## CHAPTER II
## THEORETICAL BACKGROUND AND LITERATURE REVIEW

### 2.1. Energy situation in Thailand

#### 2.1.1 Energy consumption in Thailand

Energy consumption in Thailand is divided into two parts which are renewable energy and commercial energy. Renewable energy is the energy used up and can produce up again and can be divided into fifteen categories based on raw materials which are rice husk, waste wood, sawdust, palm, bagasse, charcoal, fire-wood, cob, shell bean, biodiesel B100, waste in agriculture, coconut tapioca, biogas and waste. A another energy category is commercial energy sources such as large oil, natural gas and coal also includes power through privatization, including electricity and petroleum products.

Thailand's final energy consumption in 2011 was 70,562 ktoe, an increase of 0.4% from the previous year. The total value of final energy consumption was 1,684 billion Baht. Commercial energy consumption share was 80.5% of the total final energy consumption and the rest 19.5% was renewable energy.

Petroleum product consumption played the greatest proportion 46.9% of the total final energy consumption, followed by electricity, traditional renewable energy, coal & it products, commercial renewable energy and natural gas shared 18.0%, 13.1%, 9.3%, 6.4% and 6.3% respectively as shown in Figure 2.1.

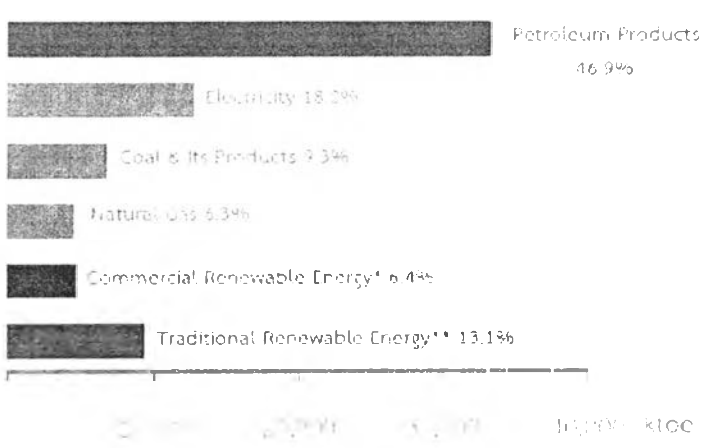


**Figure 2.1** Final energy consumptions, 2011. (Source: http://www.dede.go.th)

For final consumption by economic sector, the greatest share of 36.0% was from energy consumed in industrial sector, followed by transportation sector, residential sector, commercial sector and agriculture sector shared 35.7%, 15.5%, 7.6% and 5.2% respectively as shown in Figure 2.2.

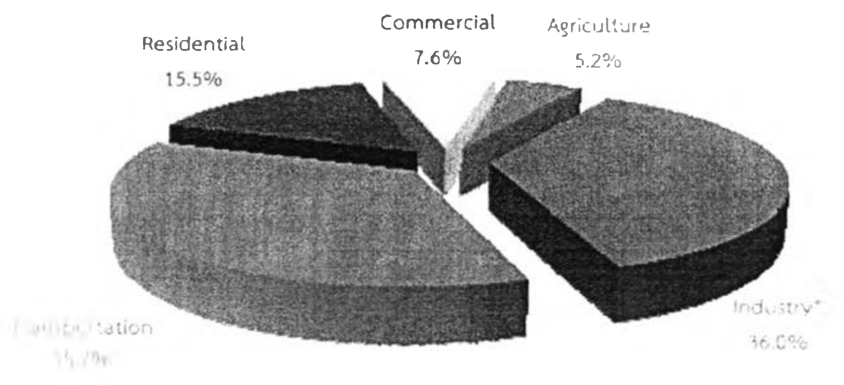


**Figure 2.2** Final energy consumptions by economic sector, 2011.
(Source: http://www.dede.go.th)

Total commercial energy production in 2011 was 51,116 ktoe which increased about 3.0% from 2010. Of this amount, the production of crude oil was 6,979 ktoe (8.7%), natural gas was 32,077 ktoe (2.1%), condensate was 4,184 ktoe (4.2%) while lignite was 6,048 ktoe (21.8%) and hydro & others (geothermal, solar cell and wind power) was 1,828 ktoe (48.5%). The total production of renewable energy & other energies (fuel wood, paddy husk, bagasse, agricultural waste, garbage, biogas, biofuel, black liquor and residual gas from production processes) was 21,583 ktoe (2.1%) as shown in Figure 2.3 (DEDE, 2010).

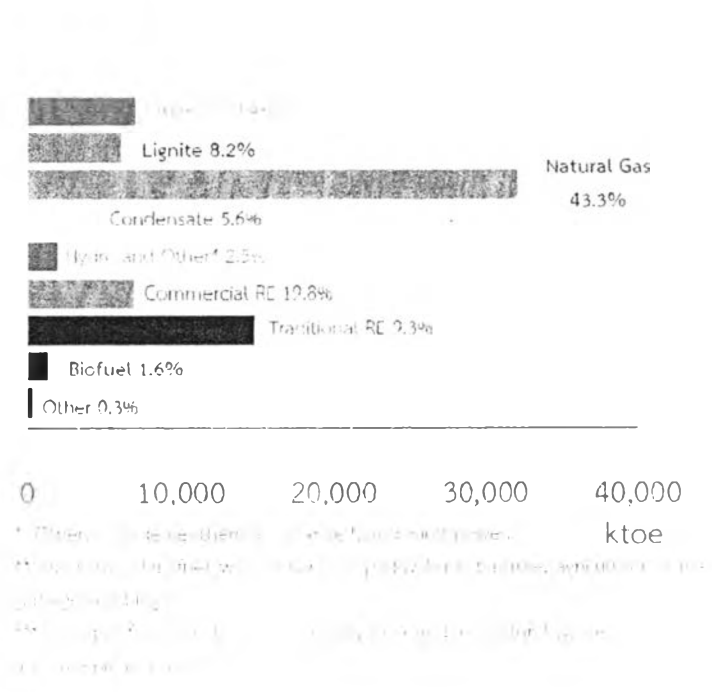


**Figure 2.3** Energy productions by fuel type, 2011. (Source: http://www.dede.go.th)

### 2.1.2 Petroleum in Thailand

2.1.2.1 Petroleum reserves

In 2007, including the reserves those contained in the Malaysia-Thailand JDA area show that the proved reserves stood at 11.19 Tcf for natural gas, 265 million barrels for condensate, and 176 million barrels for crude oil. As you can see, proved reserves of natural gas and condensate dropped marginally from last year at 4.2% and 0.50%. By contrast, crude oil reserves took a 9.5% drop. All three probable reserves surged from year 2006: by 12% for natural gas to 11.67 Tcf, by 10% for condensate to 322 million barrels, and by 71% for crude oil to 201 million barrels. The possible reserves of both natural gas and condensate declined by 17% and 12% to 6.84 Tcf and 140 million barrels while that of crude oil jumped by 25% to 52 million barrels. For crude oil, the probable and possible reserves resulted largely from the discovery in fractures of volcanic rocks that had intruded shale layers in the Wichian Buri sub-basin of Phetchabun. In the Gulf, the Banyen crude oil deposit operated by Pearl Oil (Thailand) and Yungthong deposit operated by CTEP were added to the list as shown in Table 2.1.

