic material); A - AIR quality improvements- i.e., low carbon emissions; W – limited WATER use. Finally, increasing the available supply of biomass in future should therefore depend to a greater degree on the active production of energy crops on surplus arable land (as in Europe and the USA), marginal and degraded lands, or plantation forests (IEA, 2007b).

5.4.3 Energy industry inertia

It is also known that the inertia within the bioenergy business from upstream to downstream is one of the sluggishness to utilize biomass as energy source. Growth of renewable energy use has been very lethargic in many countries. In those countries, the use of bioenergy is limited by administrative barriers and unfavorable bureaucratic conditions, including esthetical, planning or safety regulations that are not taking into consideration the specific needs of biomass applications. In the EU, the main two barriers included raw material availability and its logistic (high prices for truck transport, lacking intermediate storage capacity, and environmental concerns regarding long-distance transport by truck). A key obstacle to agriculture and bioenergy development in the West African Economic and Monetary Union (UEMOA) is inadequate infrastructure. This includes roads, railways, and telecommunications to ensure market access and to bring new areas into cultivation (UEMOA, 2008). On demand side, slow growth in bioenergy use is caused by inadequate support systems and a lack of coordinated policies. With laziness of supplanting to preferable technology, it may take several years or even decades before the old capacity is replaced, although technology is available to deal with the fuels (e.g., different types of fluidized bed boilers). Beside, power producers are generally reluctant to experiment with new biomass streams, e.g., bagasse or rice husk. Much of this reticence can be attributed to the inertia of an industry which is notoriously conservative and reluctant to embrace new technologies (Faaij and Domac, 2006).

Due to the size, often small, of bio-energy markets and the fact that biomass by-products are a relatively new commodity in many countries, biomass markets can be immature and unstable. This makes it difficult to sign long-term, large-volume contracts, as doing so is seen as too risky (Faaij and Domac, 2006). In some countries, available residues and organic wastes from agriculture, forestry and the waste treatment sector are substantial, but also limited in the near future if demand of biomass still grows at high rate like present. If not collected at the time of harvest using integrated systems, then residues, often widely distributed, will need to be brought to a central location. The method of collection will vary with the type of residue, terrain, machinery availability, location, soil access etc (IEA, 2007b). On supply side, the (sustainable) use of different types of land (marginal and degraded, and good quality agricultural and pasture land) depends on the success of accelerating the improvements in current agricultural management and integrating biomass production in a sustainable way in current land-use patterns (Faaij and Domac, 2006). However, before planting an energy crop the first question a grower should ask is “How will it be harvested, stored and processed?” (IEA, 2007b). To answer with this question properly will make the farming systems sustainable.

In cultivation practice, irrigation is an option for growing any energy crop to optimize yields. However, the cost of the irrigating equipment is usually high, water for crop growing may be limited or costly, high labour inputs can be needed, and the additional yields obtained do not always warrant the extra costs involved (IEA, 2007b). In developing countries, very large improvements can be made in agricultural productivity given the current agricultural methods deployed (often subsistence farming), but better and more efficient agricultural methods will not be implemented without investments and proper capacity-building and infrastructure improvements. More intensive land use and additional land use for biomass production may lead to macroeconomic effects on land and food prices (Faaij and Domac, 2006). For other sluggishness in bioenergy development, there is a lack of technically mature pre-treatment technologies for compacting biomass at low cost to facilitate longer storage time and transportation, although this is fortunately improving. Also, the lack of significant volumes of biomass can also hamper logistics (Faaij and Domac, 2006). Risks arising from community opposition and from the uncertain policy environment surrounding these large projects conspire with the increasingly clear – and frightening – reality of human-induced global climate change. Finally, the monopoly system of bioenergy market in some countries is limited in scope and has been slow to expand. Discussions are underway to allow third-party pipeline developers to speed up the process, but so far progress has been slow.

5.4.4 Regulation barriers

Policies in bioenergy can not only play as the key drivers for bioenergy development, but also function as potential barriers to realize bioenergy system in poor situations. Uncertainty and lack of continuity in energy policy is a key issue that applies to biomass and all other renewables. The time scales over which national governments, or their priorities, change, frequently frustrates long term policy commitments. Policies risk creating trade barriers, may be quickly outdated and hard to change or eliminate (Thornley and Prins, 2009). There can also be problems or conflicts during policy development. Common conflicts include: whether targets should be indicative or binding; which strategies, policies, or market mechanisms to apply; and harmonization (Fagernäs et al., 2006). Beside, many countries need to have a clear vision of what they are trying to develop (the resources, the sectors and the technologies appropriate to them) to ensure appropriate targeting of resources and prevent unnecessary policy and legislative shifts as the industry grows (Thornley and Prins, 2009). Regarding the actual policy instruments on a national level, it seems that investment subsidies are useful in the early stages if followed up by other policy initiatives as the industry develops. Many countries with a less developed biomass industry or scarce resources will focus on investment subsidies. Others, who are further on, will initiate policy instruments such as trading certificates, green tariffs, taxation or a combination of these. On global level, the lack of coherent policies at the national level is the greatest barrier. Few governments have explicitly realized the connection between national security, energy, land-use, employment, and economic development (Thornley and Prins, 2009).

A lack of clear technical specifications for biomass and specific biomass import regulations. This can be a major hindrance to trading (Faaij and Domac, 2006). Moreover, certification can form a serious barrier to smallholders producers. A more general barrier to international consensus has been a perceived unequal playing field between the developed countries, which are obliged to reduce CO_2 emission levels, and the developing countries, which are not held to the same limitation as the Annex I countries of the UNFCCC. In many countries biomass like paper, sewage sludge, black liquor (e.g. Austria, Germany, or the UK) or wood treated with organic preservatives are not acknowledged as biomass that can be subsidized if used as energy source. There are also the barrier concerns about energy generation in small/large scale plants and Waste to Energy (WtE) plants. The licensing of WtE plants is in many countries (e.g. Germany, the UK) an expensive and time-consuming process. Biomass is widely distributed and there is great potential for small-scale biomass power (Fagernäs et al., 2006). However, such small-scale generation will only become economic if local utilities purchase power from local plants at a rate that renders them economic. Current regulations on grid access do not guarantee a legal framework based on objective, transparent and non-discriminatory criteria. Further progress in improving grid access for electricity from renewable energy is essential for stable growth (Fagernäs et al., 2006).

For regulation barriers in developing countries, in three country case studies (Egypt, Ghana, and Zimbabwe), it has analyzed the barriers for the implementation of potential renewable energy technologies in those three countries and also identified measures to remove the barriers. The study found that a lack of institutional structure to promote renewable energy technologies was also noted as an import barrier by stakeholders for various technologies. Most of the barrier removal measures pointed out by the stakeholders indicated the need for policy intervention by the government to create a favorable environment for renewable energy technologies to take off. Thus, need for a favorable policy regime to address these issues was a clear message given by the stakeholders (Painuly and Fenhann, 2002). In the case of Southeast Asia, since most of the biomass energy projects are small in size and fully owned by the agro-industries, while the rest being Special Purpose Companies (SPC) connected to the national grid, their success[86] should be judged by key stakeholders like project owners, implementation team and the general public represented by regulatory authorities (Carlos and Khang, 2009). For Thailand, a problem with the current energy markets is that environmental costs are not adequately internalized. While the production of fossil energy causes huge GHG emissions and consequently global warming; costs of these external factors are poorly reflected in the market price for energy. This implies a hidden subsidize of fossil energy (Stangeland, 2007). The SPP programme led to a significant increase in renewable energy capacity, but the complexity of regulations and the low tariff produced only fairly large biomass projects. At the same time, the VSPP regulations were drawn up to provide streamlined interconnection arrangements for smaller renewable energy generation. A key barrier is that Thailand has yet to establish a competent, fair and independent regulatory authority. The core mandate is to ensure that decisions made in the energy sector are in the public interest, and which has sufficient legal authority to enforce compliance (Greacen, 2007).

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[86] A project is generally considered successful when it is completed on time, within budget, in accordance with agreed specifications, and to stakeholders' satisfaction (Carlos and Khang, 2009).

5.5 Opportunities in bio-energy technology development for Thailand

Although biomass is one of the most potential sources for energy generation in both developing and developed countries, practical and effective utilization of biomass resources is an important challenge. There is still much to be done to optimize the utilization of biomass with the most suitable technology, despite its wide use already. However, development of new technology for modern biomass utilization is an intensive process and often entails both high return and high risk. In order to enhance the technology development of modern biomass energy with less mission fiasco of feasible project, this section will select the factors that shold bring into consideration for proper development the new bioenergy technology in Thailand.

