Fraunhofer USA Center for
Energy and Environment

Decision Making Guide

Wood Gasification for Energy Generation

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1 Introduction

Each year millions of tons of residual wood are available nationwide. These represent an enormous potential for sustainable energy generation that can significantly reduce the dependence on imported fossil fuels, while at the same time supporting the rural economy and decreasing greenhouse gas emissions.

Due to the high efficiency, one of the most promising technologies for decentralized energy generation is the gasification of residual wood or pulpwood. Until now, there are only a handful of wood gasification plants in the U.S. This is partly due to the fact that assessments have shown that gasifiers were not economically feasible in the past. Another reason is the complexity of possible projects, including fuel supply and handling, energy generation, and distribution of the produced energy.

Currently, energy prices are rising, especially for natural gas. Therefore, renewable energy projects become more interesting as economic boundary conditions are changing. In order to overcome the barrier of complexity, this guide was developed to help communities, industry and others interested in investigating the feasibility of a wood gasification project.

Chapter 2 describes how an assessment can be carried out. It explains how a basic technical concept is developed, what aspects have to be taken into consideration, and how the economic feasibility of a project can be determined. Some non-technical or economic aspects such as determination of project partners, permitting and public acceptance are also considered.

Chapter 3 provides a detailed description of wood combustion and gasification technologies. Chapter 4 contains background information on possible business structures and financial aspects such as funding opportunities. Chapter 5 lists references and contacts.

With all this information, the guide can help implement sustainable and technically as well as economically feasible energy generation projects based on the gasification of residual wood.

2 Project Assessment

Once a wood gasification project is considered, an assessment of its general feasibility should be carried out before next steps are taken. The assessment should include technical and economic evaluations as well as organizational and logistical aspects. Only if results are positive, it does make sense to continue further detailed planning, design, permitting, construction and operation of a plant.

For the assessment a basic concept has to be developed. This outline will also be helpful

- if an application for grants shall be submitted to funding agencies
- if contacts to potential project partners (e.g. fuel suppliers) shall be established
- to evaluate the possibilities for project financing

Compared to a detailed feasibility study, the basic concept and the assessment should be less detailed and, thus, less time consuming and cost intensive. Nevertheless, all relevant aspects have to be considered so that a decision on the feasibility of a project and the following development are based on a comprehensive and complete set of information.

The following sections will describe how such a basic concept can be developed and the subsequent assessment can be carried out. However, it shall always be kept in mind that every individual project is different and, therefore, requires a somewhat different approach. Thus, results derived from a very schematic approach can only have limited validity. It is recommended that less knowledgeable project initiators acquire qualified support for the evaluation.

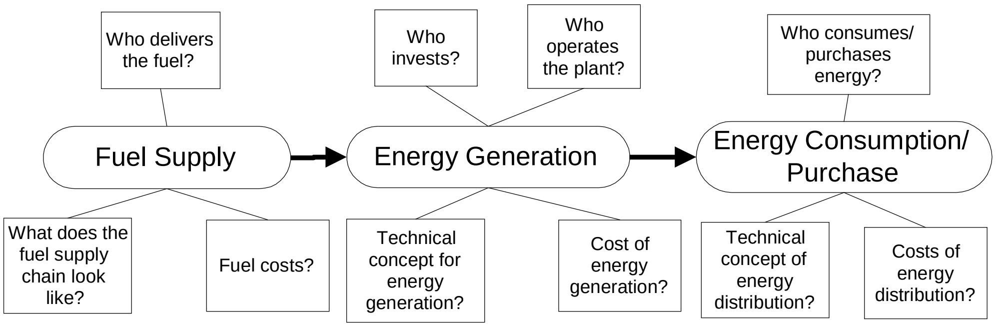
2.1 Overview of the Basic Concept

2.1.1 Aspects to be Taken into Consideration

For wood gasification projects, a comprehensive evaluation of the overall system, including fuel harvesting, processing and logistics, the energy generation plant and the energy distribution system is very important. Figure 2-1 shows the overall biomass energy system and the questions to be answered for each process step.

Figure 2-1

Overall system of a biomass energy project (Deimling et al., 2000)



In comparison to projects utilizing fossil fuels, biomass projects show some unique factors need to be considered:

- The fuel might not be available continuously over the whole year and the heating value is lower compared to fossil fuels. Thus, the optimization of fuel logistics is an important factor for an economic operation of the plant
- A market for wood chips, sawdust etc., comparable to those for coal and oil, doesn’t exist and, therefore, upfront negotiations with potential fuel suppliers are important to ensure a long-term supply and stable prices
- As plant economics often are not competitive compared to plants designed for fossil fuels, it has to be determined in an early stage if additional funding is available or if other driving factors will make up for lower return on investment
- The energetic utilization of biomass in gasifiers is far less commonly applied than other energy generation technologies. Thus, many projects still can be considered to be development or demonstration projects associated with higher technical risks
- Communities or fuel suppliers are often the first to develop a project idea. It has to be ensured that other partners (for financing, construction and operation of the plant) are involved in early stages of project planning

The early involvement of all necessary project partners in the project is important for the development of a feasible basic concept. For example, fuel suppliers can provide more reliable information on fuel availability and prices, and potential consumers can provide important information on their energy demand. If the initiator of the project isn’t the investor or operator of the plant, contacts to these parties should also be established in early project stages.

2.1.2 Goals of the Basic Concept

The development of a basic concept shall have the following goals:

- Assessment of the general technical and economic feasibility, based on the collection of all necessary data, including legal aspects as basis for a first decision

- Development of a basis for the assessment of the technical and economic risks

- Identification of criteria that lead to a cancellation of the project

- Identification of potential project partners (for fuel supply, financing and construction of the plant, consumers of the produced energy, etc.)

- Making information on the project available to all partners

- Development of the basis for applications for funding and for the assessment of financing options

- Building a basis for further project development

The early identification of criteria that might lead to the cancellation of the project can help either stop the project in an early phase when expenses are still low, or make changes (e.g. in boundary conditions) to avoid these critical circumstances at an early stage where related costs are relatively low. Some of these criteria could be for example:

- 100 % financing of the project cannot be secured, not even with public funding or changing of boundary conditions

- No partner takes the lead for further project development and/or no investor can be found

- There is not enough biomass available

- Potential energy consumers disapprove of project

- Potential consumers of (heat) energy are not located closely enough or cannot be connected in a reasonable time frame

- Permitting is too complicated or involves unreasonable additional requirements

- Necessary space is not available

- No sufficient public acceptance, which will lead to unreasonable difficulties in realization of project

2.1.3 Main Components of the Basic Concept

Based on the goals, the following questions have to be answered with the basic concept:

- What are the boundary conditions of the project, especially economics?
- Who are potential energy consumers, and what is their demand?
- How much and what kind of biomass is available? Which pretreatment steps are necessary for gasification of the biomass? Which possibilities for storage do exist?
- Which sites are available?
- What could the technical concept of the energy generation plant and the energy distribution system look like?
- Which permits are necessary?
- How high are the investment and annual operating costs (also in comparison to conventional alternatives)?
- Which funding sources are available?
- Who could be a potential project partner? Who will take the lead in financing and construction of the plant?

As shown in Table 2-1, the contents of the basic concept resulting from these questions can be divided into technical, economic, and other aspects.

Table 2-1

Main components of the basic concept (Deimling et al., 2000)

Technical Aspects (Basic Concept)	**Economic Aspects (Assessment of Economic Feasibility)**	**Other Aspects**
Definition of boundary conditions	Assessment of capital needs	Preliminary determination of project partners
Assessment of amount of biomass needed	Assessment of economic feasibility	Assessment of permit requirements
Basic concept of fuel supply	Evaluation of funding sources	Assessment of public acceptance
Basis technical concept of gasification plant and energy utilization		Preparation of next steps for project realization
Documentation		

For an initial assessment, it is not necessary to evaluate all aspects in detail or even make final decisions. It is more important that at least one solution can be found for each aspect. All aspects should be covered with the same depth. It doesn't make sense to evaluate some aspect in detail and not cover others sufficiently.

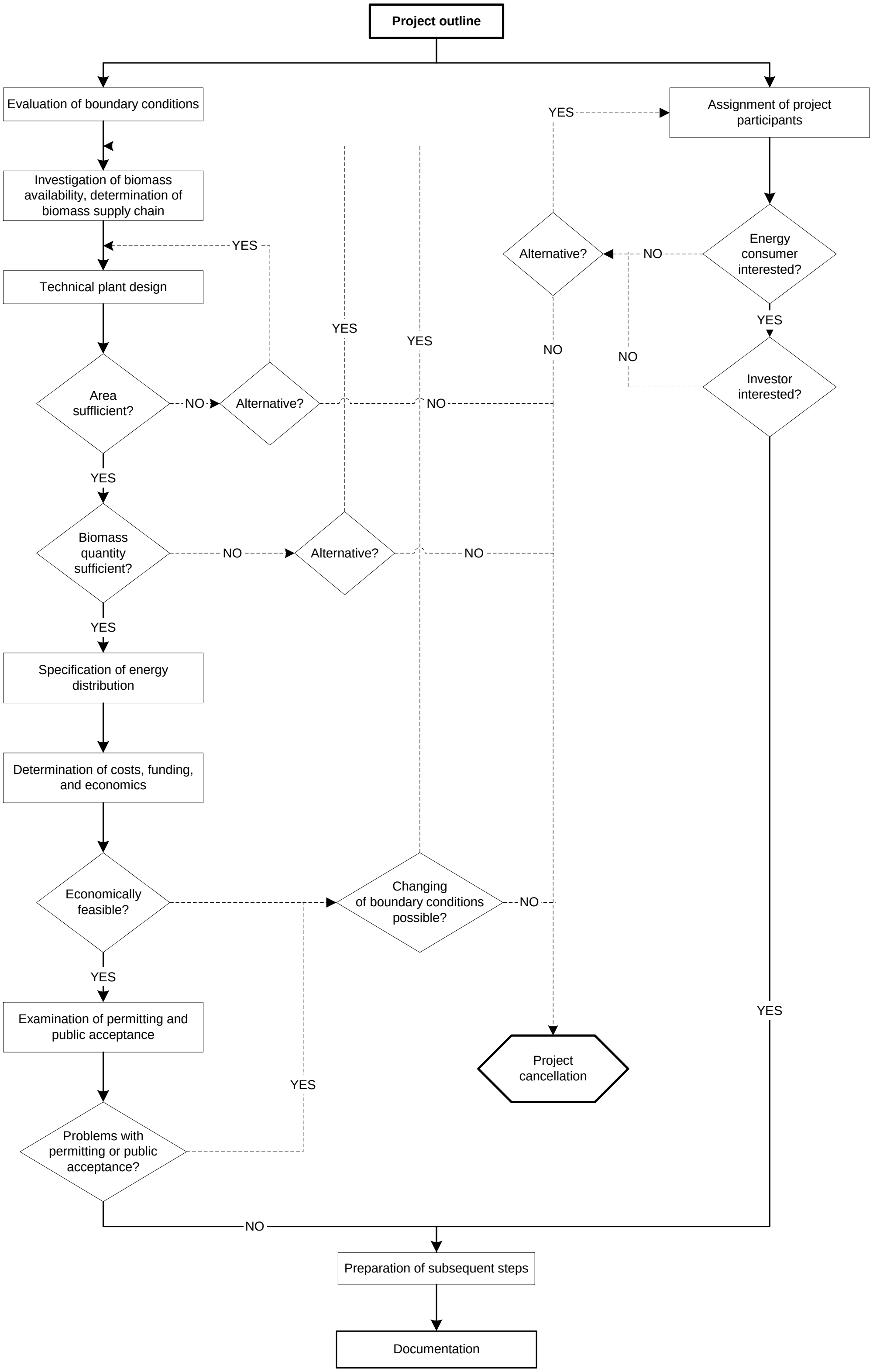
Furthermore, a sufficient documentation of the results is needed to be able to reproduce and comprehend the procedures and calculations. A short report can be used to introduce the project to other potential partners, funding institutions, etc. The report shouldn't contain extensive explanations of calculations, but briefly list the boundary conditions, assumptions made, the methodology used, the results, and the conclusions drawn from the results. Often it is helpful to begin the report with a short list of positive effects like environmental and regional benefits.

2.1.4 Proceeding with Development of the Basic Concept

From the contents and goals described above, a schematic procedure to develop a basic concept is illustrated in Figure 2-2. The order of the tasks relates to the time dependent succession.

Figure 2-2

Schematic procedure for the development of a basic concept (Deimling et al., 2000)



2.2 Basic Technical Concept

The basic technical layout is mainly needed to assess the technical feasibility. It also builds the basis for the economic feasibility assessment.

The evaluation of the technical feasibility includes the question, how far the designated technology is proven and tested, so that common guarantees and warranties can be obtained from vendors. In case the technology is still in the development or demonstration phase, the project is associated with a higher technical and economic risk. This must not necessarily be a criteria to cancel the project (it can even be the goal of a project to demonstrate a specific technology), but all project partners must be aware of this fact, and the probability of additional investment due to technical changes etc. has to be allowed for.

For most gasifiers with energetic utilization of the gas, the basic concept includes the following steps:

- Determination of boundary conditions with rough evaluation of energy demand
- Evaluation of amounts of available biomass
- Concept of biomass supply chain
- Preliminary plant concept (gasification technology, gas cleaning, etc.) including determination of thermal power (fuel input), operating parameters and design specification. Peak boilers have to be included if necessary
- Basic concept of layout for construction
- Basic design of energy distribution system

For smaller plants, not all aspects may be relevant, while for big plants with a very complex design, much more efforts are necessary. A basic design for the electric and control equipment is not usually necessary because it doesn’t influence the final decision if a plant is going to be built. A cost estimate based on the size of the plant should be sufficient.

2.2.1 Determination of Boundary Conditions

To develop the basic concept, several boundary conditions have to be determined as a first step. These include the site of the plant, data on the energy demand (especially heat) of the consumer(s), and economic conditions such as gas and electricity prices. In case of combined heat and power generation, aspects concerning the connection with the grid such as location of connection, voltage level, and amount of electricity consumed by the plant also have to be determined.

2.2.1.1 Determination of Plant Location

An important criterion for site selection is the distance of the plant from the consumers of the produced energy, which should be as small as possible. Furthermore, adequate road or rail access to deliver the fuel and enough space for storage have to be available. Potential restrictions regarding permitting or acceptance of neighbors also have to be taken into consideration, and the ownership or the option of leasing the property have to be clarified.

2.2.1.2 Determination of Heat Demand

The heat demand of the consumers of the produced energy is one of the most important factors and has to be evaluated. Main parameters of heat demand are:

- Peak heat demand
- Annual heat consumption
- Temperature level of heat needed
- Seasonal changes of demand as annual load curve (for the basic concept the assumption of a trend typical for this kind of consumer is sufficient)

The data basis for determination of the heat demand includes the following aspects:

- Number and type of buildings
- Information on number of floors, floor space, number of tenants, age of buildings
- Information on steam or gas demand of industrial consumers

The heat demand can be determined by one of the following procedures:

- Method of energy consumption: It is assumed that the heat demand will be the same as in the past, information on which is given or can be calculated from information on the fuel consumption
- Method of indicators: Heat demand is evaluated based on experience (values obtained from similar buildings). For indicators such as floor space, work places, hospital beds etc., values can be found in literature. The standard procedures that have been widely used for the heating, ventilation, and air condition (HVAC) industries are available in the guidelines developed by the Air Conditioning Contractors of America (ACCA). These guidelines (e.g., ACCA Manual J and N for residential and commercial load calculation, respectively) help estimate heating loads accurately, including heat loss from the building through walls and ceilings, leaky ductwork, and infiltration

through windows, doors, and other penetrations as well as heat gain into the building from sunlight, people, lights and appliances, etc. As rule of thumb, depending upon construction and location, a home or building requires on the order of 5 to 20 Btu/hr per square foot of floor space (GHC Bulletin, 2001).

In case several consumers shall be supplied, it has to be taken into consideration that their peak demand usually doesn't occur at the same time and, thus, the overall peak demand is lower (about 10 % – 30 %) than the sum of the individual peak demands.

In addition to the present heat demand, future developments are also important. The following aspects can influence the demand:

- Improved insulation of buildings
- More efficient heat use at industrial consumers
- Increase of demand due to extension of production of industrial consumers
- Addition of buildings

The goal is to achieve a realistic, not too optimistic estimation of future developments. It happens very often that an expected demand increase due to planned expansions of industrial plants does not occur. This is why heat generation plants were often designed too big. It is more advantageous to design a system so that it covers the current demand, but can easily be extended in the future.

2.2.2 Determination of Electricity Demand

In case electricity consumers can be supplied, their demand also has to be determined. As for heat, peak demand as well as annual consumption and seasonal variations are parameters to be investigated.

Another option is to feed electricity into the grid. This has to be negotiated with the local utility and/or utilities that are specialized in purchasing and distributing energy generated from renewables.

2.2.3 Determination of Biomass Availability

First it has to be determined which kind of biomass shall be used. For example, the combined gasification of wood chips and fuels of other consistency can require a more costly feeding system, which might be too expensive for smaller plants.

The evaluation of available amounts of biomass is associated with many uncertainties because long-term supply contracts won't be made in this early stage of the project. Therefore, only a very conservative estimate shall be the basis for plant design. Further aspects to be evaluated in this phase are:

- Transport distances for biomass to be used in the plant
- Seasonal variations in fuel supply (which influences the necessary storage capacity)
- Fuel properties (moisture content, heating value)
- Bulk density (for determination of transport and storage volumes)

2.2.4 Concept of Fuel Supply Chain

The fuel supply chain includes harvest, processing (e.g. chipping), intermediate storage, and transport to the gasifier. For the basic concept, it is not necessary to determine every detail, but to list all possible options for the respective project. However, for the following aspects, at least preliminary decisions should be made together with the potential future fuel suppliers because they are important for the basic plant design and cost assessment:

- Form (chips, saw dust, etc.)
- Method of long-term storage (centralized at gasifier or decentralized)
- Capacity of fuel storage at the gasifier
- Necessary fuel processing steps

2.2.5 Concept of Gasification Plant and Operation Parameters

To define the technical concept, the type and the capacity of the energy generation plant and its components have to be determined first. Especially, the following aspects have to be taken into consideration:

- Will the produced gas be used in existing boilers or other equipment so that only the gasifier has to be designed and built (although some changes may be necessary at the existing equipment, e.g. retrofitting of burners)?
- Shall electricity be produced? If yes, will a gas engine, a micro turbine, or a steam process be most favorable?
- Will there be just one boiler, or does it make more sense to have one boiler to cover base load and one or several others for peak load and backup?

- Will there be other, conventional fuels used to cover peak demand?
- What are the consumer’s requirements regarding security of supply?

The assessment of the consumer’s demand is the basis for determination of the technical concept. Heat losses also have to be taken into account, especially if a bigger district heating network shall be supplied.

The technical concept will be the result of a technical and economic optimization process. Several scenarios regarding base and peak load supply have to be compared. Usually, calculations for a more detailed optimization are only carried out in a subsequent stage of planning. For the first basic concept, it is usually sufficient to define the best concept based on experience.

