Renewable and Alternative Energies

Topic 6. Biomass and biofuels

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Topic 6. Biomass and biofuels

- **6.1. General aspects**.
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6.1. General aspects

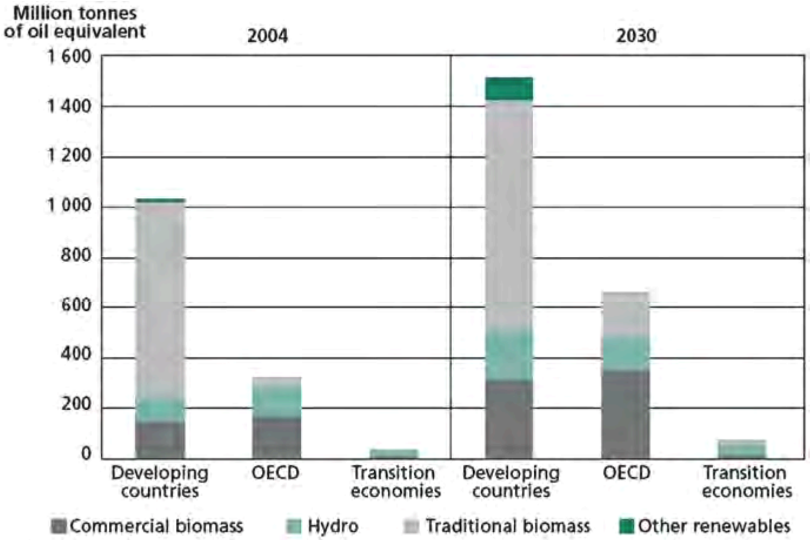
- **Energy derived from biomass** is called **bioenergy**.
- **Biomass can be vegetation** trees, grasses, plants parts such as leaves, stems and twigs, sea weeds, **and waste** products from various industries –including agriculture, forest products, transportation, and construction– that dispose of large quantities of wood and plant products.
- All of these materials can be used for the generation of energy. Since some **biomass** resources, such as trees and plants, **can be cultivated on a regular basis and replenished**, bioenergy **is considered a renewable energy** source.
- Biomass can also be **used to produce biofuels**, which is short for biomass fuel. It can be in the form of both liquid and gas. The major use of "biofuels" is in the transportation sector. Another term, **"biopower" refers to biomass power systems that produce electricity**.
- Bioenergy may be considered as a **carbon neutral system**. Carbon dioxide is released back into the atmosphere when burning biomass.

6.1. General aspects

- Carbon dioxide is a naturally occurring gas. **Plants collect and store carbon dioxide** to aid in the photosynthesis process. **As plants** or other matters **decompose**, or natural fires occur, **CO_2 is released**.
- Before the anthropomorphic discovery of fossil fuels, **the carbon dioxide cycle was stable**; the same amount that was released was sequestered, but it has since been disrupted. In the past 150 years, the period **since the industrial revolution, the carbon dioxide level in the atmosphere has risen** from around 150 to 330 ppm, and is expected to double before the year 2050.
- **The burning of** any type of **fossil fuel:** coal, natural gas, or petroleum, **releases CO_2** into the atmosphere and is considered a major contributor to the current increased level.
- Worldwide, **biomass is the fourth largest energy resource** after coal, oil, and natural gas. It is used for heating (for example, wood stoves in homes and for process heat in bioprocessing industries), cooking (especially in many developing countries), as transportation fuels, such as ethanol, and increasingly, for electric power production.

6.1. General aspects

- Combustible renewables and wastes contribute almost 10.1% of the world's total energy supply. Out of this 10.1%, more **than 90% is from biomass**.
- Although biomass contributes about 1,067 million tons oil equivalent (Mtoe) of energy worldwide, the **electricity generation from biomass is less than 2%**.
- **Developing countries dominate the use of bioenergy** and it is expected that biomass will continue to be a significant source of energy for these developing countries in the near future.
- The Figure shows the current and projected use of bioenergy in different regions of the world.



6.1. General aspects

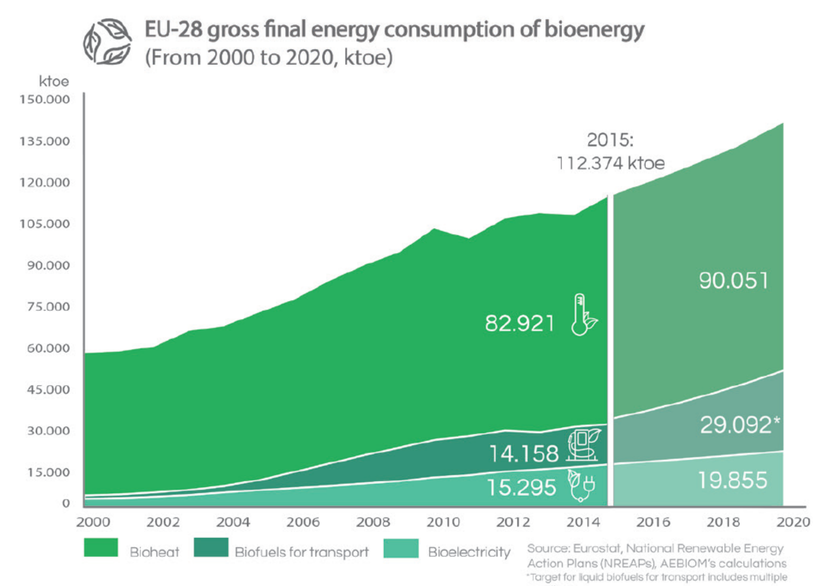
- Of all the continents, **Africa is the world's largest consumer of biomass energy** when calculated as a percentage of overall energy consumption.
- Biomass used in Africa **includes firewood, agricultural residues, animal wastes, and charcoal**.
- Biomass accounts for almost **two-thirds of the total African energy consumption**, which is equivalent to 205 Mtoe of biomass and 136 Mtoe of conventional energy.
- **Most** of Africa's biomass energy **use is in sub-Saharan Africa**. Biomass accounts for 5% of North African, 15% of South African, and 86% of sub-Saharan (minus South Africa) consumption.

6.1. General aspects

Today (2016)

Renewable Energy Policy Network For The 21st Century.
Renewables 2017 Global Status Report.

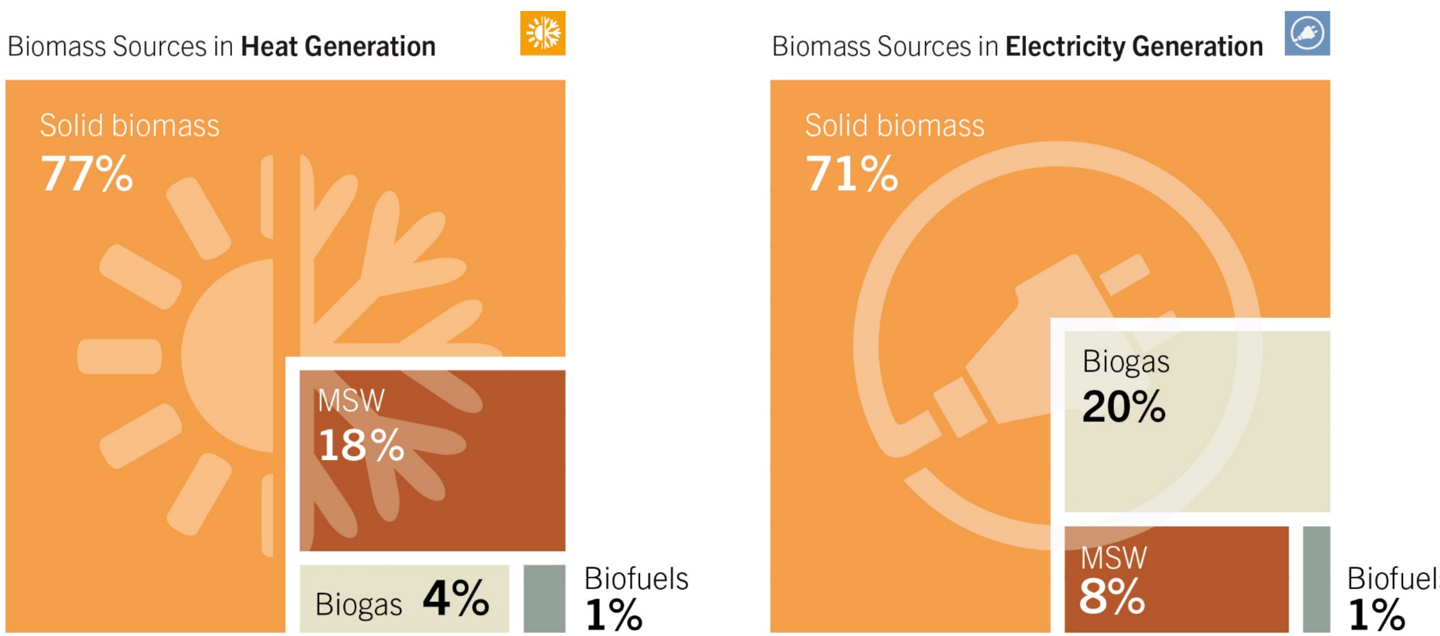
- Biomass was used to produce an estimated 62.5 EJ of primary energy.
- Bio-power total capacity of 112 GW and bio-power generation of 504 TWh.
- By country, the leaders in biopower generation were the United States, China, Germany, Brazil, and Japan.