5.5.1 Implementation of the biomass energy generation technology development in Thailand

Technologies for transformation and utilization of biomass as energy source cover a wide range, from well-established technologies to those in the research stage. Although all of these technologies have been improved, the cumulative experiences are also important. The biomass conversion technologies have been usually concentrated in gasification, densification, pyrolysis, and combustion technology (see Ch. 3.1). Cogeneration system is also attractive to many industries for providing process heat and electricity used in their own process and sold the surplus to another industry/grid for better revenue. The major challenges of biomass utilization are the difficulty in assessment of resources, low bulk density and high moisture content, laborious collection, cumbersome transportation and storage, as well as availability and reliability concerns (Suwannakhanthi, 2004). Most bioenergy conversion plants are usually designed to befit with a specific fuel type, but it is likely that the mixture of biomass available and its specific characteristics will change over time. This affects the design of the conversion plant and can even shorten its economic performances and process life due to obsolescence if suitable biomass fuels become unavailable (IEA, 2007b). There are many clean and energy-efficient technologies available on the market that can contribute to sustainable development and energy security in developing economies. In practice, however, these technologies are rarely used. Old technologies have still preferred in those countries, although they are usually less efficient, requires higher labor inputs, and involves more maintenance. The investment in new, efficient, low labor intensity plants should be a better economic proposition in the long run, assuming sufficient capital is available (IEA, 2007b).

Attaining this important objective would require investment in technological improvement, new infrastructure, including roads and energy supply, and capacity building in the agricultural sector. It is not easy for a single entity working alone if it does not have sufficient expertise and financial capacity, although there is requisite to promote biomass energy through new technology (IEA, 2010). Large bioenergy heat and power plants usually have a relatively high capital cost of around USD 1300-2500 $/kW compared to gas or coal plants at around USD 900-2000 $/kW. The supplement from increased depreciation rates would help to reduce this high capital cost barrier and help encourage potential investors to prefer that bioenergy technology (IEA, 2007b). Much experience already exists with commercial medium- and large-scale biomass based combustion systems to produce power/heat and CHP (see Ch. 3.2.4.1.6). Associated equipments and related components are also included, for example, boilers, steam turbines, gas turbines, generators and equipment for gas cleaning and for filtering. Bioethanol (1^{st} generation biofuels) may drive demand for equipment for fermentation, distillation, and purification. As is evidenced in developing countries with renewable energy targets, by the increased demand for these technologies – knowledge and products – will likely continue to climb up. However, local participation is critically important to the process of adapting technology to local needs and conditions, ensuring that bioenergy implementations are based on locally appropriate technologies (Jha, 2009).

For Thailand, in the past, much attention has been given to lower-value forms of bioenergy - such as those used for domestic heating, cooking, and lighting purposes. However, to choose the technologies suitable for the country, these can be arranged under the following different categories:

1) electricity generating technologies;
2) heat production technologies;
3) combined heat and power (CHP)-based technologies;
4) cooling technologies;
5) cooking technologies;
6) lighting technologies;
7) energy efficiency-based technologies; and
8) MSW to energy-based technologies.

Moreover, Thailand also tried to set up a long term for bioenergy technology implementation. This can be summary here (Morgera et al., 2009):

- **Short term (2008 - 2011):** to emphasis on promotion of commercial alternative energy technologies and high potential energy sources such as biofuels, co-generation from biomass and biogas with fully supports from measures provided.
- **Mid term (2012 - 2016):** to focus on development of alternative energy technology industry, encourage new alternative energy R&D to achieve economic viability including new technologies for biofuels production and introduce a model development of Green City to communities for sufficient economy and sustainability development.
- **Long term (2017 - 2022):** to enhance utilization of new available alternative energy technologies i.e. hydrogen, bio hydrogenated (BHD), extend green city models throughout Thai communities and encourage to be hub of biofuel and alternative energy technology exports in ASEAN region.

More than a decade, the new technologies from the EU have been introduced to the ASEAN rice, sugar, palm oil, and wood sectors. The SPP programmes have been offering the possibility for agro-industries to generate energy for their own from their excess biomass residues. Furthermore, their surplus power can be sold to the national grid too. The study of these programmes found out that cogeneration in most **sugar mills** today is still limited to outdated equipment using conventional steam thermal technology based on old cogeneration plants. For **oil palm mills**, power demand in these industries are generally met by operating low-pressure horizontal fixed-grate three-pass boilers of a simple design producing saturated steam at 15-20 bars. However, more efficient energy conversion technologies that utilize all solid palm oil residues, including EFBs, are currently available and are being implemented. Thus, palm oil factories have the potential of generating large amounts of electricity using their own residues. This extra power can be exported to the national grids. There are very few installations of cogeneration systems in rice mills in ASEAN due to their small plant size by nature. Cogeneration systems with medium pressure boilers (over 30 bar) and efficient extraction condensing turbines seem to meet the challenges posed by rice husk disposal (Lacrosse and Shakya, 2004).

There is still room for efficiency improvements of bioenergy in Thailand, however the lack of information and technology understanding are large barriers. Technical barriers for new technology adoption in the country were resulted from the lack of standards on bioenergy systems and equipments, which is usually the case for technology-imported countries and especially where the energy sources are so diverse. It is difficult for a power developer to procure technology without performance insurance. Therefore, the competitiveness of the various bioenergy technologies varies from close to competitive to far from. In addition, as new and advanced biomass energy technologies are still very young in the market, it is generally difficult to make profit from them and hardly to attract public interest to co-work in the field. Therefore, it is necessary that human resource development be properly planned to support the promotion of bioenergy applications. Unfortunately, the Ministry of Energy does not yet have any clear policy on human resource development for this field of activity (Prasertsan and Sajjakulnukit, 2006).

5.5.2 Strategies for future technologies

Since new plant designs and immature technologies are often found in bioenergy industries today, the risks can be partly alleviated by well design and by long term (5-10 years) warranties of spare parts from equipment manufacturers. Construction risks of new plant can be overcome by fixing contract price and purchasing insurance cover against delays and liability. Biomass for fuel production - due to biological origin - are often bulky, have a high moisture content, as well as are usually variable and unpredictable quality. For simple combustion systems, these variations in bio-feedstocks have only little impacts within reasonable bounds, however other conversion equipments such as gasifiers, gas engines, and other internal combustion engines commonly require fuels to be within stringent specifications if they are needed to operate satisfactorily or to maintain manufacturers warranties. Biomass standards for energy purpose are therefore necessitated to maintain quality within clearly defined specifications (IEA, 2007b). The storage of biomass is often necessary due to its seasonal production versus the need to produce bioenergy all year round. Therefore to provide a constant and regular supply of fuel for the plant requires either storage or multi-feedstocks to be used, both of which tend to add cost to the system (IEA, 2007b). Beside, only certain feedstocks with high energy density (*e.g.* woody biomass or coffee shells), are suited for long-distance transportation. However, it can then be converted in the nearby bioenergy plant to more transportable forms of energy carrier if not to be utilized on-site.

To succeed in modern technology adoption, the suggestions by the IEA Bioenergy on a sensible way forward for bioenergy technology include:

1) Development of new and improved biomass conversion technologies will be essential for widespread deployment and long-term success;

2) For power and heat production - more efficient advanced technologies, such as gasification and advanced steam cycles (see Ch. 3.2.4), and technologies with improved economics at a smaller scale to allow for more distributed use of biomass; and

3) For novel biomass - upgrading technologies and multiproduct biorefineries, could contribute to the deployment and overall cost-competitiveness of bioenergy.

Moreover, where additional biomass is required to ensure a the long term sufficient fuel supply for an existing bioenergy conversion plant, then increased efficiency of conversion processes, multi-feedstock supplies, or possibly the more costly option of growing energy crops should be considered (IEA, 2007b).Technology transfers also involve, however, the shift of know-how that can be protected by trade secrets or other forms of intellectual property agreements. The number of patents registered in the renewable energy sector will indicate the extent to which renewable technologies, including bioenergy, are likely to be commercially exploited in the countries where the patents are registered. Nevertheless, patents are not the only intellectual property protection that can be granted to a new technology (Jha, 2009). Thus, the focus is not merely on appropriate technology imports, but on a means of applying more technology development locally as well.