Once the technical concept is given, the necessary components for wood gas and flue gas treatment have to be determined as a next step. On this basis, the relevant design and operation parameters such as annual fuel consumption, total annual amount of gas, heat and electricity produced, ash produced, etc. can be determined. Following a preliminary layout of the whole plant including components such as pumps, gas engine or turbine, generator, etc., has to be developed. At this planning stage, only parameters that are needed to assess the technical feasibility and to estimate investment costs have to be determined for these components.

2.2.6 Basic Design of Buildings

The basic layout and design of the buildings that house the gasifier and the other components including fuel storage are needed to determine the footprint of the plant and the dimensions of the buildings, which are then needed to calculate investments costs. It can also be evaluated if the designated site provides sufficient space.

2.2.7 Basic Concept of Energy Distribution System

In case electricity will be produced, the main components for connecting the generator to the grid have to be determined.

Depending on the utilization of the heat produced by the gasifier and potentially the gas engine or turbine, a distribution system has to be built that can transport the heat in form of hot water or steam to the consumers. In case a whole area shall be supplied through a district heating network, the lengths and diameters of the pipelines as well as the number of consumer substations have to be determined. Furthermore, it has to be taken into consideration if rivers or highways, railways, etc. have to be crossed.

2.2.8 Summary of the Evaluation

Table 2-2 shows a summary of the different steps for development of the basic concept.

Table 2-2

Steps for the development of the basic concept (Deimling et al., 2000)

Steps	Parameters to be determined
Determination of boundary conditions	Plant site Energy demand of consumers
Evaluation of available fuel amounts	Amounts of fuel Distances from plant Annual variations Main fuel properties
Basic concept of fuel supply chain	Form of biomass delivered Long-term storage Processing steps
Preliminary concepts of plant	Number, types and capacities of main plant components Wood gas cleaning Flue gas cleaning Design and operation parameters Parameters of other plant components
Building	Footprint Dimensions
Energy distribution system	Connection to electricity grid Lengths and diameters of heat pipes Number of consumer substations

2.3 Assessment of Economic Feasibility

2.3.1 Economic Boundary Conditions

A first step for evaluating the economic feasibility is to determine boundary conditions such as annual percentage rate for loans and time frame of the assessment. Furthermore, economic base data have to be collected such as:

- Fuel costs including transportation
- Natural gas prices for comparison or for coverage of peak demand
- Achievable reimbursements for gas, heat, and electricity

Fuel prices and their future development are amongst the most important parameters for the economic feasibility of a gasification plant.

2.3.2 Assessment of Investment and Possibilities of Funding

The second step is to assess the overall investment costs. These are needed to calculate the annual net debt service and the total capital demand.

Investment costs for a gasifier are very site specific and depend on the size and type of gasifier, the utilization of the produced gas, existing infrastructure, the necessary size of a storage, etc. There hasn't been much information published on investment costs of existing wood gasifiers. In addition, it is difficult to compare prices of different plants, because most of the currently operated wood gasifiers on a larger scale are based on different technologies.

However, cost information on single components like gas engines (approximately \$1,000 per kW_{el} for engines capable of burning wood gas), pipes, wood storage, conveyors, boilers, etc., can be obtained relatively easily from potential suppliers, as these components can also be used for other energy generation plants and are sold in higher numbers. To get reliable price data for the gasifiers itself and the respective components for gas treatment, prices usually have to be calculated specifically for the respective site and application, based on the information developed in the basic concept.

However, the following figures can be used as reference values for a first, very rough estimate. Overall investment costs for gasifiers with electricity generation (for the whole plant including wood storage and equipment for electricity generation) are in the range of:

- For plant sizes > 10 MW_{el}, approximately \$2,000 / $kW_{el, installed}$
- For plant sizes around 5 MW_{el}, approximately \$2,500 / $kW_{el, installed}$
- For plants with capacities well below 5 MW_{el}, well above \$2,500 / $kW_{el, installed}$

If the gas from wood gasifiers is used in industrial processes and, thus, no electricity generation equipment is needed, prices are in following ranges:

- For plants bigger than 20 $MW_{fuel\ input}$, below \$250 / $kW_{fuel\ input}$
- For plant sizes around 10-15 $MW_{fuel\ input}$, around \$300 / $kW_{fuel\ input}$
- For plant sizes around 5 $MW_{fuel\ input}$, approximately \$400 / $kW_{fuel\ input}$
- For plants with capacities well below 5 $MW_{fuel\ input}$, above \$450 / $kW_{fuel\ input}$

In some cases, public funding could be available to cover at least part of the investment. Therefore, possibilities of public funding should be investigated. Especially for pilot and demonstration plants, grants could be available from, for example, the Pennsylvania Department of Environmental Protection (DEP), the US Department of Agriculture (USDA), the US Department of Energy (DoE), Sustainability Funds (usually only as a low interest loan), private foundations, etc. As the availability of grants from a specific program usually is restricted to a certain time period, websites of these organizations should be checked regularly for solicitations. Additional information is provided in chapter 4 of this guide.

2.3.3 Assessment of Operation Costs

For wood gasification plants, the following operation costs usually occur:

- Fuel costs
- Costs for maintenance and repair
- Insurance and taxes
- Personnel costs
- Costs for utilities (water, electricity) and ash disposal
- Lease for site

These costs are further described separately in subsequent sections.

2.3.3.1 Fuel Costs

Fuel costs can differ considerably depending on the location and type of fuel. Therefore, assessments have to be made for each specific site. Investigations for different project in Northwestern Pennsylvania have shown a range from $10.00/ton to $40.00/ton, averaging around $20.00/ton. Sawdust is usually the cheapest fuel, followed by wood chips and pulpwood. These costs include transportation, which is usually about $100/truckload (approximately 30 tons).

Fuel costs have the strongest influence on the overall feasibility of a gasification plant and should be determined carefully. Long-term supply has to be ensured, and average prices should be considered rather than relying only on one relatively cheap source.

2.3.3.2 Maintenance and Repair

These costs include all expenses for maintenance and repair, but exclude personnel costs of own personnel. Usually, they are not constant but vary significantly over the year. Average values over the lifetime of a gasification plant can be estimated based on investment costs, e.g., for

- Building: 1% of investment

- Gasifier and other plant components: 2-3% of investment
- Control equipment: 1.5% of investment
- District heating network: 2% of investment

For a first assessment, 2.5% of the overall investment could be considered as a conservative estimate.

2.3.3.3 Insurance and Taxes

As a first assumption, insurance costs can be estimated to be about 1% of the investment.

Taxes depend on the type of business and the plant owner's income from other activities.

2.3.3.4 Personnel Costs

Personnel are needed for administrative as well as for technical tasks. Administrational expenses depend less on the plant size than on other parameters. For a gasifier at an industrial facility, the pre-existing administrative personnel can usually carry out part of the work.

Personnel demand for plant operation and maintenance depends on the plant size and the usage of the produced energy. For small scale plants under 1 MW, only a part time control and supervision of fuel supply is necessary in a range of 0.2 – 0.4 person years. Heat generation plants of 1 – 5 MW require 1 - 3 operators. Heat generation plants of more than 5 MW require 3 - 5 people, and CHP (combined heat and power generation) plant of more than 5 MW fuel input require 4 – 7 operators.

Annual inspections and more serious maintenance and repair work should be carried out by specialized companies.

2.3.3.5 Costs for Utilities and Ash Disposal

Utilities needed by gasification plants include

- Water to cover losses in steam cycles (if steam is produced to drive turbines etc.)
- Electricity to cover the plant's demand (mainly for pumps and blowers)

Costs depend on the annual demand and local prices.

As wood contains some ash (1-3% for clean wood, more if the fuel contains soil etc.), disposal costs of approximately $50.00/ton have to be considered.

Overall, annual costs for utilities and ash disposal can be estimated to be about 0.1 – 0.5% of the investment.

2.3.3.6 Lease

In case the plant is built on leased ground, these costs have to be included in the economic assessment. Prices vary locally. Costs can also be considered if the plant owner also owns the land, but could lease it to someone else if the gasifier wasn't built.

2.3.4 Carrying Out the Economic Assessment

2.3.4.1 Simple Payback Period

The easiest way for a first, rough assessment of the economic feasibility of a project is to calculate the simple payback period. The simple payback period is the time after which the savings (if produced gas and/or electricity replaces gas and electricity that were purchased from utilities) and income from sales of produced energy equal the investment, fuel and operating costs incurred until that time. It is calculated with the projected net cash-flows (not discounted) and debt principal payments for the entire capital investment less avoided alternative investment and grants.

For example, if a plant with an overall investment of $15,000,000 generates an income of $5,000,000 annually from electricity and $800,000 from heat sales, has annual fuel costs of $1,800,000 and operating costs of $2,000,000, the simple payback period is 7.5 years:

$$\frac{\$15{,}000{,}000}{\$5{,}000{,}000/yr + \$800{,}000/yr - \$1{,}800{,}000/yr - \$2{,}000{,}000/yr} = 7.5yr$$

2.3.4.2 Net Present Value

A first basic principle of finance is that money today is worth more than the same amount of money in a year, because the money could be invested immediately to earn interest. To determine the present value (PV) of a pay-off realized in the future, the pay-off C_1 can be multiplied by a discount factor:

$$PV = discount\ \ factor \times C_1$$

The discount factor is usually expressed as the reciprocal value of 1 plus the rate of return (r), which is demanded by an investor for providing his capital for a project and accepting later returns:

$$discount\ \ factor = \frac{1}{1+r}$$

The rate of return is also referred to as discount rate or opportunity cost of capital.

In order to decide if a project is worth more than it costs, the costs have to be subtracted from the present value. The costs can be the initial investment at the present time (C_0), which is a cash outflow and, thus, a negative number. The remaining value is called net present value (NPV) and represents a net contribution to the company's value:

$$NPV = C_0 + \frac{C_1}{1+r}.$$

If a pay off is expected to occur in a period of two years instead of one, the impact of compound interest (interest on the first years return of the initial investment) has to be considered: Therefore, the present value of a pay off (C_2) in two years with the rate of return (r_2) can be calculated as:

$$PV = \frac{C_2}{(1+r_2)^2}.$$

Generally expressed, the net present value (NPV) of an extended stream of cash flows over t years initiated by an investment (C_0) can be expressed as:

$$NPV = C_0 + \sum \frac{C_i}{(1+r_i)^t}.$$

As the NPV is the net contribution to a company's value, the decision rule is to invest in any project with a NPV greater than zero. This means that the internal rate of return, which is defined as the resulting discount rate for NPV=0, has to be higher than the opportunity cost of capital.

In case cash flows occur within each year, it is necessary to also consider short-term interest within each year to provide proper results. For the evaluation of wood gasifiers for energy generation, it can be assumed that all cash flows occur at the end of each year. This is a common simplification for long-term financial assessments.

Investors usually have different opportunities to invest money. An investor's financial goal is to earn the highest interest on invested capital. However, investing money is always linked to a certain risk, and it is not sure that the amount of money invested will be paid back by the project. Therefore, a basic principle in finance is that safe money without risk is worth more than the same amount of money expected as return from a project linked with higher risks. Thus, investment in relatively new technologies has to offer a higher rate of return than for example an investment in governmental securities such as treasury bills.

Calculating the Net Present Value of a Long-Term Gasification Project

In order to assure that an investment in a wood gasification project is advantageous, each related cash flow has to be considered and discounted properly over the project period.

First, the total investment (C_0) has to be determined. Subsequently, all revenue streams and expenses (reimbursement for generated electricity and heat or savings in form of formerly paid utility bills, operation and maintenance costs, payroll expenses, etc.) have to be calculated for each single year of the operating period under consideration, as their values might differ from year to year. An annual increase of costs can be estimated based on current inflation rates.

Then, annual sums can be determined and eligible depreciation rules must be deployed to determine the pre-tax earnings and subsequently the tax liability for each year. Finally, tax-reducing incentives have to be taken into account to calculate the annual earnings. These have to be discounted with the selected opportunity cost of capital. The result of adding up the discounted cash flows (C_1 – C_t) to the initial investment C_0 is the project's net present value.

For a project with a projected life of ten to fifteen or even more years, usually more than one hundred cash flows have to be taken into account. Conducting such a profitability analysis necessitates considerable time investment and labor costs and should be done by experienced personnel.

Different scenarios are very often possible for a wood gasification project. Based on experience, the most promising ones should be chosen for an economic assessment. For comparison, one or two alternative scenarios (e.g., based on wood combustion or on conventional energy generation with fossil fuels) can also be considered.

If the economic assessment is based on the first basic concept, results are associated with inaccuracies of more than +/- 25%. The exact profitability of a project can only be determined if a detailed plant design and cost assessment with bids from suppliers are available. Even then unexpected developments in the future like changing fuel, heat or electricity prices can influence the project profitability.

In order to reduce the risk, sensitivity analyses should be carried out by varying important parameters and calculating the influence of these variations on the overall project profitability. Thus, limits can be determined for these parameters. An evaluation of the probability of exceeding these limits within the project period helps determine the risk of the project becoming uneconomic.

If the assessment shows that a proposed project is not feasible, it can be evaluated if it is possible to change boundary conditions. Some options might be supply of cheaper fuel, simplifying the plant concept, finding additional energy consumers, or reduced personnel costs by using pre-existing personnel.

2.4 Non Technical/Economic Aspects

Besides technological concept and economic feasibility, the following aspects are also very important for a successful project and, thus, should be considered in an early planning stage:

- Project partners
- Permitting
- Public acceptance
- Preparation of next steps for realization of project

2.4.1 Preliminary Determination of Project Partners

The most important partners that should be involved in a very early planning stage include

- Fuel suppliers,
- Investors
- Plant operator
- Consumers of produced energy

For the development of a first, basic concept, at least persons, companies or institutions should be identified that could potentially play one of these roles. For example, it is obvious that the energy demand covered by the plant can only be determined if potential consumers are identified.

In case the project is not initiated by the investor and/or plant operator, but by potential biomass suppliers or by energy consumers, the identification of potential investors is especially important, and discussions and negotiations shall start as soon as possible.

Furthermore, early discussions between potential project partners can clarify interests and goals of every partner and avoid misunderstandings. It also improves the database necessary for the development of the concept. However, it is not necessary to determine the final legal form of the partnership and to sign contracts. This can be accomplished during detailed planning.

2.4.2 Permitting

During the development of the basic concept it is recommendable to investigate which permits are needed for the construction and operation of the plant. However, it is not necessary to analyze the detailed process of permitting.

In Pennsylvania, permits usually can be obtained for the gasification of "clean", untreated wood, if the technologies for gasification, gas utilization (e.g. in a gas engine) and emission control are state of the art and emissions don't exceed those of comparable plants. In any case, the local DEP office shall be contacted to discuss the concept in favor and the expected efficiency and emissions. Data of comparable plants should also be provided in order to prove the efficiency and sustainability of the proposed plant.

As there are not many wood gasification plants operating, emission data need to be compared to those of wood combustion plants and gasifiers that use other fuels such as coal. Therefore, this type of facility is subject to many of the same standards and permit requirements as apply to combustion facilities.

The Pennsylvania Department of Environmental Protection (DEP) developed a database, namely eFACT (Environment, Facility, Application, Compliance Tracking System), that provides a holistic view of the clients and sites (including facilities) that DEP regulates. The guide provides general information on the permitting process, related policies, and helpful hints for the applicant. The major portion of the guide identifies the various permit and authorizations, and includes such information as: purpose; processing information; web address of the application package; statutory/regulatory sites; fee information; public comment/participation; related published materials; etc.

A land use permit for a proposed power plant is typically issued by the local or county planning department where the proposed facility is located. Project developers must also have building permits before starting construction of such a facility. The Municipalities Planning Code (MPC) establishes the basic framework for land use planning and regulation in Pennsylvania.

The size and capacity of an incineration facility typically determines whether Pennsylvania DEP regulations require application for plan approval, general permit, and an operating permit. Similarly, project developers must contact the DEP Bureau of Air Quality for more information for the gasification facility.

Incomplete combustion of biomass and char might result in nitrogen oxide and particulate matter emissions. These facilities must control emissions of methane and carbon dioxide that are present in produced gas. Emissions vary depending upon the type of equipment and the extent of gas cleanup. Dust from transporting, storing and handling biomass fuels contributes to total particulate emissions from the gasification facility site. Facility operators must control fugitive emissions from fuel storage and handling and from pollution control equipment. Detailed information related to these issues is available in the DEP Bureau of Air Quality, especially in the regulation, 25 Pa. Code, Subpart C, Article III. Air Resources.

Solid wastes from gasification may include char from incomplete combustion of biomass, ash collected in particulate control devices and residual tars collected during gas cleaning. Any solid residual generated from a power plant must be tested to determine the appropriate disposal measures. There are detailed reporting requirements for materials listed as hazardous. Operators must dispose of these materials at licensed facilities. The DEP's hazardous waste facilities plan under the state's Waste Management Act has more information about handling possible contamination problems.

Wastewater from gasification facilities potentially includes liquid discharges from gas cleaning and cooling, blowdown and other boiler wastewater. Depending upon the type of fuel used, operators must control runoff and leachate from fuel storage piles. The DEP Office of Water Management can provide detailed information about wastewater treatment and storm water control. Furthermore, facilities that require new uses of water may need to obtain a water right. The DEP Office of Water Management can also provide information about water rights.

2.4.3 Public Acceptance

A lack of acceptance in the community or even resistance of neighbors or other parties can foil a project. This problem shall be recognized early enough to prepare public relations activities if necessary. Two contrary aspects can make it difficult to determine when and how to introduce the project.

On one hand, plans should be explained openly and discussed on a fact-based level as early as possible in order to inform neighbors and others interested and not to give the impression of concealing anything from them. On the other hand, if public discussions start too early before the final concept is determined and reliable data on input and output of the plant as well as on the impact on the neighborhood are available, political and emotional discussions can endanger the realization of an otherwise feasible project.

In general, the recommendation would be to inform the community as soon as a basic concept is developed and reliable data are available. A public presentation, during which the technical concept is described in an understandable way, and in which a knowledgeable person can answer all questions, will help deal with concerns and explain the benefits to the community.

2.4.4 Preparation of Next Steps for the Realization of the Project

Once the main components of the basic concept are determined and results are positive, next steps for the realization of the plant can be prepared. A first action would be to develop a preliminary schedule and determine "actors" that are responsible for the different tasks to be performed. This includes the potential hiring of an external project developer and first discussions with competent engineering companies.

An important next step is the financing of a detailed feasibility study, which is needed for the final decision on the construction of the gasification plant. It mainly includes the same components as the basic assessment, but much more detailed information needs to be collected. Results are a detailed plant design, cost and income analyses based on offers from plant or component suppliers and energy consumers, secured fuel prices based on negotiations with fuel suppliers, etc.

The final determination of financing the plant itself should be done after this detailed information on investment and operating costs and on revenues is available. If it is possible to acquire public funding from e.g. the Pennsylvania Energy Harvest Grant or similar programs, proposals should be discussed with the respective funding agency and written in accordance with their requirements.

3 Technologies for Energy Generation from Wood

For energy supply based on wood, various technologies and processes can be applied. The different options depend mainly on the character of the wood utilized (untreated, treated, size, water content), the form of energy that is produced (electricity, heat, liquid fuel, etc.), and the capacity of the plant. Dry biomass, like wood, is well suited for thermo-chemical processes. Thermo-chemical processes are e.g. carbonization, liquefaction, pyrolysis, combustion, or gasification. Since thermo-chemical processes operate at high temperatures, the water in the solid fuel has to be evaporated before the actual conversion. This decreases the process efficiency when using biomass with high water content. As a rule of thumb, the maximum water content should be below 60 %.

