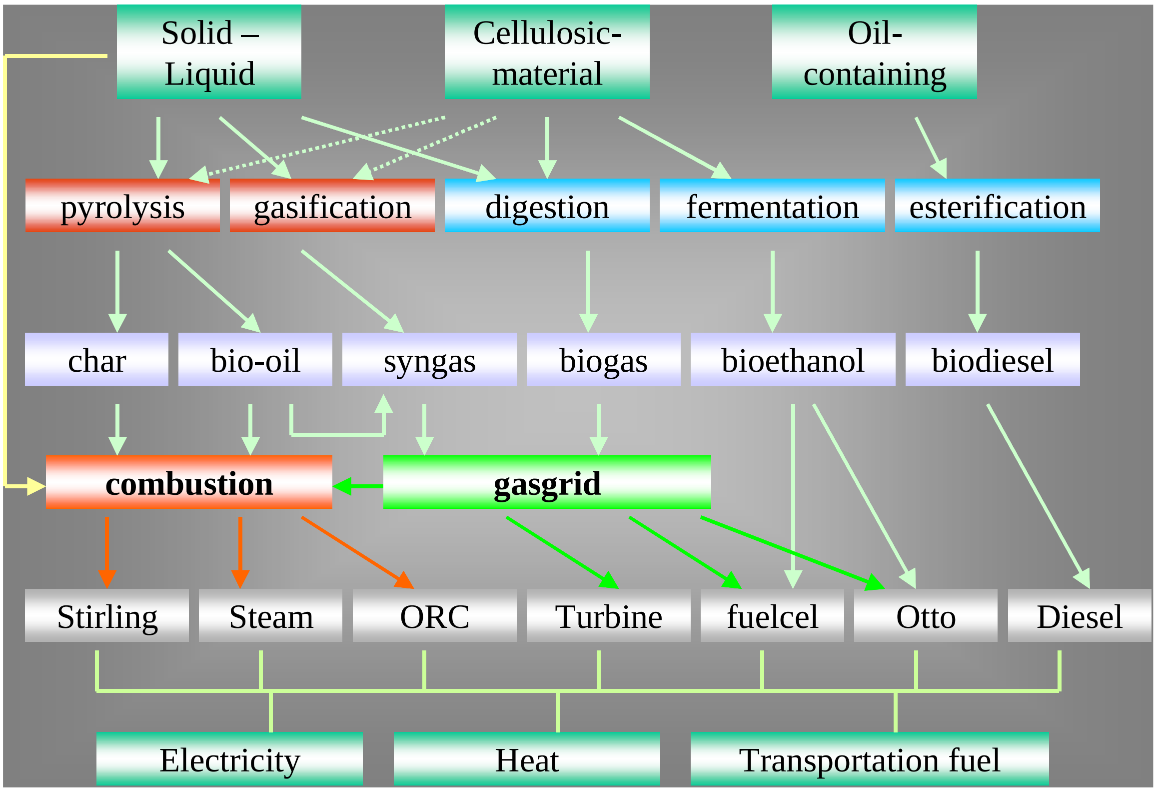
Training Course MEMR staff and TDEC teachers

Biomass has been utilised as an energy source already since the discovery of fire, and its use remained high, even after the discovery of fossil fuels, such as oil, coal and gas. In the last one or two decades, more and more attention is given to biomass because it is, under certain conditions, a renewable and sustainable energy source, which does not contribute to global warming. Besides, concerns on the supply security of fossil fuel and its future depletion, boosted the interest in biomass as a large alternative resource.

The field of biomass energy is large and diverse. Biomass energy is used globally, at scales ranging from the smallest (e.g. domestic cooking) to the largest possible (e.g. co-firing in large scale power stations). Issues pertaining to biomass are availability and exploration of resources, sustainability, conversion technologies, transport, economics and finance, just to name a few. This course on bioenergy provides an introduction into the many aspects of biomass energy. The biomass energy course consists of 4 main modules, concerning the following subjects:

Module 1:	Biomass and Bioenergy
	a. Introduction
	b. Resources
	c. Biomass to energy chain
	d. Biomass Characteristics and Pretreatment
	e. Municipal solid waste
	f. Biofuels
Module 2:	Primary conversion technology to biofuels
	a. Carbonisation and agglomeration
	b. Biomass gasification
	c. Anaerobic digestion
	d. Biomass pyrolysis
	e. Biomass combustion
Module 3:	Secondary conversion of biofuels
	a. Household energy
	b. End-use and applications
	c. Transportation fuels and biorefineries
Module 4:	General issues
	a. The need for biomass energy strategies
	b. Competing us of biomass
	c. CDM and portfolio projects
`	d. Sustainability and policy issues
	e. The project cycle
	f. Example of developing anational bioenergy strategy
	g. Biomass CHP – Example from Czech Republic
	h. CHP Best Practise

The first three modules follows the bioenergy chain while the fourth module is a more general module, applicable to all three previous modules. The next figure illustrates the bioenergy chain.



Hereafter, the contents for each module is briefly discussed:

Module 1: Biomass and Bioenergy

In this module, the most important "driving forces" behind biomass energy are explained. It is shown that practically all energy comes directly from the sun. That is true also for all fossil fuel- and biomass derived energy.

The global carbon cycle is shown, to illustrate the effect of fossil fuel use on the amount of CO_2 in the atmosphere, and the effect it has on the average temperature on earth, the "Global Warming". Biomass can be considered as a renewable fuel, that does not contribute to global warming, because the CO_2 released from biomass conversion to energy is equally consumed during the plant lifetime. This is called the "short carbon cycle", in contrast to the "long carbon cycle" of fossil fuel use.

Various advantages and disadvantages of biomass are illustrated, followed by a first important distinction: "dry" biomass versus "wet" biomass. The moisture content of biomass is an important parameter, which determines to a large extent the costs and technology of conversion.

The biomass-to-energy chain is schematically shown in the figure on the final page. It shows the many different routes for producing energy and biofuels from all sorts of biomass materials. This may be important to the demands and possibilities for the five different regions, i.e. one region may be very suitable for lignocelluloses material while another region is more suitable for oil containing crops like Jatropha.

Biomass resources are traditionally dispersed by nature and occur in numerous relatively small, local sources. With the exception of municipal and industrial wastes, these resources tend to be available in rural areas. The diversity of biomass energy technologies is partly based on its wide range of feedstocks: biomass energy originates from forests, agriculture or organic waste streams.

There are a great many ways to classify biomass types. Biomass feedstock can be classified according to:

- Physical and chemical properties (moisture content, calorific value, etc.)
- Source (energy crop, by-product/residue, waste product)
- Sector of origin (agriculture, industry, waste processing sector)
- Potential energy applications (electricity, heat, CHP or transport fuel)
- Legal status (waste or product).

Table 1 Main biomass resources

Biomass resources	**Examples**
Forest arisings (residues)	
Wood wastes	Sawmill and wood processing waste (sawdust, shavings, off-cuts, bark), construction residues
Crops residues	Bagasse, straw, rice husks, coconut shells, palm fibre)
Vegetable crops (herbaceous lignocelluloses crops)	*Miscanthus*, canary grass
Short rotation forests	Salix, poplar, eucalyptus
Sewage sludge	
Animal manures	
Wet processing wastes	e.g. food industry residues (such as coffee processing)
Green crops	
Municipal solid waste (MSW)	i.e. the organic fraction
Sugar crops	Sugar beet, sugar cane, sweet sorghum
Starch crops	Maize (corn), wheat, barley, potatoes
Oil crops	Rape seed, sunflower, oil palm, jatropha
Meat processing residues	Slaughterhouse residues

Biomass can be used as a solid fuel, or converted into liquid or gaseous forms, for the production of electrical energy, heat, chemicals or fuels. Biomass conversion technologies convert biofuels into a form usable for energy generation. Usually a distinction is made between primary and secondary bioenergy conversion processes and likewise between primary and secondary biomass resources. *Primary (unprocessed) biofuels* are those where the organic material is used essentially in its natural form (as harvested). Such fuels are directly combusted, usually to supply cooking, space heating or electricity productions needs, although there are also small- and large-scale industrial applications for steam raising and other processes requiring low-to-medium temperature process heat. *Secondary (processed) biofuels* in the from of solids (e.g. charcoal), liquids (e.g. alcohol, vegetable oil) or gases (e.g. biogas as a mixture of methane and carbon dioxide), can be used for a wider range of applications with higher efficiency rates on average, including transport and high-temperature industrial processes.

The aim of processing biofuel (= fuel produced directly or indirectly from biomass) is to provide fuels with clearly defined fuel characteristics and ensure a technically simple and environmentally sound conversion into useful energy. Such clearly defined fuels can then be used with fewer problems to meet a supply task efficiently and comfortably. The upgrade fuels can be used in specially adapted engines, turbines, boilers or ovens to provide thermal and/or mechanical energy, which in turn can be converted into electrical energy. Additionally, liquid and (potentially) gaseous fuels can be used directly, or after treatment, as transportation fuels.

Main emphasize in this module is on bioenergy resources and the biomass characteristics. Bioenergy resources can be classified as woody and non-woody biomass, residues and wastes, Jatropha, Algae, etc. Biomass characteristics include heating values, energy quality, efficiency, morphology, density, composition, ash content, moisture content. These parameters are used to describe biomass from a technical (energy conversion) point of view. The moisture content, and the various ways to describe this, are explained. Analysis methods are indicated, and the important aspect of heating values is elaborated upon. Typical values of properties for some biomass types are given. Some equipment and tests will be presented for characterisation of biomass. During the course, some exercises and practical tests will be performed on these aspects.

In the biomass-to-energy chain, logistics and pre-treatment are important steps, mainly because of the relatively low energy density (MJ/m^3) and because of the diverse properties of biomass. The usual pre-treatment steps, such as drying, sizing, and densification are very briefly discussed. Some indications are given regarding the costs of transport.

Module 2: Primary biomass conversion technologies

In primary bioenergy conversion processes primary biofuels are upgraded to, or converted into, secondary biofuels in various ways such as:
Mechanical (e.g. comminution, densification, extraction)
Thermo-chemical (e.g. pyrolysis, gasification, carbonisation, liquefaction),
Biological (e.g. anaerobic digestion, ethanol fermentation)
Chemical (e.g. esterification, i.e. biodiesel production).

As a result of the various available primary bioenergy conversion technologies, there is a wide range of solid, liquid or gaseous secondary biofuels.
Table 2 presents a comprehensive list.

Table 2 Secondary bioenergy resources

Solid	• Mechanical conversion without compression: chips, sawdust etc. • Mechanical conversion with compression: pellets, briquettes, bales etc. • Thermo-chemical conversion: charcoal (wood)
Liquid	• Alcohols o biological conversion (fermentation): ethanol (sugar crops, starch crops) o biological conversion (enzymatic hydrolysis, fermentation): ethanol (wood) o thermo-chemical conversion (FT): ethanol (all solid biomass) o thermo-chemical conversion (several processes): methanol (wood, crops, waste) o chemical conversion: methanol (biomethane) • Ethers o chemical conversion: ETBE (ethanol) o chemical conversion: MTBE (methanol) • Plant oils and biodiesel o mechanical conversion (extraction): pure plant oils ((oil crops) o chemical conversion (esterification): biodiesels (plant oil, waste fat and industrial waste based) • Pyrolysis oils o Thermo-chemical conversion: biocrude, bio-oil (all solid biomass) o Thermo-chemical conversion (thermal depolymerisation, hydrous pyrolysis): bio-oil (wet biowaste) o chemical conversion of bio-oil: various synfuels (syndiesel, syngasoline, synmethanol, syncrude • Liquefaction o thermochemical conversion - (FT process (indirect liquefaction via synthesis gas to synfuels): diesel, gasolin, kerosene and other synfuels (all solid biomass, black liquor) o thermochemical conversion - Bergius process (direct liquefaction/hydrogenation): various synfuels (all solid biomass) o thermochemical conversion – hydrothermal cracking, HTU process etc. (direct liquefaction): various synfuels (wet biowaste, all solid biomass)
Gaseous	• Biogas (and landfill gas o biological conversion (anaerobic digestion): methane, hydrogen (biowaste, crops) • Synthesis gas and synfuels o Thermo-chemical conversion (gasification) to syngas (wood gas): hydrogen, carbon monoxide, methane (all solid biomass) o Thermo-chemical conversion of syngas to synfuels (FT process): methane, LPG, DME • Other o Thermo-chemical, electrochemical and biological conversion: hydrogen (wood, crops, waste, water) o Chemical conversion: DME (methane, methanol) o Thermo-chemical conversion: pyrolysis gas (wood, crops) (wood gas, syngas)

For the further conversion of these secondary biofuels into usable energy i.e. electricity, heat and mechanical energy devices such as steam turbines, steam piston engines, Stirling engines, ORC turbines, micro turbines, gas turbines, spark ignition engines and compression ignition engines are used.

Table 3 presents options for the conversion of primary and secondary biofuels into heat.

Table 3 Conversion of primary and secondary biofuels into heat.

