UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Biomass Conversion Technology On-line Information Platform - Phase 1

Opportunity study

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EXECUTIVE SUMMARY

A. Introduction

This report is the outcome of a study carried out by BTG Biomass Technology Group BV for UNIDO. It contains a thorough assessment of available information on the world wide web on biomass conversion technologies that are commercially available in developing countries and presents recommendations on what role UNIDO could play in improving information flows and how this would best be done.

The report consists of two main parts. Part I serves as an introduction to biomass feedstocks, bioenergy conversion technologies and environmental impacts. Part II analyses the availability of relevant technology-related information on the Internet.

B. Background

UNIDO's Biofuels Strategy states that "*The production and use of biofuels have entered a new era of global growth, with both the scale of the industry and the number of countries involved reaching unprecedented levels. Surging investments in biofuels production are being driven by a variety of factors, that include the development of more efficient conversion technologies, the introduction of new government policies, growing international trade and the rising price of oil*."

Industry, and more particularly, SMEs, can play a role in biomass flows, where agricultural and forestry commodities and residues can be converted into biofuels and energy. UNIDO's role -in line with its mandate- is to ensure that its client government institutions, private sector and industry related organizations are in a position to take effective and efficient decisions on their biofuels programmes, especially with respect to the selection of available technologies and the steps required to adopt promising technologies currently under development.

UNIDO considers assisting its clients, including government institutions, private sector and industry related organizations, through the establishment of a Biomass Conversion Technology On-line Information Platform, or BIOTIP.

C. Objective and scope

The overall objective of BIOTIP is to enable biofuel promotion agencies to advise entrepreneurs to take informed decisions on the selection of appropriate and commercially available biomass conversion technologies by providing ease of access to assessed information.

At project completion, actors in this field will have a good overview of the current technology situation (including technical feasibility, environmental impact, economic viability and risk assessments) and information to decide how existing institutions can better cooperate and provide required information.

The project is organised in two phases, a preparatory phase, which this report covers, and the main implementation phase, which will be initiated based on the findings of the current opportunity study.

The main elements of this opportunity study are:

1. A thorough assessment of existing information sources on commercially available biomass conversion technologies available to developing countries;
2. Recommendations on what role UNIDO could play in improving information flows and how this would best be done.

D. Short summary of Part I

The study concentrates on **bioenergy conversion pathways** that are (a) commercially available (b) applicable in the small-to-medium capacity range (electric power demand < 10 MW_e and total energy demand < 50 MW_{th}), and (c) appropriate for use in developing countries. In Chapter 3 the report briefly describes **the state of the art**, commonly used devices, current use in developing countries, economics and environmental aspects of commercially available biomass conversion technologies, grouped into four main categories, as follows (see Table A):

Table A: Biomass conversion technologies covered in this report

Conversion process category	Conversion technology
Mechanical processes	Comminution
	Densification
	Mechanical extraction
Thermo-chemical processes	Combustion
	Gasification
	Carbonisation
Biological processes	Anaerobic digestion
	Fermentation (ethanol production)
Physical-chemical processes	Esterification (biodiesel production)

In Chapter 4 environmental aspects of biomass conversion are dealt with. Environmental aspects can be studied at various levels of detail. At the individual bioenergy plant level, the owners of small and medium-scale bioenergy projects generally need to apply for an **environmental permit** in order to get permission for operation. For larger scale bioenergy projects an **Environmental Impact Assessment (EIA)** may be required. The most complete and thorough method to assess environmental impacts of a product or production method is the **Life Cycle Assessment (LCA)**.

E. Short summary of Part II

In Chapter 5 the study sets out that members of the target group (directly SME's; indirectly government institutions, private sector and industry related organizations in developing countries) that explore the potential of bioenergy are not just interested in information on conversion technologies *per se* but are likely to seek in addition practical information on related issues such as (a) investment and operation costs, (b) suitable equipment suppliers (including retailers, wholesalers, manufacturers and providers) and (c) case studies of reference projects that can serve as showcase. The report's assessment therefore covers these additional information demands too.

First the availability of bioenergy technology information on the **world wide web** (WWW) was explored, adopting a three-step approach: (i) Determining a set of documents that comprehensively cover all relevant bioenergy conversion technologies, (ii) Sourcing precisely these, or similar/equivalent, documents on the Web, (ii) Carrying out a Web search to validate this document set and -in case of persistent information gaps- identifying additional relevant Web resources. Findings are presented at three levels of detail: (i) A long-list with for each conversion technology several highly valued documents with their URL and a short indication of their scope and relevance; (ii) A short-list with for each conversion technology the most highly valued websites and data sources; (iii) A summary table discussing for individual conversion technologies the availability and quality of suitable web resources.

The report concludes that in general the coverage of biomass **conversion technologies** on the Web is very acceptable. The documents found on the WWW or elsewhere that are included in the short-list offer comprehensive coverage of the nine conversion technologies that are the scope of this study. However, very few websites if any cover the full range of conversion technologies. Furthermore, the websites assessed are not specifically focused on developing countries. Thirdly, the assessed websites usually offer limited technical detail. Process diagrams, descriptions of unit operations, energy and environmental performance etc. are hardly ever covered. Finally, the presented technology data (such as e.g. conversion efficiencies) is not always consistent. Table B summarises the assessment of current coverage of bioenergy conversion technology information on the Web.

Table B: Pro's and con's of bioenergy conversion technology coverage on the web

Positive ("pro")	Negative ("con")
The number of existing websites offering bioenergy conversion technology overviews	1. No specific focus on developing countries (in terms of feedstock, technology & financial aspects) 2. For those not directly involved in the bio-energy field it is hard to get a good overview and source needed information
There is a lot of detailed technology information available both on the Internet and in print	1. The information is scattered 2. Inconsistency among information sources
There are various websites presenting possible ways of structuring technology information	Current website structures do not fully match or reflect the unique goal of BIOTUF (focus on SMEs and policy makers in developing countries).

The coverage of information on **costs and economics** of bioenergy plants on the WWW appears rather poor. This is also the case for information on such costs and economics presented elsewhere. Reliable data on investment and operation costs of bioenergy systems are notoriously difficult to source, in part because these costs depend on many different factors and tend to become outdated quickly. This is an important gap in the available information. Information on costs and economics of bioenergy plants is regarded very important for SME's and policy makers in developing countries, in order to be able to explore viable opportunities for bio-energy and determine the most appropriate options.

After investigating to what extent information on **manufacturers and suppliers** of bioenergy conversion technology is available on the Internet, the report concludes that there are only a few web resources that focus on bioenergy suppliers in developing countries. Most likely together these web resources cover only a fraction of the bioenergy equipment suppliers in developing countries.

The fourth item which target group members are likely to seek information on concerns **case studies** of realised bio-energy projects and systems, of a similar nature and in a similar setting, that can serve as flagship projects, success stories, showcases and good practices. A few websites were identified that present such case studies, but these have a strong focus on developed countries, in particular in Europe.

Although within the limited time available only a select portion of the Web could be reviewed the authors of this report believe that the general picture depicted above is unlikely to change much through more detailed web research.

The BioenergyWiki

A website that was given special attention is BioenergyWiki, www.bioenergywiki.net. BioenergyWiki is a very comprehensive collectively authored website on bioenergy related issues. Articles are grouped in one of the following categories: (a) Events, (b) Feedstocks, (c) Glossary, (d) News, (e) Organizations, (f) Policy, (g) Projects, (h) Publications, (i) Regions, (j) Sustainability standards, (k) Technologies and (l) Voices. On closer inspection, BioenergyWiki aims at a rather different target group (concerned citizens in the developed world) than the underlying study. The difference in target group focus is strongly reflected in the information covered.

BioenergyWiki does not cover all relevant conversion routes (e.g. anaerobic digestion is not, or hardly, covered). It contains no information on the economics and viability of biomass conversion. Its searchable organization database lists fewer than 100 companies outside North America; a rather low score. Its project database does not contain any records yet. In summary, although considered usual for a first orientation, the coverage and the level of detail offered by BioenergyWiki is considered too poor for BIOTIP purposes.

In Chapter 6 the report discusses some common ways of presenting biomass conversion technology-related information on the web, including (i) webportals (or gateways), (ii) webpage articles with integrated hyperlinks and (iii) biomass-technology matrices with associated fact sheets. It presents various real case examples of websites and discusses pro's and con's of each presentation method.

In Chapter 7 the report gives recommendations on what role UNIDO could play in setting up a BIOTIP and improving information flows on the application of bioenergy. Box A presents an overview of the recommendations.

The final chapter of the report discusses what a stand-alone BIOTIP, built around the four identified technology-related information categories, could look like.

Box A: RECOMMENDATIONS

General recommendations

- It is recommended that UNIDO develops a Biomass Conversion Technology On-line Information Platform, or BIOTIP, for SME's and policy makers in developing countries.
- It is recommended that the BIOTIP covers four technology-related information categories i.e. (a) Bioenergy conversion technologies, (b) Costs and economics of a bioenergy system, (c) Bioenergy actors, in particular equipment suppliers, (d) Case studies of realised bioenergy projects.
- It is recommended that information for the central part of the BIOTIP is provided by UNIDO itself, in order to be able to provide consistent and well-ordered information specifically aimed at SME's and policy makers in developing countries.
- It is recommended that for detailed information, the BIOTIP uses as much as possible existing initiatives (websites etc.) in each of these four information categories.
- It is recommended that UNIDO uses existing website templates and structures like those adopted by the Bioenergy Wiki www.bioenergywiki.net and the UK Biomass Energy Centre website www.biomassenergycentre.org.uk for inspiration.

On the subject of bioenergy conversion technologies

- It is recommended that UNIDO develops itself an overview of biomass energy conversion technologies that can serve as information tool for SME's and policy makers to assess how biomass can be converted into energy. The underlying study has revealed that a technology overview that focuses on bioenergy application in developing countries does not exist yet.
- It is recommended that the technology information be presented at 2 different levels of detail. On the one hand it shall provide quick but high-quality information on all relevant bioenergy conversion technologies. On the other hand it shall provide more detailed technical information, in order to help the target group members make a concrete step on the path towards the implementation of a bioenergy system. At both levels of detail the technology information presented shall be consistent and transparent.
- It is recommended that the detailed technical information be summarised in 1-2 page technical fiches, or conversion technology summary sheets.

On the subject of bioenergy costs and economics

- It is recommended that the BIOTIP contains a set of simple and robust calculation tools that enable SME's in developing countries to make an initial (preliminary) assessment of the viability of a bioenergy plant
- It is recommended that, when proven effective, these calculation tools be customised at a later stage for use in a specific developing country (taking into account e.g. local financial incentives).

On the subject of bioenergy equipment suppliers

- It is recommended that UNIDO develops an own database of bioenergy equipment suppliers (retailers, wholesalers, manufacturers and providers).
- It is recommended that when developing this database UNIDO initially concentrates on a selection of spearhead countries, where the current status of, or the prospective for, bioenergy development looks good.
- It is recommended that UNIDO develop access to this database in close collaboration with REEEP (the host of the reegle database, www.reegle.info).

On the subject of bioenergy case studies

- It is recommended that UNIDO develops its own database of case studies and success stories on bioenergy projects and plants in developing countries.
- It is recommended that UNIDO builds an initial collection of case studies from existing publications and websites.
- It is recommended that in case existing publications & websites generate insufficient relevant case studies UNIDO develops a set of bioenergy case studies of its own.

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1 INTRODUCTION

1.1 BACKGROUND

The production and use of biofuels have entered a new era of global growth, with both the scale of the industry and the number of countries involved reaching unprecedented levels. Surging investments in biofuels production are being driven by a variety of factors, that include the development of more efficient conversion technologies, the introduction of new government policies, growing international trade and the rising price of oil.

Industry, and more particularly, SMEs, can play a role in biomass flows, where agricultural and forestry commodities are converted into food/feed products, biomaterials, and biofuels. UNIDO's role -in line with its mandate- is to ensure that its client government institutions, private sector and industry related organizations are in a position to take effective and efficient decisions on their biofuels programmes, especially with respect to the selection of available technologies and the steps required to adopt promising technologies currently under development.

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1.2 OBJECTIVE AND SCOPE

The overall objective of BIOTIP is to enable biofuel promotion agencies to advise entrepreneurs to take informed decisions on the selection of appropriate and commercially available biomass conversion technologies by providing ease of access to assessed information.

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The project is organised in two phases, a preparatory phase, which this report covers, and the main implementation phase, which will be initiated based on the findings of the current opportunity study.

The main elements of this opportunity study are:

3. A thorough assessment of existing information sources on commercially available biomass conversion technologies available to developing countries;
4. Recommendations on what role UNIDO could play in improving information flows and how this would best be done.

In addition, this report offers in the opening chapters an introduction to biomass feedstocks, bioenergy conversion technologies and their environmental impacts.

1.3 TERMINOLOGY

From a renewable energy perspective, ***biomass*** can be defined as recent organic matter derived from plants as a result of the photosynthetic conversion process or from animals and which is destined to be utilises as a store of chemical energy to provide heat, electricity or transport fuels. In practice this includes (i) recently living plant material, (ii) agricultural residues including animal manure and crop waste, (iii) all material made directly or as by-product during biomass processing e.g. residues from food, feed, fibre, lumber, and organic fertiliser production, slaughterhouse wastes, black liquor, paper residues, organic fraction of municipal solid waste, sewage sludge, plant oil, and alcohol.

The term ***biofuels*** refers to biomass used as fuel, including processed liquid, solid or gaseous fuels derived originally from biomass.

1.4 READING GUIDE

This report s consists of two main parts. Part 1 (Chapters 2-4) serves as an introduction to biomass feedstocks, bioenergy conversion technologies and their environmental impacts. Part B (Chapters 5-8) covers an analysis of the availability of relevant technology-related information on the Internet and contains a sketch of what contribution UNIDO could make to improve information flows.

Chapter 2 introduces the broad range of biomass resources that are suitable for solid, liquid and gaseous biofuel production, and discusses which conversion technologies are deemed relevant for the target group. The status of each of these relevant conversion technologies is described in Chapter 3. Background and status of the technology, description of commonly used devices, current use in developing countries, main cost factors, and technology-related environmental factors are introduced.

In Chapter 4 various concepts for the environmental assessment of biomass conversion processes are presented. It covers Life Cycle Analysis (LCA) and both sector level and plant level assessment of the environmental impact of bioenergy.

Chapter 5 looks at the availability of bioenergy technology information on the world wide web (WWW). In addition to technical information *sec*, it also covers technology-related issues such as (a) investment and operation costs, (b) equipment suppliers and (c) reference projects. After setting out the adopted Internet search strategy the extent to which technology-related information in each of the identified categories is available on the Web is discussed.

Chapter 6 looks briefly into common ways of presenting biomass conversion technology-related information in each of the identified categories (technology, costs, suppliers and reference) on websites. It presents and discusses various real case examples of websites.

Chapter 7 discusses the degree to which the above information categories are already covered on the Web. It assesses the observed gaps in Internet coverage of biomass conversion technology-related information, and recommends what contribution UNIDO could make to improve information flows.

Chapter 8 discusses what a stand-alone BIOTIP, built around the four identified technology-related information categories, could look like. It discusses a possible structure for a stand-alone BIOTIP, including basic categories and menu items.

2 BIOMASS RESOURCES AND BIOFUEL CONVERSION

2.1 TYPES OF BIOMASS RESOURCES

2.1.1 Biomass resources

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 presented in this report 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).

Openshaw (1998), IEA (1998) and FAO (2004) present examples of different biomass classifications (Annex A). Openshaw (1998) makes a distinction between (a) plant biomass, (b) animal waste and (c) discarded products. Plant materials are the most important types of biomass and can be further subdivided into woody biomass, non-woody biomass, processed waste and proceeds fuels from plant biomass. IEA uses a biomass classification system for statistical purposes and makes a distinction between (a) solid biomass and animal products, (b) gases from biomass and waste, (c) liquids from biomass and waste, (d) industrial waste, (e) municipal waste and (f) charcoal (Denman, 1998). FAO categorises biomass by source and makes a distinction between (a) woody biomass, (b) herbaceous biomass, (c) biomass from fruits and seeds, and (d) other/mixtures. The FAO classification system is discussed in (FAO, 2004) which also contains an evaluation of the need for different classification systems.

For the purpose of BIOTIP, none of these biomass classification systems is very practical. Biomass of very different origin (e.g. forest residues, discarded wood, herbaceous energy crops, and straw) can be converted using precisely the same main conversion technology (e.g. combustion). For this study the FAO classification system is therefore not very suitable.

Using the potential conversion technology as classifier, this study therefore proposes the following classification system (Table 1):

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

2.1.2 Primary and secondary biofuels

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 (FAO, 2004).

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 (FAO, 2004).

2.1.3 Primary and secondary conversion processes

As introduced above, 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.

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 4 presents a list of commercial and emerging devices (engines and turbines) that convert heat into mechanical power (for transport use) and electricity. A simplified illustration of the many possible biomass conversion chains is presented in

Figure 1.

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 ○ biological conversion (fermentation): ethanol (sugar crops, starch crops) ○ biological conversion (enzymatic hydrolysis, fermentation): ethanol (wood) ○ thermo-chemical conversion (FT): ethanol (all solid biomass) ○ thermo-chemical conversion (several processes): methanol (wood, crops, waste) ○ chemical conversion: methanol (biomethane) • Ethers ○ chemical conversion: ETBE (ethanol) ○ chemical conversion: MTBE (methanol) • Plant oils and biodiesel ○ mechanical conversion (extraction): pure plant oils ((oil crops) ○ chemical conversion (esterification): biodiesels (plant oil, waste fat and industrial waste based) • Pyrolysis oils ○ Thermo-chemical conversion: biocrude, bio-oil (all solid biomass) ○ Thermo-chemical conversion (thermal depolymerisation, hydrous pyrolysis): bio-oil (wet biowaste) ○ chemical conversion of bio-oil: various synfuels (syndiesel, syngasoline, synmethanol, syncrude • Liquefaction ○ thermochemical conversion - (FT process (indirect liquefaction via synthesis gas to synfuels): diesel, gasolin, kerosene and other synfuels (all solid biomass, black liquor) ○ thermochemical conversion - Bergius process (direct liquefaction/hydrogenation): various synfuels (all solid biomass) ○ thermochemical conversion – hydrothermal cracking, HTU process etc. (direct liquefaction): various synfuels (wet biowaste, all solid biomass)
Gaseous	• Biogas (and landfill gas ○ biological conversion (anaerobic digestion): methane, hydrogen (biowaste, crops) • Synthesis gas and synfuels ○ Thermo-chemical conversion (gasification) to syngas (wood gas): hydrogen, carbon monoxide, methane (all solid biomass) ○ Thermo-chemical conversion of syngas to synfuels (FT process): methane, LPG, DME • Other ○ Thermo-chemical, electrochemical and biological conversion: hydrogen (wood, crops, waste, water) ○ Chemical conversion: DME (methane, methanol) ○ Thermo-chemical conversion: pyrolysis gas (wood, crops) (wood gas, syngas)

Source: Huttunen & Lampinen, 2005. **Note** on abbreviations used: FT= Fischer-Tropsch, ETBE = Ethyl Tertiary Butyl Ether, MTBE = Methyl Tertiary Butyl Ether, HTU = Hydro Thermal Upgrading. LPG = Liquefied Petroleum Gas (or Liquid Propane Gas). DME = Di-Methyl-Ether.

Table 3 Conversion of primary and secondary biofuels into heat.

Solid fuel combustion	• Fixed grate ○ open fire (3 stones etc.): P < 10 kW, ηth < 10% ○ improved cooking stoves: P < 10 kW, ηth < 40% ○ modern heating boilers: 5 kW-100 MW, ηth < 90% ○ steam generator ○ 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 ○ 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%

Source: Huttunen & Lampinen, 2005. **Note** on abbreviations used: η_{th} = thermal efficiency, η_e = electric efficiency. BFB= bubbling fluidised bed, CFB = circulating fluidised bed

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%

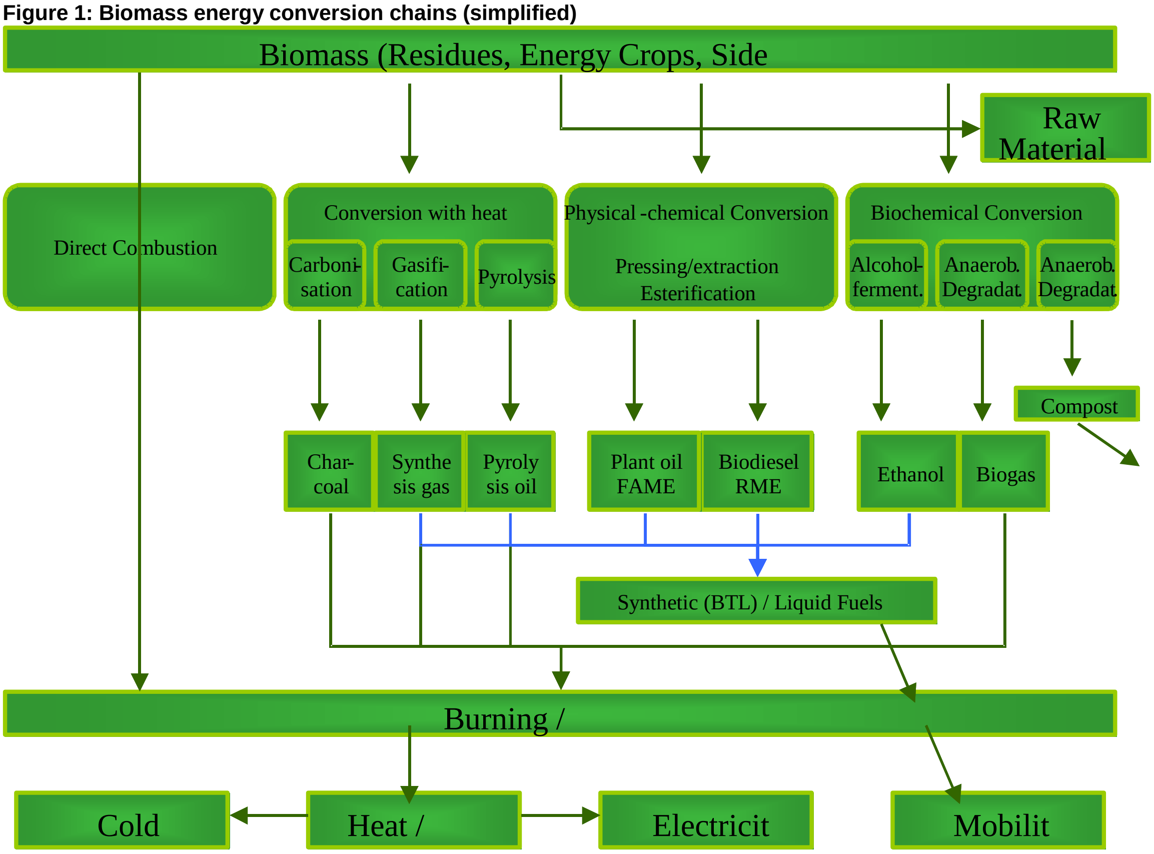
Source: Huttunen & Lampinen, 2005. **Note** on abbreviations used: η_{th} = thermal efficiency, η_e = electric efficiency, ORC = Organic Rankine Cycle.

2.1.4 Selecting relevant conversion technologies

The target group of UNIDO consists of small and medium scale enterprises (SMEs) in developing countries. For application by the target group not all biomass conversion chains are relevant: only those that are technically proven and commercially available are. Likewise, not all capacity classes -small, medium and large- are of relevance. In this study the analysis of bioenergy conversion pathways will be limited to those that are (a) commercially available (b) applicable in the small-to-medium energy demand range[1] and (c) appropriate for use in the target countries.

[1] Defined here as an electricity demand, where applicable, of less than 10 MWe and a total energy demand of less than 50 MW_{th}.