Although countries in the Southeast asia (including Thailand) have taken measures to protect the environment and to control the rate of exploitation of resources, they still continue to face difficulties such as institutional and technological limitations. Investment costs for bioenergy plants can be partly overcome by increasing the depreciation rates on plant and equipment for tax purposes. This would reduce the investment payback period, increase the return on investment, and hence help to alleviate the capital investment and long payback period barriers that bioenergy plants currently face (IEA, 2007b). In this context, Thailand lacks imposition of a mix of such policy mechanisms to support renewable energy such as Feed-in-Tariff (FIT), tradable green certificates, or environmental taxes. Bankers and financiers should be invited to become more involved during the project development process in order to fully understand the issues of bioenergy investments. For those issues example, delivered forest residues can cost double compared to that of coal at the plant gate, but the savings in CO_2 emissions and other environmental costs are rarely accounted for (IEA, 2007b). Apart from manufacturing and provision of spare parts and maintenance by indigenous technology for biomass energy, the biofuel conversion requires highly skilled engineers - for Cameroon, Tanzania, and Thailand - human capital is a bigger constraint, and significant capacity building would be required to successfully adopt second-generation biofuel technologies (IEA, 2010).

5.5.3 Development pathways and the role of Thai Government

To support ambitious goal of the country for bioenergy programmes, Thailand requires not only huge investment from both local finances and foreign direct investment, but also the role of the Government to encourage further actions in this business. The Governments play an essential role in determining the course and crucially the scale of biofuel development, in particular by means of incentives such as tax exemptions, price controls, targets, and direct subsidies. Many bioenergy projects are technically feasible, but investments do not proceed because other forms of energy appear to be more cost competitive. A significant barrier results where the relatively high costs for bioheat, biopower or biofuels cannot compete on purely economic terms with fossil fuels used to provide the same amount of useful energy (IEA, 2007b). The concept of providing a level playing field to enable true cost comparisons to be made that include all subsidies, co-benefits etc. is often suggested but rarely achieved in practice. In Thailand, there have been several endeavors to draft the energy law (Koomsup and Sirasoontorn, 2008). Also, a larger budget has been made available for the provision of technical assistance to the private sector as well as funding for pilot projects for new or unfamiliar technology. But other policy mechanisms will probably also be needed to help make decisions about how much land and which land should be allocated to bioenergy feedstock production. The market alone – reallocating land as its value rises in response to new demands – will not be an adequate mechanism to prevent unacceptable competition[87] (Larson and Kartha, 2000).

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[87] see Azar and Larson, “Bioenergy and land-use competition in Northeast Brazil”, in this issue)

The appropriate policy on biofuel production needs to follow strict these principles, Criteria, Indicators, and Monitoring:

1) Principles; e.g.: no competition with food, net energy gain, and resource conservation (land, biodiversity, etc.);

2) Criteria; e.g.: best agricultural practices, economical competitiveness;

3) Indicators; e.g.: carbon loss paid back < 10 years, positive net energy balance; and

4) Monitoring; e.g.: GHG-emissions, energy input and output, life-cycle accounting.

Therefore, the suggestions from IEA Bioenergy (2009) about bioenergy development under state mantle can be conclude here:

1) Policies should take into account the development stage of a specific bioenergy technology, and provide incentives consistent with the barriers that an option is facing. Factors such as technology maturity, characteristics of incumbent technologies, and price volatilities all need to be taken into consideration. In each development stage, there may be a specific trade-off between incentives being technology-neutral and closely relating to the policy drivers, and on the other hand creating a sufficiently protected environment for technologies to evolve and mature.

2) There are two classes of currently preferred policy instruments for bio-electricity and renewable electricity in general. These are technology-specific feed-in tariffs and more generic incentives such as renewable energy quotas and tax differentiation between bioenergy and fossil-based energy. Each approach has its pros and cons, with neither being clearly more effective.

3) Long-term continuity and predictability of policy support is also important. This does not mean that all policies need to be long-term, but policies conducive to the growth of a sector should have a duration that is clearly stated and in line with meeting certain objectives, such as cost reduction to competitive levels with conventional technologies.

4) The successful development of bioenergy does not only depend on specific policies which provide incentives for its uptake, but on the broader energy and environment legal and planning framework. This requires coordination amongst policies and other government actions, as well as working with industry and other stakeholders to establish a framework conducive to investment in bioenergy.

For additional recommendations by other studies, they can be summarized following:

1) The main measures used in developed countries to stimulate renewable energy markets have been (Jha, 2009):

- Laws requiring utilities to purchase all electricity generated from renewables;
- Laws requiring renewables to be a certain percentage of all power generation;
- Subsidies for investments in component manufacturing;
- Exemptions or reductions in taxes for component manufacturers;
- Preferential tariffs for electricity from renewables.

2) Strict regulations are in place in many countries to ensure air, water, or land pollution not occurs (IEA, 2007b).

3) For large projects, obtaining expert legal advice on these matters is unavoidable (IEA, 2007b).

4) The importance of identifying pre-existing uses of biomass or the land on which it is grown and satisfying these needs within the proposed bioenergy system or through other means.

5) So much of the discussion of the past decade on renewable fuels has been driven by supply-side considerations – namely costs and technologies. But the key to getting these new industries off the ground – as in every successful case of deliberate industry creation – is to influence demand – in this case, the demand from the automotive industry for cars that run on biofuels, and demand from the motoring public for such biofuels (Mathews, 2006).

6) From 5, rebound effects are an important consideration, when assessing the potential benefits of new and more efficient technologies. For example, ethanol blends have the potential to improve vehicle efficiency, but such efficiency gains could be reduced or even negated if biofuel adoption reduces the cost of fuel, and therefore provokes an increase rather than a decrease in overall consumption.

7) To become economic within the next decade without introducing direct supporting policies, this will occur unless the bioenergy business can produce multi-products or demonstrate co-benefits such as acting as a hedge against future fuel supply risks.

5.6 Recommendations for better management in biomass energy generation for Thailand

Because bioenergy systems are both land- and labor-intensive, they interact intimately with their local environmental and socioeconomic contexts. If designed well, bioenergy systems will contribute to sustainable livelihoods and help address environmental problems such as land degradation or agricultural waste disposal. However, on the other hand, improper systems can exacerbate social inequities and intensify pressures on local ecosystems. Beside, poor rural populations are perhaps most at risk of adverse socio-economic and environmental impacts. For this reason, the proposed bioenergy activities must be scrutinized and judged along several dimensions: how do they contribute to: 1) satisfying basic needs; 2) providing income opportunities; 3) promoting gender equity; 4) efficiently and equitably using land resources; and 5) promoting the health of the local environment. In this main section, environmental and social aspects will be discussed in order to find the best management in bioenergy industry for the most Thai society.

5.6.1 Environmental aspect

Energy access and environmental sustainability are inextricably linked. Without access to sustainable energy services, the improper use of indigenous energy sources in developing countries, such as traditional biomass, often leads to environmental degradation and resource scarcity, which place further pressure on energy supply (Saghir, 2006; Bugaje, 2006; Plas and Abdel-Hamid, 2005). Different biomass products suit for different situations. Beside, bioenergy feedstock should not be produced: 1) in lands with high biodiversity, 2) from natural forests 3) from places of high levels of carbon concentration (Savannas, Peat, etc.). Specific objectives for utilizing biomass are usually governed by: 1) the quantity, quality, and cost of the feedstock available; 2) location of the consumers; 3) type and value of the energy services required; and 4) any specific co-products or benefits that result. For example, where landfills, effluents, animal manures, wet process wastes, or sewage treatment plants are involved as waste-to-energy projects, odor pollution can be a nuisance and may need controlling (IEA, 2007b). Emission estimation from power plants was based primarily on both fuel consumption and power plant type; however, emissions vary widely by - the biomass source, fuel characteristics, combustion temperature, etc. Therefore, specific monitoring and analysis may be required.

Table 5.2: Least-cost GHG mitigation for Thailand

Mitigation Options	Energy and Transformation	Industry	Residential and Commercial	Transportation
Improving efficiency of existing facilities		√	√	
Adopting more energy efficient techniques in new capital stock	√	√	√	√
Utilizing low/zero emissions energy sources	√			

Source: Adapted from ADB, 1998 by Todoc (2004)

Although -on global level- the increase in renewables based power generation is mainly estimated to take place in hydro and wind production, the biomass and solar based production is also estimated to increase later on (IEA, 2008). The *World Energy Outlook 2009 Scenario 2* analyses how future energy demand could evolve up to 2030, if countries take coordinated action to restrict the global warming (limitation of temperature increase to 2°C). Under such CO_2-constrained conditions, biofuels could provide 9% (11.7 EJ) of the total transport fuel demand (126 EJ) in 2030, with roughly 7 EJ of this being second-generation biofuels. In this scenario, biofuels are one of the most important technologies to reduce transport emissions, after improved efficiency and plug-in hybrids and electric vehicles (IEA, 2010). IEA (2008) does not estimate huge increase in solar power production, because IEA do not believe in any major technological breakthrough in solar panel production, but estimate just slow decrease in production costs only due to increased automation in production and slight increase in efficiency.

