Biomass conversion into fuels

Source: IEA Energy Technology Essentials: Biofuel Production © OECD/International Energy Agency 2007, page 1

A biomass conversion plant

Introduction

Biomass, a source of renewable energy, is organic biological material such as wood, wood waste, municipal solid waste, straw, sugar cane, algae, and many other byproducts derived from agricultural and forestry production as well as other sources. Since biomass derives from plants generated by solar energy in thephotosynthesis process it can also be defined as the biological material on Earth that has stored solar energy in the chemical bonds of the organic material.

The fossil fuels (coal, petroleum crude oil and natural gas) are currently thought to have been formed from prehistoric, ancient biomass buried deeply underground over millions of years of geological time. Therefore, they are not considered to be renewable sources of energy.

Production of fuels and other products from biomass

Biomass fuel for electric power production

The direct combustion of biomass for producing heat and electric power provides a ready disposal mechanism for municipal, agricultural, and industrial organic wastes. In 2010, about 11,377 megawatts (MW) of electric power, amounting to 1.1% of the summertime electrical supply in the United States was generated by burning biomass that included: wood, wood waste, municipal solid waste (MSW), landfill gas, and agricultural byproducts and waste.[1]

The New Hope Power Partnership in Florida is the largest biomass power plant in North America. It generates 140 MW of power using uses sugar cane fiber (bagasse) and recycled wood as fuel.[2] It has been in operation for more than ten years.

Production of liquid transportation fuels

There are several processes available for converting the chemical energy contained in biomass into liquid automotive transport fuels such as biodiesel and ethanol.[3]

Ethanol fuel:

Source: Nathanial Gronewold (E&E Publishing)

Ethanol refinery in Columbia

Ethanol fuel is ethyl alcohol (C_2H_5OH) and it is most often used as an automotive motor fuel, mainly as an additive for gasoline (petrol). Ethanol can be produced by fermentation of sugar cane, bagasse, sugar beets, barley, potatoes, corn and many other grains as well as many agricultural byproducts and wastes.

The worldwide production of ethanol for automotive fuel in 2007 was 52,000,000,000 liters (13,700,000,000 gallons). From 2007 to 2008, the share of ethanol in global gasoline use increased from 3.7% to 5.4%.[4] In 2009, worldwide ethanol fuel production reached 73,900,000,000 liters (19,500,000,000 gallons) and was expected to reach 85,900,000,000 liters (22,700,000,000 gallons) in 2010.[5]

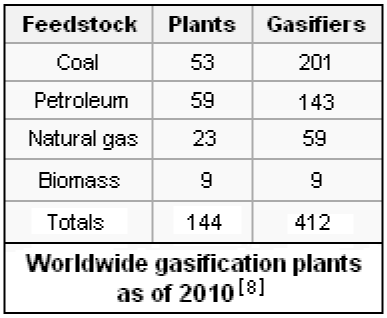
Ethanol fuel is widely used in Brazil and in the USA, and together both countries were responsible for about 86 percent of the world's ethanol fuel production in 2009.[6]

Biodiesel fuel:

Biodiesel refers to a diesel fuel produced by chemically reacting lipids such as vegetable oils or animal fats with an alcohol such as methyl alcohol (CH_3OH). The resulting biodiesel consists of esters of long-chain fatty acids. The process is known as "transesterification" and it may be carried out by several methods: the common batch process, supercritical processes and ultrasonic methods.

In 2009, the worldwide production of biodiesel was 17,900,000,000 liters (4,730,000,000 gallons). The three countries with the largest annual biodiesel production were Germany (16%), France (12%) and the United States (11%).[7]

Biomass gasification to produce syngas



Feedstock	Plants	Gasifiers
Coal	53	201
Petroleum	59	143
Natural gas	23	59
Biomass	9	9
Totals	144	412

Worldwide gasification plants as of 2010[8]

Gasification is a process that reacts carbon-containing materials (such as coal orbiomass) at high temperatures with reagent gases (namely, steam, pureoxygen and/or air) to produce a mixture of carbon monoxide (CO) andhydrogen (H_2) commonly called *syngas* (a contraction of *synthesis gas*). It has been in use since the early 1800s when coal and peat were gasified to produce what was then called *town gas* for lighting and cooking ... later to be replace by electricity and natural gas. As of 2010, 412 modern industrial-scale gasifiers were in operation in 29 countries worldwide (see adjacent table).[9]

The syngas may be directly burned as a fuel, converted into methyl alcohol or hydrogen, subjected to the methanation process to produce synthetic natural gas (SNG),[10] or converted into synthetic liquidhydrocarbons via Fischer-Tropsch process.