Figure 1: Biomass energy conversion chains (simplified)

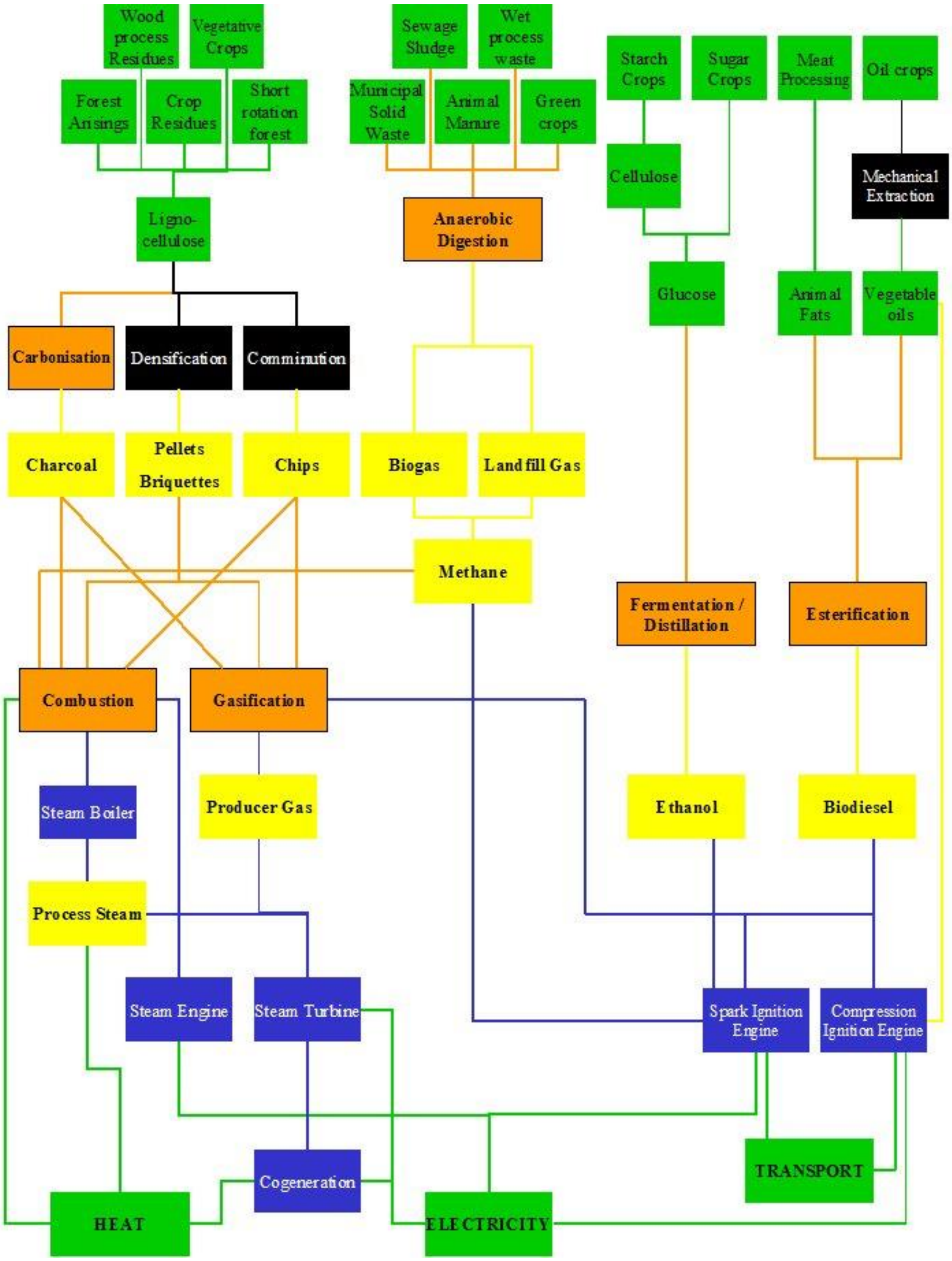


As a result, several emerging technologies that that are not considered commercial and/or conversion devices that can only be applied economically at large-scale will be excluded from further analysis. This concerns, amongst others:

- Pyrolysis and liquefaction
- Biorefineries
- Biomass-to-liquids (BtL) routes
- Cellulosic biomass-to-ethanol production
- Algae-algal biodiesel production
- Stirling engines, micro gas turbines, Organic Rankine Cycle (ORC) turbines, gas turbines

The resulting relevant technologies are presented in Table 5 and graphically depicted in Figure 2.

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



Dark green = primary biofuels,
Black = physical pre-processing,
Orange = primary biofuel conversion processes,
Yellow = secondary biofuels,
Blue = secondary biofuel conversion processes
Green = usable form of energy.

Table 5 Commercial bioenergy technologies, small-to-medium scale range

Energy product	Technology	Bioenergy resource
Direct heat	All fixed bed stove 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

Source: Based on Huttunen & Lampinen, 2005. **Note *)**: Not mentioned, but briefly discussed in this report, is the further conversion of ethanol into gelfuel for use in cooking stoves.

The conversion routes listed in Table 5 are further discussed in the next chapter.

3 BIOMASS CONVERSION PROCESSES

This Chapter discusses the main four categories of primary bioenergy conversion processes, including:

- Mechanical processes (e.g. comminution, densification, extraction)[2];
- Thermo-chemical processes (e.g. combustion, gasification, carbonisation);
- Biological processes (e.g. anaerobic digestion, ethanol fermentation);
- Physical-chemical processes (e.g. esterification, i.e. biodiesel production).

Rather than providing a lot of technical detail, this chapter presents an introduction on each conversion technology, covering background and status of the technology, description of commonly used devices, current use in developing countries, main cost factors, and technology-related environmental factors[3]. This chapter is primarily based on (Kartha et al, 2005), a report of the Stockholm Environmental Institute published by the Energy Sector Management Assistance Program (ESMAP) of the World Bank.

Annex B presents two examples of a more detailed coverage of technical information on conversion processes, covering biomass combustion and ethanol production respectively.

3.1 MECHANICAL PROCESSES (PHYSICAL PRE-PROCESSING)

3.1.1 Comminution (sizing)

Comminution involves the reduction of biomass by mechanical means into a higher valued and relatively uniform bulk material that potentially allows more convenient handling, transport and storage. There are a range of devices available to reduce biomass of different kinds to small pieces for convenience of handling, volume reduction or as a suitable feed for conversion processes. Comminution can be achieved by using a sharp cutting edge to cleave or shear the biomass (commonly wood) into engineered particles (chipping, chunking), or by using blunt impacting tools to crush or shred the material producing particles of indistinct geometry (hogging, shredding). Basic *chipper* designs include disk chippers, drum chippers and screw chippers. Each type has different strengths and weaknesses. *Shredders, grinders and mills* can be high power, high throughput units, suitable for handling low quality, mixed material, particularly if it might be contaminated with stones or soil. Common types of shredders and grinders include: shredders, hammer mills, tub grinders and stump grinders.

3.1.2 Briquetting (densification)

Biomass densification, or "briquetting", is the process of compacting loose biomass feedstocks into a uniform dense form, producing a higher quality fuel. Better and more consistent thermal and physical qualities than raw biomass allow for more complete combustion of briquettes, providing greater efficiency, reduced emissions, and greater

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2 Mechanical processes are sometimes grouped under biomass pre-treatment processes. They are included here because (unlike other pre-treatment steps such as drying, transport and storage) they represent processes that ***convert*** biomass into biofuel.

3 Examples of technology providers are not included (yet).

control for residential or industrial applications. Briquettes offer easier transport and storage, and easier mechanical handling.

Briquettes can be efficiently produced using relatively simple technologies. Stalks, husks, bark, straw, shells, pits, seeds, sawdust -virtually any solid organic byproduct of agricultural or silvicultural harvesting- can be used as feedstock. Biomass can also be briquetted along with other fuels such as coal. Biomass wastes with relatively low moisture contents (<15%) are most suitable for efficient production of briquettes.

Grover & Mishra (1996) identify 3 classes of briquetting technologies:

- Low-pressure compaction with a binder
- Medium-pressure compaction with a heating device
- High- pressure compaction

High-pressure briquetting technologies include piston presses (with either mechanical or hydraulic drive), screw extruders (with or without die heating) and rotary ring die presses. The latter technology is used to produce pellets, which are smaller (6-8 mm diameter) than briquettes (30-100 mm).

Briquettes are primarily produced commercially for specific industrial niche markets. Only in a few countries do biomass briquettes currently compete successfully with fuelwood or other unrefined biomass products (such as cow dung) for household cooking or heating. Generally, briquette production is economically viable only with biomass wastes that are free (or negative cost). Table 6 shows the typical range for various production costs across several countries. Assuming feedstocks are free, production cost generally runs between US$20 to US$36 per tonne of biomass briquettes. In Brazil, low electric costs and an abundance of sawmill wastes keep the cost of production at large briquetting plants at the lower end of this range. In some regions of India and African where fuelwood costs are higher than average, briquette sales to households are viable. However, in many other countries, this range is sufficiently higher than the local price of fuelwood that briquettes have not been able to penetrate the market.

Table 6 Typical non-fuel cost components for briquette production

Cost item	US$/tonne
Capital charge	9-12
Labour	3-5
Maintenance	3-8
Electricity	3-7
Raw materials	1-4
Taxes, material transport & miscellaneous expenses	>1

3.1.3 Mechanical extraction

Mechanical extraction is used to produce oil from oil plants. Over 300 crops can be used in fuel oil production. The suitable plants include e.g. coconut, cottonseed, groundnut, palm, rapeseed, soybean and sunflower. There are two alternative extraction technologies: mechanical pressing and solvent extraction. Solvent extraction is more effective, but it requires relatively large units and sophisticated technology, compared to mechanical extraction.

There are two fundamental production processes types for mechanical pressing. The common way in oil extraction is the treatment of feedstock in centralised industrial scale plants but small-scale pressing is also possible. In small-scale cold pressing facilities, cleaned oil seeds are exclusively mechanically pressed at maximum temperatures of 40^oC. Suspended solids are removed by filtration or sedimentation. As a co-product the press cake is left, with a remaining oil content of usually over 10%, which is used as a protein-rich fodder. Due to its higher production costs, the decentralised oil production by farmers is not widely applied today, although the chance of additional income for farmers is given.

Vegetable oil is primary used for human consumption, as animal fodder or for soap making, rather than for energy generation. Its use in pure form (pure plant oil, PPO) in Diesel engines is possible but rare due to the high viscosity of vegetable oils requiring engine modifications. It is easiest used in large engines, like buses and trucks, where only oil preheating needs to be installed. Kits are on the market to convert light Diesel vehicles for PPO use. After such conversion the vehicle can utilise PPO, diesel and biodiesel in any mixtures (Kartha et al, 2005). Under specific conditions PPO can be a promising option for rural decentralised electrification. In Samoa, a Pacific island country, power utility EPC is considering the construction of a coconut-based power unit at its Savai'i power station.

The customary way of utilising vegetable oil as a source of energy is in the form of biodiesel requiring chemical conversion called (trans-)esterification. This is discussed in Section 3.4.1.

3.2 THERMO-CHEMICAL PROCESSES

Thermo-chemical conversion can be done by combustion, gasification, carbonisation, pyrolysis or liquefaction. These processes are applicable to all forms of biomass, including wood. Combustion technologies are most widely used and mature technologies. Gasification and pyrolysis are becoming more and more important. Liquefaction is currently rarely used but it also has a long commercial history.

3.2.1 Combustion

Direct combustion is the most common way of converting biomass to energy - both heat and electricity - and worldwide it already provides over 90% of the energy generated from biomass. It is well understood, relatively straightforward, commercially available, and can be regarded as a proven technology. Compared to the other thermo-chemical primary conversion technologies it is the simplest and most developed, and biomass combustion systems can easily be integrated with existing infrastructure.

Combustion of solid biomass like wood can be used for direct heating purposes in all size classes, from single-family homes to large centralised heating systems. For heating-only use it is the simplest and cheapest technology. For power production it can be used in principle in all size classes, but commercial technology starts from about 50 kW_e.

The predominant route for power production from biomass is based on steam turbine technology. Biomass is burned in a combustion boiler to heat water and raise steam, which is expanded through a turbine to generate power. Typically, biomass systems range from a single megawatt to tens of megawatts. Essentially the same technology is used to generate power from coal, making the steam turbine a foundation of the global electric sector. It is a mature and widely disseminated technology, having been commercially available for more than 100 years.

Combustion boilers are available in different designs depending on application and biomass characteristics. The main technological options are to burn the biomass on a grate (either fixed or moving), or to fluidise the biomass with air or some other medium to provide even and complete burning. Annex B discusses the main technological options in some detail.

Steam turbine designs also vary depending on the application. To maximise power production, “condensing” turbines are used, wherein steam is cooled and expanded to sub-atmospheric pressures. For combined heat and power (CHP) applications, “back pressure” turbines are generally used, which provide steam at temperatures and pressures higher than ambient conditions.

Box 1: Steam turbines

Steam turbines are suitable for applications in a wide size range from 0.5 to 1500 MW_e. Currently the largest biomass application is 240 MW_e/560 MW_{th}. The technology is suitable for thermal power generation as well as for CHP plants. The basic steam cycle is based on the closed Rankine cycle. The heat generated in a combustion process is used to produce high pressure (100 – 300 bar) steam in a boiler and a superheater. The steam is superheated in order to increase efficiency and to achieve dry steam. Then the steam is expanded through an expansion engine, i.e. turbine, and it delivers mechanical power to drive a generator. In conventional steam cycles, water is used as the working medium.

For large steam turbine plants, water tube boilers and superheaters can be used to enable high steam parameters and the use of multi-stage turbines. Process measures like feed water preheating and intermediate tapping can be implemented for efficiency improvement. This results in electricity efficiencies of around 25% in plants of 5 to 10 MW_e. In plants around 50 MW_e and larger, up to more than 30% is possible in cogeneration mode and up to more than 40% if operated as condensing plant. In partial load the efficiency decreases.

For small-scale steam turbines only single expansion stage or few expansion stages can be used. The operation occurs at quite low steam parameters as a result of the application of firetube boilers. Plants smaller than 1 MW_e are usually operated as backpressure CHP plants and electricity net efficiencies are typically 10% to 12%. The backpressure heat can be used as process heat. Partial load decreases the efficiency considerably.

Most biomass fired steam turbine plants are located at industrial sites that have a ready supply of biomass available. At such sites, waste heat from the steam turbine can be recovered and used for meeting industrial heat needs, which enhances the economic attractiveness of such plants.

Compared with the installed capacity in the industrialized countries, there is relatively little biomass electric generating capacity installed in developing countries, due in part to institutional barriers that keep agricultural policy distinct from energy policy and in part to chronic difficulties in acquiring financing for capital-intensive agro-industrial investments. The most significant installation of steam turbine capacity in developing countries is at factories making sugar and/or ethanol from sugarcane. Over 80 developing countries grow and process sugarcane. Each factory (except those using very low technology sugar refining processes, such as open vat boiling) typically includes a steam turbine CHP system fuelled by bagasse, the fibrous biomass residue from crushing sugarcane.

The costs of steam turbine systems vary widely depending on the type of turbine, type of boiler, the pressure and temperature of the steam, and other factors. Biomass steam turbine systems generally are designed to reduce capital costs at the expense of efficiency. For example, biomass fired systems are typically designed with relatively low steam pressures and temperatures, which enables lower grade steels to be used in boiler tubes. Also, less air or water preheating might be used in order to eliminate heat exchangers. However, even with such cost reducing measures, capital costs for small-scale systems are still substantial and lead to relatively high electricity generating costs compared with conventional fossil energy power plants.

Biomass steam turbine systems raise certain environmental issues, including the potential for particulate emissions to the air. Flue gas filtration systems are required to minimise these. Ambient temperature air or water is used to cool the condenser in biomass steam cycles. If the reservoir of water or air available for cooling is not sufficiently large, thermal pollution may result. Ash generated during combustion contains much of the inorganic minerals found in the original biomass. Ideally, the ash would be returned to the soil. In many cases, it is sent to a landfill (Kartha et al, 2005).

Box 2: Steam engines

Steam engines are available in the power range 50 kW_e to 1 MW_e. They can be used in small plants where steam turbines are not available or in medium-scale plants as an alternative to steam turbines. The advantage of steam engine in comparison to steam turbine is that they are less sensitive to water droplets in the outlet, or contaminants in the steam, and that they can be operated with low-pressure, saturated steam (but this reduces efficiency). Steam piston engines enable efficiencies of 6-10% in single-stage and 12-20% in multi-stage mode. The efficiency is almost independent of the partial load. A disadvantage is the need for oil injection into the steam for lubrication before it enters the engine and there is a possibility for oil traces in the expanded steam (oil free engines are under development). Steam engines are also often noisy and they produce heavy vibrations.

3.2.2 Gasification

Like direct combustion, gasification is a high-temperature thermo-chemical conversion process, but the desired result in this case is the production of a combustible gas, instead of heat. This is achieved through the partial combustion of the biomass material in a restricted supply of air or oxygen, usually in a high-temperature environment of around 1200-1400 ^oC. The product of gasification - producer gas – contains CO, CO_2, H_2O, H_2, CH_4 and other hydrocarbons. After appropriate treatment, biomass derived gas can be burned directly for cooking or heating, can be converted to electricity or mechanical work in a secondary conversion device such as an internal combustion engine, or can be used as a synthesis gas for producing higher quality fuels or chemical products such as hydrogen and methanol.

Biomass gasification is technically analogous to coal gasification. Gasified coal was widely used in Europe and the United States until the mid 1900s for urban domestic cooking and heating. This so called "town gas" is still used in many urban areas of developing countries, including India and China. In the 1960s and 1970s, large-scale coal gasification technologies were developed and commercialised for producing fuel and synthesis gas. Producer gas from wood charcoal was a prominent civilian fuel in Europe during World War II, when it was used to run several hundred thousand vehicles.

After the first oil price shock in 1973, crash attempts were made to resurrect and install gasifier/engine systems for electricity generation from raw biomass, especially in remote areas of developing countries. Most of these systems encountered technical problems arising from the condensation of tars on downstream equipment, and by the end of the 1980s, commercialisation of gasifier/engine technology was once again virtually abandoned.

One response to the problems related to tar formation is to use charcoal, as opposed to raw biomass. Charcoal does not produce significant levels of tar, because most of the compounds with tar forming potential are removed when raw biomass is made into charcoal. Gasifier engine systems used during World War II functioned satisfactorily, because they primarily used charcoal. A main drawback, however, is that a substantial fraction of the energy in the original raw biomass is lost in the process of converting it to charcoal. A second drawback is that charcoal is more costly than raw biomass.

A second response to the problems related to tar formation has been the continued technological advancement in gasification and gas cleanup systems. In the past decade, a number of gasifier and gas cleanup designs have been developed that largely eliminate tar production and related technical problems. Transferring these research findings into commercial products is ongoing, and interest has resurfaced in gasification as a village scale source of electricity. Unlike in earlier gasification efforts, a growing number of companies worldwide now offer systems with warranties and performance guarantees. In comparison with charcoal gasifier systems, these systems entail somewhat more complicated gas cleanup and correspondingly higher system costs and maintenance requirements.

Gasification conversion technology is state of the art but product gas is partly characterised by undesired ingredients. Small gasifiers coupled to diesel or gas engines (typically 100-200 kW_e systems with an electrical efficiency of approx. 15-25%) are commercially available on the market. In India successful implementation has been achieved, with some 10 manufacturers offering power gasifiers for power levels up to 1 MW_e. Also China, Brazil, Latin America, Thailand, and Cambodia are turning increasingly to biomass power plants and gasifiers.

The cost of delivering fuel gas, electricity, or shaft power with a gasification-based system varies with the characteristics and requirements of a specific application. Capital investment is an important cost factor in all cases, especially where the capacity utilisation rate is relatively low. Operator costs are also important. When electricity is produced using a dual fuel (producer gas + diesel) engine, the cost of the diesel fuel generally is an important cost component as well. With sufficiently high capacity utilisation gasifier-engine generated electricity is easily competitive with stand-alone small-scale diesel generation.

At a biomass gasification facility, environmental emissions of potential concern are primarily liquid effluents from the gas cleanup system. Tar contaminated liquid effluent contains carcinogenic compounds such as phenols and thus requires appropriate treatment before discharging to the environment. Leakage of poisonous and odourless carbon monoxide, at the conversion facility and at points of gas use (for example, cooking stoves), is an additional danger. Other gaseous pollutant emissions are small in comparison with emissions from direct combustion of solid fuels. The solid residue from gasification of most biomass types is an inert inorganic material that has some by-product value as, for example, a mineral fertilizer or as a construction material (as is the case with rice husk ash) (Kartha et al, 2005).

Annex C summarises core technical information on biomass gasification in the form of a technical fiche.

3.2.3 Carbonisation (charcoal production)

Charcoal is a higher quality fuel than raw biomass. It is extensively used as a cooking fuel, especially in urban areas where free alternatives such as collected fuelwood and agricultural residues are unavailable. Charcoal fires are more controllable and more convenient for cooking. They are relatively smokeless and generate less indoor air pollution than do raw biomass fires. Because charcoal has a higher energy density (by nearly a factor of two) than raw biomass and keeps better, it is more easily stored and cheaply transported, increasing its economic transport distance. This makes it more easily supplied to urban areas where high population densities necessitate the import of fuel from distant sources. As a market commodity that must be purchased by households, charcoal is most commonly in use where raw biomass fuel cannot be collected free. Charcoal is also used in some industrial applications, the most notable of which is the Brazilian iron sector, which uses charcoal (mostly from wood grown in government run tree plantations) in place of coke in smelting furnaces.

Despite the fact that charcoal stoves can be more efficient than raw biomass stoves, the lifecycle efficiency is lower because of the relatively inefficient process of producing charcoal from raw biomass. Using charcoal therefore consumes more of the biomass resource. Charcoal is typically produced using a simple, traditional process that has changed little over the centuries. Wood or other biomass feedstock is heated slowly in an enclosed space with insufficient oxygen for complete combustion. This releases water and volatile compounds from the biomass through a form of pyrolysis, leaving behind primarily carbon. The most widely used method for producing charcoal is to enclose slowly burning raw biomass for a period of days to months in a simple kiln made of either a shallow pit or an earthen mound. This traditional method requires only local materials, can be built onsite, and entails minimal cost, but is subject to gross inconsistency in the quality of the product. Efficiencies are generally low and variable; they rarely exceed 25% on an energy basis. Airborne emissions of volatile organic compounds are high, and there can be substantial production of toxic liquid residues.

Major improvements in charcoal production are attainable. Improved practices based on better understanding and control of the carbonisation process can considerably improve efficiencies with no additional capital investments. Practices that have been successfully demonstrated in the field include more thorough feedstock drying, better stacking methods, improved air control, and more regular monitoring.

Further improvements can be attained using charcoal kilns with more sophisticated designs. These rely on more skilled construction and materials such as clay, bricks, or steel, and design improvements such as an external downdraft chimney.

In combination, improved practices and improved designs can increase charcoal production efficiencies by a factor of two or more compared with traditional, non-optimised methods. They also produce a higher quality charcoal that is more consistent and less contaminated by earth and stones (Kartha et al, 2005).

3.3 MICROBIOLOGICAL BIOMASS CONVERSION

Microbiological conversion means a process where micro-organisms produce useful biofuels out of long-chain primary biomass. Two such processes are widely used, and have been used for millennia: anaerobic digestion (acid fermentation) and alcohol fermentation. Both processes are possible from single-family houses up to large centralised production units.

3.3.1 Anaerobic digestion for biogas production

Anaerobic digestion is the low temperature or biological process through which combustible gas can be produced from biomass. The gas produced by anaerobic (that is, without air) digestion is called biogas. Like producer gas from thermal gasification it can, after appropriate treatment, be burned directly for cooking or heating, or it can be used in secondary conversion devices such as internal combustion engines for producing electricity or shaft work. The main application for which biogas systems have been disseminated in developing countries is to supply cooking fuel for households, and there is considerable scope for further diffusion.

Biogas generally is 60% methane and 40% carbon dioxide. Almost any biomass except lignin (a major component of wood) can be converted to biogas: animal and human wastes, sewage sludge, crop residues, carbon laden industrial processing by-products, and landfill material have all been widely used. High moisture feedstocks are especially well suited for anaerobic digestion.

In developing countries the use of biogas for household and lighting is becoming common in areas with appropriate climates, sufficient animals to provide dung as feedstock, and access to low-cost capital funds to build the digesters. Millions of small-scale digesters are installed in China and India and several thousand units are operating in other developing countries, most notably South Korea, Brazil, Thailand, and Nepal. The technology is simpler than used in the large-scale facilities widely used in industrialised countries, for example, not involving a heating system and relying on manual feedstock preparation. This results in lower biogas yields, higher operating costs per unit energy, and low or zero production during the cold season. Community-scale facilities in which one plant supplies gas to many households are used in several Asian countries, including China, although experience has been mixed. Large-scale plants are also in use at pig farms and other facilities with concentrated feedstock availability.

An estimated 5,000 digesters are installed in industrialised countries, primarily at large livestock processing facilities (stockyards) and municipal sewage treatment plants. An increasing number of digesters are located at food processing plants and other industrial facilities. Most industrial and municipal digesters are used predominantly for the environmental benefits they provide, rather than for their fuel production.

The cost of delivering fuel gas, electricity, or shaft power with a biogas system varies with the characteristics and requirements of a specific application. However, capital investment is an important cost factor in all cases, especially where the capacity utilisation rate is relatively low. Operator costs are also important.

Large-scale industrial digesters have much lower costs per unit of gas production than do small digesters, in part because throughput rates are much higher. A recent estimate of the total cost of methane from a large scale digester (300,000 GJ/year capacity or larger) with a typical industrial feedstock is less than $2/GJ (less than $0.07 per litre of diesel equivalent) under European conditions and about $1/GJ under Brazilian conditions. Large-scale digesters have thus become competitive with conventional fossil fuel options for grid connected power generation applications.

Compared with other biomass energy conversion technologies, anaerobic digestion has important, direct non-energy benefits, which include pathogen destruction and production of a natural, nutrient rich fertiliser. For example, the slurry from a cattle dung digester contains essentially the same amount of nitrogen as the input dung, but in a form that is more readily usable by plants. Furthermore, dried digester effluent contains about twice the nitrogen of dried cattle dung, because more nitrogen is lost from dung than from digester effluent during drying. Digestion also provides for environmental neutralisation of wastes by reducing or eliminating pathogens and by reducing the high chemical oxygen demand (COD) or biological oxygen demand (BOD) of feed materials.

Some precautions are needed in using biogas, particularly for household cooking. Biogas is not toxic, but an accumulation of gas in a closed living space presents explosion and asphyxiation risks. In practice, safety has not been a problem in the vast majority of cases where biogas has been used (Kartha et al, 2005).

Landfill gas (LFG) was first used as a fuel in the late 1970s, and the number of LFG energy recovery schemes exceeds 600. It is widely adopted throughout the EU and North America and increasingly deployed in other world regions.

3.3.2 Alcohol fermentation for ethanol production

Ethanol is a clean-burning alcohol fuel that is traditionally made from biomass. Two varieties of ethanol are produced from biomass today: anhydrous ethanol (100% ethanol) and hydrous ethanol (containing about 5% water). Anhydrous ethanol can be blended with gasoline for use in standard gasoline fuelled engines, up to a maximum ethanol content of about 25%. Hydrous ethanol cannot be blended with gasoline, but can be used alone as a fuel (neat fuel) in internal combustion engines specifically designed for ethanol.