6.1. General aspects

Today (2015)

Shares of Biomass Sources in Global Heat and Electricity Generation, 2015

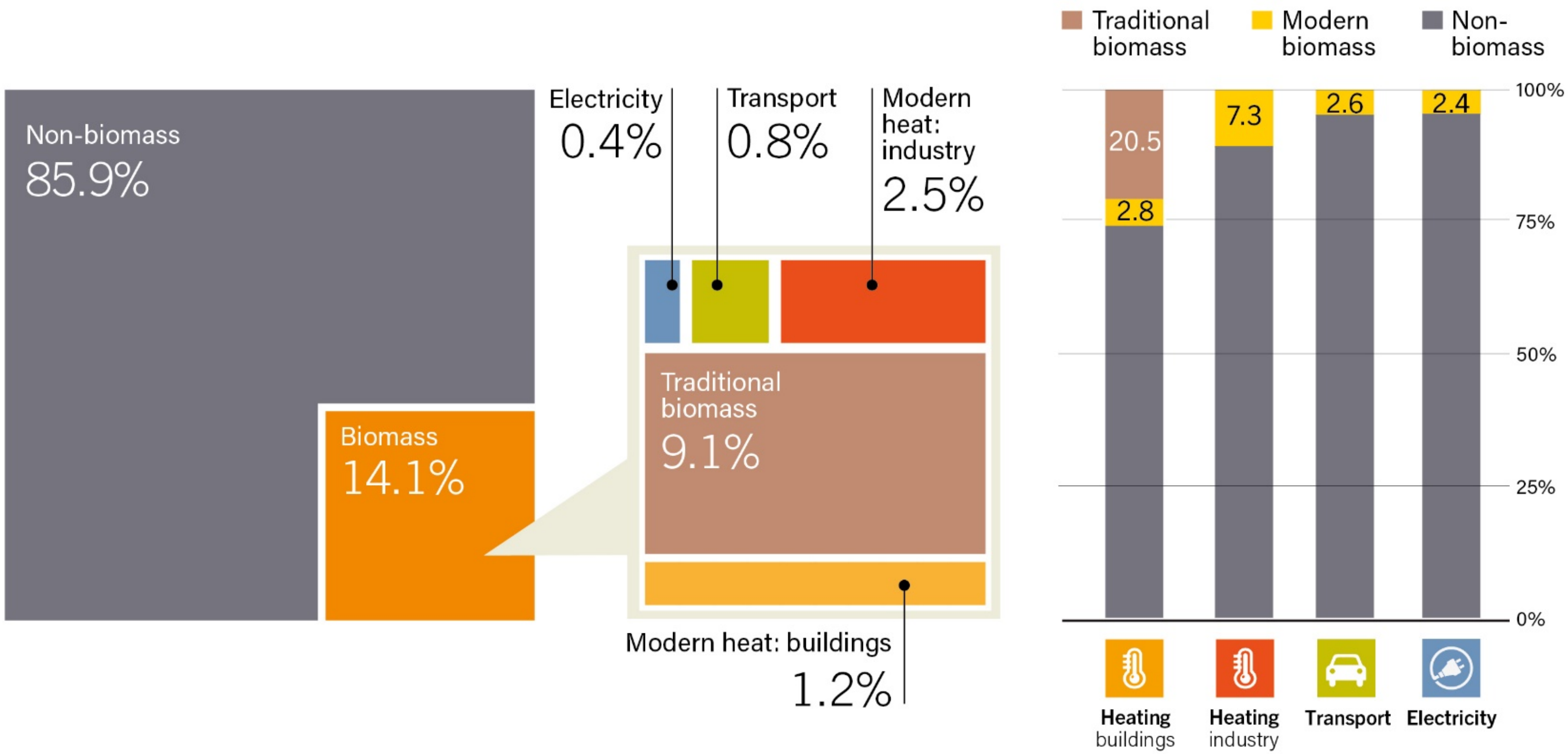


MSW: Municipal Solid Waste.

6.1. General aspects

Today (2016)

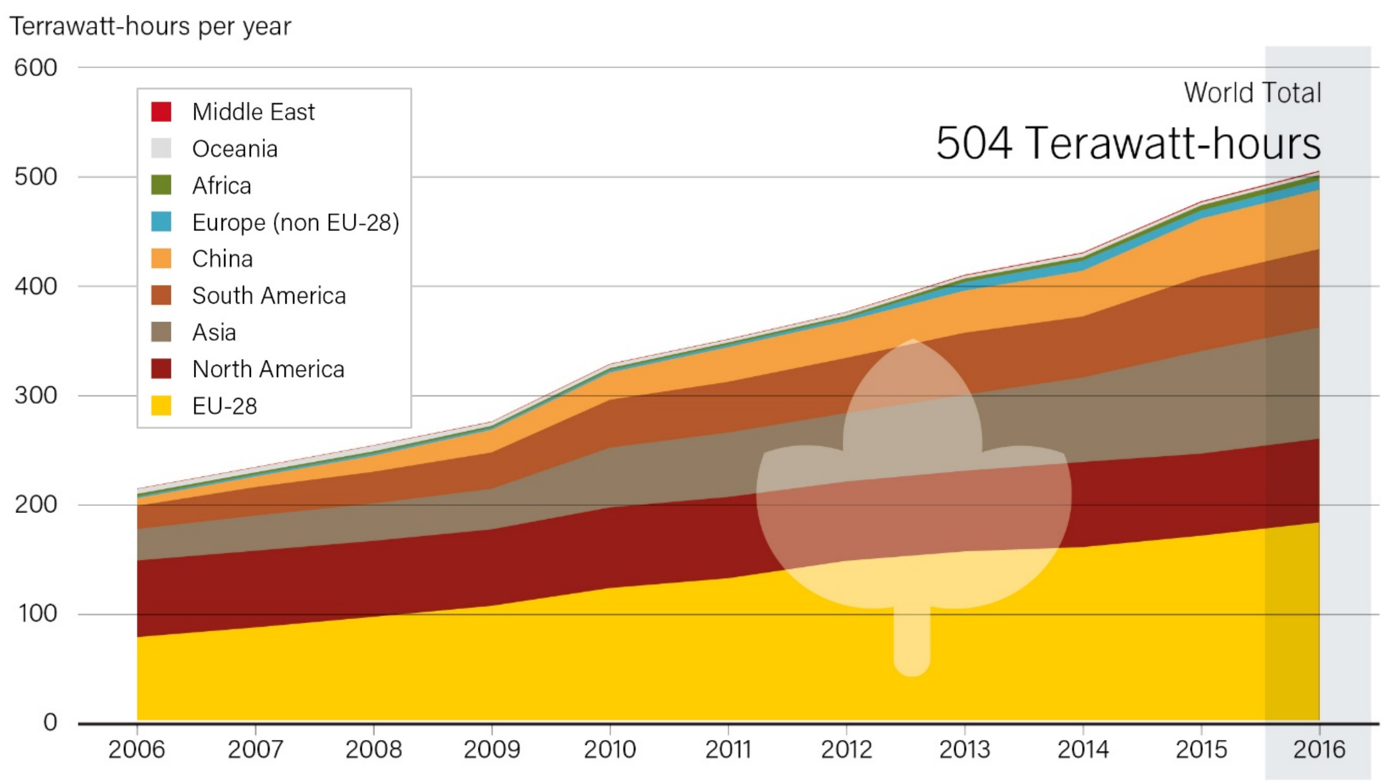
Shares of Biomass in Total Final Energy Consumption and in Final Energy Consumption, by End-use Sector, 2015



6.1. General aspects

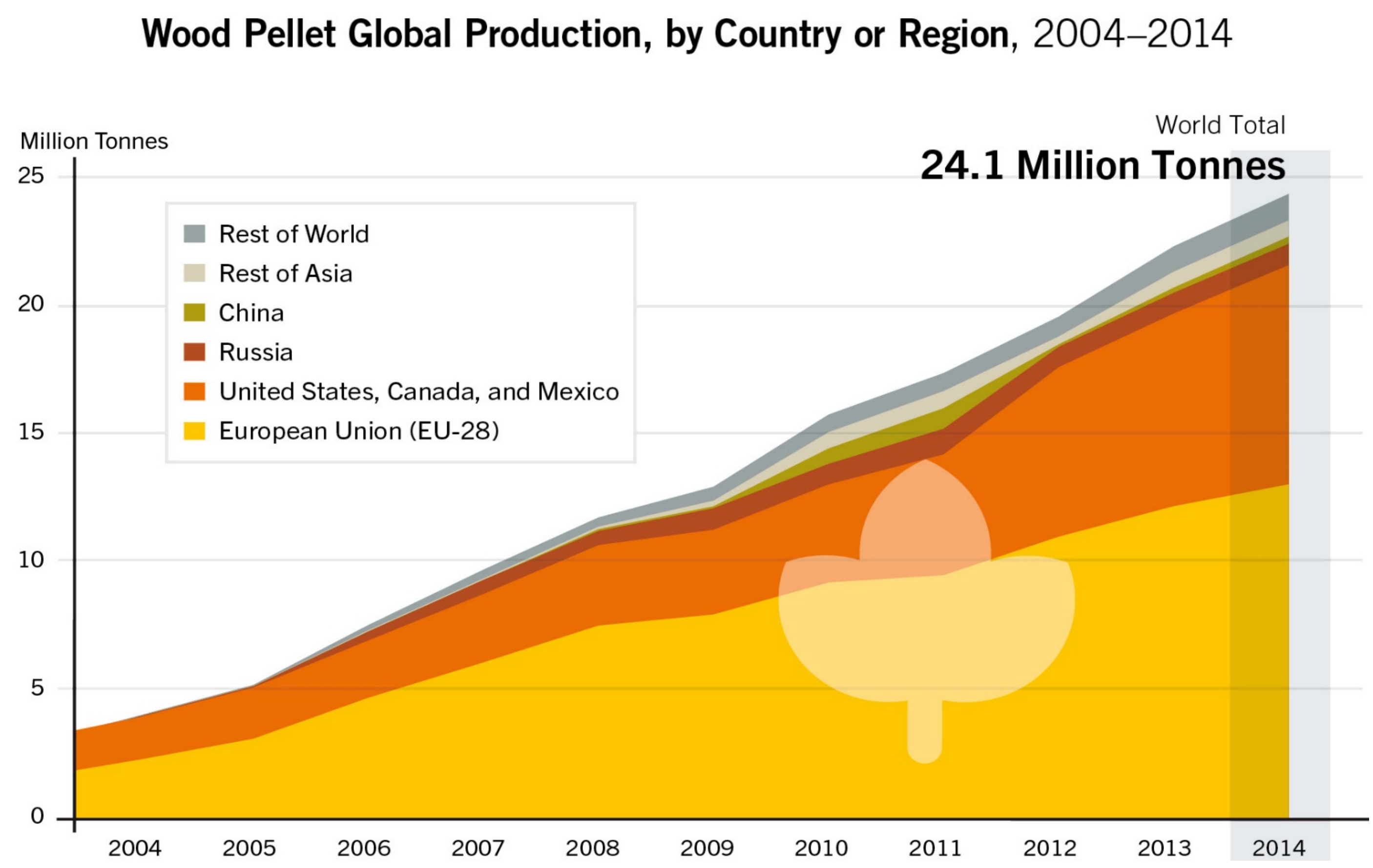
Today (2016)

