Fraunhofer USA Center for
Energy and Environment

Project Report

Gasification of Wood for Energy Generation in Clarion County

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0 Executive Summary

This report summarizes the results of a study performed by the Fraunhofer Center for Energy and Environment in collaboration with the University of Pittsburgh funded by the Pennsylvania Department of Environmental Protection. The objective of the study was to determine the economic feasibility of wood gasification for energy generation in Clarion County. Locally available, untreated residual wood generated by lumber mills and wood-processing facilities can be used to produce a flammable gas, which can then fuel a gas engine to generate electricity or to replace natural gas in industrial processes.

Local surveys were conducted to establish the type, quantity, and prices for residual wood available in Clarion County. The total amount of residual wood available is 258,000 tons per year of which 205,000 tons/yr is in the form of chipped wood, 31,000 tons/yr is pulpwood, and 22,000 tons/yr is sawdust. This quantity is significantly more wood than needed to fuel a gasification plant, thus, ensuring that alternative sources of wood are available in case another source ceases its supply, and that forest stands will not be diminished due to a shortage of residual wood sources. The prices for wood varied by type and supplier. Sawdust was the cheapest source with an average price of $17.00 per ton, whereas chipped wood costs $24.70 per ton on average, and pulpwood is $25.20 per ton including transportation.

Once biomass supply was established, potential consumers for the generated energy had to be identified. Since gasification plants are most suitable for baseload energy supply, industrial facilities are the most appropriate energy consumers because they can ideally utilize the generated energy year round for 24 hours a day. After an initial screening and interviewing process, three facilities were identified as potential sites.

Using the energy demand and layout of these sites, scenarios for energy generation based on wood gasification were developed. Subsequently, economic assessments for the scenarios were carried out including the calculation of simple payback time, net present value, and sensitivity analyses. Of the three scenarios, the first was based on production of wood gas to replace natural gas, while the second and third were based on wood gas generation coupled with a combined heat and power (CHP) plant to generate electricity and heat. The first scenario was very promising with simple payback times of less than four years and a net present value of $1,304,324. Due to the low reimbursement prices for electricity and limited utilization of off-heat from the CHP, the second and third scenario were not economically feasible with long simple payback times and negative net present values. A fourth hypothetical scenario similar to the second scenario but with a higher off-heat utilization was investigated but also failed to achieve economic feasibility.

Overall, it was concluded that under the boundary conditions and assumptions considered in this study electricity generation using wood gasification is currently not economically feasible. Generating wood gas to replace natural gas, on the other hand, seems to be a very attractive option. The scenarios did not include potential financial incentives or grants, which would further improve economics. In addition, future changes in energy generation related regulations such as the implementation of renewable energy portfolio standards could very quickly change the situation and make electricity generation also a viable option for the energetic utilization of residual wood.

Other topics covered in this report are wood gasification emissions and environmental impact as well as a short explanation of how to carry out the economic calculations.

1 Introduction

Each year, millions of tons of residual wood are available nationwide. This underutilized resource represents 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 its 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 in the past assessments have shown that gasifiers were not economically feasible. Another reason is the complexity of possible projects including fuel supply and handling, energy generation, and distribution of the produced energy.

In recent years, energy prices have experienced significant increases, especially that of natural gas. Therefore, renewable energy projects are becoming more and more interesting as economic boundary conditions are changing. In order to investigate the feasibility of wood gasification in Pennsylvania, the Department of Environmental Protection funded this project under the Pennsylvania Environmental and Energy Challenge Grant Program. Clarion County was chosen as location for the study because a lot of residual wood is available in Northwestern Pennsylvania due to the prevalence of wood related industries in this largely forested area. Local industries are available as consumers of the energy produced by a gasifier, and there was a lot of support from local stakeholders and companies.

This report provides the results of the study regarding amounts of residual wood available, the search for potential consumers of the produced energy, assessments for several specific sites, and information on environmental aspects.

In addition to this area specific study, a decision making guide was developed as part of this project. It contains background information on wood gasification technologies, the procedure of developing a basic concept for a gasifier, how to carry out economic feasibility analyses, federal and state funding opportunities and tax incentives, possible options for ownership and plant operation, permitting, etc. The guide can be used as an assessment tool and help to implement sustainable and technically as well as economically feasible energy generation projects based on the gasification of residual wood. It is available on the homepage of the Pennsylvania Department of Environmental Protection (http://www.dep.state.pa.us).

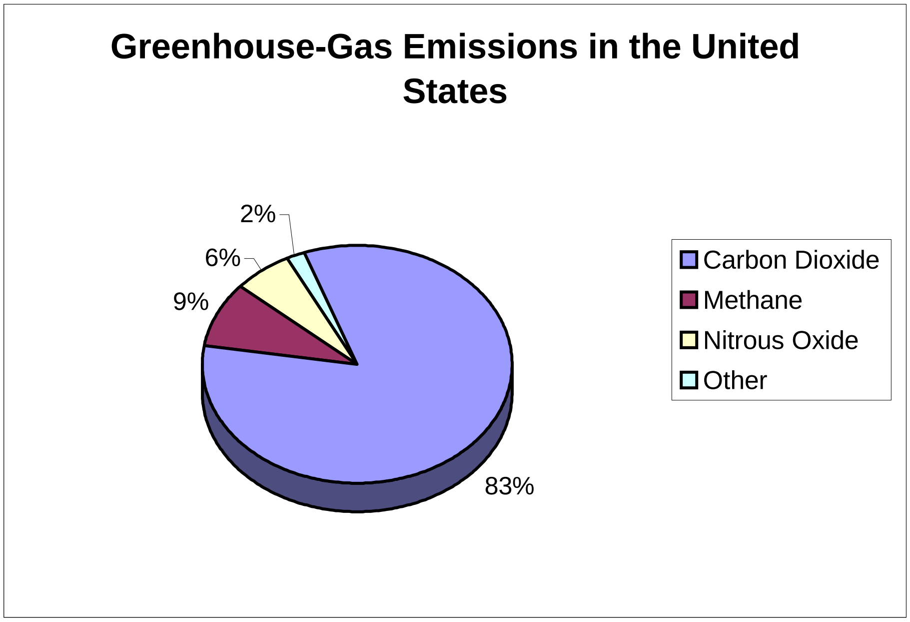
2 Justification for Wood Gasification

Increased pollution and changes in the global environment have brought on awareness for the need of cleaner fuels. Renewable energy sources offer one possibility to reduce emissions and dependency on foreign imports of fossil fuels. Within renewables, biomass plays an important role because it usually is available on a constant level.

Coal is currently the main energy source for the United States, providing 51.8% of electricity. In 2002, Pennsylvania produced 68.7 million short tons of coal, approximately 6.28% of the total 1,093.8 short tons produced by the USA alone (Freme, 2002). Though heavily relied on for energy, coal combustion is a main contributor to greenhouse gas emissions (GHG). Coal fired power plants are currently the number one source of carbon dioxide, a major source of greenhouse gas (U.S. EPA, 2002). Figure 2-1 gives a graphical representation of the percentage breakdown of greenhouse-gas emissions, while Figure 2-2 describes the man-made CO_2 sources by sector.

Figure 2-1

Present greenhouse-gas emissions in the United States (Giglio, date unknown).



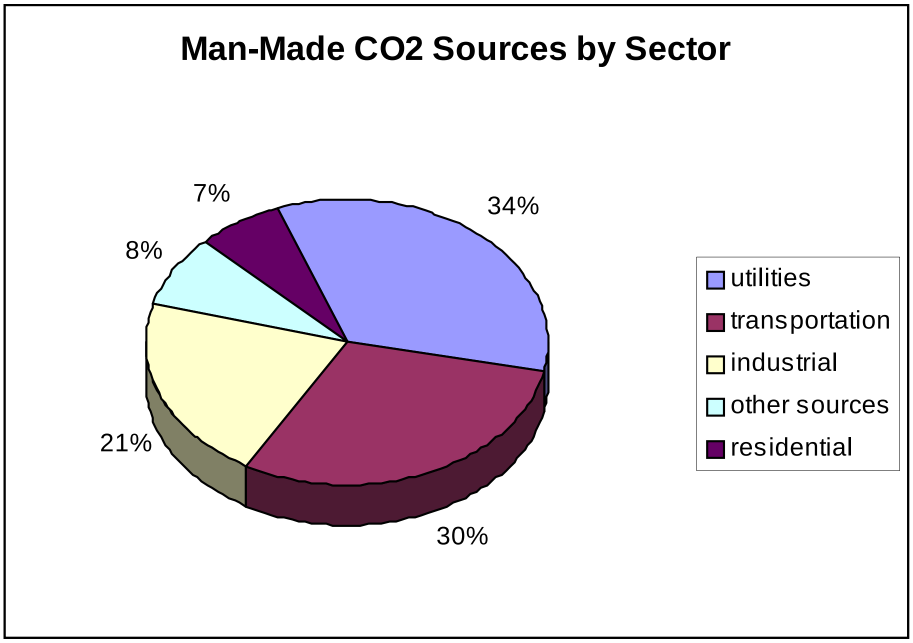


Figure 2-2

Man-made CO_2 sources by sector (Giglio, date unknown).

The earth naturally absorbs solar radiation from the sun, while longer wavelength terrestrial radiation is emitted back into space. A portion of the terrestrial radiation is absorbed by gases in the earth’s atmosphere creating a warming effect (Figure 2-3). This warming effect allows the earth to sustain life. Thus, greenhouse gases are highly necessary for the continuation of life on earth. However, unnatural amounts of greenhouse gases produced and emitted by man are not desirable.

UNFCC defines a climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is an addition to natural climate variability observed over comparable time periods.” Based on this definition, the Intergovernmental Panel on Climate Change (IPCC) concluded that humans are indeed affecting the atmospheric concentrations and distributions of greenhouse gases and aerosols and indeed affecting global warming (EPA, 2001).

A rise of 0.8-1.2 °F was seen over the past century for land surface temperatures (

Figure 2-4). The ocean surface has been warming at the same rate. IPCC announced an anticipated global average surface temperature increase from 34.52 to 42.44 °F from 1999 to 2100 (Gitay et al., 2002). IPCC suggests that continued global warming would cause sea levels to rise 0.09 to 0.88 meters by the end of this century. The effects from such an event would be disastrous.

Figure 2-3

Influence of greenhouse gases present in earth's atmosphere on climate (University of California, 2002).

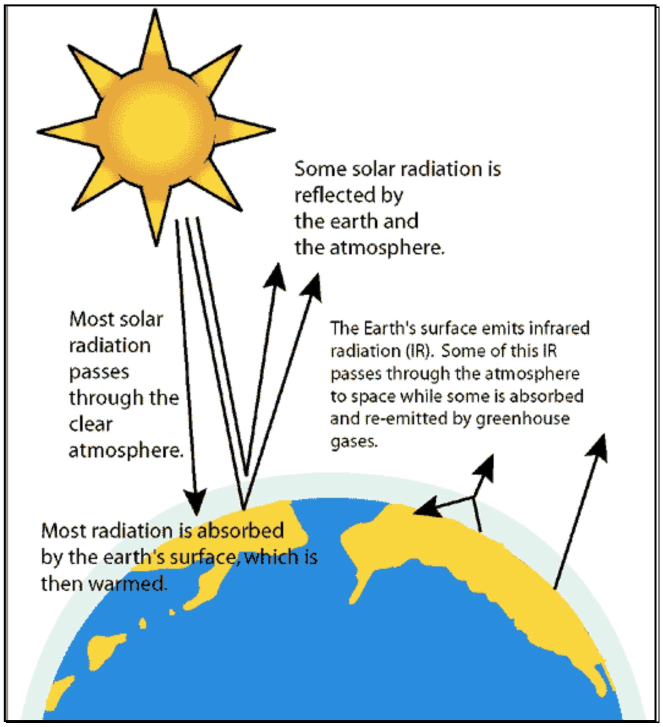
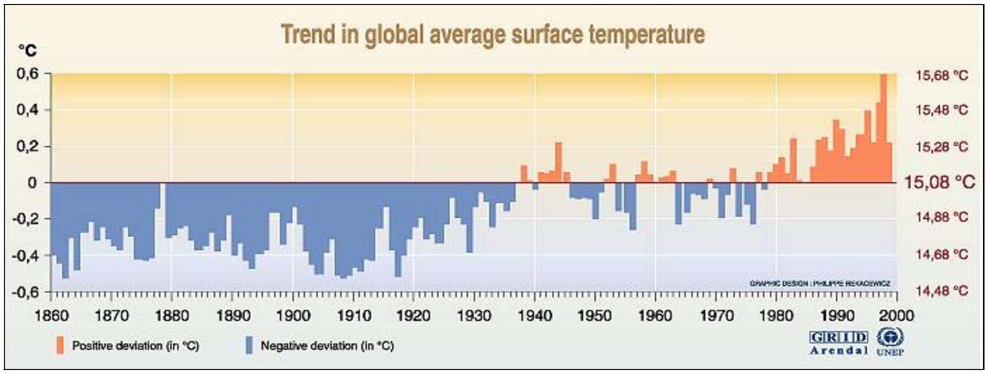


Figure 2-4

Combined land-surface air and sea surface temperatures from 1861 to 1998, relative to the average temperature between 1961 and 1990 (GRID & United Nations Environmental Protection Agency, 1999).