Source: National Energy Technology Laboratory, Dept. of Energy

Gasification plant

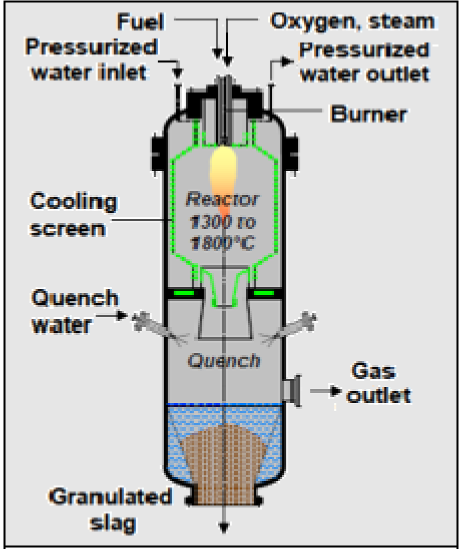
The vessel in which the gasification process takes place is called a *gasifier*. There are various types of gasifiers in current use, including:[9][11]

Counter-current fixed bed gasifier: This gasifier is a vertical, cylindrical vessel containing a bed of carbon-containing material (e.g., coal or biomass) through which steam, oxygen and/or air flow upward.

Although commonly referred to as a fixed bed gasifier, the crushed coal or biomass is fed into the gasifier through a lock hopper mounted on top of the gasifier and the carbonaceous material slowly moves downward as it is converted into syngas, which is removed from the upper portion of the gasifier, and ash or slag removed from the bottom of the gasifier.[12][13][14]

Co-current fixed bed gasifier: This gasifier is also a vertical cylindrical vessel, which is quite similar to the counter-current gasifier type except that the steam, oxygen and/or air enter at the top of the bed, flow downward co-current with the slowly moving bed of carbonaceous material, and the product syngas is removed below the bed.[12][15][16]

Fluidized bed gasifier: This gasifier is again a vertical, cylindrical vessel. It differs from the fixed bed reactors in that the feedstock biomass is very finely crushed before it enters the gasifier and the reaction bed of ground biomass is fluidized by the reagent gases (steam, oxygen and/or air) flowing upward through the bed.



Source: U.S. Department of Energy

Fig. 1: A top-fired, oxygen-blown, dry feed, entrained flow gasifier.

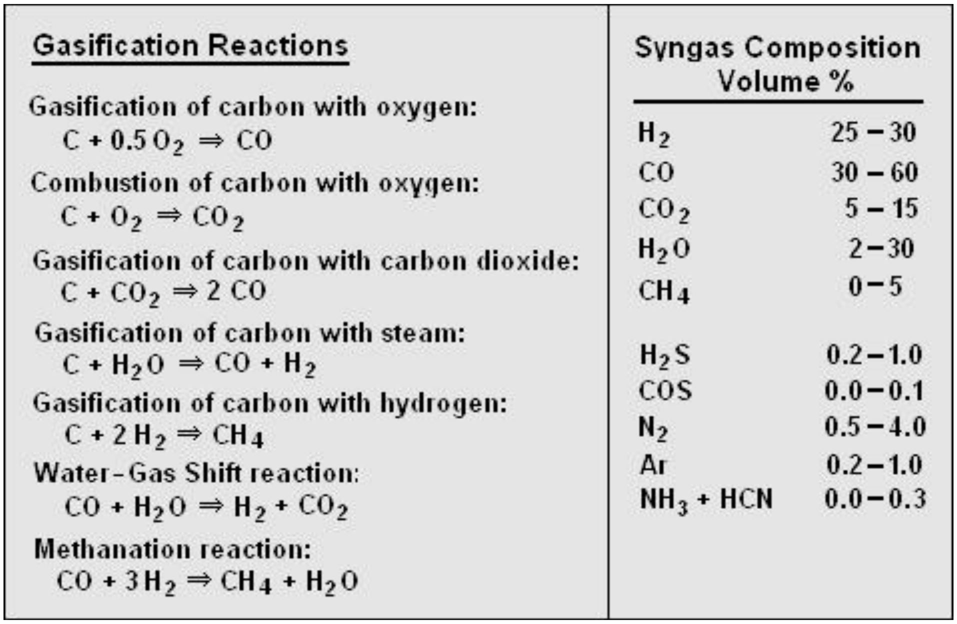
The fluidization of the reaction bed increases the height of the bed (as compared to the fixed bed gasifiers) and the finely crushed biomass results in much more biomass surface area being exposed to the reagent gases. The product syngas contains fine particles of crushed biomass which are removed by routing the syngas through a cyclone to recover the fines and recycle them back into the reaction bed.[12][17]

Entrained flow gasifier: This gasifier, like the other three discussed above, is also a vertical, cylindrical vessel. The feedstock biomass is finely crushed and flows downward co-currently with pure oxygen. Air is seldom used as a reagent gas in an entrained gasifier. The gasification reactions take place in a dense cloud of fine biomass particles.