Global Bio-Power Generation, by Region, 2006-2016



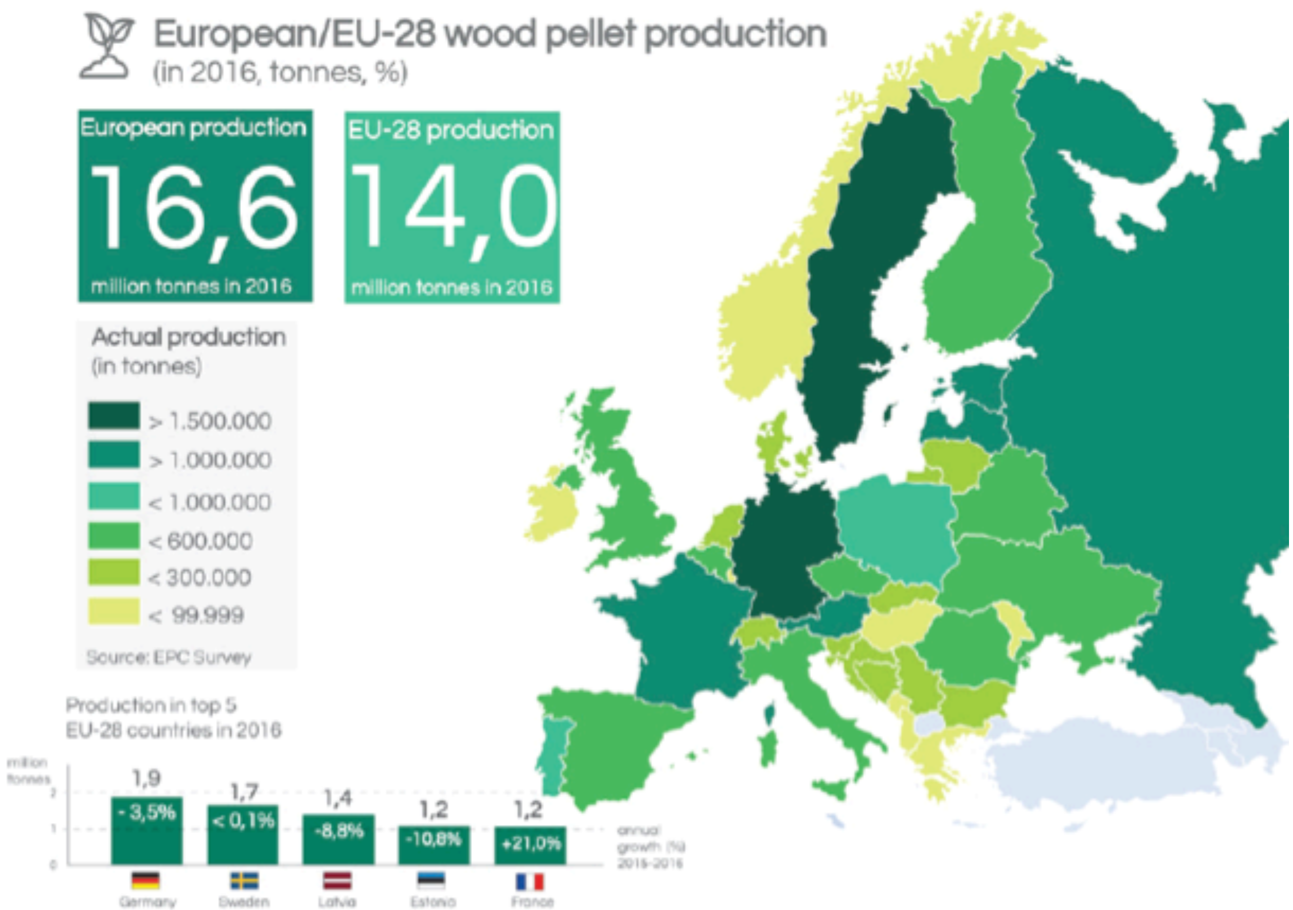
6.1. General aspects

Today (2014)



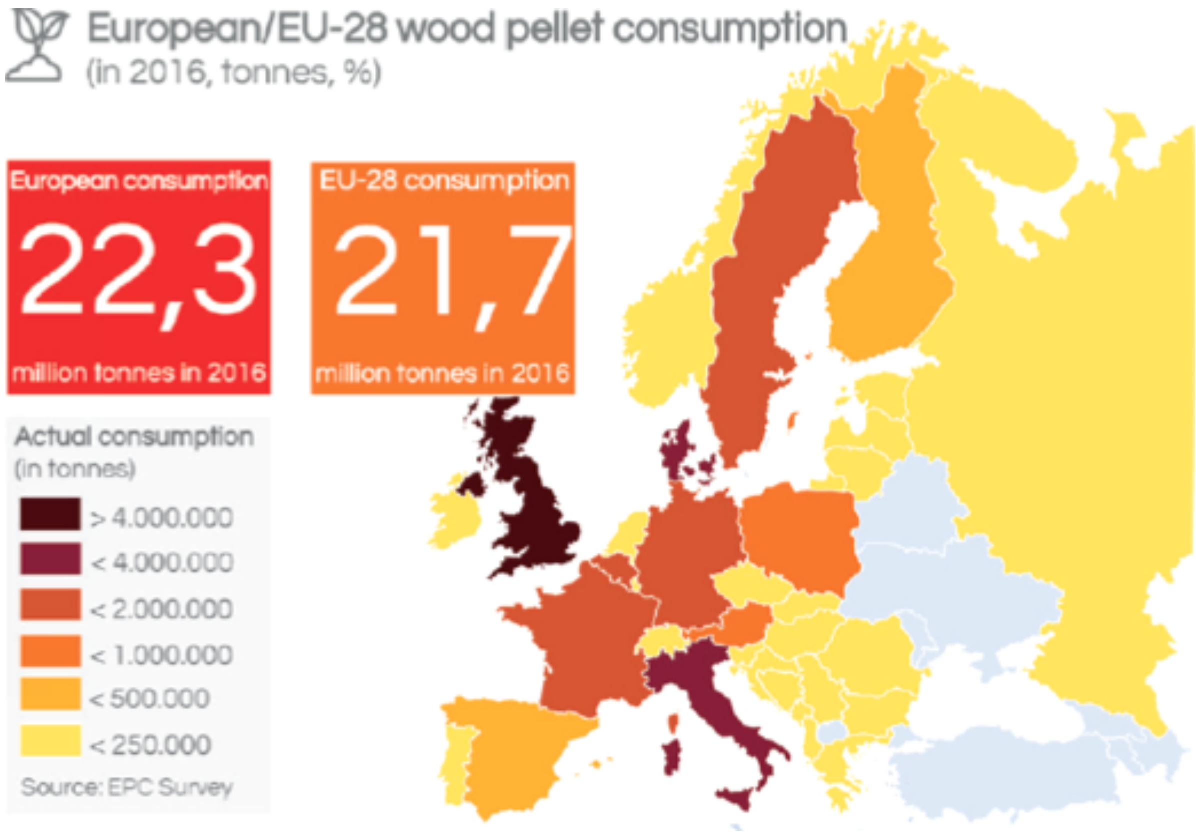
6.1. General aspects

Today (2016)



6.1. General aspects

Today (2016)



Topic 6. Biomass and biofuels

- **6.1.** General aspects.
- **6.2. Types of biomass**.
- **6.3.** Biofuels: Types and production.

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6.2. Types of biomass

Energy source of biomass

- **Plants store energy as carbohydrates or sugar, lignin and cellulose**. During photosynthesis, plants use sunlight to combine carbon dioxide from the air and water from the soil to form carbohydrates, which are the building blocks of biomass.

- While the actual ratio of components varies among species, **the main components are carbohydrates or sugars and lignin**.

- Most species also contain smaller molecular fragments called extractives. **When biomass is burned**, oxygen in the air reacts with the carbon in plants to **produce carbon dioxide and water**.

6.2. Types of biomass

Composition of biomass

- The **composition of the biomass determines its use**.
- **Biomass** that is **rich in carbohydrates**, which is essentially glucose, **is suitable for the generation of biofuels**.
- The **carbohydrate fraction consists of many sugar molecules linked together in** long chains or **polymers**. In a number of plants, **biomass is present in the form of starch**.
- **Starch is composed of glucose**, but it is a mixture of α-amylose and amylopectin. Starches found in nature are 10-30% α-amylose and 70-90% amylopectin. Starch is soluble in water and relatively easy to break down into utilizable sugar units.

6.2. Types of biomass

Composition of biomass

Lignocellulosic biomass:

- **The non-grain portion of biomass** (e.g., cobs, stalks), often referred to as agricultural stover or residues, and energy crops such as switchgrass, **contains biomass in the form of lignin or cellulose**.

- **These lignocellulosic** biomass resources **are not as readily accessible as starch**. They are also called cellulosic and **are comprised of cellulose, hemicellulose, and lignin**. Generally, lignocellulosic material contains 30-50% cellulose, 20-30% hemicellulose, and 20-30% lignin. Some exceptions to this are cotton that contains 98% cellulose and flax that has 80% cellulose.