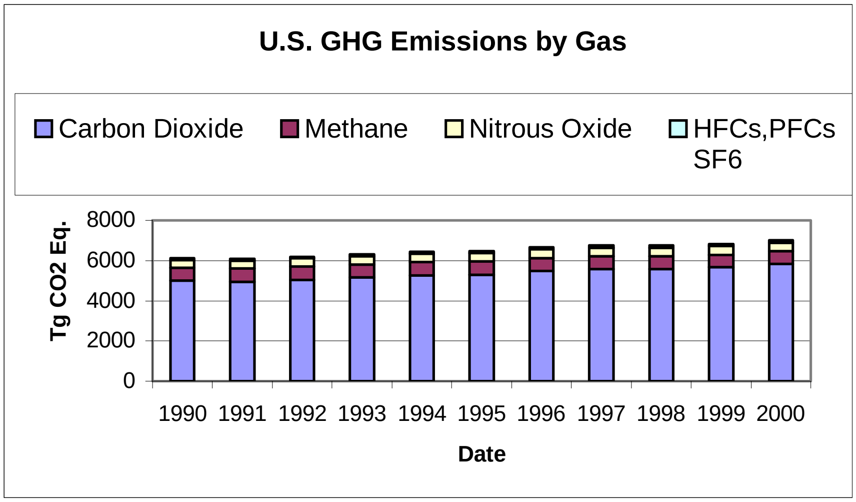
With utilization of biomass energy, the levels of greenhouse-gas emissions can be reduced. Plants require carbon dioxide as an energy source to sustain life functions. When a plant is burnt for energy generation, it releases the same amount of carbon that is consumed during its life cycle. Coal, natural gas and oil release additional carbon into the atmosphere.

Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse-gases emitted by human activities are, for example, carbon dioxide, carbon monoxide, nitrogen oxides, halogenated substances, and non-methane volatile organic compounds. In addition, aerosols - extremely small particles or liquid droplets often produced by emissions of sulfur dioxide and other pollutants - can also affect the absorptive characteristics of the atmosphere (Yeager, 2003) (EPA, 2001). The most prevalent greenhouse gas is water vapor, though it is not believe that humans directly affect water vapor concentration. However, humans do affect carbon dioxide and methane concentrations. Methane is produced primarily through anaerobic decomposition of organic matter and carbon dioxide is created by fossil fuel combustion.

As Figure 2-5 illustrates, US fossil fuel combustion in 2001 caused 5,623.3 Tg CO_2 to be released into the atmosphere. This accounted for a 16.8 % increase from 1990. Overall, total GHG emissions rose 14.2% since 1990 (2.5 % since 1999). The dominant greenhouse gas, excluding water vapor, was CO_2, though nitrous oxide emissions did increase 9.8%. Methane emissions diminished 5.6% since 1990. HFCs, PFCs and SF_6 have also increased since 1999 by 29.6% to current levels of 121.3 Tg CO_2 equivalents (EPA, 2002).

Figure 2-5

Trend of greenhouse gas emissions in the U.S. (EPA, 2002).



By releasing greenhouse-gas emissions, humans are directly linked to the increase in global warming seen over the past years. The world population has seen a tremendous boom over time. With this continued growth in population, it is only a matter of time before the earth may be unable to sustain life, if the per capita energy consumption remains on a constant level or increases and energy is produced by currently applied technologies. Emissions from factories, cars, homes and humans themselves all contribute to affect the delicate earth. Figure 2-6 and Figure 2-7 give a visual of how the world population has increased over time.

Figure 2-6

Increase in human population from 1500 to 2003 (Yeager, 2003).

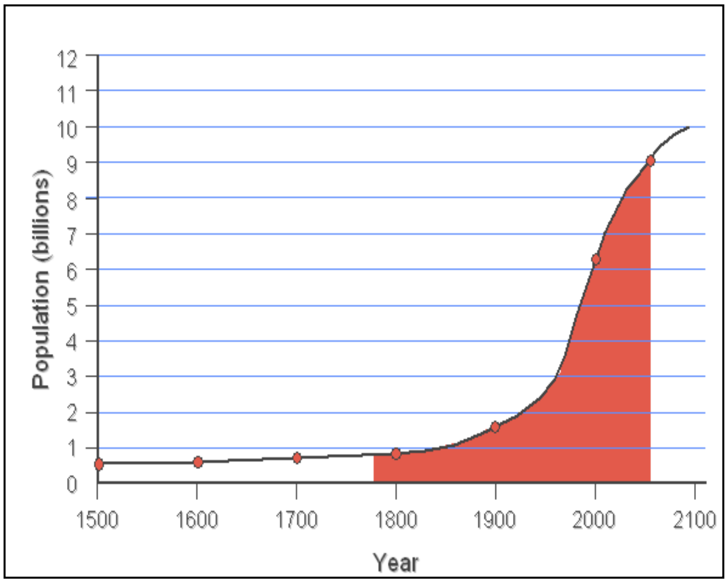


Figure 2-7

Population growth and fertility from 1900 to 2150 (Yeager, 2003).

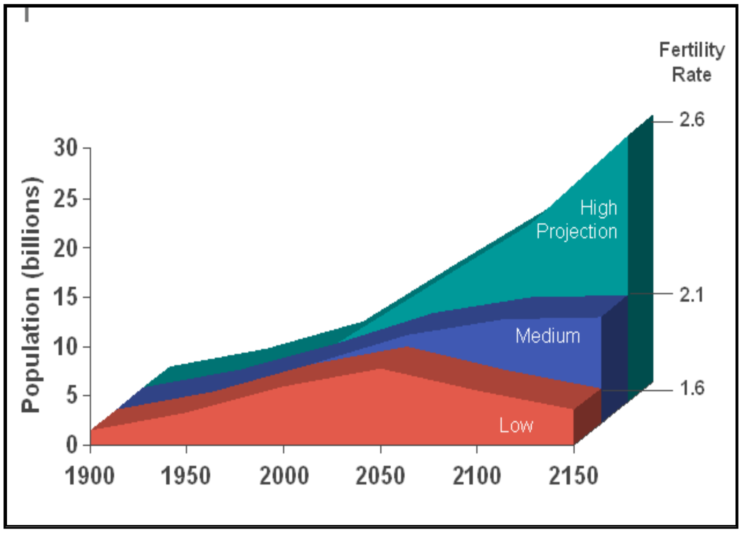


Figure 2-8 shows estimates for the future's energy demand. Given that energy consumption is expected to double in the next 50 years, meeting this level of global demand without unsustainable long-term damage to the environment represents a considerable challenge. With the dramatic increase in population and energy demand, it becomes obvious that more emphasis has to be placed on the development and application of cleaner technologies such as energy generation based on renewable resources.

Figure 2-9 shows that investments in energy research and development are currently relatively low compared to those of other industrial sectors.

Figure 2-8

Estimated energy requirements by the year 2100 (Chandler, 2003).

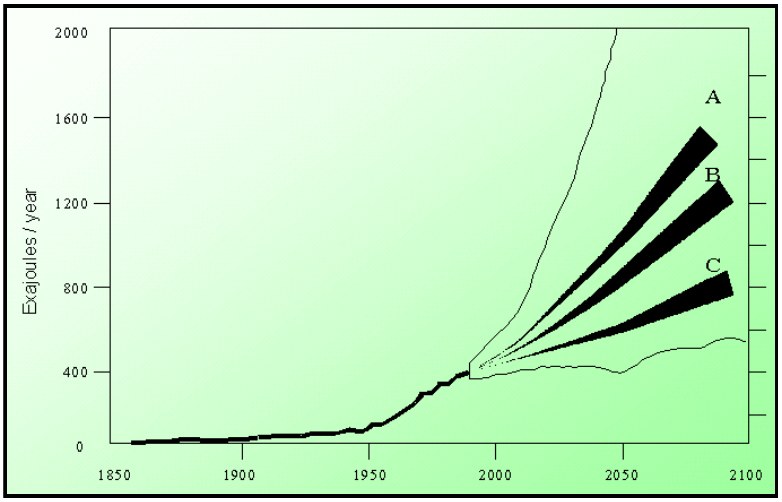
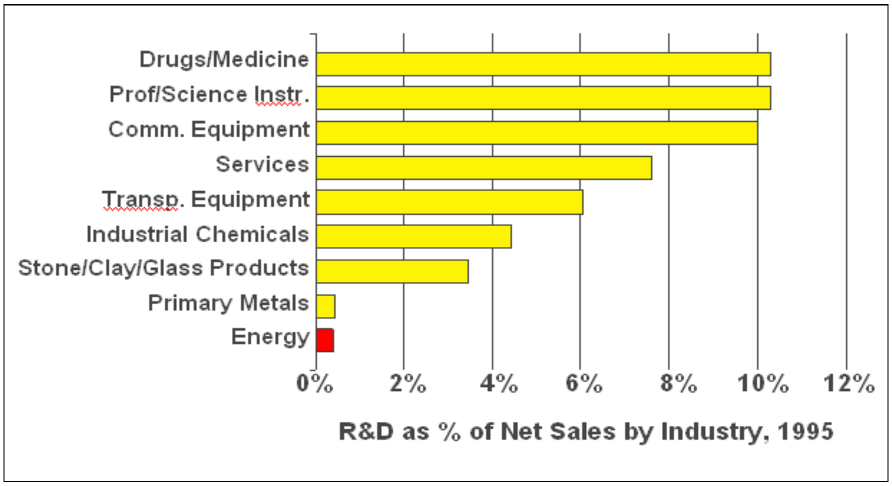


Figure 2-9

Research and development in different industrial sectors (Yeager, 2003).



Various types of renewable technologies exist: hydroelectric, wind and wave power, tidal power, biomass, solar energy (active and passive), photovoltaics, geothermal energy and ocean thermal energy. A generation portfolio including several of these technologies can help significantly to reduce the emission of greenhouse-gases and other pollutants.

Gasification of dry biomasses such as residual wood can be one component of sustainable energy generation. Therefore, its application in Clarion County is investigated in this study.

3 Wood Supply in Clarion County

3.1 Introduction

This section of the report discusses potential quantities of wood that can be supplied directly from local suppliers in Clarion County and the surrounding area for a potential wood gasifier. The survey was carried out principally through telephone interviews with logging and sawmill companies.

3.2 Procedure

Many resources were used to compile an initial list of potential biomass suppliers in Clarion County. A contact list of about 75 sawmills, logging, and procurement companies was provided by a local businessman. A few other companies were found on the internet at http://www.mfggate.com. Other potential suppliers were obtained by personal communication during the study. Altogether, 87 companies were found (Figure 3-1). Most of these companies were relatively small and have less than 5 employees. As a result, only 31 could be contacted. Among these, 17 companies could provide sufficient information and were selected as potential wood suppliers for the project (Figure 3-2). A data set was then developed, including the amount of biomass (e.g., sawdust, chipped wood, and pulpwood), characteristics, and the price of residual wood that each sawmill and logging company could provide to a wood gasifier. The data collected from these seventeen potential suppliers are summarized in Table 3-1.

3.3 Results

The subsequent sections summarize information on the total amount of wood potentially available, including sawdust, chipped wood, and pulpwood. Sawdust is defined as any wood that is finely cut to a powder or very small chips. Chipped wood is any wood that is cut into chips smaller than 2 cubic inches. Pulpwood is any wood that is not chipped. For confidentiality purposes, each supplier is represented by a number.