**Table 2.1** Thailand petroleum reserves in 2007. (Source: http://www.2dmf.go.th)

| Platform | Proved | | | Probable | | | Possible | | |
|---|---|---|---|---|---|---|---|---|---|
| | Natural Gas [1] (Bcf) | Condensate (MMbbl) | Oil (MMbbl) | Natural Gas (Bcf) | Condensate (MMbbl) | Oil (MMbbl) | Natural Gas (Bcf) | (MMbbl) | Oil (MMbbl) |
| [illegible] | 10,855.47 | [illegible] | 127.00 | 11,249.19 | 320.61 | 187.19 | 6,742.74 | 139.70 | 46.34 |
| **OTEP** | **4,970.99** | **166.89** | **64.86** | **6,755.19** | **228.96** | **91.82** | **1,160.92** | **38.28** | **6.90** |
| Baanpot | 111.20 | 4.58 | - | 386.94 | 13.66 | - | 17.38 | 0.64 | - |
| South Baanpot | 26.37 | 0.88 | - | 74.43 | 2.52 | - | 9.07 | 0.31 | - |
| Dara | - | - | - | 127.41 | 5.75 | 8.25 | 2.73 | 0.14 | - |
| Erawan | 717.04 | 23.25 | - | 489.05 | 15.59 | - | 54.1 | 1.68 | - |
| Funan | 226.86 | 9.90 | - | 256.25 | 8.34 | - | 10.51 | 0.49 | - |
| Gomin | 38.08 | 2.13 | - | 143.2 | 5.34 | - | 1.51 | 0.08 | - |
| South Gomin | 208.69 | 7.46 | - | 387.77 | 14.70 | - | 85.31 | 3.53 | - |
| Jakrawan | 284.87 | 5.44 | - | 211.83 | 4.38 | - | 17.21 | 0.35 | - |
| Moragot | 140.28 | 6.54 | - | 474.69 | 20.70 | - | 125.21 | 3.77 | - |
| North Moragot | - | - | - | 100.64 | 2.69 | - | 7.77 | 0.17 | - |
| Kapnong | 213.74 | 7.70 | 5.43 | 288.41 | 10.32 | 10.35 | 16.98 | 0.80 | 0.19 |
| Kung | - | - | - | 29.45 | 0.66 | 5.33 | - | - | - |
| Pailin | 420.55 | 16.02 | - | 401.82 | 15.75 | - | 80.8 | 2.20 | - |
| North Pailin | 517.11 | 19.35 | - | 484.44 | 16.54 | - | 182.58 | 5.97 | - |
| Pakarang | 360.01 | 11.75 | 4.33 | 267.61 | 8.80 | 5.17 | 81.14 | 2.59 | - |
| Pladang | 30.83 | 1.16 | - | 97.78 | 3.68 | - | 4.30 | 0.16 | - |
| Payta | - | - | - | - | - | - | 47.68 | 2.54 | - |
| Plamuk | 323.23 | 10.20 | 22.87 | 225.07 | 7.01 | 15.81 | 20.35 | 0.58 | 3.07 |
| Platong | 197.04 | 7.80 | 0.05 | 339.68 | 12.99 | 2.83 | 119.97 | 4.76 | - |
| Platong South | 15.39 | 0.54 | - | 82.77 | 2.92 | - | 4.96 | 0.18 | - |
| Platong SW | 36.54 | 1.46 | - | 88.77 | 3.39 | - | 17.78 | 0.69 | - |
| Ranong | - | - | - | 42.84 | 1.61 | - | 60.76 | 1.92 | - |
| Satun | 217.37 | 6.25 | - | 242.87 | 7.69 | - | 37.44 | 1.16 | - |
| South Satun | 64.69 | 1.56 | - | 123.01 | 3.04 | - | 17.08 | 0.44 | - |
| Surat | 89.52 | 2.76 | 5.84 | 231.63 | 7.39 | 18.36 | 8.35 | 0.12 | 0.93 |
| North Surat | - | - | - | 36.38 | 1.14 | 2.68 | - | - | - |
| Trat | 247.97 | 7.23 | - | 492.33 | 13.51 | - | 14.22 | 0.46 | - |
| Trat EN | 40.95 | 1.06 | - | 106.99 | 2.76 | - | 4.27 | 0.11 | - |
| Trat N | 65.21 | 1.81 | - | 72.93 | 2.00 | - | 12.47 | 0.34 | - |
| Trat S | 50.64 | 1.01 | - | 53.21 | 1.06 | - | - | - | - |
| Ubon | - | - | - | 96.16 | 2.86 | 4.89 | 49.19 | 0.33 | - |
| Ubon E | - | - | - | 60.55 | 2.08 | 3.68 | - | - | - |
| Ubon W | - | - | - | 23.68 | 1.10 | 0.21 | 23.56 | 1.34 | - |
| Yala | 144.27 | 4.83 | 7.38 | 53.16 | 1.88 | 4.13 | 7.22 | 0.29 | 0.94 |
| Yala E | 182.48 | 5.67 | 8.751 | 115.39 | 3.88 | 6.20 | 2.53 | 0.09 | - |
| Yungthong | - | - | - | 40.00 | 1.22 | 3.72 | 1.99 | 0.06 | 0.18 |
| **COTL** | **429.12** | **10.08** | **66.66** | **807.68** | **29.17** | **81.26** | **46.96** | **0.21** | **29.87** |
| Benchamas | 177.06 | 3.89 | 34.91 | 230.37 | 6.03 | 33.07 | 35.44 | 0.11 | 27.54 |
| Chaba | 14.73 | 0.50 | 2.31 | 84.75 | 2.86 | 10.40 | - | - | - |
| Jamjuree North | 3.58 | 0.04 | 0.39 | 111.42 | 3.29 | 5.72 | 0.46 | 0.01 | 0.08 |
| Jamjuree South | - | - | - | 69.05 | 1.92 | 3.54 | 1.61 | 0.04 | 0.09 |
| Lanta | 14.75 | 0.11 | 7.24 | 37.84 | 0.91 | 15.15 | 0.31 | 0.01 | 0.12 |
| Maliwan | 129.50 | 3.25 | 5.11 | 155.16 | 4.60 | 4.02 | 5.40 | 0.04 | 0.51 |
| Rajpruek | 6.22 | 0.09 | 1.69 | 1.07 | - | 2.15 | 1.01 | - | 0.86 |
| Tantawan | 83.28 | 2.21 | 5.12 | 117.92 | 3.59 | 2.20 | 2.12 | - | 0.67 |
| **PTTEP** | **2,606.47** | **69.17** | **-** | **1,699.00** | **49.18** | **-** | **2,392.57** | **66.06** | **-** |
| Arthit | 727.00 | 20.00 | - | 1,022.00 | 29.00 | - | 1,512.00 | 41.00 | - |
| Bongkot Main | 1,075.47 | 22.07 | - | 289.00 | 5.19 | - | 338.00 | 7.78 | - |
| Bongkot South | 804.00 | 11.10 | - | 382.00 | 8.99 | - | 402.00 | 5.81 | - |
| Pladu | - | - | - | - | - | - | 80.57 | 0.46 | - |
| **PTTEP Siam** | **-** | **-** | **0.11** | **-** | **-** | **-** | **-** | **-** | **-** |
| Nang Nuan | - | - | 0.11 | - | - | - | - | - | - |
| **Pearl Oil** | **19.66** | **0.19** | **8.66** | **14.67** | **0.20** | **10.84** | **7.47** | **0.11** | **6.20** |
| Banyen | - | - | 1.50 | - | - | 2.00 | - | - | 4.90 |
| Chang Dong | 13.55 | 0.19 | - | 14.57 | 0.20 | - | 7.47 | 0.11 | - |
| Jasmine | - | - | 7.05 | - | - | 8.84 | - | - | 1.30 |
| **Soco** | **-** | **-** | **1.60** | **-** | **-** | **-** | **-** | **-** | **-** |
| Bua Luang | - | - | 1.50 | - | - | - | - | - | - |
| **MTJA** [2] | **2,836.40** | **33.79** | **6.69** | **1,978.86** | **26.10** | **3.48** | **3,178.42** | **46.06** | **4.97** |
| CHESS | 1,989.00 | 24.20 | 3.45 | 1,129.50 | 14.80 | 2.40 | 2,209.50 | 34.55 | 3.60 |
| CPOC | 847.40 | 9.53 | 2.05 | 849.35 | 10.30 | 1.08 | 977.92 | 11.60 | 1.37 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.92 | 14.01 | 118.64 | [illegible] | [illegible] |
| **KHORAT PLATEAU** | **199.69** | **0.21** | **-** | **399.21** | **1.92** | **-** | **106.00** | **0.60** | **-** |
| **ExxonMobil** | **58.00** | **-** | **-** | **16.00** | **-** | **-** | **6.00** | **-** | **-** |
| Nam Phong | 58.00 | - | - | 16.00 | - | - | 6.00 | - | - |
| **Hess** | **141.69** | **0.71** | **-** | **383.21** | **1.92** | **-** | **100.00** | **0.60** | **-** |
| Sinphuhorm | 141.69 | 0.71 | - | 383.21 | 1.92 | - | 100.00 | 0.50 | - |
| **CENTRAL PLAIN** | **149.02** | **-** | **48.29** | **27.67** | **-** | **18.01** | **12.64** | **-** | **6.61** |
| **Pan Orient** | **-** | **-** | **0.33** | **-** | **-** | **4.27** | **-** | **-** | **1.81** |
| Na Sanun | - | - | 0.02 | - | - | 4.23 | - | - | 1.46 |
| Sri Thep | - | - | 0.01 | - | - | 0.02 | - | - | - |
| Wichian Buri | - | - | 0.30 | - | - | 0.02 | - | - | 0.35 |
| **PTTEPI** | **-** | **-** | **0.64** | **-** | **-** | **-** | **-** | **-** | **-** |
| Kampaeng Saen | - | - | 0.04 | - | - | - | - | - | - |
| Sang Kaja | - | - | 0.13 | - | - | - | - | - | - |
| Uthong | - | - | 0.37 | - | - | - | - | - | - |
| **Sino U.S.** | **-** | **-** | **1.16** | **-** | **-** | **1.34** | **-** | **-** | **2.37** |
| Bung Muang | - | - | 0.34 | - | - | 0.33 | - | - | 0.97 |
| Bung Ya | - | - | 0.52 | - | - | 0.77 | - | - | 0.84 |
| West Bung Ya - Nong Sa | - | - | 0.31 | - | - | 0.24 | - | - | 0.56 |
| **PTTEP Siam** | **149.02** | **-** | **44.26** | **27.67** | **-** | **8.39** | **12.64** | **-** | **2.49** |
| Sirikit et al | 143.02 | - | 44.25 | 27.57 | - | 8.39 | 12.54 | - | 2.43 |
| **Siam Moeco** | **-** | **-** | **-** | **-** | **-** | **0.32** | **-** | **-** | **1.62** |
| Arunothai | - | - | - | - | - | 0.32 | - | - | 1.52 |
| **NORTHERN INTERMONTANE** | **-** | **-** | **2.69** | **-** | **-** | **-** | **-** | **-** | **-** |
| Fang | - | - | 2.69 | - | - | - | - | - | - |
| **GRAND TOTAL** | **11,198.18** | **264.77** | **176.98** | **11,675.97** | **322.63** | **201.20** | **6,843.28** | **140.20** | **62.96** |

2.1.2.2 Petroleum potentials, supply, demand, and consumption

Thailand can produce crude oil locally but not enough for its demand. Thailand can produce oil only 25.3% of the demand (according to Figure 2.4) and import around 791 thousand barrels per day of crude oil in 2009. The majority of crude oil (83%) was imported from the Middle East (UAE, Saudi and Oman) (MOEN, 2008).

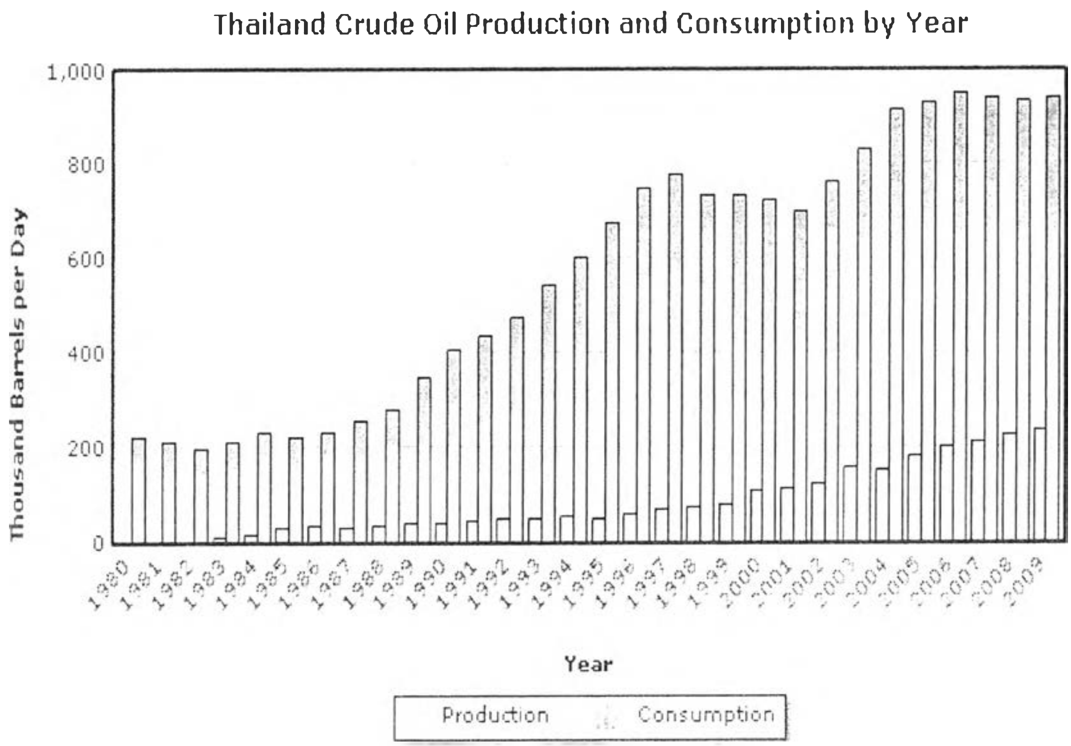


**Figure 2.4** Thailand crude oil production and consumption by year.

(Source: http://www.indexmundi.com)

2.1.2.3 Crude oil price trend

Driven in part by the relentless run up in petroleum prices as shown in Figure 2.5, increasingly, in the United States, utilities and investors are finding it important and profitable to invest in truly renewable energy solutions.