Carbonization is the upgrading of woody biomass with the aim of reaching a high yield of charcoal of best quality and with defined, constant properties, which can be then used for domestic cooking and other purposes. The technology of charcoal production is well known and has been used in full-scale processes. During the carbonization process, the organic structure of the biomass is destroyed by heat. The energy required by the process is mostly generated by partial burning of the source material. Only 33-40 % of the energy content of the biomass feed will remain in the solid product. Because of the low efficiency and the fewer ecological advantages of burning charcoal compared to direct biomass combustion, the intermediate step of carbonization is not beneficial to energy production from biomass. Therefore, the application of carbonization will be limited to raw material production for the chemical industry and for niche markets like fuel for barbeques, etc.

During liquefaction or pyrolysis the organic structure of the fuel is destroyed by heat in absence of oxygen. The goal of the process is a high yield of liquids. Byproducts are solids and gaseous materials. The separate combustion of these byproducts sometimes provides the energy needed for pyrolysis/liquefaction via indirect heat exchange. Advantage of this process is the production of a liquid fuel with a great energy density, which should be storable, easy to transport and easy to be used in combustion engines.

Despite intensive research over the past years, this technology is still in development. Problems are high costs, the lack of steady production of chemicals with defined and constant properties, especially concerning their longtime stability and the utilization in reciprocating engines. New approaches are based on relatively small, decentralized plants (in several countries) to liquefy wood and, therefore, enable long hauling distances to a central plant. This enables the application of cost-intensive advanced technology to convert the “liquid wood” into valuable fuel, which can be used in cars and trucks. Because of the sophisticated technology and the great organizational effort of such a project, this technology was also not investigated further in this project.

A structuring of two more common processes applied for energy generation from dry, solid biomass is presented in Figure 3-1.

Combustion is the conventional and traditional method of energy generation from dry biomass. In order to ensure complete conversion of the fuel, excess air is usually provided. Heat from the flames (through radiation) and the latent heat of the hot flue gases can be used directly or indirectly with a heat exchanger. For electricity production, water is evaporated to drive a steam engine or turbine.

This technology is readily available in all sizes of plants, and sufficient experience for design and operation is accessible at the appropriate institutions. However, it should be noted that an environmentally sound, efficient, convenient and reliable solid fuel combustion facility requires a more sophisticated and cost intensive technology than oil or gas combustion. Especially for the utilization of some problematic biomasses such as straw or various shells and husks, costs further increase .

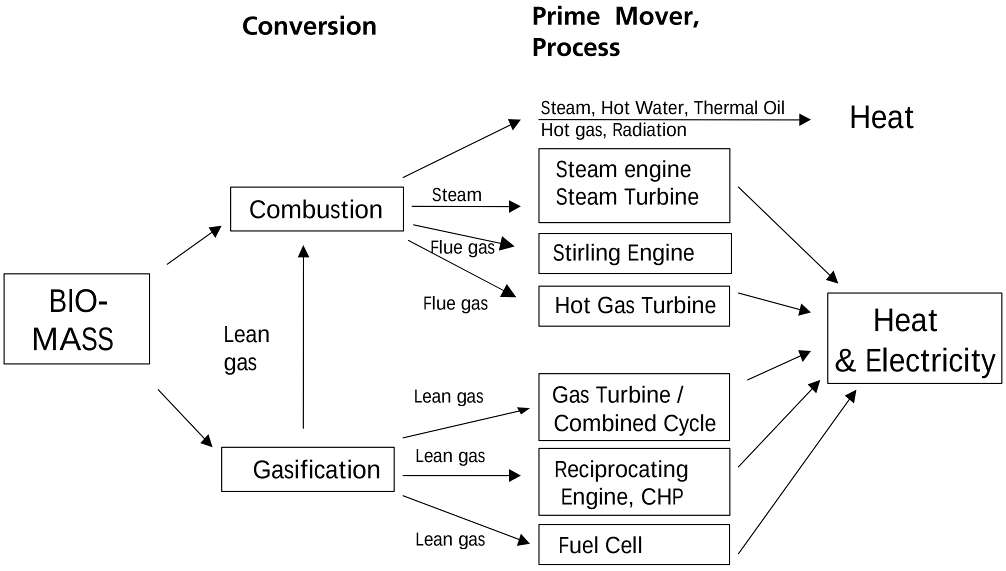
High investment costs concerning electricity production, coupled with a relatively low efficiency compared to other processes and the inability to retrofit existing gas or oil fired vessels, are the disadvantages of conventional combustion systems.

In contrast to combustion, which generates heat energy directly, gasification converts the energy contained in solid biomass into chemical energy in the form of a flammable gas. Therefore, the fuel is partially combusted with a limited amount of supplied air. The heat of the partial combustion is consumed by reactions, which convert the remaining unburned fuel into gas. The product, a gas with a low calorific value, can for example be utilized by, for example, a gas burner or combustion engines.

With the appropriate gasification technology and operating parameters, gasification offers economic and environmental advantages compared to other conversion technologies such as direct combustion. Gasification also offers economic advantages for upgrading existing natural gas or oil-fired boiler to use of woody fuels and generate electricity IC engines due to its high electrical efficiency.

Figure 3-1

Structuring of energy generation from solid biomass (Deimling et al.,2000)



Gasification (e.g. coal gasification) is a well-known technology. In spite of failure of several projects in the past due to levels of high dust and condensable organic material (tar) contents in the gas, recent research has provided solutions to these problems and made this technology cost effective, highly reliable, and a proven process.

Existing natural gas or oil-fired boilers can be converted to burn gas from wood gasification. The gas can also be used for electricity generation in internal combustion (IC) engines with relatively high efficiency. In the future, the utilization of the gas in fuel cells might offer additional opportunities to further increase process efficiency. Currently, the gas cleaning requirements of the available fuel cells and the price of the fuel cells themselves present an unsolved problem.

3.1 Fuel Supply, Storage and Feeding Systems

Since wood is a solid fuel with a significantly lower spatial energy density than coal, the fuel transport, storage, and handling requirements for wood fired plants are conspicuously different from those for fossil fueled plants. The necessity to handle greater volumes leads to a significant increase in investment and operation costs. Therefore, attention should be paid to the design of the transport, storage, and feeding system.

3.1.1 Fuel Delivery

Gasifiers need the wood in form of small particles, e.g. wood chips or sawdust. Feeding systems usually require particles smaller than 2 inches length. Depending on the size of the plant and the supplier's preferences, the fuel will either be delivered by tractor-trailer combinations or by trucks. Normally using a truck will be cheaper if the hauling distance is more than five miles and the vehicle will be fully loaded. Very big plants could also be supplied by rail if the respective infrastructure is already there.

Five types of trucks can be used: dump trucks, container dump trucks, live-bottom trailers, conventional semi-trailers, and hopper bottom trucks. In most cases the available transport volume of the truck can only be efficiently used, if the wood is transported in the form of wood chips. If fresh wood chips (approximately. 350 kg/m^3) or pellets (approximately 550 kg/m^3) are transported, the weight of the load becomes the limiting factor.

Conventional semi-trailers (up to 22 tons) need unloading equipment to be provided at the site of the plant. This can be in the form of dumping stations, which skip the complete trailer, or scoop conveyor truck unloaders. Such equipment is only justifiable for plants with continuous truck unloading during delivery time (more than approximately. 120 mmBtu/h). Hopper-bottom trucks can only be used for small size dried and dense pellets. Unloading these chips can be done extremely fast, but due to the cost of pellet production this solution will be limited to some special cases. Pellets also offer the possibility to be pneumatically transported. A blower mounted on the transport truck provides the air required for pneumatic transport. This technology is applied at some small size facilities (< 1 mmBtu/h).

If the supplier is only a few miles away, dump trucks represent the best choice for plants requiring no more than three to four loads per day. For longer distances, semi-trailers are the significantly cheaper alternative. Front-end loaders can unload the trailer by driving directly into it. The approximate unloading time for a trailer is about one hour, assuming there is a trained operator for the front-end loader. A drawback for this solution is the high risk of damaging the trailer. A compromise between dump trucks and semi-trailers is presented by trucks, which can independently load, unload, or skip a container (52 cubic yards). If the delivery is based on a pick-up from several places, the use of containers additionally shortens the loading times of the trucks. The truck arrives at the pick-up place with an empty container, unloads the empty container (five minutes), and loads another already filled container (five minutes). The empty container remains at the pick-up place where it becomes refilled. Due to the low capital cost of containers, they may remain on the pick-up site for several days. The containers are emptied by skipping them with a carrying truck (five minutes).

Trailers with a live floor offer another alternative for small plants. These trailers have loading volumes of up to 130 cubic yards and "walk" out the wood without skipping. For small plants up to 6 mmBtu/h, such a trailer or container equipped with walking floors can be simultaneously used as short term (e.g. five days) storage. Therefore, the hydraulic of the trailer/container has to be connected to a stationary hydraulic pump, which is controlled by a level meter in the fuel feeding system of the plant.

3.1.2 Fuel Storage

Fire is a significant risk of wood fuel storages. To avoid self-ignition, the storage height of wet wood (more than 15 % water content) should not exceed 4.5 yards. The amount of wood to be stored depends not only on the size of the generation plant, but also on the structure of the wood supplying entities. In general, storage for three to ten days presents an economically reasonable size.

The cheapest way to store fresh wood chips is an outside pile. Appropriate drainage of the storage place should be provided. The storage area should have a paved, tarmac, or concrete surface in to enable fuel handling with a front-end loader without the risk of polluting the wood with rocks or soil. Dry wood should be stored under a roof to avoid remoisturization from rain. In case wood with water content of more than approximately 15% will be stored, the covered storage should provide a good air exchange to remove vaporized humidity. This avoids damage to the building structure from condensed water, reduces odor, and minimizes mold formation. A common form of such storage is a roof erected over a fixed surface. Some storages have partial walls covering half the height to the roof. The walls can be planked with deals to increase the resistance against damage by the fuel handling trucks or loaders.

If the water content of the wood is always below 15 %, high silos are another possibility for storage. They offer the advantage of a small footprint. As only dried wood is stored in such a facility, no biological processes will start in the silo. Disadvantages of silos are the potential of bridging of wood chips, which might occur depending on particle size distribution and on the storage time without moving the material. Once these bridges are built, it can be difficult and cost intensive to remove the wood from the silo. Dried fuel can also be stored in hoppers below ground level, or in already existing buildings. Obviously, below ground level construction is more expensive than the other types of storages.

3.1.3 Fuel Handling

Depending on the space available, different ways of conveying the fuel into the storage are possible. Below ground level storage may allow the fuel to be directly dumped from the delivery vehicle into the storage unit. For small to midsize wood fired plants, the cheapest possibility is to unload the fuel either directly in the storage unit in or front of the covered storage. In the latter case the fuel can easily be pushed into the storage by a front-end loader. Dump trucks need sufficient height of the building to skip the load floor. For covered storages for large plants, automatic filling is recommended. The fuel is delivered to a receiving pit and then automatically distributed to the storage.

The storage is emptied by using a live floor or drag chain conveyors lowered from the ceiling of the storage unit. The latter can be simultaneously used to distribute incoming fuel (Figure 3-2). Live floor systems are also used to extract wood from outside storages. One or two times a day the wood from the fixed surface area of the storage is pushed in the walking floor area by means of a front-end loader. The front-end loader can also be used to provide a blend of different stored fuels.

Other plants use a crane to access the whole storage area. An automatic controlled crane shovel picks up the fuel and dumps it into a small receiving bin with a moving bottom for continuous extraction. The crane can also be programmed to automatically supply the receiving hopper with a fuel blend from the different storage spots.

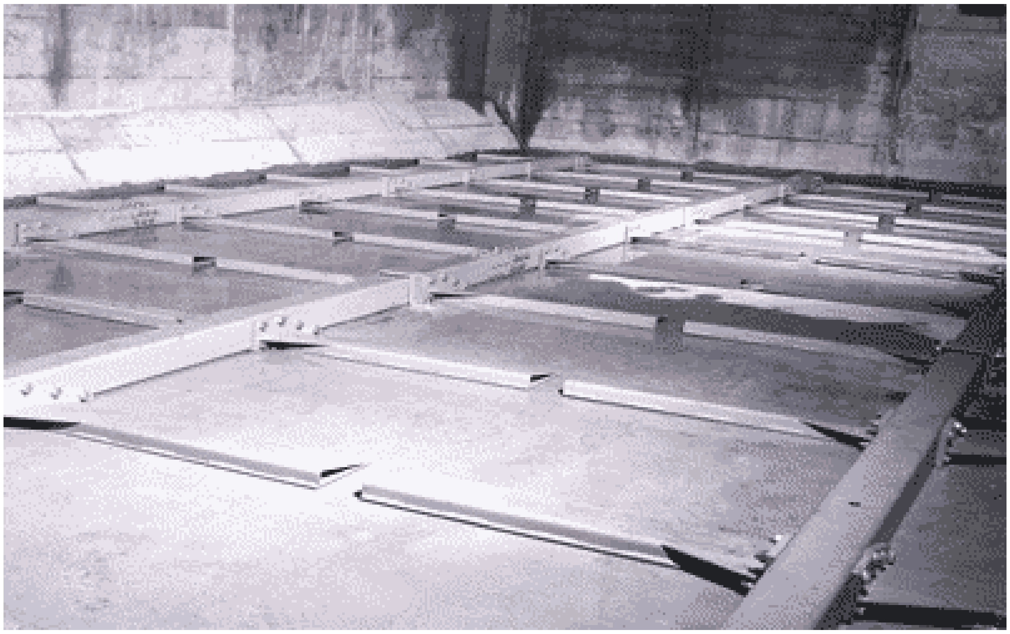


Figure 3-2

Right: moving floor (Mawera)

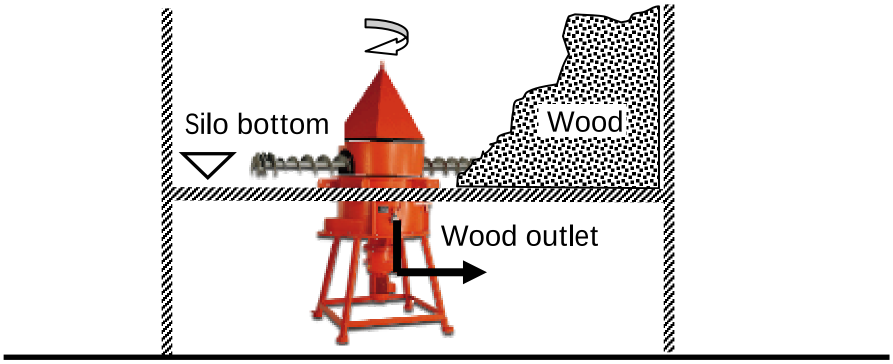
Left, below:
roofed storage with drag chain conveyor lowered from the top (Rudnick+Enners)

Right, below:
Drive in moving floor storage (Ecotec)

Round silos for dry wood can be emptied by several constructions of scrapers or screw augers (Figure 3-3).

Figure 3-3

Example for round silo extraction (Mawera)



After extracting the fuel from the storage, it can be transported by several types of conveyors, depending on the size of the plant, type of fuel, and spatial situation (Table 3-1).

Table 3-1

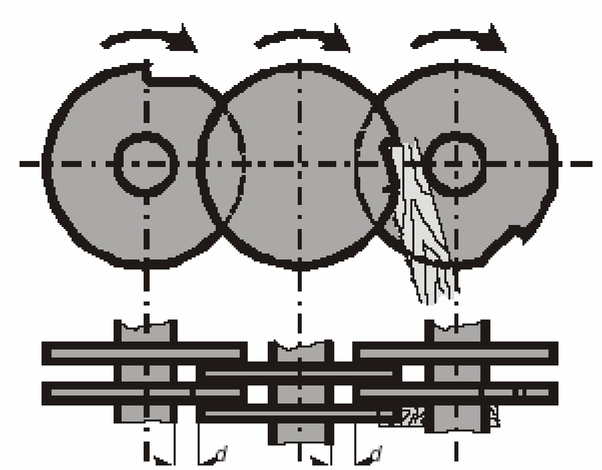
Properties of different types of conveyors

Conveyor type	Advantages	Disadvantages
Belt	Energy efficient, any type of fuel	Light parts get easily blown off, highest capital cost
Screw	Energy efficient, low space demand, inclines possible	Limited fuel size, high capital cost
Vibro	Dense bulky and stringy wood fuels, equalizing flow when used with high frequency, low cost	Not applicable for light fuel such as sawdust, limited incline
Bucket	Inclines and vertical transport	Not suitable for long horizontal transport
Pneumatic	Small, light fuels, long distance, low invest cost	Limited fuel size, high energy consumption
Chain	Rugged, transports various fuels, energy efficient	High maintenance

Depending on the quality of the supplied fuel, a quality control step may be required before further processing. A magnet mounted over a wood conveyor removes metal parts and discharges them into a container for recycling purposes. Oversize particles are normally removed by disk screens (Figure 3-4), which consist of overlapping disks that allow fuel of the proper size to fall through while oversized material is carried off to the end of the screen and collected in a container.

Figure 3-4

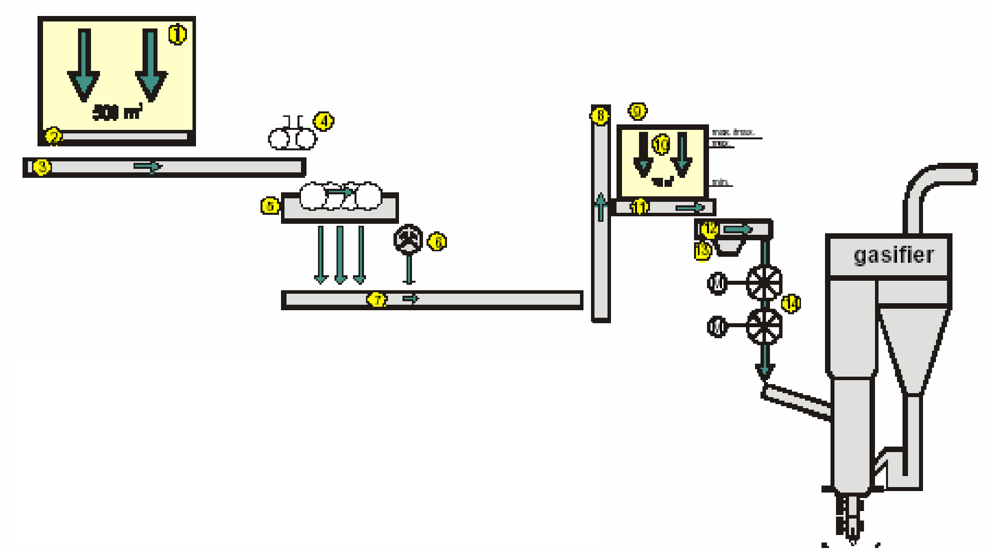
Disk screen



A typical design of a complete feeding system is shown in Figure 3-5.