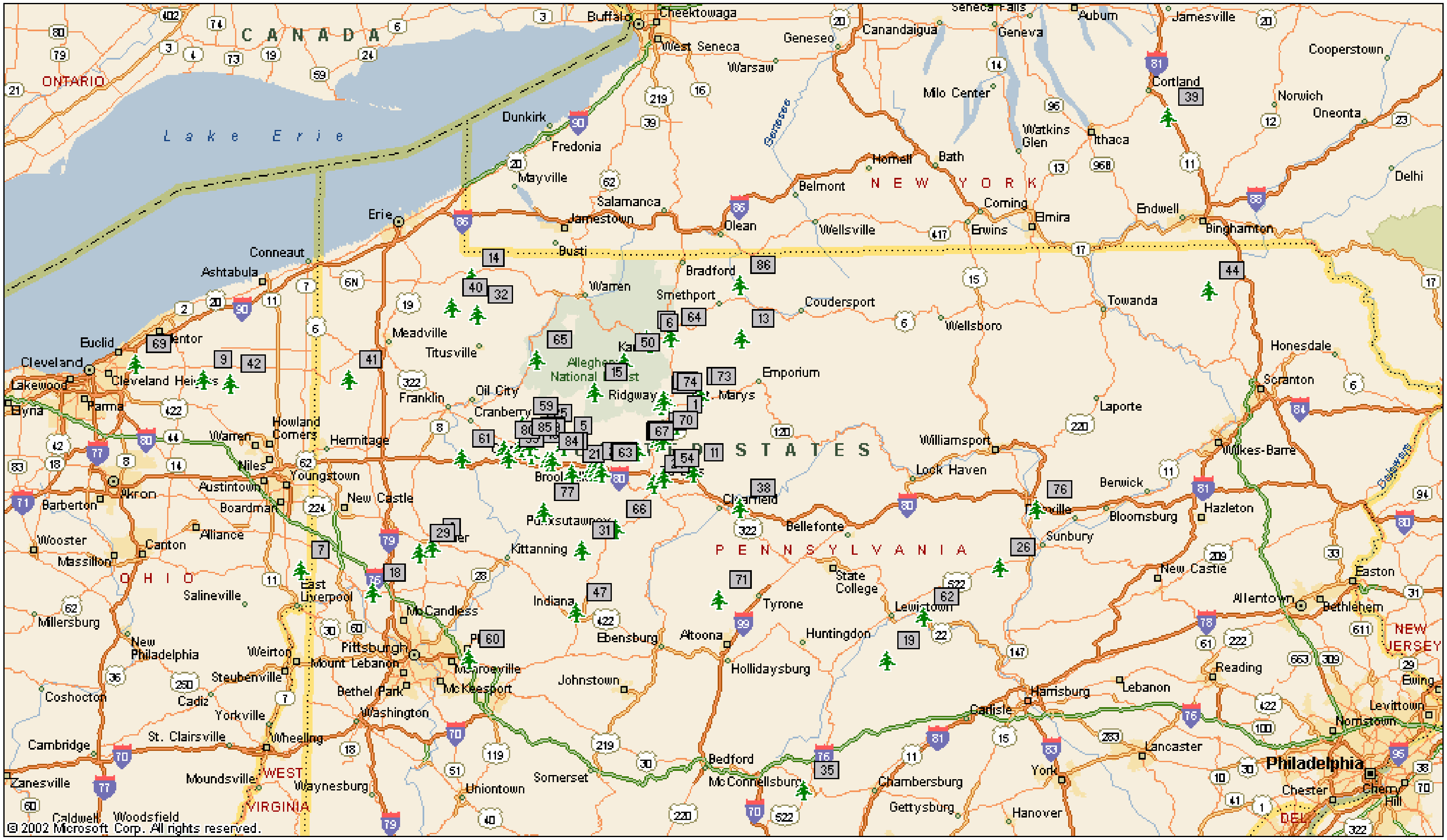
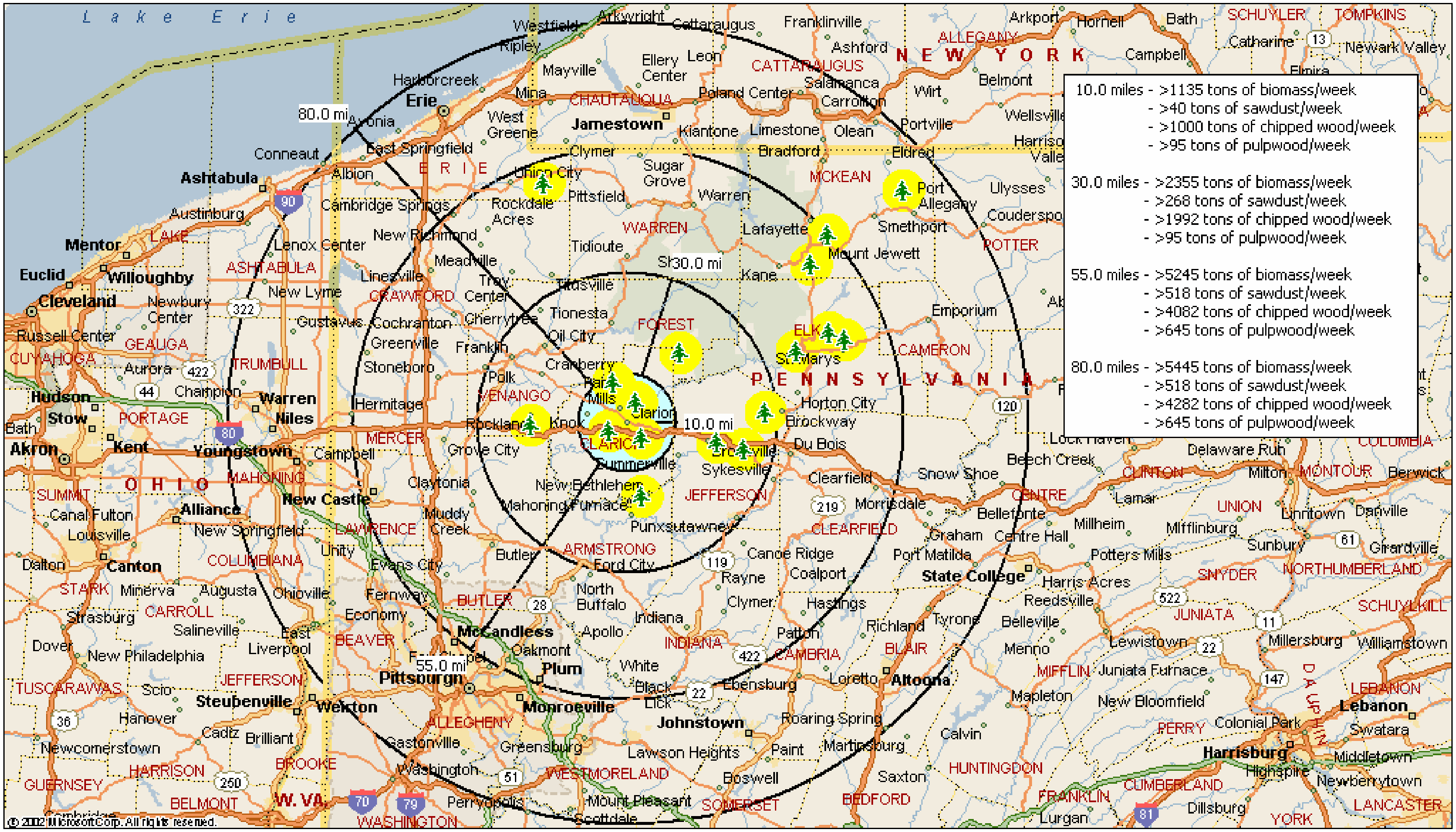


Figure 3-1 Wood suppliers located in Clarion County and the surrounding area



10.0 miles - >1135 tons of biomass/week
- >40 tons of sawdust/week
- >1000 tons of chipped wood/week
- >95 tons of pulpwood/week

30.0 miles - >2355 tons of biomass/week
- >268 tons of sawdust/week
- >1992 tons of chipped wood/week
- >95 tons of pulpwood/week

55.0 miles - >5245 tons of biomass/week
- >518 tons of sawdust/week
- >4082 tons of chipped wood/week
- >645 tons of pulpwood/week

80.0 miles - >5445 tons of biomass/week
- >518 tons of sawdust/week
- >4282 tons of chipped wood/week
- >645 tons of pulpwood/week

Figure 3-2 Biomass available from potential suppliers

Table 3-1 Data collected from seventeen potential suppliers

Supplier	**Distance (mile)**	**Type of biomass**									**Comment**
		Sawdust			**Chipped wood**			**Pulpwood**			
		Amount (ton/wk)	**Price ($/ton)**	**Transportation cost ($/ton)**	**Amount (ton/wk)**	**Price ($/ton)**	**Transportation cost ($/ton)**	**Amount (ton/wk)**	**Price ($/ton)**	**Transportation cost ($/ton)**	
6	81.4	25-50	14	Included	25-50	22-23	Included	Unlimited	22	Included	
12	17.9	50-100	280/load	Included	400	28	N/A	N/A	150-170	100/load	1
14	65.2	50	22	Included	50	27	Included	50	27	Included	
16	1.9	N/A	N/A	N/A	>1,000	26.40	Included	N/A	N/A	N/A	2
17	31	16-20	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3
25	9.6	40	13.50	100/load*	Little	23	100/load*	75	27	100/load*	
27	81.7	N/A	<20	N/A	N/A	20-24	N/A	500	20-24	Included	
33	71.7	60	10	N/A	60	12.50	N/A	N/A	N/A	N/A	
46	15	80	<20	Included	80	<30	Included	N/A	N/A	N/A	
48	60.1	N/A	N/A	N/A	1,750	22-28	N/A	N/A	N/A	N/A	
57	61	30-40	13.55	N/A	70-80	24	N/A	N/A	N/A		
59	12.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	300	Included	4
61	26.1	28	22	No transporting	112	25	No transporting	N/A	27	No transporting	5
77	17.9	N/A	N/A	N/A	400	13	Included	N/A	N/A	N/A	
78	5.1	N/A	N/A	N/A	N/A	N/A	N/A	20	20	Included	6
79	5.1	50	15	<50/load*	100	26	<50/load*	N/A	N/A	N/A	
86	86.9	N?A	N/A	N/A	200	28	10	N/A	N/A	N/A	
		Average	17.01			24.71			25.23		

N/A: information was not available.

* : One load is about 25 tons.

Comments:
1. Pulpwood is 1inch thick and 4 feet long, and its price is based on thousand feet of board.
2. This is a procurement company supplying logwood or whole tree chips
3. Sawdust price is $5 per truckload from front end loader.
4. Price for pulpwood is $300 per ton of 2X4 slab wood.
5. Wood prices are based on green weight.
6. Only logs and slabs are available.

3.3.1 Total Biomass

17 potential wood suppliers are located from one to ninety miles away from downtown Clarion each represented by a little tree in Figure 3-1 and Figure 3-2. As indicated in Figure 3-1, although additional biomass could be available from more distantly located suppliers, it was not considered in the study due to the increased transportation costs. The total amount of biomass available from the seventeen companies is 5,376 tons/wk of wood at a weighted average price of $23.05 per ton including transportation. It was found that there are 1,135 tons per week of biomass available within ten miles of downtown Clarion, which would be more than enough biomass to supply a potential wood-fueled gasification plant with an electric capacity of 5 MW_{el}.

Figure 3-3 shows the average amount of wood that can be bought at a specific cost. Based on the distance from the city of Clarion, Figure 3-4 and Figure 3-5 show the amount of biomass and its price, respectively, that each supplier can offer. The next three sections below give a more detailed analysis on the three different types of biomass available.