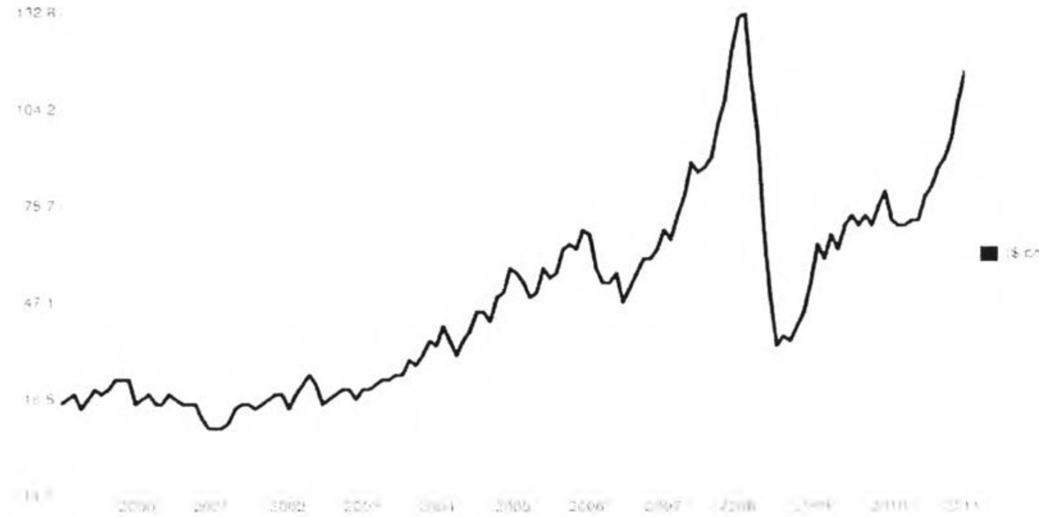

**Figure 2.5** Trend crude oil (NYMEX light sweet) prices between 2000–2010. (Source: http://www.mongabay.com)

2.1.2.4 Use of petroleum products

Products produced from crude oil were mainly consumed in transport sector shared 72.3%, followed by agricultural sector, manufacturing sector, residential sector, commercial sector, construction sector and mining sector, shared 11.0%, 8.3%, 5.0%, 2.9% and 0.5% respectively. The main proportion of petroleum products consumption was diesel (including palm diesel) shared 48.6%, followed by gasoline (including gasohol), LPG, jet fuel, fuel oil, and kerosene, shared 16.9%, 13.4%, 12.3%, 8.8%, and 0.04%, respectively (MOEN, 2009). The petroleum products use in Thailand are shown in Figure 2.6.

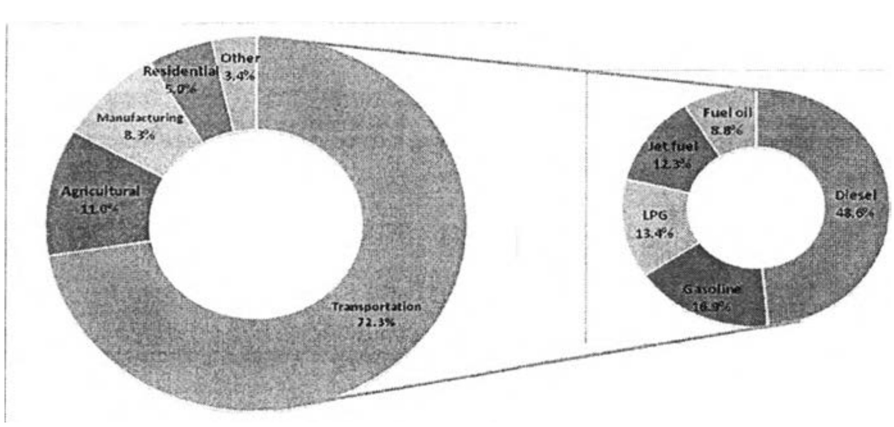


**Figure 2.6** Petroleum product uses in Thailand. (Source: http://www.energy.go.th)

### 2.1.3 Alternative and renewable energy

Nowadays, climate change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing alternative energy rapidly to replace fossil fuel to be sustainable. Alternative energy can be divided in two categories of theirs original resources; alternative energy from depleted resources such as coal, natural gas, nuclear, peat and oil sand etc. The other alternative energy comes from non-depleted resources which can be renewable. Renewable energy is energy resource that is replaced rapidly by natural processes. It comes from natural resources such as sunlight, wind, water, wave and geothermal heat, which are renewable or naturally replenished.

By the year 2011, Thailand's alternative energy consumption was 8,537 ktoe, an increase of 19.4% from the previous year. Of this amount, alternative energy consumption as electricity energy, thermal energy, biofuel (ethanol and biodiesel) and NGV shared 12.1% of the total final energy consumption. The electricity and thermal consumption which was produced from alternative energy(solar energy,wind energy, hydro energy, biomass, biogas and garbage) totalled 988 ktoe and 4,529 ktoe, biofuel consumption as biodiesel was 661 ktoe and NGV consumption totalled 2,036 ktoe, while biofuel consumption as ethanol was 323 ktoe, decreased 1.8%. as shown in Figure 2.7 (DEDE, 2011).

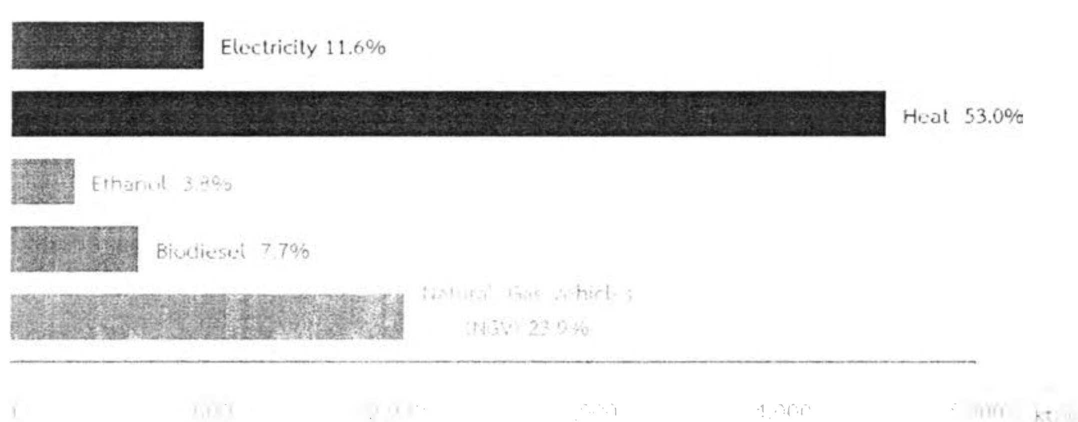


**Figure 2.7** Alternative energy consumptions in Thailand, 2011.

(Source: http://www.dede.go.th)

## 2.2. Biofuels

Biofuels are a wide range of fuels which are in some way derived from biomass. The term covers solid biomass, liquid fuels and various biogases. Because of the environmental friendly, there are increasing trend about biofuel usage around the world. National biofuel target of Thailand will increase renewable energy use from 0.5% in 2002 to 8.0% in 2011 which comprise of 1% of power generation, 4% of heat process and 3% of biofuel in transportation.

### 2.2.1 Biofuel generations

Biofuel can be derived into four generation which are:

2.2.1.1 First generation biofuels

First-generation or conventional biofuels are biofuels made from sugar, starch, and vegetable oil. The important first generation biofuels are:

*2.2.1.1.1 Bioalcohol*

Biologically produced alcohols, most commonly ethanol, and less commonly butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches.

The ethanol production methods used are enzyme digestion (to release sugars from stored starches), fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat (often unsustainable natural gas fossil fuel, but cellulosic biomass such as bagasse, the waste left after sugar cane is pressed to extract its juice, can also be used more sustainably)

The fermentation method generally uses three steps: (a) the formation of a solution of fermentable sugars (Milling dry/wet); (b) the fermentation of these sugars to bioethanol (Ethanol process); and (c) the separation and purification of the ethanol (Product recovery), usually by distillation as shown in Figure 2.8.

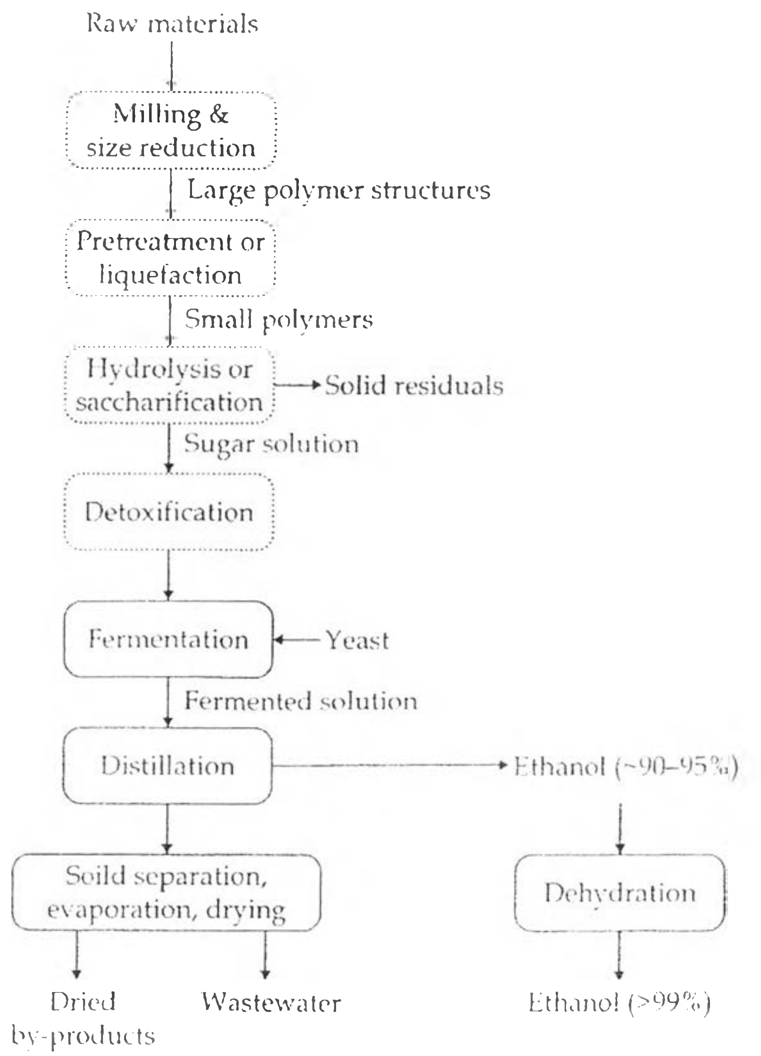


**Figure 2.8** Overview of the ethanol production process. (Source: Nag, 2008)

*2.2.1.1.2 Biodiesel*

Biodiesel is an alternative fuel for diesel engines that is gaining attention in the United States after reaching a considerable level of success in Europe. Its primary advantages are that it is one of the most renewable fuels currently available and it is also non-toxic and biodegradable. It can also be used directly in most diesel engines without requiring extensive engine modifications. Biodiesel can be used in any diesel engine when mixed with mineral diesel. In some countries manufacturers cover their diesel engines under warranty for B100 use (pure biodiesel which is the lowest emission diesel fuel).

Biodiesel is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters (FAMEs). Feedstocks for biodiesel include animal fats, vegetable oils, soy, rapeseed, jatropha, mustard, flax, sunflower, palm oil, and algae. As stated by Biodiesel Development and Promotion Strategy (18 January 2005), the main feedstock for biodiesel production is oil palm. Because oil palm is a plant with high competitive potential due to its lower costs in production and marketing compare with other plants. Besides, palm can be utilized diversity in consumption goods (Biodiesel, 2010).

*2.2.1.1.3 Biogas*

Biogas is methane created when organic material is anaerobically digested by anaerobes. During production, there is a solid byproduct called digestate. This can be used as a biofuel or fertilizer. Landfill gas is created in landfills due to natural anaerobic digestion and is a less clean form of biogas. Dried manure, charcoal and wood are examples of solid biofuels.

*2.2.1.1.4 Vegetable oil*

Vegetable oil is used in several old diesel engines that have indirect injection systems. This oil is also used to create biodiesel, which when mixed with conventional diesel fuel is compatible for most diesel engines. Used vegetable oil is converted into biodiesel. Sometimes, water and particulates are separated from the used vegetable oil and then this is used as a fuel (http://www.biofuel.org.uk).