Figure 3-5

Complete feeding system



From the moving floor storage (1) the fuel drops into a collecting conveyor (2). At the end of a belt conveyor (3), a magnet (4) removes metal parts. Small size particles drop through the disk screen (5). In the given example oversize pieces directly drop off into a chipper (6). Fine particles are collected by a belt conveyor (7) and relayed to a vertical bucket elevator (8). The fuel drops into a short time bin (9) with moving floor bottom (10) and a transverse auger screw (11). The bin (9) buffers downtimes of the upstream equipment. A dosing belt (12) of a balance (13) provides a controlled mass flow towards cellular wheel sluices (14).

Air is added between the sluices to seal the slightly pressurized gasifier atmosphere against the ambiance.

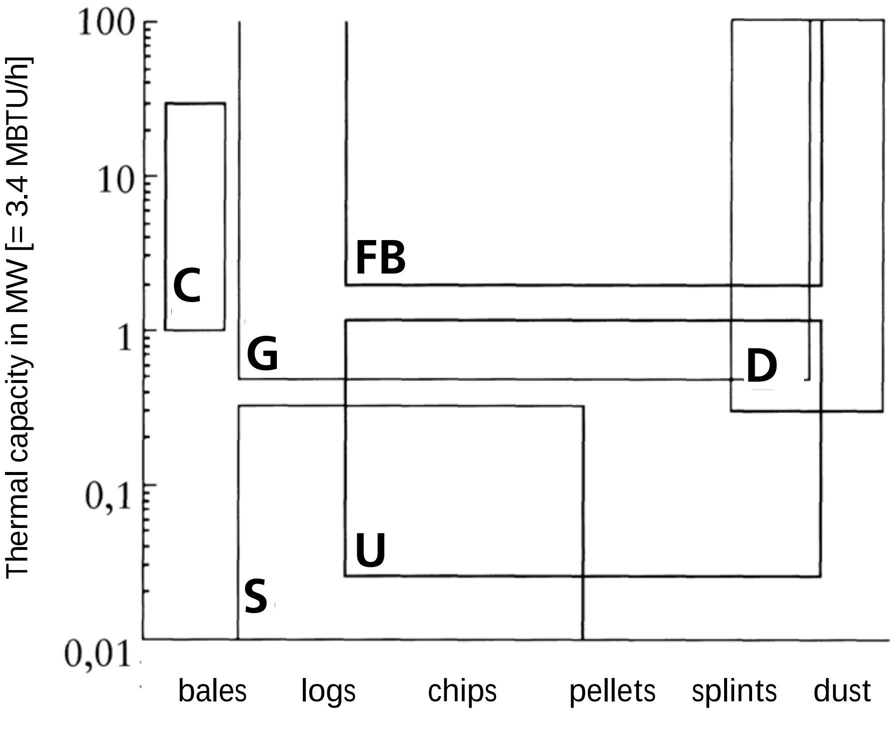
3.2 Direct Combustion

Although this guide is for wood gasification, in order to give a comprehensive picture of energy generation from wood, following most common combustion technologies are described briefly.

The choice of the most appropriate technology depends on the plant size, the water content of the fuel, and some other fuel characteristics such as particle size distribution, ash content, and ash melting temperature. The biomass can be available in the form of bales, logs, pellets, wood chips, splints, or dust. Figure 3-6 presents an overview of the application of the different technologies, depending on thermal capacity and fuel size.

Figure 3-6

Field of application of the different biomass combustion technologies (Spliethoff, 1998)



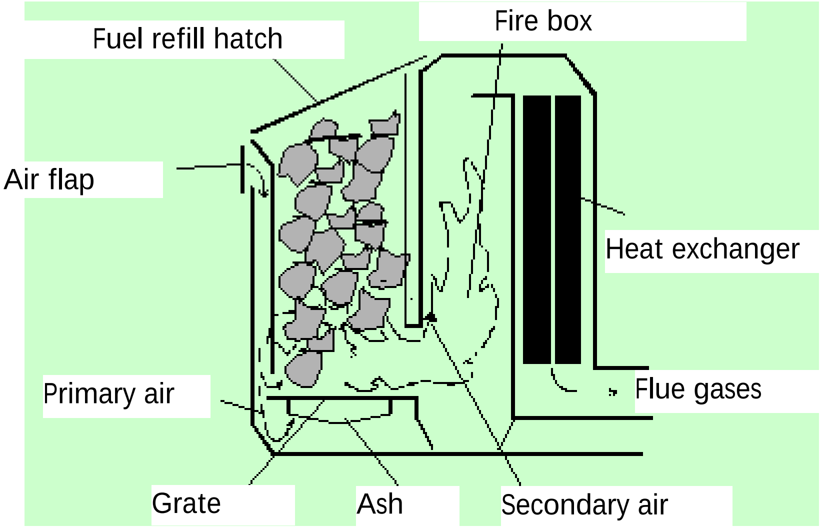
(C Cigar burner, G Grate firing, S Shaft firing, U Underfed Stoker, FB Fluidized Bed, D Dust suspension firing)

Shaft Firing

This type of firing process is operated manually and fueled with relatively large wood pieces (1-3 ft. in length), which are stored in the shaft. The wood slides down by gravity, when the lower pieces are burned. The flame burns sideways or downward into the firebox. Air supply, by natural or induced draft, is split into primary and secondary air. Due to the design of the air manifold, the storage shaft and the firebox are air-cooled. After complete combustion of the gases in the firebox, the flue gases are fed into a heat exchanger. The ash is removed through the bottom grid. The combustion control is usually restricted to manual control of the airflow. Due to the lack of control over the fuel supply, choking the air supply causes incomplete combustion leading to higher concentrations of carbon monoxide and volatile organic compounds. The advantage of low investment cost explains the wide-spread use of this combustion type. Other disadvantages, aside from high emissions during partial load, are the high maintenance requirements and very limited fuel flexibility. The capacity ranges from 68,500 to 850,000 Btu/h. A typical sideways burning shaft firing is shown in Figure 3-7.

Figure 3-7

Shaft firing with sideways fire box (Spliethoff, 1998)

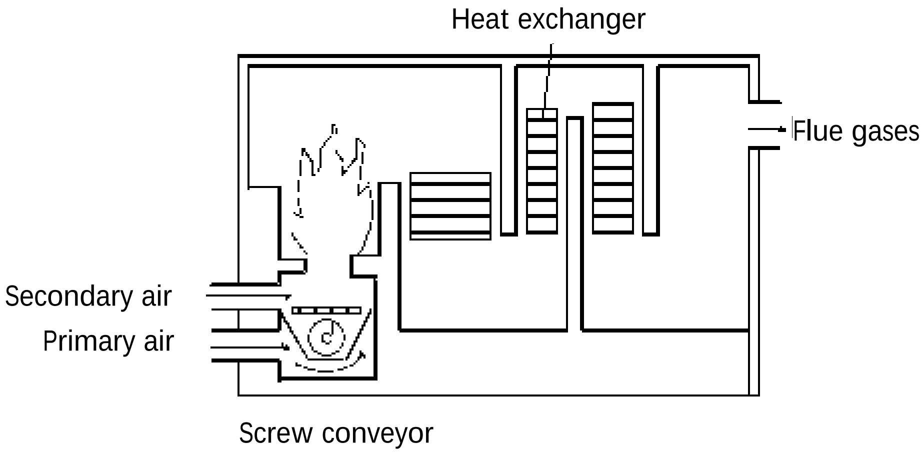


Underfed Stoker

This kind of firing has an automated fuel supply via screw conveyor from below to a fire trough with a bottom grid through which primary air is supplied. The fuel is dried and gasified in the trough. The gases are transported upwards with the primary air. They ignite at the glow layer on the top of the fuel pile in the trough. Secondary air is injected from above to achieve complete combustion. Underfed stoker firings are principally good to control by variation of fuel and primary and secondary air. This system is commonly used in the wood processing industry. It is able to burn wood chips, pellets, and coarse and fine sawdust up to a certain amount. The maximum fuel size is limited by the fuel supply conveyor system. The technology offers automatic operation, and the design is simple and robust compared to others. The capacity ranges from 68,500 Btu/h to 6 mmBtu/h. However, the distribution of the different combustion zones becomes irregular with increasing size. Small "eruptions" of the fuel caused by deflagration of unburned gases occur. These unstable combustion conditions result in higher emissions compared to alternative combustion technologies. A diagram for an underfed stoker firing combustion unit is shown in Figure 3-8.

Figure 3-8

Underfed Stoker firing (Spliethoff, 1998)

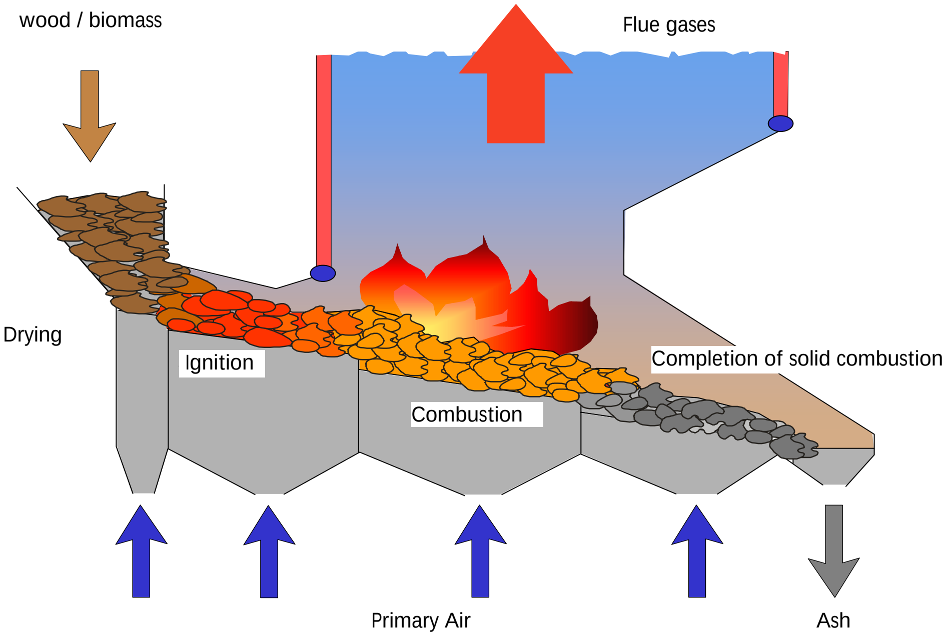


Grate Firing

In the capacity range of 3 mmBtu/h and larger, grate firing is the most common technology. The fuel is supplied on one side and transported by a traveling or reciprocating grate (Figure 3-9 and Figure 3-10).

Figure 3-9

Reciprocating grate firing



As the fuel travels on the grate, it passes the drying, ignition, combustion and the burnout zone. Primary air is supplied from the bottom through the grate. Secondary Air is supplied from above to complete the combustion of the gases.

Figure 3-10

Reciprocating grate, empty (top) and view on the burnout zone during operation (bottom)

One special type of grate combuster is the spreader stoker (Figure 3-11), in which the wood is catapulted from one side above the grate. Small particles already combust during flight. Large, heavy particles cover the greatest horizontal distance before they drop onto the grate. Due to the fact that the grate transports the fuel layer back towards the side of the fuel supply, large fuel pieces have the longest residence time in the combustion zone.

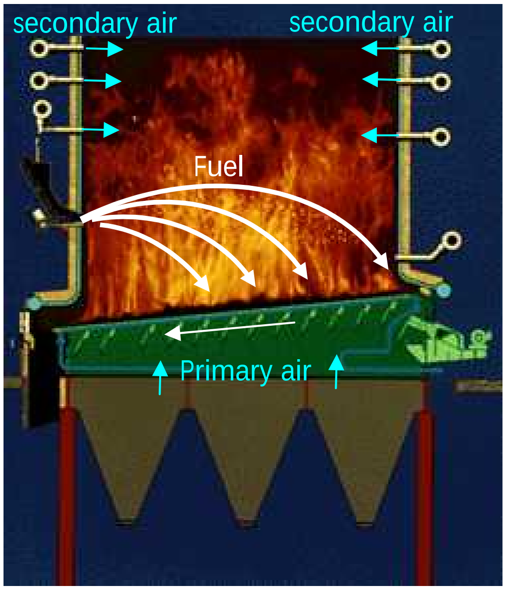


Figure 3-11

Spreader Stoker Grate firing
(Detroit Stoker Company)

In general, grate firing combustors are able to burn a variety of fuels, but the fuel has to be very well mixed and have a constant moisture content. Otherwise grate areas with incomplete ignition / combustion may occur. The upwards-moving gases of these areas contain high amounts of carbon monoxide (CO) and volatile organic compounds (VOC). In order to burn these compounds, they have to be mixed with the other hotter upwards-moving combustion gases. This should be accomplished by injecting secondary air at a high speed to facilitate turbulent mixing and complete combustion. However, the mixing efficiency is limited because of the difference in the viscosity of the hot combustion gases and cold secondary air. This leads to higher emissions when fuel characteristics vary. Other problems can be grate blocking by ash slagging or inert containments such as nails, wire etc. Very dry fuel can damage the grate because of high combustion temperature and insufficient cooling by primary air.

Technologies to handle these problems are available but sophisticated and cost intensive. Additionally, extensive knowledge in operating these technologies is required, especially when adapting the combustion conditions to changing feedstocks.

Fluidized Bed Combustion

Aside from conventional combustion, fluidized bed technology is used for several other thermal reaction systems, such as drying, coating, calcination, gasification, etc.

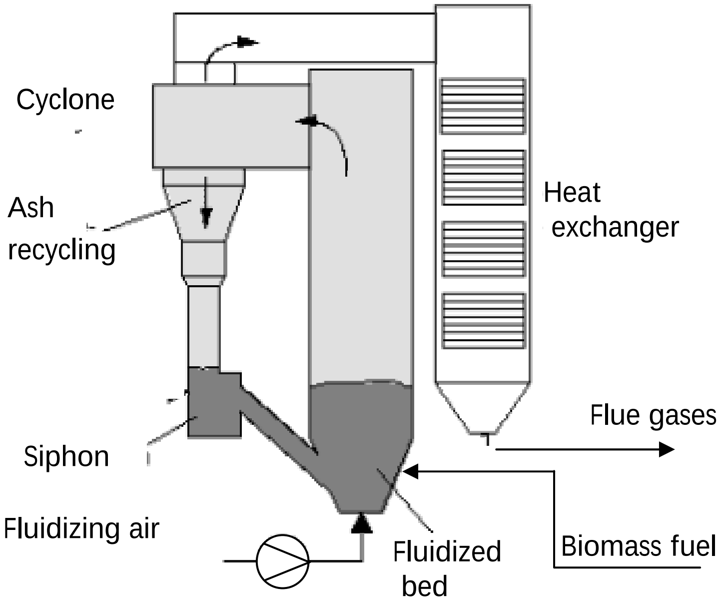
A fluidized bed system consists of a vessel containing a bulk bed of solid particles, generally (but not restricted to) inert materials such as sand. The fuel is supplied from the top, for example, by screw feeders, directly into the bed.
The bottom of the vessel consists of a plate with nozzles or orifices, through which gas (e.g. air) is injected into the bed. If the gas flow rate is high enough, the bed becomes highly agitated, flows and mixes freely. Bubbles, similar to those in a briskly boiling fluid, pass through the bed. The upper surface of the area containing the solids is diffused and no longer well defined. The bed material is said to be "fluidized" because it has the appearance and some of the properties of a boiling fluid. Increasing the gas flow results in increased entrainment of bed particles. In the space above the bed, the so-called freeboard, entrained particles are separated from the gas stream and drop back into the bed.

The movement of the bed facilitates the distribution of the supplied feedstock material over the whole cross section of the bed. Due to the thermal capacity, the bed material represents a large heat energy buffer, which equalizes vertical, horizontal and temporal temperature variations in the system. The bed material prevents localized spots with extremely high or relatively low temperatures. The average temperature in the bed is higher than the average temperature of the reaction zone in other systems such as in the fuel layer and the zone above combustion for grate firing. Additionally, the turbulent mixing of the bed helps avoid the formation of an ash layer on the fuel particles and keeps a clean particle reaction surface exposed to the surrounding gases. This maximizes the reaction rate and char conversion. Areas with instable or inefficient reaction conditions or the potential of slagging due to ash melting are avoided. Optimal process control enables low emissions. Additionally, reactive or catalytic bed material can be used to achieve even higher gas qualities.

The solid residence time can be increased significantly by capturing particles contained in the exiting gases and reinjecting them into the reaction zone. A further extension of the reaction zone, which provides these optimal conditions, can be achieved by using much higher gas velocities for the fluidization. This results in the entrainment of large portions of the solids. In contrast to the a bubbling bed system, the high gas velocities and solids loading in essence "stretch" the bed over the complete height of the reactor / combustion chamber such that the separation between bed (dense solids zone) and freeboard (dilute solids zone) is not well defined anymore. This is called a circulating fluidized bed (CFB). The solids leaving the reactor are separated from the gas stream using a hot cyclone and recycled back into the bed (Figure 3-12).

Figure 3-12

Circulating fluidized bed combustion (Spliethoff, 1998)



In fluidized bed combustion systems, the heat is extracted from the bubbling bed by using submerged heat exchange surfaces (tube bundles) or water-cooled walls. Circulating fluidized bed systems also use the reactor walls as heat exchange surfaces and, sometimes, additional heat exchangers. These add-on heat exchangers are partially submerged into the bed below the cyclone.

The advantage of fuel flexibility is in contrast to higher investment and operating costs. CFB combustion plants typically have a capacity of more than 100 mmBtu/hr fuel input, whereas bubbling bed combustors usually have a capacity above 35 mmBtu/hr fuel input.

3.3 Gasification

Gasification represents an alternative method of thermal biomass utilization. The first widespread commercialized gasifier for wood was developed during the 1920's in Europe. Especially the lack of fossil fuels during and after World War II enhanced the popularity of these gasifiers. They were mainly used to power trucks and agricultural vehicles such as shown in Figure 3-13. However, based on previous experience, it can be concluded that due to the careless handling of the condensed hydrocarbons (tar) from the wood gas these systems would not comply with current regulatory standards. Reliability and convenience of operation are further drawbacks of these early models.

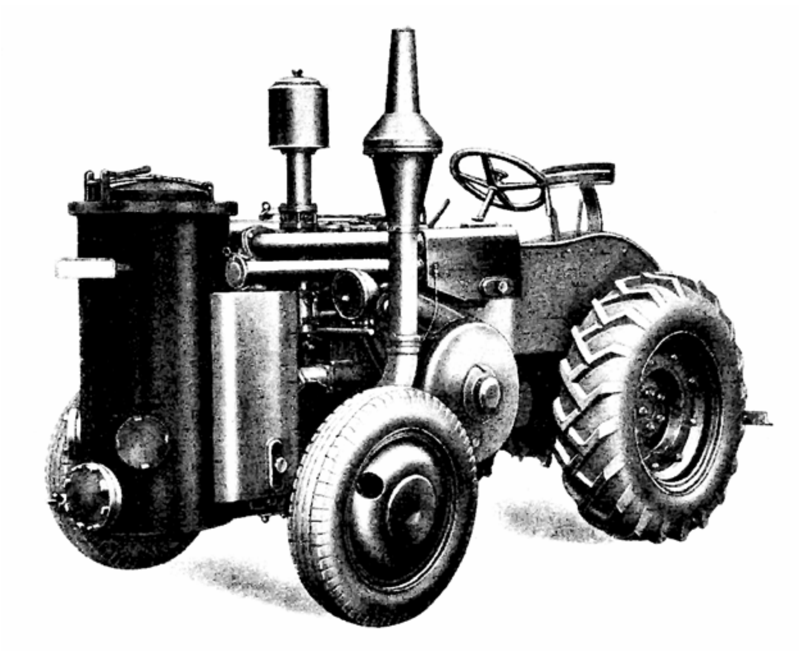


Figure 3-13

Tractor with Imbert gasifier (1942)

3.3.1 Reactions of the Gasification of Biomass

Before closer consideration, a brief description of the various parallel and successive processes and reactions, which are common in all types of gasifiers, is given.