The syngas exits from the bottom section of the gasifier and is routed through a cyclone (and perhaps a water scrubber) for removal of the fines. Entrained gasifiers operate at temperatures of about 1000 to 1800 °C and at pressures of 30 to 70 bar which is a much higher pressure than is the case for other types of gasifiers. The adjacent Fig. 1 depicts an entrained flow gasifier of the type discussed here.[9][12][17][18]

Gasification chemistry

It is difficult to state exactly what chemical reactions occur during gasification. However, most researchers have reached agreement on the primary reactions and the syngas composition ranges shown just below:[9][12]



Gasification Reactions

Gasification of carbon with oxygen:
$C + 0.5\,O_2 \Rightarrow CO$

Combustion of carbon with oxygen:
$C + O_2 \Rightarrow CO_2$

Gasification of carbon with carbon dioxide:
$C + CO_2 \Rightarrow 2\,CO$

Gasification of carbon with steam:
$C + H_2O \Rightarrow CO + H_2$

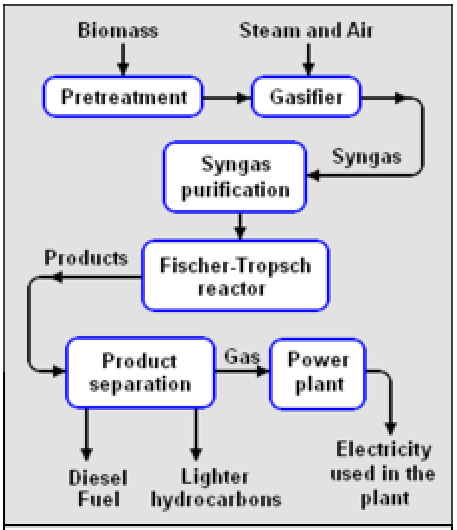
Gasification of carbon with hydrogen:
$C + 2\,H_2 \Rightarrow CH_4$

Water-Gas Shift reaction:
$CO + H_2O \Rightarrow H_2 + CO_2$

Methanation reaction:
$CO + 3\,H_2 \Rightarrow CH_4 + H_2O$

Syngas Composition	Volume %
H_2	25 – 30
CO	30 – 60
CO_2	5 – 15
H_2O	2 – 30
CH_4	0 – 5
H_2S	0.2 – 1.0
COS	0.0 – 0.1
N_2	0.5 – 4.0
Ar	0.2 – 1.0
NH_3 + HCN	0.0 – 0.3

Fischer-Tropsch synthesis of liquid hydrocarbons



Source: Milton Beychok

Fig. 2: Biomass-To-Liquids (BTL)

Fischer-Tropsch synthesis is a catalytic chemical process developed in the 1920s to convert a mixture of carbon monoxide and hydrogen (i.e., syngas), into hydrocarbon molecular chains of varying lengths.

The process was invented by Franz Fischer and Hans Tropsch working in Germany's Kaiser Wilhelm Institute (today the Max Planck Institute) in the 1920's. It was first commercialized in Germany in 1936 and it was used extensively by Germany during World War II to produce synthetic fuels. Later, facing isolation and embargoes during the apartheid era (1948 - 1990), South Africa turned to coal gasification and the Fischer-Tropsch process to supply significant quantities of its hydrocarbon fuel needs. Since that time, the process has been extensively improved and refined.[19][20]

The process is relatively simple: syngas is fed at high temperatures through catalysts (usually the transition metals cobalt or iron) which facilitate the hydrocarbon formation. When paired with syngas from the gasification of fossil fuels or biomass, the Fischer-Tropsch process is a method of converting any available carbon source into hydrocarbon liquids consisting of molecules having from five to 20 carbon atoms in accordance with the following equation for the formation of alkanes (C_nH_{2n+2}), which are the primary hydrocarbons formed:[19][21]

$$\mathbf{(2n + 1)\ H_2 + n\ CO \Rightarrow C_nH_{2n+2} + n\ H_2O}$$

where n is an integer. For example, if n = 5, the equation represents the formation of pentane (C_5H_{12}) which is a liquid hydrocarbon that is a component of gasoline (petrol). As another example, if n = 12, the equation represents the formation of dodecane ($C_{12}H_{26}$) which is a liquid hydrocarbon component of diesel fuel.