6.2. Types of biomass

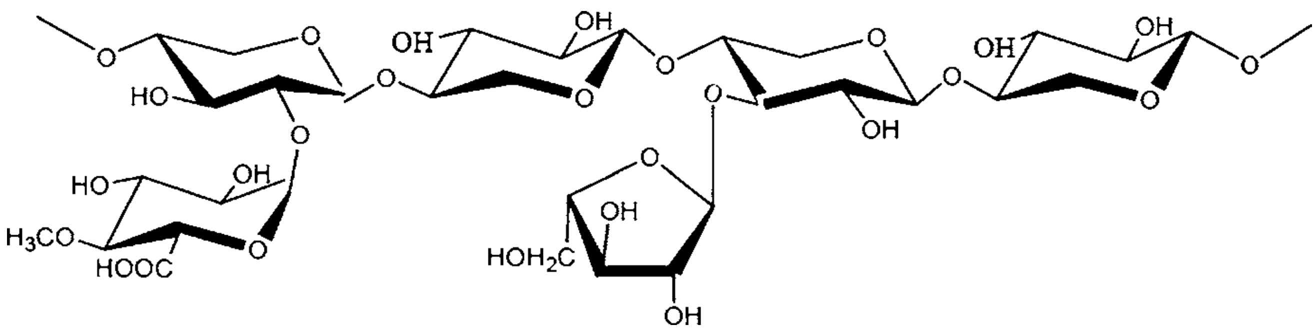
Composition of biomass

Hemicellulose:

- **Hemicellulose is** also **a polymer containing primarily 5-carbon sugars** such as xylose and arabinose.

- **Glucose and mannose molecules are dispersed throughout within the structure**. It forms a short chain polymer that interacts with cellulose and lignin to form a matrix in the plant wall, strengthening it.

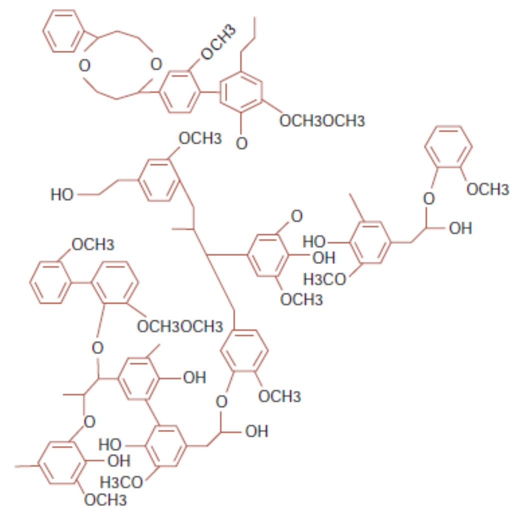
- **Hemicellulose is more easily hydrolyzed than cellulose**. Much of the hemicellulose in lignocellulosic materials is solubilized and hydrolyzed to pentose and hexose sugars.



6.2. Types of biomass

Composition of biomass

Lignin:



- **Lignin helps bind the cellulose/hemicelluloses matrix** while adding flexibility to the mix.
- The molecular **structure of lignin polymers is very random** and disorganized and consists primarily of carbon ring structures containing benzene rings with methoxyl, hydroxyl, and propyl groups.
- They are **interconnected by polysaccharides** (sugar polymers).
- The **ring structures** of lignin **have great potential as valuable chemical inter-mediates**. However, the separation and recovery of lignin from plants is difficult.
- **Lignin can be burned to produce the electricity** required for the ethanol production process. Burning lignin directly can provide more energy than needed and selling extra electricity may help the process economics.

6.2. Types of biomass

Biomass resources may be divided into following categories:

1) Biomass processing residues:
- Pulp and paper industry residues.
- Forest residues.
- Agricultural or Crop residues.

2) Municipal Solid Wastes (MSW):
- Landfill gas.

3) Urban wastes.

4) Animal wastes.

5) Energy Crops:
- Herbaceous energy crops.
- Woody energy crops.
- Industrial crops.
- Agricultural crops.
- Aquatic crops.

6.2. Types of biomass

1) Municipal Solid Wastes (MSW):

- All industrial processes that use biomass produce byproducts and waste streams called residues, which have significant energy content. Some of these residues can be used to generate electricity. Others may be recycled back to the soil as a source of fertilizer.
  - *Pulp and paper industry residues:* paper industry generates significant amount of biomass residues from the processing of plants where cellulose fiber is separated from the plants by making the pulp. These are used for power generation in paper mills. This power actually contributes a significant percent of the overall power consumption of paper mills.
  - *Forest residues:* these include wood from forest thinning operations, biomass from logging sites of commercial hardwood and softwood processing operations, and removal of dead and dying trees.
  - *Agricultural or Crop residues:* these are the biomass discarded during harvesting. They can be collected and prepared as pellets, chips, stacks or bales. Agriculture crop residues include corn stover, wheat straw, rice straw and nut hulls. Corn stover is expected to become a major biomass resource for bioenergy applications.

6.2. Types of biomass

2) Biomass processing residues:

- These are waste paper, cardboard, wood waste and yard wastes.
  - *Landfill gas:* biomass in various landfills **is decomposed using bacteria to produce methane**, which can be captured and used to create energy, most often through anaerobic digestion (AD).

3) Urban wastes:

- **The construction industry generates a significant amount of wood wastes**. Urban wood wastes generally consist of lawn and tree trimmings, tree trunks, wood pallets and other construction and demolition wastes made from lumber.

4) Animal wastes:

- These include cattle, chicken and pig manure. These can be **converted to gas or burned directly** for heat and power generation. The wastes may be processed to generate methane, which can be burned further to generate electricity. Generally, **anaerobic digestion methods are used for the conversion** of animal manure **to methane**.

6.2. Types of biomass

5) Energy Crops:

- These are **fast-growing plants, trees, and other herbaceous biomass resources, which are harvested specifically for energy production**. These crops **can be grown, cut and replaced quickly**.
  - *Herbaceous energy crops:* they are perennials, but it takes **2-3 years before they can be harvested. These include grasses** such as switchgrass, bamboo and wheatgrass.
  - *Woody energy crops:* include silver maple, eastern cottonwood, and sycamore. Generally, **they are fast-growing hardwood trees** and have a short-rotation time between harvesting; these trees may be **used within 5-8 years after planting**.
  - *Industrial crops:* include **plants** such as kenaf and straws. They are **more fibrous than others and are considered**. These plants are **grown specifically to produce industrial chemicalsas industrial crops**.
  - *Agricultural crops:* **include** cornstarch, corn oil and other **vegetable oils**. They generally yield sugars, oils, and extracts. Soybeans and sunflowers seeds are used to produce oil, which can be **used to make fuels**. These plants are also **called oil-plants**.
  - *Aquatic crops:* there is a wide variety of **aquatic biomass resources** such as algae, giant kelp, other seaweed, and marine microflora. They can be **used for bioenergy generation**. Giant kelp extracts are already used for thickeners and food additives.

6.2. Types of biomass

5) Energy Crops:

- Global **biomass resources** vary **greatly from one country to another**.

- Also, it is **extremely difficult to make an annual estimate of these resources**. A number of variables such as rainfall, the use of fertilizers and pesticides, and the availability of irrigation systems can significantly affect the yield of the energy crops, and, thereby, the estimation.

6.2. Types of biomass

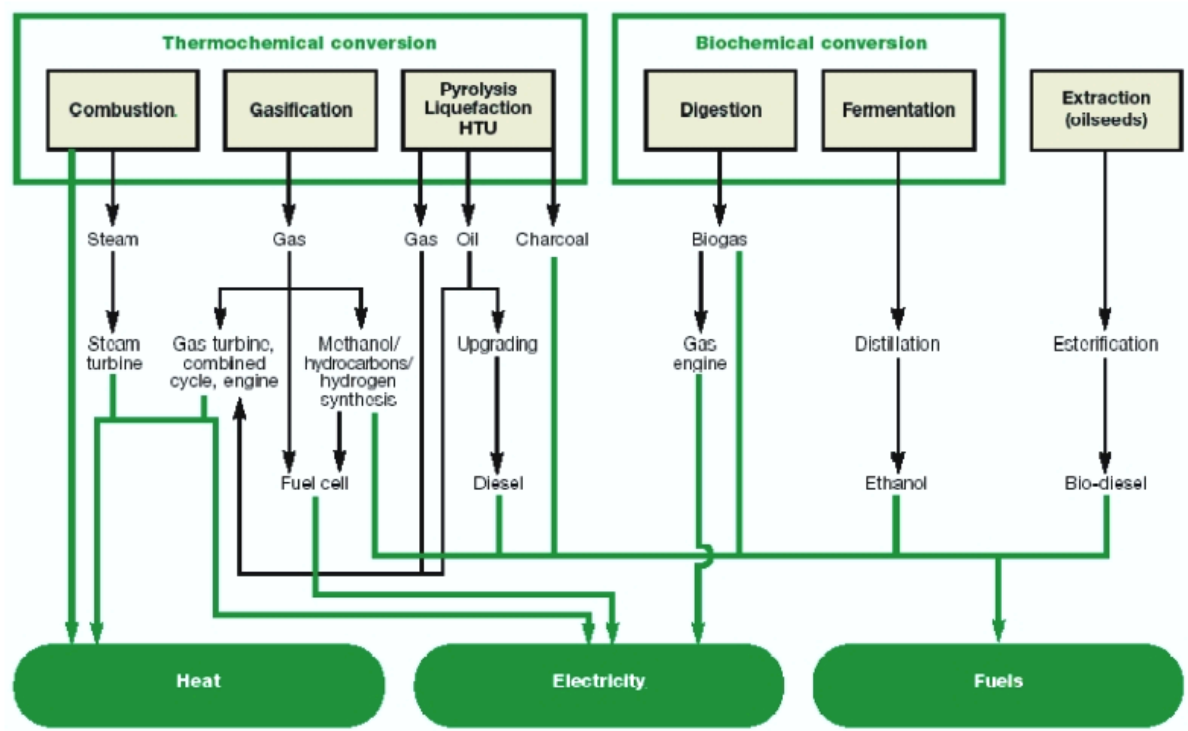
Use of biomass

Biomass may be used for three applications:

A) *Process **heat** and steam **generation**.*

***B) Electrical** power **generation**.*

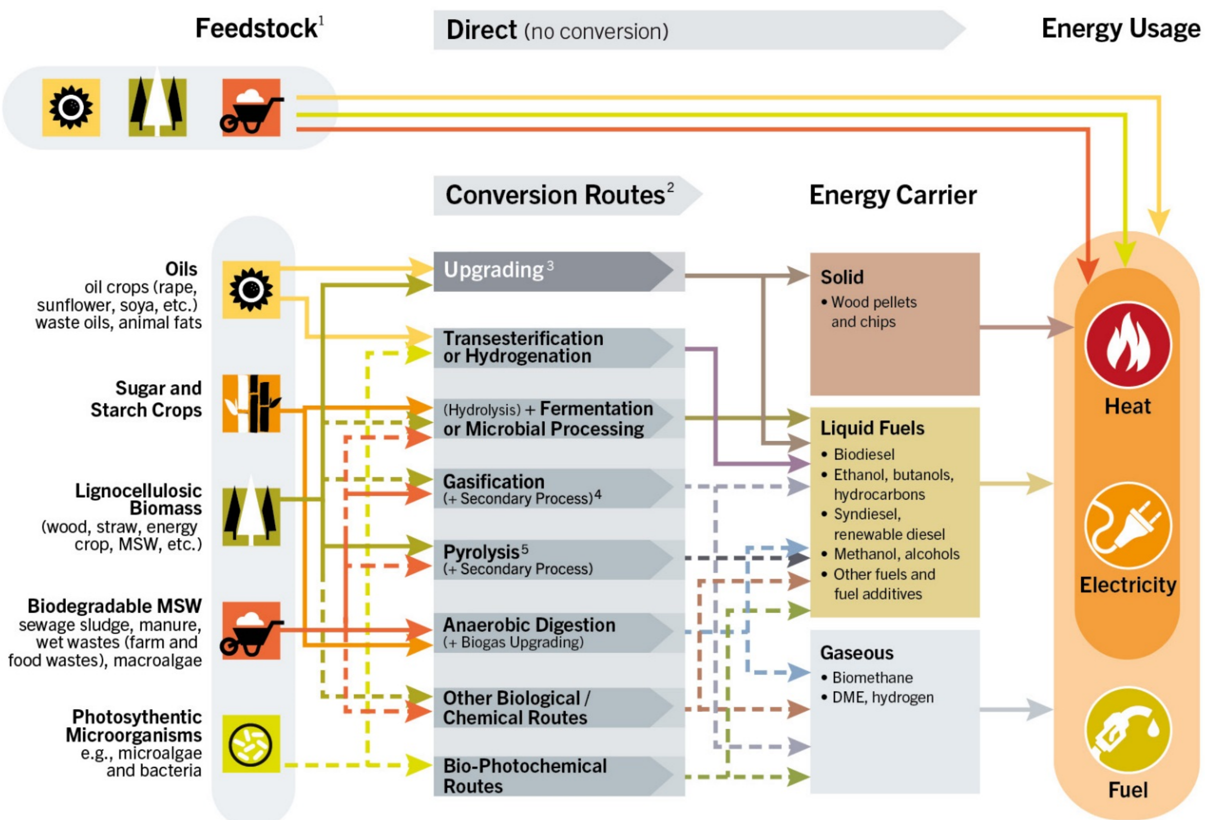
***C) Liquid fuels:** biofuels and biodiesels.*



6.2. Types of biomass

Use of biomass

Bioenergy Conversion Pathways

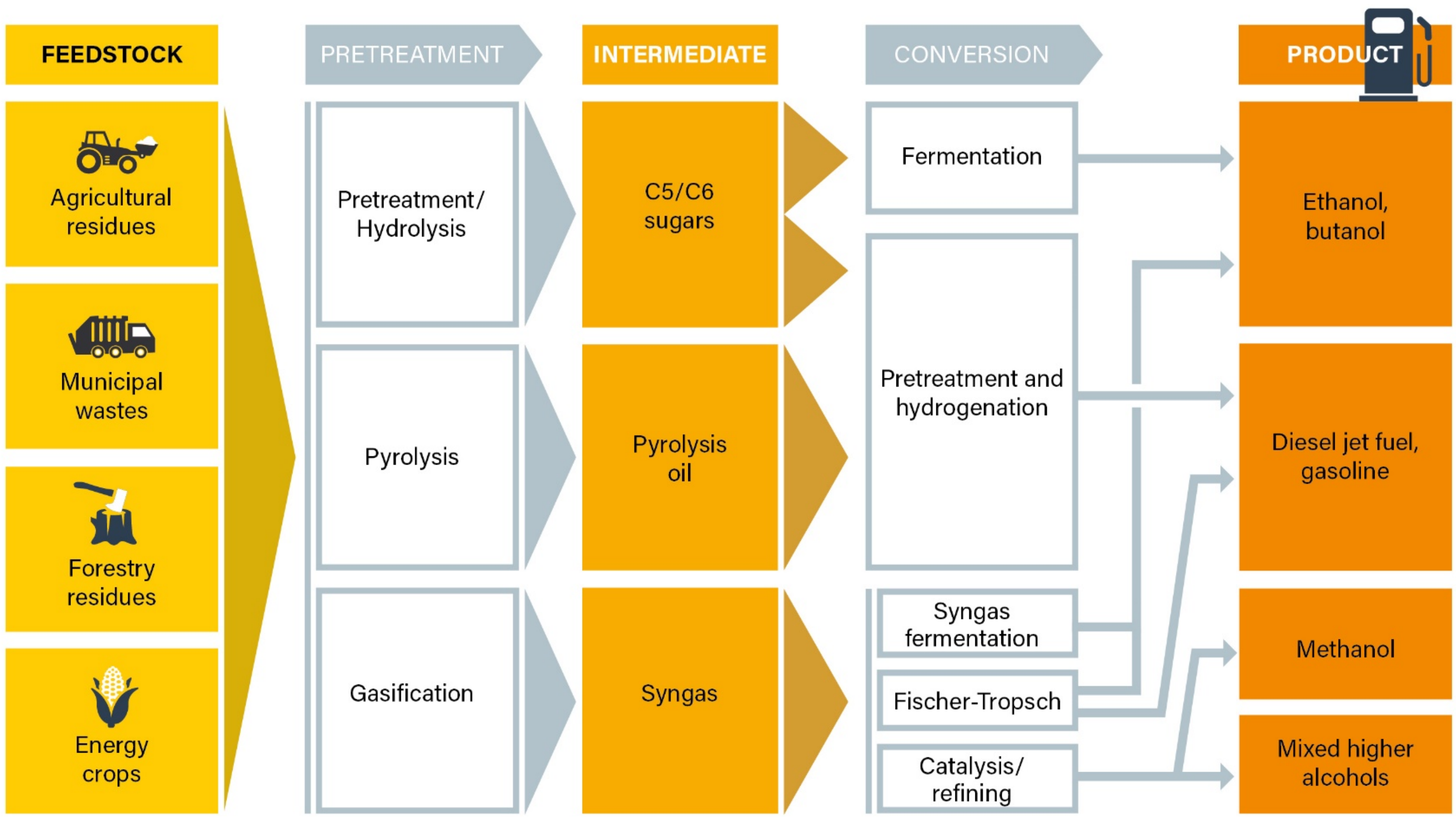


Solid lines represent commercial pathways, and dotted lines represent developing bioenergy routes.

6.2. Types of biomass

Use of biomass

Some Conversion Pathways to Advanced Biofuels



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6.2. Types of biomass

A) Process heat and steam generation

Higher Heating Value (HHV):

- The higher heating value **takes into account the latent heat of vaporization of water** in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical (e.g., in a gas-fired boiler used for space heat).

- HHV **assumes all the water component is in liquid state** at the end of combustion (in product of combustion) and that **heat below 150°C can be put to use**.

- It is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapor produced. Such measurements often use a **standard temperature of 25°C**.

6.2. Types of biomass

A) Process heat and steam generation

Lower heating value (LHV):

- LHV calculations assume that the **water** component of a combustion process **is in vapor state at the end of combustion**.
- It is determined by subtracting the heat of vaporization of the water vapor from the higher heating value (HHV). **The energy required to vaporize the water therefore is not released as heat**.
- It is useful in comparing fuels where condensation of the combustion products is impractical, **or heat at a temperature below 150°C cannot be put to use**.

6.2. Types of biomass

A) Process heat and steam generation

- The main use of biomass in the industrial sector is to produce heat and electricity. The **combined heat and power (CHP) plants generate both electricity and useful heat and steam**.
- CHP plants can achieve **efficiencies greater than 35%** by using biomass. **Paper, chemical, and food-processing industries** are the main users of CHP plants.
- In biomass powered CHP facilities, **steam turbines are used to generate electricity**.
- The **steam condition**, temperature and pressure, **depends on the type of biomass** used as boiler fuel.
- Chemically **untreated wood-like biomass** can generate **steam at 540°C**, whereas the steam produced using **waste wood** is at approximately **450°C**. The steam pressure is in the range of 20-200 bar.

6.2. Types of biomass

B) Electrical power generation

There are four primary classes of biomass power systems:

1) Direct-fired system.

2) Co-fired biopower plants.

3) Gasification process.

4) Small, modular systems.

6.2. Types of biomass

B) Electrical power generation

1) Direct-fired system:

- In direct-fired biomass power plants, the **biomass fuel is burned in a boiler**, similar to a coal power plant, **to produce high-pressure steam**. The steam is introduced into a steam turbine to generate electricity. Direct-fired biomass power boilers are typically in **the range of 20-50 MW** compared to a range of 100-1,500 MW for pure coal fired plants.

- Because of the small capacity, its **efficiency** is in the low **20% range**. Although techniques exist to enhance biomass steam generation efficiency over 40%, it may not be economical.

6.2. Types of biomass

B) Electrical power generation

2) Co-fired biopower plants:

- Co-firing involves **substituting biomass for a portion of coal in an existing power plant furnace**. Up to about **15% biomass can be mixed** with coal for an existing fuel feed, thus, burning these together. In some plants, a separate boiler feed for the biomass is used.

- Most of the existing power plant equipment can be used without major modifications.

- The preparation of biomass for co-firing employs **well-known, commercially available technologies**.