Drying: After preparation, the fuel is fed into the gasifier. The biomass moisture evaporates, due to the high temperatures.

Pyrolysis: After the fuel is dried completely, thermal pyrolysis starts. Due to thermal degradation, primary gaseous hydrocarbons (tar) and pyrolysis coke are produced at temperatures of up to 900 °F. By continuing heat exposure, the primary products are partially fragmented into smaller and more stable molecules.

Oxidation: At the prevalent operating temperature some of the pyrolysis products will be oxidized. Hydrocarbons and coke will be converted to smaller molecules such as CO, H_2, H_2O, CO_2 and CH_4. The exothermal oxidation reactions supply the energy for the fuel drying, pyrolysis and autothermic gasification, which also includes the subsequent reactions (e.g. shift reactions).

Reduction: Some of the oxidation products are reduced because of the limited oxygen supply. The major parts of the combustible gas compounds are generated by this reaction. CO_2 and H_2O react with solid coke to form CO and H_2.

Additionally, some other parallel reactions occur. The reactions occurring during gasification can be basically divided into homogeneous (gas reacts with gas) and heterogeneous (gas reacts with solid) reactions (Table 3-2).

Table 3-2

Main reactions of biomass gasification

Primary Pyrolysis:				
Biomass/Wood	$\rightarrow$	Primary Tar (CH_xO_y), H_2O, CO_2, CO, CH_4, C_2H_4, Coke (C)		(R.1)
Secondary Pyrolysis:				
Primary Tar		Secondary Tar (CH_xO_y), CO, CO_2, C_2H_4, CH_4, H_2		(R.2)
Homogeneous Gas Phase Reactions:				
Sec. Tar (CH_xO_y)	$\rightarrow$	C, CO, H_2		(R.3)
$H_2 + 0{,}5\ O_2$	$\Leftrightarrow$	H_2O	$\Delta_R H°_{298} = -242$ kJ/mol	(R.4)
$CO + H_2O$	$\Leftrightarrow$	$CO_2 + H_2$	$\Delta_R H°_{298} = -41$ kJ/mol	(R.5)
$CO + 0{,}5\ O_2$	$\Leftrightarrow$	CO_2	$\Delta_R H°_{298} = -283$ kJ/mol	(R.R)
$CH_4 + 0{,}5\ O_2$	$\Leftrightarrow$	$CO + 2\ H_2$	$\Delta_R H°_{298} = -110$ kJ/mol	(R.7)
$CH_4 + CO_2$	$\Leftrightarrow$	$2\ CO + 2\ H_2$	$\Delta_R H°_{298} = +247$ kJ/mol	(R.8)
$CH_4 + H_2O$	$\Leftrightarrow$	$CO + 3\ H_2$	$\Delta_R H°_{298} = +206$ kJ/mol	(R.9)
Heterogeneous Reactions:				
$C + \frac{1}{\varphi} O_2$	$\Leftrightarrow$	$\left(2 - \frac{2}{\varphi}\right) CO + \left(\frac{2}{\varphi} - 1\right) CO_2$	$\Delta_R H°_{298} = -393$ kJ/mol (with $\varphi = 1$)	(R.10)
$C + CO_2$	$\Leftrightarrow$	$2\ CO$	$\Delta_R H°_{298} = +173$ kJ/mol	(R.11)
$C + H_2O$	$\Leftrightarrow$	$CO + H_2$	$\Delta_R H°_{298} = +131$ kJ/mol	(R.12)
$C + 2\ H_2$	$\Leftrightarrow$	CH_4	$\Delta_R H°_{298} = -75$ kJ/mol	(R.13)

(R.4)	H_2-Combustion / Oxidation
(R.5)	Shift-Reaction
(R.R)	CO-Oxidation
(R.7)	CH_4-Combustion / partial Oxidation
(R.8)	Dry Reformings Reaction
(R.9)	Steam Reforming
(R.10)	Oxidation (partial) of Carbon
(R.11)	Boudouard-Reaction
(R.12)	Heterogeneous water gas reaction.
(R.13)	Hydrogengasification

3.3.2 Basic Types of Gasification Processes

As a general criterion, gasification processes can be distinguished between allothermic and autothermic processes. Allothermic means that the heat of reaction is supplied to the reactor from outside sources. Autothermic means it is produced in the reactor itself by the gasification reactions. In allothermic processes, there is a further choice of heat transfer using either direct contact of the fuel with gaseous, liquid or solid heat carriers or indirect contact via heat exchange surfaces. Typically allothermic gasifiers use steam as gasifying agent.

This results in a gas with a high hydrogen content, which might be beneficial especially for downstream industrial gas applications, for hydrogen based energy supply (in the future), for fuel cells, for hydrogen powered cars, or as an intermediate product for the production of high quality liquid bio fuels. The demand for external heat and its associated technical and financial requirements represent the reason why allothermic gasifiers are rarely used for heat and power generation.

In autothermic processes, heat is commonly supplied by the partial combustion of fuel with air and oxygen. As a result, the raw gas will contain (apart from any nitrogen from the air) an appreciably higher amount of carbon monoxide and carbon dioxide than in allothermic processes. On the other hand, autothermic processes possess the great advantage of avoiding any losses associated with heat transfer. The amount of heat required for the reaction can be adjusted very readily and precisely.

In particular, partial combustion with oxygen makes it possible to run autothermic gasifiers at a considerably higher temperature than can be achieved with allothermic gasifiers. This higher temperature markedly accelerates the reactions involved in gasification.

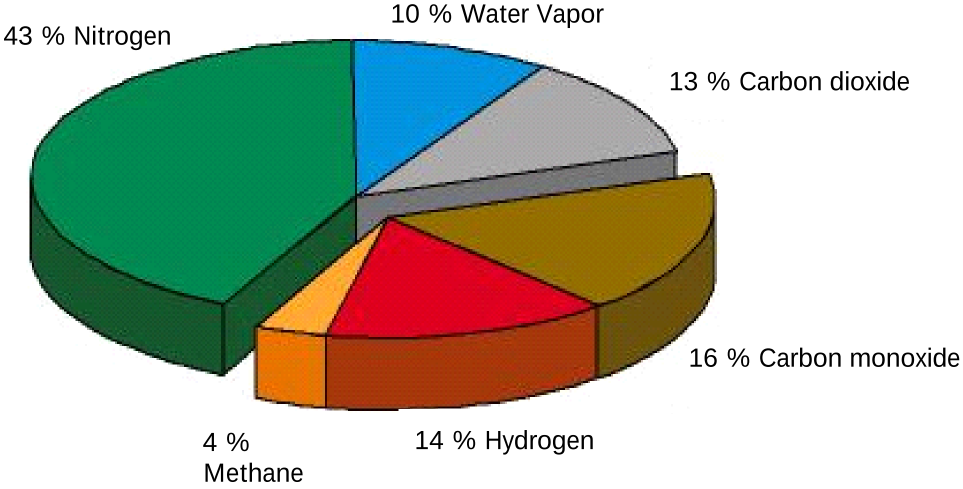
Compared to air blown gasification, allothermic and oxygen gasification requires additional cost intensive equipment. This causes economic disadvantages for these technologies especially for small plant sizes. Compared to fossil fuels, biomass exhibits much lower energy content per unit of volume. Therefore, fuel must be available in the vicinity because the transportation costs associated with fuel supply strongly influence the financial prospects of a plant. Hence, the capacity of biomass-fired plants will never reach fossil fired plant dimensions. To achieve economic feasibility for small plant sizes, the plants must be designed as simple as possible.

Compared to allothermic or oxygen blown gasifiers, air blown gasifiers incur lower equipment and operating costs. Due to economic reasons, the most common gasifiers utilizing biomass are air blown, operating at atmospheric pressure. Pressurized, air blown biomass gasifiers offer advantages only in combination with downstream gas utilization, which requires high gas pressures (e.g. gas turbines). Otherwise, the process disadvantages associated with the fuel lockers to feed the fuel into the pressurized gasification reactor, investment and maintenance cost, are not justifiable.

Aside from technology and the type of biomass employed, the moisture content of the fuel has a significant effect on the gas composition. As would be expected, the moisture influences the resulting heating value of the produced gas due to dilution by steam and consumption of additional heat energy from partial combustion to evaporate the water. Therefore, more air is required to maintain the operation temperature of the gasifier, which causes additional gas dilution by air nitrogen and partial combustion products. Moisture levels of up to 25 % normally represent the most economic and technically reasonable values. A typical gas composition of an air blown gasifier is shown in Figure 3-14.

Figure 3-14

Typical composition of lean gas from an air blown gasifier

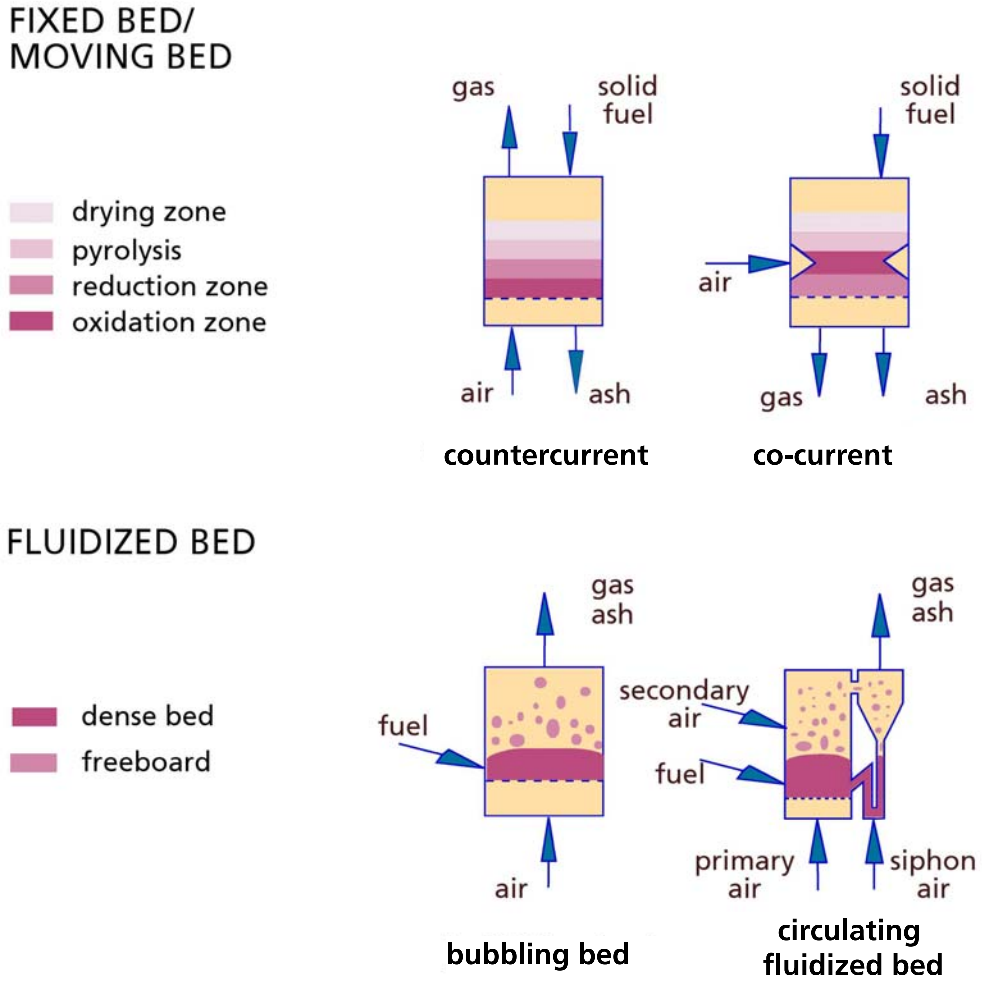


3.3.3 Basic Design Types of Gasification Reactors

As shown in Figure 3-15, gasifier types suitable for biomass gasification can be chiefly divided into two groups: fixed/moving bed and fluidized bed.

Figure 3-15

Basic design types of gasification reactors



Fixed Bed

Fixed bed gasifiers are vertical shaft reactors in which the air flows through the bulk of the biomass.

In the simplest and most common, small-sized, countercurrent, up-draft gasifier design, the air is introduced to the biomass through grates at the bottom of the gasifier. The produced gases are drawn upward and out of the gasifier via an exit on the top of the unit. The fuel fed from the top contacts the hot gases as they are drawn upward. This encounter between fuel and the hot gases results in drying the wet feedstock, which enables the gasifier to operate with very wet fuel. The pyrolysis zone is located below the drying zone. Due to the upward gas stream, gaseous pyrolysis products, primarily tars, are directly transported out of the gasifier without passing the high-temperature reduction and oxidation zones. Hence, up to 30 % of the heating value of the gas of an up-draft gasifier can be provided by tars.

In another design of a countercurrent gasifier, a stoker screw feeder above the grates pushes the fuel upward through the gasifier. The air enters the unit at the top and leaves the gasifier after passing through the fresh fuel on the grates. This design reduces bridging of the biomass, which often interrupts the operation of fixed bed gasifiers.

In a co-current down-draft gasifier, the air is typically introduced above the bottom grates through a set of nozzles. Biomass enters the system from the top of the unit and is converted into gas as it descends. Before leaving the unit, the gas passes through a bed of hot charcoal extending up from the grates. Due to the fact that the major part of the tar contained in the gas is destroyed by reactions on the hot charcoal surface, the gas finally leaving on the bottom of the down-draft gasifiers exhibits low tar concentrations. The disadvantage of the co-current compared to the countercurrent gasifier is the low carbon conversion rate. Together with the ash, a significant part of the biomass carbon is removed out of the system through the bottom grates.

The particle size of the fuel for fixed bed gasifiers has to meet a narrow range to reduce the risk of plugging, bridging and channel building of the biomass bulk bed. With increasing size of the gasifier, the greater diameter of the bulk complicates a homogeneous movement of the fuel over the whole cross section.

In general, the advantage of fixed bed gasification is the simple, low-cost and robust design, whereas the disadvantages are strong fluctuations in gas quality, low fuel flexibility, the upper limit on the maximum plant size and high maintenance requirements. The maintenance issues can attributed to disturbances of the bed movement or clogging of the ash removal system caused by melting and slagging of the biomass ash in high temperature regions.

The number of practical applications of fixed bed gasifiers is very limited especially with regard to today's common process control requirements to ensure the continuous quality of the products from the gasification plant for subsequent utilization.

Fluidized Bed Gasifiers

The fluidized bed gasifier consists of a vertical, typically fully refractory lined tube, without moving parts or heat exchange surfaces. Similar to fluidized bed combustion described above, the highly agitated, free-flowing and well-mixed fluidized bed provides optimal reaction conditions over the whole cross section of the bed.

The advantages of fluidized bed gasifiers are:

- Availability in a wide range of plant sizes
- Simple design enables economic feasibility even for small plant sizes
- Great fuel flexibility concerning the type, moisture, ash content, and particle size (from dust up to 4", average size of the fuel input 1-2 ")

- Relatively tolerable concerning fuel contaminants such as metal parts, wires, nails, glass, etc.
- Gas production with constant quality, quantity, and temperature
- Easy to operate, proven, common, reliable, and low maintenance technology, which ensures high availability
- Outstanding possibilities of process control, therefore, also biomass with low ash melting temperatures can be utilized
- Fast reactions to changes of the plant load demand

In bubbling bed gasifiers, carbon particles tend to float in the reducing atmosphere above the surface of the bed. In circulating fluidized beds, the carbon captured in the cyclone is mixed back into the bed together with the circulated bed material at oxidizing conditions above the distributor plate. Hence, as carbon conversion is faster in oxidizing than in reducing conditions, gas from circulating fluidized beds shows a lower coke content.

Furthermore, circulating fluidized bed (CFBG) gasifiers can provide longer contact times between a catalytic bed material and the gas. This is especially important for the reduction of (secondary) tars, which predominantly occur in the upper part of the gasifier (Figure 3-16).

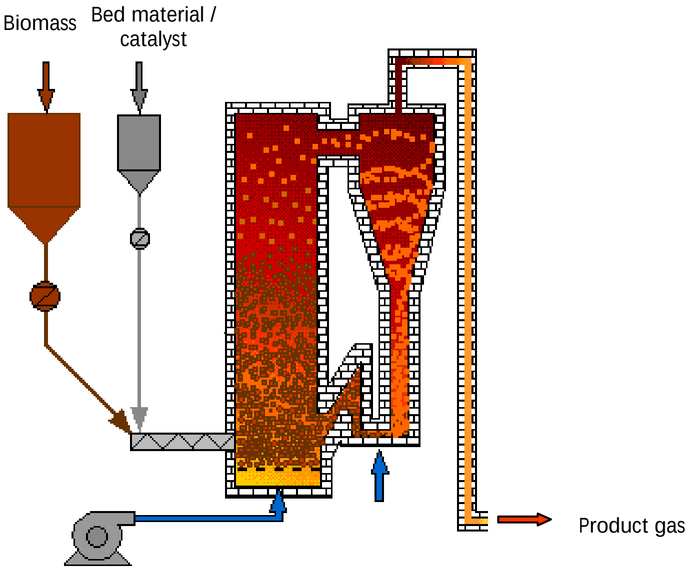


Figure 3-16

Functional diagram of a circulating fluidized bed gasifier (CFBG)

The drawback of fluidized bed gasification is the increased particulate loading in the produced gas, which is about one magnitude higher compared to fixed bed reactors. Therefore, dust removal from the produced gas is essential.

The following Table 3-3 summarizes the differences between various types of gasifiers.

Table 3-3

Comparison of the characteristics of the basic gasifier types

	Content of		**Fluctuations in gas quality**	**Scale-up possibilities**	**Typical thermal plant capacity [MW]**	
	Tar	**Dust**			**min.**	**max**
Fixed bed co-current	Very low	Low	Very large	Very Limited	0,05	1.5
Fixed bed counter current	Very high	Low	Large	Limited	0,5	10
Bubbling bed	Medium	High	Very low	Good	0,5	30
Circulating fluidized bed	Low	Very high	Very low	Very Good	1	100

3.4 Utilization of Gas Produced by Gasification

Once wood has been converted into a gas, it can be used to generate thermal, mechanical, or electrical energy. For example, the gas can be used to fuel boilers to produce steam or to fuel reciprocating engines (internal combustion engines) and gas turbines to produce electricity and heat.

The following section will give a short overview of the different technological alternatives, their associated requirements regarding the fuel gas quality and the possible processes to achieve these requirements for gasifier gas.

3.4.1 Gas Combustion for Direct Process Heating

Based on developments of the prices for fossil fuels, the substitution with gas from biomass is becoming increasingly attractive. The gas can be burned in vessels for steam production and for water heating or thermal oil heating. Combustion of the gas for direct heating by radiation or through hot flue gases can be the simplest application. However, the requirements for the fuel gas quality may vary depending on the process that will be supplied with the heat.