Lesser amounts of alkenes (C_nH_{2n}) and alcohols ($C_nH_{2n+1}OH$) are formed in accordance with these equations:[21]

$$\mathbf{n\ CO + 2n\ H_2 \Rightarrow C_nH_{2n} + n\ H_2O}$$

$$\mathbf{n\ CO + 2n\ H_2 \Rightarrow C_nH_{2n+1}OH + (n - 1)\ H_20}$$

There are a good many different reactor designs for the Fischer-Tropsch process as well as different operating conditions. There are two general process temperature ranges:[22]

- Low temperature (200 to 260 °C): Designs using this temperature are referred to LTFT (a contraction of "low temperature Fischer-Tropsch") and generally use a cobalt catalyst.
- High temperature (300 to 350 °C): Designs using this temperature are referred to HTFT (a contraction of "high temperature Fischer-Tropsch") and generally use an iron catalyst.

The LTFT designs produce predominantly hydrocarbons in the boiling range of diesel fuel and waxes. Fixed-bed reactors are considered to be the "conventional" technology for LTFT designs and slurry phase reactors are considered to be "advanced" technology.

The HTFT designs produce predominantly gaseous alkene hydrocarbons having two to four carbon atoms, and liquid hydrocarbons in the boiling range of gasoline. Circulating fluidized bed reactors are considered to be the "conventional" technology for HTFT designs and fixed fluidized bed reactors are considered to be "advanced" technology.

References

1. Table 4. U.S. electric net summer capacity, 2006 - 2010, U.S. Energy Information Administration (EIA), part of the U.S. Department of Energy (DOE).
2. New Hope Power Partnership, Agriculture & Renewable Energy: The Partnership for a New Frontier, Florida Public Service Commission (FPSC) Workshop, July 26, 2007.
3. ABC's of Biofuels, Office of Energy Efficiency and Renewable Energy (EERE) in the U.S. Department of Energy (DOE).
4. Assessing Biofuels (2009), United Nations Environment Programme (UNEP).
5. Global ethanol production to reach 85.9 billion litres (22.7 billion gallons) in 2010, Renewable Fuels Association (RFA).
6. Ethanol Industry Statistics, Renewable Fuels Association (RFA).
7. Production of biofuels in the world in 2009, from the Biofuels Platform published in Switzerland.
8. Gasification 2010 Worldwide Database, National Energy Technology Laboratory (NETL), U.S. Department of Energy (DOE)
9. Gasification Technologies ProgramOverview, National Energy Technology Laboratory (NETL), U.S. Department of Energy (DOE). (An excellent overview of the worldwide gasification technology.)
10. Milton R. Beychok (May 1975), "Process and environmental technology for producing SNG and liquid fuels", *U.S. EPA report EPA-660/2-75-011.*
11. Gasification in Detail: Types of Gasifiers, National Energy Technology Laboratory ((NETL), U.S. Department of Energy (DOE).
12. Generic gasifier modelling: Evaluating model by gasifier type, J.P. Visagie (October 2008), Master's dissertation, University of Pretoria, South Africa.
13. Milton R. Beychok (March 1974), "Coal gasification for clean energy", *Energy Pipelines and Systems.*
14. Milton R. Beychok (September 1974), "Coal gasification and the Phenosolvan process", *American Chemical Society 168th National Meeting,* Atlantic City, New Jersey.
15. M.J. Groeneveld and W.P.M. Van Swaaij, "The Design of Co-Current Moving-Bed Gasifiers Fueled by Biomass" published in the book: Jerry Latham Jones and Shirley B. Radding (Editors) (1980), *Thermal conversion of solid wastes and biomass*, Volume 130 of ACS symposium series, American Chemical Society, ISBN 0-8412-0565-5.
16. Gasoification of solid Waste — Potential and Application of Co-current Moving Bed Gasifiers, M. J. Groeneveld and W.P.M. Van Swaaij, Dept. of Chemical Engineering, Twente University of Technology, The Netherlands.
17. Fischer-Tropsch Fuels from Coal and Biomass, Thomas G. Kreutz, Eric D. Larson, Guangjian Liu and Robert H. Williams, Princeton Environmental Institute, Princeton University,Princeton, NJ. Presented at 25th Annual International Pittsburgh Coal Conference, September 2008.

18. Entrained Flow Gasification of Biomass: Ash behaviour, feeding issues, and system analyses, A. van der Drift, H. Boerrigter, B. Coda, M.K. Cieplik and K. Hemmes (April 2004), Energy research Centre of the Netherlands (ECN).
19. Fischer-Tropsch (FT) Synthesis, National Energy Technology Laboratory (NETL), U.S. Department of Energy (DOE).
20. Hans Schulz (October 4, 1999). "Short history and present trends of Fischer–Tropsch synthesis".*Applied Catalysis A: General*, Volume 186, Issue 1 - 2, pp. 3 - 12.
21. The Fischer-Tropsch (FT) Process: Production of synthetic fuels, from the Knowl website.
22. Fischer-Tropsch synthesis, Burtron H. Davis (2010), AccessScience, McGraw-Hill Companies.

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