A more recently explored ethanol based option is ethanol gel, a clean burning fuel consisting of gelatinised ethanol bound in a cellulose thickening agent and water with a heating value of 22.3 MJ/kg. Cookstoves specially designed for use with ethanol gel have been developed in the last few years, as have ethanol gel burners that can be retrofitted into several traditional African cooking stoves. Used in such appliances, ethanol gel is a highly controllable, easily lit cooking fuel with high turndown (ratio is approximately six) and a heating efficiency of roughly 40%. Initial market penetration has occurred in Zimbabwe (since 2000) and South Africa, with the establishment of 80,000 liter/month and 30,000/month production facilities, respectively.

Ethanol is produced by fermentation and distillation from sugars (sugar cane, molasses), starches (cassava, corn) and cellulose (wood, agricultural residues). Sugars are most appealing, since they already contain the simpler sugar forms, glucose or fructose. The crops used for ethanol production vary by region, including sugar cane in Costa Rica and Brazil, grain and corn (maize) in North America, grain and sugar beets in France, and surplus wine grapes in Spain. If woody and fibrous biomass is used, the cellulose has to be hydrolysed into sugars before fermentation. This technology is being demonstrated in e.g. Sweden. Ethanol can be produced in all size classes, from individual households to centralised industrial plants. Annex B discusses the conversion processes in somewhat more detail.

Sugarcane is grown in over 80 developing countries, and generally the most efficient and cost effective source of ethanol today. Production costs are among the lowest in the world in the state of Sao Paolo in Brazil, because of the large scale of production, the relatively low cost of labour, and the emphasis placed on cane varieties and cultivation practices to maximise yield. In Sao Paolo the cost of the sugarcane feedstock accounts for over half of the ethanol production costs.

A promising strategy for improving the competitiveness of cane ethanol is to make more energy efficient use of the bagasse and cane trash (tops and leaves). By reducing distillery energy demands and adopting more efficient biomass cogeneration technology, onsite energy demands can be met while producing a surplus of electricity for export and sale to the national grid. The tops and leaves of the cane could be collected and used in the non milling season to allow year round electricity generation, and the electricity revenue could be credited against ethanol costs. Such strategies are increasingly being considered by both ethanol and sugar producers.

Ethanol can be blended with gasoline or used as pure fuel in ethanol powered Otto engines. The technology of ethanol production from sugar and starch crops is already developed to a large extent. Conversion of lignocellulosic biomass is not available on a commercial scale yet.

Producing sugarcane, converting it to ethanol, and using it in vehicles all present environmental challenges, including how to maintain soil productivity and how to prevent water contamination and air pollution (Kartha et al, 2005).

3.4 PHYSICAL-CHEMICAL BIOMASS CONVERSION

3.4.1 (Trans)esterification for biodiesel production

The term biodiesel generally refers to methyl esters (sometimes called “fatty acid methyl ester”, or FAME) made by transesterification, a chemical process that reacts as feedstock oil or fat with methanol and a potassium hydroxide catalyst. The feedstock can be vegetable oil, such as that derived from oilseed crops (e.g. soy, sunflower, rapeseed, cottonseed, jatropha etc.), used frying oil (e.g. yellow grease from restaurants) or animal fat (beef tallow, poultry fat, pork lard). In addition to biodiesel, the production process typically yields as co-products crushed bean “cake”, an animal feed, and glycerine.

Chemical properties and performance characteristics of biodiesel are very similar to petroleum based diesel fuel. Biodiesel fuel is non-toxic, biodegradable, and lower emitting than ordinary diesel fuel. It can readily replace or be blended with diesel fuel or heating oil in standard diesel engines and boilers, requiring very few, if any, equipment modifications. It can also be used in vehicle diesel engines, either in its 100% “neat” form or more commonly as a 5%, 10% or 20% blend with petroleum based diesel.

Biodiesel from fatty acid methyl esters (FAME) can be produced by a variety of esterification technologies, though most processes follow a similar basic approach. First the oil is filtered and pre-processed to remove water and contaminants. If free fatty acids are present, they can be removed or transformed into biodiesel using pre-treatment technologies. The pre-treated oils and fats are then mixed with an alcohol (usually methanol) and a catalyst (usually sodium or potassium hydroxide). The oil molecules (triglycerides) are broken apart and reformed into esters and glycerol, which are then separated from each other and purified. The resulting esters are biodiesel.

Biodiesel production technology is available at a wide range of scales, and can be produced in large oil refinery sized plants or at the village level using simple technology. It is fairly expensive to produce biodiesel, with feedstock cost making up the bulk of the production costs. A recent study from the State of Western Australia (2006) suggests that production cost can range from as low as 47 cents US$ (63 cents Aus$) if manufactured from palm oil in a large scale plant up to 142 cents US$ (190 cents Aus$) per litre using canola oil as feedstock in a small-scale plant. Compared with some of the technologies being developed to produce ethanol and other biofuels, the biodiesel production process involves well-established technologies that are not likely to change significantly in the future.

As biodiesel fuel is non-toxic, biodegradable, and lower emitting than ordinary diesel fuel, it can help to reduce smog precursors and particulate matter in areas where diesel fuel combustion contributes significantly to air pollution. It also produces lower greenhouse gas emissions than fossil fuels such as diesel (Kartha et al, 2005).

4 ENVIRONMENTAL ASSESSMENT OF BIOMASS CONVERSION

4.1 INTRODUCTION

Environmental impact assessments of different types, scope and coverage exist. Life Cycle Assessment (LCA) is generally regarded as the most complete and thorough method to assess the environmental impacts of a product or a method of production. Policy makers can use LCA to determine the effects of policy actions. For example, the Dutch government has used LCA extensively to determine best practices for management of diverse types of biomass and waste, like kitchen and garden waste.

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).

In the next section general information on Life Cycle Analysis is presented, followed by examples of typical sector studies related to bioenergy and information on environmental impacts. In the third section attention is paid to environmental assessments needed for permit application and for sustainability certification.

4.2 LIFE CYCLE ANALYSIS

In ISO 14040 LCA is defined as the *"compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle"*. Thus, LCA is a tool for the analysis of the environmental burden of products at all stages in their life cycle – from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (in effect, therefore, 'from the cradle to the grave').

LCA is a core topic in the field of environmental management. Its history goes back to the early seventies. SETAC (the Society of Environmental Toxicology and Chemistry) was the first international body to act as an umbrella organisation for the development of LCA. It is a scientific organisation with its roots in academia, industry and government and, as such, has been able to offer a science-based platform for the coherent development of LCA as a tool.

ISO (the International Organization for Standardization) is a worldwide operating private organisation, including national bodies from both industrialised and developing countries, which aims to standardise a wide range of products and activities. One of its key activities is the development of the 9000 series of standards, which is aimed at the integration of quality aspects into business practice. The 14000 series of ISO standards includes the standard 14001 on Environmental Management Systems, as well as a series of standards relating to LCA (the 14040 series). These ISO activities began in 1994 and aim to produce the first complete series of LCA standards. The following general standards and technical reports have been or are being produced by ISO in the 14040 series:

- ISO 14040: A standard on principles and framework. 1st Edition 1997
- ISO 14041: A standard on goal and scope definition and inventory analysis. First Edition 1998
- ISO 14042: A standard on life cycle impact assessment. 1st Edition 2000
- ISO 14043: A standard on life cycle interpretation. 1st Edition 2000

ISO has played a major role in bringing together the different schools of LCA, by requiring agreement on every single word of the different standards. The international standards and additional technical reports have also greatly enhanced the acceptance of LCA as a tool for decision support by both industry and government. The Dutch CML is active in LCA development and published *LCA - An operational guide to the ISO-standards (Guinée et al.)* in three downloadable reports, see http://www.leidenuniv.nl/cml/ssp/.

A third international player in the field of LCA is UNEP (the United Nations Environmental Programme), represented by its Department of Technology, Industry and Economics in Paris. UNEP's focus is mainly on the application of LCA, particularly in developing countries. An important contribution was the publication in 1996 of UNEP's user-friendly and easy-to-read guide to LCA, entitled *Life Cycle Assessment: What it is, and what to do about it*. A second publication of interest is Towards Global Use of Life Cycle Assessment, published in 1999. Several introductory and more detailed guidelines and reports can be found on their website: http://lcinitiative.unep.fr/.

Phases of an LCA

LCA's generally are carried out in four phases:

1. Goal and Scope Definition, the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined;

2. Inventory Analysis of extractions and emissions, the energy and raw materials used, and emissions to the atmosphere, water and land, are quantified for each process, then combined in the process flow chart and related to the functional basis;
3. Impact Assessment, the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance;
4. Interpretation, the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

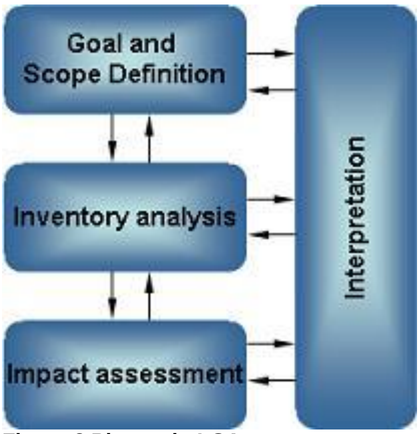

Figure 3 Phases in LCA

Ad 1. The Goal and scope definition is the phase in which the initial choices which determine the working plan of the entire LCA are made. The goal of the study is formulated in terms of the exact question, target audience and intended application. The scope of the study is defined in terms of temporal, geographical and technological coverage, and the level of sophistication of the study in relation to its goal.

Ad 2. The Inventory analysis is the phase in which the product system (or product systems if there is more than one alternative) is defined. In this context, defining includes setting the system boundaries (between economy and environment, with other product systems, and in relation to cut-off), designing the flow diagrams with unit processes, collecting the data for each of these processes, performing allocation steps for multifunctional processes and completing the final calculations. Its main result is in an inventory table listing the quantified inputs from and outputs to the environment associated with the functional unit, in terms of kgs of carbon dioxide, mgs of phenol, kgs of iron ore, cubic metres of natural gas, etc.

Ad 3. Life Cycle Impact Assessment (LCIA) is the phase in which the set of results of the Inventory analysis – mainly the inventory table – is further processed and interpreted in terms of environmental impacts and societal preferences. To this end, a list of impact categories is defined, and models for relating the environmental interventions to suitable category indicators for these impact categories are selected. The actual modeling results are calculated in the characterisation step, and an optional normalisation serves to indicate the share of the modeled results in a worldwide or regional total. Finally, the category indicator results can be grouped and weighted to include societal preferences of the various impact categories.

Ad 4. Life Cycle Interpretation is the phase in which the results of the analysis and all choices and assumptions made during the course of the analysis are evaluated in terms of soundness and robustness, and overall conclusions are drawn. The main elements of the Interpretation phase are an evaluation of results (in terms of consistency and completeness), an analysis of results (for instance, in terms of robustness), and the formulation of the conclusions and recommendations of the study.

Lifecycles can cover a lot of issues like for instance: energy use, carbon dioxide emissions, depletion of abiotic & biotic resources, land competition, loss of biodiversity, desiccation, climate change, stratospheric ozone, human toxicity, marine ecotoxicity, terrestrial ecotoxicity, freshwater sediment ecotoxicity, acidification, eutrophication, waste heat, malodorous air & water, noise, etc.

According to (CML 2001) reporting on an LCA is likely to result in a main report of 20-80 pages, accompanied by annexes with process data and specific characterisation factors, comprising some 50-500 pages, depending on the goal and scope of the LCA.

4.3 ENVIRONMENTAL IMPACTS OF BIOENERGY – SECTOR LEVEL

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.

To give an example, Elsayed (2003) performed an extensive analysis of the greenhouse gas savings of a number of bioenergy options for the UK. Key results are shown in Figure 4. The figure provides a general impression of GHG savings, but care should be taken that for individual cases the situation can be different, and that assumptions made need to be carefully analysed. In particular assumptions on the use of fertilisers can have considerable impact on the outcome of the study, as fertiliser production is energy intensive and the use of N- fertiliser can lead to emissions of N_2O, a strong greenhouse gas.

Especially in the transport sector, a wealth of well-to-wheel analyses is available to show the effects of introducing biodiesel and bio-ethanol from various crops & technologies. A recent rather complete analysis coordinated by the European Commission’s Joint Research Centre is the *Well-to-wheels analysis of future automotive fuels and powertrains in the European context*, see http://ies.jrc.ec.europa.eu/WTW. This type of sector-level studies is mainly used to support policy-making processes.

Selected Biofuel Technology	Energy Requirement (MJ/MJ)	Carbon Requirement (kg CO_2/MJ)	Methane Requirement (g CH_4/MJ)	Nitrous Oxide Requirement (g N_2O/MJ)	Total Greenhouse Gas Requirement (kg eq CO_2/MJ)
Biodiesel from oilseed rape	0.437 ± 0.024[a]	0.025 ± 0.001[a]	0.028 ± 0.002[a]	0.048 ± 0.006[a]	0.041 ± 0.002[a]
Biodiesel from recycled vegetable oil	0.188 ± 0.018[a]	0.013 ± 0.002[a]	0.007 ± 0.001[a]	-	0.013 ± 0.002[a]
Combined Heat and Power (large scale with industrial load) by combustion of wood chip from forestry residues	0.139 ± 0.012[b]	0.007 ± 0.001[b]	0.002[b]	0.005[b]	0.008 ± 0.002[b]
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option A)	0.102 ± 0.019[b]	0.005 ± 0.001[b]	0.001[b]	-	0.005 ± 0.001[b]
Combined Heat and Power (small scale) by gasification of wood chip from short rotation coppice (Option B)	0.092 ± 0.016[b]	0.004 ± 0.001[b]	-	-	0.004 ± 0.001[b]
Electricity (large scale) by combustion of miscanthus	0.272 ± 0.019	0.018 ± 0.001	0.008	0.021	0.026 ± 0.001
Electricity (large scale) by combustion of straw	0.607 ± 0.038	0.029 ± 0.002	0.025 ± 0.003	0.111 ± 0.011	0.066 ± 0.004
Electricity by combustion of wood chip from forestry residues (large scale)	0.309 ± 0.023	0.016 ± 0.001	0.004	0.019	0.022 ± 0.001
Electricity by combustion of wood chip from short rotation coppice (Option A)	0.381 ± 0.056	0.018 ± 0.003	0.004	0.025 ± 0.003	0.025 ± 0.003
Electricity by combustion of wood chip from short rotation coppice (Option B)	0.352 ± 0.048	0.016 ± 0.002	0.003	0.023 ± 0.003	0.023 ± 0.003
Electricity by gasification of wood chip from forestry residues (large scale)	0.133 ± 0.009	0.007	0.003	-	0.007
Electricity by gasification of wood chip from short rotation coppice (Option A)	0.169 ± 0.027	0.008 ± 0.001	0.003	0.001	0.008 ± 0.001
Electricity by gasification of wood chip from short rotation coppice (Option B)	0.154 ± 0.023	0.007 ± 0.001	0.003	-	0.007 ± 0.001
Electricity by pyrolysis of wood chip from forestry residues (large scale)	0.284 ± 0.022	0.014 ± 0.001	0.014 ± 0.002	-	0.014 ± 0.001
Electricity by pyrolysis of wood chip from short rotation coppice (Option A)	0.331 ± 0.040	0.016 ± 0.002	0.014 ± 0.002	0.001	0.016 ± 0.002
Electricity by pyrolysis of wood chip from short rotation coppice (Option B)	0.312 ± 0.035	0.014 ± 0.002	0.014 ± 0.002	0.001	0.015 ± 0.002
Ethanol from lignocellulosics (wheat straw)	- 0.028 ± 0.037[a]	0 ± 0.002[a]	- 0.024 ± 0.005[a]	0.043 ± 0.005[a]	0.013 ± 0.002[a]
Ethanol from sugar beet	0.496 ± 0.044[a]	0.034 ± 0.003[a]	0.013 ± 0.001[a]	0.018 ± 0.002[a]	0.040 ± 0.003[a]
Ethanol from wheat	0.464 ± 0.032[a]	0.024 ± 0.002[a]	0.028 ± 0.003[a]	0.012 ± 0.001[a]	0.029 ± 0.002[a]
Heat (small scale) by combustion of wood chip from forestry residues (large scale)	0.100 ± 0.006	0.005	0.017	0.005	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option A)	0.092 ± 0.006	0.005	0.017	0.005	0.007
Heat (small scale) by combustion of wood chip from woodland management (Option B)	0.094 ± 0.006	0.005	0.017	0.005	0.007
Rapeseed Oil from oilseed rape	0.291 ± 0.018[a]	0.015 ± 0.001[a]	0.020 ± 0.002[a]	0.046 ± 0.006[a]	0.031 ± 0.002[a]

Figure 4 Example of energy and carbon requirements of diverse bioenergy options. Source: Elsayed 2003.

4.4 ENVIRONMENTAL IMPACT OF BIOENERGY – PLANT LEVEL

4.4.1 Introduction on environmental impacts at the plant level

As indicated in the introduction, the implementation of large bioenergy projects requires that an environmental impact assessment study be made. In the previous chapters it has been illustrated that 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.

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. Land Use Consultants (2007) contains a thorough assessment of the environmental impact of producing various types of biomass feedstocks, including short rotation coppice, short rotation forestry, forest residues and low grade timber, perennial grasses and conventional crops.

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.

4.4.2 Example: environmental impacts of biomass combustion

As outline above, environmental impacts of bioenergy production depend on many factors, including the technology used. For illustration purposes the environmental impacts of the operation of a biomass combustion plant (the most widely applied bioenergy conversion technology) are presented in somewhat more detail below (REIC, 2007)

Issues that arise when operating a biomass combustion plant include:

- Impacts on neighbourhood amenities
- Impacts of vehicle movements
- Impacts on air quality
- Impacts on soil quality
- Impacts on water quality
- Visual impacts

Impacts on neighbourhood amenities:
These impacts include e.g. noise, light, dust, and smell. Engines and chipper and other equipment used to prepare fuel can be potential sources of **noise**. **Light pollution** can cause serious physiological and ecological problems, and wastes energy and money. The design of the site will be important to minimise **dust and smell** problems but they are unlikely to be problems beyond the limit of the site itself.

Impacts of vehicle movements
The effects of vehicle movements to and from the bioenergy plant will be felt most strongly in the direct vicinity of the plant, as traffic will concentrate here. Besides fuel deliveries there will also be some traffic generated by workers at the energy plant and ancillary services. Rural roads are likely to be affected by increased traffic flow. A range of measures can be taken to minimise traffic impact, such as locating the energy generating plant close to the biofuel source, close to existing industrial faculties, or close to a motorway junction or railway siding. Alternative approaches include densifying the biomass at source, or developing and using alternatives to road transport, such as rail or water transport.

Impact on air quality
As with the combustion of any fuel there will always be emissions to the air from the combustion of biomass,. However, wood has much lower sulphur content than coal. The principal emissions that arise from a biomass combustion plant are: particulates, carbon dioxide (CO_2), carbon monoxide (CO), organics, nitrogen oxide (NO_x), sulphur oxides (SO_x) and water vapour. Through good combustion process control and appropriate flue gas cleaning the level of harmful emissions can be minimised. Water vapour will cause a visual plume but has minimal pollution implications.

Box 3: CO_2 emissions from biomass combustion

All renewable energy plants, including bioenergy plants, involve some fossil fuel emissions in the manufacture, installation and servicing of plant. Bioenergy also involves some emissions in the harvesting and transport of the biomass fuel. However, bioenergy still results in far lower emissions of CO_2 than using fossil fuel energy. Biomass energy is often cited as being CO_2-neutral since the CO_2 released on combustion is only that taken in during growth of the biomass crop. The gas is simply recycled.

Impact on soil quality

Biomass combustion results in two sources of ash: bottom ash that is collected in the combustion unit (the residues left in the primary chamber) and fly ash that is collected from the flue gases. Collected ash can be used as a valuable by-product as a nitrate fertiliser, or as a raw material in the brick and cement industries. The biomass being burnt is likely to contain small qualities of heavy metals and the disposal of ash therefore needs consideration. Analysis of the content of the ash is advised before any use is determined. If no use is identified, the ash can be disposed of (sent to landfill suite).

Impact on water courses

Contamination of watercourses is possible as surface runoff, from plant processes themselves, or as sewage. Surface water can pick up contaminants such as chemicals from stored wood, dust from chipping operations, or oil spills. Using bunds, settlement ponds and covering wood stores etc can avoid this. Wastewater can be produced from the cooling systems when wood is converted into liquid or gaseous form before being used as a fuel. These wastewaters are likely to require treatment before discharging to watercourses or sewers.

Visual impact

There will be a visual affect from the construction of any new bioenergy plant, or the addition of any chimneys. A plant situated on industrial estates will be easier to integrate into the surrounding area, than those on Greenfield sites. However, on-farm plant will be easily integrated into a farm building complex. A scheme generating electricity will require connection to the grid. In that case overhead power lines may also cause visual effects.

Exact requirements concerning the limitation of environmental impacts can vary considerably between countries, technologies and plant locations, and it is questionable if BIOTIP could capture such locally determined provisions and conditions in a generic website.

5 BIOENERGY TECHNOLOGY INFO ON THE WEB

5.1 INFORMATION NEEDS OF BIOTIP USERS

The premise of this opportunity study is the development of a Biomass Conversion Technology On-line Information Platfrom (BIOTIP) for use by SME's in developing countries. In the experience of the authors, target group members are not just interested in information on conversion technologies *per se* when they are in the early stages of exploring the potential to implement a bioenergy plant. Besides technical information, when considering such investment they are likely to seek in addition practical information on related issues such as (a) investment and operation costs, (b) equipment suppliers and (c) case studies/reference projects that can serve as showcase. The authors decided including these additional information demands as well (see Table 7).

Table 7 The four identified technology information pillars

Biomass Energy Conversion Technology Information "Complex"			
Pillar 1	Pillar 2	Pillar 3	Pillar 4
Technical information *sec*	Costs and Economics	Suppliers	case studies/ reference projects

This Chapter discusses to what extent technology-related information in each of the identified categories (technology, costs, suppliers and reference) is available on the Web, or in other data sources. Special attention is given to the extent that the Bioenergy Wiki (see Box 5) already covers the identified information categories.

5.2 INTERNET SEARCH STRATEGY

The Internet search was started by first determining which sources could be considered. Table 8 shows a wide number of potential Internet sources that can be researched[4].

Table 8 Overview of available Internet resources

Organisations	**Informal Organisations**	**Publications**	**Specialist subject tools**	**Individuals**
• Libraries • Professional associations • Regulatory bodies • Universities • Governments • Commercial companies • Trade associations	• Special interest groups • Wikis • Blogs • Mailing lists • Message boards	• Books • Newspapers • Magazines • Reports • Pictures • Databases	• Subject gateways • Specialised search engines	• Teachers • Librarians • Experts • Colleagues

[4] Source: Intute interactive tutorial to improve Internet research skills. www.vts.intute.ac.uk/acl/tutorial?sid=1142227&op=preview&manifestid=194&itemid=12027

From the more than 20 categories six types of websites were selected that would seem the most relevant. These key websites include:

- Organisational Websites
- Databases
- Full Text of Documents and Technical Reports
- Learning Materials, FAQs and Glossaries
- Search Tools Guides and Gateways
- Blogs and Wikis

An initial scan of bioenergy web resources resulted it an unwieldy collection of more or less relevant websites, webpages and webdocuments. The following picture emerged:

- Many websites and webpages that contain information on bioenergy technologies are limited in scope (technologies covered), and the level of technical detail is usually modest. Websites were of most value when they presented (access to) full text of documents, commonly in PDF format.
- It would seem that many webportals (gateways) and other webpages listing weblinks are only occasionally updated.
- Wiki's and weblogs are being expanded continuously, but the information added covers mainly news items and new technology developments and deployment. There is often modest coverage of existing technologies.

Based on the preliminary results of the initial scan, the authors concluded that it would be more effective to first apply their existing professional knowledge of relevant documents, before scanning and searching the Web *in extenso*. This resulted in the following three-step approach to identify the most relevant documents:

- Step 1: Determine a set of documents that comprehensively cover all relevant bioenergy conversion technologies
- Step 2: Source exactly these, or similar/equivalent, documents on the Web
- Step 3: For each conversion technology, carry out a Web search to (a) validate this document set and (b) identify additional relevant Web resources.

Where the authors did not have substantial *a priori* knowledge of existing documents the first two steps were largely skipped. Where they did have such knowledge the intensity of the subsequent web search was somewhat restricted. Box 4 presents some of the main groups of websites assessed, including (a) bioenergy technology networks, (b) international biomass associations, and (c) wiki's and weblogs[5]. In principle only materials in English were included in the further Web search.

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[5] A weblog (or blog) is a website which contains periodic, chronologically ordered posts on a common webpage. A wiki is hypertext-based collaborative software that enables documents to be authored collectively using a web browser. The best-known example is Wikipedia.

Although only a fraction of the many websites that deal one way or the other with biomass energy could be reviewed and no guarantees can be given the authors believe that continued research is unlikely to change the general picture and outcome of this opportunity study.

Box 4: A selection of assessed bioenergy sites

Bioenergy technology networks are in general an excellent source of introductory information. IEA Bioenergy Agreement (www.ieabioenergy.com), in operation since 1978, offers a gateway to various networks, known as “tasks” on various bioenergy themes. Current tasks include *inter alia* socio-economic issues (task 29), combustion (task 32), gasification (task 33), pyrolysis (task 34), biogas (task 37), liquid biofuels (task 39) and GHG balances (task 38).