Solid fuel combustion	• Fixed grate
	  o open fire (3 stones etc.): P < 10 kW, ηth < 10%
	  o improved cooking stoves: P < 10 kW, ηth < 40%
	  o modern heating boilers: 5 kW-100 MW, ηth < 90%
	  o steam generator
	  o electricity/CHP, ηe < 20%
	• Other grate types: 100 kW – 500 MW, ηe < 25%
	• Fluidised bed (BFB and CFB): 1 MW – 500 MW, ηe < 40%
	• Pulverised: 10 MW – 1500 MW, ηe < 45%

Solid fuel gasification	• With integrated gas combustion o BIGCC: 1 kW – 500 MW, ηe < 50%
Liquid fuel combustion	• 1 kW – 500 MW, ηe < 60%
Gaseous fuel combustion	• 1 kW – 1000 MW, ηe < 70%

As an example, a well-known conversion technology for biomass is **gasification**. The principle of gasification is already known for ca. 100 years, and interest in it has always been high. The most quoted advantage of gasification is the promise of high efficiencies and low emissions. That is claimed for small-scale electricity generation with a gas engine, as well as for large scale electricity production with turbines (IGCC: gasification integrated with a combined cycle of gas and steam turbine). Over the years a large number of concepts have been developed, and some of these are shown in the modules.

Commercial gasification is, until now, limited to simple technology, in which the producer gas is burnt directly for heat production. Gasification for power production or other more advanced purposes, is however experiencing a number of significant problems. The most severe ones are tar contamination and ash melting. A large number of tar conversion/elimination concepts have been developed over the years, but not a single one has emerged as the clear “winner”.

In the course, non-technical problems which play a role in gasification (and in many other bioenergy implementation projects) are identified. The course will incorporate some exercises and probably some field visits, dependent on the possibilities and availability.

Biomass **combustion** can be considered the “work horse” of bio-energy. The technologies are robust and proven, and are commercially available from a large number of suppliers. Most biomass combustion systems are for heat only, although combination with a steam cycle is possible allowing for electricity generation as well. Such systems are however seldom applied at a small scale (<1 MW_e). Some fundamentals, process parameters and combustion efficiencies are discussed in the course, and an example of a small heat boiler system is given. In “Combustion Theory”, a typical mass balance calculation associated with biomass combustion is illustrated through an example. The course will contain some basic exercises on biomass combustion

One of the very few technologies which allow electricity generation from wet biomass is **anaerobic digestion**. This concerns a biological process, in which a combustible gas is extracted from wet biomass, such as manure. It is furthermore a commercially available technology, which can be applied at the very small to the medium (few MW) scale.

Fast pyrolysis is a promising technology is near commercialisation, with a small number of plants commercially sold. The principle of making a uniform, versatile liquid from a diverse fuel such as biomass is explained in the course. This process is carried out with an efficiency of about 75% on an energy basis. If the char and non-condensable gas can be utilised, the efficiency even rises to 95%.

Pyrolysis oil can play an important role as a biomass fuel commodity, being produced at locations were biomass has a low or even negative value, and subsequently transported to large-scale, highly efficient conversion installations located where a demand is for electricity. Countries with an abundance of biomass available are sometimes called “green OPEC” countries in this respect. The process of biomass fast pyrolysis is elaborated, with emphasis on the reaction mechanisms, oil composition and emerging reactors.

Bio-oil, the main product of biomass fast pyrolysis, can be utilised in a number of applications. Co-firing in power plants for the production of green electricity has already been mentioned in the previous module. The application as a boiler fuel is also more or less proven, but there is still no boiler manufacturer offering bio-oil boilers under full guarantees. Many other applications are identified and examined in research laboratories, like syngas or hydrogen production from bio-oil, upgrading to transportation fuel, and separation of chemicals from bio-oil.

Other biomass technologies which are widely applied are **carbonisation** (charcoal production) and **landfill gas** generation. Production of bio-diesel from rape seed oil and bio-ethanol from starch and sugars, is proven but expensive technology. It is not economically viable without the help of subsidies. Moreover the feedstock types suitable for these technologies are limited.

Part of this module is also processing Municipal Solid Waste (MSW) for energy generation. MSW is available is very large quantities and contains considerable amounts of energy (in average MSW contains about 50% organic material). The MSW is becoming available very widely and needs to be collected and processed at a central location to make it economically feasible. Furthermore, it contains substantial amounts of contaminants which needs to be considered in producing energy from it. The course will contains some exercises on MSW treatment and energy production from it.

Module 3: Secondary conversion processes

This module covers energy production from biofuels like household energy production and application. Some calculation examples will be presented and practical tests conducted, dependent on the availability of material.

Main emphasis will be on the production from (combined) heat and power. Table 4 presents a list of commercial and emerging devices (engines and turbines) that convert heat into mechanical power (for transport use) and electricity.

Table 4 Conversion of heat into mechanical power and electricity,

ICE reciproating engines	• Otto (4-stroke and 2-stroke): 100 W - 10 MW, ηe < 35% • Diesel (4-stroke and 2-stroke): 1 kW - 50 MW, ηe < 45% • Wankel: 1 kW - 500 kW, ηe < 30%
ECE reciprocating engines	• Stirling: 50 W - 500 kW, ηe < 50% • Steam engine: 10 kW - 1 MW, ηe < 15%
Internal combustion (IC) turbines	• Gas turbine (GT): 500 kW - 500 MW, ηe < 45% • Microturbine: 10 kW - 500 kW, ηe < 30%
External combustion (EC) turbines	• Steam turbine (ST): 100 kW - 1500 MW, ηe < 50% • ORC turbine and other vapour turbines: 10 kW - 10 MW, ηe < 25% • Hot air turbine, 100 kW-10 MW
Combined Cycle	• Combined cycle: 0.5-1000 MW, ηe < 80%

Transportation fuels and biorefineries will be elaborated as one of the most emerging technologies. The opportunities and various concepts are presented and the status of these routes.

Module 4: General issues

In this module, several aspects are outlined which is related to the whole bioenergy chain, and can therefore not be allocated to one of the previous modules.

The implementation of large bioenergy projects requires that an environmental impact assessment study be made. Many types of biomass feedstocks and conversion technologies are available; each of which have specific environmental effects. The impact of these effects depends on the location of the plant. For instance, environmental effects like traffic movements, noise, dust will lead to less impacts if the biomass plant is located in an industrial area far from residences or areas with high nature conservation value. National and local legislation specifies what effects are considered acceptable or not.

Commercial bioenergy technologies for the small-to-medium scale range is illustrated in Figure 2.

Figure 2: Commercial bioenergy technologies, small-to-medium scale range

Energy product	Technology	Bioenergy resource
Direct heat	Various types	All solid biomass
	Gaseous or liquid fuel burners	All gaseous & liquid secondary biofuels
Solid secondary biofuel production	Charcoal by carbonisation	All solid biomass
	Briquettes/pellets by densification	All solid biomass
	Chips by comminution	All solid biomass
Electricity	Steam engine	All solid biomass
	Gasification with Otto or Diesel engine	All solid biomass
	Otto and Diesel engines	All gaseous & liquid secondary biofuels
Gaseous and liquid secondary biofuels for transport traffic, CHP and work engine use	Methane (upgraded biogas) by anaerobic digestion	Animal and human manure and sludge, kitchen biowaste, straws, non-wood energy crops, food industry waste
	Ethanol by fermentation *)	Sugar and starch crops
	Pure plant oil by mechanical extraction	Oil crops
	Biodiesel by esterification	Oil crops, kitchen waste fat, industrial waste fat, ethanol

Environmental impacts occur during the production of biomass, during the construction of a bioenergy plant and during the operation of a bioenergy plant

Key environmental concerns during the **production** of biomass include: soil erosion, water and air pollution, chemical contaminants, landscape (monoculture, deforestation), biodiversity, and archaeology. Factors that determine the nature of the impact include the type of bioenergy feedstock grown, the management of the biomass crop, the nature of the land-use the bioenergy crops replace and the scale of bioenergy development and its spatial distribution.

Lately, the environmental and social impact of biomass production has been receiving a lot of international attention. Many government, NGO's and multilateral organizations work on the development of sustainability criteria that can be used to assess if biomass is produced in an environmentally and socially acceptable manner. A well-known example is the set of Cramer sustainability criteria developed by the Netherlands' Government.

The use of biomass for energy production also leads to environmental effects during the **construction** of a bioenergy plant. Impacts to be considered when building a biomass combustion plant include effects on existing archaeology, ecology and public rights of way; potential noise nuisance; dust; light pollution; pollution of water courses and the restoration of the site following construction.

Last but certainly not least the use of biomass for energy production leads to environmental effects during the **conversion** of biomass into energy. Typically environmental effects to consider include: emissions to air, emissions to soil, emissions to water, (internal) energy use, noise, odour, vehicle movements.

To make a first assessment of the potential of bioenergy, entrepreneurs and other target group members need not just technology **information** *sec* but also information on technology-related subjects such as

- Investment and operation costs
- Equipment suppliers (manufacturers, etc.)
- Case studies/reference projects

It is recommend to integrate these four categories, with assistance of others. A summary of bioenergy information on the web is given below at the end of this information package

Biomass energy receives considerable stimulants from a variety of governments and institutions, because it is mostly a renewable and sustainable energy source. This can help projects which are not yet feasible or entail a high risk. In this module some international facilities are discussed, but it should be noted there are many more available.

The key to the implementation of biomass-to-energy concepts is the **finance and economics**. If an investment in a bioenergy plant generates sufficient return-on-investment (ROI), the plant will materialise.

Using a biomass fast pyrolysis plant as an example, an application case is developed. Important aspects are total investment, annual costs and annual income. If the investment can be paid back within a certain number of years, the project is feasible. Payback times which are considered feasible vary from country to country and, more important, from investor to investor.

As with all investment projects, the feasibility of biomass energy plants is strongly connected to local circumstances. A multitude of factors influences the feasibility, but there are a few ones always recurring:

- availability and price of biomass;
- prices for heat and electricity;
- permits, taxes and duties.

The main driving forces behind the use of bioenergy are the reduction of greenhouse gas emissions and a reduction of the dependency on fossil fuels. These two impacts are therefore often emphasised in environmental assessments on sector level. Furthermore, use of bioenergy should not lead to other negative environmental impacts.

On a sector level, countries using biomass for energy purposes are becoming increasingly aware of the environmental effects of large-scale biomass use for energy production. The production of energy crops like eucalyptus for charcoal, sugar cane for bio-ethanol production, jatropha for biodiesel production consumes a certain amount of fossil energy, thereby reducing the net greenhouse gas and energy savings of the produced biofuel. Moreover, if not properly managed, increased production of biomass in plantations could lead to loss of biodiversity, competition with food, loss of soil quality etc. These impacts have been studied in a great number of studies, and within Europe there’s a tendency for biomass certification on project level to prevent the environmental (and social) negative by-effects of biofuel production.

On the individual project level, initiators of larger bioenergy projects generally have to perform a separate Environmental Impact Assessment (EIA), when applying for an environmental permit, showing that the project or plant has reasonable energy use, emissions of greenhouse gases, pollutants, etc. compared to other options. In general, the types of potential impacts to be studied as prescribed by law.

Smaller bioenergy projects generally need to apply for an environmental permit as well. Project owners have to show that the environmental impacts are below certain legal limits (e.g. emissions of nitrous oxide) and that sufficient measures are taken to avoid or reduce local environmental damage (e.g. to prevent leaking of oil into the soil).

A question that entrepreneurs typically raise at an early stage concerns the investment and operation costs of the technology under consideration. Unfortunately there is no easy answer to this question, as these costs depend on many different factors. When overview studies discuss costs they normally present price ranges and stress that due to the variability of data in the data sources and conditions assumed all cost figures should be considered as *indicative*.

Competition between and integration of biomass for energy applications and for other end uses is an important issue. Various types of biomass can be utilized for different end-uses other than energy, e.g. as raw material for the pulp and paper industry, as raw material for the (chemical) industry (e.g. tall oil or ethanol), as animal fodder (e.g. straw) or for humans consumption (e.g. ethanol or palm oil). This competition can be directly for biomass, but is also often focussed on land availability.

Throughout human history biomass in all its forms has been the most important source of all our basic needs, often summarized as the six "Fs": Food, Feed, Fuel, Feedstock, Fibre and Fertiliser.

Biomass products are also frequently a source of a seventh "F" - Finance. Until the early 19th century biomass was the main source of energy for industrial countries, and indeed, still continues to provide the bulk of energy for many developing countries biomass. Food versus fuel is a very old issue that is frequently brought up despite the fact that a large number of studies have demonstrated that land availability is not the real problem. While theoretically large areas of (abandoned/degraded) crop land are available for biomass cultivation, biomass production costs are generally higher due to lower yields and accessibility difficulties.

Deforested areas may be easier as they may have more productive soil, but is generally considered unsustainable in the long term. Food security, i.e. production and access to food, would not probably be affected by large energy plantations if proper management and policies were put in place. However, in practice food availability is not the problem, but the lack of purchasing power of the poorer strata of the population. A new element to take into account is

climatic change, which introduces a high degree of uncertainty.
Increasing competition for wood will increase the price of wood and lower the supply of wood for raw material of forest industry and decreasing competitiveness of European Pulp and paper industry

A major part of the training will be the sustainability and policy issues related with bioenergy. This subject gains an increasing interest from the world community. The challenges and barriers will be presented and possible solutions (strategies) to solve them. Furthermore, some more general aspects as CDM (Carbon Development Mechanism) and a typical biomass project cycle are presented. The module will also include some examples from the practise or success stories. It depends on the available time whether these can be presented or not. They will be anyway available on the CD-rom and the report, which will contain hardcopies of all presentations.

Bioenergy Project Development Guide *

A successful biomass energy project requires diligent research and planning. Areas of project research include understanding the energy conversion technology, assessing the quality and availability of biomass resources and investigating the characteristics of potential sites. Project planning involves consideration of economics, permit requirements and site-specific design elements. The following suggested planning steps provide general guidance for the development of biomass energy projects.