Figure 3-3

Tons per week vs. costs

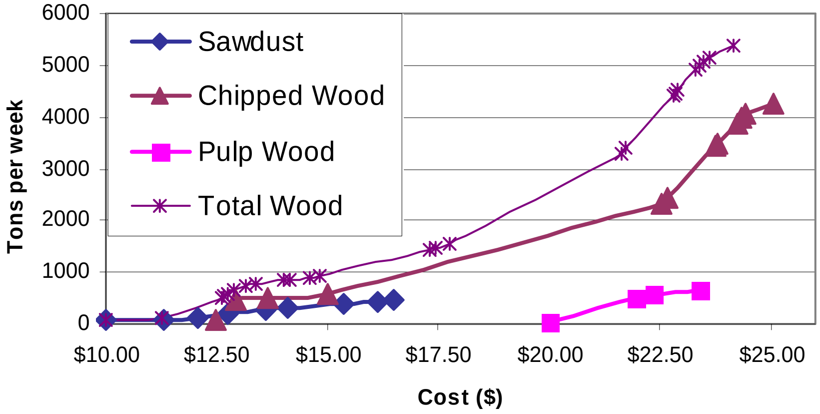


Figure 3-4

Total biomass available vs. Distance from Clarion

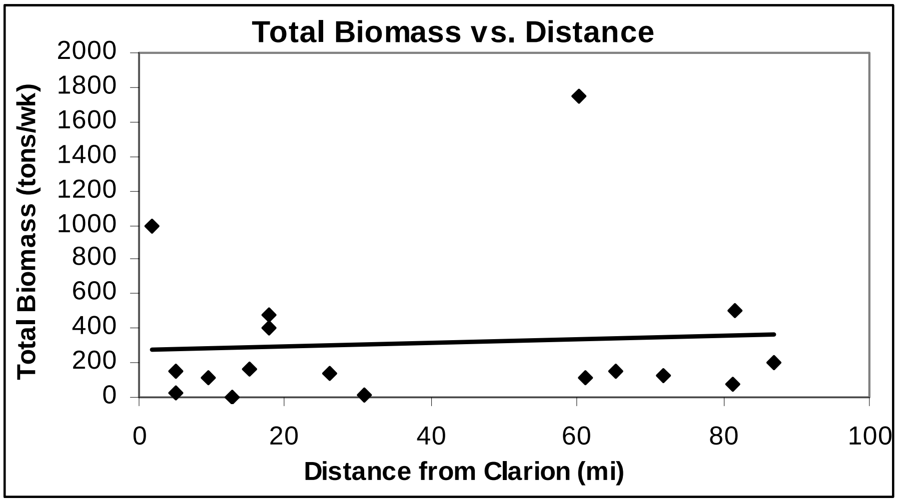
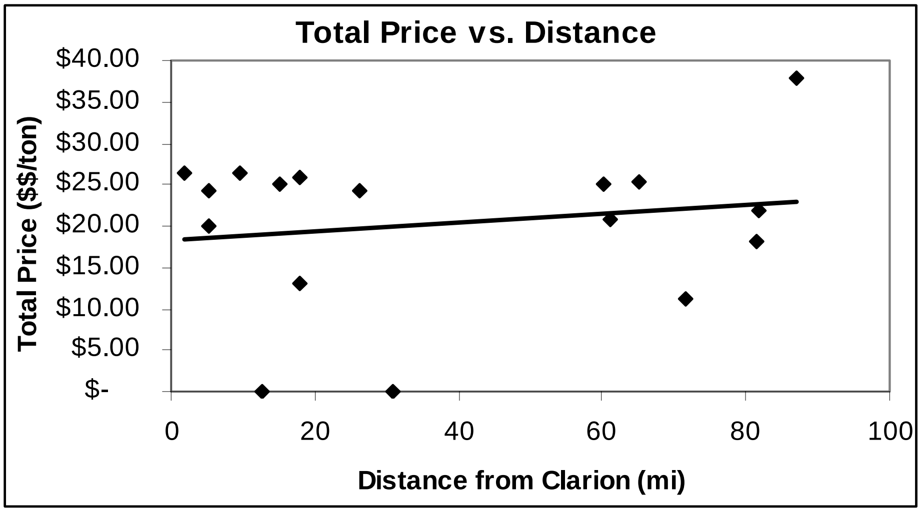


Figure 3-5

Total price of biomass vs. distance from Clarion



3.3.2 Sawdust

Sawdust is the cheapest type of residual wood, compared to chipped wood, pulpwood or slab wood. In total, nine companies verified contributions. From these nine companies, an estimated amount of 436 tons/week of sawdust could be supplied for the plant at an average price of $17.01 per ton. The transportation cost was roughly $100 per truckload (about 30 tons) and is included in the above price. These companies were anywhere from five to eighty miles away from downtown Clarion. All nine sawmills were very interested in the potential business that use of their residual sawdust for a gasifier would bring.

From Figure 3-6 and Figure 3-7, it can be seen that wood suppliers closest to downtown Clarion can supply the largest amount of sawdust, but at a slightly higher cost. Although there may not be enough sawdust to fuel a gasification plant alone, this low cost residual wood would play an important role in keeping the fuel costs to a minimum.

Figure 3-6

Amount of sawdust vs. distance from Clarion

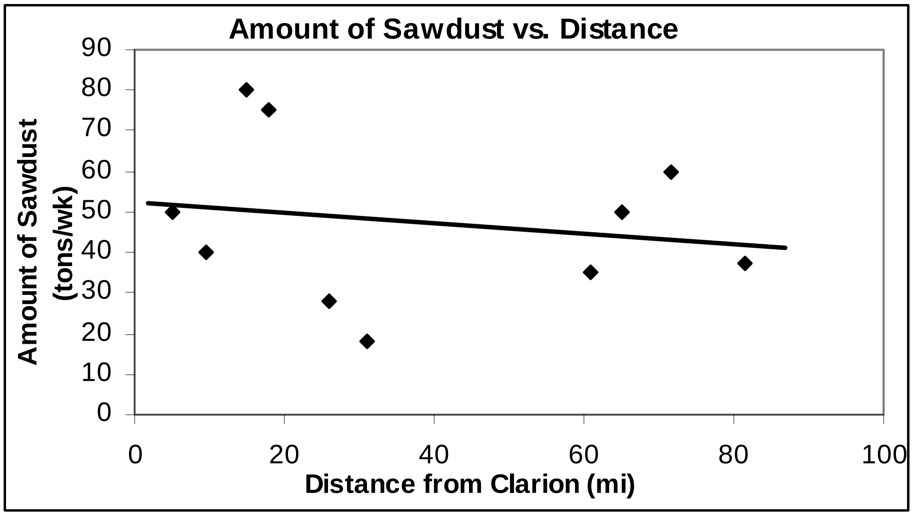
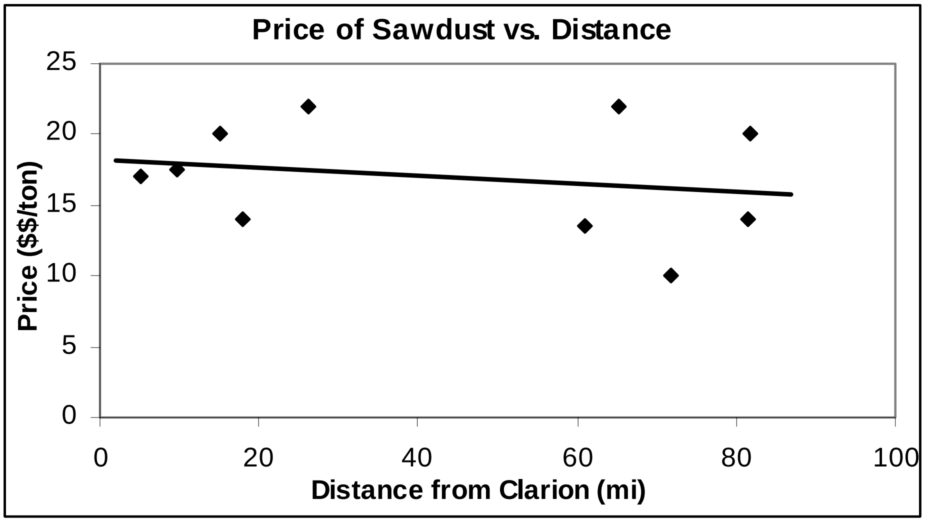


Figure 3-7

Price of sawdust vs. distance from Clarion



3.3.3 Chipped Wood

There were more potential suppliers for chipped wood than for sawdust. In total, twelve companies verified supply potential. From these twelve companies, an estimated amount of 4,265 tons/week of chipped wood could be supplied at an average price of $24.71 per ton. The transportation cost was again roughly $100 per truckload (about 30 tons) and was included in the price given above. These wood providers ranged from a two to eighty mile distance from downtown Clarion. All twelve of them were also very interested in the potential business that the use of the chipped wood for energy generation would bring. Figure 3-8 shows that the suppliers closest to the city of Clarion can provide the most chipped wood. Figure 3-9 verifies that the price of chipped wood is fairly constant with respect to a supplier's distance from downtown Clarion. The price is reasonable, but it is significantly higher than that for sawdust.

Figure 3-8

Amount of chipped wood vs. distance from Clarion

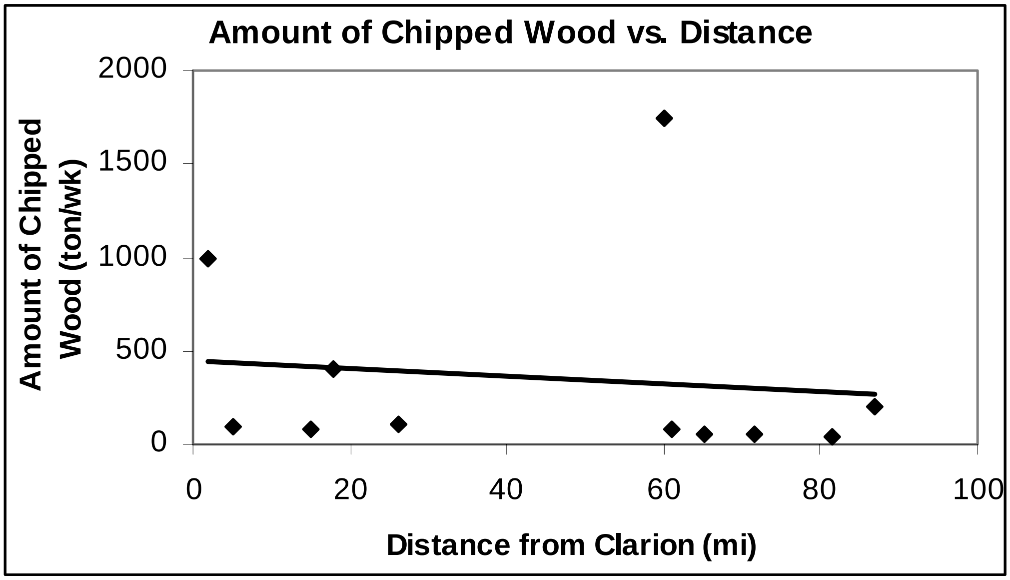


Figure 3-9

Price of chipped wood vs. distance from Clarion

3.3.4 Pulpwood

There were four companies in total that verified sources of pulpwood. From these companies, more than 645 tons/week of pulpwood could be supplied at an average price of $25.23 per ton. The transportation cost was again roughly $100 per truckload (about 30 tons) and is included in the above price. These pulpwood providers are located from five to eighty miles away from downtown Clarion. All four of them were also very interested in the potential business. Figure 3-10 and Figure 3-11 show that there is more pulpwood available outside of Clarion and at a lower price.