For pre-existing boilers or furnaces, gasification presents a cost-efficient solution to retrofit this equipment to wood utilization or to adapt old biomass combustors to actual emission standards. With the exception of some thermal operations of the bulk processing industry (e.g. calcination of clinker), it is necessary to remove the dust from the gasifier gas, if the gas should be used for direct heating. Depending on the desired maximum dust content technical solutions are:

- Cyclones operating at the temperature of the gas exiting the gasifier. (Filter candles, applicable at this temperature are very expensive and only economically feasible in plants for electricity generation of 45 mmBtu/h or more)

- Cooling the gas down to 950 ^{o}Fahrenheit followed by a cyclone. At this temperature, no condensation of high molecular organic compounds occurs, but the viscosity of the gases is significantly lower than at the temperature of the gasifier exit. This increases cyclone efficiency

- Cooling the gas down to 950 ^{o}Fahrenheit followed by ceramic or metallic filters. This enables dust emissions lower than for any other solids-fueled combustion

After dust removal, the gas can be burned in a gas burner, which is adapted to the required air to gas ratio, high temperature, and dust content. When retrofitting existing equipment, it has to be considered that gasifier gas generates lower flame and flue gas temperatures than oil or natural gas combustion. Without further measures this may reduce the maximum capacity of a retrofitted combustion facility. Alternatives are:

- The installation of an air preheater to achieve higher combustion temperatures,

- Consideration of bigger heat transfer surfaces. When using existing equipment, heat exchange surfaces can be provided in the form of an upstream fire box expansion or by placing additional heat exchangers downstream.

Depending on the wood used as feedstock for gasification, trace compounds like ammonia and hydrogen sulfide may occur. The effects of these compounds on downstream process equipment have to be considered, especially at high temperatures. However, one of the advantages of gasification in combination with specialized low-NO_x gas burners is the ability to utilize fuels with high nitrogen contents without producing significant emissions of nitrogen oxides. The combustion products of hydrogen sulfide can be easily removed from the flue gases by using common dry adsorption technology. This highly efficient flue gas cleaning additionally removes dust and other trace elements. In this case, usually the use of more expensive gasifier gas dust removal technology aside from a cyclone is unnecessary. Alternative cleaning of the wood gas before combustion would offer the advantage of a significant smaller volume flow to be treated compared to treatment of the flue gas stream. However, due to the process conditions (e.g. higher temperature), elaborate technology is required. This technology is still in the state of development and not readily available or proven to work in long-term applications yet.

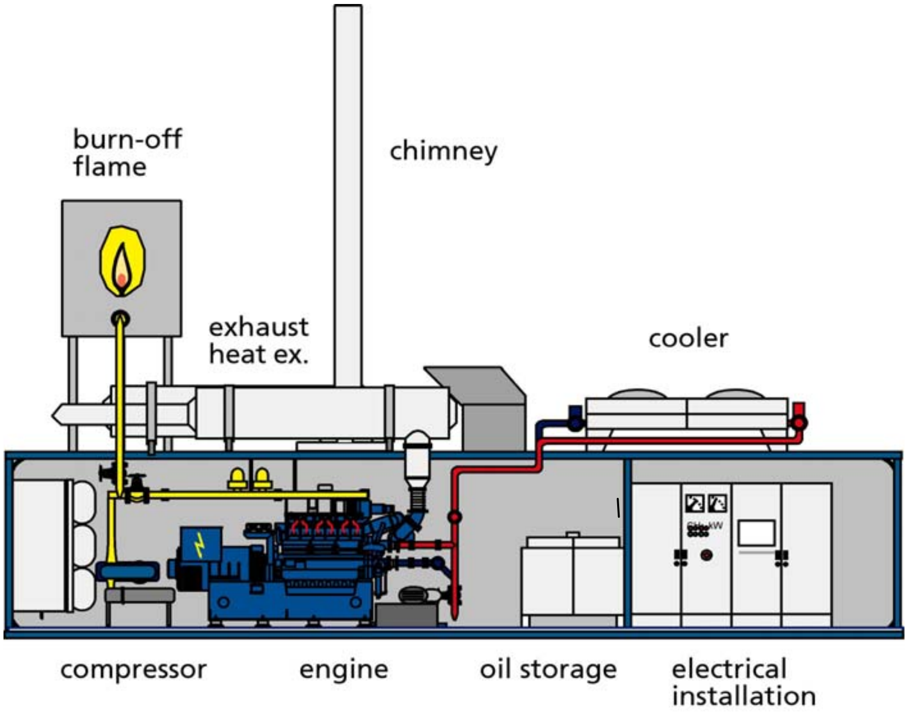
The combination of gasification with a low-NO_x gas burner and dry adsorption for flue gas treatment enables low specific emissions comparable to those from significantly bigger, spreader stoker or fluidized bed combustion plants. Therefore, gasification technology offers the potential for environmentally sound and economically feasible solutions at a plant size significantly smaller than economically viable conventional plants.

3.4.2 Wood Gas Utilization in Reciprocating, Internal Combustion Engines

Due to significant progress in the utilization of lean gas in reciprocating gas engines, this gas utilization option has become a wide-spread technology for combined electricity and heat generation from various gases. The best-known application is the electricity generation from landfill gas. A typical, housed IC engine including cooler, gas flare, and auxiliary equipment is shown in Figure 3-17.

Figure 3-17

Reciprocating engine with flare, cooler, and auxiliaries housed in a container



The combination of gasification with IC engines, in particular, offers readily available applications for electricity generation from solid biomass. For plant sizes of 1.5 MW_{el} or more, electric efficiencies exceeding 30 % can be reached. This combination actually represents the best opportunity for attaining economic feasibility in this plant size range, which explains the increasing global interest in the development of processes that are able to provide gas from solid biomass, which meet the engine's requirements.

Issues associated with these requirements are:

- Dust content has to be controlled to avoid abrasion

- Ammonia content, which may cause corrosion and problems regarding emission limits, has to be controlled

- Low tar content has to be maintained, as condensing tar in the gas supply, carburetor or on the engine valves would cause severe operation disturbances

- Dew point has to be maintained to avoid liquid water, which could for example damage the turbo charger and cause other engine malfunctions

- Fluctuations in the gas heating value and amount have to be kept low to ensure constant power production

- Avoid high hydrogen concentration in the gas since it leads to pinging of the engine

- The ignition and combustion speed has to be fast enough to ensure complete fuel burning during the work cycle, which otherwise would result in high carbon monoxide emissions

In order to achieve required gas quality, the gas usually has to be treated before entering the engine. Available wood gas treatment processes can be mainly divided into wet processes with and dry processes without scrubbing. The drawback of processes using water as washing liquid is the transfer of tars from the gas to the water phase. Invest and operation cost intensive equipment is needed to upgrade the water to allow discharge into the public sewage system. Other systems use organic washer liquid, which is fed into the gasifier after usage. Consequently, the consumption of this washing liquid is quite costly. These systems are still in the phase of development.

Depending on the type and the operation parameters of the gasification process, a significant portion of the heating value of the gas can be contained in the tars. Therefore, the most promising systems do not remove the tars but instead convert them into major gas components like hydrogen, methane, steam, and carbon monoxide or dioxide, which is more reliable and economically feasible. The energy content of the tars remains in the gas and can be used downstream.

A dry gas treatment process fundamentally consists of the following operation units:

- If a fluidized bed gasifier is used, catalytic active bed material can be used to provide a raw gas with low tar content for the gas cleaning following downstream

- Dust removal from the gas at high temperatures as far as needed for the next process step

- Catalytic tar reforming either with a catalytic fixed bed, a nickel based catalytic monolith, or a fluidized bed catalyst

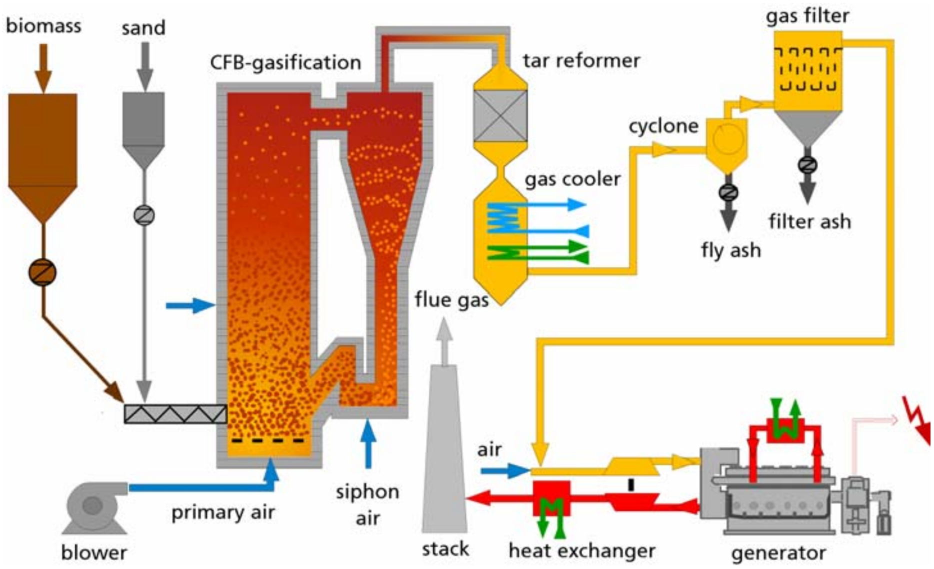
- Gas cooling

- Final dust removal with a fabric filter

An example for such a plant configuration is shown in Figure 3-18.

Figure 3-18

CFBG with catalytic tar reforming, gas cooler, final gas dedusting and gas engine

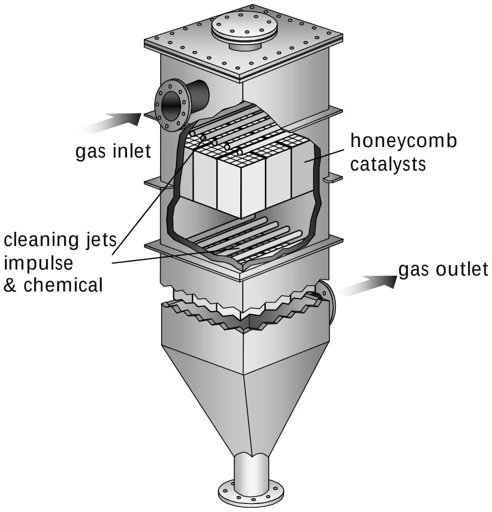


The catalyst is operating at the high temperature of the gas leaving the gasifier. If a CFB gasifier is used, the catalyst has to be able to handle the high dust content of the hot gas. Therefore, preferred technologies are based on monolith catalysts in a honeycomb design or fluidized catalytic beds. Even though the fluidization velocity of such fluidized bed catalytic systems is much lower than the gas velocities in fluidized bed gasifiers, entrainment of the catalyst still presents a problem.

A commonly used catalytic material for such purposes is dolomite. Dolomite is an inexpensive material, but particle wear, particle entrainment and deactivation presupposes a steady feed of a new catalyst. The cost of the new material and the disposal represents a significant part of the operation costs of such a plant. Therefore, when using clean wood, fixed bed catalysts can be more economic. Honeycomb monolith catalysts with straight, smooth channels allow the major part of the dust particle to flow through without getting attached to the walls. Only small amounts of dust remain on the monolith and can be removed on-line by quick, pressurized gas injections. During operation, the catalyst can also be partially charged with a cleaning gas, which enables the in-situ removal of catalyst contamination such as traces of sulfur or coke via chemical reactions. Cleaning gas can be for example a mixture of water vapor and air. The schematic apparatus design for such a process for tar removal is shown in Figure 3-19.

Figure 3-19

Schematic apparatus design for catalytic tar removal, using a catalyst fixed on honeycomb carrier



The nitrogen contained in clean wood does not lead to any problems concerning the gas engine or the compliance of the nitrogen oxide emissions of the engine with the environmental requirements. This might be different if treated wood such as residues from particleboard production is utilized. The residues might contain glue, which is used to bind the particles. The glue causes approximately 3-6 times higher nitrogen content of the gasifier feedstock. In the gasifier, the major fraction of the nitrogen is converted into molecular nitrogen N_2, but a minor part is converted into ammonia. This might cause ammonia concentrations in the wood gas above the limits defined by the gas engine manufactures. Hence, the gas treatment outlined above can be extended by an ammonia scrubber to remove the ammonia from the tar free, filtered, and cooled fuel gas. As opposed to water based tar scrubbing, the ammonia removal can be operated close to the dew point temperature of the wood gas. The washing liquid of an ammonia scrubber is water mixed with an inexpensive organic acid to maximize the solubility of the ammonia in the liquid. Only a small fraction of the liquid has to be removed from the washing cycle and fed back into the gasifier. By cooling the washing liquid down to a little below the dew point of the gas, water vapor of the wood gas is condensed to maintain the liquid amount of the washing cycle.

It has to be noted that problems related with phase separation, thickening of the circulating washing liquid, plugging of the orifices by aged tar components etc., which occur during operation of a tar scrubber, do not interfere the ammonia scrubber operation.

3.4.3 Gas Utilization in (Micro) Gas Turbines

Gas turbines are an alternative to reciprocating engines. However, in a capacity range below 5 MW_{el}, gas turbines show significantly lower efficiencies. In addition, plants with an electricity output below 5 MW_{el} will possibly be operated by personnel who run the power plant beside their major daily business. The basic O&M requirements for reciprocating engines are well known and professional service companies are stationed all over the country. The opposite is the case for gas turbines.

An interesting alternative has gained momentum during the last years. Microturbines are available with capacities between 30 – 60 kW and have dimensions similar to a refrigerator. These systems have electric efficiencies in the range of 20 – 30%, averaging around 26%. A diagram of a microturbine and housed aggregate from the Capstone Turbine Corporation is shown in Figure 3-20.

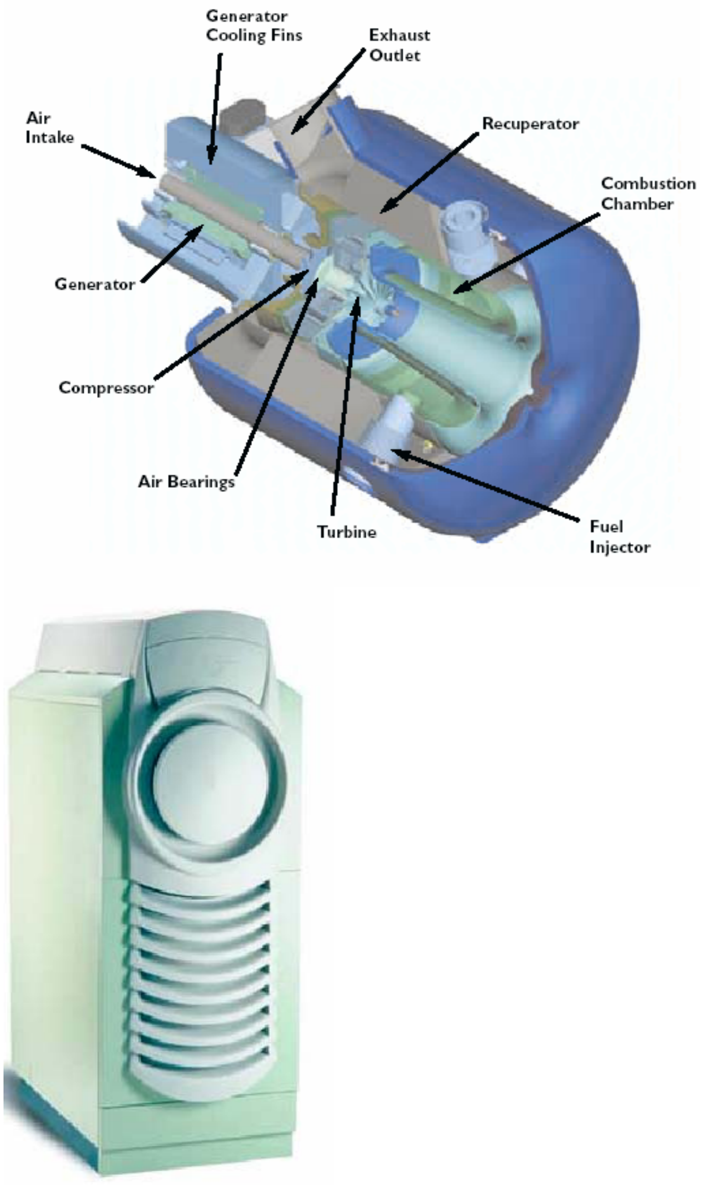


Figure 3-20

Functional diagram of a microturbine and completely housed aggregate (Capstone Turbine Corporation)

Gas turbines in the capacity range of about 10 MW_{el} in combination with pressurized gasification offer significant advantages for stand-alone power production. In this case, the hot, cleaned, pressurized gasifier gas is fed directly into the combustion chamber of the turbine. The turbine compressor provides pressurized air for the turbine combustion as well as for the gasifier. Operation of such a plant requires a minimum size of approximately 75 MW fuel input to be economically feasible. The hot flue gases from the turbine can be fed into an off-heat boiler to produce steam, which can drive a steam turbine. The overall efficiency of this process can reach 36%. However, a plant of this setup incurs additional substantial investment and operational costs. For small-scale gasification/turbine systems, there is still a lack of operational and technical experience. Research to further explore this option is ongoing.

3.4.4 Gas Utilization in Fuel Cells

There is no doubt that fuel cells will be a very interesting way of gas utilization in the future. Unlike the thermal power systems mentioned above, the efficiency of fuel cells is not restricted by the Carnot efficiency. Even under partial load, fuel cells provide high efficiency conversion.

However, specific prices for fuel cells are still drastically higher than for any other conversion technology. Although fuel cells show a great potential for a cost decrease, it cannot be expected that the costs will become competitive during the next few years. Furthermore, due to impurities of gasification gas such as dust and tar, and due to severe process conditions such as high temperatures, gas cleaning of thermal gasifier gas for fuel cell requirements is a difficult task. Applicable process solutions are still in their early phase of development.

In conclusion, these technical and financial barriers preclude fuel cells from consideration as an applicable scenario for current projects.

3.4.5 Co-firing of Gas Produced from Biomass

Co-firing of wood gas with other fuels in existing plants may offer several advantages. Thermal gasifier gas can be co-fired together with natural gas, oil, or solid fuels. Co-firing allows limited but uncomplicated substitution of traditionally used, non-renewable energy sources with continuing use of the existing equipment.