2.2.1.2 Second generation biofuels

During recent years, the productions of many first generation biofuels have faced heavy criticism regarding its sustainability. On the one hand, rises in agricultural commodity prices have spurred discussions as to which extent first generation biofuels can be produced without endangering food production. On the other hand, the release of GHG associated with land use changes led to controversial discussions on the effectiveness of first generation biofuels to reduce global carbon emissions. Despite the fact that some of the currently produced biofuels are performing well in terms of economic and environmental sustainability, ongoing debates shifted focus onto second generation biofuels, which are based on non-edible biomass and promise to avoid the sustainability concerns related to current biofuel production (http://www.iea.org).

Second generation biofuels can help solve these problems and can supply a larger proportion of our fuel supply sustainably, affordably, and with greater environmental benefits. Second generation biofuels are those biofuel derived from lignocellulosic crops. Plants are made from lignin, hemicellulose and cellulose; second generation technology uses one, two or all of these components. These biofuels can be manufactured from various types of biomass. Biomass is a wide ranging term meaning any source of organic carbon that is renewed rapidly as part of the carbon cycle. Biomass is all derived from plant materials but can also include animal materials. The two main conversion routes for Second generation biofuels are

1) *Bio-chemical route:* This process is based on enzymatic-hydrolysis of the lignocellulosic material through a variety of enzymes that break the cellulosic material into sugars. In the second step of the process, these sugars are fermented into alcohol which is then distilled into ethanol.
2) *Thermo-chemical route:* The first step in the process is the gasification of the feedstock under high temperature into a synthesis gas. This gas can then be transformed into different types of liquid or gaseous fuel, so-called "synthetic fuels" (e.g. BTL-diesel, bio-SNG).

The goal of second generation biofuels processes are to extend the amount of biofuels that can be produced sustainably by using biomass consisting of the residual non-food parts of current crops, such as stems, leaves and husks that are left behind once the food crop has been extracted, as well as other crops that are not used for food purposes (non food crops), such as switch grass, grass, jatropha, whole crop maize, miscanthus and cereals that bear little grain, and also industry waste such as woodchips, skins and pulp from fruit pressing, etc. the classification of second generation biofuels from lignocellulosic feedstocks as shown in Table 2.2.

**Table 2.2** Classification of second generation biofuels from lignocellulosic feedstocks. (Source: Eisentraut, 2010)

| Biofuel groups | Specific biofuels | Production process |
|---|---|---|
| Bioethanol | Cellulosic ethanol | Advanced enzymatic hydrolysis and fermentation |
| Synthetic Biofuel | Biomass-to-liquids (BTL)<br>Fisher-Tropsch (FT) diesel synthetic diesel<br>Biomethanol<br>Heavier alcohols (butanol and mixed)<br>Dimethyl ether (DME) | Gasification and synthesis |
| Methane | Bio-synthetic natural gas (SNG) | Gasification and synthesis |
| Bio-hydrogen | Hydrogen | Gasification and synthesis or biological processes |

The problem that second generation biofuel processes are addressing is to extract useful feedstocks from this woody or fibrous biomass, where the useful sugars are locked in by lignin, hemicellulose and cellulose. These are complex carbohydrates (molecules based on sugar). Lignocellulosic ethanol is made by freeing the sugar molecules from cellulose using enzymes, steam heating, or other pretreatments. These sugars can then be fermented to produce ethanol in the same way as first generation bioethanol production. The by-product of this process is lignin. Lignin can be burned as a carbon neutral fuel to produce heat and power for the processing plant and possibly for surrounding homes and businesses. While the production of first generation biofuels are in an advanced state regarding both are processing and infrastructure, second generation technologies are mainly in a pilot or demonstration stage and are not yet operating commercially. The main obstacle for second-generation biofuels is high initial investment costs as well as higher costs for the end-product compared to fossil fuels or many first generation biofuels.

### 2.2.2 Bioethanol situation in Thailand

As seen from Figure 2.6, transportation is the one of the largest sectors of energy consumption and gasoline is the second rank of petroleum products demanded (22%) in Thailand. Thus, this work will focus on bioethanol.

The top 8 countries ethanol producers are shown in Table 2.3. In 2009, the world's giant ethanol fuel producer were the United States and Brazil with produced 10.6 and 6.5 billion US gallons respectively, accounting for 88% of world production of 19.53 billion US gallons. While Thailand ranked at the $5^{th}$ with 435.2 million gallons.

2.2.2.1 Background of ethanol usage in Thailand

Ethanol that use as fuel in Thailand known as gasohol (blending of gasoline and ethanol) production in Thailand had originated by the Royal Project of King Bhumibol in 1985, in the Study Project on Gasohol Production for an Alternative Energy by producing ethanol from cane. Later on, awakening of promising ethanol occurred towards the public and private sectors to participate in development and tests with engines. In 2000, the national oil company PTT carried out the tests of using gasohol (The mixture of ethanol and gasoline) in cars and found that it helps reducing of pollution, saves energy and no effect to the car performance. Alcohol production from fresh cassava bulb has been conducted by Thailand Institute of Science and Technology (TISTR) which then would delivery to Bangchak oil refinery for gasohol production. An experiment for distribution in 2001 was for five Bangchak gas stations in Bangkok gasohol price was slightly lower than of the unleaded gasoline 95, thus getting satisfied achievement from the people acceptances. In 2008 PTT and Bangchak petroleum started supplying E20 in January, after that, PTT lunched E85 to the country in August.

**Table 2.3** World's ethanol producers.

**Annual Fuel Ethanol Production by Country 2009**
**Top 8 countries**

| World rank | Country/Region | Production[1] (M US gallons) | Main feedstock |
|---|---|---|---|
| 1 | United States | 10,600.0 | Corn[2] |
| 2 | Brazil | 6,577.89 | Sugarcane[2] |
| 3 | European Union | 1,039.52 | Sugar beet, wheat[3] |
| 4 | China | 541.55 | Corn, cassava, sweet sorghum, potato sweet[2] |
| 5 | Thailand | 435.20 | Sugarcane molasses, Cassava[2] |
| 6 | Canada | 290.59 | Corn[2] |
| 7 | India | 91.67 | Sugarcane[4] |
| 8 | Colombia | 83.21 | Sugarcane[5] |
| | World Total | 19,963.70 | |

Sources: [1] RFA [2] APEC [3] Baka *et al.* (2009)
[4] http://www.ers.usda.gov [5] http://www.ethanolindia.net

2.2.2.2 Gasohol consumption in Thailand

The current blends of ethanol with gasoline in the Thai market are E10 (10% ethanol with 90% gasoline) in Octane 91 and Octane 95, E20 (20% ethanol with 80% of gasoline) in Octane 95, and E85 in Octane 95 (85% of ethanol with 15% of gasoline). Table 4 illustrates that the gasoline consumption is dramatically increasing since the start in 2004. The most recent available data of gasohol sales in Thailand was for the month of February 2012 at 4,195.21 million liter or 11.50 million liter per day, 70 times higher than 2004.

2.2.2.3 The advantages of gasohol usage in Thailand

Gasohol is good for the environment

Overall, ethanol is considered to be better for the environment than gasoline. Ethanol-fueled vehicles produce lower carbon monoxide and carbon dioxide emissions, and the same or lower levels of hydrocarbon and oxides of nitrogen emissions. E85, a blend of 85% ethanol and 15% gasoline, also has fewer volatile components than gasoline, which means fewer emissions from evaporation. Adding ethanol to gasoline in lower percentages, such as 10% ethanol and 90% gasoline (E10) reduces carbon monoxide emissions from the gasoline and improves fuel octane.

Gasohol is widely available and easy to use

Flexible fuel vehicles that can use E85 are widely available and come in many different styles from most major auto manufacturers. E85 is also widely available at a growing number of stations throughout the United States. Flexible fuel vehicles have the advantage of being able to use E85, gasoline, or a combination of the two, giving drivers the flexibility to choose the fuel that is most readily available and best suited to their needs.

Gasohol is good for the economy

Ethanol production supports farmers and creates domestic jobs. And because ethanol is produced domestically, from domestically grown crops, it reduces U.S. dependence on foreign oil and increases the nation's energy independence (http://www.environment.about.com).

2.2.2.4 Ethanol plant in Thailand

There are 19 ethanol plants operating in commercial scale in Thailand as shown in Table 2.4 (DEDE, February 2012). The total production capacity is 3,065,000 liters per day.

**Table 2.4** Existing ethanol plants in Thailand. (Source: http://www.dede.go.th)

| No | Plant | Site | Capacity (l/d) | Feedstock / Raw Material |
|---|---|---|---|---|
| 1 | PawnWiLai Inter Group Trading | Ayuddhya | 25,000 | Molasses/ Fresh Cassava Tubers |
| 2 | Thai Agro Energy | Suphanburi | 150,000 | Molasses |
| 3 | Thai Alcohol | NakornPath-om | 200,000 | Molasses |
| 4 | Khon Kaen Alcohol | Khon Kaen | 150,000 | Molasses/Starch liquid |
| 5 | ThaiNguan Ethanol | Khon Kaen | 130,000 | Fresh Cassava Tubers/ Cassava Chips |
| 6 | Thai Sugar Ethanol | Kanchanaburi | 100,000 | Molasses |
| 7 | KI Ethanol | Nakorn Ratch-sima | 100,000 | Molasses |
| 8 | Petro Green (Kan-laseen) | Kanlaseen | 230,000 | Molasses/sugarcane juice |
| 9 | Petro Green (Chaiya-poom) | Chaiyapoom | 230,000 | Molasses/sugarcane juice |
| 10 | EkrathPattana | Nakorn Swan | 230,000 | Molasses |
| 11 | ThaiRungRueng Energy | Saraburi | 120,000 | Molasses/Baggage |
| 12 | Ratchburi Ethanol | Ratchburi | 150,000 | Cassava Chips/Molasses |
| 13 | ES Power | Sakaew | 150,000 | Molasses/Cassava Chips |
| 14 | Maesawd Clean Energy | Tak | 200,000 | Sugarcane Juice |
| 15 | SupThip | Lopburi | 200,000 | Cassava Chips |
| 16 | TaiPing Ethanol | Sakaew | 150,000 | Fresh Cassava Tubers/ Cassava Chips |
| 17 | PSB Starch Production | Chonburi | 150,000 | Fresh Cassava Tubers/ Cassava Chips |
| 18 | Petro Green (Dan-Chang) | Suphanburi | 200,000 | Molasses/sugarcane juice |
| 19 | Khon Kaen Alcohol (Boh Ploy) | Kanchanaburi | 200,000 | Molasses/sugarcane juice |
| **Total Production Capacity** | | | **3,065,000** | |

## 2.3. Biomass, lignocellulosic materials and agricultural residues

### 2.3.1 Definition of biomass

Biomass is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, plants capture the sun's energy. When the plants are burned, they release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, with only as much used as is grown, the battery will last indefinitely. Biomass are including the living and dead organisms (that come from biodegradable wastes). Biomass can equally apply to both animal and vegetable derived material. For these reason, the organic materials as fossil fuels, which have been transformed by geological processes into substances such as coal or petroleum are not include.

The vital difference between biomass and fossil fuels is one of time scale. Biomass takes carbon out of the atmosphere while it is growing, and returns it as it is burned. If it is managed on a sustainable basis, biomass is harvested as part of a constantly replenished crop. This is either during woodland or arboricultural management or coppicing or as part of a continuous program of replanting with the new growth taking up $CO_2$ from the atmosphere at the same time as it is released by combustion of the previous harvest. This maintains a closed carbon cycle with no net increase in atmospheric $CO_2$ levels, as shown in Figure 2.9. But for fossil fuels, they contain carbon that has been out of the carbon cycle for a very long time. Their combustion therefore disturbs the carbon dioxide content in the atmosphere.