The European Commission also sponsors thematic bioenergy networks, including EUBIONET, the Bioenergy Network of Excellence, ThermalNet, LAMNET and AD-Nett. EUBIONET II (www.eubionet.org) is a bioenergy network analysing current and future biomass fuel market trends and biomass fuel prices in Europe. The Bioenergy Network of Excellence (www.bioenergy.org, NoE) links eight leading bioenergy institutes in Europe. ThermalNet (www.thermalnet.co.uk) covers the three main thermo-chemical routes (pyrolysis, gasification and combustion) for conversion of biomass to heat, electricity and higher value fuels. It integrates the three technology-specific networks PyNe, GasNet and CombNet. The European Anaerobic Digestion Network (www.ad-nett.org), now defunct, aimed at disseminating information on technical developments in the anaerobic digestion of agro-industrial waste. The Latin America Thematic Network on Bioenergy LAMNET (www.bioenergy-lamnet.org), which operated from Jan 2002-Dec 2004, aimed at the promotion of sustainable bioenergy use in Latin America and other emerging countries.

Biomass trade associations: EUBIA (European Biomass Industry Association (www.eubia.org/about_biomass.0.html) and AEBIOM (European Biomass Association, www.aebiom.org/article.php3?id_article=62) present some technical information on biomass conversion routes. Likewise, national biomass and biogas associations and trade associations specialised in specific biofuels (examples include SVEBIO, FINBIO, European Biodiesel Board EBB, European Bio-ethanol Fuel Association eBIO, Fachverband Biogas etc.) often offer brief technology introductions.

Wiki’s: Wikipedia (en.wikipedia.org/wiki) hosts various articles on biofuel technologies. Some seem to be of good quality, others do not meet Wikipedia's on quality standards yet. Biofuel technologies are also covered in another web encyclopaedia, NationMaster www.nationmaster.com/index.php). Alternative energy and appropriate technology encyclopaedias provide similar coverage. Examples are Pure Energy Systems (www.PESWiki.com) and Appropedia www.appropedia.org. The Bioenergy Wiki (www.bioenergywiki.net) is discussed in Box 5.

Weblogs: Biopact Blog (biopact.com) is an effort to establish a mutually beneficial 'energy relationship' between European and African citizens on biofuels and bioenergy. It is an excellent information source on news on bioenergy projects in developing countries. Pacific Biofuel (pacbiofuel.blogspot.com) is a forum on biofuel developments in the Pacific. This blog features news, articles, analysis, experiences, proposals, opinions on how to promote the use of biofuel applications. Further blogs that when addressing bioenergy seem to focus mainly on liquid biofuels include Greenedia (www.greenedia.com) and Maria Surma Manka's weblog Maria Energia (mariaenergia.blogspot.com).

Special mention deserve the four interlinked BIOenergy Blogs: BIOstock Blog, BIOconversion Blog, BIOoutput Blog and BIOwaste Blog. BIOstock Blog (biostock.blogspot.com) covers mostly agriculture and forestry feedstock issues - which are used, how they're transported, and what new processes are being developed. BIOconversion Blog covers international issues, process R&D, facility deployments, and new developments. BIOoutput Blog covers output of the conversion processes - emissions, biofuels, electricity, green chemicals - and new uses for them. BIOwaste Blog covers urban waste and waste output from conversion technologies.

Box 5: The Bioenergy Wiki

BioenergyWiki www.bioenergywiki.net is hosted by the National Wildlife Federation in the USA. It is maintained in co-operation with the CURES network (Citizens United for Renewable Energy and Sustainability), headquartered in Germany. BioenergyWiki has financial (?) support of six North American organisations and advisory support from a 7-member international Steering Committee from 5 different countries.

BioenergyWiki has a very comprehensive and impressive website structure presenting a wide range of bioenergy related issues. Articles are grouped in one of the following categories: (a) Events, (b) Feedstocks, (c) Glossary, (d) News, (e) Organizations, (f) Policy, (g) Projects, (h) Publications, (i) Regions, (j) Sustainability standards, (k) Technologies and (l) Voices. Within most categories a further detailing into subcategories is made. For example, the category "organization" is subsequently split into:

- International Organizations
- Non-Governmental Organizations organized by country
- Companies
  - *Companies by region*
  - *Companies by product*
- Biofuel consumption by companies
- Industry organizations organized by country
- Research organizations organized by country

Articles are interlinked and the website is very easy to use. Links that are **coloured blue** indicate that more detailed information is presented at the next level. If it is **coloured red** the link is the last one in the information chain.

A rapid expert assessment shows that BioenergyWiki is an ambitious and impressive website but that for the moment its content (number of articles in each category) is rather uneven. This can be illustrated by a few examples:

- The level of technical detail presented is poor, and with a few exceptions (e.g. gasification, pyrolysis) the website does not present much more than the basic structure.
- Geographical coverage is skewed, with a strong focus on North America (USA and Canada), Brazil, a handful of European countries (Belgium France, Germany, Lithuania, Netherlands, Spain, Sweden, Switzerland, UK) and e.g. a tiny bit on (South) Africa. However, most countries are not being covered at all
- The policy document section is nearly empty and the projects section is fully empty.

From the prospective of BIOTIP another important observation to make is that Bioenergy Wiki seems to aim at a different audience. Where BIOTIP is meant to serve the needs of entrepreneurs in developing countries, Bioenergy Wiki addresses concerned citizens in the developed countries. The difference in target group strongly shows through in the information presented. For example, Bioenergy Wiki has extensive coverage of new and emerging technologies that are not yet considered commercial.

5.3 INFORMATION ON BIOMASS CONVERSION TECHNOLOGIES

As first step a preliminary set of documents was determined that collectively would cover the full width, depth and state-of-the-art of bioenergy conversion technologies. This step involved identifying relevant documents (including digital documents) from the BTG library, determining their relevance, and selecting the most relevant ones. Next, the Web was searched to source exactly these documents. For those documents that could not be found on the Web similar/equivalent alternatives were sought. If considered relevant, the alternatives documents were added to the preliminary document set[6]. The third step involved a further Web search[7] to validate this document set and to identify relevant Web resources.

Results of the above search strategy include:

- A long-list with for each conversion technology several highly valued documents (hardcopy or PDF), each with their URL (if available) and a short indication of their scope and relevance. This long-list is presented in Annex D[8].
- An overview with for each conversion technology the 1 or 2 most highly valued websites and data sources. This overview is presented below from Table 9 onwards.
- A third overview discussed the extent to which existing technology information was found to be easily accessible on the Web (see Table 14).

The findings of the survey, for bioenergy conversion technologies in general and for each relevant conversion technology separately, are presented below.

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.

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6 The original document, probably only available in print, was kept on the list.

7 Keywords used include: biomass, bioheat, biopower, biofuels, conversion, comminution, size reduction, densification, briquetting, pelleting, extraction, pure plant oil (PPO), straight vegetable oil (SVO), combustion, gasification, pyrolysis, carbonisation, charcoal production, anaerobic digestion, biogas, organic waste, landfill gas, alcohol fermentation, bioethanol, (trans) esterification, biodiesel, production, generation, conversion, application, technology, equipment, plant, system, etc.

8 It should be stressed that no claim is made that this is the best list imaginable.

Table 9 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

Table 10 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:	

Table 11 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)

Table 12 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)

Table 13 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)

In the opinion of the authors the above list offers comprehensive coverage of relevant biomass energy conversion technologies. One of the best general sources on these technologies is *Energie aus Biomasse. Grundlagen, Techniken und Verfahren* (Kaltschmitt and Hartmann, 2001), which unfortunately is only available in German and in print. A summary article, *Renewable Energy from Biomass* (Kaltschmitt, Thrän and Smith, 2002) appeared in the Encyclopedia of Physical Sciences and Technology[9]. Two alternative sources of high quality have the disadvantage that they are either in German or available in print only: *Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen* (FNR, 2005)[10] and *The Brilliance of Bioenergy - In Business and In Practice* (Ralph E H Sims, 2002).

Looking specifically at webresources, at least three websites were found to present a reasonable to good level of detail (depth, width, state of the art) on biomass conversion technologies in general i.e. the Biomass Energy Centre (UK), the Biomass Energy Home Page from the State of Oregon, and the Educational Website on Biomass and Bioenergy from IEA Bioenergy Task 29. For individual conversion technologies the websites of the IEA and EU bioenergy technology networks are often the best starting point. For individual conversion technologies the availability and quality of suitable web resources is considered good to very good (see Table 14).

Table 14 Accessibility to web information on individual biomass conversion technologies

Conversion Technology	**Web coverage**
Comminution	No recent stand-alone document identified, but is covered quite well in various general bioenergy technology publications, including (Kaltschmitt and Hartmann, 2001), (BENET, 2002) and (FNR, 2005). Probably additional relevant info can also be found by searching agromachinery literature.
Briquetting	In the nineties two technology overviews were published i.e. (Eriksson and Prior, 1990) and (Grover and Mishra, 1996). Both are available as PDF.
Extraction	A Danish technology overview, published by Folkecenter for Renewable Energy (Ferchau, 2000), is available as PDF.
Combustion	Covered by two technology networks (IEA Task 32 & EU CombNet), but the most relevant publication (Van Loo and Koppejan, 2007) is only available in print. Fair coverage at the educational website www.aboutbioenergy.info
Gasification	Also covered by 2 technology networks (IEA Task 33 & EU GasNet). The most relevant publications (Knoef, 2005) and (Foley & Barnard, 1983) are only available in print. However, an alternative source is (Bridgwater et al, 1999).
Carbonisation	In the eighties two technology overviews were published by FAO, in 1985 and 1987. Both are available as PDF. The technological state-of-the-art has not progress much since. The overview article from Antal Jr. and Grønli from 2003 may be difficult to access for outsiders.
Anaerobic digestion (AD)	Two practical and recently updated documents in German on AD include (Staufen, 2006) and (FNR, 2006). Only the latter is available as PDF. GTZ sponsored the (undated) Biogas Digest which is mainly targeted at *small-scale*

9 http://ehs.sph.berkeley.edu/krsmith/publications/Kaltschmitt%20Biofuel%20final.pdf

10 http://www.fnr-server.de/pdf/literatur/pdf_189leitfaden_2005.pdf

	use in developing countries. (Remade Scotland, 2003) and (AEA Technology Environment 2001) present anaerobic systems for the digestion of *organic solid waste*.. *Landfill gas* technology is introduced in 2 overviews from the last decade i.e. (SCS Engineers, 1987) and (CADDET, 2000). All these documents are available as PDF.
Bio-ethanol production /Liquid biofuels	Production of bio-ethanol and other liquid biofuels is covered in detail in (Worldwatch Institute, 2007) which is only available in print. An alternative document that is available as PDF is (WIP, 2007)
Biodiesel production /Liquid biofuels	Mittelbach and Renschmidt (2004) have authored a comprehensive handbook on biodiesel production, which is only available as hardcopy. See also the comments concerning (Worldwatch Institute, 2007) and (WIP, 2007) above.

As discussed in Box 5, technology coverage at BioenergyWiki is currently somewhat disappointing, with some of the relevant conversion routes not or hardly being covered (e.g. anaerobic digestion).

5.4 INFORMATION ON COSTS AND ECONOMICS

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 (such as Bauen, 2004 and Faaij, 2004) 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*. As an example, Table 15 below shows performance data including investment cost ranges for main commercial and emerging conversion routes of biomass to power and heat. Annex E looks as some conversion routes of biomass to liquid transport fuels.

Table 15 Performance data for selected conversion routes of biomass to power and heat

Conversion option		Typical capacity range	Net efficiency (LHV basis)	Specific Investment costs range (€/kW)
Combustion	Heat	Industrial 1-5 MW_{th}	Up to 70-90%	300-700/kW_{th} for larger furnaces
	CHP (Stirling)	<0.1 MW_e [2)]	11-20% [2)]	3,700-5,200/kW_e [2)]
	CHP (ORC)	0.16-1,6 MW_e [3)]	10-20% [3)]	1,700-4,000 /kW_e [3)]
	CHP (Steam turbine)	5-25 MW_e [2)]	20-40% [1)] 30-35% [2)]	1,500-2,500/kW_e [1)] 2.200-3,700/kW_e [2)]
Gasification	Heat	Usually around 100's kW_{th}	80-90% overall	Several 100's /kW_{th} depending on capacity
	CHP gas engine	0.1-1 MW_e	15-30%	1,500-3,000 €/kW_e[1)] depending on configuration
Biogas production	Anaerobic digestion	Up to several MW_e	25-35% (electrical) [1)]	2,000-5,000 €/kW_e [1)]
	Landfill gas	Generally several 100's kW_e	25-35% (electrical) [1)]	1,000-1,200 €/kW_e [1)]

Sources: Faaij, 2004 with following exceptions [1)] Bauen, 2004 [2)] IEA, 2007 [3)] BTG , 2007.

Note: Stirling engines, and ORC turbines are considered emerging technologies. Price ranges generally reflect European conditions.

In the experience of the authors information on the (true) investment and operation costs of any bioenergy system is notoriously difficult to find. To help prospective project developers to make their own informed decisions, various financial calculation tools and models have been developed and made available at the Web, including some sophisticated analytical tools and decision support systems. The tools may allow various other types of assessment in addition to a financial assessment.

For practical use one or more of the calculators in Table 16 may be considered[11]. Using these models typically require some basic knowledge of e.g. (a) energy streams in energy plants, (b) basic financing principles and (c) MS-Excel (or similar spreadsheet programme). Box 6 discusses the models further.

Box 7 very briefly explores the potential to generate certified emission reductions (reduced greenhouse gas emissions) and associated revenues from a bioenergy production initiative by developing it as a Clean Development Mechanism (CDM) project.

Table 16 Selected biomass energy calculation tools and models

Calculation model or tool	**Bioenergy pathways covered**	**Output**
RETScreen® International Clean Energy Decision Support Centre www.retscreen.net	Biomass heating	
California Biomass Collaborative Energy Costs Calculator biomass.ucdavis.edu/calculator.html	Biomass + CHP, biomass OR gasifier OR biogas OR landfill gas + power	Annual costs of electricity
NRELS's ProForm, poet.lbl.gov/Proform	Not assessed	IRR and NPV + revenue from carbon credits.
COGEN3's TFA Model, www.cogen3.net/tfaform.html	(Biomass) cogeneration	Technical - Financial Analysis Model
Energy Centre Hungary www.energiakozpont.hu*)	Biodiesel	Profitability and return analysis
Interactive Recalculator www.recabs.org **)	Combustion, gasification and biogas	Economic comparisons

*): www.energiakozpont.hu/ekkhthu/szolgaltatasokh/szolgh_kiadv/biodiesel/biodiesel2002/welcome.html

**): Beta test version. Fully operational in September 2007

The Bioenergy Wiki has no dedicated category on the economics and viability of biomass conversion, nor does it provide easy access to any of the identified calculations tools and models.

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11 Note that the calculation tools were not actually tested by the authors.

Box 6: Web-based models and tools to calculate bioenergy economics

RETScreen® (Renewable Energy Technology Screen) provides training materials and a Clean Energy Project Analysis Software. The software utility is an "energy awareness, decision support and capacity building tool that consists of a standardised and integrated project analysis software which can be used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy efficient and renewable energy technologies compared to conventional energy projects. In addition to the software, the tool includes product, cost and international weather databases; an online manual; a case study based college/university-level training course and electronic textbook; and an Internet-based Marketplace".

ProForm "is a software tool designed to support a basic assessment of the environmental and financial impacts of renewable energy and energy efficiency projects. Given the necessary data, ProForm calculates basic financial indicators and avoided emissions of CO2 and local air pollutants expected from a project. As a spreadsheet-based tool, ProForm is designed to be simple enough to be easily usable, yet sophisticated enough to provide credible results. A typical application of ProForm would be in preparation of a project proposal that the developers might submit to potential investors, financiers, or a national climate change office."

The **Energy Cost Calculator** developed by the California Biomass Collaborative at the University of California computes for 5 bioenergy pathways (biomass power, biomass CHP, biomass gasification, biogas and landfill gas-to-energy) the level annual cost of energy in both current and constant dollars using a revenue requirements methodology. The calculators are intended to be simple and easy to use annual cost of energy in both current and constant dollars.

The **Technical-Financial Analysis (TFA) Model** developed by Carl Bro in the frame of the EC-ASEAN COGEN3 project provides users with a good indication about the viability of projects (Internal Rate of Return, Net Present Value, and Pay Back Time). Greenhouse gas emission reduction can also be calculated. The model is intended for pre-evaluation of (biomass) cogeneration projects and is implemented in standard Microsoft Excel spreadsheet.

The nameless tool developed by Energy Centre Hungary in the frame of the **OPET Biodiesel Project** in 2001 is a calculation model for the profitability and return analysis of investments of vegetable oil and/or biodiesel production.

RECaBS (Renewable Energy Costs and Benefits for Society), a project under the IEA's Implementing Agreement on Renewable Energy Technology Deployment, is currently developing the **Interactive Recalculator.** Users can do their own economic comparisons of renewable energy (RE) technologies and traditional electricity generating technologies. Economic values of various externalities - air emissions, system integration, security of supply, employment – can be included.

Box 7: A short discussion of the limitations on using the Clean Development Mechanism

Clean Development Mechanism (CDM) projects are conventional projects that generate an additional income stream through monetising the carbon benefit (reduced greenhouse gas emissions). In comparison with conventional projects there are various supplementary project requirements, including the "additionality" requirement.

The project must be implemented by industrialised nations in developing countries where both sides are Party to the Kyoto Protocol and have a Designated National Authority for the CDM. An example of a project might entail the realisation of an power plant based on renewable energy sources - wind, biomass, small hydro, etc – or a fuel switch to lower carbon intensive fuels in the energy sector or in the industry.

To implement a CDM project, project participants must prepare a **project design document**, including a description of the baseline and monitoring plan to be used, an analysis of environmental impacts, comments received from local stakeholders and a description of the additional environmental benefits that the project will generate.

An operational entity[12] will then review the project design document and, after providing an opportunity for public comment, decide whether or not to **validate** it. If a project is duly validated, the operational entity will forward it to the CDM Executive Board -the official body supervising the CDM- for formal **registration**.

Once a project is up and running, participants will **monitor** the project. They will prepare a monitoring report including an estimate of the Certified Emission Reductions (CERs) generated by the project and will submit it for **verification** by an operational entity. To avoid conflict of interest, this will usually be a different operational entity to that which validated the project design document.

Following a detailed review of the project, which may include an on-site inspection, the operational entity will produce a **verification** report and, if all is well, it will then **certify** the CERs as legitimate. In sequence, the EB will **issue** the CERs and distribute them to project participants as requested.

The CDM project cycle can thus be said to include seven stages – Design, Validation, Registration, Monitoring, Verification, Certification and Issuance. (Completing CDM registration is an elaborate process consisting of may time-consuming steps). Carbon credits can only be generated after CDM registration is fully completed. A bioenergy project that may qualify as CDM activity should not be considered if the transaction costs overweigh the financial returns.

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[12] An accredited operational entity validates and subsequently requests registration of a proposed CDM project. An operational entity (usually another one) also verifies and certifies emission reduction of a registered CDM project activity.

To make economic sense and to attract the interest of carbon developers and traders a project should in general only be developed if it generates at least 25-50,000 tons of CO_2-equivalents per year in order to keep unit transaction costs within reasonable limits. For a single bioenergy plant for the production of heat and/or electricity this threshold will be very hard to meet.

To use the emission reduction potential of small projects and at the same time keep the transaction costs down a portfolio approach may be adopted. However this requires that a range of similar projects be developed at the same time. Again, an individual bioenergy plant cannot meet this requirement by itself.

In practice it may be found that for most small-to-medium scale bioenergy projects the development as CDM activity is not a financially attractive option.

5.5 INFORMATION ON EQUIPMENT MANUFACTURERS AND SUPPLIERS

When the end-user has some idea what technology to apply and what costs this would incur a further question that (s)he would like to see answered is where the required equipment can be sourced. The authors have therefore investigated to what extent information on manufacturers and suppliers of bioenergy conversion technology is available on the Internet, and have made the following observations.

Over the years a large number of initiatives to set-up directories and databases containing profiles (names, coordinates, description of expertise etc.) of i.a. biomass energy equipment suppliers have been initiated. Assessing the various sources it was found that only a few of such directories and databases have a strong focus on biomass (or renewable) energy, have true global coverage and are kept up-to-date. It appears that many earlier initiatives have been of a one-off nature, e.g. because funding was available only for a limited time from a particular project or on the occasion of a certain event. Maintaining any database is time-consuming and takes a long-term commitment and associated resources. Some highly regarded directories were discontinued in recent years, or are no longer kept up-to-date after funding dried up[13].

In the experience of the authors, the most useful global directories of suppliers[14] in the bioenergy field are (i) Buyer's Guide - Renewable Energy World Magazine (www.renewable-energy-world.com/buyersguide/index.cfm), (ii) Green Pages - The Global Directory for Environmental Technology www.eco-web.com, and (iii) The Source for Renewable Energy energy.sourceguides.com. In addition to these three examples

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13 Examples are the GREENTIE Directory database, the Common Purpose for Clean Energy’s Who's Who in Renewable Energy, and the Juniper’s Worldwide Directory of Gasification and Pyrolysis Technology Suppliers and Processes. The GREENTIE Directory www.greentie.org/index.php is a searchable international directory of >6000 suppliers whose technologies help to reduce greenhouse gas emissions. Although still accessible maintenance of the database ceased in March 2005. The Juniper Directory was available as a regularly updated hardcopy. It contained descriptions of various gasification and pyrolysis technologies.

14 Suppliers may include retailers, wholesalers, manufacturers and providers.

there are many other directories with a more restricted coverage (either fewer bioenergy options or a smaller geographical scope). In particular in the field of bio-ethanol and biodiesel many of such directories have seen the light in recent years. Annex F presents an overview of assessed directories and databases.

However, the authors observe that these renewable energy databases fail to present a complete picture of bioenergy businesses worldwide, as each of the databases has a rather limited number of records on supplies from developing countries.

Fortunately, there is a new initiative to develop a renewable energy database that could help fill this gap. This initiative, launched in 2006, is called reegle - the Information Gateway for Renewable Energy and Energy Efficiency. reegle advertise itself as a one-stop shop for high quality information on renewable energy and energy efficiency. It has fabulous search options: the website offers a facility to carry out searches using keywords and offers various search filters to refine search results[15]. reegle would seem to have the potential to develop into a truly global directory of the renewables industry. However, at the moment the number of actors in the category *business and industry* is still quite small. For example, a random search, on the country Uganda, did not return a single hit.

As discussed in Box 5, the Bioenergy Wiki also offers a searchable database of bioenergy actors, including companies. At the moment there are less than 100 entries for North America and also less than 100 entries for the rest of the world. To be of any use for BIOTIP the number of entries will need to grow at least tenfold.

5.6 INFORMATION ON CASE STUDIES

The fourth technology-related item on which the target group is expected to seek information on concerns realised 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 is included in many of the web resources and documents in the field of bioenergy, such as those identified in Tables 9-14 in Chapter 5. It can also be found in the renewable energy yearbooks that the European Commission published throughout the nineties.

Nowadays this type of information is increasingly published in digital format. ManagEnergy (www.managenergy.net), another initiative of the European Commission, offers a database with >500 renewable energy case studies. This database includes many bioenergy case studies. In addition, ManagEnergy provides a gateway to >25 other

[15] reegle (www.reegle.info) uses state of the art technology and derives its content from evaluated and pre-selected databases covering the following areas related to renewable energy and energy efficiency: jurisdiction & laws, policies & measures, finance & investment, reports & analyses, latest news, stakeholders. The information provided on reegle is derived from three different sources: existing databases of its knowledge partners (WB, IEA, WEC, ECEE, CLASP and the Energy Charter Secretariat), pre-selected key internet sources and its own internal database.

websites featuring case studies (and other useful documents). A disadvantage is that many of the case studies from this and other indicated sources concern applications in developed, rather than developing, countries.

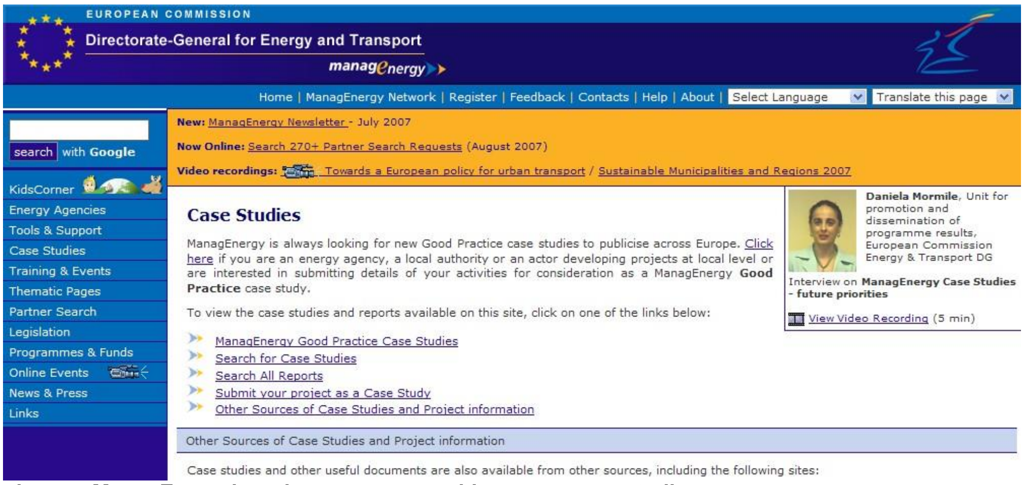

Figure 5 ManagEnergy's webpage on renewable energy case studies

A webpage that is fully dedicated to renewable energy case studies in developing countries can be found at the website of Dr. Eric Martinot[16]. Renewable energy specialist Martinot collected these case studies mainly from the following five sources:

- Collections (Sources/Groups) of Case Studies
- Bonn Renewables 2004 Conference Case Studies
- GEF Project Case Studies
- GEF Renewable Energy Project Briefs
- Other Selected Case Study Sources

A portion of Martinot's case studies focus on biomass energy systems. The list, available at www.martinot.info/case_studies.htm, seems to have been updated last in October 2005), and subsequently does not include some case study sources of more recent date[17]. Websites of equipment suppliers and manufacturers are also a potential source of case studies.