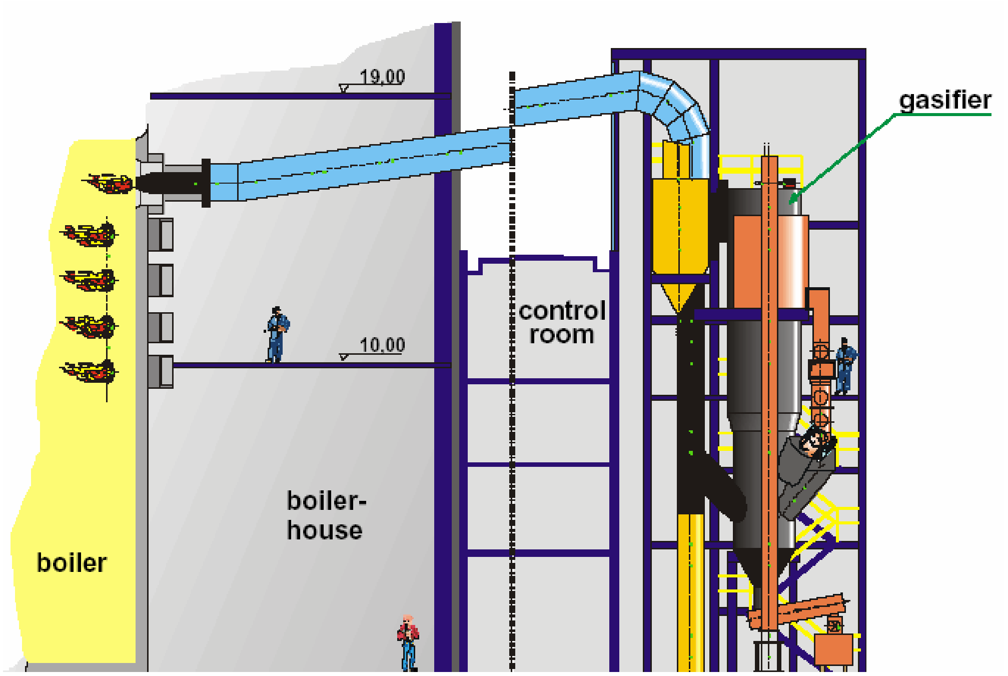
Generally, energy supply from biomass is more investment cost intensive than energy generation from widely-spread fossil energy sources such as oil or gas. Therefore, it is necessary to operate a biomass plant near 100 % capacity year-round in order to reach economic feasibility of the investment. Hence, these plants are mostly designed for base load capacity, whereas electricity peak demand is covered by the grid and heat peak demands are covered by additional equipment using oil or gas.

In case of co-firing, no additional equipment is needed. The achievable maximum capacity of the plant while co-firing wood gas will be reduced compared to the maximum capacity of burning fossil fuels only. In case that the original higher maximum capacity is needed temporarily, the plant has to run on 100% fossil fuel for the time of full load operation. In most cases, this will still be the most economical solution to utilize biomass.

Another advantage of co-firing is the possibility to use the high efficiency of a very large plant. A plant fueled with biomass only would never be built in this size and consequently not operate with the same efficiency. An example of a co-firing plant that was realized in various locations is shown in Figure 3-21 (co-firing of gas in a coal fired boiler). Co-firing projects using wood gas to fire kilns or boilers are operating in sizes up to 300 mmBtu/h.

Figure 3-21

10 MW thermal CFBG gasifier with hot gas pipeline to coupled coal burning boiler (Oestereichische Draukraftwerk AG)



Furthermore, co-firing in IC engines is possible. Co-firing of natural gas and lean gas in a reciprocating engine may even enable lower nitrogen oxide emissions compared to natural gas firing and lower carbon monoxide emissions compared to lean gas application. Conventional dual fuel engines use a jet injection of gasoline to ignite the lean gas. The gasoline is providing a significant amount of the fuel input to the engine.

However, as a rule of thumb for first project assessments, the gas treatment system for the lean gas has to be designed to meet the same gas quality criteria as for exclusively firing the thermal gasifier gas in the same plant.

3.5 Cogeneration of Electricity, Heat and Cold

3.5.1 Efficiency and Attributes of the Cogeneration of Heat and Electricity

Cogeneration is defined as the generation of both thermal and electrical energy at the same time. A stand-alone power plant looses a large part of the chemical energy of the fuel as off-heat to the environment. A modern conventional power plant reaches total electric efficiencies between 40% and 60%. Cogeneration plants minimize the energy losses by using a part of the off-heat for heating purposes. In this case, up to 90 % of the energy input provided by the fuel can be used. In other words, the total efficiency of a cogeneration plant, the sum of the thermal and the electric efficiency, is comparable to the total efficiency of a plant generating heat only. For a heat only generation plant, the total efficiency is equal to its thermal efficiency.

Figure 3-22 presents a comparison of the typical energy flows in a cogeneration facility on the left side, and, on the right side, a stand alone power plant producing the same amount of electricity, supplemented by a stand alone heating plant, which supplies the same amount of heat energy as the cogeneration facility.

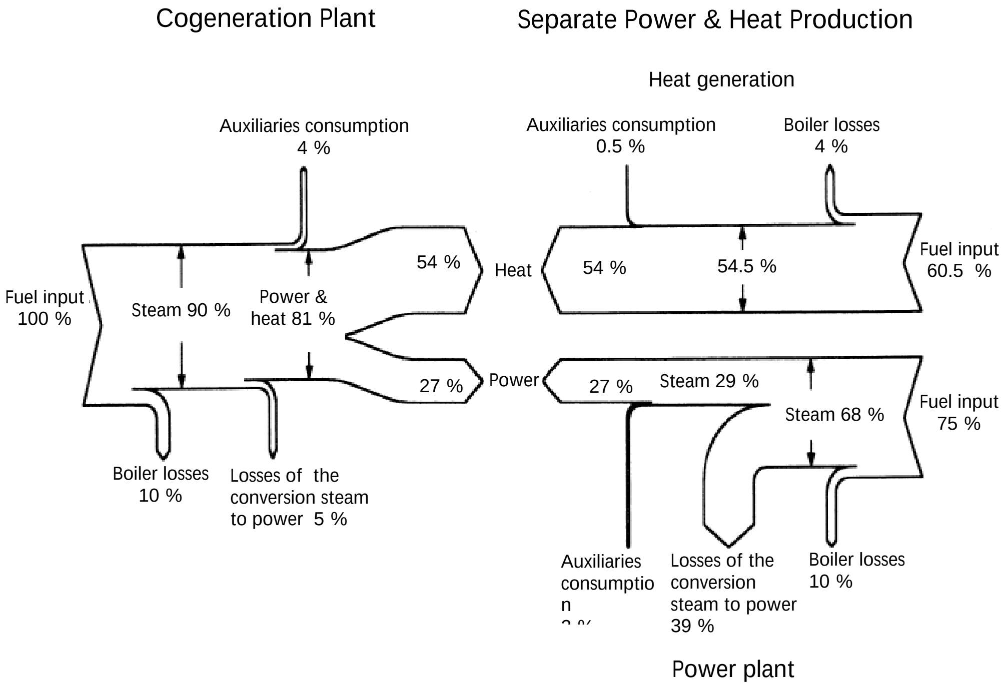


Figure 3-22

Energy flows in a cogeneration plant and separate heat and power production plants, all numbers related to 100 % fuel input in the cogeneration plant (AGFW - Arbeitsgemeindschaft für Wärme und Heizkraftwirtschaft)

The main attributes of a cogeneration process are:

- During standard operation, no transfer of heat-losses from steam condensation into the environment
- High total efficiency comparable to that of a heat only generation plant
- Higher total efficiency as in the case of separate heat and power generation
- Consequently, fuel savings and lower emissions compared to separate heat and power generation,
- Suitable for base load operation

Every opportunity to improve the economic feasibility has to be used because biomass plants are investment cost intensive. Mainly due to fuel logistics, the size and, therefore, the electric efficiency of biomass power plants will always be significantly lower than that of large modern, mostly fossil fuel fired plants. On the other hand, when using cogeneration, the limited size increases the possibility to find a plant site where 100 % of the produced heat can be sold. However, when off-heat is utilized, the electric efficiency usually is slightly lower than when electricity is generated exclusively. Therefore, cogeneration offers economic advantages as long as the revenue from selling heat and electricity exceeds the revenue that would be generated from a plant generating only electricity.

3.5.2 Applicable Process Configurations for Combined Heat and Power (CHP) Generation

Steam Cycle

If a steam-cycle is used, three basic plant configurations are eligible depending on the requirements of the heat consumer.

- Topping a cogeneration system with a backpressure turbine:
  The steam vessel produces steam at a higher pressure than required for heating purposes. This pressure difference drives a backpressure turbine to generate electricity.

- Condensing extraction turbine:
  For applications with temporal fluctuations of the heat demand, this process offers the best possibilities for adaptation. The steam produced in the vessel is fed into the turbine. Depending on the heat demand, various amounts of steam are extracted at one or more locations at required pressure levels. The fraction of the steam that is not used for heat supply leaves the turbine at the outlet and is fed into a condenser. The temperature level of the heat recovered from the condenser is too low to enable heat utilization.

The condenser is needed within the steam cycle. If no low temperature water from ground or surface water resources is available or the ambient temperatures are too high for an air-cooled condenser, an additional wet cooling tower is needed. This results in higher system costs, complexity, and lower overall efficiency, because unusable waste heat is discharged into the environment.

- Bottom cycle:
  Bottom cycle configurations use the exhaust heat from high temperature processes. This exhaust heat may be provided in form of steam or hot water. Steam can also be produced from other forms of process heat such as hot air, flue gases, thermal oil, etc. Because of the low efficiency of low-pressure systems and other drawbacks, these systems are not very common.

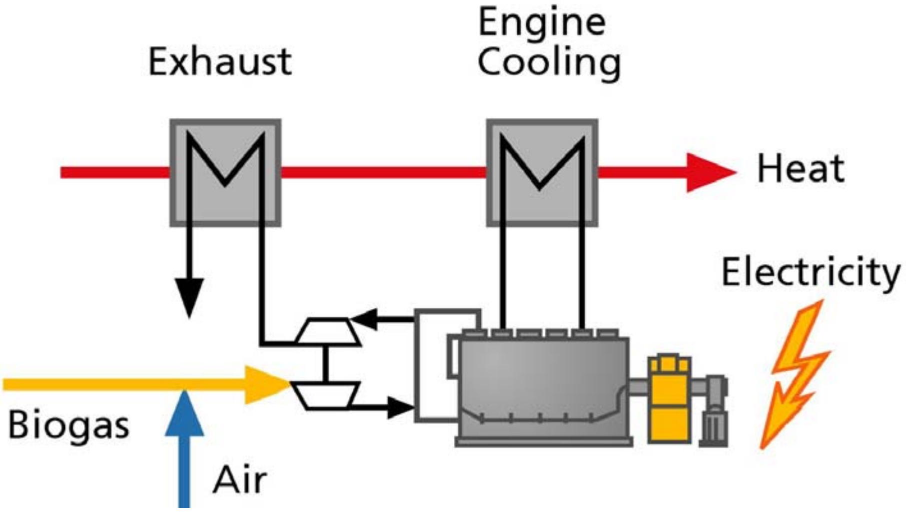
Reciprocating Gas Engines

If gas is combusted in a reciprocating engine, waste heat for heating purposes can be recovered from the approximately 760 ^{o}Fahrenheit hot flue gases and from the approximately 195 ^{o}Fahrenheit warm cooling water of the engine. The off-heat of the flue gases can be used for the production of low-pressure steam for process heating. Normally, the properties of this steam do not enable economically feasible power production with an additional steam turbine or steam engine. As a rule of thumb, 35 % of the chemical energy input of a reciprocating engine will be converted into electricity, 12 % can be recovered from the flue gases, and 27 % from the cooling water. A diagram of heat recovery from an IC engine fueled by biogas is given in Figure 3-23.

Additional heat on a high temperature level (approximately 1,550 ^{o}Fahrenheit) can be recovered from the gas cooler at the outlet of the gasifier. As a rule of thumb, the additional amount of heat available can be estimated to be 15 % in relation to the fuel input into the gas engine.

Figure 3-23

Process scheme for heat recovery from an IC engine fueled by biogas



Gas Turbines

Because of the high flue gas temperatures at the turbine outlet, the heat recovered from the turbine flue gases can be used for steam or hot water production. If the flue gas temperature is too high, outside air can be mixed with the flue gas. This increases the oxygen content in the turbine flue gas and offers the option to burn additional fuel in a waste heat recovery boiler by using the turbine flue gas and air mixture instead of air alone to provide the oxygen for the combustion.

Combined cycle plants use the recovered off-heat from the gas turbine to operate a steam cycle. The steam cycle can either use a backpressure or condensing turbine and offers the cogeneration possibilities outlined above. However, the investment for an additional steam cycle for a plant in the feasible size range of wood gasifiers cannot be justified as it would be too expensive.

3.5.3 Combined Heat, Cold and Power (CHCP) Generation

The production of cold from heat by using adsorption, absorption or steam jet ejector chillers offers another possibility for the utilization of off-heat generated by a CHP plant. Especially during summer time, when heat demand decreases, this represents another opportunity to enhance the economic feasibility of power production from renewable energy sources, coupled with the substitution of fossil produced electricity (which is usually used to drive compression chillers) by heat generated from renewables.

Examples for the use of alternative cold generation technologies are found in industrial applications, residential and commercial buildings as well as ice rinks, hospitals, farms or airports. Important parameters for the selection of the appropriate technology include amount and temperature of the available waste heat and cooling requirements, seasonal and daily variations of cold demand, and prices.

4 Business Structures and Financial Aspects

This chapter of the report summarizes information on organizational and financial aspects of a renewable energy project.

4.1 Business Structure

For a renewable energy plant, the developer will typically form a separate special purpose corporation or partnership to develop, own, and operate the project. There are several different business structures, which could be utilized as framework for a renewable energy project. The options imply different levels of risk, liability and financing/funding opportunities. Following will be a brief description of business structures and their significance (gathered from the Internal Revenue Service and from the Pennsylvania Small Business Development Center).

Cooperative

The cooperative is an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly-owned and democratically controlled enterprise.

A cooperative operates under the following basic principles:

- Controlled democratically, one membership, one vote
- Offers open membership to all who can use its services. No one will be denied membership on the grounds of age, race, color, religion, sex or national origin
- Emphasizes service rather than profit. The cooperative way provides limited return on investment
- Operates on a nonprofit basis by returning margins to members.
- Cooperation with other cooperatives

Sole Proprietorship

A sole proprietorship, by definition, means one owner. Most small businesses operate as sole proprietorships. This is the simplest form of organization and allows the single owner to have sole control and responsibility. The business may use a fictitious name, but the business does not have a separate legal existence apart from its owner. Some advantages of the sole proprietorship are less paperwork, a minimum of legal restrictions, owner retention of all the profits, and ease in discontinuing the business. The sole proprietor does not need to file a separate income tax return for the enterprise because the activity is reported on the owner’s federal and Pennsylvania individual income tax returns.

Disadvantages include unlimited personal liability for all debts and liabilities of the business, limited ability to raise capital, and termination of the business upon the owner's death. A small business owner may select the sole proprietorship to begin. Later, he or she may decide to form another type of organization.

General Partnership

A partnership is similar to a sole proprietorship, except that two or more parties are involved. In a business partnership, the parties that join forces can be individuals, corporations, trusts, other partnerships, or a combination of all of the above. Advantages are that it is easy to establish and the profits are not directly taxed.

Some disadvantages are:

- The partners share unlimited personal liability for the firm's debts and liabilities
- The business terminates with the death of a partner (in the absence of advance planning for business continuation),
- Any one of the partners can commit the firm to obligations.

A general partnership is formed by an agreement entered into by each partner. This agreement may be informal, but it is recommended that a written agreement by signed by all partners.

Limited Partnership

A limited partnership is a partnership formed by at least two persons. The partnership must have at least one general partner and at least one limited partner. The general partner assumes the personal liability for the debts and obligations of the partnership; the limited partners do not have any personal liability beyond the capital contributions they make to the partnership. The limited partners have limited exposure to liability and are not involved in the day-to-day operations of the limited partnership.

Limited Liability Partnership

A Limited Liability Partnership (LLP) is a partnership that provides liability protection for all limited partners. A limited partnership is a partnership formed by at least two people. The partnership must have at least one general partner and at least one limited partner. The general partner in a limited partnership has the same rights, obligations, and duties as a partner in a general partnership. Whereas the limited partner is only liable for the capital contributions they make to the partnership. The limited partners are strictly limited to money and property. They are also not involved in the day-to-day operations of the partnership.

Limited Liability Corporation

A limited Liability Corporation (LLC) is a hybrid between a partnership and a corporation, with the benefit of a tax advantage and fewer formalities than a corporation. Generally, LLC’s must be comprised of at least two members. However, recently single member LLC’s have been allowed in most states.

Corporation

A corporation is the most complex form of business organization. It is a legal entity with all rights, privileges and responsibilities of a person; possessing the attributes of limited liability, centralized management, continuity of life and fee transferability of interest. It acts as a single person. The corporation owns the business and in turn, may issue shares of stock to individuals investing in the corporation. One advantage of organizing as a corporation is that a stockholder's liability is limited to the amount paid for his/her share(s) of stock. Another advantage is that the corporation's continuity is unaffected by the death or transfer of shares by any of the shareholders. Some disadvantages are extensive record keeping, close regulation, and double taxation (taxes on profits and taxes on dividends paid to owners).

S Corporation

An S corporation is either a general corporation or close corporation that has elected to be taxed pursuant to Subchapter S of the IRS code. Generally a corporation is taxed twice, through the corporate income tax, and then through the individual shareholder. By becoming an S corporation the profits of the corporation are not taxed to the individual shareholder. A disadvantage of an S corporation is that all of its shareholders must be US citizens, and that the corporation is governed by the bylaws that limit the flexibility the company has with profit distributions, and management.

Non-Stock Corporation:

A non-stock corporation is a group organized for the sole purpose of generating profit, and no part of that profit is distributed to its members. A non-stock corporation is owned and operated by its members because there are no stockholders. There can be different classes of members that should be defined using the by laws. Generally non-stock corporations are used by religious, educational or charitable organizations.

Municipal Utility

The municipal utility as a business structure implies that the potential renewable energy plant is owned and operated by the municipality. This arrangement has the advantages that income and property tax do not have to be paid.

4.1.1 Specific Situation in Pennsylvania, State and Federal Support

4.1.1.1 Energy Market and Deregulation

When evaluating the economic prospects of a gasification project, it is important to consider the current situation of the energy market and anticipated future trends. Since the gasifier can be used to replace natural gas or electricity from the grid at a specific site, the cost savings based on their replacement are some of the most influential factors for a project's overall economics. Therefore, a brief discussion of the energy market and current and future prices for electricity and natural gas in Pennsylvania are given below.

The Pennsylvania House Bill (H.B.) 1509, entitled the "Electricity Generation Customer Choice and Competition Act", was enacted in December 1996. The main purpose of this legislation was to give all electricity consumers a chance to choose among competitive generation companies. The market opening was scheduled to begin for one third of the consumers by 1/1999, two thirds by 1/2000 and all consumers by 1/2001, but following agreements between utility companies and the Public Utilities Commission (PUC) this goal was reached in January of 2000. Under deregulation, the unbundling of electric services has transformed the power industry into three components: generation, transmission, and distribution. Of these, generation has become unregulated and open to competition. Distribution services and rates will remain regulated by the state.

Local utilities, who operate and maintain the transmission lines, will continue to deliver power to the customer. Figure 4-1 shows the power system components and the impact of deregulation on the each.