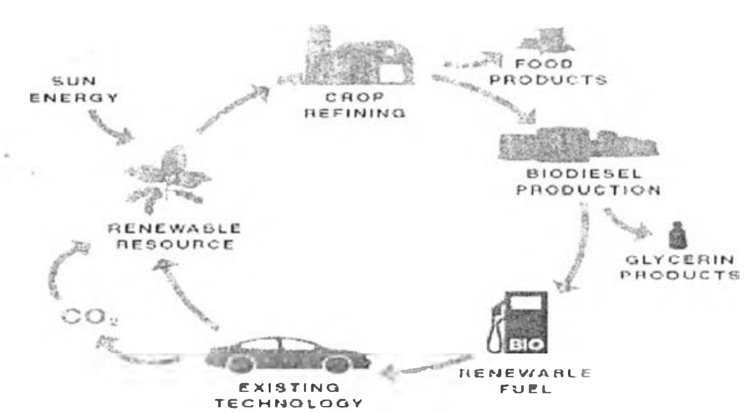


**Figure 2.9** The carbon cycle of biomass. (Source: http://www.allgreencars.co.uk)

### 2.3.2 Categories of biomass materials

Within this definition, biomass for energy can include a wide range of materials. The realities of the economics mean that high value material for which there is an alternative market, such as good quality, large timber, are very unlikely to become available for energy applications. However there are huge resources of residues, co-products and waste that exist around the world which could potentially become available, in quantity, at relatively low cost or even negative cost where there is currently a requirement to pay for disposal.

There are five basic categories of material:

- Virgin wood: from forestry, arboricultural activities or from wood processing
- Energy crops: high yield crops grown specifically for energy applications
- Agricultural residues: residues from agriculture harvesting or processing
- Food waste: from food and drink manufacture, preparation and processing, and post-consumer waste
- Industrial waste and co-products: from manufacturing and industrial processes (http://www.biomassenergycentre.org.uk).

### 2.3.3 Application of biomass materials

The varieties of applications for biomass are

- Food and fodder crops: food e.g. carbohydrates, lipids, proteins, vitamins.
- Fiber: material e.g. paper pulp, timber, furniture, textiles.
- Chemical: bio-product e.g. pharmaceutical, flavoring, lubricant.
- Energy: biofuel e.g. bioethanol, biodiesel.

In general there are two main approaches to using plants for energy production: growing plants specifically for energy use, and using the residues from plants that are used for other things (http://www.altenergystation.com).

Because biomass fuels are normally less dense, lower in energy content, and more difficult to handle than fossil fuels, they usually do not compare favorably to fossil fuels on an economic basis. However, biomass fuels have several important on environmental advantages. Biomass fuels are renewable and sustainable use in greenhouse gas neutral (biomass combustion releases no more carbon dioxide than absorbed during the plant's growth). Biomass fuels contain little sulfur compared to coal (reduced sulfur dioxide emissions) and have lower combustion temperatures (reduced nitrogen oxide emissions). However, unless biomass is efficiently and cleanly converted to a secondary energy form, the environmental benefits are only partially realized, if at all. For this reason, efficient, modern biomass utilization must be favored over traditional applications (NEPO, 2000).

### 2.3.4 Lignocellulosic-based bioethanol in Thailand

According to the previous information, feedstocks for produce ethanol that come from first generation biofuels have problem about the competition of food and energy market. So, the second generation biofuels were developed to compensate this problem by using non-edible material. It is a type of biofuels produced from lignocellulose, a structural material that comprises much of the mass of plants.

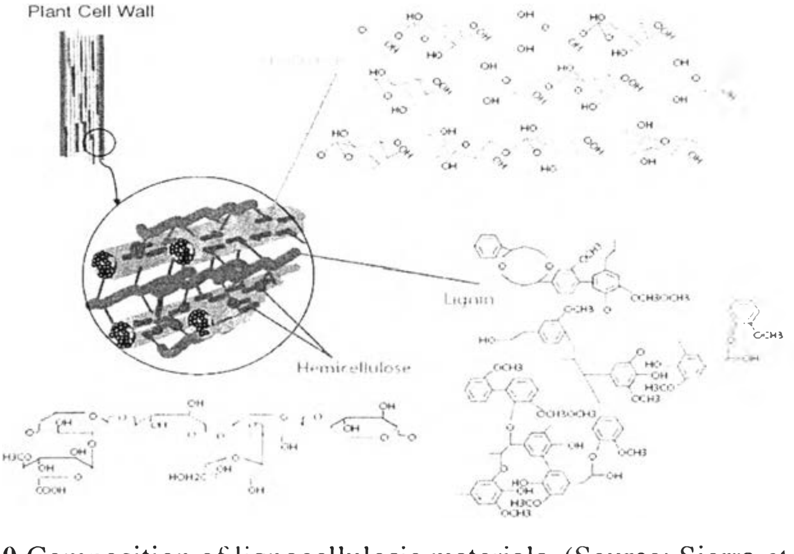


**Figure 2.10** Composition of lignocellulosic materials. (Source: Sierra *et al.*, 2008)

2.3.4.1 <u>Composition of Lignocellulosic materials</u>

Lignocellulosic biomass is the least expensive, most abundant renewable feedstock on earth, with around 200 billion tons produced annually (Zhang, 2008). It requires less input (such as water and fertilizer) per unit of biomass produced when compare with grain and crop. It is composed of three major components: cellulose, hemicelluloses, and lignin as shown in Figure 2.10.

Cellulose is the major component of most non-food energy crops or lignocellulosic materials. Cellulose is an organic compound with the formula $(C_6H_{10}O_5)n$, a polysaccharide consisting of a linear chain of several hundred to over ten thousand $\beta(1\rightarrow4)$ linked D-glucose units. Cellulose is derived from D-glucose units, which condense through $\beta(1\rightarrow4)$-glycosidic bonds. This linkage motif contrasts with that for $\alpha(1\rightarrow4)$-glycosidic bonds present in starch, glycogen, and other carbohydrates. The seemingly minor difference in linkages makes a major difference in reactivity. For the same enzyme loading, amylase hydrolyzes starch about 100 times faster than cellulase hydrolyzes cellulose. This is because the hydrogen bonds between adjacent cellulose polymers form crystalline structures that give plants structural strength, but make them particularly difficult to digest.

Hemicellulose is any of several heteropolymers (matrix polysaccharides) such as arabinoxylans, present along with cellulose in almost all plant cell walls. While cellulose is crystalline, strong, and resistant to hydrolysis, hemicellulose has a random, amorphous structure with little strength. It is easily hydrolyzed by dilute acid or base as well as myriad hemicellulase enzymes include xylose, mannose, galactose, rhamnose, and arabinose. Hemicelluloses contain most of the D-pentose sugars. Xylose is always the sugar monomer present in the largest amount.

Lignin, a polymer of phenyl propane units linked in three-dimensional structure, acts as "glue." It is a very complex molecule. A plant can be compared to fiberglass, where the cellulose is analogous to the glass fibers and the lignin serves as the epoxy resin. Chemical bonds have been reported between lignin and both cellulose, and hemicelluloses. Lignins are extremely resistant to chemical and enzymatic degradation. Biological degradation can be achieved mainly by certain fungi. The contents of cellulose, hemicelluloses, and lignin in common lignocellulosic materials are shown in Table 2.5.

One barrier to the production of ethanol from biomass is that the sugars necessary for fermentation are trapped inside the lignocellulose. Lignocellulose has evolved to resist degradation and to confer hydrolytic stability and structural robustness to the cell walls of the plants. This robustness or "recalcitrance" is at-robustness to the cell walls of the plants. This robustness or "recalcitrance" is attributable to the crosslinking between the polysaccharides (cellulose and hemicellulose) and the lignin via ester and ether linkages. Ester linkages arise between oxidized sugars, the uronic acids, and the phenols and phenylpropanols functionalities of the lignin to extract the fermentable sugars, one must first disconnect the celluloses from the lignin, and then acid-hydrolyze the newly freed celluloses to break them down into disaccharides (Cellobiose) and into simple monosaccharides (glucose-$C_6H_{12}O_6$). Another challenge to biomass fermentation is the high percentage of pentoses in the hemicellulose, such as xylose, or wood sugar. Unlike hexoses, like glucose, pentoses are difficult to ferment.

**Table 2.5** Contents of cellulose, hemicellulose, and lignin in Thailand based lignocellulosic materials.

| Lignocellulosic materials | Cellulose (%) | Hemicellulose (%) | Lignin (%) |
|---|---|---|---|
| Rice straw[Inoue *et al*, 2009] | 26 | 16 | 4 |
| Cassava rhizome[Pattiya *et al*, 2007] | 28 | 40 | 22 |
| Cassava stalk[Kingsuwannarat, 2002] | 32 | 14 | 27 |
| Sugarcane bagasse[Inoue *et al*, 2009] | 36 | 20 | 23 |
| Sugarcane trash[Singh *et al*, 2007] | 40 | 25 | 18-20 |
| Jatropha [Gunascelan *et al*, 2009] | 33 | *NA* | *NA* |
| Oil palm fronds[Wanrosli *et a*, 2007] | 47 | 35 | 15 |
| Oil palm EFB[Alriols *et a*, 2009] | 37 | 24 | 24 |

2.3.4.2 Categories of Lignocellulosic materials

Lignocellulosic materials can be grouped into four main categories: agricultural residues (including rice straw, corn stover and sugarcane bagasse), dedicated energy crops, wood residues (including sawmill and paper mill discards), and municipal paper waste. However, this work focuses mainly on agricultural residues.

2.3.4.3 Potential of agricultural residues in Thailand

Thailand is agricultural country and has a lot potential of agricultural goods and also the country is one of the leading producers and exporters in the world market. The potential of biomass materials in Thailand are both virgin wood and agricultural residues. At the present time, more than 30% of whole Thai area is forest. However, the forest area in Thailand has decrease from 53% in last 50 years (RFD, 2009). Focusing on agricultural residues, it is a big challenge for change that residues to ethanol especially from rice, sugarcane, and cassava. All of them is the major crops and release a lot of residues. The quantities of agricultural residues are calculated from agricultural product multiply by crops to residue ratio (CRR), this result is call total agricultural residues. However, some of agricultural residues are used in other activity for example fodder for animal. Therefore, the potential of agricultural residues that use for energy (Available unused residues) are calculated from total agricultural residues multiply by surplus available factor (SAF). These two ratios are conversion factor. The potential of agricultural residues in Thailand is shown in Table 2.6.

Thailand has continued to promote domestic biofuel utilization. Production and consumption of bioethanol in Thailand have continued to increase at a fast rate due to aggressive policies of the Thai government in reducing foreign oil import and increasing domestic renewable energy utilization.