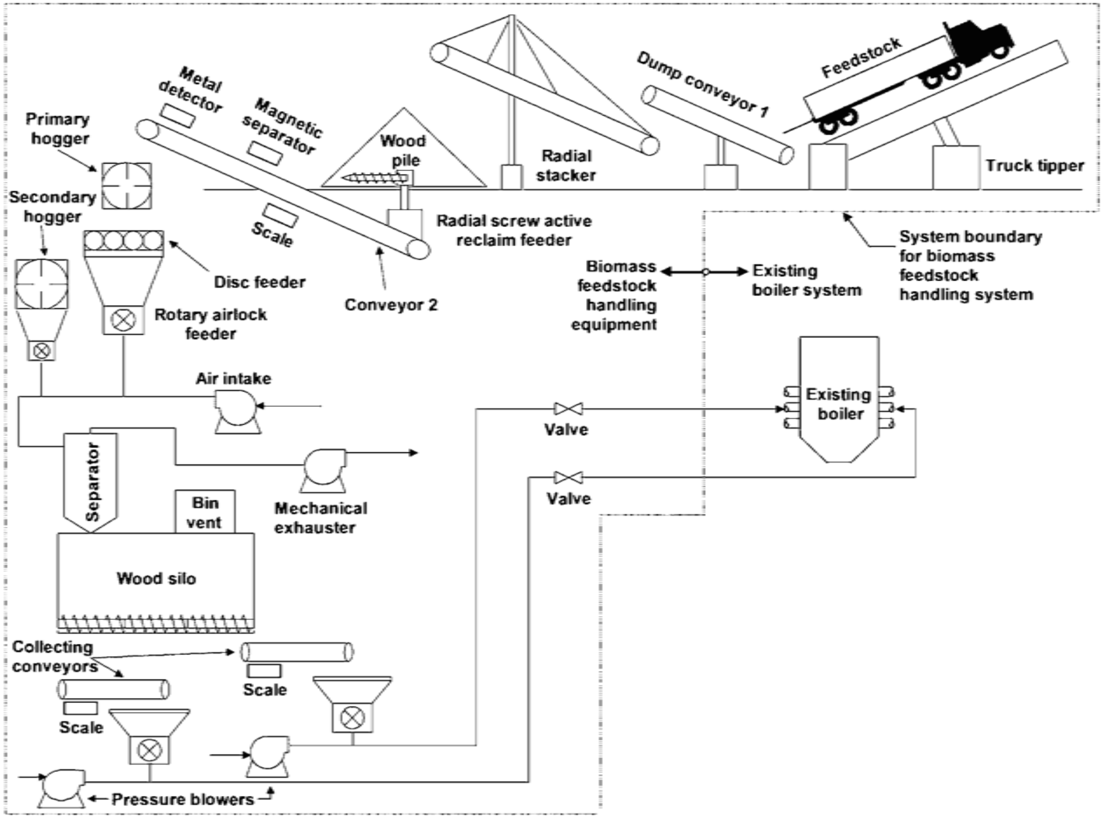
- As a result, co-firing offers the **most economic alternative to building a new biomass power plant**. The replacement of biomass can also reduce sulfur dioxide (**SO_2**), nitrogen oxides (**NO_x**) and other air emissions.

6.2. Types of biomass

B) Electrical power generation

2) Co-fired biopower plants:

- After "tuning" the boiler for peak performance, there is little or no loss of efficiency from adding biomass. The **efficiency** can be in the **range of 33-37%**.



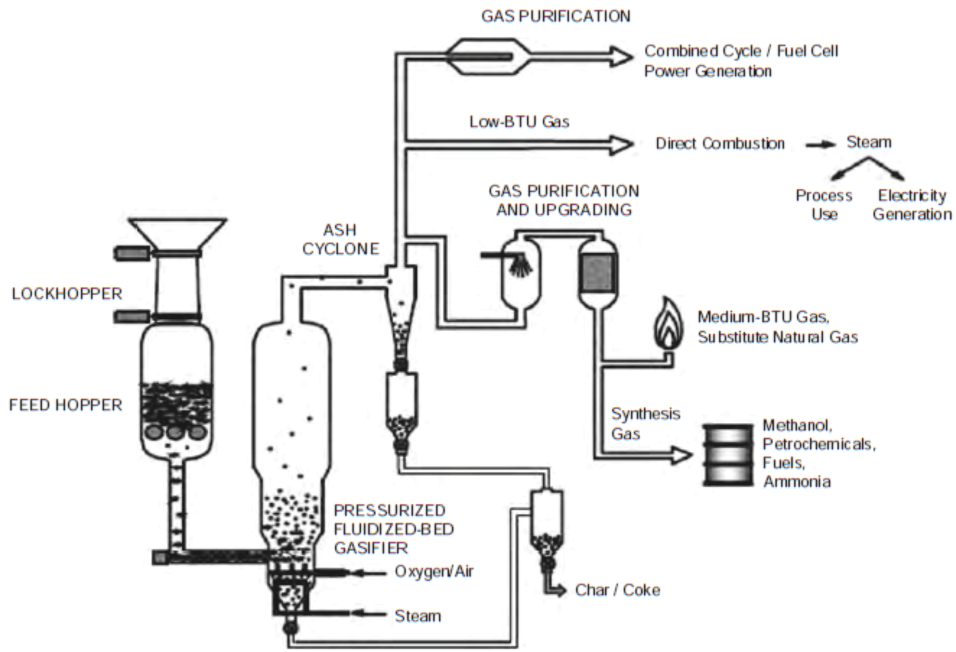
6.2. Types of biomass

B) Electrical power generation

3) Gasification process:

- The working principle of biomass gasifiers is the same as that of other gasifiers, such as coal gasifiers. **The solid biomass particles break down when heated at a high temperature in the absence of oxygen to form** a flammable gaseous product, called **biogas**.

- The **biogas is** next **cleaned and filtered for use in** more efficient power generation systems called **combined-cycles**, which combine a **gas turbine and a steam turbine** to produce electricity. The **efficiency** of these systems can **reach 60%**.



6.2. Types of biomass

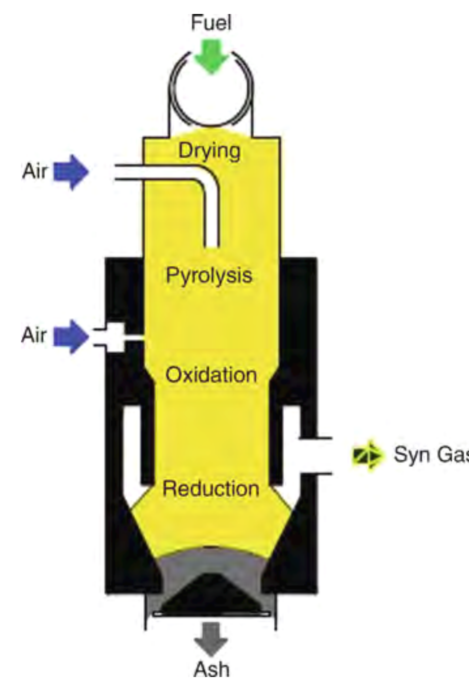
B) Electrical power generation

3) Gasification process:

- **Gasification is a two-step process**. The **first step** is called **pyrolysis**. During pyrolysis, the **volatile components of the fuel are vaporized at temperatures below 600°C**. The vapor produced in this step includes various hydrocarbons, hydrogen, carbon monoxide, carbon dioxide and water vapor.

- Because biomass fuels tend to have more volatile components than coal, **pyrolysis plays a larger role in biomass gasification** than in coal gasification. Char (fixed carbon) and ash are the by-products, which are not vaporized.

- In the **second step, char is** further **burned**. The **design of the gasifier is** extremely **crucial for** high **efficiency** and the success of the process. **Generally, all three stages of burning: pyrolysis, oxidation, and reduction are accommodated in a single burner** to reduce the installation and operating costs and to increase the efficiency.



6.2. Types of biomass

B) Electrical power generation

3) Gasification process:

- *Advantages of gasification:*
  - Biogasification offers several advantages including **reduced emissions, increased efficiencies, and flexibility**.
  - **Emissions from a biogasifier could be extremely low** compared with conventional power plants.
  - Furthermore, these systems **can achieve high efficiencies**. The use of advanced biomass gasifier and gas turbines can increase the electricity generation from the biomass by 50% or more. Various combinations of thermal cycles may further enhance the efficiency.

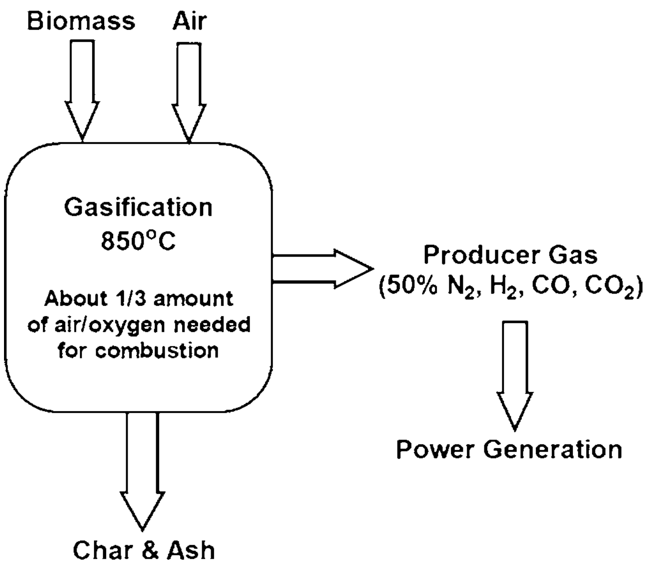
6.2. Types of biomass

B) Electrical power generation

4) Small, modular systems:

- Modular systems **employ** some of **the same technologies** mentioned above, **but on a smaller scale** that is more **applicable for** use in **remote areas**, villages, farms, and small industries.

- There are **many opportunities** for using these systems **in developing countries**. Large amounts of biomass are available in these areas for fuel that a small, modular system can utilize.



- **Small systems**, those with rated capacities of **5 MW and smaller**, could **potentially provide power to a small community**.

- By **adopting a standardized modular design**, 5 kW-to-5 MW, **systems can be designed at a lower cost**.

6.2. Types of biomass

B) Electrical power generation

4) Small, modular systems:

- The **hot gas** from the gasification unit **is cleaned and used for electricity generation**. **Waste heat** from the turbine or engine **can also be captured** and directed to other applications.