Figure 3-10

Amount of pulpwood vs. distance from Clarion

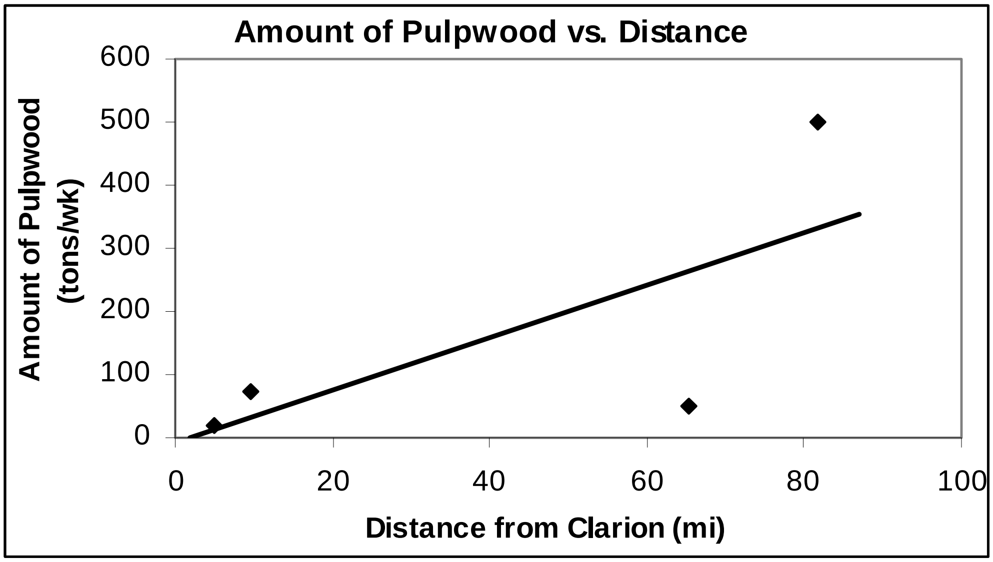
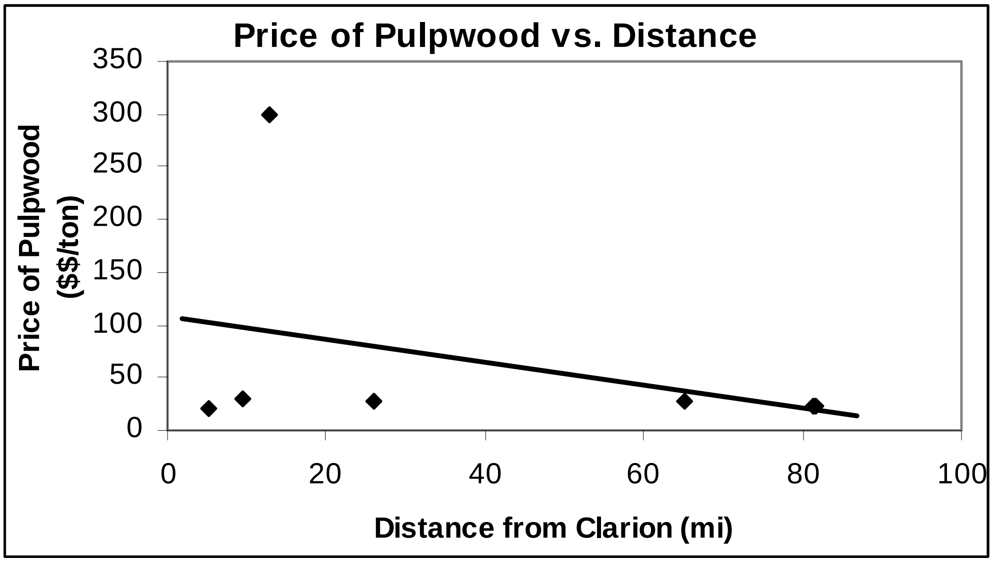


Figure 3-11

Price of pulpwood vs. distance from Clarion



3.4 Thermal Energy Potential of Biomass

The heating value of a wood fuel is commonly expressed by either higher heating value (HHV) or lower heating value (LHV). The difference between the two values is the amount of energy (latent heat) that is necessary to vaporize water contained in the fuel or created in the combustion process when hydrogen in the fuel is combined with oxygen in the air supplied. One type of wood releases more heat than the other simply because it has less moisture, not because the wood is different.

It has been reported that dry wood of any species has a heating value of 20 MJ/kg (8,600 Btu/lb) (Slusher, 1995). However, to better reflect real conditions and the usable amount of energy stored in the wood, usually the lower heating value (LHV) is used. The lower heating value of dry wood has been reported to be 18.25 MJ/kg (7,850 Btu/lb). Considering inherent moisture and ash contents in the wood, the LHV of a certain amount of wet wood can be calculated as following:

LHV (wet) = [18,250 kJ/kg * (1 – MC/100) * (1- AC/100)

– (2,442.5 * MC/100) kJ/kg] * total amount of wood, kg

where,

LHV = lower heating value, kJ/kg

MC = inherent moisture content in wood, %

AC = ash content of wood, %

2,442.5 = enthalpy for saturated water vapor at 25^{o}C, kJ/kg

Accordingly, the heating values of sawdust, chipped wood, and pulpwood available for the gasifier are listed in Table 3-2 as the sum over one year. In addition, the capacity of a potential plant based on available fuel input is given.

Table 3-2

Heating values of waste wood available in Clarion County

Type	Moisture content, %	Ash content, %	Amount, ton/yr	LHV, MJ (mmBtu)	Capacity, MW
Sawdust	40	5	22,370	210,848,435 (200,000)	6.7
Chipped wood	40	5	204,720	1,929,588,360 (1,830,210)	61.2
pulpwood	40	5	30,960	291,813,480 (276,785)	9.3
Total			258,050	2,432,250,275 (2,306,995)	77.2

3.5 Discussion

There is more than enough residual wood available in Clarion County from the companies included in the survey to fuel a potential wood gasifying plant. Altogether they can supply fuel for one or several plants with a total fuel capacity of 77.2 MW, whereas the reasonable size for one gasifier lies in the range of approximately 5 – 25 MW fuel input. It can be expected that additional biomass is available from some of the companies that could not be contacted. This means that a potential plant would have sufficient backup suppliers if another source of residual wood was lost.

Chipped wood would probably be the best fuel to use. This wood would be cleaner than green wood and sawdust, it is plentiful, the price seems to be reasonable, and it would be more convenient to purchase the biomass from one supplier. Two of the biggest suppliers could provide 1,750 tons/week at $22-28 per ton and over 1,000 tons/week at $26.40 per ton, respectively.

Wood suppliers all appear to be very excited about the impact that this potential biomass energy project would have on the local forestry industry. Apparently, the local paper industry has been in decline. Hence, the Clarion County sawmills and logging companies have lost one of their largest customers for residual wood. A potential wood gasifier could use this excess supply.

4 Economic Assessment

4.1 Carrying Out the Economic Assessment

4.1.1 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:

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

4.1.2 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 payoff realized in the future, the payoff 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 payoff 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 payoff (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) an 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, more than one hundred cash flows usually 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.

Very often, different scenarios are 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 is 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 determining 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, reduced personnel costs by using already existing personnel.

5 General Site Selection

Once the wood supply in Clarion County was established, the demand for energy had to be determined. Due to the high investment costs associated with wood gasification plants, the plant should be operated near full capacity year-round, which means that only baseload supply scenarios are suitable for this technology. Although generated electricity can be fed into the grid, low electricity reimbursement rates make it more attractive to utilize the generated energy onsite and only feed surplus electricity into the grid. In addition, the possibility to utilize waste heat, which can only be used onsite unless a district heating system exists, further improves economic prospects. Another increasingly interesting option is the generation of gas from wood to replace natural gas.

Residential and commercial energy users generally exhibit significant fluctuations in their energy demand on a daily and seasonal basis due to higher electricity demand during the day compared to at night and high heat and cooling demand during the winter and summer, respectively, compared to spring and fall. In contrast, industrial energy consumers often have a much higher and more constant energy demand. Thus, mainly industrial sites were considered in this study.

Students from the University of Pittsburgh compiled information on potential consumers in Clarion County and performed a first screening to narrow down the list of potential sites. A list of all of the companies throughout Clarion County was compiled using information from the Clarion Chamber of Commerce and www.mfggate.com. Overall, 76 companies were identified. Then the size, number of employees, and industrial sector were determined for each company. Using a set of guidelines, a list of companies to be contacted was established. The guidelines included that companies should have at least ten employees and have a larger scale production type business. After looking at each company's number of employees, the majority of the companies in Clarion County could be deemed as too small for this study. The list was then reviewed again to determine if the business would possibly have a large energy use. For example, a candy store with eleven employees is not going to use enough energy to consider further investigation. A lumberyard with eleven employees however, could have a very large energy demand, and it would be relevant to take a closer look at this company. The number of companies to be contacted was narrowed down to 23, which were called for an initial interview. After a brief introduction of the project, these companies were then asked a set of questions such as:

- What is your electricity use per month?
- When is your peak usage time of electricity?
- Who is your current electricity provider?

- What are you currently paying per kWh?
- What do you use for heating/cooling?
- When is your peak usage?
- Who is your provider of heating/cooling?
- What are you currently paying for heating/cooling?
- Do you have any use for steam, hot water, thermal oil, etc?
- Is your heating unit (boiler) located centrally, connected, or spread throughout the company?
- Do you know of any other companies that might benefit from wood gasification?

Once all of these questions were answered, the results were then used to determine, which of the facilities showed enough potential to justify a site visit and meeting with plant managers and operators for an in depth investigation of energy demand and supply.

Based on the initial screening and interviews of industrial facilities in Clarion County, the sites with the highest potential for utilizing energy generated onsite from biomass were selected. These sites were investigated more in depth to establish their energy demand and utilization. With the demand and plant layout as basis, various wood gasification scenarios were investigated to determine their economic feasibility.

6 Feasibility of a Wood Gasification Plant at Industrial Site A

6.1 Potential Application of Gasification Technology

In order to determine the potential for the implementation of a wood gasification plant at the first potential site, a meeting with plant managers and officials was held to get more detailed information about the plant operation in terms of energy consumption and generation. The facility operates three shifts a day year round, which makes it suitable for baseload energy supply from a gasifier. Various process steps require energy input in the form of heat and electricity.

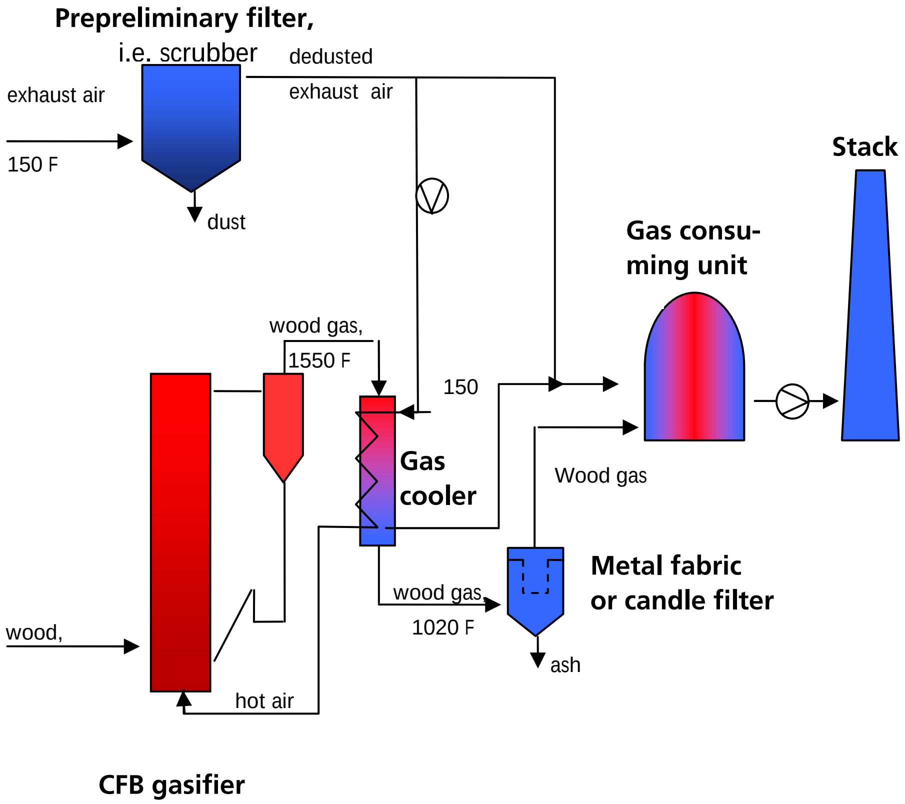
One unit currently exhibits an energy demand of 40 mmBtu/h from outside sources, which is covered by natural gas. This means that about 40 mcf/h of natural gas could be substituted by energy from wood gas.

The following energy supply based on wood gasification is envisioned. Residual wood is fed into a circulating fluidized bed gasifier to generate a flammable gas, which leaves the gasifier at a temperature of approx. 1,550º F. For use in the plant, the wood gas has to be filtered. In order to implement a cost efficient metal filter (sinter metal candles or metal fabric) for dust removal, the temperature of the wood gas has to be decreased to approx. 1,020º F. The cooling medium for this process step is a portion of an already dedusted exhaust air stream. While the wood gas is cooled, the exhaust air employed as cooling medium will be heated up and can be largely used as the air needed by the gasification plant. The dedusted wood gas is provided to the unit that is currently fueled by natural gas. In order to accommodate for the change in fuel, the existing equipment has to be retrofit with a special hot gas burner containing a reducing damper to control the hot gas flow.

The flow scheme of the process is presented in Figure 6-1.