1. **Choose the technology**. Biomass energy is not one technology. The first step in a biomass energy project is choosing the technology to develop.

2. **Biomass resource assessment**. The choice of technology will determine the kinds of biomass resources the project will require. Each technology has its own set of fuels or feedstocks. Find out what regional areas have supplies of those fuels or feedstocks. Consider using an outside contractor to do the resource assessment. Based on the resource assessment, list possible sites for the proposed biomass energy facility. Identify fuels or feedstock resources available in each location. Because the proposed facility could experience interruptions in the supply of preferred biomass resources, research the availability of backup fuels (including fossil fuels) and feedstocks.

3. **Preliminary project plan**. Drawing up a preliminary plan is a way to organise the project. Developing a general description of the proposed project is a necessary step before deciding whether the project is feasible. Identify project goals. Describe the technology and develop a conceptual process design. Include basic information about facility size and design considerations. List the outputs or products of the proposed facility. Calculate the estimated production of usable energy and the estimated value of any marketable by-products. If development of the facility will reduce or mitigate an environmental problem, describe and quantify the environmental benefits. Describe the market for the electric power, steam, fuels and other products the project will produce.

4. **Select the project site**. Select preferred and alternate sites. Secure rights to the site or sites through options, ground leases or other agreements. Selection criteria may include: a) Fuel or feedstock supply (availability, quality, quantity, competing users); b) Land costs; c) Access to markets for energy products (for example, the likelihood of negotiating a power sales contract); d) Site access and transportation costs; e) Local social and economic impacts; f) Labour availability and skills; g) Local environmental impacts; h) Zoning restrictions; i) Necessary permits; j) Water use rights and availability; k) Utility availability; l) Waste disposal.

5. **Examine the economics.** Prepare a financial and economic feasibility assessment. Estimate construction and operation costs and projected revenue.

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* This section is based on the Project Guide developed by the State of Oregon. The original URL is http://www.oregon.gov/ENERGY/RENEW/Biomass/guide.shtm

Include any by-product revenue. Include offsets or savings made possible by the project.

The preceding steps should provide the information necessary to decide whether the project is feasible. If the project appears eligible for the required permits and if anticipated benefits and revenues outweigh the estimated costs, then the project can move forward.

6. **Work with the public agencies**. Development of biomass energy facilities is normally subject to required permits and standards. Discuss the preliminary project plan with local planning departments. City or county planners can supply information about zoning, land use regulations and ordinances. Call the Department of Energy to ask about eligibility for energy loans, tax credits or other incentives. The Department of Environmental Quality will answer questions about permit requirements. For new business information, contact the Economic Development Department.

7. **Project proposal**. Review the preliminary project plan. Develop a project proposal that includes cost, design and site details. Prepare preliminary plant and system engineering designs. Examine technical options and alternative plans. Identify potential emissions, effluents and other environmental impacts. Describe the local social and economic effects. Draw up a construction plan.

8. **Negotiate with buyers for energy products**. Contact potential buyers of the project´s energy output. Having a contingency contract with a buyer will increase the likelihood of obtaining financing. Absent signed contracts, obtain letters of interest from potential buyers. Make the final selection of a site for the proposed project before moving to the next step.

9. **Business plan**. Have an accountant or business consultant prepare a financial evaluation and business plan. Financing should cover estimated costs including contingencies for possible delays in permitting, construction and start-up. Include tax incentives. Analyse effects of fuel supply costs and fluctuations. Analyse electricity sales prices, if applicable. Include estimated costs of environmental compliance. Assess potential financing options.

10. **Project financing**. Contact financial institutions and present the business plan. Work with the Department of Energy if the project is eligible for tax credits or energy loans.

11. **Apply for local, state and federal permits**. Contact the city or county for zoning information, land use permits and building permits. Contact the Department of Energy and the Department of Environmental Quality for information about environmental permits. The Environmental Policy Act may require an environmental assessment for certain projects.

12. **Project timetable**. Identify tasks and project milestones. Establish project deadlines using critical path analysis. Include permit application dates. Allow sufficient time for processing of permit applications. Obtaining necessary

permits for a small project may take a few months; obtaining permits for a larger facility could take a year or longer.

13. **Permit compliance plan**. Incorporate permit conditions in the project plan. Some permits will be issued with conditions. Permits may require monitoring of environmental impacts. Developers may need to take actions and incur expenditures to mitigate environmental impacts.

14. **Construction**. Construction can begin after all required permits and authorisations have been issued. Construction activities may require separate permits. Obtain legal advice before signing engineering, procurement and construction contracts.

15. **Start-up**. Completing construction requires attention to detail. Document all modifications to the design plan made during construction. Conduct on-site review to prepare a final checklist of items needing correction or completion. Start-up and testing may require environmental monitoring. Optimise facility operation during the start-up period.

A Bioenergy Policy Success Story of Mauritius

The Mauritian experience in cogeneration is one of Africa's success stories in the energy sector. Through extensive use of cogeneration in the country, the sugar industry is self-sufficient in electricity and sells excess power to the national grid. In 1998, close to 25% of the country's electricity was generated from the sugar industry, largely through a by- product of bagasse. By 2002, electricity generation from sugar estates stood at 40% of total electricity demand in the country. Government support and involvement has been instrumental in the development of the cogeneration program in Mauritius. First, in 1985, the Sugar Sector Package Deal Act (1985) was enacted to encourage the production of bagasse for electricity generation. The Sugar Industry Efficiency Act (1988) provided tax incentives for investments in the generation of electricity and encouraged small planters to provide bagasse for electricity generation. Three years later, the Bagasse Energy Development Programme (BEDP) for the sugar industry was initiated. In 1994, the Mauritian Government abolished the sugar export duty, an additional incentive to the industry. A year later, foreign exchange controls were removed and the centralization of the sugar industry was accelerated. These measures have resulted in the steady growth of bagasse-based electricity flowing into the country's grid. Bagasse-based cogeneration development in Mauritius has delivered several benefits: reduced dependence on
imported oil, diversification in electricity generation, and improved efficiency in the power sector in general. Using a variety of innovative revenue-sharing measures, the cogeneration industry has worked closely with the Government of Mauritius to ensure that substantial benefits flow to all key stakeholders in the sugar economy, including the poor smallholder sugar farmer. The equitable revenue sharing policies in Mauritius provide a model to emulate for ongoing and planned modern biomass energy projects in other African countries.(Source; Sustainable Bioenergy Development in UEMOA Member Countries, 2008)

Bioenergy case studies

There are a large number of existing case studies and success stories on bioenergy projects and plants in developing countries. It concerns realized projects and systems, of a similar nature and in a similar setting, that can serve as flagship projects, success stories, showcases and good practices. Information on such plants in the form of plant descriptions and case studies are included in the course from CHP Best Practise but many more examples can be found from literature and the internet. Therefore, this information package also contains useful links to internet sites, which is by no means complete.

Site visits

Site visits to facilities using thermal conversion technologies will be made depending on the availability in the region. Students can be asked to make a summary report, discuss them in a plenary session, and/or answer specific questions.

Case study throughout the course

1. during the course several theoretical aspects are presented about all possible routes to produce energy from raw biomass material.
2. from this theory, a case study will be conducted in which the participants have to formulate what they consider as being the most appropriate route considering the local circumstances and potentials for utilizing the local available biomass, the conversion route and end-use. This should also include the local policy issues and legislation issues. As an example, this could be the production of biodiesel from Jatropha or bioethanol production from lignocelluloses biomass or pellets from local residues for heat production. This can be done in small groups of five students; in this way, more cases can be performed in parallel, students have to discuss and explain their case study to the others.
3. as an additional step some practical work or tests can be performed to learn more about the different (or preferential) route, like:
    a. producing and harvesting the feedstock (for the first year, materials may not be available: in this case it need to be purchased). Of course, this can not be realized during the two-weeks course, but can be done over a one-year curriculum.
    b. Pre-treat the feedstock to make it suitable for the chosen conversion route
    c. perform the conversion of biomass to the selected form of energy. This is the most important step and requires equipment and testing apparatus
    d. etc.

Practical part:

Some preliminary notes:

- The practical part has to be given in the five provinces, i.e. required training equipment has to be procured five times.
- The topics on biomass are still open (no biomass related topics were identified) and therefore, BTG proposes to focus on one curriculum for all provinces. It can be expected that the socio-economic status and bioenergy situation in e.g. Yogyakarta and Central Java are quite different from that in WNT or Papua. You may therefore consider a modular approach, where for each curriculum the relevant modules are picked or selected.
- The number of hours/year for the training course at the SMK's are not determined but are important to know the extent of the course.
- It is not clear what kind of facilities are available at the SMK's
- Field trips to local industry can be included and can be scheduled in co-operation with the local SMK and local partner

Furnishing laboratory

A laboratory is needed to conduct experiments and perform analyses. Dependent on the availability at each SMK, a minimum set of requirements will be defined. This includes lab-tables, fume hoods[1], chemicals, ovens, balances, gas chromatograph (GC)[2], etc. The most relevant equipment must be considered for each region. Should it only be lab equipment or also workshop equipment? Considering the main topics, a small briquetting press, an oil expeller or a "garage-scale" biodiesel plant could be just as relevant!

Another useful equipment for testing could be a multi-purpose biomass conversion device, which can be used as carboniser, pyrolyser, gasifier, combustor and in different modes, i.e. fixed bed and fluid bed[3]. There will be two installations based on the same principle but aiming a different purpose:

1. installation made of Perspex glass in which students can actually see the behaviour of the biomass under varying process conditions
2. installation made of steel, surrounded by electrical heated oven, in which different products can be made (charcoal, gas, oil) using the different modes of operation

[1] A fume hood or fume cupboard is a type of local ventilation device that is designed to limit the user's exposure to hazardous or noxious fumes, vapors or dusts. A fume hood is typically a large piece of equipment enclosing five sides of a work area, the bottom of which is most commonly located at a standing work height.

[2] Gas-liquid chromatography (GLC), or simply gas chromatography (GC), is a common type of chromatography used in analytic chemistry for separating and analyzing compounds that can be vaporized without decomposition. Typical uses of GC include testing the purity of a particular substance, or separating the different components of a mixture (the relative amounts of such components can also be determined).

[3] Such device exists at BTG and probably can be delivered as hardware, or perhaps as a design tool for local construction in Indonesia for each SMK contributing to the course.

Topics for the practical part include:

- Biomass characterization:
    - how to determine moisture, ash, density, composition, heating value, volatiles, contaminants. What kind of equipment is needed for these determinations.
    - Discuss influence of morphology, density, ash, moisture on thermal conversion processes
- Biomass pretreatment, for instance
    - storage, reception handling (SRH)
    - briquetting
    - agglomeration
    - sizing
    - pelletising
    - carbonization: students can produce charcoal form the raw biomass, which can then be subsequently used for the following conversion technologies
- Biomass conversion technologies
    - Combustion: wood stoves (how to determine efficiency)
    - Combustion of biogas/producergas in gas and diesel engines
    - Combustion behaviour under fixed bed and fluid bed conditions (minimum fluidization velocity, mixing behaviour, etc.)
    - Fixed bed and fluid bed gasification (gas composition, tar sampling, efficiency determination, waste streams, safety related aspects)
    - Pyrolysis (oil yield, water content oil, pH determination of the oil, char content in the oil, ..)
    - Torrifaction (product yield, grindability of the product, product quality over time of exposure, …
- Biomass utilization or application
    - Experiments can be done in second hand equipment like engines, steam turbines or boiler
    - NO_x-formation at combustion
    - Emission measurements (dust, CO, SOx, NOx, …
    - Efficiency determination
    - Product quality
    - Determination overall efficiency of the biomass-to-energy chain

Some other practical tests

- Fill a test-tube (tabung-reaksi) with a small wood particle(s) and heat it with a Bunsen burner (pembakar Bunsen). Notice down what happens during the experiment. Results can be discussed after the experiment
- Water boiling test and determining stove efficiency
- Collect different biomass resources and discuss the difference between them and their consequences for energy conversion
- Use simple briquetting press or extruder to densify biomass material. Determine bulk density before and afterwards.
- Prepare an open-fire outside of for instance wood. Ignite the wood and notice what happens (different stages of primary conversion). Discuss the results afterwards.
- Check on www.YouTube.com for various videos on all biomass related aspects and technologies. If possible, try to select gasification and you will find many examples.

Experimental work on pyrolysis (as far as possible)

The type of laboratory facilities which are required depend to a large extent on the type of result desired.

Typical results are:

- mass and energy balances,
- product characterization and quality data and
- bio-oil application related data.

For each of these categories, the required measurement devices are presented hereunder.

Mass balance determination

1. Weight measurement of biomass: by using a scale.
2. Weight measurement of the bio-oil: by using a scale.
3. Weight measurement of the pyrolysis gas: The volume flow is calculated by dilution with a known volumetric flow of nitrogen and measurement of the nitrogen concentration by a gas chromatograph. The density of the pyrolysis gas is calculated from the gas composition measurement.
4. Weight measurement of the char. First char is sampled from the reactor. Then the weight fraction of carbon in the char is determined by elemental analysis of the char. Finally a combined measurement of the CO_2 content and volume flow of the flue gas is sufficient to calculate the mass flow of char. The volume flow of flue gas is measured with a rotameter and the carbondioxide content in the flue gas flow is measured with a gas chromatograph or an electrochemical cell.

Minimum instrument requirement: scales, gas chromatograph, rotameters.

Energy balance determination

1. Energy content of the biomass: by using a bomb calorimeter.
2. Energy content of the bio-oil: by using a bomb calorimeter.
3. Energy content of the pyrolysis gas: from calculation of the gas composition.
4. Energy content of the char: by using a bomb calorimeter.