Bioenergy Wiki contains a special category for descriptions of bioenergy projects. At the moment this category is fully empty.

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16 A research fellow with the Worldwatch Institute, currently residing in Beijing as visiting faculty at Tsinghua University. He initiated the case study list in the 2000-2003 period when he served as renewable energy programme manager for the Global Environment Facility (GEF) at the World Bank in Washington DC.

17 For example, the World Bank's Renewable Energy Toolkit, permanent URL **go.worldbank.org/YIPTTI4VY0**, is not yet listed

5.7 SUMMARY AND REVIEW

The presence of technology-associated information on the Web can be summarised as follows:

Conversion technologies: as discussed in Table 14, web coverage of most technologies, including briquetting, carbonisation, mechanical extraction (PPO production), bio-ethanol production, biodiesel production, and anaerobic digestion is considered good. When documents that only appeared in print are also considered coverage of all investigated conversion technologies (the above technologies plus combustion, gasification, and secondary conversion) is considered good.

Costs and economics: information on the (true) investment and operation costs of any bioenergy system is notoriously difficult to find. In the literature (overview studies) normally quite wide cost ranges are presented, that should be considered as indicative only. Fortunately, the Internet offers a few calculation tools and models that entrepreneurs can use to determine the financial viability of a bioenergy initiative.

Suppliers: there are several databases with worldwide coverage on the Internet that include businesses and other actors in the bioenergy field. However it would seem that together these only cover a limited part of all bioenergy equipment suppliers in developing countries. The number of entrees in reegle and Bioenergy Wiki´s actor databases is even more restricted. The preliminary conclusion is that coverage on Internet of bioenergy equipment suppliers in developing countries is poor.

Case studies: Likewise, Internet coverage of bioenergy project or system case studies in developing countries is modest, with only one good source identified thus far.

As for the **Bioenergy Wiki,** it has been illustrated that the extent to which the above information categories are currently covered in the Bioenergy Wiki is meagre. Bioenergy Wiki offers an excellent frame but little content (technical details) on conversion technologies. It does not cover costs or economics of bioenergy options as such, and its case studies database is empty. At the moment it lists less than 200 bioenergy companies worldwide, which equals on average less than 1 per country.

6 WAYS OF PRESENTING BIOENERGY INFO ON THE WEB

This chapter discusses for each of the four technology-related information categories common ways of presenting information on the Internet.

6.1 WAYS OF PRESENTING TECHNICAL INFORMATION ON THE WEB

There are many different ways to present technical information on the web. Four examples are presented below:

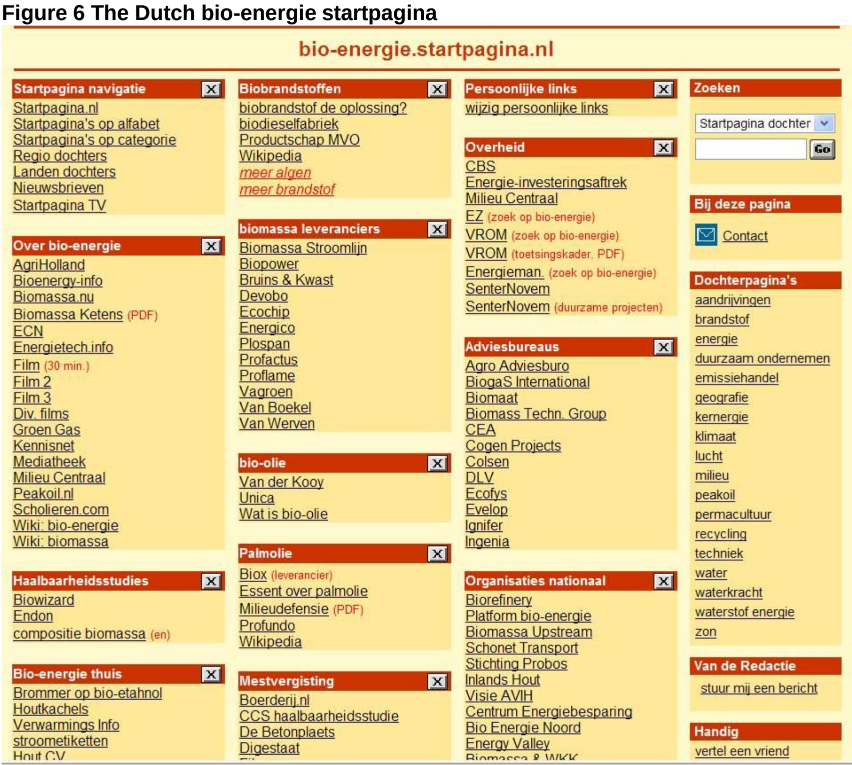
- Webportals (or gateways) of different kinds
- Webpage articles with integrated hyperlinks
- Biomass-technology pathway tree
- Biomass-technology matrix with associated fact sheets

Some pro’s and con’s of each presentation method are described below.

Webportals

In their simplest forms, webportals can be little more than unsorted ”no thrills” lists of weblinks to other web resources. Two examples of such list are the reports database maintained by the National Biodiesel Board in the US[18] and the linklist to Bioenergy Related Web Sites maintained by Bioenergy Australia[19]. For easier use weblinks are commonly grouped in various categories. An example of this is www.bio-energie.startpagina.nl (see Figure 6).

Figure 6 The Dutch bio-energie startpagina



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18 http://www.biodiesel.org/resources/reportsdatabase/viewall.asp

19 http://www.bioenergyaustralia.org/links.html

The big advantage of these sites is that they can present large numbers of weblinks (easily 100 or more), and thus a complete overview of relevant resources, in a single screenshot. The site has a simple linear structure and is thus is easy to develop and maintain, at very low cost. The disadvantage of just listing weblinks is that no details and no context can be shown, as there is simply no room for this.

To overcome the last disadvantage the bare weblinks can be accompanied with a small description, either taken from the referred weblink, or developed separately. Examples of these two respective options are the China New Energy biomass link site, http://www.newenergy.org.cn/english/website/biomass.htm (Figure 7) and the Charcoal Making Page at the Survival & Self Reliance Studies Institute website, www.ssrsi.org/sr2/Indust/charcoal.htm (Figure 8). The inclusion of short descriptions give users an indication of the relevance of the referred website for their purpose. A disadvantage is that the number of weblinks that can be captured in a single screenshot drops dramatically, as both exampled below illustrate. Furthermore, all that is presented is still not more than a list of weblinks, without much context.

Figure 7 China New Energy biomass link site

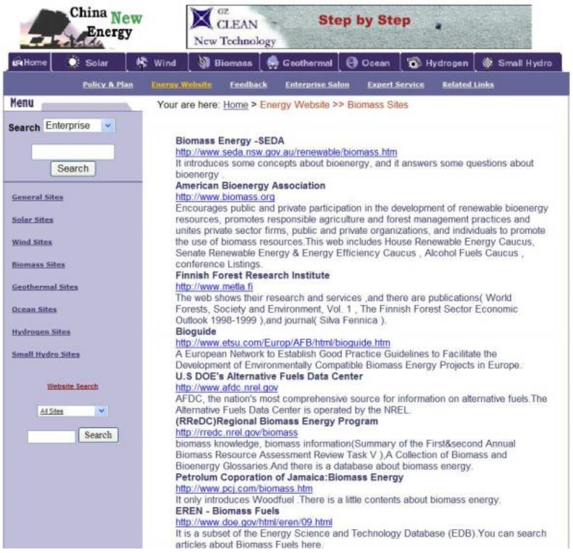


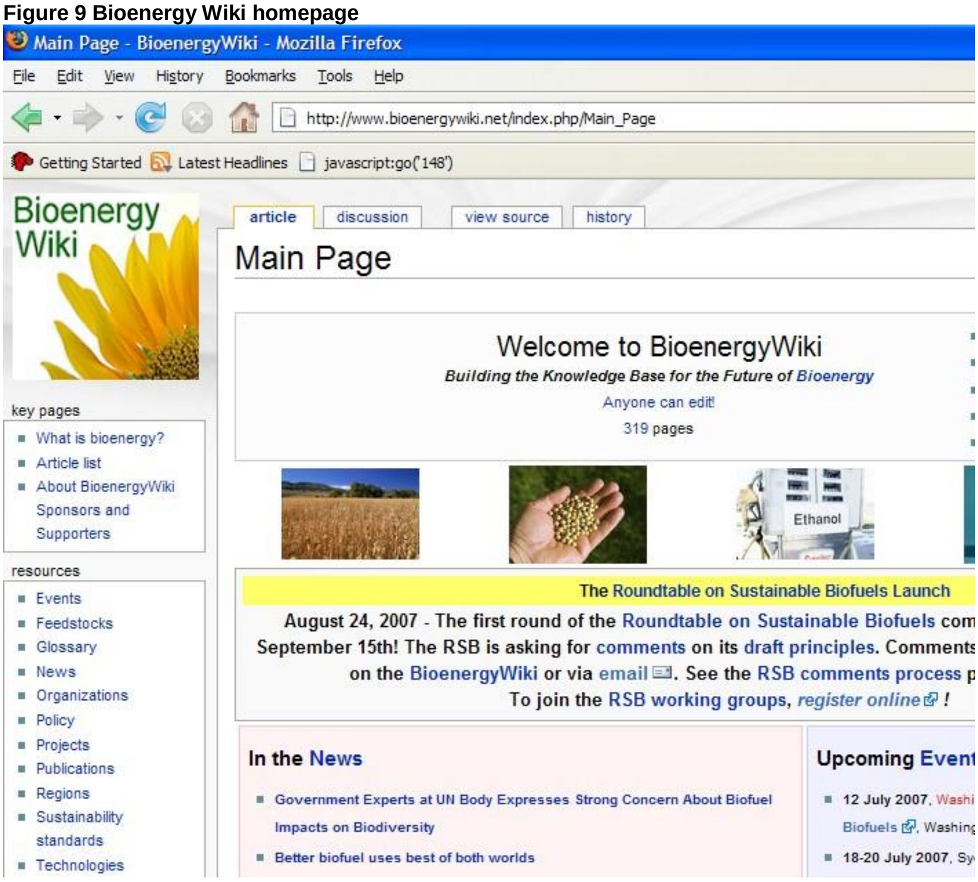
Figure 8 SSRSI Charcoal Making Page

Webpage articles with integrated hyperlinks

For subjects that are relatively new to website users, such as biomass energy, it may be useful to include context e.g. an introduction on relevant concepts. A practical manner to present such introductory information is as an article with internal links that lead the user to deeper webpages where (s)he can find additional details on the subjects that (s)he is particularly interested in. Examples include:

- The various biomass-related webpages and wiki's (e.g. www.bioenergywiki.net)
- The Oregon Bioenergy Home Page www.oregon.gov/ENERGY/RENEW/Biomass/BiomassHome.shtml
- The UK Biomass Energy Centre website www.biomassenergycentre.org.uk.
- IEA Task 29 Educational Website on Biomass and Bioenergy, www.aboutbioenergy.info

Figure 9 Bioenergy Wiki homepage



Biomass-technology pathway tree

A very different way of offering access to technology details is by presenting an illustration that shows the core components of the nine relevant biomass-to-energy pathways of Figure 2. Core components for a pathway include the biomass feedstock, the conversion unit (reaction unit) and the energy device (engine or turbine). The core components can be represented by a thumbnail-size picture or drawing. In this manner, the core elements of all relevant biomass-to-energy pathways can be shown in a single overview screenshot.

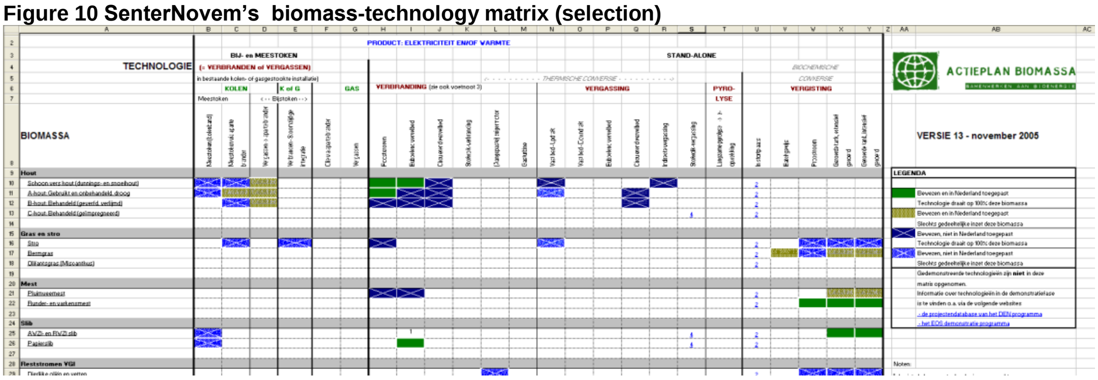
A disadvantage of this way of presenting information is that the user will need (quite) a bit of technical background to understand how and where to access the website.

This way of structuring the homepage can be combined with the encyclopaedia type explanatory articles discussed above. The main difference is than the way the homepage interface looks and the method of approach to the respective sub-levels. With the exception of the graphically more attractive one or two upper levels the deeper structure of the website will not be that much different than that of the previous option.

Biomass-technology matrix with associated fact sheets

A rather technically oriented method of providing access to information on bioenergy conversion technologies is the so-called biomass-technology matrix. Cells in this matrix link directly to a relevant fact sheet that presents concise information on the conversion technology in question. An example is the biomass-technology matrix developed by the Dutch Biomass Action Plan (see Figure 10).

Figure 10 SenterNovem's biomass-technology matrix (selection)



An advantage of this presentation method is that information is presented in a compact manner: just by clicking the correct matrix cell a technical fiche becomes available. Disadvantages are that quite a bit of technical background on conversion technologies is needed to pick the correct matrix cell, and that it is laborious to get a complete picture of existing technologies.

6.2 WAYS OF PRESENTING ACTOR INFORMATION ON THE WEB

Just as is the case with technical information, there are various ways to present actor information on the web. For a start, information on biofuel actors such as (a) promotion agencies (b) universities and research institutes and (c) manufacturers and suppliers can be presented at different level of detail. In a simple classification systems at least 3 different levels of detail can be determined, as follows:

Level 1: Only name, coordinates and indication of activity areas. Name and coordinates alone are of little use without at least some knowledge of the fields of activities of the actor in question. Business directories that offer just this level of detail include e.g. *Buyer's Guide Renewable Energy World Magazine* www.renewable-energy-world.com/buyersguide/index.cfm and *The European directory of small-scale cogeneration suppliers* www.cogen.org/cogen-challenge/Downloadables/European_Directory_Suppliers.pdf. An example from the REW Buyer's Guide is shown in Figure 11.

Level 2: Same data a Level 1, but with in addition a brief profile that presenting may include information on e.g. uses, clients, feedstock, product range, capacities, geographical regions of operation. Examples of directories offering this level of detail are reegle – the information Gateway for Renewable Energy and Energy Efficiency (www.reegle.info), *Who's Who in European Cogeneration 2002-2003*, www.cogen.org/Downloadables/Publications/Who_is_Who_2002_03.pdf and *The Worldwide Directory of Gasification and Pyrolysis Technology Suppliers and Processes. Part Two: Listing of Suppliers and Licensees* (only available in print). An example from reegle is shown in Figure 12.

Figure 11 A sample database record from the REW's magazine Buyer's Guide

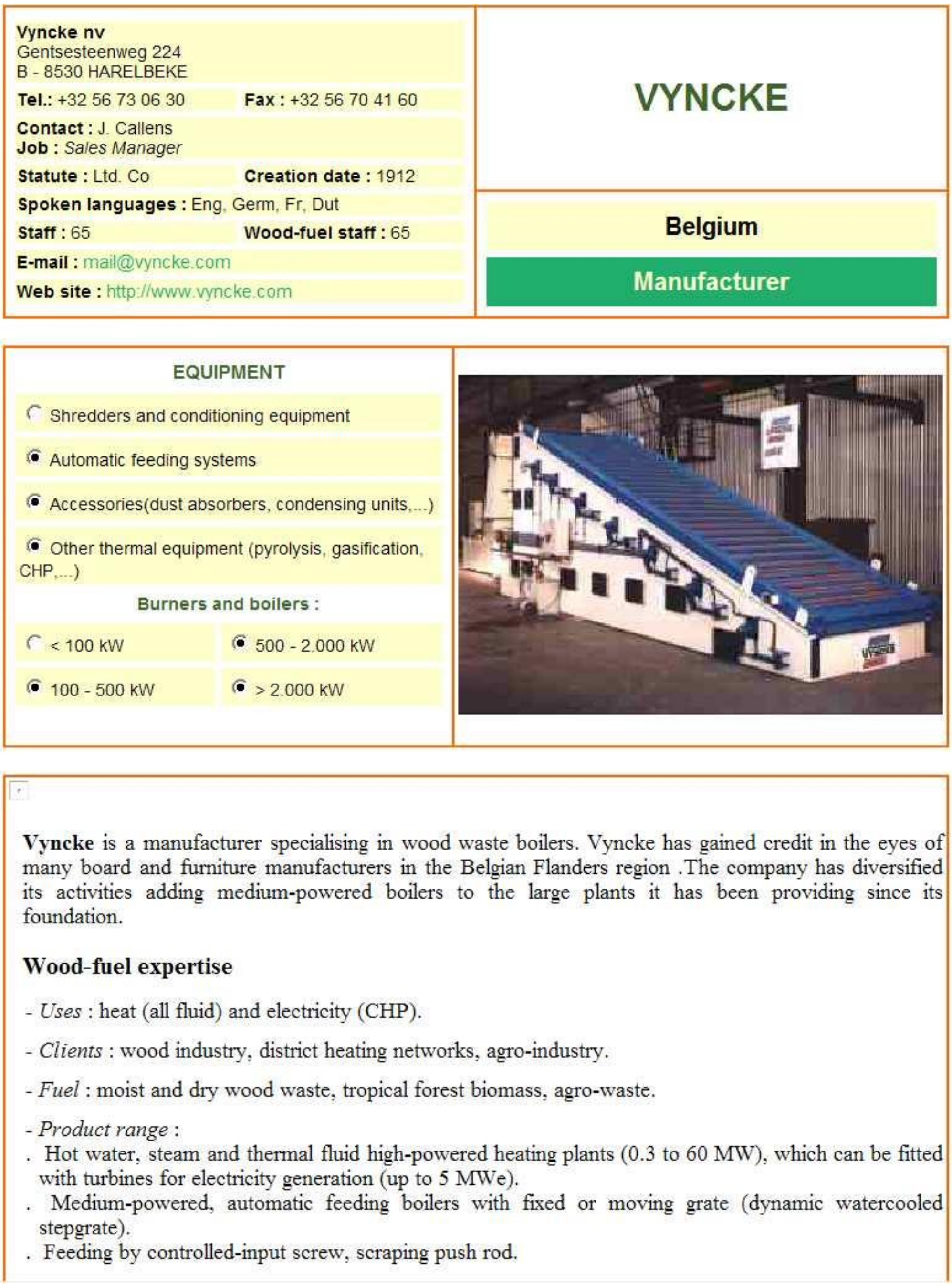
Figure 12 A sample database record from reegle

Level 3: Same data as Level 2 but with in addition a more detailed organisation profile, graphical material (pictures, illustrations and the like) and other relevant examples that best illustrate the organisations activities in the bio-energy field. This could involve:

- For agencies: examples of specific projects/activities that have been sponsored
- For universities: short list (up to 5 items) of research outcomes (e.g. publications)
- For suppliers: technical data of products being offered such as process descriptions, process diagrams, flow sheets, mass & energy balances, environmental performance, status & references

Examples of supplier directories offering Level 3 type of detail are *Small and medium scale biomass boiler and stove manufacturers in Europe. Part 1-Austria and Bulgaria*, www.tekes.fi/opet/pdf/BC_Aus_Bul.pdf and *European Catalogue Wood-fuel for heating systems*, www.biomasse-normandie.org/wood_fuel_opeur.php3. An example from the latter is shown in Figure 13 below.

Figure 13 A sample database record from the EU wood heating catalogue



Vyncke nv
Gentsesteenweg 224
B - 8530 HARELBEKE

Tel.: +32 56 73 06 30 **Fax :** +32 56 70 41 60

Contact : J. Callens
Job : *Sales Manager*

Statute : Ltd. Co **Creation date :** 1912

Spoken languages : Eng, Germ, Fr, Dut

Staff : 65 **Wood-fuel staff :** 65

E-mail : mail@vyncke.com

Web site : http://www.vyncke.com

VYNCKE

Belgium

Manufacturer

EQUIPMENT

- ○ Shredders and conditioning equipment
- ● Automatic feeding systems
- ● Accessories(dust absorbers, condensing units,...)
- ● Other thermal equipment (pyrolysis, gasification, CHP,...)

Burners and boilers :

- ○ < 100 kW
- ● 500 - 2.000 kW
- ● 100 - 500 kW
- ● > 2.000 kW

Vyncke is a manufacturer specialising in wood waste boilers. Vyncke has gained credit in the eyes of many board and furniture manufacturers in the Belgian Flanders region .The company has diversified its activities adding medium-powered boilers to the large plants it has been providing since its foundation.

Wood-fuel expertise

- *Uses* : heat (all fluid) and electricity (CHP).

- *Clients* : wood industry, district heating networks, agro-industry.

- *Fuel* : moist and dry wood waste, tropical forest biomass, agro-waste.

- *Product range* :
. Hot water, steam and thermal fluid high-powered heating plants (0.3 to 60 MW), which can be fitted with turbines for electricity generation (up to 5 MWe).
. Medium-powered, automatic feeding boilers with fixed or moving grate (dynamic watercooled stepgrate).
. Feeding by controlled-input screw, scraping push rod.

Unless the length of the total list of organisations is rather short some form of *search tool* is usually included to help find a specific organisation more quickly. For a web-based directory this could be a search engine with search fields for e.g. name, country, keywords, or activity classification of the organisation. Figure 14 presents an example. For a printed directory this could involve one or more alphabetic lists of organisation names or classifications (A-Z listing and classified listing). To further assist the user the A-Z list is often in the form of a matrix with additional columns in which the fields in which a specific organisation is active are ticked.

Figure 14: The reegle search engine

6.3 WAYS OF PRESENTING OTHER RELEVANT INFORMATION ON THE WEB

The other two categories of practical information that prospective BIOTIP users are likely to seek information on are (a) investment and operation costs and (b) showcase projects.

Regarding *investment and operation costs* it was observed in Section 5.4 that at best indicative costs could be given. To help users make their own calculations, a list of annotated weblinks to useful calculation tools and models (see Table 15) can be provided.

A practical way of presenting *case studies* of showcase projects is in the form of an annotated list. If the number of case studies becomes large it may be more effective to provide access through a search engine.

7 RECOMMENDATIONS ON UNIDO'S ROLE AND CONTRIBUTION

This chapter discusses the degree to which the identified information categories are already covered on the Web and presents recommendations on what role UNIDO could play in setting up a BIOTIP and improving information flows on the application of bioenergy.

Recommendation 1: It is recommended that UNIDO develops a Biomass Conversion Technology On-line Information Platform, or BIOTIP for SME's and policy makers in developing countries as an one-stop-shop (or at least a first-stop-shop) to provide information to anyone interested in implementing a biomass conversion technology in a developing country.

Recommendation 2: It is recommended that BIOTIP covers four technology-related information categories discussed earlier in Section 5.1 i.e. (a) Bioenergy conversion technologies, (b) Costs and economics of a bioenergy system, (c) Bioenergy actors, in particular suppliers, (d) Case studies of realised bioenergy projects.

Recommendation 3: It is recommended that information for the central part of the BIOTIP be provided by UNIDO itself, in order to be able to provide consistent and well-ordered information specifically aimed at SME's and policy makers in developing countries.

Recommendation 4: It is recommended that for detailed information, the BIOTIP would use as much as possible existing initiatives (websites etc.) in each of these four information categories. This is symbolised in Figure 15.

Figure 15 The four suggested BIOTIP components

Recommendation 5: It is recommended that UNIDO uses existing website templates and structures like those adopted by the Bioenergy Wiki www.bioenergywiki.net and the UK Biomass Energy Centre website www.biomassenergycentre.org.uk for inspiration.

7.1 BIOENERGY CONVERSION TECHNOLOGIES

Several websites (including UK Biomass Energy Centre, Oregon Bioenergy Home Page, Task 29 Educational Website on Biomass, EUBIA's About biomass) already offer general overviews and brief descriptions of relevant bioenergy conversion technologies. Bioenergy Wiki has a structure allowing future presentation of both existing and merging bioenergy technologies.