Figure 6-1

Process scheme of wood gas generation for the industrial site



6.1.1 Basic Gasification Plant Engineering Data

It can be assumed that several synergistic effects between the gasifier and the existing equipment can be taken advantage of to reduce equipment and personnel needs for the gasifier.

The gasifier has a capacity of 12.3 MW (42 mmBtu/h) fuel Input. Considering a worst-case scenario of 5% heat losses, the gasifier will generate 11.7 MW (40 mmBtu/h) for use at the industrial site. The capacity factor of the plant will be more than 95%, which represents an annual operating time of more than 8,322 h.

6.1.2 Wood Supply

The following plant design is based on wood with an average water content of 40% and an ash content of $5\%_{dry}$. The wood demand of the gasifier plant is

5.18 short tons/h (4.7 metric t/h), which is equivalent to 43,025 short tons per year.

6.1.3 Wood Storage and Preparation

The gasifier plant will be equipped with a 24 h, short-term, semi-housed fuel storage. The housed storage area of 61 x 33 ft = 2,013 sq. ft (187 m^2) is equipped with an approx. 1,600 sq. ft (150 m^2) sized walking floor. The building height is sufficient to accommodate unloading from dump trucks directly inside the storage building. After passing a disc screen and a ferrous metal remover, the wood is transported to the gasifier by drag chain conveyors.

6.1.4 Gasifier

A building with a height of 82 ft and a footprint of approximately 1,600 sq. ft houses the wood dosing and feeding equipment, the gasification air blower, the start up burner, the gasifier, the gas cooler and the bed ash removal system. Approx. 3,350 scf/minute (5,700 Nm^3/h) of preheated air are fed into the riser of the gasifier. The largest two objects inside the building are the riser with an outer diameter of approx. 8 ft and a height of 66 ft and the cyclone of the circulating fluidized bed system with an outer diameter of approx. 12 ft and a height of approx. 30 ft, including the cone shaped portion. The wood gas, which exits at the top of the cyclone, is passed through the vertically mounted gas cooler at a rate of approx. 6,350 scf/minute (10,800 Nm^3/h). The cooled gas leaves the cooler at the bottom and then enters the gas filter.

6.1.5 Gas Filter

The hot gas metal filter is situated in a separate building next to the gasifier building. It has a 529 sq. ft footprint and a height of 20 ft. Aside from the filter, the building also houses the fly ash handling system and other auxiliary equipment of the plant. The gas is then transported to the unit in the industrial plant via a hot gas pipeline.

6.1.6 Other Plant Components

Due to the synergistic effects with the existing facility, the gasifier can be controlled from an existing control room. Furthermore, it is assumed that no additional social rooms for the employees of the gasification plant must be provided.

6.2 Investment Costs

The estimated investment costs for the different plant components are listed in Table 6-1. The costs include the direct costs and all indirect costs such as fuel transportation to the plant site, excavation and site preparation, foundation, interior mechanics, installation/construction, painting, heat insulation, process control equipment, legal fees and permits, engineering, insurance, construction financing, start up, etc.

Table 6-1

Complete investment cost of different plant components and total sum

Buildings		$482,000
Fuel storage and conveying system		$397,000
Fuel feeding and dosing system		$297,000
CFB gasifier with air supply, start burner, bed ash handling		$1,004,000
Gas cooler and filter with ash handling system		$712,000
Hot gas pipeline, hot gas burners		$356,000
Engineering & project management, construction contingencies, insurance and financing, legal fees & permits		$873,000
	Sum	**$4,121,000**

6.3 Operating Costs

The operating costs of the plant running 8,322 h/year can be divided into the following main categories.

6.3.1 Fuel Costs

Fuel costs clearly represent the largest expense for the plant operation. The economic investigations are based on average wood prices attained during the local wood supply survey. According to the survey, the weekly amount of 825 short tons (750 metric tons) needed for the plant is expected to be available at a price of $15.45/short ton equivalent to $17.00/metric ton.

6.3.2 Labor Costs

As mentioned earlier, the fact that the gasifier will be operated at an industrial plant will have a positive effect on plant economics including labor cost. The additional average labor requirement of the new plant can be estimated with 4 h/day for each, one skilled and one unskilled worker year round, plus general benefits and administrational requirements.

6.3.3 Maintenance & Operation

Due to the fact that the gasification plant is processing moist materials, handling hot dust or ashes and is operating at high temperatures, the annual maintenance costs are up to 3% of the investment costs of the plant. Operation costs include the costs for auxiliary energy, such as electricity, pressurized air, fuel for the start up burner, steam for steam jet pulse cleaning of the filter and operating cost contingencies.

6.3.4 Ash Disposal

Basically, ash from clean wood combusting facilities can be used as a fertilizer and soil amendment. Even though the fuel conversion rate of the gasification process is significantly higher than 96%, due to the low ash content of clean wood, the ashes may contain considerable amounts of carbon. Therefore, ash disposal or thermal treatment may be required. For further investigations a worst-case scenario of $45/ton for ash disposal costs is used. Depending on the permitting circumstances or future regulatory changes, these costs may be significantly reduced if the gasifier ash can be used otherwise.

6.3.5 Insurance

Generally, insurance costs can be expected to range from 0.7 – 1% of the investment costs. Thus, these costs were assumed to be 1% for further economic analysis of this gasification plant.

A summary of all annual operating costs is presented in Table 6-2.

Table 6-2

Annual operation costs of the gasification plant

Fuel purchase		$665,000/year
Labor		$129,000/year
Maintenance & Operation		$241,000/year
Ash disposal		$113,000/year
Insurance		$41,000/year
	Sum	**$1,189,000/year**

6.4 Simple Payback Period

After estimating the direct and indirect costs, the potential income from the plant is approximated in order to get a first impression of plant economics based on the simple payback period. The natural gas price assumed for income calculations is $6.5/mcf. This number is significantly lower than the average gas prices for industry ($6.89/mcf) and for commercial ($7.44/mcf) entities in Pennsylvania in 2002 as given by the Energy Information Administration. The gasification plant would generate a revenue stream of $2,235,000/year by replacing purchased natural gas with wood gas. This results in a simple payback period of 3.9 years. The simple payback calculation results are displayed in Table 6-3.

Table 6-3

First simple payback control of the gasification plant

Sum investment costs		$4,121,000
Sum operation costs		$1,189,000/year
Revenues		$2,235,000/year
	Simple Payback	**3.9 years**

This payback period is quite promising for an energy supply project, especially for energy supply based on renewable energy sources. Therefore, further analysis is justified and performed in the following sections.

6.5 Profitability Calculation

Table 2-5 shows the profitability calculations for the above outlined scenario. Several, additional assumptions have to be made to enable these calculations.

Review period:
For energy supply projects, a normal lifetime for the energy generation plant used in financial analyses is 15 years. Due to the dependence of the revenue streams of the gasifier on the existing production process, the review time was shortened to 10 years. The actual, technical lifetime of a gasifier plant is expected to be 15 years or more.

Financing structure:
The assumptions for the financing structure of the project are presented in Table 6-4.

Table 6-4

First simple payback control of the gasification plant

	Share of total investment	Interest rate
Tax free industrial bonds	35 %	4 %
Commercial loan	35 %	7 %
Equity	30 %	Internal rate of return: 18 %

Even though public grants and low interest loans should be available for such an environmentally sound project, they are not considered for this investigation. Also, potentially avoided alternative costs may increase the performance of the project. Possible positive influences like these are hard to predict at the current state of the project and, therefore, not incorporated.

Price increase rates:
The price increase rates for all costs and incomes are set at 3%. Potential natural gas price increases at a higher rate than 3%, as recently experienced in Pennsylvania and further predicted for the future by the Energy Information Agency and other entities, are disregarded.

Tax rates:
Taxes rates are very site and business specific, and to explore each possible option would be too extensive for this purpose. Therefore, the federal tax rate is set at 25% and the state tax rate at 10% for further calculations. Potential improved economics of the project due to the possibility to transfer or write off taxes or to use accelerated depreciation applicable to biomass projects were not considered.

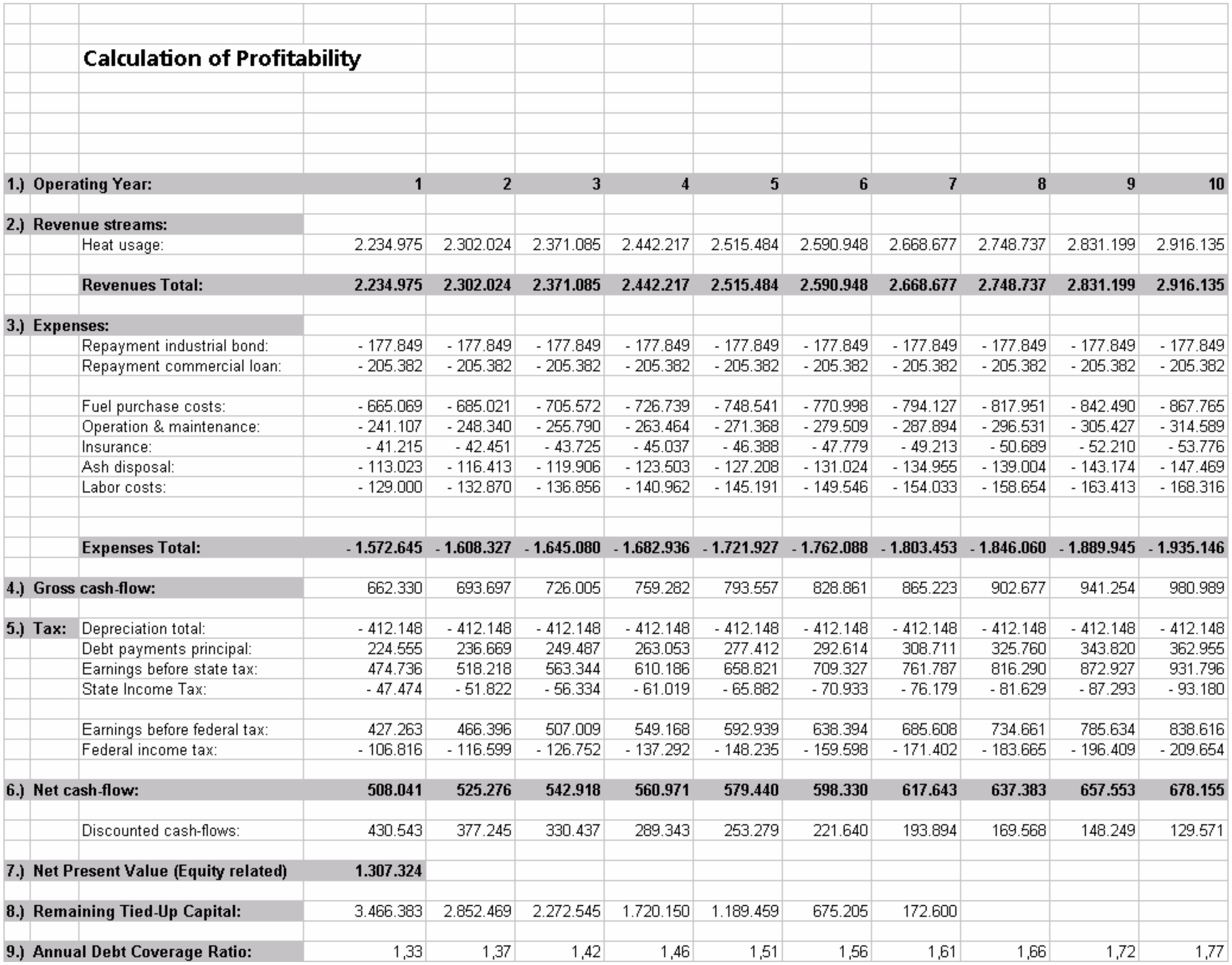
6.5.1 Net Present Value and Annual Debt Coverage Ratio

As shown in Table 6-5, a profitability calculation over 10 years was performed. The net present value (NPV) is a widely used tool for making business decisions. A NPV greater than zero signals a positive investment opportunity. The NPV for this scenario is $1,304,324, which means that this project is worth investing in from an investor's point of view.