Minimum instrument requirement: bomb calorimeter, gas chromatograph.

Product characterization

1. Bio-oil

    Density by weight measurement of a specified bio-oil volume.

    Viscosity by a cone and plate rotaviscosimeter.

    Water content by Karl Fisher titration.

2. Char

    Char density by weight measurement of a specified char volume.

    Char heating value by a bomb calorimeter.

    Char pore surface by a BET nitrogen adsorption surface analyser.

Minimum instrument requirement: bomb calorimeter, scales, rotaviscosimeter.

Homework per module

Module 1 General

1. Consider an average family of four living in the northern half of the United States. If the family saved all of its municipal solid waste (MSW) and burned it, could the family harvest enough energy to heat its home? What conclusions can you draw? Use the following assumptions:
    - The family uses about 125 million BTU[4] of heat energy annually to heat its home
    - MSW production is about 3 dry pounds per person per day (assume 365 days / year)
    - MSW has heat content of 8,000 BTU per pound

2. Dry waste wood biomass is found to have a sulfur content of 0.1% (percent of its dry weight) and a heating value of 8,000 BTU per pound. Colorado coal-fired power plants burn Wyoming sub-bituminous coal which has a sulfur content of 1.0% and a heat content of 10,000 BTU per pound. If dry wood waste were used to replace coal at a power plant, how much would sulfur dioxide emissions be reduced? Express your answer as a percentage change in sulfur emissions. What conclusions can you draw? (Sulfur dioxide is a pollutant implicated in the creation of acid rain.)

3. US residents consume roughly 10 million barrels (42 gallons per barrel) per day of gasoline for transportation fuel. Advanced cellulosic fermentation technologies are projected to produce about 110 gallons of ethanol from a ton of cellulosic biomass (e.g., switchgrass) or about 275 gallons of ethanol from an acre of energy cropland. How many acres of land would need to be devoted to cellulosic biomass production if ethanol replaced 10% of gasoline consumed in the US? Compare your answer with the total land area of France and the state of California. What conclusions can you draw? **Hint:** Recall that ethanol provides only about 2/3 the miles per gallon attainable from gasoline.

4. The US has a lot of federally owned land. Unfortunately, uncontrolled natural forest fires destroy large areas in the western US every summer. In 2002, about 1 million acres of standing timber in national forests were consumed. Some consideration is being given to improved management practices that could produce electrical power from residual forest thinnings. Estimate the lost energy content of burned US forests during 2002. Assuming the US average electricity demand load is about 300,000 MW, how much forested land would be needed to produce all of the country's power? Is this a sustainable alternative? A few facts to consider:
    - The total forested area on US federal lands in the lower 48 states is about 600 million acres with a standing stock density of about 100 dry metric tonnes of wood per acre.
    - Woody plants and trees capture solar energy via photosynthesis at an average rate of about 0.8 W/m2 which corresponds to producing about 5-10 dry tons of biomass per acre annually with an average heating value of 8,000 BTU/lb (dry). Note that 1 acre = 43,560 ft2 = 0.405 hectare = 4,047 m2.
    - A representative heat-to-work conversion efficiency of a biomass fired electric power plant is about 35%

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[4] A BTU (British Thermal Unit) is a measure of heat energy and is defined as of heat required to raise the temperature of one pound of liquid water by 1 degree Fahrenheit. 1 BTU is equal to 1,055 joules or 0.00029 kWh, so it doesn't represent much energy. 1 Therm is equivalent to 100,000 BTUs. BTU and Therm units are commonly used in the heating and air conditioning trades.

Module resources

In the Netherlands, a small amount of the electricity is produced by combustion or gasification of biomass. Most from this biomass is from forestry residues. How much hectares is needed to provide sufficient fuel for a 1 Mega Watt (MW) wood-fired power station? Give a global indication in the order of 1, 10, 100 or 1000 hectare.
To answer this question, you need to know the moisture content and heating value of the biomass. Furthermore, you need to estimate the wood yield of one hectare.
Mega = 1,000,000
Watt = J/s

Open questions for discussion:

1. What are the advantages of various solid, gaseous and liquid biofuels?
2. Why is biomass one of the most important RET (Renewable Energy Technologies)? What are the advantages and disadvantages compared to other RET's?
3. Why do have pellets improved combustion characteristics over raw material?
4. CHP (Combined Heat and Power) is an important issue in Europe. Is this also valid to Indonesia?
5. Is food security an issue in competing use of biomass in Indonesia? And is this valid to all regions in the country?

Module MSW

How much energy can be produced from the MSW generated in Bandung and how much covers this from the energy demand?

What can MSW contribute in your region

- How much MSW is generated
- How many inhabitants
- How much energy does it contain
- What technology is suitable for energy production
- How much energy can be generated from this MSW amount
- What percentage of the energy demand does this cover

Module Pyrolysis

What can you do with the pyrolysis oil?
What happens if you fuel your car with it?
What happens in a gas turbine?
What happens in a boiler?
What happens if the process is not fast but slow?

Why do I want to convert my biomass into pyrolysis oil? Answers:

- Intermittent energy source: The production and the application of the bio-oil can take place at different locations and different moments in time.
- Availability: Pyrolysis oil can be stored for long periods of time, and is therefore available when necessary.
- Transportation: Transportation of pyrolysis oil is very convenient. Existing infrastructure can be used for transportation of pyrolysis oil;
- Second generation biofuel: Pyrolysis oil produced from non-food related biomass is a second generation biofuel and therefore does not compete with the food industry.
- Reducing dependency on fossil fuels: Pyrolysis oil can be used in applications where it substitutes for crude oil, doing so it offers a unique way to reduce your dependency on fossil fuels.
- Applications: Pyrolysis oil can easily substitute fossil fuels as oil and gas in existing boiler and turbine applications. Refitting the systems requires limited investments and therefore pyrolysis offers a unique opportunity to make your energy supply sustainable.

Module Gasification:

What happens when you gasify rice husk in a fixed bed gasifier?
Can rice husk be used as fuel for entrained flow gasification?
Calculate density of producergas

Bioenergy applications
Following statements present six modern bioenergy applications that may be relevant for developing the bioenergy market in developing countries. What is your opinion of, or experience with, each of these applications?

1. Electricity from combustion of solid biomass
    - Modern biomass fired power (or CHP) plants can supply electricity to industry or the national grid
    - Main benefits are substitution of energy imports and improving the grid
    - Depending on the circumstances, such power plants are generally economic from 1 MWe upward
    - At large scales, production becomes more efficient and cost effective but the logistics (and sustainability) of the biomass supply gets more complicated
    - Larger installations may greatly benefit from CDM

2. Industrial biogas (including landfill gas)
    - Biogas plants are generally small or medium scale (up to several MWe)
    - The economics are often connected to the benefits from waste treatment and other environmental benefits
    - CDM prospects are often good for this type of project

3. Transport fuels (import substitution / export)
    - Resources for the production of ethanol or biodiesel can be obtained from residues (e.g. from agro-industries) but most often require production on dedicated plantations
    - Given quality requirements of liquid biofuels, processing is only feasible on large scales
    - An alternative is the local use or export of straight vegetable oils
    - Sustainability of liquid biofuel production is an important aspect
    -

4. Vegetable oil for small scale power production
    - Vegetable oils can be used in modified diesel engines for (off grid) electricity or shaft power generation
    - This type of project has a high potential for MFP applications (as already done in Mali) and as such for improving energy access to the poor
    - Energy access and local oil production can provide an economic impulse in rural areas.

5. Modern cooking fuels
    - Ethanol based cooking fuels or charcoal from crop residues are convenient and clean household fuels that contribute to the fight against deforestation
    - Their production may induce economic impulse in rural areas.

6. Family scale biogas
    - Digestion of animal manure in small digestion units, providing biogas for cooking and lighting, are highly successful in Asia
    - The application could provide energy to millions of households in the region but depends on several requirements at household level
    - A key issue is the development of companies for construction and maintenance of biogas units

General exercises (after module 2)

1. If biomass is applied on a large-scale, a number of barriers will have to be overcome. Give at least five of these barriers.

Answer: Transportation, Fire, Diseases, Water-demand competition, Food competition, Erosion, Need of agricultural-pesticides, Growth limitation, Bio-Diversity, Landscape infraction.

2. How can you determine the higher heating value(HHV) of Bio-fuels? Describe the process.

Answer: By using a bomcaloriemeter. A sample of dry Biomass is placed inside a closed container in a oxygen rich environment and will be ignited by a sparkspiral. The energy released in the combustion of this sample is transferred to an enclosed water container which will absorb this heat. The amount of water is known, together with the rise in temperature. Therefore it is possible to calculate the higher heating value on the basis of energy preservation with use of:

*Mbr*HHV = Mw*Cw*dTw (note: the wall of the water container is properly isolated).*

3. During combustion, all thermal conversions take place. Which order is right?

a) Combustion → Pyrolysis → Gasification
b) Pyrolysis→ Gasification→ Combustion
c) Pyrolysis→Combustion → Gasification
d) Gasification → Pyrolysis → Combustion
e) Gasification → Combustion → Pyrolysis

4. Is it useful to blend substrate with wood during anaerobic digestion for the purpose of increasing the gas production? Elaborate on why or why not.

Answer: No not useful, because wood contains a lot of lignin which is hard to break down for anaerobic bacteria's and thus goes of the cost of the volume of the digester and the on that related gas yield.

5. Which two processes are most used with anaerobic digestion?

Answer: Continue process and Batch process.

6. A cattle breeder wants to install an anaerobic digesting installation on his farmyard and asks you for advice. Name at least five points that need attention to see whether this is useful.

Answer: Amount of available dung, composition of the dung (max. yield), amount of available co-substrates, parasitic electrical consumption, use of waste heat, end-use digestate, available subsidies, contracts (like suppliers co-substrate), permits, location, quotations (turn key installation?), feed-in tariff electricity, financing (bank loan, investors).

Basic principles of combustion (after module combustion)

Combustion chemistry

If the matter is a gas, 1 kmol of this gas has the volume of around 22.4 m_n^3 (normal cubic meter). The unit of volume, the normal cubic meter (m_n^3), is defined at a temperature of 273.15K and a pressure *p* = 1013.25 mbar.

For every matter the mass of 1kmol can be calculated from its composition. For the components that are important in combustion, these are:

H_2 = 2 kg/kmol N_2 = 28 kg/kmol
S = 32 kg/kmol O_2 = 32 kg/kmol
C = 12 kg/kmol

In example C_3H_8 (propane gas) consists of 3 carbon atoms and 8 hydrogen atoms. Per kmol, this gives:

$$C_3H_8 \rightarrow 3 \cdot 12 + 8 \cdot 1 = 44 \text{ kg.}$$

General combustion equations

The conversions that take place during a combustion process are shown in figure 1.

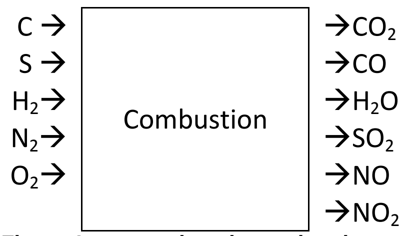

Figure 1: conversions in combustion

Theoretical oxygen demand

Elaborating on the combustion equation of carbon at complete combustion gives:

$$1 \text{ kmol C} + 1 \text{ kmol } O_2 \rightarrow 1 \text{ kmol } CO_2$$

Written out in the mass equation:

$$12 \text{ kg C} + 32 \text{ kg } O_2 \rightarrow 44 \text{ kg } CO_2$$

Because the volume of the gaseous components is 22.4 m_n^3 under normalised circumstances, the equation will be shown as follows:

$$12 \text{ kg C} + 22.4 \ m_n^3 \ O_2 \rightarrow 22.4 \ m_n^3 \ CO_2$$

or for 1 kg C:

$$1 \text{ kg C} + 1.867 \ m_n^3 \ O_2 \rightarrow 1.867 \ m_n^3 \ CO_2$$

A preceding approach gives the following for H_2 and S:

$$1 \text{ kg } H_2 + 5.6 \ m_n^3 \ O_2 \rightarrow 11.2 \ m_n^3 \ H_2O$$

and

$$1 \text{ kg S} + 0.7 \ m_n^3 \ O_2 \rightarrow 0.7 \ m_n^3 \ SO_2$$

Higher heating value: water in vapour phase
Lower heating value: water is condensed in a liquid
The condensation heat is also called latent heat
The temperature at which the flue gas condensates is called the dewpoint

Theoretical air amount and flue gas amount
The air we inhale is moist. Thus the combustion air is also moist. If we want to determine the theoretical air amount and flue gas amount, we use the following air composition in volume percentages (vol. %) in combustion calculations:

Nitrogen (N_2)	78.1 vol.%
Oxygen (O_2)	20.7 vol.%
Hydrogen (H_2O)	1.2 vol.%

1 m^3 air contains 0.207 m^3 oxygen. To gain 1 m_n^3 oxygen for the combustion, 4.83 m_n^3 is needed. The theoretical air amount L_0, the theoretical flue gas amount V_0 and the volume dry flue gas V_{0d} is calculated in the following example. The used method of calculation can also be used with other fuels.

Example (to be calculated by the teachers)
Given:
1 m_n^3 of a gaseous fuel with the following composition in volume percentages:

Methane (CH_4)	82 vol.%
Nitrogen (N_2)	14 vol.%
Carbon oxide (CO_2)	4 vol. %

Question:
Calculate the theoretical combustion air demand L_0 and the theoretical flue gas volume V_0.