**Table 2.6** Energy potential of agricultural residues in Thailand, 2009 (Source: http://www.dede.go.th)

| Products | Productions (Tons) | Residues | Available unused residues for energy (Tons) | Heating values (MJ/kg) | Energy potentials (TJ) | (ktoe) |
|---|---|---|---|---|---|---|
| Sugarcane | 66,816,446 | Bagasse | 4,190,794.31 | 14.4 | 60,347.44 | 1,428.54 |
| | | Top & trash | 13,439,727.21 | 17.39 | 233,716.86 | 5,532.52 |
| Paddy | 31,508,364 | Husk | 3,510,598.90 | 14.27 | 50,096.25 | 1,185.87 |
| | | Straw | 25,646,547.96 | 10.24 | 262,620.65 | 6,216.73 |
| Soybean | 190,480 | Stalk, leaves, shell | 170,383.17 | 19.44 | 3,312.35 | 78.41 |
| Maize | 4,616,119 | Corn cob | 584,539.15 | 18.04 | 10,545.09 | 249.62 |
| | | Stalk | 2,758,777.36 | 18.04 | 49,768.34 | 1,178.11 |
| Oil palm | 8,162,379 | Empty bunches | 1,024,868.34 | 17.86 | 18,304.15 | 433.29 |
| | | Fiber | 162,970.06 | 17.62 | 2,871.53 | 67.97 |
| | | Shell | 38,959.04 | 18.46 | 719.18 | 17.02 |
| | | Shaft | 2,203,740 | 9.83 | 21,824.24 | 516.62 |
| Cassava | 30,088,025 | Stalk | 2,439,236.19 | 18.42 | 44,930.73 | 1,063.60 |
| | | Rhizome | 1,834,466.88 | 18.42 | 33,790.88 | 799.89 |
| Coconut | 1,380,980 | Shaft | 628990.82 | 15.4 | 9686.46 | 229.3 |
| | | Spathe | 464250.95 | 16.23 | 7534.79 | 178.36 |
| | | Shell | 128936.58 | 17.93 | 2311.83 | 54.73 |
| Rubber tree | 3,090,280 | Branch/Shaft | 312,118.28 | 14.98 | 4,675.53 | 110.68 |
| **Total** | **145,853,073** | | **59,539,905.20** | | **504,339.40** | **11,938.60** |

2.3.4.4 <u>Focus on cassava in Thailand</u>

Each year in Thailand agricultural industries generate millions of tons of various lignocellulosic material feedstocks as agricultural residues i.e. cassva rhizome, cassava stalk, rice straw, rice husk, sugar cane bagasse, corn stover and corn fiber. The Thai government has a policy to encourage fuel ethanol production from agricultural residues. This work will focus on one of the importance agricultural residues in Thailand which is cassava rhizome.

Cassava rhizome is an attractive lignocellulosic material for bioethanol production. Production of cassava in Thailand was about 25.2 million tons per year which ranked 1[st] for cassava producer in South-East Asia and 3[rd] in the world as shown in Figure 2.11-2.12. Furthermore, Every kilogram of cassava is accompanied by production of 0.08-0.09 kg of the cassava rhizome. So, it gives an estimation of about 2.2 -2.3 million tons of cassava rhizome produced per year and a large part of this is going as firewood and rest as waste.

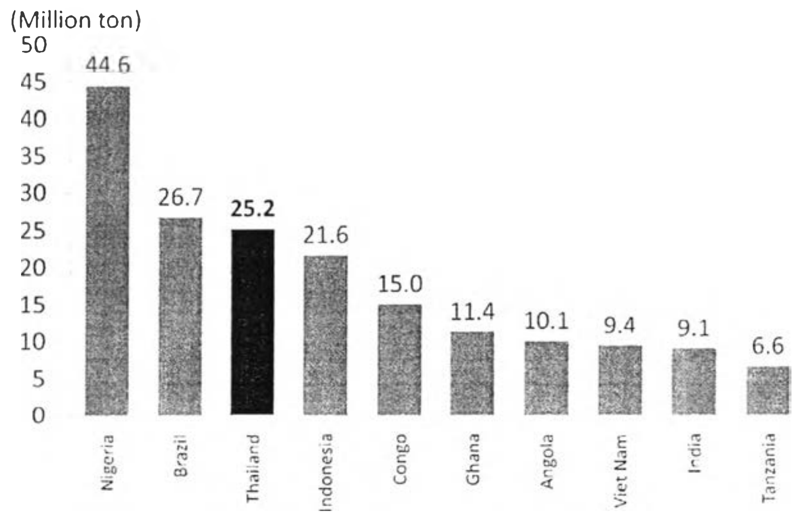


**Figure 2.11** World producers of cassava by the major producing countries.

(Source: ที่มา: FAO, http://faostat.fao.org, 2008)

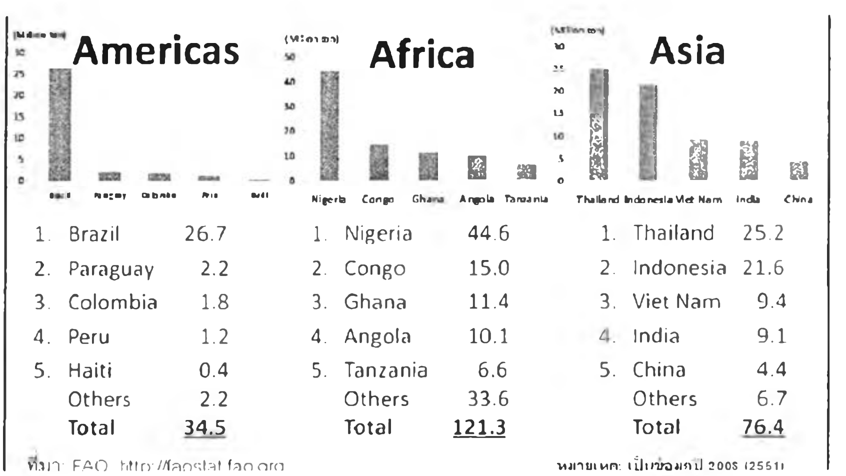


**Figure 2.12** World production of cassava by continent.

(Source: ที่มา: FAO, http://faostat.fao.org, 2008)

Cassava rhizome has several characteristics that make it a potential feedstock for fuel ethanol production. It has high cellulose and hemicelluloses content that can be readily hydrolyzed into fermentable sugars. In terms of chemical composition, the rhizome contains cellulose (28.0%), hemicellulose (40.0%) and lignin (22.0%) (Pattiya *et a.l*, 2007).

For ethanol production, treatment of distilled mash in anaerobic digester produces biogas. This biogas is collected and reserved for plant use. 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).

2.3.4.5 Study on lignocellulosic-based ethanol process

Morales *et al.* (2008) worked on using computer aided tools for sustainable design and analysis of bioethanol production by considering the production of 99.95% pure ethanol from lignocellulosic materials where the hydrolytic enzyme is purchased. Hardwood chips were used as the feedstock and PRO/II simulator was used as simulation program. The base case process was based on NREL process (Wooley *et al.*, 1999). The main operations of the process are shown in PRO/II flowsheets in Figure 2.13.

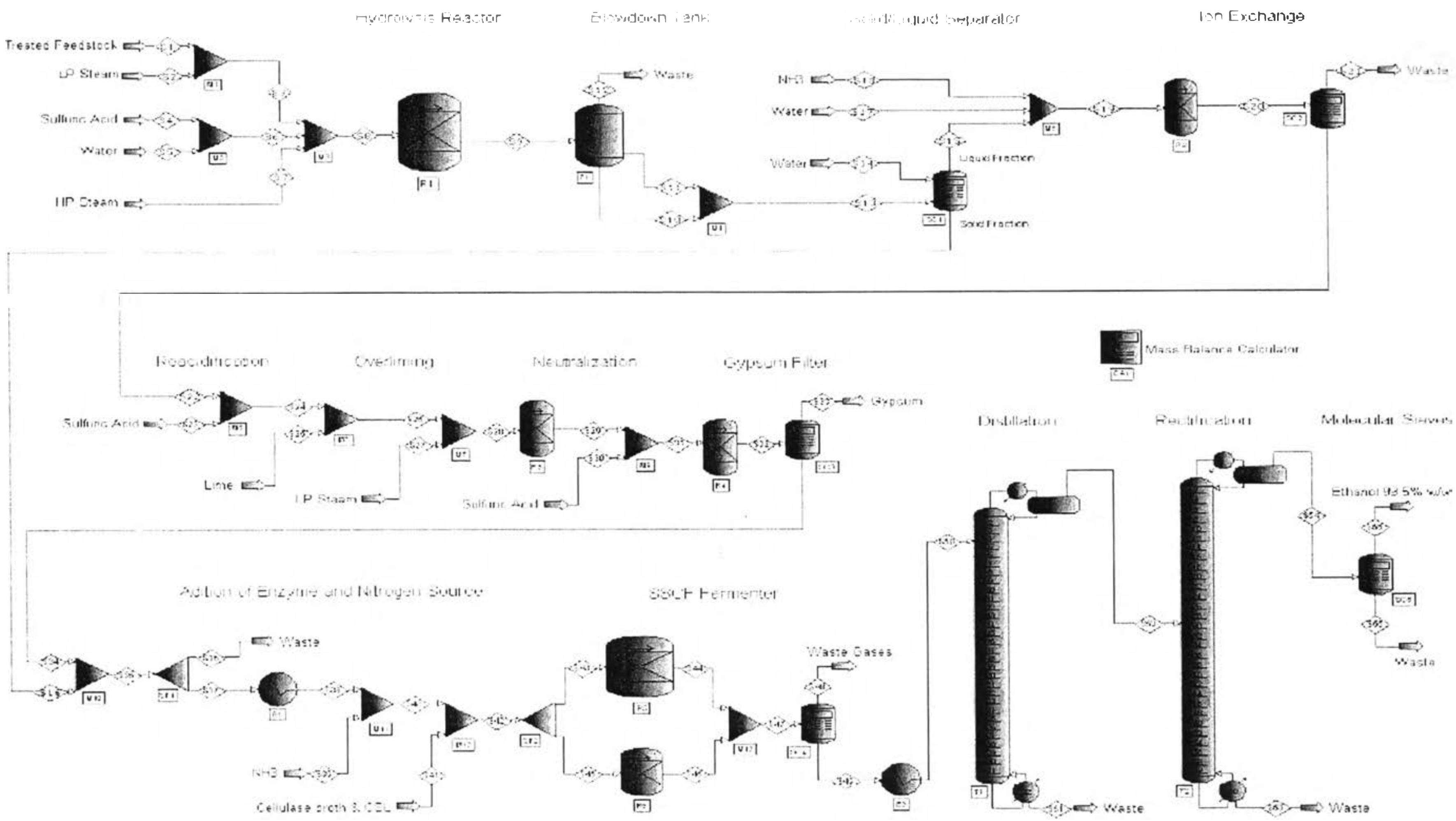


**Figure 2.13** The main operations of the bioethanol process from lignocellulosic biomass(Source: Morales *et al*., 2008

## 2.4. Sustainable development

### 2.4.1 Definition of sustainable development

Sustainable development (SD) is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In other words, development that meets the needs of current generation without compromising the needs of future generations is termed as sustainable development. Sustainable development has three components: environment, society, and economy. If you consider the three to be overlapping circles of the same size, the area of overlap in the centre is human well-being as shown in Figure 2.14. (http://www.det.wa.edu.au).

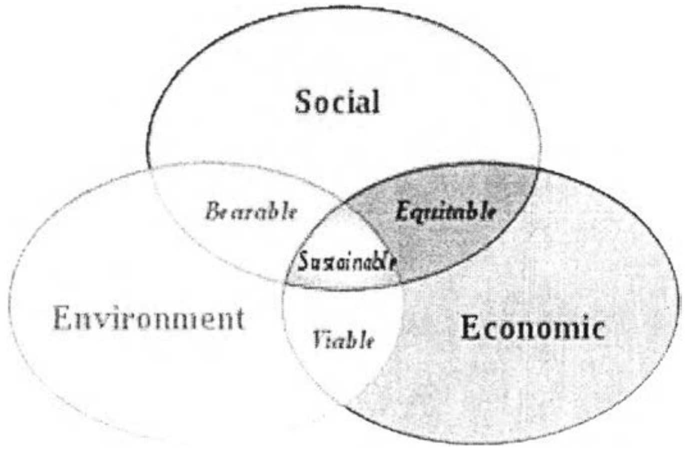


**Figure 2.14** Sustainable development concept. (Source: http://en.wikipedia.org)

### 2.4.2 Sustainable energy for future

At present, the environmental problem is the main issue for the entire world to be interested. The major energy source is still the fossil fuels which are non-renewable and also impact to environmental. The energy that sustainable, renewable and environmental friendly is now replacing fossil fuel.