- **Small modular systems provide combined** heat and power **operations much better than large central facilities**.

- **For a small community**, small modular systems can have an added **economic benefit**, since **the biomass waste stream can be a source of energy**. Otherwise, a landfill needs to be designed and operated.

- **The flexibility to use more than one fuel is another advantage**.

Topic 6. Biomass and biofuels

- **6.1.** General aspects.
- **6.2.** Types of biomass.
- **6.3. Biofuels: Types and production**.

6.3. Biofuels: Types and production

C) Liquid fuels

- **Biomass can be converted** directly **into liquid fuels, called "biofuels"**, which can be **used as transportation fuel replacing petroleum**.

- Liquid fuels from biomass **can be produced by a number of routes**, depending on the characteristics of the biomass and methods employed.

The two most common types of biofuels are ethanol and biodiesel:

1) Ethanol.

2) Biodiesel.

6.3. Biofuels: Types and production

C) Liquid fuels

1) Ethanol:

- Also known as ethyl alcohol or grain alcohol, can be **used** either **as an alternative fuel or as an** octane-boosting, pollution-reducing **additive to gasoline**.
- The **potential** of biofuels for transportation **may be limited since it may come at the expense of global food production**.

There are four basic steps for converting biomass into bioethanol:

I) **Production of biomass** such as corn or sugar cane.

II) **Conversion of biomass into a useable fermentation feedstock** (typically some form of sugar).

III) **Fermentation of the biomass intermediates** using suitable microorganisms including yeast and bacteria for the production of ethanol.

IV) **Processing of the fermentation product into fuel-grade ethanol and bypro-ducts** that can be used to produce other fuels, chemicals, heat and/or electricity.

6.3. Biofuels: Types and production

C) Liquid fuels

2) Biodiesel:

- Biodiesel **is a form of diesel fuel manufactured from vegetable oils, animal fats, or** recycled restaurant **greases by esterification**.
- It is considered to be **safe, biodegradable and produces less air pollutants** than petroleum-based diesel.
- The **energy content** of biodiesel is about **90% that of petroleum diesel**.
- A **variety of vegetable oils can be used** for the production of biodiesel.
- **Rapeseed and soybean oils are most commonly used**; soybean oil alone accounts for about 90% of all feedstocks. Other oils such as mustard, flax, sunflower and palm oil have also been explored. Several researchers have also proposed the use of algae for biofuel production.

6.3. Biofuels: Types and production

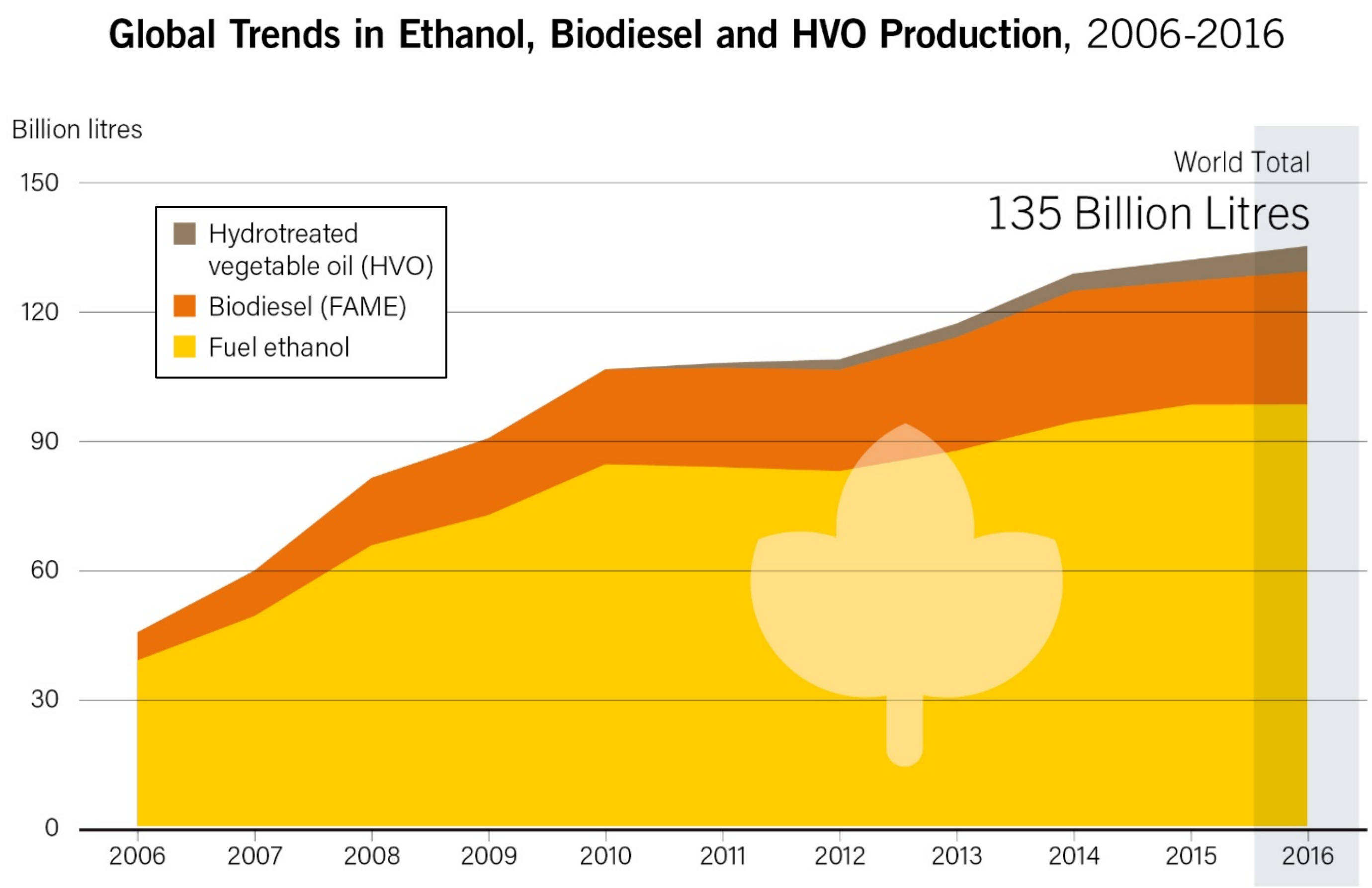
C) Liquid fuels

2) Biodiesel:

- Although **biodiesel may be considered a renewable energy source, significant agricultural land must be dedicated to a continuous and reliable supply** of feedstock.
- **Animal fats and the by-products** of the production of Omega-3 fatty acids **from fish oil** can also be **used as feedstock**. For the commercial production of **vegetable oils**, about **20 different species are used**.
- **Biodiesel production is increasing rapidly. Europe**, the largest producer and user of biodiesel, **produces** most of it **from rapeseed oil**. The **USA**, the second largest producer and user of biodiesel, makes it **from soybean oil and recycled restaurant grease**.

6.3. Biofuels: Types and production

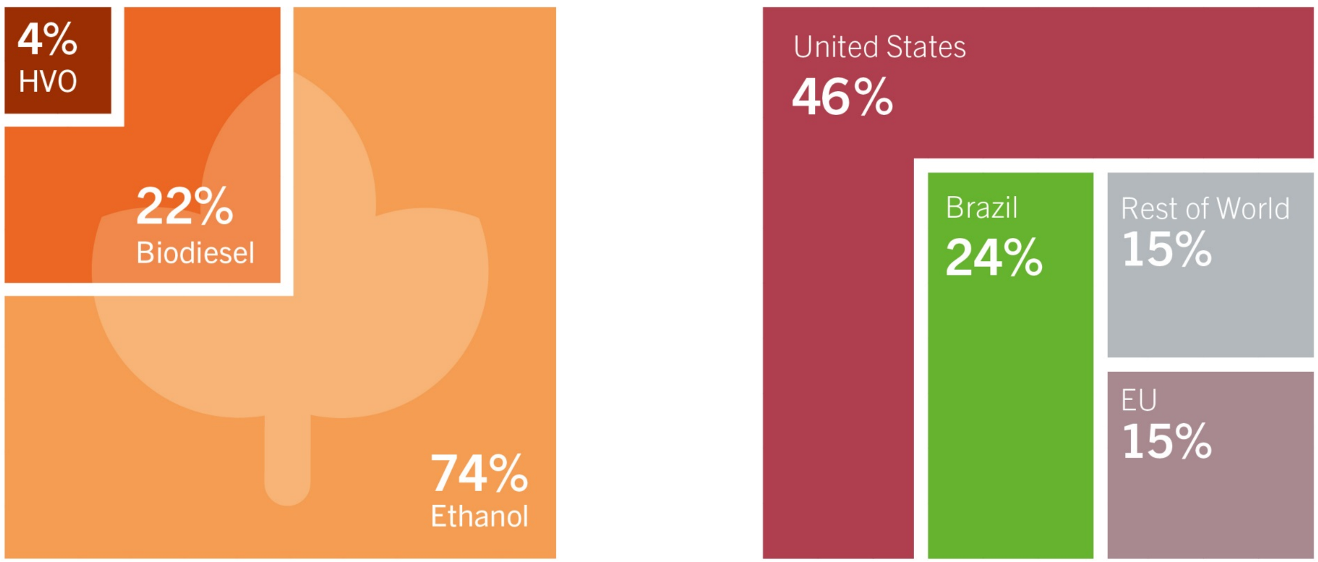
C) Liquid fuels: Today (2016)



6.3. Biofuels: Types and production

C) Liquid fuels: Today (2015)

Biofuels Global Production, Shares by Type and by Country/Region, 2015



HVO: Hydrotreated vegetable oil.

6.3. Biofuels: Types and production

C) Liquid fuels

Biodiesel production method:

- **Vegetable oils** generally **contain 16 and 22 carbon atoms** that are generally in the form of triacyl glycerides (TAG), which on transesterification with methanol produce glycerol as a by-product and fatty acid methyl ester (FAME) as the precursor to biodiesel.

There are three basic routes for synthesis of biodiesel or alkyl esters from oils and fats:

1) Base catalyzed transesterification of the oil with alcohol.