The annual debt coverage ratio is a widely used tool for lenders to evaluate the ability for a project's income to cover the monthly and annual debt service, which is equal to the total payments of principal and interest paid in that year for the loan. An annual debt coverage ratio of less than 1 indicates inadequate coverage, i.e. the cash flow generated by the project is less than the loan payments. For example, an annual debt coverage ratio of 0.95 indicates negative cash flow. There would only be enough cash flow to pay 95% of the loan. Commonly, lenders will grant loans on projects that have a minimum annual debt coverage ratio of 1 to 1.3.

Table 6-5

Calculation of profitability for gasifier



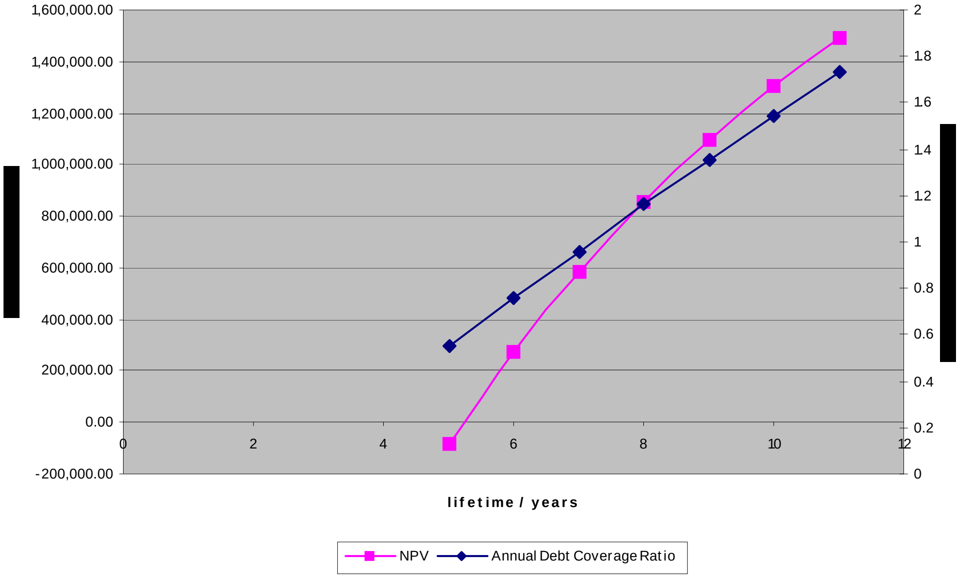
Calculation of Profitability

1.)	Operating Year:		1	2	3	4	5	6	7	8	9	10
2.)	Revenue streams:											
		Heat usage:	2.234.975	2.302.024	2.371.085	2.442.217	2.515.484	2.590.948	2.668.677	2.748.737	2.831.199	2.916.135
		Revenues Total:	**2.234.975**	**2.302.024**	**2.371.085**	**2.442.217**	**2.515.484**	**2.590.948**	**2.668.677**	**2.748.737**	**2.831.199**	**2.916.135**
3.)	Expenses:											
		Repayment industrial bond:	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849	- 177.849
		Repayment commercial loan:	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382	- 205.382
		Fuel purchase costs:	- 665.069	- 685.021	- 705.572	- 726.739	- 748.541	- 770.998	- 794.127	- 817.951	- 842.490	- 867.765
		Operation & maintenance:	- 241.107	- 248.340	- 255.790	- 263.464	- 271.368	- 279.509	- 287.894	- 296.531	- 305.427	- 314.589
		Insurance:	- 41.215	- 42.451	- 43.725	- 45.037	- 46.388	- 47.779	- 49.213	- 50.689	- 52.210	- 53.776
		Ash disposal:	- 113.023	- 116.413	- 119.906	- 123.503	- 127.208	- 131.024	- 134.955	- 139.004	- 143.174	- 147.469
		Labor costs:	- 129.000	- 132.870	- 136.856	- 140.962	- 145.191	- 149.546	- 154.033	- 158.654	- 163.413	- 168.316
		Expenses Total:	**- 1.572.645**	**- 1.608.327**	**- 1.645.080**	**- 1.682.936**	**- 1.721.927**	**- 1.762.088**	**- 1.803.453**	**- 1.846.060**	**- 1.889.945**	**- 1.935.146**
4.)	Gross cash-flow:		662.330	693.697	726.005	759.282	793.557	828.861	865.223	902.677	941.254	980.989
5.)	Tax:	Depreciation total:	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148	- 412.148
		Debt payments principal:	224.555	236.669	249.487	263.053	277.412	292.614	308.711	325.760	343.820	362.955
		Earnings before state tax:	474.736	518.218	563.344	610.186	658.821	709.327	761.787	816.290	872.927	931.796
		State Income Tax:	- 47.474	- 51.822	- 56.334	- 61.019	- 65.882	- 70.933	- 76.179	- 81.629	- 87.293	- 93.180
		Earnings before federal tax:	427.263	466.396	507.009	549.168	592.939	638.394	685.608	734.661	785.634	838.616
		Federal income tax:	- 106.816	- 116.599	- 126.752	- 137.292	- 148.235	- 159.598	- 171.402	- 183.665	- 196.409	- 209.654
6.)	Net cash-flow:		**508.041**	**525.276**	**542.918**	**560.971**	**579.440**	**598.330**	**617.643**	**637.383**	**657.553**	**678.155**
		Discounted cash-flows:	430.543	377.245	330.437	289.343	253.279	221.640	193.894	169.568	148.249	129.571
7.)	Net Present Value (Equity related)		**1.307.324**									
8.)	Remaining Tied-Up Capital:		3.466.383	2.852.469	2.272.545	1.720.150	1.189.459	675.205	172.600			
9.)	Annual Debt Coverage Ratio:		1,33	1,37	1,42	1,46	1,51	1,56	1,61	1,66	1,72	1,77

In Figure 6-2, the net present value and annual debt coverage ratio are shown for various lifetime periods. Although, from a technical point of view, a gasification plant is expected to have a lifetime of at least 15 years, the plant would even have a positive NPV and an annual debt coverage ratio of 1.16 with a lifetime of 8 years from an investment decision point of view.

Figure 6-2

Annual debt coverage ratio & net present value versus lifetime



6.5.2 Sensitivity Analysis

Since the calculations made during this economic feasibility assessment are largely based on assumptions, a sensitivity analysis was performed. In addition, this analysis also helps demonstrate the influence of anticipated changes in the future. This analysis illustrates the effect on the overall net present value (NPV) when an individual variable is changed by +/- 20 percent. It should be noted that for the analysis only one variable was changed at a time as shown by its corresponding trend line. If more that one variable changes, which in reality is more than likely to occur, there is either a cumulative or a canceling effect on the NPV depending on whether the factors both have a positive/negative or oppositional influences.

A total of nine factors were analyzed. These factors are operating life, hours of full load per year, fuel price, heat price, debt capital costs, operating and maintenance cost, state and federal tax rate and total investment cost. In order to keep the graphs concise, the variables were split into two separate figures. Figure 6-3 shows the influence of operating life, hours of full load per year, heat price and debt capital costs. As can be seen, the most influential factor on the NPV is the heat price, which represents the cost of natural gas. Consequently, if there was a 20% increases in the cost of natural gas, the net present value of the gasification would more than double from $1,304,324 to $2,802,305. On the other hand, a 20 percent decrease in the price of natural gas would result in a NPV of $-187,656. An increase in the price of wood of 20% would result in a NPV of $862,456. The operating life and the hours of full load per year also have a large influence on the NPV, while the debt capital cost does not.

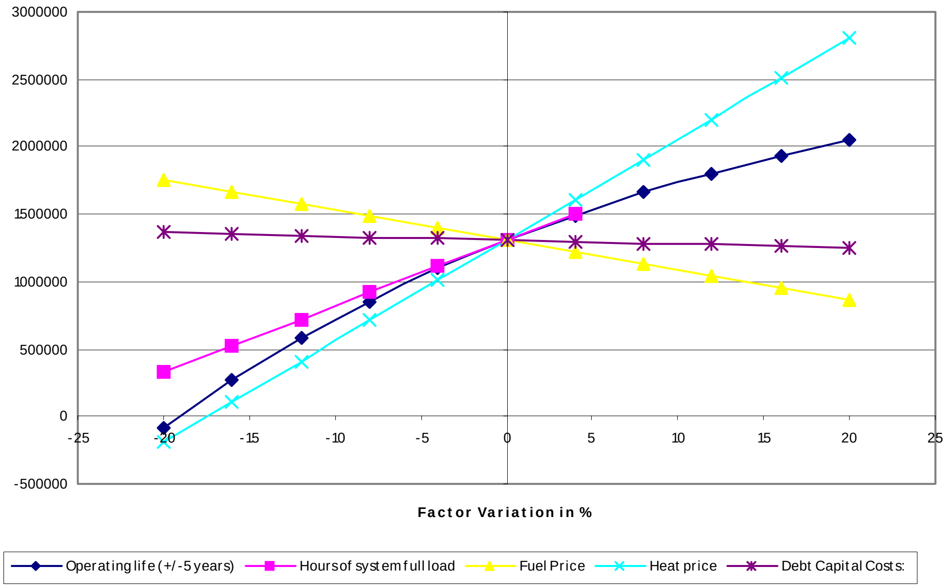


Figure 6-3

Sensitivity analysis, variation of operating life, hours of full load per year, heat price, fuel price and debt capital costs

Figure 6-4 exhibits the influence of operating and maintenance cost, state and federal tax rate and total investment cost. The most influential factor is the investment cost. For example, a 20% decrease in the total investment cost results in a NPV of $1,934,084. The remaining variables do not seem to affect the NPV significantly.

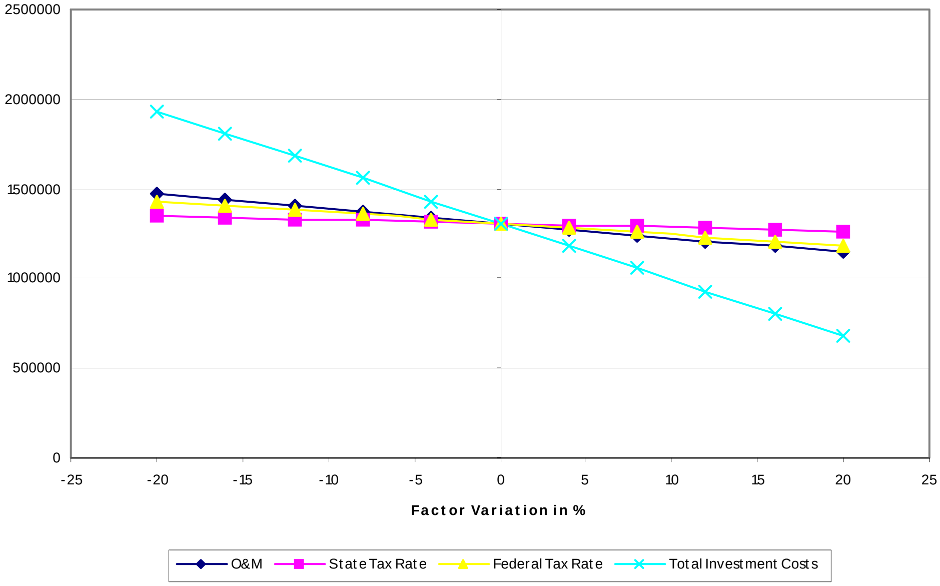


Figure 6-4

Sensitivity analysis chart, variation of operating and maintenance cost, state and federal tax rate and total investment cost

6.5.3 Conclusion

In conclusion, this site shows great potential for generating energy with a wood-fired gasifier integrated into the production facility as envisioned in the above scenario. The gas generated by the plant would replace approximately 340,000 mcf of natural gas a year. The CO_2 emissions reduced by using the renewable wood fuel for energy generation would be over 19,000 tons annually. The economic indicators used in this evaluation with a simple payback period of 3.9 years, an internal rate of return of 18 %, a net present value of $1,304,324, and an annual debt coverage ratio of 1.54 over a ten year period all signal that this could be a sensible investment. Considering the fact that no funding or financial incentives were incorporated into the economic calculations, which nevertheless are most likely available, the prospects of this scenario are even better.

7 Feasibility of a Wood Gasification Plant at Industrial Plant B or an Existing Power Plant

The concepts for both sites, the industrial facility and the power plant are very similar. Therefore, assessments for both sites were carried out in parallel, which is also reflected in the joint description.