The World Bank estimates that air and water pollution costs for Thailand are about 1.6-2.6% of GDP per year (World Bank, 2002). More specifically, airborne particulate matter was estimated to have caused 3,300 premature deaths and to have led to almost 17,000 hospital admissions, at a total health care cost of up to US$ 6.3 billion. Improving local environmental quality therefore brings tangible economic and health benefits. The power generation sector accounts for 12% of air pollution in Thailand, estimated at around 280,000 tonnes of sulfur dioxide (SO_2) emissions for 2002 (Mulugetta et al., 2007). Air pollutant emissions from biomass such as CO and TSP (Total Suspended Particulates) were high due to lower efficiency and incomplete combustion of biomass-fired electricity generation plants (Santisirisomboon et al., 2001; Santisirisomboon et al., 2003). If this problem is considered in new biopower project evaluation, there is a good chance for a modern technology. Table 5.3 below also shows the estimated death caused by indoor and outdoor air pollution in 2002 in various countries. Additionally, the agriculture sector in fact is responsible for most of the methane (CH_4) emissions, which accounts for a significant amount of GHG emissions and making methane an important GHG after CO_2. At the moment, there is little incentive for investment in CO_2 reductions alone in Thailand. It means looking at two possible avenues: exploring the emissions trading profit following CDM portfolio or reducing local air pollution as a matter policy priority (Mulugetta et al., 2007). The latter option is discussed below.

Table 5.3: Estimated deaths caused by indoor and outdoor air pollution in 2002

Country	**Indoor air polltion**		**Outdoor air pollution**	
	Population using solid fuel (%)	Deaths per year	Annual PM (mg/m^3)	Deaths per year
Cambodia	>95	1,600	51	200
Indonesia	72	15,300	114	28,800
Malaysia	<5	<100	28	500
Myanmar	>95	14,700	75	3,900
Philippines	45	6,900	34	3,900
Singapore	<5	-	48	1,000
Thailand	72	4,600	77	2,800
Viet Nam	70	10,600	66	6,300
World	52	1,497,000	61	865,000

Source: modified from Zhang (2008)

To produce energy crop, land use change will only happen on a large scale if the landowners can gain more revenue or other benefits from growing a new energy crop than is being received from the traditional crops currently being grown. A grower should consider the implications of water demand and rainfall when choosing a species and variety, not only on the biomass yield but also on any downstream water users (IEA, 2007b). Intensive agriculture would require higher inputs of fertilizer and irrigation water, which are concerns regarding the sustainability of bioenergy measures (IEA, 2010). Many biofuel technologies may still pose similar problems because they will depend on large-scale monocultures that threaten biodiversity, food production, or land rights. In the longer term genetically modified crops grown specifically for energy purposes may become feasible and accepted perhaps more so for energy crops than for food ones (IEA, 2007b). However, nutrients should be returned to forests and land through ash from biomass combustion to alleviate nutrients loss and need for fertilizers (see Ch. 4.X). Using secondary residues as feedstock is expected to have only little negative impact on the environment, since these residues are usually disposed at the processing site and not returned to the field. Because soil nutrient levels may be depleted gradually if large quantities of biomass material such as crop residues are removing continually from the same land for long term to supply nearby conversion plants, this problem must monitored carefully (IEA, 2007b). However, with the cultivation on vulnerable tropical soils in Thailand, such energy crop plantations could contribute to reduce advancing degradation with both environmental and social benefits. The soil carbon stock can be increased through both roots and leaf litter (IEA, 2010).

5.6.2 Social aspect

Employment[88] is one of the key functions in bioenergy industry. Among various renewables, bioenergy is the most labour-intensive technology and has the highest employment-creation potential. However, the level at which it can contribute depends on local demographic and economic conditions (Domac et al., 2005). As a labour intensive technology to local, regional, and national employment - the main issue is: will the bioenergy project

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[88] What does the term **employment** from the perspective of bioenergy projects mean? **Direct employment** results from operation, construction, and production. In case of bioenergy systems, this refers to **total labor** necessary for crop production, construction, operation, and maintenance of conversion plant and for transporting biomass. **Indirect employment** is jobs generation within the economy as a result of expenditures related to fuel cycles. Indirect employment results from all activities connected, but not directly related, like supporting industries, services and similar. The higher purchasing power, due to increased earnings from direct and indirect jobs may also create opportunities for new secondary jobs, which may attract people to stay or even to move in. These latter effects are referred to as **induced employment** (Domac et al., 2005).

provide earnings that are high enough to make it worthwhile to mobilize local resources for implementation? There is little doubt that biomass can provide useful employment both for agricultural workers, possibly in the off-season when some harvesting or processing of energy crops can be carried out, and also for skilled and unskilled workers at the bioenergy processing plant. Since bioenergy technology implementation depends on securing a reliable supply of sustainably produced biomass, it can create much needed employment opportunities in rural areas (Fig. 5.5). Beside, the increased deployment of modern bioenergy generation as a reliable and affordable source of energy could be part of the solution to overcoming their current constraints concerning GDP growth. Job creation and regional growth would probably be the most important drivers for the implementation of biofuel production projects, especially the second generation, in both major economies and developing countries (IEA, 2010).

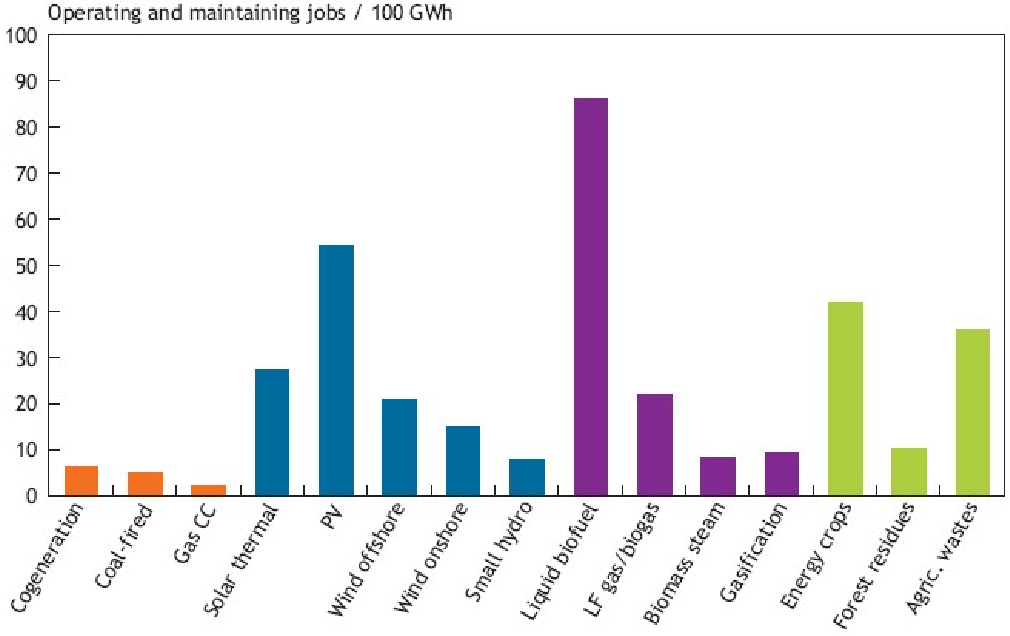

Fig. 5.5: Employment requirements[89] for energy projects
Source: IEA (2007b)

Due to the expected increasing demand for bioenergy and biomaterials, costs for feedstocks are likely to increase. With regard to the domestic economy, production of second-generation biofuels based on agricultural residues could be beneficial to farmers, since it would add a value to these byproducts. For residue production, moreover, existing farm labor could be used, which could extend employment periods after the harvesting season. This may lead to reduce the necessity to support farmers and smallholders (IEA, 2010). However, the collection and transport of biomass can result in increased use of vehicles, higher local air emissions from their exhausts, and greater wear and tear on the road infrastructure. Who should pay for the extra costs is difficult to determine. Where the roads are maintained by higher charges placed on local ratepayers, most of whom receive little benefit from the passing of heavy trucks through their district, the problem is hard to resolve (IEA, 2007b). The implications of biofuel expansion for human health have received less attention than some of the other costs and benefits. Some biofuels are likely to generate health benefits. For

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[89] Labour is required for operating and maintaining various renewable energy projects after their construction, with bioenergy projects also requiring additional labour to produce and deliver the biomass to the plant.

example, diverting sugarcane bagasse to ethanol production instead of burning it in the field reduces several forms of air pollution harmful to health. In the case of low bioenergy technology, not only is the heat from the burning wasted, but because of poorly designed chimneys, the indoor air pollution is more severe.