However, few websites if any cover the full range of the nine biomass conversion technologies considered in this study. Furthermore, the websites assessed are not specifically focused on developing countries, presenting biomass-technology combinations and suitable applications of relevance for these world regions. Thirdly, the assessed websites usually offer limited technical detail. Process diagrams, descriptions of unit operations, energy and environmental performance etc. are hardly ever covered. Finally, presented technology data (such as e.g. conversion efficiencies) is not always consistent. Table 17 summarises the authors' assessment of current coverage of bioenergy conversion technology information on the Web

Table 17: Pro's and con's of bioenergy conversion technology coverage on the web

Positive ("pro")	Negative ("con")
The number of existing websites offering bioenergy conversion technology overviews	1. Limited level of detail 2. No specific focus on developing countries (in terms of feedstock, technology & financial aspects)
There is a lot of detailed technology information available both on the Internet and in print	1. The information is scattered 2. Inconsistency among information sources
There are various websites presenting possible ways of structuring technology information	Current website structures do not fully match or reflect the unique goal of BIOTUF (focus on SMEs and policy makers in developing countries).

Recommendation 6: It is recommended that UNIDO develops itself an overview of biomass energy conversion technologies that can serve as information tool for SME's and policy makers to assess how biomass can be converted into energy. This scoping study has revealed that a technology overview that focuses on bioenergy application in developing countries does not exist yet.

Recommendation 7: It is recommended that the technology information be presented at 2 different levels of detail. On the one hand it shall provide quick but high-quality information on all relevant bioenergy conversion technologies. On the other hand it shall provide more detailed technical information, in order to help the target group members make a concrete step path implementating a bioenergy system. At both levels of detail the technology information presented shall be consistent and transparent.

Recommendation 8: It is recommended that the detailed technical information be summarised in 1-2 page technical fiches, or conversion technology summary sheets.

7.2 ECONOMICS OF A BIOENERGY SYSTEM

Reliable information on investment and operational costs of bioenergy systems is notoriously hard to get, partly because these are very site-specific. There is little UNIDO can do to overcome this situation. However, UNIDO can assist entrepreneurs by:

- Improving the accessibility and availability of bioenergy calculation tools and models
- Making available, where practically possible, cost data (investment costs, conversion efficiencies, etc.).
- Developing and making available a set of simple tools for the financial evaluation of bioenergy projects

Table 18 Comparison of Bioenergy Wiki and proposed BIOTIP technology templates

Standard Bioenergy Wiki template	Streamlined BIOTIP template
• 1 Types of Gasification Technologies o 1.1 Fixed Bed Gasification o 1.2 Fluidized Bed Gasification o 1.3 Novel Designs for Gasification • 2 Feedstocks o 2.1 Pretreatment o 2.2 Qualifications • 3 Products o 3.1 Intermediate products o 3.2 Main products o 3.3 By-products • 4 Advantages of Gasification • 5 Commercialization Status • 6 Sustainability and Environmental Concerns o 6.1 Societal Impacts • 7 Projects • 8 Publications • 9 Companies • 10 Note	1 Types of Gasification Technologies o 1.1 Fixed Bed Gasification o 1.2 Fluidized Bed Gasification o 1.3 Novel Designs for Gasification • 2 Feedstocks • 3 Products • 4 Advantages of Gasification • 5 Commercialization Status in developing countries • 6 Framework conditions and limitations • 7 Cost-related factors • 8 Environmental Concerns • 9 Examples in developing countries

What SMEs and policymakers need is a simple, clear and robust tool that enables them to get a first impression of the viability of bio-energy options in their (developing) country. Already available on the Internet are a number of (sometimes good) calculation tools and models, such as such as RETScreen®, CBC's (Bio)Energy Costs Calculator, NREL's ProForm, or COGEN3's TFA Model. The usefulness of such existing calculation tools, however, seems somewhat restricted as (a) they are typically not specifically developed for developing countries, (b) they are sometimes too detailed for practical use by the target group and (c) they do not seem to include a simple model for a rapid "*quick-and-dirty*" preliminary viability assessment.

To overcome these restrictions, two possible approaches can be adopted. Existing calculation tools may be adopted by inclusion of local data. Alternative, a set of simple but relevant calculation tools may be developed from scratch. The second approach has the added advantage that various bioenergy conversion routes (for production of heat, electricity and transport fuels) can be mutually compared.

Recommendation 9: It is recommended that the BIOTIP contains a set of simple and robust calculation tools that enable SMEs in developing countries to make an initial (preliminary) assessment of the viability of a bioenergy plant.

It is therefore proposed to first make new simple spreadsheets models for inclusion in BIOTIP. The spreadsheets could make use of the basic structure of existing bioenergy calculation tools (such as RETScreen® etc.). In a second stage, the spreadsheets models may be adopted for use in developing countries. In a third stage, each spreadsheet model can be customised for use in a specific developing country (taking into account e.g. local financial incentives, if available).

Recommendation 10: It is recommended that, when proven effective, these calculation tools be customised at a later stage for use in a specific developing country (taking into account e.g. local financial incentives).

For more detailed costs calculations an instrument such as UNIDO's COMFAR would appear useful. COMFAR III Expert is a computer software package that allows the user to simulate the short- and long-term financial and economic situation of investment projects. The software permits the analysis of industrial as well as non-industrial projects, whether new investments, rehabilitations, expansions, joint venture or privatisation projects[20]. It can be used in combination with UNIDO's Manual for the Preparation of Industrial Feasibility Studies.

7.3 BIOENERGY STAKEHOLDERS

Stakeholders of particular relevance to BIOTIP are (a) biofuel promotion agencies, (b) universities and research institutes and (c) technology manufacturers and suppliers. In this report it was concluded that no comprehensive and up-to-date overview of these stakeholders exists. However, there are various existing initiatives and databases that UNIDO could use as a good starting point.

The actor database developed by reegle, the Information Gateway for Renewable Energy and Energy Efficiency, includes the following actors:

- Business and Industry: Business Association, Financing, Manufacturer/Installer, Other Business/Industry, Project Developer
- International Partnerships and Initiatives
- International and Regional Organisations
- Media
- NGO

[20] http://www.unido.org/doc/3383

- National government and government agencies: Energy Agency, Ministry, Other Governmental, Regulator
- Research/University

reegle thus covers all identified BIOTIP stakeholder groups. In combination with its excellent search facilities it offers the type of instrument that BIOTIP needs. It is therefore commendable that UNIDO has taken the initiative to contact REEEP (the host organisation of reegle) to explore the concrete possibilities of co-operation and using a reegle-type search engine[21]. In their initial discussions UNIDO and REEEP agreed that the latter would name UNIDO as a reegle partner, would include a short description of BIOTIP at the reegle website and would direct WWW users to the UNIDO/BIOTIP website once it is operational.

Recommendation 11: It is recommended that UNIDO develops its own database of bioenergy equipment suppliers (retailers, wholesalers, manufacturers and providers).

Recommendation 12: It is recommended that UNIDO develops access to this database in close collaboration with REEEP (the host of the reegle database, www.reegle.info).

A possible approach to builds this database includes the following steps:
- Determine the level of detail that should be included in a bioenergy actor profile.
- Develop a template for a bioenergy actor profile. If some sort of co-operation were agreed with reegle it could be practical to simply emulate the reegle template.
- Using the recommended renewable energy actor databases, identify and select known bioenergy actors in the target countries. This yields a basic list.
- Using biofuel promotion agencies and UNIDO nodes in the target countries, try to identify additional bioenergy actors to expand the basic list.
- Contact the selected bioenergy actors by email and invite them to submit a completed bioenergy actor profile. If no email address is known contact the bioenergy actors by regular mail.
- Incorporate the returned information in a bioenergy actor database.

When initial response is low it may be necessary to send reminders. When completed profiles are returned it may be near-impossible to check and guarantee the quality of the submitted information. Furthermore, it may be difficult to obtain the interest from well-known reputable companies to submit the information in a prescribed format. In such case it may be necessary to convert whatever company material is received to the standard format. Or they may not feel the need to submit any information at all. On the other side, there could be a large but less desirable interest from relatively new companies that have little relevant experience.

From the experience of the authors, the sketched approach is comprehensive but also time-consuming.

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[21] Such co-operation can easily be established as the reegle team at the REEEP International Secretariat is co-located with UNIDO at Vienna International Centre!

Recommendation 13: It is recommended that when developing the suppliers database UNIDO initially concentrates on a selection of spearhead countries, where the current status of, or the prospective for, bioenergy development looks good. If the results are satisfactorily, the numbers and groups of countries covered could be expanded gradually.

7.4 BIOENERGY CASE STUDIES

There are likely to be a large number of existing case studies and success stories on bioenergy projects and plants in developing countries. However, the authors have only identified a single database that serves as a gateway to a fair number of such case studies. It seems that few new entries were added to the database since October 2005. UNIDO could therefore consider setting-up a bioenergy case study database as a central element of BIOTIP.

Recommendation 14: It is recommended that UNIDO develops its own database of case studies and success stories on bioenergy projects and plants in developing countries.

As first step an initial collection of case studies may be derived as follows:

- Retrieve the case studies listed by Dr. Eric Martinot (www.martinot.info/case_studies.htm) that focus on biomass energy systems.
- Carry out an additional Web search, in which specifically the websites of (development) organisations operating in closely related fields such as renewable energy, rural energy, appropriate technology, poverty alleviation, sustainable development, climate change, environment etc. are researched with the aim to identify additional case studies targeted
- Retrieve case studies from existing publications and websites. Some examples of publications that contain relevant bioenergy case studies from developing countries are: Schenkel (1995), Kartha and Larson (2000), Sims (2002), Kammen *et al* (2002), Kartha *et al* (2005), Huttunen and Lampinen (2005), UN DESA (2007) and GTZ´s Biogas Digest (undated). The BioPact blog (biopact.com, see Box 4) can also serve as a source of inspiration. It goes without saying that the authors/publishers would have to approve the inclusion of the case study in BIOTIP.
- Invite UN system sister agencies that are a member of UN-Energy as well as other international organisations that participate in the Global Bioenergy Partnership to make available relevant case studies.

Recommendation 15: It is recommended that UNIDO builds an initial collection of case studies from existing publications and websites, including those outlined above.

Recommendation 16: It is recommended that in case existing publications and websites generate insufficient relevant and recent case studies UNIDO develops a set of bioenergy case studies of its own.

New case studies may be developed adopting the following procedure:

- Determine the level of detail that should be included in a bioenergy case study.

- Develop a bioenergy case study template. For inspiration the template that is in use by the EU's ManagEnergy website can be considered (URL: http://www.managenergy.net/download/CaseStudyTemplate.doc).
- Identify candidate case studies. A practical way to do this is to check the presentations of speakers at relevant conferences, for example UNIDO's high-level biofuel conferences held in Malaysia and Ethiopia in July 2007, or the various conferences that were held around the globe in the frame of the EU supported LAMNET project www.bioenergy-lamnet.org.
- Contact the selected persons by email or otherwise and invite them to submit a completed bioenergy case study. Alternatively, ask the persons to submit background material that would help UNIDO to put together the case study itself.
- Validate the returned information, if possible, and incorporate it in a case study database.
- Repeat the above exercise, involving more individuals and organisations (including equipment suppliers), in case the number of case studies developed is still deemed insufficient. In particular the assistance of biofuel promotion agencies and UNIDO nodes in the target countries may be sought. It may also be helpful to put an invitation to submit case studies at the websites and in newsletters of UNIDO and its partner organisations.

7.5 SUMMARY ON THE ROLE AND CONTRIBUTTION OF UNIDO

Based on the premises that UNIDO wants to make maximum use of existing bioenergy webresources, including those not specifically targeted at developing countries, UNIDO's potential role and contribution in the development of a BIOTIP was discussed above. For each of the four technology-related information, the possible coverage in BIOTIP, useful building blocks, and candidate organisations for collaborations were identified categories were outlined. This is summarised in Table 19.

Table 19 Suggested coverage of BIOTIP

	Conversion technologies	Costs & Economics	Suppliers	Case studies
Potential BIOTIP component	• (Detailed) bioenergy technology profiles	• Calculation tools to help determine BE feasibility	• Annotated list of weblinks or (searchable) database	• Annotated list of weblinks or (searchable) database
Potential input material	• Most relevant bioenergy info websites (<5); • Open & grey literature (on Web / in print)	• Existing webbased calculation models and tools	• reegle search engine • Webbased supplier directories	• Martinot's webpage • Open & grey literature
Potential collaborating organisations	• Biomass energy conversion expert(s)	• Biomass energy feasibility expert(s)	• REEEP (reegle website host) • National partners (biofuel promotion agencies)	• UN-Energy and GBEP networks • Past workshop speakers • National partners (biofuel promotion agencies)

Notes: UN-Energy is the interagency mechanism on energy of the UN system. UNIDO is heading UN-Energy and facilitator for the Africa component within UN-Energy's the Policy Coherence and Operational Cooperation programme.

REEEP = Renewable Energy and Energy Efficiency Partnership, based in Vienna. See www.reeep.org.

GBEP = Global Bioenergy Partnership, based at FAO HQ in Rome. See www.globalbioenergy.org

Bioenergy Wiki is not included in the above table. In the opinion of the authors there is little to gain for UNIDO from Bioenergy Wiki at the current time, other than that it offers an example of a technology description profile. This is not meant to indicate that UNIDO should not collaborate with Bioenergy Wiki. However, Bioenergy Wiki can be a destination, rather than a source, for BIOTIP information. For example, Bioenergy Wiki could adopt the BIOTIP technology description once completed, or the information on equipment suppliers and other bioenergy actors in developing countries.

8 PROPOSED STRUCTURE OF BIOTIP

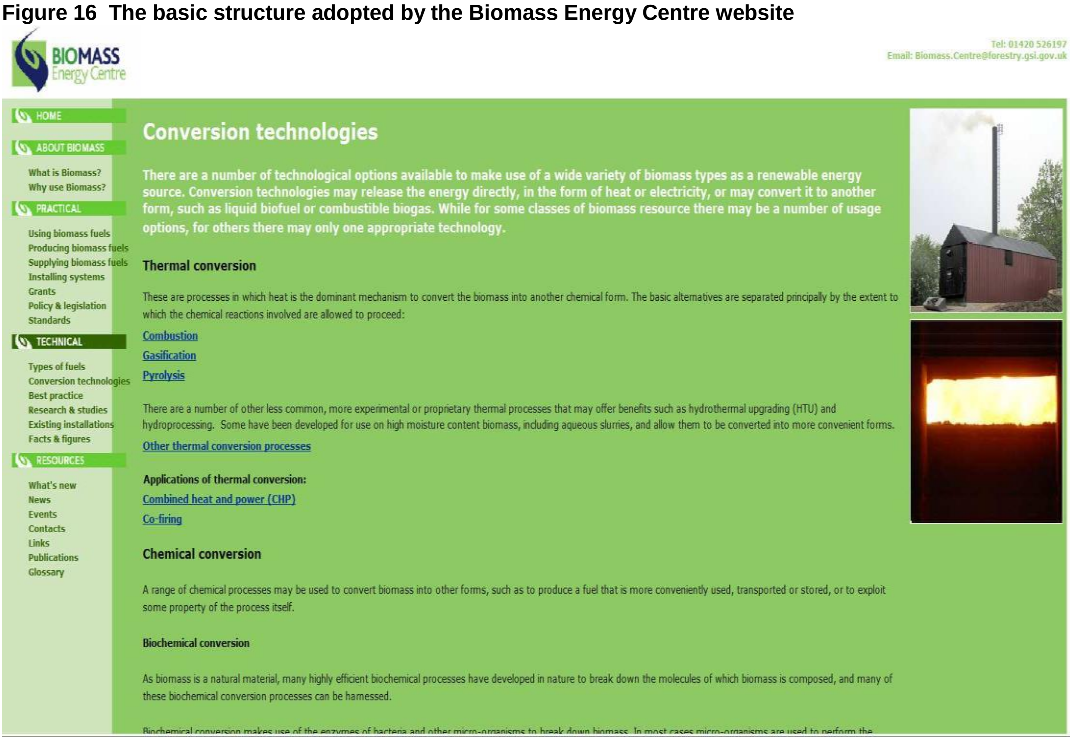
This chapter discusses what a **stand-alone** BIOTIP, built around the four identified technology-related information categories, could look like[22].

The structure of the Biomass Energy Centre website ("*A one-stop-shop to provide information to anyone with an interest in biomass derived solid, liquid and gaseous fuels and associated conversion technologies*") is well thought through. It is recommended that BIOTIP examines the structure of this website for inspiration.

The approach followed is that each and every page on the website has a fixed menu on the left, which gives direct access to the main menu items, grouped in four basic categories. In the centre of the screen relevant information on a particular menu item is presented in articles of typically not much longer than 1 screen length. Further details, if any, are presented in linked follow-up articles. A column on the right of the screen, if used, shows links to related pages, pictures, glossary terms etc. See Figure 16.

If BIOTIP adopts a similar structure as the UK Biomass Energy Centre website www.biomassenergycentre.org.uk, with information being presented at increasing levels of detail, it could contain the following basic categories and menu items (see Table 20 and Table 21):

Figure 16 The basic structure adopted by the Biomass Energy Centre website



22 It is understood that the host of the Bioenergy Wiki site has requested UNIDO to provide content for its section on biomass conversion technologies. The structure proposed here for a stand-alone BIOTIP allows for such technical information being exported to Bioenergy Wiki whilst maintaining the integrity of BIOTIP.

Table 20 Basic BIOTIP categories and their scope

Basic category	Scope
About Biomass	Some of the properties, pros and cons, of biomass fuels.
Practical	Issues to consider when planning biomass systems
Technical	Attributes of conversion technologies
Resources	Useful information including publications and links

Table 21 Main BIOTIP menu elements

Basic category	Menu items
About Biomass	What is Biomass?
	Why use Biomass?
	Types of Biomass
Practical	Using biomass fuels
	Producing biomass fuels
	Supplying biomass fuels
	Bioenergy project development guide
Technical	Conversion technologies
	Technology suppliers (database with search engine)
	Case studies of existing installations (database with search engine)
Resources	Viability check (set of simple financial evaluation tools)
	Further reading (websites; technology handbooks; best practice guides etc.)
	Conversion factors and figures
	Glossary of terms

Category 1, **ABOUT BIOMASS,** briefly introduces what biomass is and why to use it for energy generation. This can be followed by specifics on various biomass types. If desired, a high level of detail can be included under the last heading. For instance, for each relevant type (or relevant group) of biomass material, a discussion of current uses and potential energy applications may be included. Combining two existing classification systems (Openshaw, 1998 and FAO, 2004; see Annex A) a possible frame for grouping biomass types could look as follows:

Table 22 Overview of different biomass feedstocks

Material classes	Sources	Examples
Woody biomass	Forest and plantation wood	Trees, tree section and logs
		Thinning and logging by-products
		Slabs
		Shrubs
		Stumps
		Bark
		Bamboo
		Palms
	Wood processing industry by-products	Edgings and cross-cut ends
		Wood shavings, grinding and saw dust
		Particle/fibre board, plywood, cork production, and viscose by-products

		Fibre sludge
		Black liquor from pulp mills
	Used wood	Demolition wood
		Recovered construction wood
		Woody bulk waste
		Used paper
Herbaceous biomass	Energy crops	Energy grass
		Energy whole cereal crops
	Agricultural by-products	Straw
	Agro-industrial by-products	Bagasse
		Textile industry by-products (cotton tow; sisal waste etc.)
	End use material	Used clothes
		Used insulation material
Biomass from fruits and seeds	Energy crops	Energy grain
	Agricultural by-products	Stones, shell and husks (e.g. from rice, or coffee processing industries)
	Agro-industrial by-products	Oil extraction meal (plant oil cake)
		Processing industry waste water
		Brewery and starch processing industry by-products
	End use material	Used vegetable oil
Processed fuels from plant biomass	Carbonised biomass	From wood
		From residues
	Densified biomass	Briquettes
		Pellets
	Extracted biomass	Plant oils (pal, rape, sunflower, jatropha etc.)
	Liquid biomass fuels	Bio-ethanol (and methanol)
		Biodiesel
	Gaseous biomass	Producer gas (wood gas)
		Biogas
		Landfill gas
Others /mixtures	Animal by-products	Dung
		Manure
		Poultry waste
	Horticultural by-products	Bushes (such as coffee and tea)
	Agro-industrial by-products	Slaughterhouse by-products
		Bio-sludge
	End use material	Kitchen waste
		Sewage sludge
		Bone meal

Category 2, **PRACTICAL INFORMATION,** can discuss issues to consider when planning biomass systems, including handling and storage, fuel quality, market maturity, etc. A basic project development guide could also be part of it (example attached as Annex G).

In Category 3, **TECHNICAL INFORMATION** on bioenergy conversion technologies would be central. Technological information can be presented at different levels, with each level offering additional details. Table 23 presents relevant bioenergy conversion technologies and examples use. Table 24 presents a possible system for detailing technical information.

Table 23 Relevant bioenergy conversion technologies

Category	Technology	Examples
Physical pre-processing	Comminution	Chippers: disk /drum/screw chippers Shredders and grinders: shredders, hammer mills, tub grinders and stump grinders
	Densification	Briquetting machines: mechanical piston, hydraulic piston, screw extrusion Pelletisers: e.g. rotary ring die
	Mechanical extraction (PPO production)	Small-scale pressing Industrial scale
Thermo-chemical processing	Combustion	Fixed-bed combustion: fixed grates, moving grates, travelling grates, rotating grates and vibrating grates. Fluidised-bed combustion: bubbling fluidised bed and circulating fluidised bed Dust combustion
	Gasification	Fixed-bed: updraft (or counter current), downdraft (or co-current) Fluidised-bed (bubbling, circulating or pressurised)
	Carbonisation (charcoal production)	Traditional methods: pits, mounds, beehives, metal kilns, etc Industrial scale retort systems
Bio-chemical processing	Anaerobic digestion (biogas production)	Household scale digestion Dairy waste (manure) digestion Organic waste/MSW digestion Landfill gas production
	Alcohol fermentation (bio-ethanol production)	Sugar-to-ethanol Grain-to-ethanol Cellulosic biomass-to-ethanol
Physical-chemical processing	Esterification (biodiesel production)	

Table 24 Levels of bioenergy technology details

Level	Content
0	Overview of bioenergy conversion technology categories
1	Introduction of the technology category
2	Introduction of the bioenergy technology
3	Detailed description of the bioenergy technology
4	Detailed description of the technology system components (unit operations)

Most existing bioenergy websites, such as UK Biomass Energy Centre, offer technical details up to level 2^+. To be of additional value to its intended users (SME's in developing countries), BIOTIP should offer one or more of the following: broader coverage of relevant technologies, more detailed coverage of technologies, or better discussion of the relevance in developing countries. E.G. BIOTIP could offer technology information at level 3 or 4, in the latter case offering such details as process diagrams, energy and environmental balances, etc.

BIOTIP's technical information section may contain two further elements. By providing access to a supplier database, either directly or through reegle, it would assist users to inform themselves on possible technology suppliers. By providing direct access to case studies, it will inform users on existing technology applications.

The fourth and last category, **RESOURCES**, would offer links to both internal and external resources. Internal resources may include a glossary of terms and a table of conversion factors. External resources may include documents recommended for further reading and study, such as technical handbooks and best practice guides. (Annex D contains a preliminary inventory of some useful external resources). It could also include weblinks to financial calculation models and tools that the BIOTIP user can apply to carry out his/her own viability check.

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Annex A: Examples of biomass classifications

A1. Biomass classification according to Openshaw (1998)

There are two broad types of biomass used for energy purposes, namely plant materials and (processed or unprocessed) animal dung. A third minor fuel source is from non-energy biomass products that have been discarded after their useful lifetime and then burnt as fuel. Plant materials are the most important types of biomass and the other two types are derived from plants.

Plant biomass can be subdivided into four categories. These are:

i) Woody biomass:

a. trees;
b. shrubs and scrub;
c. bushes such as coffee and tea;
d. sweeping from the forest floor;
e. bamboo;
f. palms.

The greatest concentration of woody biomass is in natural forests, woodlands and plantations. Plantation trees include both forest and farm crops such as fruit orchards, spice bushes, oil palms and beverage bushes as well as trees grown for their fibres. But trees outside the forest are important, especially those on farm. Other woody biomass to consider are road and riverine trees/bushes, hedges/live fences, shelterbelts, small clumps, urban trees and garden trees. All these latter types may contribute a significant proportion of fuelwood consumption, principally because they are close to demand.

ii) Non-woody biomass:

a. energy crops -sugar cane, cassava;
b. cereal straw;
c. grass;
d. cotton, cassava and tobacco stems and roots (partially woody);
e. banana, plantain etc.;
f. soft stems - pulses, potatoes etc.;
g. swamp/water plants.

Non-woody biomass may be grown specifically for energy such as sugar cane and cassava for ethanol production. Most crop residues will be used seasonally, although where wood is scarce, they may be stored and used year round. Some crops such as cotton and tobacco have to be uprooted and burnt either in situ or for energy purposes as a disease prevention precaution. As a fuel, crop residues require more tending than wood and generally they have a lower energy value per unit weight at the same moisture content.

iii) Processed waste:
a. cereal husks and cobs;
b. bagasse;
c. cotton tow, sisal waste etc.;
d. pineapple and other fruit waste;
e. coffee cherries, husks & parchment;
f. nut shells, flesh etc.;
g. plant oil cake;
h. sawmill waste;
i. black liquor from pulp mills;
j. municipal waste;

Processed wastes are produced mainly at factories or grinding mills, but maize cobs may accumulate at the household. Because they are present in concentrated amounts, they can be used at the factories themselves or sold to industries such as brick, tile and pottery manufacturers. Some processed waste, such as sawmill bark, off-cuts, shavings and sawdust, may have been measured already, in the field, as roundwood.

iv) Processed fuels from plant biomass:
a. charcoal (wood and residues);
b. briquettes/pellets/densified biomass;
c. ethanol/ methanol (wood alcohol);
d. plant oils - palm, rape, sunflower, jatropha, etc.;
e. bio-diesel/petrol;
f. producer gas;
g. biogas.