Answer:
It is most useful to presume volumes, so do not calculate in reverse from volume through kmol to mass C and H.
The reaction equation is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

We assume that the other components do not join the combustion. If we further assume that the volume of 1 kmol gas is 22.4 m_n^3, we are allowed to replace the unit kmol by 1 m_n^3. In the preceding reaction equation this will show as follows. The oxygen demand for 0.82 m_n^3 gas (methane) will be:

$$0.82\ m_n^3\ CH_4 + 0.82 \cdot 2\ m_n^3\ O_2 \rightarrow 0.82\ m_n^3\ CO_2 + 0.82 \cdot 2\ m_n^3\ H_2O$$

Thus, 1.64 m_n^3 O_2 is needed for this combustion. Furthermore, 0.82 m_n^3 CO_2 and 1.64 m_n^3 H_2O are produced.

Questions combustion technology

If not given otherwise, the combustion calculations have to be based on the air composition according to

according to	Nitrogen (N_2)	78.1 vol.%
	Oxygen (O_2)	20.7 vol.%
	Hydrogen (H_2O)	1.2 vol.%

1.

a. Give the chemical combustion equation of ethane (C_2H_6).
b. Calculate the theoretical air amount L_0 for the combustion of 1 m^3 ethane.
c. Calculate the flue gas volume if the fuel combusts completely with an air factor 7%.
d. Calculate the flue gas volume if the flue gasses have a temperature of 220°C.

2. Given is 1 kg wet pure carbon, it contains 10% water.
Calculate:

a. The flue gas volume for the combustion of this amount of carbon at complete combustion with an air factor 1.
b. The higher heating value of this kg of wet carbon.

3. The higher heating value of a certain wood-type is 20 612 kJ per kg dry fuel. The ash percentage is negligible small. The hydrogen level of this dry fuel is 6%.
Calculate the lower heating value of this wood-type if the water content is 40%.

4. Calculate the higher and lower heating value of a gas with the following composition per m_n^3:
82 % CH_4, 3% C_2H_6 and 15% N_2.
CH_4 : *higher heating value* = 39 850 kJ/m_n^3
C_2H_6 : *higher heating value* = 70 380 kJ/ m_n^3

5. Calculate the oxygen level in the flue gasses of a fuel if the level $CO_{2,max}$ = 18.6%, while they measure a CO_2-content of 13% and 0% CO during the flue gas analysis.

6. A combustion engine consumes 25kg fuel per hour. The lower heating value of this fuel is 42 MJ/kg and the composition expressed in mass percentages is 80% C and 20% H. The mass of the oxygen in the air is 23% and the combustion is completely with an air factor of 50%.
Calculate:

a. The amount of combustion air required per hour.
b. The total flue gas volume in m_n^3/hour.
c. The CO_2-content in the flue gases.

7. Cokes are combusted on a grid. The coke composition in mass percentages is: 76% C, 14% ash and 10% water. The flue gases are and contains 12% CO_2 and 2% CO.
Calculate the volume of the flue gas in m_n^3 per kg fuel

8. Producer gas combusts completely in a boiler with an air surplus of 20%. The gas composition per m_n^3 is 60% H_2, 38% CO and 2% CO_2. The higher heating value of 1 m_n^3 H_2 is 12 745 kJ and of CO 5476 kJ. The condensation heat of water at 25 °C: r = 2443 kJ/kg.
Calculate:

a. The total flue gas volume in m_n^3.
b. The lower heating value of the fuel.

9. The volume percentage O_2 and CO_2 of the flue gasses of a gaseous fuel are measured at two combustor modes (figure 1).

Measurements	1st	2nd
O_2 vol%	6	8.5
CO_2 vol%	10	8

Figure 2

The measured percentages are valid for dry flue gas samples.

Calculate:

a. $CO_{2,max}$ of the first measurement.
b. Whether the O_2-content of the second measurement is correctly measured. If not, what should be the correct value?
c. The air factor of the first measurement. Here it can be said that L_0/V_{0d} = 1.

L_0 = theoretical air demand
V_{0d} = theoretical dry flue gas amount

10. How much wood is needed to bring one litre of water to the boil?

Data
Specific heat capacity of water = 4200 J kg-1 K-1
Mass of 1 litre of water = 1 kg
Heat value of wood = 15 MJ kg-1
Density of wood = 600 kg m –3
1 cubic centimetre (1 cm3 = 10-6 m3)
Calculation
Heat energy needed to heat 1 litre of water from 20 ºC to 100 ºC = 80 x 4200 J = 336 kJ
Heat energy released in burning 1 cm3 of wood = 15 x 600 x 10-6 MJ = 9.0 kJ
Volume of wood required = 336 + 9.0 = 37 cm3.
Experience suggests that on an open fire much more than two thin 20 cm sticks would be needed. But a well-designed stove using small pieces of wood could boil the water with as little as four times ‘input’ – an efficiency of 25%.

Recommended reading (from **http://www.inforesources.ch/pdf/focus09_3_e.pdf**)

Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen
2020 Focus 16. www.ifpri.org/sites/default/files/focus16_01_0.pdf
A set of policy briefs by various contributors, who share their views on key points concerning why agriculture has to be carefully included in the international climate change negotiations. The brief provides science and technology options, concluding with a strong plea for agriculture and for ongoing negotiations to address climate change, which will provide a unique opportunity to combine low-cost mitigation and essential adaptation outcomes with poverty reduction.

Aurélie Leplus. 2003
Biofuel Energy from Coconut in the Pacific Island
The Lory cooperative pilot project. MSc Thesis. Wageningen: Wageningen Agricultural University. www.riaed.net/IMG/pdf/Thesis_Copra_Biofuel.pdf
The coconut is an abundant and valuable source in the Pacific region and its products and by-products have an important role in the islands' economies. The study analyses coconut oil production at the Lory cooperative pilot project in Vanuatu for fuel use and its potential as a sustainable energy carrier at the village level. Coconut fuel has
the potential to offset imported petroleum and to improve revenues for the local population.

Jeffrey C. Milder, Jeffrey A. McNeely, Seth A. Shames and Sara J. Scherr. 2008
Biofuels and Ecoagriculture: Can Bioenergy Production Enhance Landscape-Scale Ecosystem Conservation and Rural Livelihoods?
www.ecoagriculture.org/documents/files/doc_282.pdf
Ecoagriculture, an approach with the threefold aim of biodiversity and ecosystem services conservation, sustainable agriculture production and viable local livelihoods, is used as a framework for evaluation of the effects of biofuel production on multiple landscape variables. The recommendations include i.a. the incorporation of biofuels into multifunctional agricultural landscapes in the context of smallholder production for local use, as well as the need for well-designed national biofuel programmes and further research.

Sonja Vermeulen, Annie Dufey and Bill Vorley. 2008
Biofuels: Making Tough Choices
Sustainable Development Opinion. London: International Institute for Environment and Development. www.iied.org/pubs/pdfs/17032IIED.pdf
National biofuel policies may strive for different goals, such as export or rural development, energy security or climate mitigation. At the same time, their design is unavoidably linked to negotiations between governments and other interest groups and requires trade-offs. This short publication introduces the "decision tree" as a tool to support the complex process of decision-making.

Biogas Sector Partnership Nepal
www.bspnepal.org.np
Operating as the implementing agency for the Biogas Support Programme Nepal (BSP), the Biogas Sector Partnership specializes in the development and dissemination of biogas plants as a means of protecting the environment while improving livelihoods and addressing social and sustainability issues. Its activities include technical and capacity development as well as the development of partnerships and fundraising, while keeping an eye on socioeconomic and gender questions. In its website, the BSP, provides ample information about the project itself as well as technical information, success stories and a list of publications.

Literature

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Information on websites

The following abbreviations are used in these tables:
W = website
WP = web portal
FS = fact sheet
E = electronic document
H = hardcopy (document is only available in print)
G = document in the German language

Highly valued data sources on bioenergy conversion in general

MODERN BIOMASS CONVERSION TECHNOLOGIES (GENERAL COVERAGE)	
W:	• The UK Biomass Energy Centre website www.biomassenergycentre.org.uk • Bioenergy Home Page of the Sate of Oregon (USA), www.oregon.gov/ENERGY/RENEW/Biomass/BiomassHome.shtml • IEA Task 29 Educational Website on Biomass and Bioenergy, www.aboutbioenergy.info • EUBIA's About biomass, www.eubia.org/about_biomass.0.html
WP:	• REPP's Bioenergy Reference Sites, www.repp.org/articles/static/1/1010424940_7.html • Univ. of Reading's Biomass Energy Links, www.rdg.ac.uk/energy/book/biomasites.htm
E:	• S. Kartha, G. Leach and S. C. Rajan, Advancing Bioenergy for Sustainable Development. Guideline for Policymakers and Investors. ESMAP, Washington DC, April 2005 • S. Kartha and E. Larson, Bioenergy Primer: Modernised Biomass Energy for Sustainable Development. UNDP, New York, 2000. • Renewable Energy from Biomass. M. Kaltschmitt, D. Thrän and K.R. Smith, 2002 • Bioenergy Technology Evaluation and Potential in Costa Rica. S. Huttunen and A. Lampinen, University of Jyväskylä, Finland, 2005
H:	• The Brilliance of Bioenergy - In Business and In Practice. Ralph E H Sims, 2002 • Wood fuels basic information pack. BENET, Jyväskylä, Finland (2002)
G:	• Energie aus Biomasse. Grundlagen, Techniken und Verfahren. M. Kaltschmitt & H. Hartmann (eds.). Springer Verlag, Heidelberg, 2001 • Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen. FNR, Gülzow, Germany, 2005

Highly valued data sources on mechanical biomass conversion processes

MECHANICAL BIOMASS CONVERSION PROCESSES (*PHYSICAL PRE-PROCESSING*)	
Comminution (sizing)	
W:	• Biosystems Engineering & Soil Science, University of Tennessee, bioprocessing.ag.utk.edu/grinding_surveypage.htm
E:	• Production Technology of Forest Chips in Finland. M. Kallio & A. Leinonen. VTT Processes, Finland (September 2005) • Developing technology for large-scale production of forest chips, P. Hakkila. TEKES Wood Energy Technology Programme, Finland (2004)
H:	• Forest Residue Harvesting Systems. C.P. Mitchell and C.M. Hankin. ETSU (1993)
Briquetting	
FS:	• EUBIA's Biomass pelleting, http://www.eubia.org/111.0.html
E:	• Biomass Briquetting: Technology and Practices. P. Grover & S. Mishra. FAO, Bangkok, 1996. • The briquetting of agricultural wastes for fuel. S. Eriksson and M. Prior. FAO, Rome, 1990
H:	• Briquetting of biomass: A compilation of techniques and machinery. M. Petterson. Swedish University of Agricultural Sciences, Umeå, February 1999
Mechanical extraction of vegetable oil	
W:	• Coconut Oil for Power Generation, SOPAC, www.sopac.org/tiki/tiki-index.php?page=CocoGen
E:	• Equipment For Decentralised Cold Pressing Of Oil Seeds, Erik Ferchau. Folkecenter for Renewable Energy, 2000. • Liquid biofuels in Pacific Island countries. Jan Cloin. SOPAC Miscellaneous Report 628. Suva, Fiji, April 2007
H:	

Highly valued data sources on thermo-chemical biomass conversion processes

THERMO-CHEMICAL BIOMASS CONVERSION PROCESSES	
Combustion	
W:	• IEA Bioenergy Task 32: Biomass Combustion and Co-firing, www.ieabcc.nl • European Biomass Combustion Network (CombNet), www.combnet.com

FS	• Steam turbine power (and heat) systems, Table 2.1 (p. 122) in Kartha et al, ESMAP, 2005
E:	
H:	• The Handbook of Biomass Combustion and Co-firing. S. van Loo and J. Koppejan (ed.) Earthscan. 2nd edition to be published in October 2007 • Energy from Biomass: A review of combustion and gasification technology. P. Quaak, H. Knoef, H. Stassen. World Bank, Washington DC (1998)
Gasification	
W:	• IEA Bioenergy Task 33: Thermal Biomass Gasification, www.gastechnology.org/iea • European Biomass Gasification Network (GasNet), www.gasnet.uk.net
FS	• Biomass gasification, Table 2.2 (p. 126) in Kartha et al, ESMAP, April 2005
E:	• An assessment of the possibilities for transfer of European biomass gasification technology to China. A.V. Bridgwater, A.A.C.M. Beenackers, K. Sipila. European Commission, 1999 • Wood gas as engine fuel. FAO, Rome (1986)
H:	• Handbook Biomass Gasification. Harrie Knoef (ed.), BTG, 2005 • Biomass Gasification in Developing Countries. G. Foley and G. Barnard. Earthscan, (1983)
Carbonisation	
WP:	• SSRSI Charcoal Making Page, www.ssrsi.org/sr2/Indust/charcoal.htm
E:	• Industrial production of charcoal, M. Grønli, SINTEF Energy Research, 2005, folk.ntnu.no/lekangso/kurs2005/presentations/Day4-6_Bio-Energy/background/Gronli.pdf • Industrial charcoal making. FAO, Rome, 1985 • Simple technologies for charcoal making. FAO, Rome, 1987 (reprint)
H:	• Charcoal Production - A Handbook. A.C. Hollingdale, R. Krishnan & A.P. Robinson. Commonwealth Secretariat (reprint 1999) • Charcoal making in developing countries. Gerald Foley IED/Earthscan Publications Ltd (1986)
A:	• The Art, Science, and Technology of Charcoal Production. M.J. Antal Jr. and M. Grønli. *In*: Ind. Eng. Chem. Res., Vol. 42, No. 8, pg. 1619-1640 (2003)