Within economical viewpoint, renewable energy projects have natural socio-economic advantages - e.g. the use of local fuel (i.e. for biomass projects), potential income flows to communities and reduced outflow of foreign exchange - and environmental benefits. These benefits must be weighed against the generally higher cost of delivered energy from renewable sources. Access to culitvated land is a fundamental precondition in realizing the potential role of agriculture in reducing poverty. Unfortunately, one of the side effects of biofuel targets is a “scramble to supply”, in which companies or powerful investors rush to buy up new land, potentially displacing vulnerable communities, whose rights to the land are poorly protected. Limitation by socio-political acceptance (community and market agreement) is also seen as constraining factor in achieving renewable energy targets in many jurisdictions (Wüstenhagen et al., 2007). These are important issues because effective knowledge networking and effective communication between government institutions and local people are seen as a first step to encourage further market penetration of renewable energy systems (Nguyen, 2007).

Table 5.4: Benefits associated with local bioenergy production

Dimension	Benefit
Social Aspects	Increased Standard of Living (Environment/Health/Education) Social Cohesion and Stability Migration effects (mitigating rural depopulation)/Regional development/Rural diversification
Macro Level	Security of Supply / Risk Diversification Regional Growth Reduced Regional Trade Balance Export Potential
Supply Side	Increased Productivity Enhanced Competitiveness Labour and Population Mobility (induced effects) Improved Infrastructure
Demand Side	Employment Income and Wealth Creation Induced Investment Support of Related Industries

Source: Domac et al. (2005)

The most of the community in Thailand are still inattentive to different types of sustainable energy technologies and their benefits. Hence, this kind of barrier could be overcome with the training programs to assist public understand the actual benefits from those technologies. If the industry is new in the local region, then prepared, printed, and presented educational material can be a useful tool to explain what the plant will look like and what all the possible impacts might be (IEA, 2007b). Education and technology promotional campaigns would act almost as a panacea for overcoming most of the barriers (Adhikari et al., 2008). Finally, the demand for energy is expected to rise dramatically in Asian region within the next few decades, as industrial output continues to grow in this region. As a highly leading industrialized member of the region, Thailand has a high energy demand in industries sector. Because biomass is mostly used as fuel in rural households and industries, there is much potential for the development and generation of bioenergy utilized in the country properly.

5.7 Summary

Thailand relies heavily on energy imports due to the limitation in indigenous energy resources. At present, petroleum products account for half of its total final energy consumption and almost of them is imported, while predominant source of electricity is natural gas, partially imported from Burma, Indonesia, and Malaysia (see Ch. 1.2). Therefore, the energy situation of the country is quite insecure. For many years Thailand has attempted to reform its energy sector. These endeavors started long before the first financial crisis in 1997 (Koomsup and Sirasoontorn, 2007). The country also highlights the importance of promoting energy efficient solutions to save natural resources and limit CO_2 emissions. Although Thailand has a huge potential for renewable energy utilization, its total amount of generated energy from renewables is relatively small but could be enlarged substantially. Thailand has therefore introduced many aspects of financial support to renewable energy especially for bioenergy programme, namely: subsidies to SPPs and VSPPs useing renewable energy, funds for research and development in areas related to renewable energy technologies, and financial incentives via various agencies that adopts or implements renewable energy projects in form of tax exemption, low interest rates, and guaranteed power price. Moreover, Thailand has also focused on grid-connected biomass-based renewable energy programs[90], but this is still facing some barriers. The key objectives of using these types of generation are summarized (Lidula et al., 2007):

- To promote power generation using non-conventional energy to diversify the mixed generation in Thailand
- To promote efficient use of domestic energy resources
- To reduce power generation using import/commercial fuels
- To decrease the environmental impact
- To distribute power generation to rural areas
- To encourage public participation in power generation.

The main target in energy sector for Thailand is to balance security of energy supply, environmental impact, and economical competitiveness. Because no single system will be capable of meeting all future requirements, a portfolio of technologies will be necessary. With a view to strengthening national energy security and competitiveness, the current strategies of the energy sector focus on four priority areas (EPPO, 2003): 1) Energy efficiency; 2) Development of renewable energy; 3) Enhancing energy security; and 4) Development of Thailand as a regional energy centre. Although a Long Term Energy and Climate Strategy are under preparation, environmental issues are driven by political considerations. Besides, Thailand is an important member of several international organizations, such as WTO, APEC, ASEAN and GMS. A number of agreements have been signed in order to strengthen the relationship and political power in the region. Occasionally, some of agreements have conflicted with national policy agendas. For instance, Thailand wishes to import more energy from neighboring countries; however, national policy emphasizes decreased import dependency. Such conflicts could obviously affect other sectors of the economy.

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[90] Although the energy mix for power generation is not expected to change significantly, those countries that increase the amount of renewable energy in their mix will need to address grid reliability.

The Kyoto Protocol and other international accords[91] are driving new types of energy generation, in particular renewable energies with low CO_2 emissions. Nevertheless, the fossil fuels have been dominant because of affordability (not more available for long term) and existing process technologies. Hence, the policy decisions in the coming years have to be very cautious to manage that use better. The carbon foot print[92] can be controlled by substituting natural gas, petroleum products, and coal in the primary energy mix, mixing up of renewables with fossil fuels, replacing with nuclear energy, capturing and sequestering CO_2 and improving the efficiency of the current process technologies. Especially, the mix up of alternative sources, renewables and fossil fuels in the overall energy mix are promising options to mitigate the thread of irreversible global climate change. Countries have already started to formulate a holistic and robust energy policy and investing significantly for the clean and sustainable energy programs (Thavasi and Ramakrishna, 2009).

Further development of bioenergy technologies is needed mainly to improve the efficiency, reliability and sustainability of bioenergy chains. Besides, an increase in the production of bioenergy must be based on a sustainable use of biomass. This necessitates the increased use of biomass for energy purposes to be realized without any negative impact on food production or biodiversity (Stangeland, 2007). In Thailand, coordination among relevant institutions and greater private sector participation could enhance the adoption of the modern bioenergy generation technologies. Policies intended to stimulate the growth of renewable energy can have diverse effects. A decision to replace 5-10% of a country's electrical supply within a short timeframe can be achieved. Concerning consumer protection, the Act of Renewable Power should requires licensees to meet the technical, engineering, and service quality standards set by the Regulator. If bioenergy feedstock production displaces other local biomass needs or intensifies local environmental pressures, the Act should introduce a fund to be set up to compensate those licensees who provide services to low-income consumers or remote areas at prices below actual costs. Apparently, this is to be used as a tool to support the social objective of uniform tariffs and rural electrification.

For the biofuels, able to make a large and sustainable contribution to the world energy economy, governments will need to enact consistent, long-range, and coordinated policies that are informed by broad stakeholder participation. Optimization of the biofuel productions will be determined by the type of feedstock, conversion efficiency, costs, and GHG emissions reduction. Policy priorities should include these following aspects: 1) Strengthen the market. 2) Speed the transition to next generation technologies; 3) Encourage broad rural economic benefits and protect the resource base; 4) Facilitate sustainable international biofuel trade; and 5) Efficiency and improved public transport. Among various renewable technologies under various studies for Thailand, biogas for power generation and biomass for energy production have very higher potential than other renewables, therefore they should be considered as the highest priority option to fulfill the energy demand of the country.

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[91] For example: the sixth Conference of Parties (COP6, 2000) in the Hague of Netherland, COP6bis (2001) in Bonn of Germany, COP7 (2001) in Marrakech of Morocco, COP13 (2007) in Bali, or the first Meeting of the Parties to Kyoto Protocol (MOP1, 2005) in Montreal of Canada.

[92] A carbon footprint is made up of the sum of two parts, the primary footprint and the secondary footprint. The **primary footprint** is a measure of our direct emissions of CO_2 from the burning of fossil fuels including domestic energy consumption and transportation (e.g. car and plane). The **secondary footprint** is a measure of the indirect CO_2 emissions from the whole lifecycle of interested products.