2) Acid catalyzed esterification of the oil with alcohol.

3) Lipase catalyzed transesterification

6.3. Biofuels: Types and production

C) Liquid fuels

1) Base catalyzed transesterification of the oil with alcohol:

- It is **mostly used for the production of biodiesel**. This method has **several advantages** over the other two methods; it requires a **low temperature** 65°C **and pressure** 1.4 bar, a **conversion in the range of 98%** is achievable, **by-products have various uses** and values, and **methyl ester is produced directly** without any intermediate reactions.

2) Acid catalyzed esterification of the oil with alcohol:

- An acid catalyzed esterification method is **preferred if feedstock has a high free fatty acid (FFA)** content. It requires higher reaction temperatures (100°C) and longer reaction times than base catalyzed transesterification.

3) Lipase catalyzed transesterification:

- **Lipase** (an enzyme) **is used as a biocatalyst for synthesis of biodiesel** from oil and FFA. It can be **carried out at much milder operating conditions** and **can overcome the problems of conventional chemical processes**.

6.3. Biofuels: Types and production

C) Liquid fuels

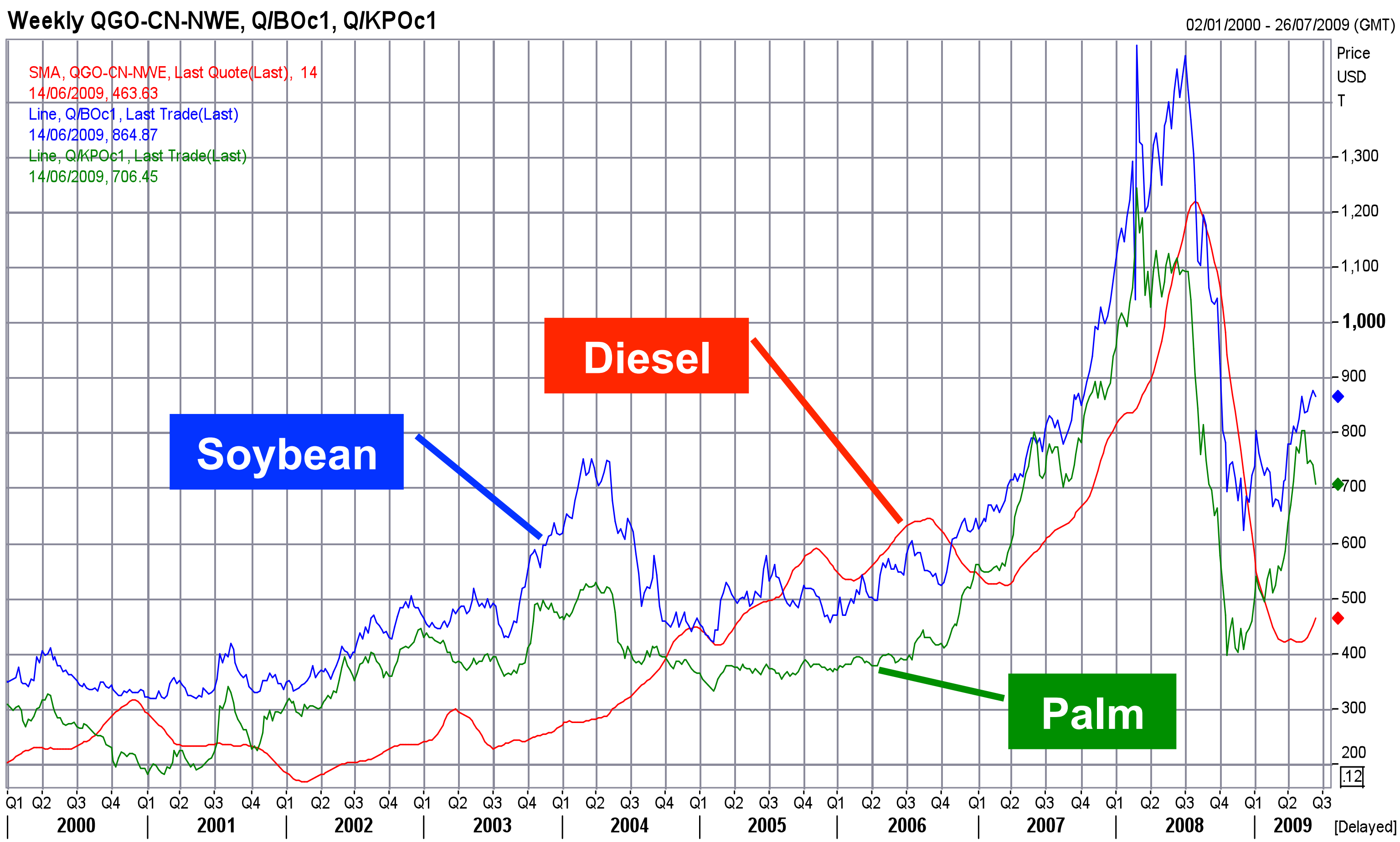
Land requirements for biofuel production

COUNTRY GROUPING	2004		2030					
			Reference scenario		Alternative policy scenario		Second-generation biofuels case	
	(Million ha)	*(Percentage of arable land)*	*(Million ha)*	*(Percentage of arable land)*	*(Million ha)*	*(Percentage of arable land)*	*(Million ha)*	*(Percentage of arable land)*
Africa and Near East	–	–	0.8	0.3	0.9	0.3	1.1	0.4
Developing Asia	–	–	5.0	1.2	10.2	2.5	11.8	2.8
European Union	2.6	1.2	12.6	11.6	15.7	14.5	17.1	15.7
Latin America	2.7	0.9	3.5	2.4	4.3	2.9	5.0	3.4
OECD Pacific	–	–	0.3	0.7	1.0	2.1	1.0	2.0
Transition economies	–	–	0.1	0.1	0.2	0.1	0.2	0.1
United States of America and Canada	8.4	1.9	12.0	5.4	20.4	9.2	22.6	10.2
World	**13.8**	**1.0**	**34.5**	**2.5**	**52.8**	**3.8**	**58.5**	**4.2**

Note: – = negligible.
Sources: FAO, 2008a; IEA, 2006.

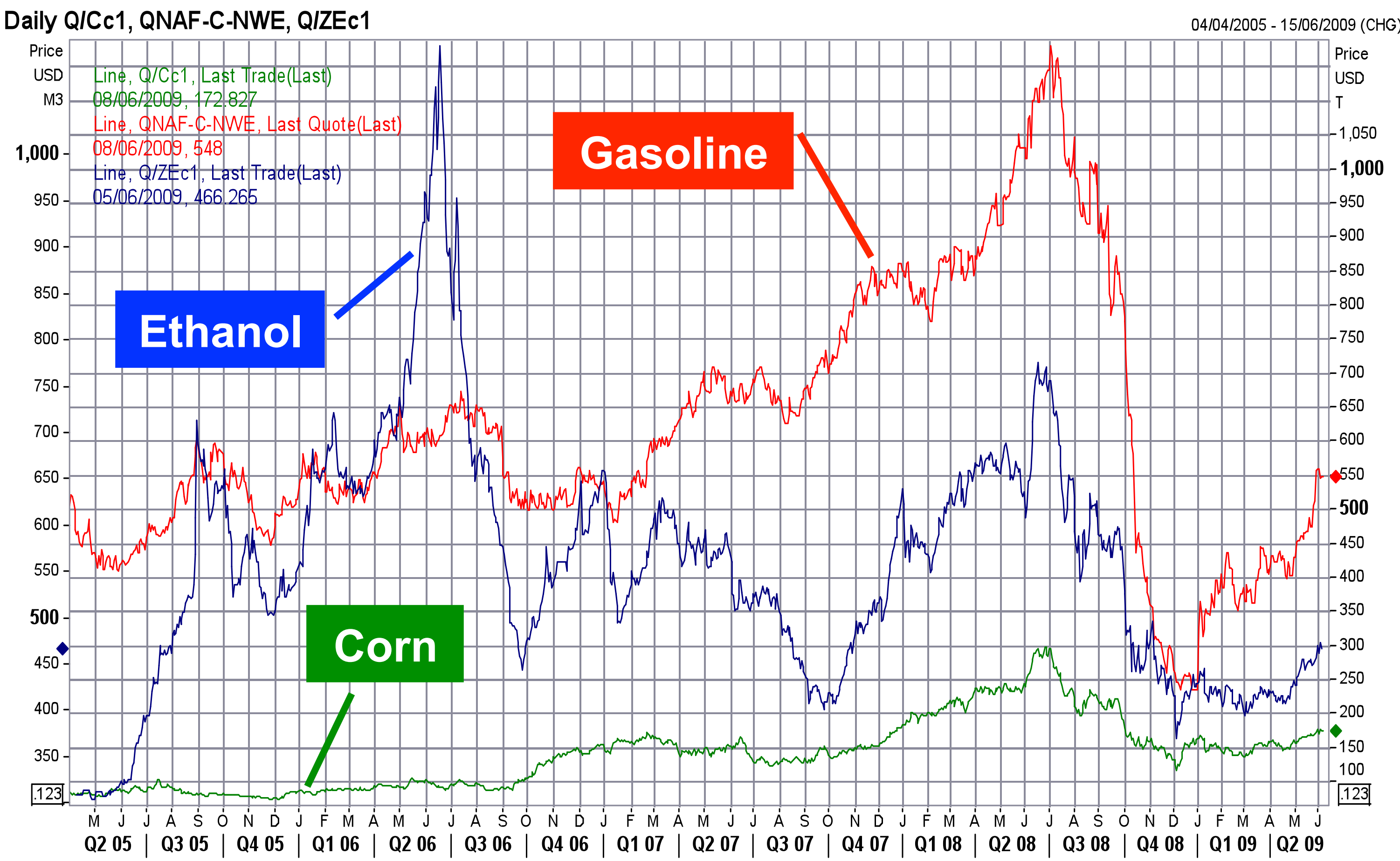
6.3. Biofuels: Types and production

C) Liquid fuels



6.3. Biofuels: Types and production

C) Liquid fuels



Sources

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