Highly valued data sources on biological biomass conversion processes

BIOLOGICAL BIOMASS CONVERSION PROCESSES	
Anaerobic digestion – general	
W:	• IEA Bioenergy Agreement Task 37, Energy from Biogas and Landfill Gas www.novaenergie.ch/iea-bioenergy-task37 • Beginners Guide to Biogas, www.adelaide.edu.au/biogas/ • Anaerobic Digestion Systems Web Site, www.anaerobic-digestion.com • Biogas Technology @ Biomass Energy Home Page, State of Oregon, www.oregon.gov/ENERGY/RENEW/Biomass/biogas.shtml
FS	• Biogas from anaerobic fermentation, Table 2.4 (p. 129) in Kartha et al, ESMAP, April 2005
E:	• Biogas Production and Utilisation, IEA Bioenergy Agreement Task 37 (2005)
G:	• Handreichung Biogasgewinnung und –nutzung (3rd edition). P. Scholwin, T. Wiedele, & H. Gattermann. FNR, Gülzow, Germany (2006)

Anaerobic digestion – animal manure	
W:	
E:	• Biogas Digest. 4 Volumes. GTZ (German Agency for Technical Cooperation) • Biogas technology: A training manual for extension. FAO / Consolidated Management Services, Kathmandu (1996)
H:	• Biogas – Praxis. Grundlagen - Planung - Anlagenbau - Beispiele – Wirtschaftlichkeit (3rd edition). Heinz Schulz and Barbara Eder. ökobuch Verlag, Staufen (2006)
Anaerobic digestion – solid waste and waste water	
W:	• Anaerobic Granular Sludge Bed Technology Pages, http://www.uasb.org/index.htm
E:	• Methane production by anaerobic digestion of wastewater and solid wastes. T.Z.D. de Mes et al. In: Bio-methane & bio-hydrogen : status and perspectives of biological methane and hydrogen production. Dutch Biological Hydrogen Foundation, 2003 • An introduction to Anaerobic Digestion of Organic Wastes. Remade Scotland, 2003 • Biogas and More! Systems & Markets Overview of Anaerobic Digestion. AEA Technology Environment for IEA Bioenergy Agreement Task 24 (2001)
H:	• Biogas from Municipal Solid Waste. Overview of Systems and Markets for Anaerobic Digestion of MSW. IEA Bioenergy Anaerobic Digestion Activity (1996)
Anaerobic digestion – landfill gas (LFG)	
W:	• Landfill Gas Web Site, www.landfill-gas.com/index.php • Landfill Gas To Energy @ California Energy Commission, www.energy.ca.gov/pier/renewable/biomass/landfill/index.html
E:	• International Perspective on Energy Recovery from Landfill Gas. IEA Bioenergy and IEA CADDET (Feb 2000) • Comparative Analysis of Landfill Gas Utilization Technologies. SCS ENGINEERS (March 1997)

Highly valued data sources on physical-chemical biomass conversion processes

PHYSICAL-CHEMICAL BIOMASS CONVERSION PROCESSES	
Liquid biofuels: general	
FS:	• IEA Energy Technology Essentials: Biofuel Production (2007), www.iea.org/Textbase/techno/essentials2.pdf
W:	• IEA Bioenergy Task 39 Commercializing 1st- and 2nd-Generation Liquid Biofuels from Biomass, www.task39.org
E:	• Biofuel Technology Handbook. Dominik Rutz and Rainer Janssen, WIP Renewable Energies, Munich, Germany, 2007 • IEA (2004), Biofuels for transport. An international perspective. International Energy Agency (IEA), Paris, France.
H:	• Biofuels for Transport – Global Potential and Implications for Sustainable Energy and Agriculture. Worldwatch Institute, 2007
Liquid biofuels: (trans)esterification for biodiesel production	
W:	• BDPedia - Biodiesel WWW Encyclopedia: All the answers & links. http://www.bdpedia.com/
E:	• Biodiesel Production and Economics, Department of Agriculture and Food, Government of Western Australia (May 2006)
H:	• Biodiesel: The Comprehensive Handbook. M. Mittelbach and C. Remschmidt (2004)

General Websites on CDM and JI:

- CFU website on CDM methodologies: Carbon Finance at the World Bank: Methodology (www.carbonfinance.org)
- Website of the UNFCCC: CDM: CDM-Home (http://cdm.unfccc.int/ and http://ji.unfccc.int/)
- Website on CDM (and JI) procedures (Ministry of the Environment Japan, Institute for Global Environmental Strategies: www.iges.or.jp/en/cdm/report01.html
- Website (UNEP, Risø Centre): CDM (and JI) pipeline overview http://cd4cdm.org/index.htm

Website on Waste Management

- World Bank website: www.worldbank.org/solidwaste

Websites useful for country information and data:

- IPCC Methodology reports (e.g. National Guidelines for National GHG Inventories) : http://www.ipcc.ch/pub/guide.htm
- Website for energy statistics (International Energy Agency): http://www.iea.org/Textbase/stats/index.asp
- Website on Climate Analysis Indicators Tool (World Resources Institute): http://cait.wri.org/
- Website on emissions from oil and gas industry (US EPA Gasstar): http://www.epa.gov/gasstar/index.htm

- National Clean Development Mechanism (CDM) Authority, Contact person. Ms. Masnellyarti Hilman, Deputy Minister for Nature Conservation Enhancement and Environmental Destruction Control, Ministry of Environment, 4th Floor Building B Jalan D.I. Panajaitan kav. 42 Kebon Nanas Jakarta, Phone: (62-21)8580-111, Fax: (62-21)8580111/8577-661, climate@menlh.go.id
- Indonesia’s DNA Website: http://dna-cdm.menlh.go.id/en/
- Note: Project can be linked to more than one sectoral scope
- Information searched under: http://cdmpipeline.org/ http://cdm.unfccc.int , http://dna-cdm.menlh.go.id/en/ (05.12.2007)

http://www.noordhoffuitgevers.nl/wps/portal/wnvo/binasenglish Binas English edition is a full colour work of reference, and contains a clear overview of tables, charts, formulas and illustrations for physics, chemistry, biology and mathematics.

Websites on gasification

http://www.youtube.com/watch?v=0PZr9uXegZw

http://gasifiers.bioenergylists.org/quality

http://www.fao.org/DOCREP/T0512E/T0512e00.htm

http://www.youtube.com/watch?v=xF_zFimqTXw

http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=iea/homepage.xml

http://www1.eere.energy.gov/biomass/feedstock_databases.html

http://www.biogas.nl/

http://www.docrenewableenergy.info/en_f-18~d-42234~n-renewable+energy+biomass+BIOMASS+ENERGY+POTENTIALS+AND+UTILIZATION+IN+INDONESIA.DOC~

http://www.oecd.org/document/25/0,3343,en_2649_33785_39633881_1_1_1_1,00.html

http://www.soi.wide.ad.jp/class/20070041/slides/02/

http://www.nrel.gov/data/pix/searchpix.php?query=BIOMASS%20and%20hydrolysis&display_type=tiled&max_display=100&search_home=searchpix_visual.html&search_reverse=1

http://www.learner.org/courses/envsci/unit/text.php?unit=10&secNum=1#

http://en.wikipedia.org/wiki/Energy

http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/biodiesel.htm

Straw briquetting
http://www.youtube.com/watch?v=Ln4_AGU_d-Y

Useful resources on bioenergy conversion technologies

Bioenergy (biomass conversion in general)

Title: Advancing Bioenergy for Sustainable Development. Guideline for Policymakers and Investors. Volumes I, II, and III
URL: http://www.esmap.org/filez/pubs/30005BiomassFinawithcovers.pdf
(or http://www.energycommunity.org/documents/SustainableBioenergyFinal.pdf)
Authors: Sivan Kartha, Gerald Leach and Sudhir Chella Rajan
Publisher: Energy Sector Management Assistance Program (ESMAP), World Bank, Washington DC (April 2005)
Relevance: Volume II contains bioenergy technology introduction, technical fiches and developing country case studies

Title: Biomass energy production in Australia: status, costs and opportunities for major technologies.
Authors: C.R. Stucley, S.M. Schuck, R.E.H. Sims, P.L. Larsen, N.D. Turvey and B.E. Marino
Publisher: Rural Industries Research and Development Corporation RIRDC (Feb 2004), Barton, ACT, Australia
Relevance: Examines in some detail the elements of bioenergy, from the nature of biomass as a fuel source, issues related to its production, harvesting and transport, its conversion into primary and secondary products and services, costs and economics of bioenergy in its various forms, and co-values and co-products associated with bioenergy.

Title: Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit von Bioenergie-anlagen. (Zweite Auflage)
URL: www.fnr-server.de/pdf/literatur/pdf_189leitfaden_2005.pdf
Publisher: Fachagentur Nachwachsende Rohstoffe (FNR), Gülzow, 2005
Relevance: General manual / standard book on the use of bioenergy. In German

Title: Clean Energy for Development and Economic Growth: Biomass and other renewable energy options to meet energy and development needs in poor nations
URL:
http://www.energyandenvironment.undp.org/undp/indexAction.cfm?module=Library&action=GetFile&DocumentAttachmentID=1030
Author: Daniel M. Kammen, Robert Bailis and Antonia V. Herzog
Publisher: UNDP, 2002
Relevance: Explores linkages between renewable energy, poverty alleviation, sustainable development, and climate change in developing countries. Special emphasis on
biomass-based energy systems.

Title: Modern biomass conversion technologies
URL: http://www.accstrategy.org/simiti/Faaij.pdf
Author: André Faaij
Publisher: Presented at Abrupt Climate Change (ACC), 30.9-1.10 2004, Paris, France

Title: Bioenergy Technology Evaluation and Potential in Costa Rica
URL: ebooks.jyu.fi/1795_6900/9513921549.pdf
Author: Suvi Huttunen and Ari Lampinen

Publisher: University of Jyväskylä, Finland (April 2005). Research Reports In Biological And Environmental Sciences #81
Relevance: Includes an introduction on many conversion technologies

Title: Planning and Installing Bioenergy Systems. A Guide For Installers, Architects And Engineers
Publisher: German Solar Energy Society and Ecofys (January 2005). BN 1844071324
Relevance: Planning manual for bioenergy plants. Contents include: Biomass Overview • Anaerobic Digestion • Biofuel • Small-scale Heat Ovens • Large-scale Boilers • Gasifiers

Title: Manual for biofuel users
URL: www.cbss.st/basrec/documents/bioenergy/dbaFile10431.pdf
Author: Villu Vares (ed.)
Publisher: Tallinn University of Technology (TUT), Tallinn, 2005. Produced in the frame of Baltic Sea Region Energy Co-operation (BASREC)
Relevance: Manual on the use of solid biofuels

Title: Bioelectricity Vision: Achieving 15% of Electricity from Biomass in OECD Countries by 2020
URL: www.wwf.de/fileadmin/fm-wwf/pdf_misc-alt/klima/biomassereport.pdf
Author: Ausilio Bauen, Jeremy Woods and Rebecca Hailes
Publisher: WWF International and AEBIOM, April 2004

Tile: The Brilliance of Bioenergy - In Business and In Practice
Author: Ralph E H Sims
Publisher: James & James (Science Publishers) Ltd, London (UK). February 2002
Relevance:

Title: Wood fuels basic information pack. 2nd edition 2002.
Author: Varpu Savolainen and Håkan Berggren (ed.)
Publisher: BENET Bioenergy Network of Jyväskylä Science Park Ltd (Finland). ISBN 952-5165-19-1
Relevance: Covers i.a. production techniques of woodfuels

Title: Wood for Energy Production: Technology - Environment - Economy.
URL: http://www.videncenter.dk/uk/engwood.htm
Author: Helle Serup
Publisher: Centre for Biomass Technology. ISBN: 87-90074-28-9. 2nd Revised Edition, 2002
Relevance:

Title: Renewable Energy from Biomass
URL: http://ehs.sph.berkeley.edu/krsmith/publications/Kaltschmitt%20Biofuel%20final.pdf
Authors: Martin Kaltschmitt, Daniela Thrän and Kirk R. Smith
Published in: Encyclopedia of Physical Sciences and Technology, Third edition, Volume 14. Academic Press/Elsevier, Burlington, USA (2002)
Relevance: Overview article. Extensive reference to Kaltschmitt's German language *Energie aus Biomasse* (see below).

Tile; Energie aus Biomasse. Grundlagen, Techniken und Verfahren
Authors: M. Kaltschmitt & H. Hartmann (eds.)
Publisher: Springer Verlag, Heidelberg, 2001, ISBN 3-540-64853-4
Relevance: In German. Very exhaustive overview on technologies and processes for producing energy from biomass.

Title: RWEDP Wood Energy Database
URL: http://www.rwedp.org/d_database.html
Publisher: FAO's Regional Wood Energy Development Programme in Asia
Relevance: Database containing a wealth of data on various aspects related to wood energy for the 16 RWEDP member countries. RWDEP operated from 1985 through 2001, and the website was maintained until December 2002.

Title: Bioenergy Primer: Modernised Biomass Energy for Sustainable Development

URL: http://www.energyandenvironment.undp.org/undp/index.cfm?module=Library&page=Document&DocumentID=5029
Authors: Sivian Kartha and Erid D. Larson (2000)
Publisher: United Nations Development Programme, New York, USA,
Relevance: Selected web resources on bioenergy / biomass conversion in general are mentioned in the main body of the report.