The new bioenergy technologies can not only improve the energy efficiency and nation’s energy security, but also increase the competitiveness of private entities. However, the rate of development and diffusion of newer technologies raise questions over the future scale of investment that will be required. Challenges to the advancement of renewables in Thailand include policy and institutional aspects, technology, finance and investment, information and knowledge, public support as well as realizing externalities. An effective way to help ensure that bioenergy projects fulfill local needs is to engage local participants, but the Thai public still requires the motivate support and accelerate learning processes in modern bioenergy technology. The commercial production and conversion of biomass is rurally based and labor-intensive, and can thereby provide important employment opportunities. Biofuels introduces the trade-offs involved in turning agricultural products into transportation fuels. In Thailand, a detailed look on ethanol and biodiesel of the first generation biofuel had been in well progress, but this may raise food prices in the future. On the other hand, the development of second generation biofuel still not overcomes. Biofuels production is often associated with farmers in rural or poor areas. It has the potential to produce new incomes for farmers while generating new jobs and new business to alleviate poverty and improve farmers’ life standards (Yan and Lin 2009), especially the second generation biofuel. Finally, Thailand also needs to support indigenous technology for bioenergy. Compared this to earlier sustainable development criteria’s from the Thai DNA (ONEP, 2006), focus on the ‘local content’ has been intensified.

Chapter 6: Conclusion

As the age of cheap energy resources comes to its end, the exploration of new energy sources will play an important role at a global level. Energy sources have been generally grouped into three categories: fossil fuels (e.g. coal, petroleum, and natural gas), renewable sources, and nuclear sources (Demirbas, 2000a, b; Parikka, 2004). To meet environmental and energy security objectives across the country around the world, the use of renewable energy sources is rapidly expanding as a to response these ambitions. Among the various renewable energy technologies (e.g. hydroelectricity, wind farm, photo-electricity/heat), only biomass technology allows for a diverse group of energy forms (e.g. heat, electricity, biofuels), offering an umbrella of different operating conditions. Bioenergy covers the whole spectrum of applications from economically competitive and mature technologies (such as produced heat production from industrial byproducts in forest industries) to higher cost and less technically mature options (such as generated electricity through gas engines using biogas from dedicated energy crops at the farm scale). Also, many reasons are devoted for developing bioenergy systems (security of energy supply, reduction of greenhouse gas emission, development of rural regions etc.). However, the negative effects of the expansion of bioenergy use are frequently questioned, especially competition for feedstock or production resources, such as land or water.

The three main routes for generating modern energy from biomass that are available are: thermo-chemical, bio-chemical, and mechanical extraction systems. The thermo-chemical conversion technologies are pyrolysis, gasification, and liquefaction. Biomass can be burned to produce heat and electricity, changed to gas-like fuels such as methane, hydrogen, and carbon monoxide, or transformed to a liquid fuel. Liquid fuels, known as biofuels, generally include mainly two forms of alcohol (ethanol and methanol) and a well know biodiesel, Fatty Acid Methyl Ester (FAME). Bioethanol, biodiesel, and diesel-like from biomass by Fischer-Tropsch synthesis are modern biomass-based transportation fuels. Biomass cogeneration is also one of the modern technologies to produce both heat and power from biomass, solid wastes, and agricultural residues. This advanced technology has made modern biomass cogeneration plants more efficient, environment-friendly, and under certain conditions cost-effective compared to public utility grids and fossil-fuel boilers or generators. Gasifiers are used to convert biomass into a combustible gas. The combustible gas is then used to drive a highly efficienct, combined cycle gas turbine. Besides, combustible gas energy from gasification devices or anaerobic digesters can be applied in reciprocating engines, turbines, micro turbines, fuel cells etc. The coupling of biomass gasification with gas turbine power generation is promising for modernizing biomass-based electric power generation at a scale of 30-100 MW_e.

In Thailand, where biomass is abundant and a relatively low value product, most bioenergy practices like at present is devoted mainly for traditional local use or small-scale industry with low energy efficiency, outside the commercial energy market. Traditional combustion technology is also often poorly controlled, leading to toxic components in the smoke, which is detrimental to one’s health. A significant fraction of this biomass use does not fulfill basic requirements and sustainability of the Thai’s society. Thanks to the new policy, however, renewable sources are targeted as one of the alternative energy sources that have a high potential to fulfill the soaring energy demand of the country. The government has declared their goal to increase the level of renewable energy utilization from just 0.5% in 2003, to a figure of 8% (approximately 6,600 KTOE) by the year 2011. To reach this ambitious scheme for renewable energy, biomass-based energy is expected to take the biggest share of 60% from this 8% target or about 3950 KTOE.

With this 8% goal, the government is encouraging the power generating sector to produce electricity around 1,900 MW_e from renewable sources. Apart from ongoing Small Power Producers (SPP) and Very Small Power Producers (VSPP) programs, Independent Power Producers (IPPs) are asked for joining the Renewable Portfolio Standard (RPS), which has been introduced to accelerate renewable energy utilization. Under this standard, private power producers who wish to sell power to the Electricity Generating Authority of Thailand must produce 5% of their installed energy generating capacity from renewable sources. Nevertheless, it should be noted that biofuels, bioethanol (gasohol) and biodiesel, are readily penetrated to the Thai energy market, but their sustainability is still doubtful due to their generation from the first biofuel technology, so the competition between food and fuel still remains. Currently, bioethanol is produced mainly from cane molasses and cassava roots, however sugarcane can be switched to be used as feedstock if necessary but thereby facing higher costs and food competitions. Conversely, although biodiesel was introduced to the public at the same time in Thailand, bioethanol has successfully penetrated into the market before biodiesel thanks to its readiness in feedstock supply. Biodiesel has faced a feedstock distributing problem, since it was first promoted. Its main feedstock is oil palm requiring 3-4 years for bearing the fruits. Moreover, an expansion of oil palm plantation areas is not easy due to limited suitable areas in the South of Thailand. Therefore, its new cultivation area has been planned to expand in other areas such as the north eastern parts of Thailand or neighbouring countries.

To support the alternative energy programme and alleviate the food threaten by this energy scheme, the increase in cultivated area or crop yield improvement is necessary. Therefore, the potential of the residues from agricultural sector and wood-based industry, coinciding with the ambitious renewable target, ~~is~~ has revealed that the biomass from these two main suppliers has a significant potential for energy production equivalent to 596 PJ by 2009, 648 PJ by 2011, and 872 PJ by 2016, or about 13%, 10%, and 9% of total energy demand in each year, respectively, based on the county’s historical yields, prospective yield by different literatures, and national goal (both planted area and yield target). The study shows that a biomass supply chain has a significant potential for energy production. The strategy of using these excess agricultural residues as a source of biomass for large-scale and local-scale energy production is also developed in a circumstance where agricultural residues are abundant and under utilized to cover the hauling costs. A case study has been demonstrated how to choose the suitable technology for electricity generation under various critical constrains including project cost, technical availability, environment, regulatory and state policy, as well as social and logical constraints. The result shows that the low temperature circulating fluidised bed combustor (LT-CFB) is the best option for rice straw feedstock to generate electricity between 4-6 MW_e, while the downdraft fixed bed (DFB) gasifier is the compromising technology for cassava rhizome with capacity below 1 MW_e for local application. The method applied in this case study can provide ample visibility for other countries, where the concern about the optimal technology to deal with their biomass residues devoting for energy use with design of the facility and the fuel supply chain is still open.

The Thai government has promoted the use of biomass energy since 1992. Among the driving forces, the concerns about dependency on fossil fuel imports, the environmental impacts from fossil fuel use, and the realization of climate change effects are mostly mentioned. Any biomass utilization is also influenced by local context - including location relative to supply and demand, infrastructure, climate and soil, land and labour availability, as well as social and governance structures -, therefore the initiatives support the modern technology to enter the market easily and the reduction of barriers specific to non-liberalized energy markets is still necessitated. Although Thailand has introduced non-financial support mechanisms, including standard power purchase agreements (PPAs), preferential arrangements for small generators and information support, an effective system of financial and non-financial incentives must also be in place to ensure appropriate conditions to exploit biomass potential. Non-economic barriers can also make biomass energy more costly and less competitive against conventional energy technologies.