Sustainable energy is the provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable energy sources are most often regarded as including all renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bioenergy, and tidal power. It usually also includes technologies that improve energy efficiency.

Apart from the energy sources that have to sustain, the processes which producing these energy are also importance because the main part that influence environment problem are released from the processes. If the processes are designed to minimize waste and optimize the utility consumption, the environmental impact will decrease. The next topics will mention about the energy situation and the way to improved the energy usage for more sustainable in Thailand.

## 2.5. Life Cycle Assessment (LCA)

As mention in the sustainable development topic, environmental issue is one of the importance parts that have to be analyzed. The efficiency of biofuel in terms of energy and environmental aspect can evaluate by the method call "Life Cycle Assessment (LCA)".

### 2.5.1 Definition of LCA

Life cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages during its entire life cycle of a product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal by identifying and quantifying energy and materials used and wastes released to the environment: to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements as shown in Figure 2.15 (SETAC, 1993).

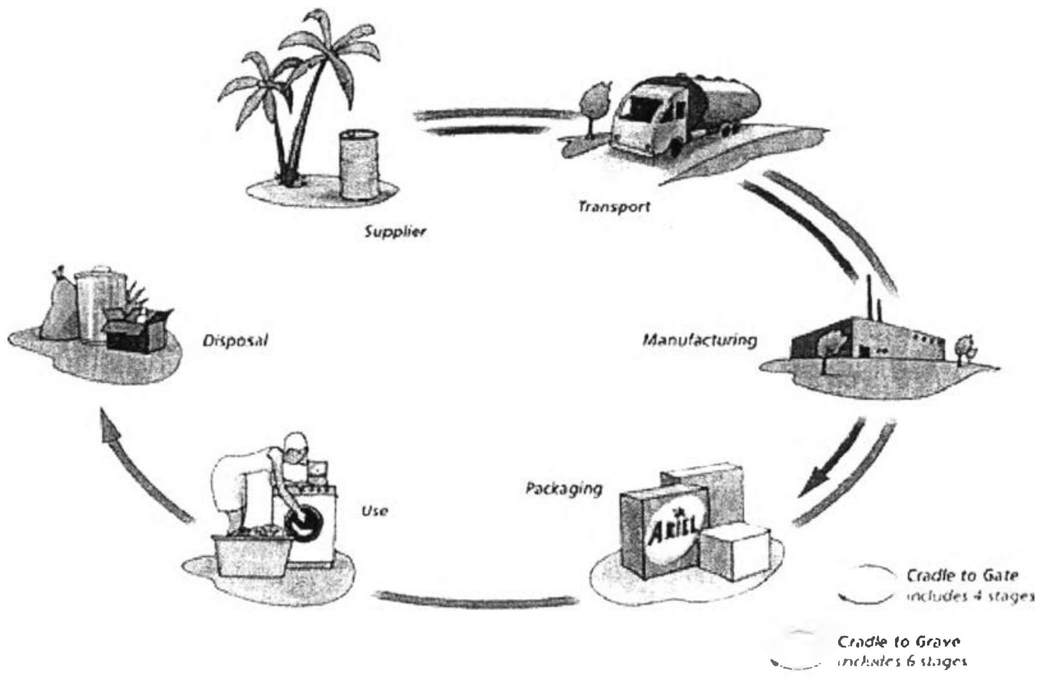


**Figure 2.15** Structure of the life cycle assessment.

(Source: http://www.scienceinthebox.com)

In the case of petroleum-derived fuels, this means LCA includes everything from the time the oil is extracted from the ground, transported to the refinery, made into fuel and distributed to your local gas station. This is also known as a Well-to-Wheels Study because it starts at the oil well and ends at the wheels or more specifically the tailpipe of your car or truck.

For a crop like corn ethanol, the LCA is much more complex. Tracking of the energy and emissions it takes to plant the corn, and make the fuels, fertilizers, and pesticides to grow the corn. Estimating whether growing the corn increases or decreases carbon in the soil. Appraising how much fuel it takes to get the corn to the ethanol refinery and how much energy is consumed and the amount of emissions that are generated in the bioethanol plant. Corn ethanol refineries typically make a co-product called distillers grain, which is a high-protein feed for cattle. This production is counted as a credit in our accounting spreadsheet. It also includes the impact of getting ethanol to the service station by rail and truck.

### 2.5.2 Overview of LCA

In LCA substantially broader environmental aspects can be covered, ranging from GHG emissions and fossil resource depletion to acidification and toxicity aspects, hence it is a good tool for quantifying environmental impacts of a defined product system. However, LCA as it stands has its limitations such as the difficulties in data acquisition and validation, and the misleading results due to the choice of methodology especially on allocation issues. Figure 2.16 illustrates the life cycle of biofuels involving $CO_2$ emission.

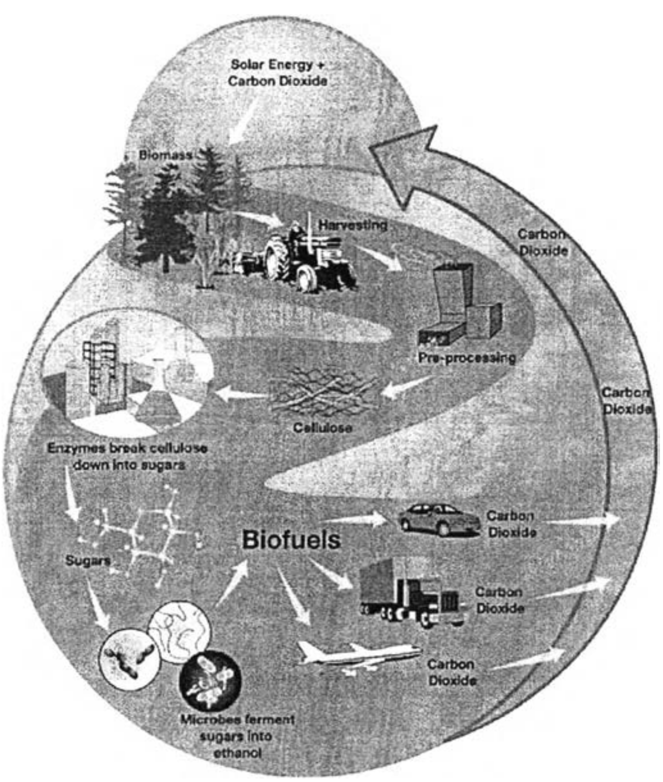


**Figure 2.16** Life cycle of biofuels. (Source: http://peda.gov.in)

The objectives of LCA are to compare the full range of environmental effects assignable to products and services in order to improve processes, support policy, provide a sound basis for informed decisions and also increase environmental awareness on the part of the general public, industry and governments. The precursors of life cycle analysis and assessment (LCAs) were the global modeling studies and energy audits of the late 1960s and early 1970s. These attempted to assess the resource cost and environmental implications of different patterns of human behavior.

LCAs were an obvious extension, and became vital to support the development of eco-labeling schemes which are operating or planned in a number of countries around the world. In order for eco-labels to be granted to chosen products, the awarding authority needs to be able to evaluate the manufacturing processes involved, the energy consumption in manufacture and use, and the amount and type of waste generated. To accurately assess the burdens placed on the environment by the manufacture of an item, the following of a procedure or the use of a certain process, two main stages are involved. The first stage is the collection of data, and the second is the interpretation of that data.

### 2.5.3 Methodology of LCA

The LCA framework was standardized by the International Organization for Standardization (ISO). According to the ISO 14040 and 14044 standards, a life cycle assessment is derived in four distinct phases consisting of:

2.5.3.1 <u>Goal and Scope Definition</u>

The first step is where the intention of the use of LCA is defined, and where the setting of the boundaries (what is and is not included in the study) for the product system takes place and assumptions based upon the goal. In this phase, formulate and specify the goal and scope of study in relation to the intended application are required. For the example of a packaging study might choose to define the functional unit as —packaging of 1,000 liters of milk in containers of 1 liter. Taking this, the relevant significant comparison can be between 1,000 carton boxes and 40 returnable polycarbonate bottles, which can be used in average 25 times.

Usually what LCA does is compare different ways of obtaining the same function. Therefore in order to guarantee fairness and relevance it is crucial to be comparing between product systems that actually provide the same function, being this assured through carefully defining the functional unit. Finally, the goal and scope including a description of the method applied for assessing potential environmental impacts and which impact categories those are included.

2.5.3.2 Inventory Analysis (LCI)

This step is where all the necessary input and output data for the processes regarding the product system is gathered. The energy and raw material inputs and environmental releases associated with each stage of production are quantified. Other types of exchanges or interventions such as radiation or land use can also be included. These gathered data are related with the reference flow given by the functional unit. Typically the data for the different processes is combined over the life cycle and presented as the total emissions of a substance or total use of resource.

Finally, the results of the inventory which provides information about all inputs and outputs in the form of elementary flow to and from the environment from all the unit processes involved in the study are obtained.

2.5.3.3 Impact Assessment (LCIA)

Analyze and compare the impacts on human health and the environment burdens associated with raw material and energy inputs and environmental releases quantified by the inventory. In this phase, "Life Cycle Impact Assessment" (LCIA) is aimed at evaluating the contribution to impact categories such as global warming, acidification, ozone depletion and etc.

The first step of LCIA is termed "characterization". Here, impact potentials are calculated based on the LCI results. The next steps are "normalization" and "weighting", but these are both voluntary according the ISO standard. Normalization provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). Weighting implies assigning a weighting factor to each impact category depending on the relative importance.

2.5.3.4 Interpretation

Evaluate opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle. In this phase, "Interpretation" is the most important one. An analysis of major contributions, sensitivity analysis and uncertainty analysis leads to the conclusion whether the ambitions from the goal and scope can be met.

All conclusions are drafted during this phase. Sometimes an independent critical review is necessary, especially when comparisons are made that are used in the public domain. Finally, an improvement, in which recommendations are made based on the results of the inventory and impact stages, is also analyzed. These may include modifying a production process, using different raw materials, or choosing one product over another (ISO 14040 and 14044, 2006).

To understand easily, the framework within which life cycle assessment is carried out is shown in Figure 2.17. Two main activities—inventory analysis and impact assessment—are preceded by a vitally important planning phase and followed by extended interpretation, which will normally involve checking the results both against the initial goals and for self-consistency.