Charcoal is by far the most common processed fuel from plant biomass. The wood raw material usually has been measured, but if charcoal is made from such products as coffee husks or coconut shell it may not have been measured. Briquetting plants are generally small and few are profitable. Many machines have been abandoned throughout Africa and elsewhere. The raw material for briquettes is, for example, groundnut shells, papyrus or sawdust.

Source: Keith Openshaw (1998), Estimating Biomass Supply: Focus On Africa. In: Biomass Energy: Data, Analysis and Trends. Conference Proceedings. Paris, France, 23-24 March 1998. IEA/EC/UNEP. pg. 241-254.

A2. Classification of combustible renewables & waste classification according to IEA

A. Solid Biomass and Animal Products

- Wood
- Vegetal material and waste
  - *Wood waste* - *Includes sawdust, chips, shavings, bark, etc.*
  - *Forest waste* - *Includes logging residues, tops, etc.*
  - *Other Wood Wastes*
  - *Sugarcane bagasse*
  - *Rice/paddy husks*
  - *Coconut shells, fibre, pith*
  - *Maize cobs and stalks*
  - *Groundnut husks (includes peanuts)*
  - *Coffee husks*
  - *Wheat stalks and husks*
  - *Cotton stalks and waste (includes gin trash)*
  - *Mustard stalks and waste*
  - *Other straw*
  - *Olive pressing waste*
  - *Other vegetal material and waste*
- **Black liquor**
- **Animal products (for publications, combined with other solid biomass)**
  - *Dung*
  - *Other animal products*
- **Other solid biomass and animal products**

B. Gases from Biomass and Wastes

- *Landfill gas*
- *Sludge and sewage gas*
- *Other gases from biomass and wastes*

C. Liquids from Biomass and Wastes

- *Alcohols (ethanol, methanol, etc.)*
- *Bio-additives (e.g. from oleaginous plants)*
- *Other distilled liquids from biomass & wastes*

D. Industrial waste

E. Municipal waste

F. Charcoal

Source: J. Denman (IEA Energy Statistics Division), IEA Biomass Energy Data: System, Methodology and Initial Results, In: Biomass Energy: Data, Analysis and Trends. Conference Proceedings, Paris, France, March 1998, IEA/EC/UNEP, pg. 19-38.

A3. UBET Biomass classification according to FAO, 2004

Table 3: Overview on the most important biofuel supply sources

Material classes	Sources	Examples
woody biomass	forest and plantation wood	energy forest trees
		energy plantation trees
		short rotation trees
		thinning by-products
		logging by-products
		complete tree
		whole tree
		tree section
		slabs
		shrubs
		stumps
		bark
	wood processing industry by-products	edgings
		cross-cut ends
		wood shavings
		grinding dust
		saw dust
		particle/fibre board by-products
		plywood by-products
		cork production by-products
		viscose by-products
		fibre sludge
		black liquor
	used wood	demolition wood
		recovered construction wood
		woody bulk waste
		used paper
herbaceous biomass	energy crops	energy grass
		energy whole cereal crops
	agricultural by-products	straw
	agro-industrial by-products	bagasse
		textile industry by-products
	end use material	used clothes
		used insulation material
biomass from fruits and seeds	energy crops	energy grain
	agricultural by-products	stones
		shells
		husks
	agro-industrial by-products	oil extraction meal
		brewery by-products
		starch processing industry by-products
	end use material	used vegetable oil
others /mixtures	animal by-products	dung
		manure
		poultry waste
	horticultural by-products	bushes
	landscape management by-products	road side green
		protected areas management by-products
	agro-industrial by-products	slaughterhouse by-products
		bio-sludge
	end use material	kitchen waste
		sewage sludge
		bone meal

Annex B: Two examples of technology briefs

B1. Technology brief biomass combustion [*]

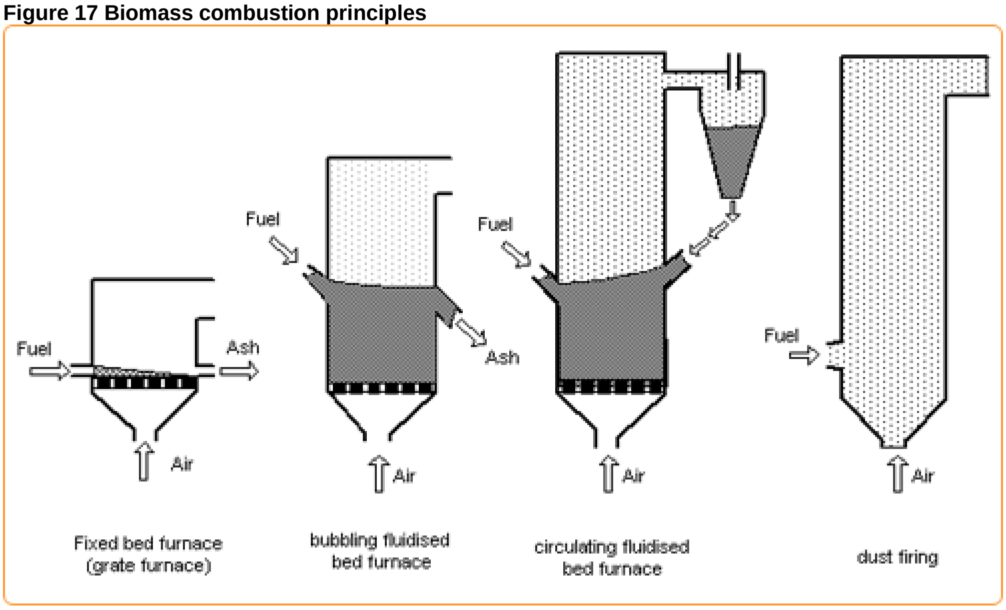
Introduction

Combustion is the most common way of converting biomass to energy - both heat and electricity - and worldwide it already provides over 90% of the energy generated from biomass. It is well understood, relatively straightforward, commercially available, and can be regarded as a proven technology. Compared to the other thermo-chemical primary conversion technologies (gasification, pyrolysis), it is the simplest and most developed, and biomass combustion systems can easily be integrated with existing infrastructure.

Modern industrial combustion plants are equipped with process control systems supporting fully automatic system operation thus eliminating the need for manual fuel-feeding, which reduces the relatively high personnel costs, but also results in lower emissions. The following combustion technologies can, in principle, be distinguished:

- fixed-bed combustion,
- fluidised bed combustion,
- dust combustion.

Figure 17 Biomass combustion principles



The desire to burn uncommon fuels, improve efficiencies, cut costs, and decrease emission levels continuously results in new technologies being developed. For further implementation of biomass combustion, combustion technology should further be optimised to keep it competitive as gasification and pyrolysis develop. Co-firing biomass with coal in traditional coal-fired boilers represents one combination of renewable and fossil energy utilisation that derives the greatest benefit from both fuel types.

[*] This technology brief originates verbatim from IEA Task 29.

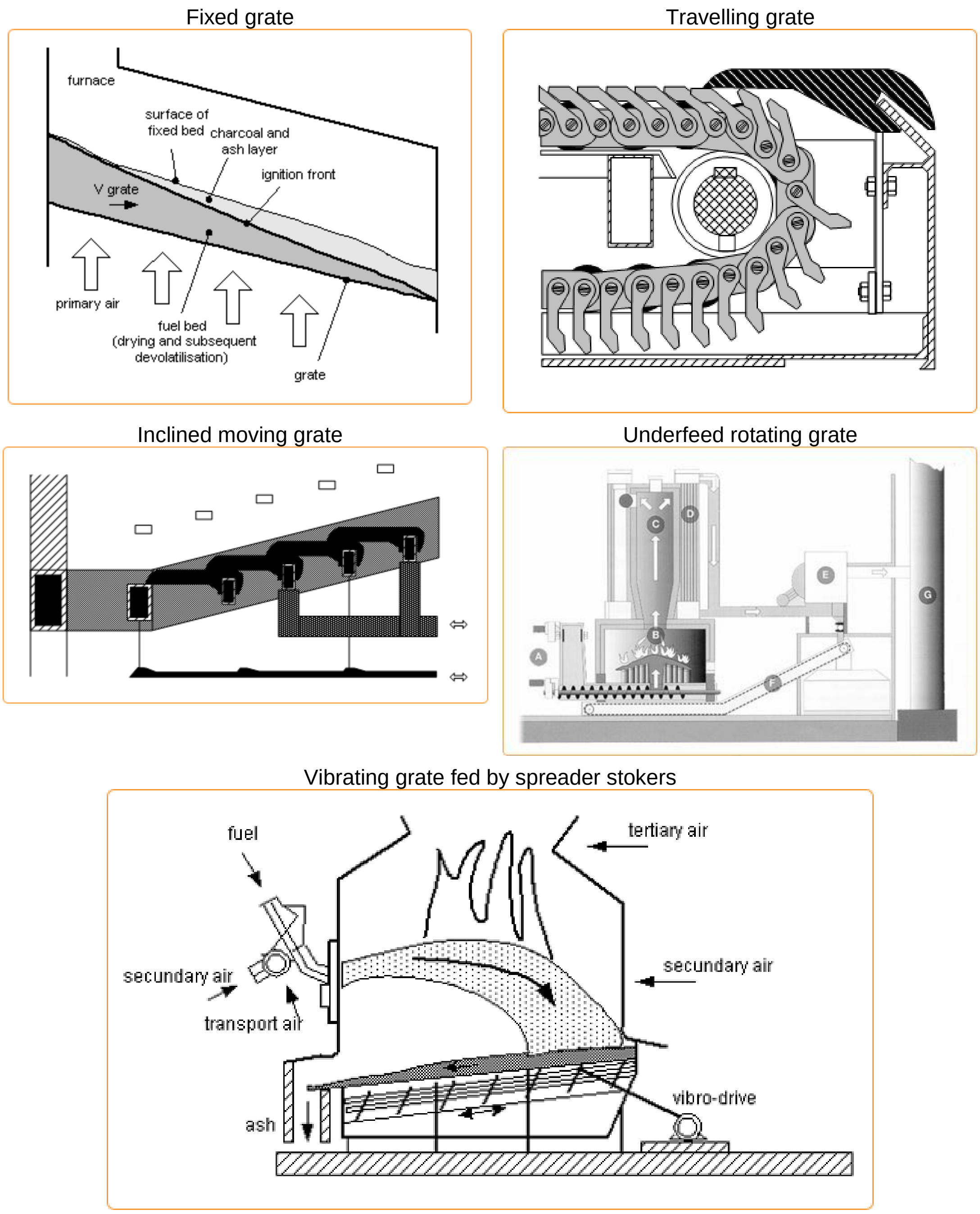
Fixed-bed combustion

Fixed-bed combustion systems include grate furnaces and underfeed stokers. Primary air passes through a fixed bed, in which drying, gasification, and charcoal combustion takes place. The combustible gases produced are burned after secondary air addition has taken place, usually in a combustion zone separated from the fuel bed.

Grate furnaces are appropriate for biomass fuels with a high moisture content, varying particle sizes (with a downward limitation concerning the amount of fine particles in the fuel mixture), and high ash content. Mixtures of wood fuels can be used, but current technology does not allow for mixtures of wood fuels and straw, cereals and grass, due to their different combustion behaviour, low moisture content, and low ash-melting point. A good and well controlled grate is designed to guarantee a homogeneous distribution of the fuel and the bed of embers over the whole grate surface. This is very important in order to guarantee an equal primary air supply over the various grate areas. Inhomogeneous air supply may cause slagging, higher fly-ash amounts, and may increase the excess oxygen needed for a complete combustion. Furthermore, the transport of the fuel over the grate has to be as smooth and homogeneous as possible in order to keep the bed of embers calm and homogeneous, to avoid the formation of holes and to avoid the elutriation of fly ash and unburned particles as much as possible. There are various grate furnace technologies available: **fixed grates, moving grates, travelling grates, rotating grates and vibrating grates**. All of these technologies have specific advantages and disadvantages, depending on fuel properties, so that careful selection and planning is necessary.

Underfeed stokers represent a cheap and operationally safe technology for small- and medium-scale systems up to a nominal boiler capacity of 6 MWth. They are suitable for biomass fuels with low ash content (wood chips, sawdust, pellets) and small particle sizes (particle dimension up to 50 mm). Ash-rich biomass fuels like bark, straw, and cereals need more efficient ash removal systems. Moreover, sintered or melted ash particles covering the upper surface of the fuel bed can cause problems in underfeed stokers due to unstable combustion conditions when the fuel and the air are breaking through the ash-covered surface. An advantage of underfeed stokers is their good partial-load behaviour and their simple load control. Load changes can be achieved more easily and quickly than in grate combustion plants because the fuel supply can be controlled more easily The fuel is fed into the combustion chamber by screw conveyors from below and is transported upwards on an inner or outer grate. Outer grates are more common in modern combustion plants because they allow for more flexible operation and an automatic ash removing system can be attained easier. Primary air is supplied through the grate, secondary air usually at the entrance to the secondary combustion chamber. A new development is an underfeed stoker with a rotational post-combustion, in which a strong vortex flow is achieved by a specially designed secondary air fan equipped with a rotating chain.

Figure 18 Operating principles of fixed-bed combustors



Fluidised-bed combustion

Within a fluidised bed furnace, biomass fuel is burned in a self-mixing suspension of gas and solid-bed material into which combustion air enters from below. A fluidised bed consists of a cylindrical vessel with a perforated bottom plate filled with a suspension bed of hot, inert, and granular material. The common bed materials are silica sand and dolomite. The bed material represents 90-98% of the mixture of fuel and bed material. Primary combustion air enters the furnace from below through the air distribution plate and fluidises the bed so that it becomes a seething mass of particles and bubbles. The intense heat transfer and mixing provides good conditions for a complete combustion with low excess air demand. The combustion temperature has to be kept low (usually between 800-900°C) in order to prevent ash sintering in the bed. This can be achieved by internal heat exchanger surfaces, by flue gas recirculation, or by water injection (in fixed-bed combustion plants combustion temperatures are usually 100-200°C higher than in fluidised bed units).

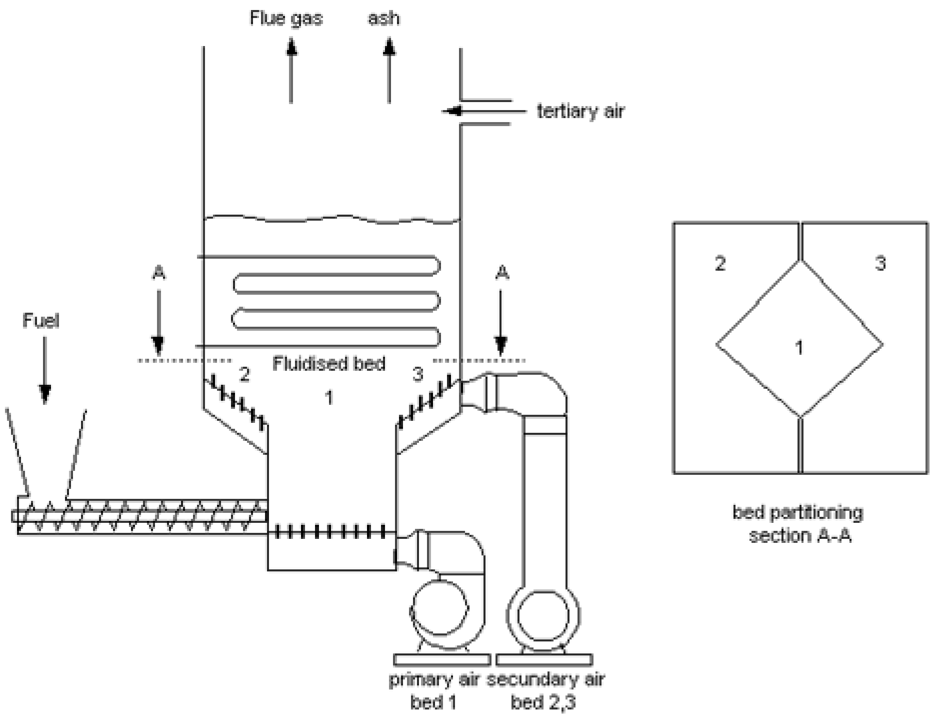
Due to the good mixing achieved, fluidised bed combustion plants can deal flexibly with various fuel mixtures (e.g. mixtures of wood and straw can be burned) but are limited when it comes to fuel particle size and impurities contained in the fuel. Therefore, appropriate fuel pre-treatment system covering particle size reduction and separation of metals is necessary for fail-safe operation.

Depending on the fluidisation velocity, **bubbling fluidised bed** and **circulating fluidised bed** combustion can be distinguished.

Bubbling fluidised bed
For plants with a nominal boiler capacity of over 20 MWth, BFB furnaces start to be of interest. In BFB furnaces, a bed material is located in the bottom part of the furnace (see figure below). The primary air is supplied over a nozzle distributor plate and fluidises the bed. The bed material is usually silica sand of about 1.0 mm in diameter; the fluidisation velocity of the air varies between 1.0 and 2.5 m/s. The secondary air is introduced through several inlets in the form of groups of horizontally arranged nozzles at the beginning of the upper part of the furnace (called freeboard) to ensure a staged-air supply to reduce NOx emissions. In contrast to coal-fired BFB furnaces, the biomass fuel should not be fed onto, but into, the bed by inclined chutes from fuel hoppers because of the higher reactivity of biomass in comparison to coal. The fuel amounts only to 1 to 2% of the bed material and the bed has to be heated (internally or externally) before the fuel is introduced. The advantage of BFB furnaces is their flexibility concerning particle size and moisture content of the biomass fuels. Furthermore, it is also possible to use mixtures of different kinds of biomass or to co-fire them with other fuels. One big disadvantage of BFB furnaces, the difficulties they have at partial load operation, is solved in modern furnaces by splitting or staging the bed.

By increasing the fluidising velocity to 5 to 10 m/s and using smaller sand particles (0.2 to 0.4 mm in diameter) a CFB system is achieved. The sand particles will be carried with the flue gas, separated in a hot cyclone or a U-beam separator, and fed back into the combustion chamber (see figure below). The bed temperature (800 to 900°C) is controlled by external heat exchangers cooling the recycled sand, or by water-cooled walls. The higher turbulence in CFB furnaces leads to a better heat transfer and a very homogeneous temperature distribution in the bed. This is of advantage for stable combustion conditions, the control of air staging, and the placement of heating surfaces right in the upper part of the furnace. The disadvantages of CFB furnaces are their larger size and therefore higher price, the even greater dust load in the flue gas leaving the sand particle separator than in BFB systems, the higher loss of bed material in the ash, and the small fuel particle size required (between 0.1 and 40 mm in diameter), which often causes higher investments in fuel pre-treatment. Moreover, their operation at partial load is problematic. In view of their high specific heat transfer capacity, CFB furnaces start to be of interest for plants of more than 30 MWth, due to their higher combustion efficiency and the lower flue gas flow produced (boiler and flue gas cleaning units can be designed smaller).

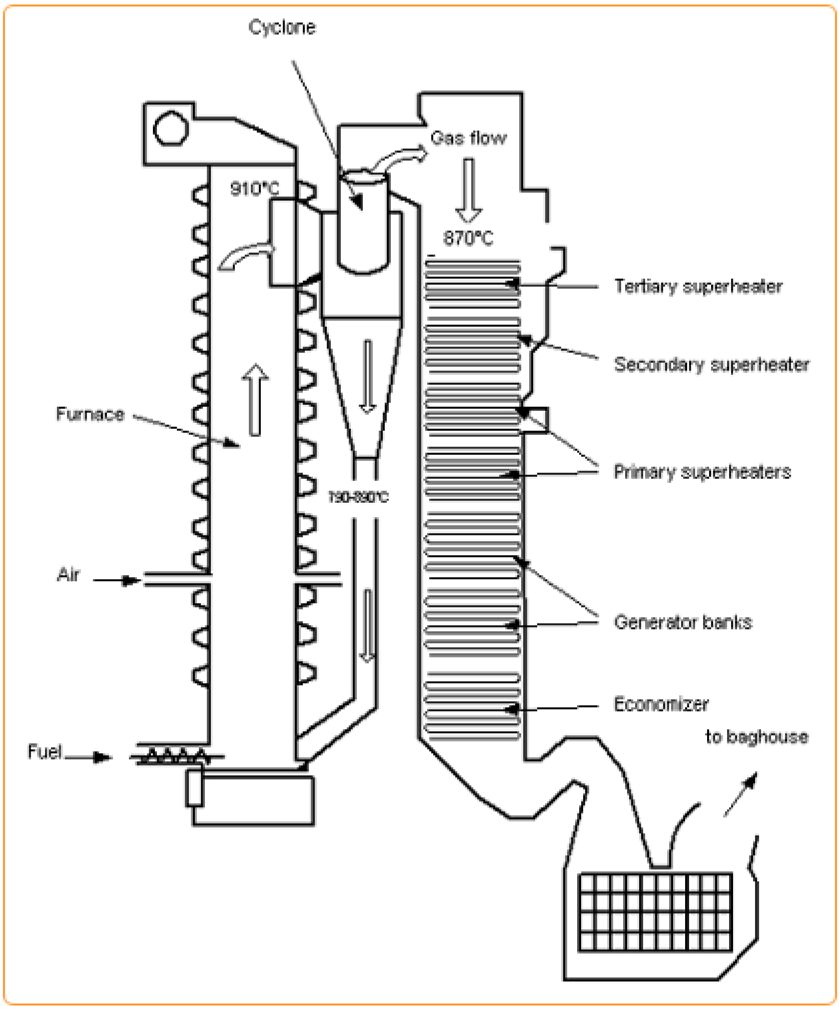
Figure 19 Operating principles of a BFB



Circulating fluidised bed

By increasing the fluidising velocity to 5 to 10 m/s and using smaller sand particles (0.2 to 0.4 mm in diameter) a CFB system is achieved. The sand particles will be carried with the flue gas, separated in a hot cyclone or a U-beam separator, and fed back into the combustion chamber (see figure below). The bed temperature (800 to 900°C) is controlled by external heat exchangers cooling the recycled sand, or by water-cooled walls. The higher turbulence in CFB furnaces leads to a better heat transfer and a very homogeneous temperature distribution in the bed. This is of advantage for stable combustion conditions, the control of air staging, and the placement of heating surfaces right in the upper part of the furnace. The disadvantages of CFB furnaces are their larger size and therefore higher price, the even greater dust load in the flue gas leaving the sand particle separator than in BFB systems, the higher loss of bed material in the ash, and the small fuel particle size required (between 0.1 and 40 mm in diameter), which often causes higher investments in fuel pre-treatment. Moreover, their operation at partial load is problematic. In view of their high specific heat transfer capacity, CFB furnaces start to be of interest for plants of more than 30 MWth, due to their higher combustion efficiency and the lower flue gas flow produced (boiler and flue gas cleaning units can be designed smaller).

Figure 20 Operating principles of a CFB

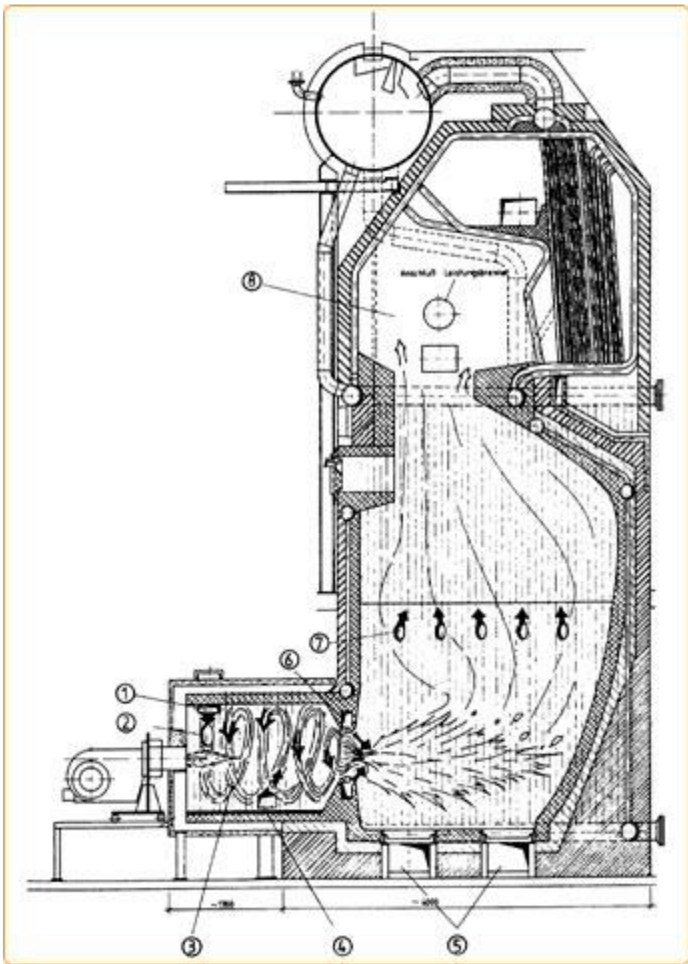


Dust combustion

Dust combustion is suitable for fuels available as small particles (average diameter smaller 2 mm). Fuels like sawdust and fine shavings are pneumatically injected into the furnace, while the transportation air is used as primary air. Fuel quality in dust combustion systems has to be quite constant and a maximum fuel particle size of 10-20 mm has to be maintained and the fuel moisture content should normally not exceed 20% (w.b.). Due to the explosion-like gasification of the fine and small biomass particles, the fuel feeding needs to be controlled very carefully and forms a key technological unit within the overall system. Fuel/air mixtures are usually injected tangentially into the cylindrical furnace muffle to establish a rotational flow (usually a vortex flow). The rotational motion can be supported by flue gas recirculation in the combustion chamber. Due to the high energy density at the furnace walls and the high combustion temperature, the muffle should be water-cooled. Fuel gasification and charcoal combustion take place at the same time because of the small particle size. Combustion takes place while the fuel is in suspension, and gas burnout is achieved after secondary air addition. Therefore, quick load changes and an efficient load control can be achieved.