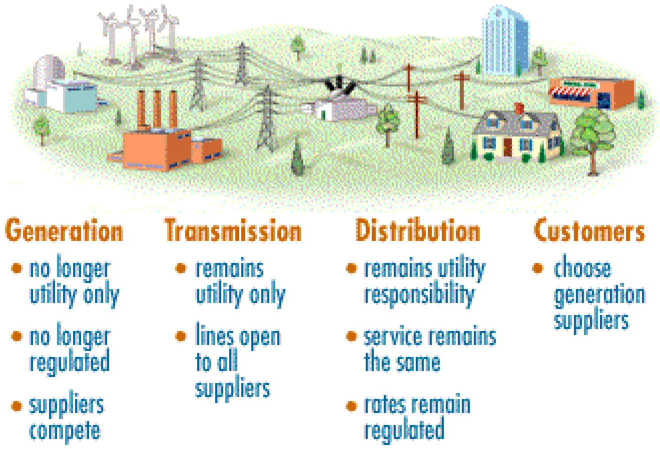


Figure 4-1

Market deregulation implications from www.energyguide.com

In June 1999, Governor Tom Ridge signed the Natural Gas Choice and Competition Act into law that mandated natural gas choice to all customers on November 1, 1999. The bill eliminates the state's 5 percent gross receipts tax on gas service beginning January 1, 2000. In addition, the bill provides protections for low-income consumers and requires all natural gas suppliers in the competitive market be licensed by the Pennsylvania Public Utility Commission (PPUC).

The restructuring process of the electricity and natural gas industries and the according regulatory changes have had several effects on the energy market. These will be outlined below.

Customer Choice Program

Since the start of market opening in 1999, customers in Pennsylvania have been allowed to choose their electric supplier. Substantial customer education programs have been established in order to increase the general knowledge of arising market opportunities. As of April 1st, 2003, a total of 275,910 customers in Pennsylvania have switched to an alternative electricity supplier. This number can be further classified into residential customers (245,378) followed by commercial (29,561), and industrial (953). The total load supplied by alternative suppliers is 2,621 MW of which 568.3 MW was for residential, 1243.8 MW for commercial, and 809 MW for industrial customers (Pennsylvania Office of Consumer Advocate, 2003).

Six electricity retailers for Green Power have been certified by the Public Utilities Commission (PUC) and are now selling electricity, generated from renewable and cogeneration sources, to customers who are willing to pay a higher price for more environmentally friendly products. This opened a new market opportunity for environmentally sound energy provided by distributed generation technologies.

The deregulation of the gas market in Pennsylvania has also initiated customers to switch to alternative suppliers. As of April 2003, out of a total of 2,067,574 residential gas consumers, 209,711 (10.1%) customers were being supplied by alternative gas suppliers (Pennsylvania Office of Consumer Advocate, 2003).

Stranded Costs Recovery

Additionally, the H.B. 1509 allows stranded costs recovery for utility companies entering the competitive market.

Stranded costs are defined as known and measurable costs, caused by investments made for electricity generating facilities before the market deregulation was enacted, that are not recoverable in a competitive market. Examples are net plant investments, permission costs, unfunded portions of nuclear power plant decommissioning costs as well as certain labor costs like early retirement (LGC Consulting, 1996).

Recoverable stranded costs were based on individual negotiations between the PUC and electricity distribution companies (EDC) that took place prior to the creation of the competition. The total amount for all EDC´s was set in 1998 at $11.8 billion with a recovery time of 10 to 12 years (Miller, 2002).

For the recovery of stranded costs, all customers in the same rate class pay the same transition charge (TC) per kWh as part of the non-generation portion of their customer bill. For example, the TC for industrial customers (Tariff PL4, which will be used in chapter 6) is decreasing from 0.214 cents/kWh in 1999 to 0.115 cents/kWh in 2008 in the PPL Corporation service territory (PPL, 2001).

Installing an on-site generation system at an industrial site usually reduces the amount of electricity purchased from the electricity grid. According to law it is required that "...the fully allocated share of transition or stranded costs shall be recovered from the customer through a competitive transition charge (CTC)" (General Assembly of Pennsylvania, 1995). Consequently, the amount of the CTC can be equal or even less than the previous paid TC for the purchased electricity. The period for collection of the CTC is limited to a maximum of nine years after switching to another customer or to the general end of the stranded costs recovery period.

Electricity

Dramatic increases in natural gas prices in 2002, which led to substantial increases in U.S. electricity prices, diminished the competitiveness of some electricity suppliers. Many left the market, initiating a customer return to "providers of last resort"—suppliers designated for customers dropped by their competitive suppliers. After 2001, however, this service was provided not by incumbent utilities but by the suppliers that offered the best rates. For example, most customers of southwestern Pennsylvania's Duquesne Light finished paying stranded costs in March 2002, and now 27 percent of the electricity load in the territory is supplied competitively. Even with the increase in natural gas prices, Pennsylvania's electricity prices have been reduced by about 8 percent (in real dollars) since restructuring legislation was enacted in 1996 (Center for the Advancement of Energy Markets, 2003).

The average electricity prices for residential, commercial, and industrial consumers differ due to the variations in quantitiy that is consumed by these entities. For example, an industrial facility with a high electricity demand will be able to get electricity at much lower rates than a residential consumer. In 2000, the average electricity price for residential customers in Pennsylvania was \$27.94/mmBtu (10.23 cents/kWh), whereas the average price for commercial entities was \$22.80/mmBtu (7.79 cents/kWh), and \$16.50/mmBtu (5.64 cents/kWh) for industrial consumers (Energy Information Administration, 2002).

According to the Annual Energy Outlook from the Energy Information Administration, national average electricity prices are projected to decline from 7.3 cents per kilowatthour in 2001 to a low of 6.3 cents (2001 dollars) by 2007 as a result of cost reductions in an increasingly competitive market. After 2008, average real electricity prices are projected to increase by 0.4 percent per year as a result of rising natural gas prices and a growing need for new generating capacity to meet electricity demand growth (Hutzler, 2003).

Natural Gas

Similarly to electricity, natural gas prices also vary between residential, commercial, and industrial consumers. In 2000, residential consumers had to pay on average \$8.20/mmBtu, while commercial entities could buy natural gas for an average of \$7.46/mmBtu, and industrial rates were as low as \$4.86/mBtu on average in Pennsylvania. In 2001, these numbers increased to \$11.47/mmBtu, \$10.68/mmBtu, and \$7.47/mmBtu for residential, commercial, and industrial consumer, respectively (Energy Information Administration, 2003).

According to the Energy Information Administration, the average wellhead price of natural gas in the 2000-2001 heating season (October 2000-March 2001) is estimated to have been 144 percent higher than the average recorded for the 1999-2000 heating season. The length of time that nominal gas prices have remained this high is unprecedented. In early July, the Federal Reserve Chairman told a Senate Panel: "Today's tight natural gas markets have been a long time coming, and distant futures prices suggest that we are not apt to return to earlier periods of relative abundance and low prices anytime soon" (Reeves, 2003).

4.1.1.2 State Support for DG Technologies

Fostering the market introduction of sustainable energy in Pennsylvania, several initiatives are available within the state. The most important ones are outlined below.

KOZ – Keystone Opportunity Zones

Key stone opportunity zones are limited areas with greatly reduced or no local and state tax burden for residents and businesses designated by local communities and approved by the state. They are a partnership between each community and region among state and local taxing bodies, school districts, economic development agencies and community-based organizations and are intended to stimulate economic development in theses areas.

Pollution Prevention Assistance Account (PPAA)

The purpose of this program is to help small businesses implement pollution prevention and energy efficiency equipment or processes. The eligibility is limited to businesses with 100 or fewer employees in the fields of agriculture, industrial manufacturing, export services, hospitality, defense conversion-related services, construction, and child care services. Eligible businesses may apply for loans of up to $100,000 or 75% of the total project cost, whichever is less, at an annual fixed interest rate of 2%. The remaining 25% of the project cost must be financed from other sources (e.g. equity or private lender).

Sustainable Energy Funds

The Electricity Generation Customer Choice and Competition Act contained no provisions to support renewable energies. However, it did require that low-income and energy efficiency programs be maintained at current levels or higher. Renewables funding programs were subsequently created through individual settlements with the state's four major distribution utilities: FirstEnergy (formerly General Public Utilities (GPU)), West Penn Power Company, PECO, and Pennsylvania Power & Light (PP&L). Each utility created its own "Sustainable Energy Fund" with the goals of promoting (1) the development and use of renewable energy and advanced clean energy technologies, (2) energy conservation and efficiency, and (3) sustainable energy businesses. Each utility has established an oversight board and designated a fund administrator (Birge, 2003). Eligible technologies include solar thermal, photovoltaics, landfill gas, wind, biomass, hydroelectric, fuel cells, geothermal heat pumps, municipal solid waste.

FirstEnergy's Sustainable Energy Fund totals $12.1 million and is collected by its two Pennsylvania subsidiaries, Metropolitan Edison and Pennsylvania Electric (Penelec) through December 2004. Funding will continue at a rate of 0.01¢/kWh beginning in 2005. In 1999-2000, $1.1 million was spent on photovoltaic projects and $600,000 on solar water heating projects (Birge, 2003).

West Penn Power’s Sustainable Energy Fund totals $11.4 million, covering the period of 1999-2005, that will be administered by a 7-member independent board. Funds after this date will be collected annually at a rate of 0.01¢/kWh. The funds are to be used to promote the development and use of renewable and clean energy technologies and energy efficiency. Specific funding of more than $390,000 was set aside for a PV program and $220,000 for a solar water heating program in 1999 and 2000 (Birge, 2003).

PECO’s Sustainable Development Fund totals $32 million to be collected from January 1999 through December 2006. Funding will continue at a rate of 0.02¢/kWh beginning in 2007. The PECO/Unicom 2000 merger settlement added $12 million for new wind development, $4 million for a photovoltaic program, and $2.5 million for public education about renewables (Birge, 2003).

PP&L’s Sustainable Development Fund totals $20.5 million to be collected from January 1999 through December 2004. Funds after this date will be collected annually at a rate of 0.01¢/kWh. The first programs funded by PP&L’s fund were approved in November 2000 (Birge, 2003).

Renewable Portfolio Standards

Pennsylvania’s December 1996 electricity restructuring law did not establish a renewable portfolio standard. However, as with the state’s public benefits funds for renewables, a renewable energy portfolio requirement was subsequently established through individual utility restructuring settlements with PECO, PP&L, GPU, and Allegheny (West Penn).

In the case of PECO, for example, on January 1, 2001, 20% of PECO's residential customers were to be assigned to a provider of last resort-default supplier other than PECO via a competitive bidding process . To qualify for the "competitive default service" bidding process, an electric generation supplier had to agree to provide in 2001 at least 2.0% of its generation portfolio from renewable resources (See eligible technologies above). The renewable energy increment was to increase 0.5% annually thereafter.

Other utility settlement agreements contained similar provisions, although GPU's portfolio requirement was only 0.2% renewables and municipal solid waste was an eligible fuel source. However, these agreements contained a clause that eliminated the requirement if the increase in cost as a result of using renewable energy exceeded a certain level. Only PECO's bid process was successful, with New Power picking up 299,000 customers and Green Mountain Power taking over about 50,000. New Power later went out of business and the number of Green Mountain Power's customers has dropped to about 32,000. (Griffith, 2003)

Net Metering

Pennsylvania's Public Utility Code states that qualifying facilities of less than 50 kilowatts may opt for net energy billing. Each utility is required to file its policy for net billing with the Public Utilities Commission (PUC). Individual utility tariff filings and operating procedures vary by utility. In some cases the maximum system size eligible for net metering is less than 50kW. For example, West Penn Power Company's Net Energy Metering Rider applies to systems that do not exceed 10 kW while PECO Energy Company offers net metering for systems up to 40 kW. Eligible generation facilities include solar thermal electric, photovoltaics, wind, biomass, and hydroelectric. The specific interconnection standards vary by utility and should, thus, be discussed with the local utility. (Birge, 2002)

Pennsylvania Energy Harvest Grants

In 2003, a program called "Pennsylvania Energy Harvest Grant" was introduced by the Pennsylvania Department of Environmental Protection to fund projects that promote awareness and build markets for cleaner or renewable energy technologies. The program explicitly includes biomass energy projects. In 2003, the deadline for proposals was September 19. The program might be continued in 2004. Additional information can be found on the DEP website at http://www.dep.state.pa.us/.

4.1.1.3 Federal Support for DG Technologies

Federal incentives as well as the state incentives explained above support the commercialization of DG technologies.

The PURPA obliged the utilities in 1978 to purchase from and to deliver (back- up power) electricity to qualifying facilities (QF). QF are distinguished in small power production facilities and cogeneration facilities. Small power production facilities utilize biomass, waste, renewable resources or any combination thereof and have a power production capacity below 80 MW on-site. Cogeneration facilities are neither restricted in their fuel source nor in plant size, but must produce electricity and heat. They must produce at least 5% useful heat as well as the electric output plus the half of the useful heat must be more than 42.5% of the annual fuel input. Ownership by electric utilities is limited to less than 50%. The purchase price of QF electricity for the supplying utility has to be at the same level than avoided costs for alternative electricity (Vasenda, 1992).

Currently, the PURPA regulations are not applicable as they expired. However, the legislation has been proposed to be reenacted and discussion is ongoing.

In contrast to the PURPA regulations that were adjusted by certain state legislations, the federal government created several nationwide monetary incentives.

Farm Bill

In 2002, the Farm Security and Rural Investment Act known as the "Farm Bill" was released by the federal government. Title IX of the bill specifically deals with energy related topics. From this program, the United States Department of Agriculture makes funding available for different purposes. For example, an "Energy Systems and Energy Efficiency Improvement Program" was funded in cooperation with the Department of Energy and provided $23 million in grants for a joined biomass research and development initiative. Further solicitations can be expected.

General Business Tax Credit

Within the general business tax credit, several components to stimulate business development in different areas are lumped together. New renewable DG technologies may be affected by the 3 components of this tax reduction outlined in subchapters below.

In general, the amount of the taxpayer's federal income tax is reduced by the amount of the general business tax credit sum. The remaining amount of tax liability cannot fall below the larger amount of the taxpayer's tentative minimum tax or 25% of the net regular tax liability.

In case the total amount of the tax credit earned in a certain year cannot be claimed because of this minimum-tax restriction, the remaining sum can be carried back to the preceding year or carried forward to the following twenty years (Tax Guide, 2002).

Renewable Energy Production Tax Credit

The Renewable Energy Production Tax Credit (PTC), first established in 1992, is an inflation indexed tax credit given to qualifying wind and biomass energy facilities for the first 10 years after the facility is commissioned. The tax was originally set at 1.5 cents/kWh but has been adjusted to inflation to 1.8 cents. Commissioning of the facility must have occurred after the enactment of the law and before the current expiration date, which is December 31, 2003. The tax credit applies to all wind power facilities owned by a tax-paying entity and to all tax-paying biomass power facilities that use either a closed-loop or poultry waste fuel source. (A biomass fuel source is considered “closed loop” if it is planted specifically for use in energy production and is not a waste or surplus product from some other activity.)

The value of the PTC is reduced if the facility owner also receives certain types of State or local financial incentives, such as initial-cost buydowns or investment tax credits. Wind and biomass facilities, as well as other renewable energy facilities, also benefit from an accelerated capital cost depreciation schedule of 5 years. The PTC and all extensions of the tax credit, as well as the 5-year depreciation allowance, to all new wind capacity construction are provided through 2003.

Further extension of the PTC to 2007 is included in both the House and Senate versions of the Energy Policy Act of 2002. The House version would expand eligibility for the credit to facilities using landfill gas and certain “open-loop” biomass fuels, including agricultural residue and landscaping trimmings. The Senate version would include those facilities and would also expand eligibility to additional agricultural animal wastes and to geothermal and solar facilities. The Senate version would further allow assignment of the credit by non-tax-paying entities to certain tax-paying entities.

Research and Development (R&D) Credit

Another tax credit that can possibly support the introduction of gasification technologies is the Research and Development Credit. This credit is available for increased research activities in any scientific or technological field in order to generate new information in these areas. This information shall enable the business to improve competitiveness and expand its product or service range. The net income tax can be reduced by a 20% share of the total amount of research expenditures undertaken by the enterprise itself as well as 13% of contract research expenditures.

Renewable Energy Production Incentive

The Renewable Energy Production Incentive (REPI) is part of an integrated strategy in the Federal Energy Policy Act of 1992 to promote increases in the generation and utilization of electricity from renewable energy sources and to further the advances of renewable energy technologies.

This program, authorized under section 1212 of the Energy Policy Act of 1992, provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Eligible electric production facilities are those owned by State and local government entities (such as municipal utilities) and not-for-profit electric cooperatives that started operations between October 1, 1993 and September 30, 2003.

Qualifying facilities are eligible for annual incentive payments of 1.5 cents per kilowatt-hour (1993 dollars and indexed for inflation) for the first ten-year period of their operation, subject to the availability of annual appropriations in each Federal fiscal year of operation. Qualifying facilities must use solar, wind, geothermal (with certain restrictions as contained in the rulemaking), or biomass generation technologies (except for municipal solid waste combustion).

If there are insufficient appropriations to make full payments for electric production from all qualifying facilities, tier 1 applicants receive incentive payments first. Tier 1 receives either full payments or pro rata payments if funds are insufficient to cover all requests. Tier 1 qualifying facilities are facilities that use solar, wind, geothermal, or closed-loop (dedicated energy crops) biomass technologies to generate electricity. If funds are available after making full payments to these facilities, payments from the remaining funds are then made to tier 2 qualifying facilities. Tier 2 projects consist of open-loop biomass technologies, such as landfill methane gas, biomass digester gas, and plant waste material that is fired (either 100% biomass or co-fired with another fuel) in a generation facility to generate electricity. If there are insufficient funds to make full payments to all tier 2 qualifying facilities, payments are made to those facilities on a pro rata basis. Pro rata payments result in a portion of the electricity production being fully paid and the remainder not receiving payment. Electricity for which payment is not made may be added to the next fiscal year's electricity production and submitted by the qualifying facility for payment consideration, providing the annual application is made in a timely manner within the ten fiscal year eligibility window. In 2001, only 7% of tier 2 was funded.

Depreciation Rules

In order to improve the monetary conditions for investments in biomass, solar and wind energy systems, the federal government allows depreciation of these technologies under the terms of the accelerated cost recovery system since 1994 (Internal Revenue Service, 2003). A business entity is, therefore, allowed to adopt a double declining balance method with a five-year depreciation schedule for the amount of investments in the mentioned renewable technologies.

Thus, the common depreciation rate can be doubled to 40% allowing to switch to the straight-line depreciation method as soon as the yearly straight-line depreciation rate gets higher. This occurs in the 4th year.

5 References and Contacts

5.1 Helpful Contacts and Links

Following will be a list with helpful links from various organizations and governmental departments that can be used to gather information and make contacts for gasification project development.

Fraunhofer Center for Energy and Environment:
http://www.fraunhofer.org/CEE/homepagecee.htm

Pennsylvania Department of Environmental Protection:
http://www.dep.state.pa.us/

Pennsylvania Office of Consumer Advocate:
http://www.oca.state.pa.us/Default_IE.htm

United States Department of Energy – Biopower Site:
http://www.eere.energy.gov/biopower/main.html

DSIRE-Database for State Incentives for Renewable Energy:
http://www.dsireusa.org

Energy Information Administration: http://www.eia.doe.gov/

Pennsylvania Public Utility Commission: http://puc.paonline.com/

Northeastern Regional Biomass Program: http://www.nrbp.org/

University of Pittsburgh: http://www.pitt.edu/

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