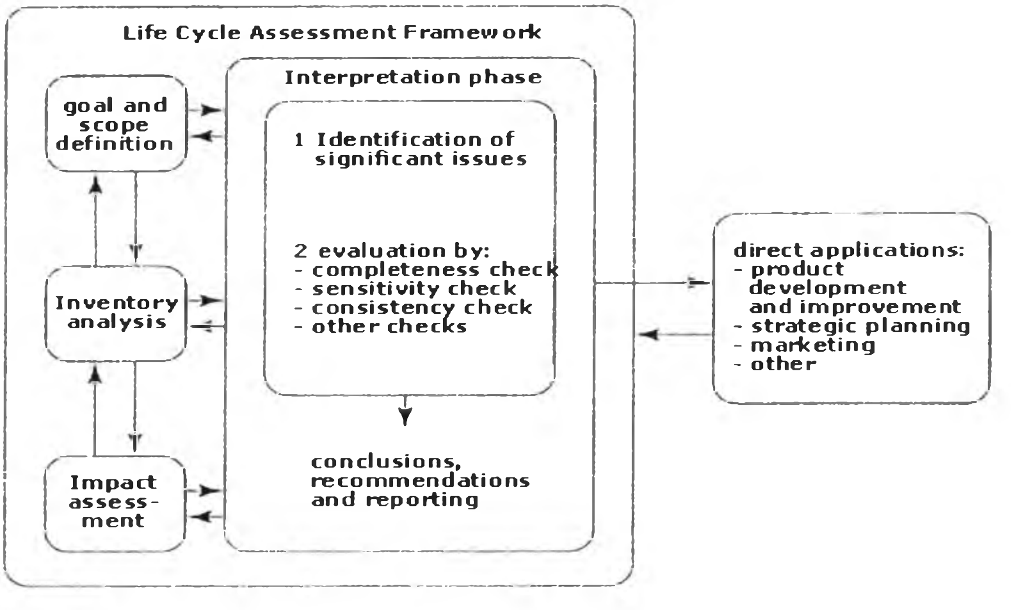


**Figure 2.17** Life cycle assessment framework. (Source: http://www.ami.ac.uk)

### 2.5.4 LCA studies on bioethanol

Bioethanol has become the new challenge on the reduction of fossil resource use and global warming concern. After that, many research teams have conducted the LCA on bioethanol in various materials including sugar, starchy, and lignocellulosic materials.

In 2008, Searcy *et al.* compared the LCA emission renewable energy routes that convert straw/corn stover into usable energy were examined. The conversion options studied were ethanol by fermentation, syndiesel by oxygen gasification followed by Fischer Tropsch synthesis, and electricity by either direct combustion or biomass integrated gasification and combined cycle (BIGCC). The greenhouse gas (GHG) emissions were 830 g $CO_2$ e/kWh for direct combustion, 839 g $CO_2$ e/kWh for BIGCC, 2,060 g $CO_2$ e/L for ethanol production, and 2,440 g $CO_2$ e/L for FT synthesis of syndiesel. The comparison in unit per mega joules is shown in Table 2.7.

**Table 2.7** Comparison of GHG emission from difference sources.
(Source: Searcy *et al.*, 2008)

| **Method** | **Emission (g $CO_2$/MJ)** |
|---|---|
| Direct Combustion | 230.56 |
| BIGCC | 233.06 |
| Fermented Ethanol | 97.31 |
| FT Syndiesel | 67.40 |

The result showed that bioethenol choice gave more attractive than those from electricity choices. However, syndiesel emitted the lowest emission with 67.40 g $CO_2$ per mega joules. By this, it means that the use of lignocellulosic materials in conversion process to be ethanol is better than use it to generate electricity.

In 2009, Luo and co-workers worked on lifecycle assessment and life cycle costing of bioethanol from sugarcane two cases in Brazil. The two cases engaged were: base case—bioethanol production from sucrose, and heat and electricity generation from bagasses using the current technology (1); future case—bioethanol production from both sucrose and bagasses (2), and heat and electricity generation from wastes. His study performed LCA and compared gasoline with E10, E85 and Ethanol as well. The result is shown in Figure 2.18.

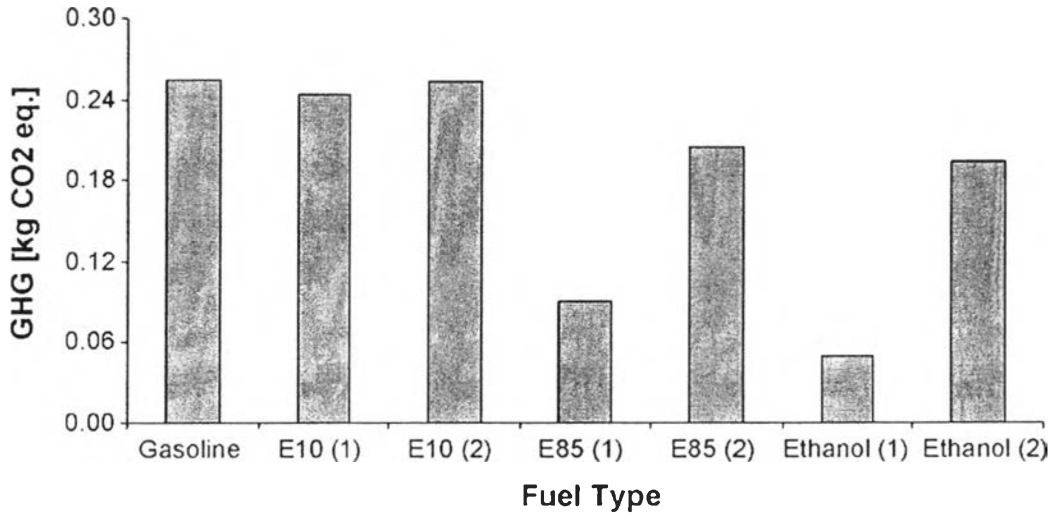


**Figure 2.18** Green house gas emission of ethanol from sugarcane.
(Source: Luo *et al.*, 2009)

When GHG emissions were concerned, burning bagasse for electricity generation (base case) was a much better option than converting bagasse to ethanol (future case). They also performed life cycle costing, the result indicated that driving with ethanol fuels was more economical than gasoline, and the future case was economically more attractive than the base case, which have been the driving force for the promotion of advanced technologies converting bagasse to ethanol.

In 2009, González-García and coworkers studied on the life cycle assessment of flax shives in Spain. They compare the emission in difference allocation method, economic and mass. Three scenarios (EA1, EA2 and EA3) based on economic allocation were evaluated according to the large difference in the market prices (from 15 to 36 €/ton regardless of their final destination). Mass allocation (scenario MA) was also assumed in order to estimate the effect of allocation. The comparison of global warming potential in difference allocation methods are shown in Figure 2.19.

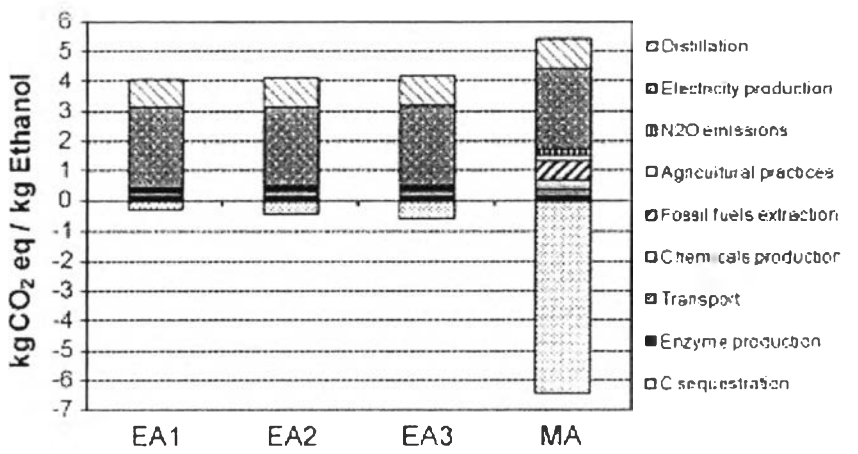


**Figure 2.19** The comparison (between allocation factors) of $CO_2$ equivalent emission for ethanol production and main process involved (Source: González-García *et al.*, 2009).

Activities related to the ethanol conversion plant, such as distillation and electricity production, are the main hot spots in this impact category. In addition, when mass allocation is assumed, there is a remarkable contribution from fossil fuel extraction due to a higher amount of diesel from agricultural machineries being allocated to the flax shives. Moreover, it is important to remark the positive effect of the carbon sequestered during crop growth (9.9 ton $CO_2$/ha), which contributes to offset the GHG emissions. This effect is more outstanding in the mass allocation (highest allocation factor) since more $CO_2$ taken up during the crop growing is allocated to flax shives.

In 2011, Neupane *et al.* worked on the attributional life cycle assessment of woodchips for bioethanol production. An in-depth LCA of woodchips shows that harvesting and woodchips processing stage and transportation to the facility stage emit large amount of environmental pollutants compared to other life cycle stages of ethanol production as shown in Figure 2.20. Their analysis also found that fossil fuel consumption and respiratory inorganic effects are the two most critical environmental impact categories in woodchips production. They have used Eco-indicator 99 based cradle-to-gate LCA method with a functional unit of 4 $m^3$ of dry hardwood chips production.

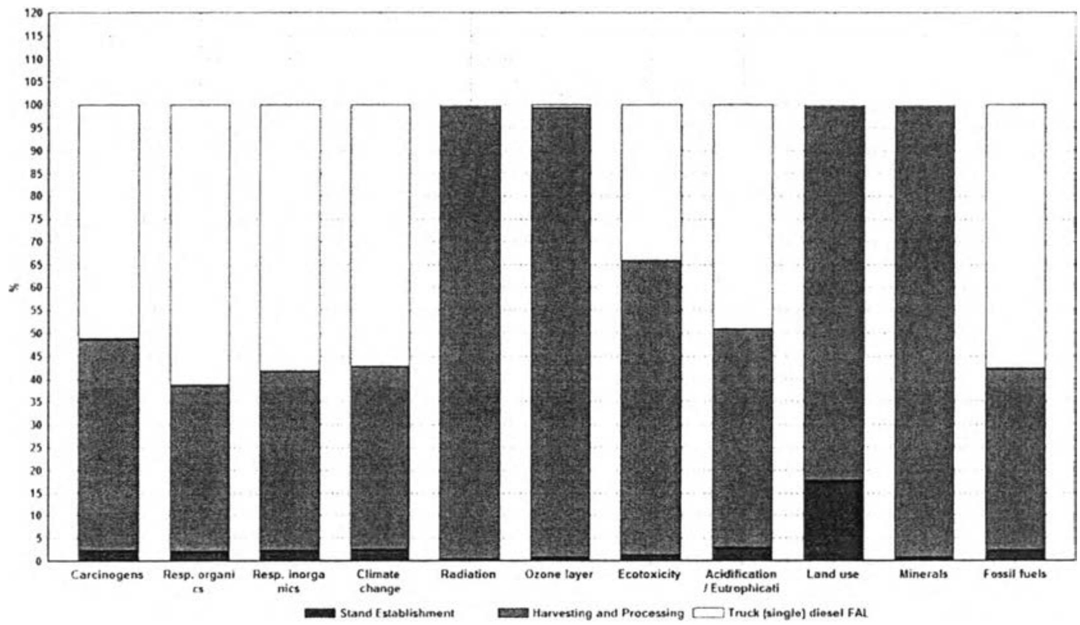


**Figure 2.20** The characterized impact factor for natural regeneration scenario. (Source: Neupane *et al.*, 2011).

In their work, they applied an LCA approach to analyze the environmental impacts of each process steps for woodchips production in view of the impending large scale bioethanol production in the U.S. Using an appropriate LCA method and following the ISO 14040 standards have allowed them to assess the different environmental impacts in each process step of woodchips production. The dominant environmental contributors are fossil consumptions and respiratory inorganics in the natural regeneration and the artificial regeneration scenarios. Transportation of woods from forest site to a facility has significant impact factor, followed by harvesting and processing of woodchips. Since most of the impacts are due to the combustion of fossil fuels (diesel and gasoline) used for operating machineries, one option to reduce the life cycle impacts of woodchips production on the environment is to increase the fuel efficiency of equipments used in harvesting and processing and transportation. This could be done by balancing the size and power capacity of equipments with the tree size to be harvested. They also recommend establishing a prospective biorefinery at proximity to biomass area in order to minimize transportation distance and consequently cost. This however, might increase the transportation distance and costs for producing biomass-based end products.