Muffle dust furnaces in combination with a water-tube steam boiler) are being used more and more for fine wood wastes originating from the chipboard industry. This technology is available for thermal capacity between 2 and 8 MW. The outlet of the muffle forms a neck, where secondary air is added in order to achieve a good mixture with the combustible gases. Due to the high flue gas velocities, the ash is carried with the flue gas and is partly precipitated in the post-combustion chamber. Low excess air amounts and low NOx emissions can be achieved by proper air staging. Besides muffle furnaces, cyclone burners for wood dust combustion are also in use. Depending on the design of the cyclone and the location of fuel injection, the residence time of the fuel particles in the furnace (their burnout) can be controlled well.

Figure 21 Operating principle of a dust combustion plant (muffle furnace) in combination with a water-tube steam boiler



<u>Technology evaluation and applications range</u>

Table 25 lists advantages and disadvantages of various solid biomass combustion technologies. Table 26 details typical capacities and fuel properties for wood combustion techniques.

Table 25 Technological evaluation biomass combustion technologies (Van Loo & Koppejan, 2002).

Advantages	Disadvantages
Underfeed stokers • Low investment costs for plants < 6 MW_{th} • Simple and good load control due to continuous fuel feeding • Low emissions at partial load operation due to good fuel dosing	• Suitable only for biofuels with low ash content and high ash-melting point (wood fuels) • Low flexibility in regard to particle size
Grate furnaces • Low investment costs for plants < 20 MW_{th} • Low operating costs • Low dust load in the flue gas • Less sensitive to slagging than fluidised bed furnaces • Suitable for energy crops and agricultural residues	• No mixing of wood fuels and herbaceous fuels possible • Efficient NO_x reduction requires special technologies • High excess oxygen (5-8 vol%) decreases efficiency • Combustion conditions not as homogeneous as in fluidised bed furnaces • Low emissions level at partial load operation is difficult to achieve
Pulverised fuel combustion • Low excess oxygen (4-6 Vol. %) increases efficiency • High NOx reduction by efficient air staging and mixing possible if cyclone or vortex burners are used • Very good load control and fast alternation of load possible	• Particle size of biofuels is limited (<10-20 mm) • High wear out of the insulation brickwork if cyclone or vortex burners are used • An extra start-up burner is necessary
BFB furnaces • No moving parts in the hot combustion chamber • NO_x reduction by air staging works well • High flexibility concerning moisture content and kind of biomass fuels used • Low excess oxygen (3-4 Vol%) raises efficiency and decreases flue gas flow	• High investment costs, interesting only for plants > 20 MW_{th} • High operating costs • Low flexibility with regard to particle size (< 80 mm) • High dust load in the flue gas • Operation at partial load requires special technology • Medium sensitivity concerning ash slagging • Loss of bed material with the ash • Medium erosion of heat exchanger tubes in the fluidised bed
CFB furnaces • No moving parts in the hot combustion chamber • NO_x reduction by air staging works well • High flexibility concerning moisture content and kind of biomass fuels used • Homogeneous combustion conditions in the furnace if several fuel injectors are used • High specific heat transfer capacity due to high turbulence • Use of additives easy • Very low excess oxygen (1-2 vol%) raises efficiency and decreases flue gas flow	• High investment costs, interesting only for plants > 30 MW_{th} • High operating costs • Low flexibility with regard to particle size (< 40 mm) • High dust load in the flue gas • Partial-load operation requires a second bed • loss of bed material with the ash • High sensitivity concerning ash slagging • Loss of bed material with the ash • Medium erosion of heat exchanger tubes in the furnace

Table 26 Typical capacities and fuel properties for wood combustion techniques

Type	Typical size range	Fuels	Ash	Water content
understoker	20 kW - 2.5 MW	wood chips, wood residues	<2%	5%-50%
Dual-chamber	20 kW - 1.5 MW	dry wood (residues)	<5%	5%-35%
moving grate	150 kW - 15 MW	all wood fuels; most biomass	<50%	5%-60%
understoker with rotating grate	2-5 MW	wood chips, high m.c.	<50%	40%-65%
BFB	5-15 MW	various biomass, d< 10mm	<50%	5%-60%
CFB	15-100 MW	various biomass, d< 10mm	<50%	5%-60%
dust combustor, entrained flow	5-10 MW	various biomass, d< 5mm	<5%	<20%

Source: Van Loo and Koppejan, 2002.

Note on abbreviations used: m.c. = moisture content, d = diameter

B2. Technology brief ethanol production *

Introduction

Ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or materials that can be converted into sugar such as starch or cellulose. Sugar beets and sugar cane are obvious examples of feedstock that contain sugar. Corn, wheat and other cereals contain starch (in their kernels) that can relatively easily be converted into sugar. Similarly, trees and grasses are largely made up of cellulose and hemi-cellulose, which can also be converted to sugar, though with more difficulty than conversion of starch.

Ethanol is generally produced from the fermentation of sugar by enzymes produced from yeast. Traditional fermentation processes rely on yeasts that convert six-carbon sugars (mainly glucose) to ethanol. Because starch is much easier than cellulose to convert to glucose, nearly all ethanol in northern countries is made from widely-available grains. The organisms and enzymes for starch conversion and glucose fermentation on a commercial scale are readily available. Cellulose is usually converted to five- and six-carbon sugars, which requires special organisms for complete fermentation. The key steps in the feedstock-to-ethanol conversion process, by feedstock type, are shown in Figure 2.1 and discussed in the following sections.

Sugar-to-Ethanol Production

The least complicated way to produce ethanol is to use biomass that contains six-carbon sugars that can be fermented directly to ethanol. Sugar cane and sugar beets contain substantial amounts of sugar, and some countries in the EU (e.g. France) rely on sugar beet to produce ethanol. Until the 1930s, industrial-grade ethanol was produced in the United States through the fermentation of molasses derived from sugar crops. However,

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* This technology brief is based on *Biofuels for transport. An international perspective*, International Energy Agency (IEA), Paris, 2004.

the relatively high cost of sugar in the US has since made sugar cane more expensive than grain crops as an ethanol feedstock. In Brazil and in most tropical countries that produce alcohol, sugar cane is the most common feedstock used to produce ethanol. As discussed in Chapter 4, costs of ethanol production from sugar cane in warm countries are among the lowest for any biofuels.

The Sugar-to-Ethanol Production Process

In producing ethanol from sugar crops, the crops must first be processed to remove the sugar (such as through crushing, soaking and chemical treatment). The sugar is then fermented to alcohol using yeasts and other microbes. A final step distils (purifies) the ethanol to the desired concentration and usually removes all water to produce "anhydrous ethanol" that can be blended with gasoline. In the sugar cane process, the crushed stalk of the plant, the "bagasse", consisting of cellulose and lignin, can be used for process energy in the manufacture of ethanol. This is one reason why the fossil energy requirements and greenhouse gas emissions of cane-to-ethanol processes are relatively low.

Grain-to-Ethanol Production

In IEA countries, most fuel ethanol is produced from the starch component of grain crops (primarily corn and wheat in the US and wheat and barley in Europe – though sugar beets are also used in Europe). In conventional grain-to-ethanol processes, only the starchy part of the crop plant is used. When corn is used as a feedstock, only the corn kernels are used; for wheat, it is the whole wheat kernel. These starchy products represent a fairly small percentage of the total plant mass, leaving considerable fibrous remains (e.g. the seed husks and stalks of these plants). Current research on cellulosic ethanol production (discussed below) is focused on utilising these waste cellulosic materials to create fermentable sugars – ultimately leading to more efficient production of ethanol than from using just the sugars and starches directly available.

The Grain-to-Ethanol Production Process

The grain-to-ethanol production process starts by separating, cleaning and milling (grinding up) the starchy feedstock. Milling can be "wet" or "dry", depending on whether the grain is soaked and broken down further either before the starch is converted to sugar (wet) or during the conversion process (dry). In both cases, the starch is converted to sugar, typically using a high-temperature enzyme process. From this point on, the process is similar to that for sugar crops, where sugars are fermented to alcohol using yeasts and other microbes. A final step distils (purifies) the ethanol to the desired concentration and removes water. The grain-to-ethanol process also yields several co-products, such as protein-rich animal feed (e.g. distillers dry grain soluble, or DDGS) and in some cases sweetener, although this varies depending on the specific feedstock and process used.

Cellulosic Biomass-to-Ethanol Production

Most plant matter is not sugar or starch, but cellulose, hemicellulose and lignin. The green part of a plant is composed nearly entirely of these three substances3. Cellulose and hemicellulose can be converted into alcohol by first converting them into sugar (lignin cannot). The process, however, is more complicated than converting starch into sugars and then to alcohol.

Today, there is virtually no commercial production of ethanol from cellulosic biomass, but there is substantial research going on in this area in IEA countries.

A large variety of feedstock is available for producing ethanol from cellulosic biomass. The materials being considered are agricultural wastes (including those resulting from conventional ethanol production), forest residue, municipal solid wastes (MSW), wastes from pulp/paper processes and energy crops.

The Cellulosic Biomass-to-Ethanol Production Process

The first step in converting biomass to ethanol is pre-treatment, involving cleaning and breakdown of materials. A combination of physical and chemical (e.g. acid hydrolysis) processes is typically applied, which allows separation of the biomass into its cellulose, hemicellulose and lignin components. Some hemicellulose can be converted to sugars in this step, and the lignin removed.

Next, the remaining cellulose is hydrolysed into sugars, the major saccharification step. Common methods are dilute and concentrated acid hydrolysis, which are expensive and appear to be reaching their limits in terms of yields. Therefore, considerable research is being invested in the development of biological enzymes that can break down cellulose and hemicellulose. The first application of enzymes to wood hydrolysis in an ethanol process was to simply replace the cellulose acid hydrolysis step with a cellulose enzyme hydrolysis step. This is called separate hydrolysis and fermentation (SHF). An important process modification made for the enzymatic hydrolysis of biomass was the introduction of simultaneous saccharification and fermentation (SSF), which has recently been improved to include the co-fermentation of multiple sugar substrates. In the SSF process, cellulose, enzymes and fermenting microbes are combined, reducing the required number of vessels and improving efficiency. As sugars are produced, the fermentative organisms convert them to ethanol.

Finally, researchers are now looking at the possibility of producing all required enzymes within the reactor vessel, thus using the same “microbial community” to produce both the enzymes that help break down cellulose to sugars and to ferment the sugars to ethanol. This “consolidated bioprocessing” (CBP) is seen by many as the logical end point in the evolution of biomass conversion technology, with excellent potential for improved efficiency and cost reduction.

Annex C: Sample of a Technology Summary Sheet

Energy services	Electricity	Shaft power	Cooking gas[a]	Heat[a]
Range of output	5 to 500 kW_e	5 to 500 kW	10 to 1200 Nm^3/hr	40 – 5,000 MJ_{th}/hour
Range of biomass input[b]	~5 to ~500 kg/hour		~3 to ~300 kg/hour	
TECHNICAL PARAMETERS[c]				
Basic equipment	Gasifier, gas cleanup, diesel engine		Gasifier, gas cleanup, gas distr., stove	Gasifier & furnace; or Gasifier, gas cleanup, furnace
Fuel inputs	Per kWh: 1-1.4 kg biomass + ~ 0.1 litre diesel (gives 60-70% diesel replacement)		Per MJ_{th}: 0.1 to 0.15 kg biomass	
Energy outputs	~ 1 kWh per (kg biomass + 0.1 litre diesel)		6 – 10 MJ_{th}/kg biomass	
Acceptable biomass	Wood chips, corn cobs, rice hulls, cotton stalks, coconut shells, palm nut shells, soy husks, saw dust, biomass briquettes			
Biomass requirements	Sized (10-150 mm, depending on gasifier design), dried (~5-20% moisture)			
Useful by-products	Waste heat, Mineral ash	Waste heat, mineral ash	Mineral ash	Mineral ash
Key to good performance	Good gas cleanup (esp. tars), high capacity utilization			High capacity utilization
Special safety concerns	Leakage of (poisonous) carbon monoxide, exposure to (carcinogenic) tars			
Technology availability	From several multinationals and (in some countries) from domestic companies			
Difficulty of maintenance	Diesel engine maintenance		Low	Low
Key cost factors	Capital, diesel fuel, operating Labor		Capital, operating labor	
Other attributes	Can operate exclusively on diesel fuel, if necessary			can burn gas in existing oil boilers + furnaces
ENVIRONMENTAL AND SOCIOECONOMIC PARAMETERS				
Environmental strengths	Reduced pollution compared with diesel fueled engine		Reduced particulate emissions compared with direct burning of solid fuel.	
Environmental concerns	Wastewater cleanup, clean combustion			clean combustion
Direct job creation	Modest (excluding biomass collection work)			
Operator skill required	Low to modest			

a. Typical gas energy content is 4 to 5 MJ/Nm^3. Typical gas composition (volume%) is 20% CO, 10% CO_2, 18% H_2, 2% CH_4, 50% N_2.

b. Assuming an average input biomass energy content of 17.5 MJ per kilogram.

c. Systems are under precommercial development at much greater scales as well, ranging up to 10s of MW. See the discussion of gasifier/gas turbine systems in section A.2.1.4.

Source: Sivan Kartha *et al*, (2005)

Annex D: 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

Other (renewable energy publications with bioenergy coverage)

Title: Renewable Energy: Power for a Sustainable Future (Second Edition)
Author: Godfrey Boyle, editor
Publisher: Oxford University Press and the Open University, 2004), 464 pp.
Relevance: Updated from the 1996 edition. Undergraduate course textbook on renewable energy technologies, science, economics, environmental impacts, and market issues. Chapter 2 by Janet Ramage, Jonathan Scurlock and Stephen Larkin covers bioenergy

Title: World Energy Assessment: 2004 Update,
Authors: Jose Goldemberg and Thomas B. Johansson, editors
Publisher: UNDP, New York, 2004), 85 pp.
Relevance: An update to the 2000 edition (below).

Title: World Energy Assessment: Energy and Challenge of Sustainability
Author: Jose Goldemberg (ed)
Publisher: UNDP, New York, 2000, 508 pp.
Relevance: Comprehensive look at all dimensions of energy: technical, economic, social, environmental, security, economic, resources, future scenarios, rural energy, and policy. The chapter on renewable energy technologies was written by WC Turkenburg *et al*.

Annex E: An illustration of the costs of bioenergy conversion systems

Heat and power generation

The costs of generation energy from biomass depends on such factors as technology, feedstock quality and costs, regional location, and size of the plant. Large-size plants require biomass transportation over long distances. Small size means higher investment cost per kW and lower electrical efficiency relative to coal plants. As a result, any indication of bioenergy generation costs is always indicative.

Table 27 the principal technologies for bioheat and bioelectricity with their investment costs and conversion efficiencies.

Based on the assumptions concerning the investment costs and energy conversion efficiencies as presented in Table 27 energy generation costs of systems can be determined

At fuel costs of 5-7 €/GJ (80-100 € per ton biomass, the production of *heat* costs about 10-12 €/MWth in solid biomass boilers in the MW range. If the prices of biomass is set at zero, heat production costs fall to 3-7 €/MWth.

Assuming biomass costs of 3 US$/GJ, (IEA, 2007) calculates the costs of solid-biomass based *electricity* production at 8-10 €ct/kWh (11-13 US$ct/kWh). This is in compliance with the 6-12 € cents/kWh price range presented in (Bauen, 2004).

Table 27 Global overview of performance data for the main conversion routes of biomass to power and heat

Conversion option		Typical capacity range	Net efficiency (LHV basis)	Investment costs range (€/kW)
Combustion	Heat	Industrial 1-5 MW_{th}	Up to 70-90%	300-700/kWth for larger furnaces
	CHP (Stirling)	<0.1 MW_e [2]	11-20% [2]	3,700-5,200/kW_e [2]
	CHP (ORC)	0.16-1,6 MW_e [3]	10-20% [3]	1,7000-4,000 /kW_e [3]
	CHP (Steam turbine)	5-25 MW_e [2]	20-40% [1] 30-35% [2]	1,500-2,500/kW_e [1] 2.200-3,700/kW_e [2]
Gasification	Heat	Usually around 100's kWh	80-90% overall	Several 100's /kW_{th} depending on capacity
	CHP gas engine	0.1-1 MW_e	15-30%	1,500-3,000 €/kW_e[1] depending on configuration
Biogas production	Anaerobic digestion	Up to several MW_e	25-35% (electrical) [1]	2,000-5,000 €/kW_e [1]
	Landfill gas	Generally several 100's kW_e	25-35% (electrical) [1]	1,000-1,200 €/kW_e [1]

Important note: Doe the variability of data in the data sources and conditions assumed, all cost figures should be considered as **indicative**. Price ranges generally reflect European conditions. Domestic heating system, medium-to-large stand-alone power, co-firing and BIC/CC are not included in the overview (considered not relevant for SMEs).
Sources: Faaij, 2004 with following exceptions [1] Bauen, 2004) [2] IEA, 2007) [3] BTG.

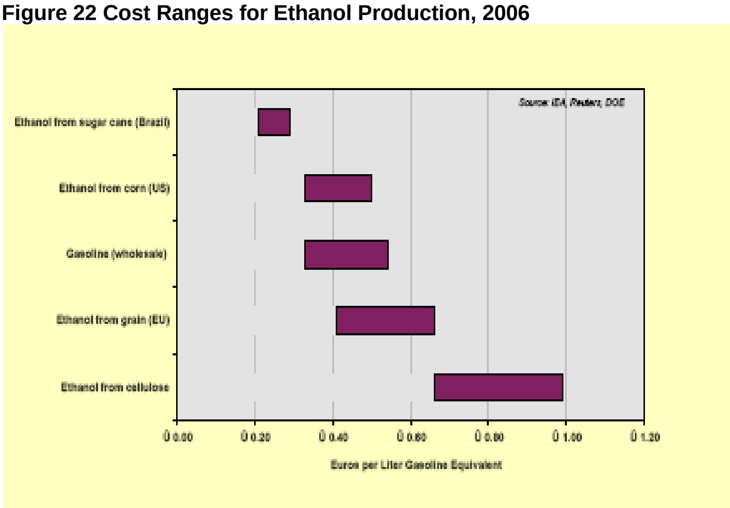
Liquid transport fuels

Like for other liquid biofuels, the largest *bio-ethanol* production costs component is the feedstock, although some 50% of this cost can be recovered by selling the co-products. The plant size has also a major impact on the costs. For a corn-based bio-ethanol plant the tripling in mill size would result in costs reduction of some 0.05 €/litre, which equals 40% on specific investment and 15020% operating costs (Girard et al, 2005).

Sees costs share the largest part of *biodiesel* production costs from 60 to 80% of the total costs. Seeds production costs vary widely depending on where the crops is grown: quality of soils and seeds, climate, quantity and prices of fertilisers and pesticides etc., all of which will affect yields and production costs.

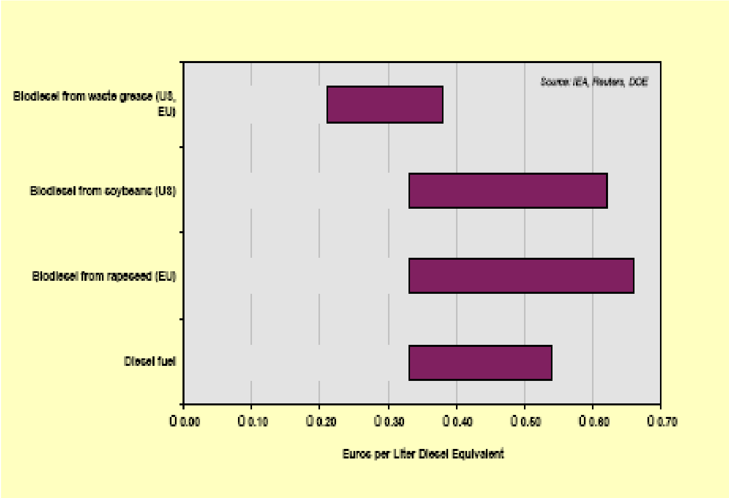
Figure 22 and Figure 23 present costs range for bio-ethanol and biodiesel production costs respectively.

Figure 22 Cost Ranges for Ethanol Production, 2006



Source: Worldwatch Institute, 2007

Figure 23 Cost Ranges for Biodiesel Production, 2006



Source: Worldwatch Institute, 2007

Annex F: Review of directories and databases

Global directories and databases

Title: reegle - the Information Gateway for Renewable Energy and Energy Efficiency
URL: www.reegle.info
Publisher: Secretariat of REEEP (Renewable Energy and Energy Efficiency Partnership)
Notes: reegle advertise itself as a one-stop shop for high quality information on renewable energy and energy efficiency. It has great search options but at the moment the number of developing country actors in the category business and industry is small.

Title: Buyer's Guide - Renewable Energy World Magazine
URL: http://www.renewable-energy-world.com/buyersguide/index.cfm
Publisher: PennWell Corporation, Tulsa, Oklahoma
Notes: Service and equipment locator, information on RE products and company details. Separate categories for (i) Biofuels for transport and (ii) Biomass and Energy from Waste. Coverage is global. When operated by James & James this directory was known as the World Directory of Renewable Energy Suppliers and Services

Tile: Green Pages - The Global Directory for Environmental Technology
URL: http://www.eco-web.com
Publisher: ECO Services International
Notes: Directory with information and reference source on green products and technology. Operational since 1994. Features a total of 7,000 leading suppliers from 151 countries. Contains a separate category for New & Renewable Energy Technologies.

Title: The Source for Renewable Energy
URL: http://energy.sourceguides.com
Publisher: Momentum Technologies LLC
Notes: Comprehensive online buyer's guide and business directory to more than 11,000 renewable energy businesses and organisations worldwide. Contains a separate category for biomass energy businesses

Title: (European Commission) ManagEnergy Initiative
URL: http://www.managenergy.net/index.html
Publisher: European Commission Directorate-General for Energy and Transport
Notes: Website includes a partner database with some 3500 organisations, including 380 energy agencies, which can provide valuable expertise and partnerships on energy activities at local and regional levels. The coverage is mainly but not exclusively Europe.

Title: EcoBusinessLinks - Green Directory
URL: www.ecobusinesslinks.com
Publisher:
Notes: Directory with over 7,000 green links. Bioenergy options covered include liquid transport fuels (pure plant oil, biodiesel and bioethanol)

Other directories and databases (smaller topical or geographical coverage)

Tile: European Catalogue Wood-fuel for heating systems
URL: http://www.biomasse-normandie.org/wood_fuel_opeur.php3
Author(s): Biomasse Normandie, France, 2002
Publisher: European Commission
Note: This catalogue registers more than 200 European professionals active in the wood-fuel sector: networks, manufacturers of thermal equipment, energy agencies and organisations involved in promoting and providing services. Contains detailed presentations. Originally developed as part of a THERMIE Programme Action.

Title: Official Directory of Wood Energy Professionals
URL: http://www.itebe.org/portail/affiche.asp?arbo=2&num=180
Publisher: International Association of Bioenergy Professionals (ITEBE), France
Notes: Lists actors in the wood energy industry. Strong focus on France. Originally published biannually (5th Print Edition released in 2004). In three languages (English, French, Deutsch). Now an electronic database but rather difficult to access

Title: Renewables made in Germany. Information about German renewable energy industries, companies and products
URL: www.renewables-made-in-germany.com
Editor: Deutsche Energie-Agentur HmbH (dena)
Notes: With up-to-date contact details of German renewable energy companies/institutions

Title: Guide to UK Renewable Energy Companies
Author: Department of Trade and Industry
Publisher: James & James
Notes: Part 2 of this guide lists renewable energy companies and organisations in the UK. The guide was printed annually (6th Print Edition released in 2001).

Title: Small and medium scale biomass boiler and stove manufacturers in Europe
URL: http://www.tekes.fi/opet/b11.htm
Publisher: OPET Finland (2002)
Notes: OPET Finland is co-ordinating action to collect information about European boiler and stove manufacturers.

Title: European directory of small-scale cogeneration suppliers
URL: www.cogen.org/cogen-challenge/Downloadables/European_Directory_Suppliers.pdf
Publisher: COPGEN Europe, 2006
Note: This directory is aimed at helping potential users of cogeneration to find product specifications and supplier contact details.

Title: The Worldwide Directory of Gasification and Pyrolysis Technology Suppliers and Processes. Part Two: Listing of Suppliers and Licensees
Publisher: Juniper Consultancy Services Ltd, UK, 2000, ISBN 1-9035350-3-4
Note: Detailed supplier directory. Now discontinued.

Title: India Solar

URL http://www.indiasolar.com/index.htm

Coordinator: India Solar

Note: Contains list of (a) biomass gasifiers manufacturers amd (b) biomass research Institutes in India

Title: Gasifiers Inventory

URL: www.gasifiers.org

Webmaster: Harrie Knoef (BTG Biomass Technology Group, Netherlands)

Note: Database on biomass gasifier manufacturers and plants

Annex G: An Example of a 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.

* 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

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