Important socio-economic benefits of biomass energy should also be referred to, especially stimulation of jobs (direct, indirect, and induce jobs), regional development (odour reduction, local air improvement, local water quality improvement), salinity mitigation and land repair, weed eradication, fire hazard reduction, and new business opportunities. For the last option, an increased use of biomass for energy purposes also means that more and more biomass is internationally traded, in a similar way to fossil fuels. This development is highly advantageous and a prerequisite for the expansion of bioenergy. However, as the volumes of biomass for energy being traded internationally grows, so the impact on the trade of other products also increases, with increased scope for both synergy and competition. These will make bioenergy more competitive.

Finally, substantial non-economic barriers, such as infrastructure, grid-related problems, regulatory and administrative hurdles, public acceptance continue to be a major impediment to the use of biomass development for energy. Bioenergy systems also use the same resources of the biomass traditional routes for food, fodder, fertilizer, and raw material for industrial processes. Removal of biomass from farm/forest- land also means removal of mineral nutrients from the soil. A number of studies illustrate that competition between food and fuel most often causes problems when changes occur but are not handled well by both market actors and policy makers. In particular the introduction of a wide range of policy measures designed to stimulate the rapid development of bioenergy may lead to rapid changes in the volumes and types of biomass which are required, or in the energy products which are in demand. The soil depletion is also occurred when biomass is excessively removed from crop land. Therefore, all of this requires right managements to utilized biomass as energy in good manners.

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Appendices

A. SPP generators and lists of Ethanol and Biodiesel Plants in Thailand

Table A-1: SPP generator supplying power to the grid, August 2006

Fuel	Number of Projects	Generating capacity (MW_e)	Sale to EGAT (MW_e)
Non-conventional energy			
Bagasse	31	605.40	181.80
Paddy husk	5	53.40	41.80
Paddy husk and wood chips	2	57.80	49.00
Black liqour	1	32.90	25.00
Municipal waste	1	2.50	1.00
Waste gas from carbon black manufacturing	1	19.00	6.00
Bagasse, wood bark, and paddy husk	3	114.90	64.00
Palm residue and cassava root	-	-	-
Paddy husk, bagasse, and eucalyptus	1	3.00	1.80
Wood bark, wood chips, and black liquor	1	87.20	50.00
Rubber wood chips	-	-	-
Bagasse, paddy husk, other biomasses	2	-	-
Natural gas (byproduct of crude oil)	-	-	-
Corncobs, cassava rhizome, and paddy husk	-	-	-
Total	**48**	**988.60**	**429.90**
Commercial energy			
Natural gas	21	2,277.61	1,465.20
Coal	4	392.20	196.00
Oil	1	10.40	9.00
Total	**26**	**2,680.21**	**1,670.20**
Mixed fuel			
Waste gas from production process/oil/coal	1	108.00	45.00
Black liquour/coal	1	40.00	8.00
Coal and eucalyptus bark	2	328.00	180.00
Total	4	476.00	233.00
Overall total	78	4,145	2,333

Source: http://www.eppo.go.th/power/data cite by Greacen (2007)

Table A-2: List of Fuel Ethanol Plants Currently on Operation in Thailand
Updated on 26 January 2007

Name	Location	Feedstock	Capacity (liter/day)	Commencing Date
Pornwilai International Group Trading Co., Ltd.	Ayuthaya	Molasses	25,000	Oct. 2003
Thai Alcohol Pub., Ltd.	Nakhon Pathom	Molasses	200,000	Aug. 2004
Thai Agro and Energy Co., Ltd.	Suphanburi	Molasses	150,000	Jan.y 2005
Thai Nguan Ethanol Co., Ltd.	Khon Kaen	Cassava	130,000	Jan. 2006
Khon Kaen Alcohol Co., Ltd.	Khon Kaen	Cane/Molasses	150,000	Jan. 2006
Petrogreen Co., Ltd.	Chaiyaphum	Cane/Molasses	200,000	Dec. 2006

Source: DEDE (2008)

Table A-3: List of Biodiesel (B100) Plants in Thailand
Updated on 26 January 2007

Name	Location	Feedstock	Capacity (liter/day)	Commencing Date
Bangchak Petroleum Public Co., Ltd.	Bankok	Used grease oil, CPO, RBD PO	50,000	
Bio Energy Plus Co., Ltd.	Ayutthaya	Stearin, RBD PO	100,000	
Sun Tech Palm Oil Co., Ltd.	Prachin Buri	CPO, Stearin	200,000	
Patum Vegetable Oil Co., Ltd.	Pathum Thani	CPO	300,000	
Bangkok RE. Co., Ltd.	Chachoengsao	CPO	200,000	
Green Power Corporation Co., Ltd	Chumporn	Stearin	200,000	
A I Energy Co., Ltd.	Samut Sakhon	CPO	250,000	
Weera Suwan Co., Ltd.	Samut Sakhon	Stearin, RBD PO	200,000	
Thai Oleochemical Co., Ltd.	Rayong	n.a.	685,800	

Source: DEDE (2008)

B. List of Criteria for Technology Selection

Table B-1: List of project evaluations and their criterions

Year	Name	Main Criteria
2008	The Model of Power Plant Selection Based on Improved Fuzzy Neural Network	1. Economic Factors 2. Environment Factors 3. Social Factors
2008	Fuzzy AHP Assessment of Water Management Plans	1. Economical issues 2. Technical criterion 3. Environment & ambience 4. Social issues 5. Political impacts
2009	A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process	1. Economic 2. Technical 3. Environmental 4. Socio-political
2004	The technology selection process	1. Financial factors 2. Technical factors 3. Environmental factors 4. Institutional factors 5. Community and managerial factors
2003	Linking technology choice with operation and maintenance in the context of community water supply and sanitation	1. Financial sustainability 2. Technical aspects 3. Environmental factors 4. Management capacity
1999	Common Power Plant Siting Criteria	1. Economic Impacts 2. Community Impacts 3. Public Health & Safety Concerns 4. Environmental Impacts 5. Land Use Impacts 6. Site Requirements
1999	Project selection criteria by strategic orientation	1. Financial related criteria 2. Technical related criteria 3. Environmental related criteria 4. Risk related criteria 5. Organizational needs related criteria 6. Management support related criteria
2006	Criteria for Assessment/Selection of Innovative Projects	1. Financial type criteria 2. Technical type criteria 3. Marketing type criteria 4. Organizational type criteria
2007	Evaluation of liquid bio-fuels using the Analytic Hierarchy Process	1. Economic Criterion 2. Environmental Criterion 3. Resource Criterion 4. Potential Criterion

C. Comparison of different types of Biomass Combustion Technologies

Table C-1: General comparison

Parameter	Pile Combustion	Stoker Combustion	Suspension Combustion	Fluidized Bed Combustion
Grate	Fixed / Stationary Grate	Fixed or moving grate	No grate or moving grate	No grate
Fuel Size	Uniform size of the fuel in the range of range 60 to 75 mm is desired & % fines should not be more than 20%	Uneven fuel size can be used	Preferable for high % of fins in the fuel	Uniform size fuel in the range of 1 to 10 mm.
Combustion	Difficult to maintain good combustion due to : 1) Air fuel mixing is not Proper 2) Bed height is in stationary condition resulting in clinker formation 3) Difficult to avoid air Channeling 4) Due to intermittent ash removal system it is difficult to maintain good combustion	The combustion is better & an improved version of pile combustion,. Since most of the fuel is burnt in suspension the heavier size mass falls on the grate. If the system has a moving grate the ash is removed on a continuous basis & therefore the chances of clinker formation are less.	It is similar to stoker combustion, but since the fuel sizes is small & even the combustion efficiency is improved as maximum amount of fuel is combusted during suspension.	It is similar to stoker combustion, but since the fuel sizes is small & even the combustion efficiency is improved as maximum amount of fuel is combusted during suspension.
Bed temperature	1250-1350 ºC	1000-1200 ºC	1250-1350ºC	800-850ºC
Moisture	High moisture leads to bed choking & difficult combustion conditions	Combustion condition not very much disturbed with 4-5 % increase in moisture	Same as Stoker Combustion	It can handle fuels with high moisture condition up to 45-50%, but high moisture in the fuels is not desirable, & adequate precautions are to be taken up in the design stage itself.
Draft Conditions	Natural Draft / Forced Draft/ Balance Draft	Forced Draft / Balance draft	Balance draft	Balance draft
Maintenance	Not much maintenance problems	Frequent problems due to moving grate	Variation in fines in fuel leads to delayed combustion thereby affecting the boiler tubes	Erosion of boiler tubes embedded in the bed is quite often

Source: UNEP-DTIE (2007)