Comminution

Title: Production Technology of Forest Chips in Finland.
URL: www.bio-south.com/pdf/ForestRes_Prod.pdf
Author: Markku Kallio & Arvo Leinonen
Publisher: VTT Processes, Project report PRO2/P2032/05, September 2005

Title: Developing technology for large-scale production of forest chips
URL: www.tekes.fi/english/programm/woodenergy.
Author: P. Hakkila
Publisher: TEKES Wood Energy Technology Programme. Technology Report 5/2004.

Title: Forest Residue Harvesting Systems.
Author: C.P. Mitchell and C.M. Hankin
Publisher: Wood Supply Research Groups, University of Aberdeen, UK, 1993. ETSU report B/W1/00136/REP.

Densification

Books

Title: Briquetting biomass wastes for fuel. Summary report
Authors: Sören Eriksson and Mike Prior
Publisher: SEBRA, Trosa, Sweden, February 1989
Relevance: Summary of project results. Short overview of main briquetting technologies. Country reviews. Economics. Markets.

Title: The briquetting of agricultural wastes for fuel
URL: http://www.fao.org/docrep/T0275E/T0275E00.htm
Authors: Sören Eriksson and Mike Prior
Publisher: FAO Environment and Energy Paper no. 11, FAO, Rome, 1990
Relevance: Good overview document. Discusses different presses (mechanical piston, hydraulic piston, screw extruders, pelletisers). Economics. Includes 5 country reviews.

Title: Briquetting of Vegetable Residues
Author: Y. Schenkel, J. Carré and P. Bertaux, CRA, Gembloux (Belgium)
Publisher: Centre for the Development of Industry ACP – EU (1995)
Relevance: Technology assessment, case studies, agri-residues, questionnaire, manufacturers

Title: Biomass Briquetting: Technology and Practices
URL: www.rwedp.org/acrobat/fd46.pdf
Authors: P.D. Grover & S.K. Mishra
Publisher: Regional Wood Energy Development Programme (RWEDP) in Asia, FAO, Bangkok, 1996.
Relevance: Contains some information on screw press and piston press technologies. Book is often quoted by recent authors.

Title: Briquetting of biomass: A compilation of techniques and machinery
Author: Magnus Petterson
Details: Students' reports no. 22 (1999), Swedish University of Agricultural Sciences, Umeå, February 1999
Relevance: Compilation of technical information on binderless briquetting techniques. Contacts of 44 manufacturers worldwide

Title: Wood pellets in Finland – technology, economy and market
URL: www.tekes.fi/opet/pdf/OPET_report5_june2002.pdf
Authors: Eija Alakangas and Paavo Paju
Publisher: OPET Report 5, VTT Processes, Jyväskylä, Finland, 2002
Relevance: Chapter 3 covers production technologies

Short articles and fact sheets

Title: Refined Bio-Fuels Pellets and Briquettes. Characteristics, uses and recent innovative production technologies
URL: wip-munich.de/downloads/dissemination/newsletters_brochures/Leaflet_2_Pellets.pdf
Publisher: ETA / WIP / EUBIA
Relevance:

Title: Biomass pelleting / The pelleting of wood
URL: www.eubia.org/111.0.html & www.eubia.org/196.0.html
Publisher: European Biomass Industry Association (EUBIA)
Relevance: Fact sheet type information on pelleting technologies and economics

Mechanical extraction

Title: Short note on Pure Plant Oil (PPO) as fuel for modified internal combustion engines
URL: valenergol.free.fr/dossiers/IPTS/Short%20note%20on%20pure%20plant%20oil.pdf
Author: Peder Jensen
Publisher: Institute for Prospective Technological Studies, Seville, Spain
Relevance: short summary of main characteristics of pure plant oil (PPO) as a fuel for internal combustion engine automotive applications.

Title: Equipment For Decentralised Cold Pressing Of Oil Seeds
URL: www.folkecenter.net/mediafiles/folkecenter/pdf/dk/efdcpos_ef.pdf
Author: Erik Ferchau
Publisher: Folkecenter for Renewable Energy. November 2000.

Title: Coconut Oil for Power Generation by EPC in Samoa (website)
URL: http://www.sopac.org/tiki/tiki-index.php?page=CocoGen
Moderator: Jan Cloin
Publisher: SOPAC Secretariat, Suva, Fiji.

Combustion

As the most common way of converting biomass to energy, combustion is often covered to a smaller or larger extent in general biomass technology publications. Sources that specifically focus on aspects of (industrial) biomass combustion include:

Title: The Handbook of Biomass Combustion and Co-firing. 2nd edition
Author: Sjaak van Loo and Jaap Koppejan (ed.)
Publisher: Earthscan. To be published in October 2007. ISBN: 1844072495
Relevance: This handbook presents both the theory and application of biomass combustion and co-firing, from basic principles to industrial combustion and environmental impact. First edition published in 2002

Title: Bioheat Applications in the European Union: an Analysis and Perspective for 2010
URL: www.jrc.nl/publications/scientific_publications/2004/EUR%2021401%20EN.pdf
Author: B. Kavalov and S. D. Peteves
Publisher: Joint Research Centre, 2004
Relevance:

Title: IEA Bioenergy Task 32: Biomass Combustion and Co-firing
URL: http://www.ieabcc.nl/
Leader: Sjaak van Loo
Relevance: A technology expert network o biomass combustion operating under IEA Bioenergy

Title: European Biomass Combustion Network (CombNet)
URL: http://www.combnet.com/index2.php?p=homepage
Leader: Sjaak van Loo
Relevance: A technology expert network on biomass combustion operating under ThermalNet

Gasification

An up-to-date overview of documents on biomass gasification technology is presented at URL www.gasnet.uk.net/sections.php?name=Qm9va3M=

Title: Handbook Biomass Gasification
Author: Harrie Knoef (ed.)
Publisher: BTG Biomass Technology Group BV (September 2005)
Relevance: Covers a wide range of themes relevant to biomass gasification

Title: Small-scale biomass gasifiers for heat and power; a global review
Author: H. E.M. Stassen
Publisher: World Bank, TechnicalPpaper no. 296 (1995), ISBN 0-8213-3371-2
Relevance:

Title: Wood gas as engine fuel
URL: ftp://ftp.fao.org/docrep/fao/t0512e/t0512e00.pdf
Publisher: FAO, Forestry Paper 72 (1986), Rome, ISBN 92-5-102436-7
Relevance: Summary of modern wood gasification technology and the economics of its application to internal combustion engines.

Title: Biomass Gasification in Developing Countries.
Author: Foley, G., and Barnard, G.,
Publisher: Earthscan, London (183), ISBN 0-905347-39-0 174 pp
Relevance: Detailed appraisal of the prospects for biomass gasification in developing countries, based on a World Bank study. Topics covered include economics, commercial status, practical considerations affecting gasifier feasibility in specific applications.

Title: An assessment of the possibilities for transfer of European biomass gasification technology to China
URL: ec.europa.eu/energy/res/sectors/doc/bioenergy/final_report_for_publication.pdf
Author: A.V. Bridgwater, A.A.C.M. Beenackers, K. Sipila
Publisher: European Commission, 1999, ISBN 92-828-6268-2
Relevance: Assessment of the opportunities in China for European biomass gasifier manufacturers

Title: Biomass Gasification in Europe
Author: M. Kaltschmitt, C. Rösch, L. Dinkelbach (eds.)
Publisher: European Commission, October 1998. Report EUR 18224. ISBN: 92-828-4157-X
Relevance: Contains country reviews on research, development, demonstration and deployment of biomass gasification technologies.

Title: IEA Bioenergy Task 33: Thermal Biomass Gasification
URL: www.gastechnology.org/iea
Leader: Suresh Babu
Relevance: A technology expert network on biomass combustion operating under IEA Bioenergy

Title: European Biomass Gasification Network (GasNet)
URL: www.gasnet.uk.net
Leader: Hermann Hofbauer
Relevance: A technology expert network on biomass gasification operating under ThermalNet

Carbonisation

Books

Title: Industrial charcoal making
URL: www.fao.org/docrep/x5555e/x5555e00.htm
Publisher: FAO Forestry Paper 63, FAO, Rome, 1985
Relevance: Practical manual on industrial technologies for charcoal making. Discusses charcoal properties, modern carbonising retort systems, environmental considerations, cost and quality control etc.

Title: Simple technologies for charcoal making
URL: www.fao.org/docrep/X5328e/x5328e00.htm
Publisher: FAO Forestry Paper 41, FAO, Rome, 1987 (reprint)
Relevance: Practical manual on labour-intensive methods for charcoal making. Discusses charcoal properties, traditional carbonising methods (pits, mounds, beehives, metal kilns, etc.), retort systems, cost and quality control etc.

Title: Charcoal production and pyrolysis technologies.
Author: Per Thoresen (ed.)
Publisher: REUR Technical Series no. 20, FAO, Rome (1991), 180 pg.
Relevance: Workshop proceedings covering selected carbonisation technologies applied around the world. Contains a chapter by M Trossero on Evaluation of charcoal making technologies in developing countries.

Title: Charcoal Production - A Handbook
Authors: A.C. Hollingdale, R. Krishnan & A.P. Robinson
Publisher: Commonwealth Secretariat, 1999 (reprint), 159 pg, ISBN 0 85092 380 8
Relevance: This handbook covers methods of charcoal manufacture; details on traditional and modern kilns; the uses of charcoal and its by-products; techniques for analysing charcoal to facilitate product control and standardisation.

Title: Charcoal making in developing countries
Author: Gerald Foley
Publisher: International Institute for Environment and Development (IIED) / Earthscan Publications Ltd (1986), 100 pg, ISBN: 0905347608
Relevance: Comprehensive charcoal production technology overview

Title: The Art, Science, and Technology of Charcoal Production
Author: Michael Jerry Antal, Jr. and Morten Grønli
Published: *In*: Ind. Eng. Chem. Res., Vol. 42, No. 8, pg.1619-1640 (2003)
Relevance: Article summarises the knowledge of the production and properties of charcoal. A similar article is published as chapter 9 in Fast Pyrolysis of Biomass: A Handbook. Volume 3. (A V Bridgwater, ed.) CPL Press (2005), 221 pg, ISBN: 1872691927

Other data sources

Title: SSRSI Charcoal Making Page
URL: www.ssrsi.org/sr2/Indust/charcoal.htm

Description: This site contains many relevant links to charcoal making. Operated by the Survival & Self Reliance Studies Institute
Relevance: Contains many relevant links. Seems up-to-date.

Title: Developments in charcoal production technology
URL: http://www.fao.org/docrep/005/y4450e/y4450e11.htm
Author: Hubert E.M. Stassen
Relevance: Short article

Title: Charcoal production and use in Africa: what future?
URL: http://www.fao.org/docrep/005/y4450e/y4450e10.htm
Author: Philip Gerard
Relevance: Short article

Anaerobic digestion

General

Title: Biogas Production and Utilisation
URL: www.iea-biogas.net/Dokumente/Brochure%20final.pdf
Author: Members of IEA Bioenergy Agreement Task 37
Publisher: IEA, Paris, 2005
Relevance: General introduction, prepared by international expert group

Title: IEA Bioenergy Agreement Task 37
URL: http://www.novaenergie.ch/iea-bioenergy-task37/
Moderator: Nova Energie, Switzerland
Relevance: IEA working group covering biological treatment of the organic fraction of municipal solid waste (OFMSW) as well as the anaerobic treatment of organic rich industrial waste water.

Anaerobic digestion technology briefs:
www.btgworld.com/technologies/anaerobic-digestion.html
www.biogas-energy.com/docs_en/BiogasEnergy.pdf

The Anaerobic Digestion Archives
http://listserv.repp.org/pipermail/digestion_listserv.repp.org/
General discussion about technical aspects of anaerobic digestion, moderated by Paul Harris, University of Adelaide.

Title: Beginners Guide to Biogas
URL: www.adelaide.edu.au/biogas/
Note: Provides some introductory material. Moderated by Paul Harris

Title: Anaerobic Digestion and Biogas
URL: http://www.mrec.org/anaerobicdigestion.html
Author: Midwest Rural Energy Council (Wisconsin, USA)
Relevance: Links to resources on the topic of anaerobic digestion

Title: Anaerobic Digestion Systems Web Site
URL: http://www.anaerobic-digestion.com/index.php
Moderator: Enviros (consulting company)
Relevance: Supplier independent information on AD and related subjects.