Table C-2: Emission comparison

Resource	SO_x, lb/MWh	NO_x, lb/MWh	CO, b/MWh	PM-10, lb/MWh	Comments
Biomass Technology (Wood biomass -unspecified)					
Stoker Boiler, Wood Residues	0.08	2.1	12.2	0.50 (total part.)	Based on 23 California grate boilers - uncontrolled
Fluidized Bed, Biomass	0.08	0.9	0.17	0.3	Based on 11 California fluid bed boilers
Coal Technology					
Bituminous Coal Stoker Boiler	20.2 (1% S coal)	5.8	2.7	0.62	PM Control only (baghouse)
Pulverized Coal Boiler	14.3	6.9	0.35	0.32 (total part.)	Average US PC boiler (baghouse and FGC)
Fluidized Bed Coal Boiler	3.7	2.7	0.35	0.30 (total part.)	Baghouse for PM, Ca sorbents for SOx

Source: Richard Bain, NREL, Introduction to Biomass Thermal Conversion (2004)

D. Comparison of different types of Biomass Gasification Technologies

Table D-1: Comparison of different gasifier

Characteristics	Fixed bed		Fluidised bed		Indirect gasifier	
	Updraft	Downdraft	Bubbling	Circulating	Char	Gas
Carbon conversion	****	****	**	****	*****	**
Thermal efficiency	*****	****	***	****	***	***
CGE	*****	***	***	****	***	***
Turndown ratio	***	**	****	****	****	****
Start-up facility	*	*	***	***	*****	*****
Management facility	****	****	**	**	*	*
Control facility	**	**	****	****	*****	*****
Scale-up potential	***	*	***	*****	***	***
Sized feed elasticity	****	*	**	**	**	**
Moisture feed elasticity	****	**	***	***	*	*
Ash feed elasticity	*	*	****	****	***	****
Fluffy feed elasticity	****	**	*	***	***	*
Sintering safety	*	*	***	*****	*****	***
Mixing	*	*	****	*****	*****	****
Cost safety	*****	****	**	**	*	*
Tar content	*	*****	**	***	**	**
Particulate content	*****	***	***	**	**	****
LHV	*	*	*	**	*****	*****

Remark: * poor, ** fair, *** good, **** very good, ***** excellent
Source: modified from Juniper (2000) and Bridgwater (1994) by Belgiorno et al. (2003)

E. Current and advanced Biofuel conversion Technologies

Table E-1: Current and advanced biofuel conversion Technologies in the coming year

Reference Name (Feedstock-Product-Process)	Acronym	Feedstock	Conversion Technology	Fuel Type	Size Range* (MGY)	Description
Current Representative Technologies						
Grain to Ethanol - Dry Mill	GEt-DM	Grains / Starches	Enzymatic Fermentation	Ethanol	5 to 100	Dry milling process - grains are ground into a flour, and the starch is converted into sugar and then fermented to ethanol
Grain to Ethanol - Wet Mill	GEt-WM	Grains / Starches	Separation and Fermentation	Ethanol	50 to 300	Wet milling process - grain separated into components and starch is yeast fermented and distilled.
Fatty Acid to Methyl Ester	FAME	Seed Oil / Waste Oils / Animal Fats	Esterification	Methyl Esters	1 to 80	Vegetable oils and fats are filtered and converted via base catalyzed transesterification, producing biodiesel and glycerin, which must be separated.
Sugar to Ethanol Fermentation	SEt-F	Sugars	Fermentation	Ethanol	5 to 100	Sugar crops such as sugar cane are milled and fermented to produce ethanol
New Technologies Projected to be in Use by 2015 to 2025						
Lignocellulosics to Ethanol - Enzymatic Hydrolysis/Fermentation	LnCEt-H/F	Lignocellulosic Biomass	Hydrolysis and Fermentation	Ethanol	20 to 100+	Cellulose and hemicellulose converted to sugars via hydrolysis. Various options for hemicellulose conversion (pretreatment). Conversion of sugars to alcohol via fermentation.
Lignocellulosics to Ethanol - Gasification/Fermentation	LCEt-G/F	Lignocellulosic Biomass	Gasification and Fermentation	Ethanol	50 to 100+	Cellulose and hemicellulose converted to sugars via hydrolysis. Various options for hemicellulose conversion (pretreatment). Conversion of sugars to alcohol via fermentation.

Source: NYSERDA (2010)

Table E-1: Current and advanced biofuel conversion Technologies in the coming year (Continue)

Reference Name (Feedstock-Product-Process)	Acronym	Feedstock	Conversion Technology	Fuel Type	Size Range* (MGY)	Description
New Technologies Projected to be in Use by 2015 to 2025						
Grain to Ethanol - Dry Mill	GEt-DM	Grains / Starches	Enzymatic Fermentation	Ethanol	5 to 100	Dry milling process - grains are ground into a flour, and the starch is converted into sugar and then fermented to ethanol
Lignocellulosics to Middle Distillates - Fischer Tropsch	LCMD-G/FT	Lignocellulosic Biomass	Gasification and Fischer Tropsch Synthesis	Middle Distillates, Gasoline	5 to 100+	Gasification to produce syngas, which is then cleaned and purified. The clean syngas then undergoes catalytic synthesis (reactor with Co catalyst to maximize diesel fraction). The product is separated and upgraded.
Lignocellulosics to Mixed Alcohol - Gasification/Thermocatalysis	LCMA-G/TC	Lignocellulosic Biomass	Gasification and Thermochemical Conversion	Mixed Alcohols	15 to 100+	Syngas production via biomass gasification, followed by catalytic conversion to mixed alcohols.
Lignocellulosics to Mixed Alcohol Digestion/Hydrogenation	LCMA-D/H	Lignocellulosic Biomass	Digestion/ Hydrogenation	Mixed Alcohols	30+	Anaerobic digestion of biomass with methanogenic inhibition followed by evaporation and fermentation. Produces a mixture of alcohols, carboxylic acids, ketones, and biofuels.
Lignocellulosics to Gasoline - Pyrolysis/Hydrotreating	LCGa-P/H	Lignocellulosic Biomass	Pyrolysis then Coprocessing via Hydrotreatment / Hydrocracking	Bio-oil, Diesel, Gasoline	5 to 100+	Biomass conversion to bio-oil via fast pyrolysis, co-processing with fossil fuels in petroleum refinery.

Source: NYSERDA (2010)

Table E-1: Current and advanced biofuel conversion Technologies in the coming year (Continue)

Reference Name (Feedstock-Product-Process)	Acronym	Feedstock	Conversion Technology	Fuel Type	Size Range* (MGY)	Description
New Technologies Projected to be in Use by 2015 to 2025						
Lignocellulosics to Butanol - Hydrolysis/Fermentation	LCBu-H/F	Lignocellulosic Biomass	Thermochemical Conversion or Multistage Fermentation	N-butanol, Iso-butanol	5 to 100	Pretreated biomass is fermented in two steps by *Clostridia* (n-butanol) or *E. coli* (iso-butanol), or partially fermented and then hydrogenated.
Hemicellulose to Ethanol: Pulp and Paper Application	HCEt-H/F	Hard- and Softwoods	Hot Water Extraction Hydrolysis and Fermentation	Ethanol	4 to 16	Extraction and autohydrolysis of hemicellulose from chipped, debarked pulpwood; fermentation to produce ethanol.
High Moisture Biomass: Biorefinery Heat and Power	HMB-CHP	Manures, Food Wastes, Biosludges	Digestion or Gasification	Methane, Syngas	Biorefinery Heat and Power	Anaerobic digestion of biomass or hydrothermal gasification followed by purification processes to produce a clean gaseous fuel for biorefinery CHP.
Black Liquor Conversion to Middle Distillates or DME	BLMD-G/FT, BLDMEG/TC	Pulp Mill Byproducts	Gasification and Thermocatalysis	FT Liquids, DME	20 to 65	Gasification of black liquor to form syngas, then either catalytic synthesis to FT Middle distillates or to DME.
Algae to Biodiesel (Methyl Ester)	ARD or AME	Microalgae	Esterification	Methyl Esters or Renewable Diesel	5 to 100	Pressing to remove oil, and esterification or hydrotreating to form long-chain fuels.
Fatty Acids to Diesel Fuel - Hydrotreatment (Green Diesel)	FADe-H	Seed Oil / Waste Oils / Animal Fats	Oil Extraction then Coprocessing via Hydrotreatment	Renewable Diesel	5 to 200	Biomass oils conversion to diesel and other hydrocarbons via hydrotreating methods as in petroleum refinery

Source: NYSERDA (2010)