Dairy manure

Titles: **Biogas Digest**. Vol. 1: Biogas Basics. Vol.2: Biogas – Application and Product Development. Vol. 3: Biogas - Costs and Benefits and Biogas – Programme Implementation. Vol. 4: Biogas – Country Reports

URL: www.gtz.de/de/dokumente/en-biogas-volume1.pdf
www.gtz.de/de/dokumente/en-biogas-volume2.pdf
www.gtz.de/de/dokumente/en-biogas-volume3.pdf
www.gtz.de/de/dokumente/en-biogas-volume4.pdf
Publisher: GTZ (German Agency for Technical Cooperation)
Relevance: Extensive documentation on household and village scale biogas plants in developing countries, prepared in the frame of GTZ's Information and Advisory Service on Appropriate Technology

Title: Biogas technology: A training manual for extension
URL: http://www.fao.org/sd/EGdirect/EGre0021.htm
Publisher: FAO / Consolidated Management Services, Kathmandu, 1996
Relevance: Training manual for Nepal

Title: Handreichung Biogasgewinnung und –nutzung (3rd edition)
URL: www.fnr-server.de/pdf/literatur/HR_Biogas.pdf
Author: Fachagentur Nachwachsende Rohstoffe, Gülzow, Germany (2006)
Relevance: Written in German. Chapter 3 by P. Scholwin, T. Wiedele, & H. Gattermann, discusses biogas plant technology

Title: Biogas – Praxis. Grundlagen - Planung - Anlagenbau - Beispiele - Wirtschaftlichkeit. 3rd edition.
Authors: Heinz Schulz and Barbara Eder:
Publisher: ökobuch Verlag, Staufen bei Freiburg (2006), ISBN: 3-936896-13-5
Relevance: Written in German. Chapter 3 discusses biogas plant technology. chapter 7 biogas plant planning and economics

Title: Dairy Waste Anaerobic Digestion Handbook. Options for Recovering Beneficial Products From Dairy Manure
URL: www.makingenergy.com/Dairy%20Waste%20Handbook.pdf
Author: Dennis A. Burke P.E.
Publisher: Environmental Energy Company, Olympia WA (June 2001)
Relevance: Introduction to the anaerobic digestion of daily manure

Organic waste / Municipal solid waste

Title: Anaerobic Reactors. Volume 4 in the Biological Wastewater Treatment series
Author: Carlos Augustos de Lemos Chernicharo
Publisher: IWA Publishing (March 2007), UK. ISBN 1843391643
Relevance: Presents fundamentals of anaerobic treatment in detail, including its applicability, microbiology, biochemistry and main reactor configurations.

Title: An introduction to Anaerobic Digestion of Organic Wastes. Final Report
URL: www.bioenergywm.org/documents/Anaerobic%20Digestion.pdf
Author: Fabien Monnet (Remade Scotland), November 2003
Relevance: Discusses i.a. AD processes, by-products, types of facilities

Title: Methane production by anaerobic digestion of wastewater and solid wastes
Authors T.Z.D. de Mes ; A.J.M. Stams,; J.H. Reith, and G. Zeeman.
In: Bio-methane & bio-hydrogen : status and perspectives of biological methane and hydrogen production, J.H. Reith, R.H. Wijffels and H. Barten (eds)
URL: www.biohydrogen.nl/publicfiles/16_20804_2_Bio_methane_and_Bio_hydrogen_2003.pdf
Publisher: Dutch Biological Hydrogen Foundation, 2003
Relevance: Chapter 4 of the publication reviews and evaluates various anaerobic digestion technologies. Discusses the situation in the Netherlands as well as international developments

Title: Anaerobic digestion of biodegradable organics in municipal solid wastes
URL: http://www.seas.columbia.edu/earth/vermathesis.pdf
Author: Shefali Verma (thesis)
Publisher: Columbia University, May 2002

Relevance: In-depth examination of the status of anaerobic digestion technologies for the treatment of the organic fraction of municipal solid wastes (MSW).

Title: Biogas and More! Systems & Markets Overview of Anaerobic Digestion
URL: http://websrv5.sdu.dk/bio/pdf/biogas.pdf
Author: AEA Technology Environment, Culham, Abingdon, UK, July 2001
Publisher: IEA Bioenergy Agreement Task 24 Energy From Biological Conversion Of Organic Waste
Relevance: Special attention to digestion of municipal solid waste (MSW). A prior edition (Feb 1998) was published by Resource Development Associates, Washington DC, USA

Title: Review of Current Status of Anaerobic Digestion Technology for Treatment of Municipal Solid Waste
URL: http://ns.ist.cmu.ac.th/riseat/documents/adreview.pdf
Author: Regional Information Service Center for South East Asia on Appropriate Technology (RISE-AT), Chiang Mai University, Thailand (November 1998)
Relevance: Summarises the current status of Anaerobic Digestion Technology for Treatment of Municipal Solid Waste (MSW). Review of systems in operation worldwide.

Title: Biogas from Municipal Solid Waste. Overview of Systems and Markets for Anaerobic Digestion of MSW
Author: IEA Bioenergy Anaerobic Digestion Activity
Publisher: Danish Energy Agency (Copenhagen) & Novem (Utrecht, The Netherlands)
Relevance: Discusses technology, market and suppliers for MSW digestion

Title: Anaerobic Granular Sludge Bed Technology Pages (website)
URL: www.uasb.org/index.htm
Moderator: Jim Field & Reyes Sierra
Relevance: Aims to inform the public on the application of anaerobic bioreactor systems for wastewater treatment and sustainable environmental technology

Landfill gas

Title: International Perspective on Energy Recovery from Landfill Gas (REV-3)
URL: http://www.caddet.org/public/uploads/pdfs/Report/ar06.pdf
Publisher: IEA Bioenergy and IEA CADDET Cenbtre for Renewable Energy (Feb 2000)
Relevance: Reviews of the status of energy from landfill gas in IEA countries. Chapter 2 discusses landfill gas utilisation, collection and treatment technologies.

Title: Comparative Analysis of Landfill Gas Utilization Technologies
URL: http://www.nrbp.org/pdfs/pub07.pdf
Author: SCS ENGINEERS, March 1997
Publisher: Northeast Regional Biomass Program (USA)

Title: Landfill Gas Web Site
URL: http://www.landfill-gas.com/index.php
Moderator: Enviros (consulting company)
Relevance: Devoted to scientific and technical issues in landfill gas.

Liquid biofuel production

Note: This category covers technologies for the production of pure plant oil by mechanical extraction, the (trans-)esterification of vegetable oil into biodiesel, and the alcoholic fermentation of sugar and starch crops into bio-ethanol.

Title: GAVE: Climate neutral gaseous and liquid energy carriers (website)
URL: http://gave.novem.nl/gave/index.asp
Leader: SenterNovem

Relevance: GAVE supports climate neutral gaseous and liquid energy carriers. The website hosts hundreds of documents on this subject

Title: VIEWLS: Clear Views on Clean Fuels (website)
URL: www.viewls.org
Leader: SenterNovem
Relevance: The VIEWLS website covers Data, Potentials, Scenarios, Markets and Trade of Biofuels. Restrcited access to hundreds of documents on these subjects

Title: IEA Bioenergy Task 39 "Commercializing 1st- and 2nd-Generation Liquid Biofuels from Biomass"
URL www.task39.org
Leader: Jack Saddler, University of British Columbia, Canada
Relevance: Global network dedicated to the development and deployment of biofuels for transportation fuel use.

Title: Biofuels for Transport - Global Potential and Implications for Sustainable Energy and Agriculture
Author: Worldwatch Institute in association with BMELV, FNR and GTZ
Publisher: Earthscan, July 2007, ISBN: 1844074226
Note: Circulated earlier in a restricted audience under the title "*Biofuels For Transportation. Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century*"
Relevance: A comprehensive analysis, which takes the reader from an introduction to specific biofuels, through the prospects for technology and agriculture, to the economic, social and environmental implications

Title: Biofuel Technology Handbook
URL: www.biofuelmarketplace.com/Files/545fdcfd-5b78-4a24-b443-679fef162b6c/technology_handbook_v1.pdf
Authors: Dominik Rutz and Rainer Janssen
Publisher: WIP Renewable Energies, Munich, Germany, 2007
Relevance: This document gives an overview of relevant technological aspects of biofuels

Title: Biofuels for Transportation - Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century. Conference Handout
URL: www.gtz.de/de/dokumente/en-biofuels-conference-handout-2006.pdf
Publisher: BMELV, GTZ and Worldwatch Institute
Relevance: Summarises the findings of the *Biofuels for Transport* study

Title: Biofuels for transport. An international perspective
URL: www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf
Authors: Lew Fulton, Tom Howes, and Jeffrey Hardy (IEA)
Publisher: International Energy Agency (IEA), Paris, 2004
Relevance: Excellent treatment of biofuels technologies, costs, benefits, market issues, and existing and past policies from around the world. Bibliography of more than 150 references.

Title: Biofuels. Technologies Status and Future Trends. Feedstock and Product Valorisation. Assessment of Technologies and DSTs. Pre-Print
Author: A. Sivasamy, P. Foransiero, S. Zinoviev, S. Miertus, F. Mueller-Langer, D. Thraen & A. Vogel
Publisher: International Centre for Science and High Technology, UNIDO, Italy
Relevance:

Title: International Resource Costs of Biodiesel and Bio-ethanol
URL: www.senternovem.nl/mmfiles/Costsofbiobioethanol_tcm24-187060.pdf or www.dft.gov.uk/pgr/roads/environment/research/cqvcf/internationalresourcecostsof3833
Author: AEA Technology Environment
Publisher: UK Department for Transport, United Kingdom, June 2003
Relevance: Good overview of the sources of biofuels around the world and their likely costs.

Title: GEF-STAP Biofuels Workshop: Summary, Findings & Recommendations
URL:
www.gefweb.org/Documents/council_documents/GEF_30/documents/C.30.Inf.9.Rev.1ReportoftheGEF-STAPWorkshoponLiquidBiofuels.pdf
Author: Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility
Relevance:

Title: A Review of LCA Studies on Liquid Biofuel Systems for the Transport Sector (Final Version 11 October 2005). Background Paper
Author: Eric D. Larson (Princeton Environmental Institute)
Note: Originally presented at the GEF/STAP Workshop on Liquid Biofuels for the Transport Sector, 29 August – 1 September 2005, New Delhi, India
Relevance:

Title: Review of existing and emerging technologies for the large-scale production of biofuels in developing countries. Technology state-of-the-art. Background Paper
Authors: Philippe Girard, Abigaïl Fallot, Fabien Dauriac (CIRAD)
Publisher: Energy for Sustainable Development, Vol 10 No 2 (2006), ISSN 0973-0826
Note: Paper originally presented at the GEF/STAP Workshop on Liquid Biofuels for the Transport Sector, 29 August – 1 September 2005, New Delhi, India
Relevance: Describes various routes for converting biomass into transport fuel.

Title: Liquid Biofuel in South East Asia: Resources and Technologies
URL: www.ris.org.in/article3_v8n2.pdf
Authors: Linoj Kumar, Prabha Dhavala, Anandajit Goswami, & Sameer Maithel
Relevance:

Title: Liquid biofuels in Pacific Island countries
URL: http://www.sopac.org/tiki/tiki-download_file.php?fileId=1064
Author: Jan Cloin
Publisher: SOPAC Secretariat, Suva, Fiji. Miscellaneous Report 628 (April 2007)
Relevance: Discusses the potential use of PPO, biodiesel and bio-ethanol in the Pacific

Title: Small-scale Production and Use of Liquid Biofuels in Sub-Saharan Africa: Perspectives for Sustainable Development
URL: http://www.un.org/esa/sustdev/csd/csd15/documents/csd15_bp2.pdf
Publisher: UN Dep't of Economic and Social Affairs (UN-DESA), New York, April 2007
Relevance: Background paper no. 2 to the 15th Session of the Commission on Sustainable Development (CSD), held 30 April-11 May 2007 in New York. The paper assesses the status and analyses the perspectives of small-scale biofuel production and use in sub-Saharan Africa. Contains 5 case studies on liquid biofuel production in developing countries

Title: Biodiesel Production and Economics
URL: www.agric.wa.gov.au/content/SUST/BIOFUEL/BiodieselProductandEconvs12vs111.pdf
Publisher: Department of Agriculture and Food, Gov't of Western Australia (May 2006)
Relevance: Provides comprehensive info & WWW resources for bio-diesel. Covers >1000 relevant web links on biodiesel related topics. Intended to be a one-stop biodiesel resource, both for information and for WWW links, for use by beginners and experts alike.

Title: Biodiesel: The Comprehensive Handbook
Author: Martin Mittelbach and Claudia Remschmidt
Publisher: Martin Mittelbach (2004), ISBN: 3-200-00249-2
Relevance: First comprehensive handbook on biodiesel. Covers feedstocks, process technologies, fuel properties, quality specifications, exhaust emissions, environmental impacts and non-energy uses.

Title: BDPedia - Biodiesel WWW Encyclopedia
URL: www.bdpedia.com
Relevance: All the answers & links.

Production of (combined heat and) power

Title: Energy from Biomass: A review of combustion and gasification technology
Authors: Peter Quaak, Harrie Knoef, Hubert Stassen
Publisher: World Bank, Technical Paper No. 422 (1998), ISBN 0-8213-4335-1
Relevance Describes gasification and combustion technology in general terms. Compares steam-cycle and gasifier-engine concepts.

Title: Wood energy through steam engines. Draft report
Authors: TARGET Technologia e Servizi S.r.k., Rome (October 1987)
Publisher: FAO Forestry Department , Rome
Relevance: Discusses small-scale biomass-based power generation

Title: Techno-Economic evaluation of selected decentralised CHP plants based on biomass combustion in IEA partner countries.
URL: http://www.ieabcc.nl/publications/IEA-CHP-Q2-final.pdf
Author: Ingwald Obernberger and Gerold Thek
Publisher: BIOS Bioenergiesysteme, Graz, Austria (March 2004)
Notes:

Title: Small-scale biomass CHP technologies
URL: www.opet-chp.net/download/wp2/small_scale_biomass_chp_technologies.pdf
Author: M. Kirjavainen, K. Sipilä, E. Alakangas, T. Savola and M. Salomon
Publisher: VTT Processes, Espoo (April 2004)
Relevance:

Title: Energetische Nutzung von Biomasse durch Kraft-Wärme-Kopplung: Tagungsband zu der Veranstaltung am 16./17. Mai 2000 in Gülzow
URL: http://www.fnr-server.de/pdf/literatur/pdf_95gfg14_kwk.pdf
Publisher: Fachagentur Nachwachsende Rohstoffe (FNR), Gülzow (2000)
Relevance: In German