7.1 Potential Application of Gasification Technology

The industrial facility identified as a potential gasifier site is a lumber mill. The facility operates several kilns and 1 central boiler. The dry kilns run 24 hours seven days a week. The rest of the plant operates 19 hours a day for five to six days per week. This facility generated some thousand short tons of waste waste used as fuel in 2002 of which 96% consist of untreated, residual wood and 4% consist of bark. This residual wood is currently utilized to fire a boiler for steam production for wood drying purposes. In 2001 and 2002, the production plant used an average of 4.2 million kWh of electricity. Natural gas consumption at this facility is negligible.

The third facility that was identified as having a high potential for a wood gasification plant is a waste fuel-fired power plant. A circulating fluidized bed is used to produce steam that drives a dual turbine generator set. The produced power is sold to service approx. 32,000 homes. The fuel for the power plant consists of waste product from the surrounding bituminous coal producers. Sulfur emissions are controlled by using lime. The ash produced during the combustion process is hauled back to the mining areas as neutralizing agent.

The facility has been and is expected to generate power at a capacity factor between 95 and 97%. Based on communications with the power plant operators, the plant is operated at full capacity. This means that there is no opportunity for the plant to utilize additional steam that could potentially be supplied from the waste heat of a wood gasification unit unless the output of the waste coal-fired CFB unit would be reduced. Since waste coal is a less costly fuel source than residual wood, this option is currently not economically feasible.

The most suitable application at both sites appears to be a standard combined heat and power plant consisting of a CFB wood gasifier, catalytic converter for hot gas tar removal, gas cooler and filter, and IC gas engines, which drive a generator to produce electricity. Due to the low revenues from electricity sale achievable in Pennsylvania, a certain minimum plant size is required to enable economic feasibility. Therefore, two plant sizes with an electric capacity of 5 MW and 10 MW were analyzed. The amount of heat supplied to a potential customer will be assumed to be equivalent to the current heat demand of industrial plant B, approx. 52 billion Btu per year or 1.93 MW.

7.1.1 Basic Gasification Plant Engineering Data

Due to the fact that the lumber mill is already operating large wood storage and handling facilities, it can be assumed that several synergic effects will reduce the capital and operating costs of a gasification plant at this site. The existing logistic system can easily handle the additional task of wood supply for the new wood fueled biomass power and heat plant. The same can be expected for a gasification plant at the power plant. The power plant already requires an enhanced logistic system for fuel supply based on trucks.

The envisioned gasifiers for the 5 MW_{el} and 10 MW_{el} scenarios require a fuel input of 18.0 MW (61,6 mmBtu/h) and 35,6 MW (121,5 mmBtu/h), respectively, including heat losses. Due to higher complexity of the plant compared to the plant described in chapter 6, more maintenance time is required. Thus, the annual operation of the plant is assumed to be 85%, which is equivalent to 7446 h/year.

7.1.2 Wood Supply

The plant design is based on wood with an average water content of 40% and an ash content of $5\%_{dry}$. The wood is dried via a low temperature belt dryer to a water content of 20% to ensure wood gas quality that meets IC engine specifications. The heat for the drying process will be recovered from the cooling water of the IC engines via heat exchangers. The wood consumption of the gasifier plants is 5.3 short tons/h (4.9 metric t/h) for the 5 MW_{el} plant and 10.5 short tons/h (9,6 metric t/h) for the 10 MW_{el} plant. Based on the heating value of wet wood with a water content of 40 %, the electric efficiency of the plant will be higher than 29,5 %, which is significantly higher than conventional steam cycle processes in the same capacity range using wood as fuel.

7.1.3 Wood Storage and Preparation

As mentioned above, due to the existing enhanced fuel logistic systems at the sites, it was assumed that fuel storage for 5 days would be sufficient. Additionally, the gasifier plants will be equipped with short-term, semi-housed fuel storage with 24-hour fuel supply capacity. The wood will be either directly dumped into the 24 h storage or moved from the open 5-day storage into the 24 h storage via a front-end loader. The semi-housed fuel storage also contains the belt dryer. Walking floor units and drag chain conveyors up- and downstream of the dryer enable fully automatic dryer and short-term storage operation. After passing a disc screen and a ferrous metal remover, the wood is transported to the gasifier via drag chain conveyors.

7.1.4 Gasifier and Gas Treatment

Adjacent to the wood storage, another building contains the wood dosing and feeding equipment, the gasification air blower, start up burner, the gasifier, the hot catalytic tar removal unit and the bed ash removal system. After cooling, the gas is filtered via a conventional fabric bag house filter, at a temperature slightly above the dew point of the water vapor contained in the gas. The gas cooler, the filter with fly ash handling system and other auxiliary equipment of the plant are situated in the lower part of the building next to the gasifier. The wood gas is supplied to the IC engines via a gas duct. The IC engines are situated in a standard container, housing all auxiliary engine equipment.

7.1.5 Other Plant Components

As mentioned earlier, no waste heat of the gasification plant is assumed to be sold in this scenario. However, some off-heat will be recovered to replace some of the heat demand of the lumber mill. Subsequent to tar removal, the wood gas is cooled by transferring heat to the cold feed air for the gasifier. At this point, the gas is still too hot for the fabric filter. Thus, approx. 2.5 mmBtu/h of additional heat per MW of electric generation capacity can be recovered. In case of the lumber mill, this heat will be sufficient to cover the 52 billion Btu per year heat demand of the facility. Additional heat could be recovered from the flue gas of the IC engine. However, this option would require the addition of a waste heat boiler. Since waste heat from the gas cooling will be sufficient to cover the current heat demand, this additional equipment cost was not incorporated into economic analyses.

Due to the existing equipment present at both sites, the wood fueled power plant can be controlled from an existing control room. Furthermore, it is assumed that no additional social rooms for the employees operating the gasification plant must be provided

7.2 Investment Costs

The estimated investment costs for the different plant components are listed in Table 7-1. The costs include all direct and indirect costs such as transport of construction material to the plant site, excavation and site preparation, foundation, interior mechanics, installation/construction, painting, heat insulation, process control equipment, legal fees and permits, engineering, insurance, construction financing, start up, etc.

Table 7-1

Complete investment costs of different plant components and total sum for gasification plants with 5 or 10 MW electric capacity

	$5\ MW_{el}$	$10\ MW_{el}$
Buildings	$641,000	$1,012,000
Fuel storage, belt dryer and conveying system	$502,000	$855,000
Fuel feeding and dosing system	$389,000	$573,000
CFB gasifier with air supply, start burner, bed ash handling	$1,127,000	$1,309,000
Gas tar removal, cooler and filter with ash handling system	$1,152,000	$1,964,000
IC engine, transformer	$5,730,000	$10,239,000
Engineering & project management, construction contingency, insurance and financing, legal fees & permits	$2,409,000	$3,622,000
Sum	$11,950,000	$19,574,000

7.3 Operating Costs

Based on plant operation for 7,446 h/year, the annual operating costs are summarized in their respective categories.

7.3.1 Fuel Costs

Fuel costs are the most significant expense for the plant operation. As shown in the wood supply chapter, the wood prices increase as the wood consumption goes up. Therefore, the 10 MW_{el} design will incur higher wood costs per unit weight than the 5 MW_{el} design. For the 5 MW_{el} plant, which has a weekly wood consumption of 750 short tons, the wood price would be $14.75/short ton ($16.25/metric ton). The 10 MW_{el} plant has a weekly wood consumption of 1,500 short tons and would, thus, have to purchase wood at a price of $18.77/short ton ($20.65/metric ton).

7.3.2 Labor Costs

It can be expected that the labor costs at both sites would be lower compared to a stand-alone plant because a labor force already exists that work in the areas of fuel supply and handling, and power generation. Therefore, the additional average labor requirements for the 5 MW_{el} design was estimated to be 8 h/day for one skilled and 4 h/day for one unskilled worker on 365 days per year, plus general financial and technical administrational requirements. For the 10 MW_{el} scenario, the labor was estimated to be 8 h/day for skilled and 10 h/day for unskilled employees, plus administrational expenses.

7.3.3 Maintenance & Operation

Due to the fact that the plant is processing solids like moist wood, hot dust or ashes and is operating at high temperatures, the annual maintenance costs are up to 3 % of the investment costs. Operating costs include expenses for auxiliary energy, such as electricity, pressurized air, fuel for the start up burner, steam for steam jet pulse cleaning of the filter and operating cost contingencies.

7.3.4 Ash Disposal

The wood ash disposal cost was assumed to be $45/ton. This is a worst-case assumption since alternative uses for this material might exist. The power plant is currently using its waste coal combustion ashes as a neutralizing agent at the mining sites. In addition, it is also investigating the use of the ash as a cement additive, road manufacture additive or soil amendment. The wood ash could potentially be used for these or similar purposes, which would significantly reduce the ash disposal cost. However, pretreatment of the wood ashes prior to utilization might be necessary for some applications to reduce the carbon content of the ash. For ashes with a higher carbon content, which is governed by the feed material, co-firing would be an option at the power plant depending on permitting requirements. Therefore, it would be necessary to investigate these alternative utilization options in the next project development phase.

7.3.5 Catalyst

The cost for the catalyst was estimated based on an operating time of three years. For the 5 MW plant design, this cost was assumed to be 0.9% of the investment cost with a total of $107,000/year. For the 10 MW plant, 0.8% of the investment cost were estimated for the cost of the catalytic converter, which resulted in an annual cost of $157,000.

7.3.6 Insurance

Generally, annual insurance costs can be expected to range from 0.7 – 1% of the investment. Therefore, 1% is assumed for further economic analyses of the gasification plant.

A summary of all annual operating costs is presented in Table 7-2.

Table 7-2

Complete operating costs of different plant components and total sum for gasification plants with 5 or 10 MW electric capacity

	5 MW_{el}	10 MW_{el}
Fuel purchase	$807,000	$1,964,000
Labor (including avoided for current wood boiler operation at Georgia Pacific)	$204,000	$293,000
Maintenance & Operation	$538,000	$944,000
Ash disposal	$139,000	$275,000
Catalyst	$107,000	$157,000
Insurance	$119,000	$196,000
Sum	$1,914,000	$3,829,000

7.4 Simple Payback Period

The simple payback time reflects the time it would take to recover the investment cost based on annual operating expenses versus annual revenue. Due to the fact that the lumber mill uses its residual wood to cover its heating requirements, there are no substantial savings as usually associated with the replacement of natural gas. Thus, the heat price assumed for income calculations is $5.96/MWh, which corresponds to the price of wood and is approx. five times lower than the cost of natural gas.

Revenues from electricity generation were assumed to be 6 cents/kWh. This price is below the average electricity price paid by the lumber mill. Since a large portion of electricity will be sold to the power grid, the price largely depends on a power purchase agreement that has to be entered by the owner/operator of the gasifier and the local utility. Due to the fact that Pennsylvania currently does not have a Renewable Portfolio Standard, the utility is not required to pay higher rates for green power. However, green power can be sold for higher prices than electricity generated from fossil fuels, and other projects in Pennsylvania are negotiating to achieve up to 7 c/kWh. Therefore, the assumption of 6 cents/kWh as an average price for replacement of electricity purchased from the grid and electricity sold to the grid can be justified. In the following assessment, sensitivity analyses will be carried out where the electricity price is varied up to 20%, which reflects a price range from 4.8 – 7.2 cents/kWh.

The 5 MW_{el} plant design with an investment of $11,950,000 has annual expenses of $1,914,000. With an annual income of $2,307,000, it would take 30 years to recover the initial investment.

The 10 MW_{el} plant with an investment of $19,574,000 has annual operating costs of $3,872,000, whereas the revenue is $4,536,000 each year. This results in a simple playback period of 27.7 years. The simple payback calculation results are shown in Table 7-3.

Table 7-3

Simple payback period for gasification plants with 5 or 10 MW electric capacity

	5 MW_{el}	**10 MW_{el}**
Sum investment costs	$11,950,000	$19,574,000
Sum operation costs	$1,914,000	$3,829,000
Revenues (heat income based on alternative wood based heat supply, 5,96 $/mmBtu and 6 Cent/kWh)	$2,307,000	$4,536,000
Simple Payback	30 years	27.7 years

These simple payback periods are very high and suggest that under current circumstances the possibility of competitively generating energy from biomass using wood gasification is doubtful at both sites. Since these results are not very promising and the difference between 5 MW_{el} and 10 MW_{el} generation is small in terms of the simple payback period, profitability calculations were only carried out for the 5 MW_{el} scenario.

7.5 Calculation of Profitability

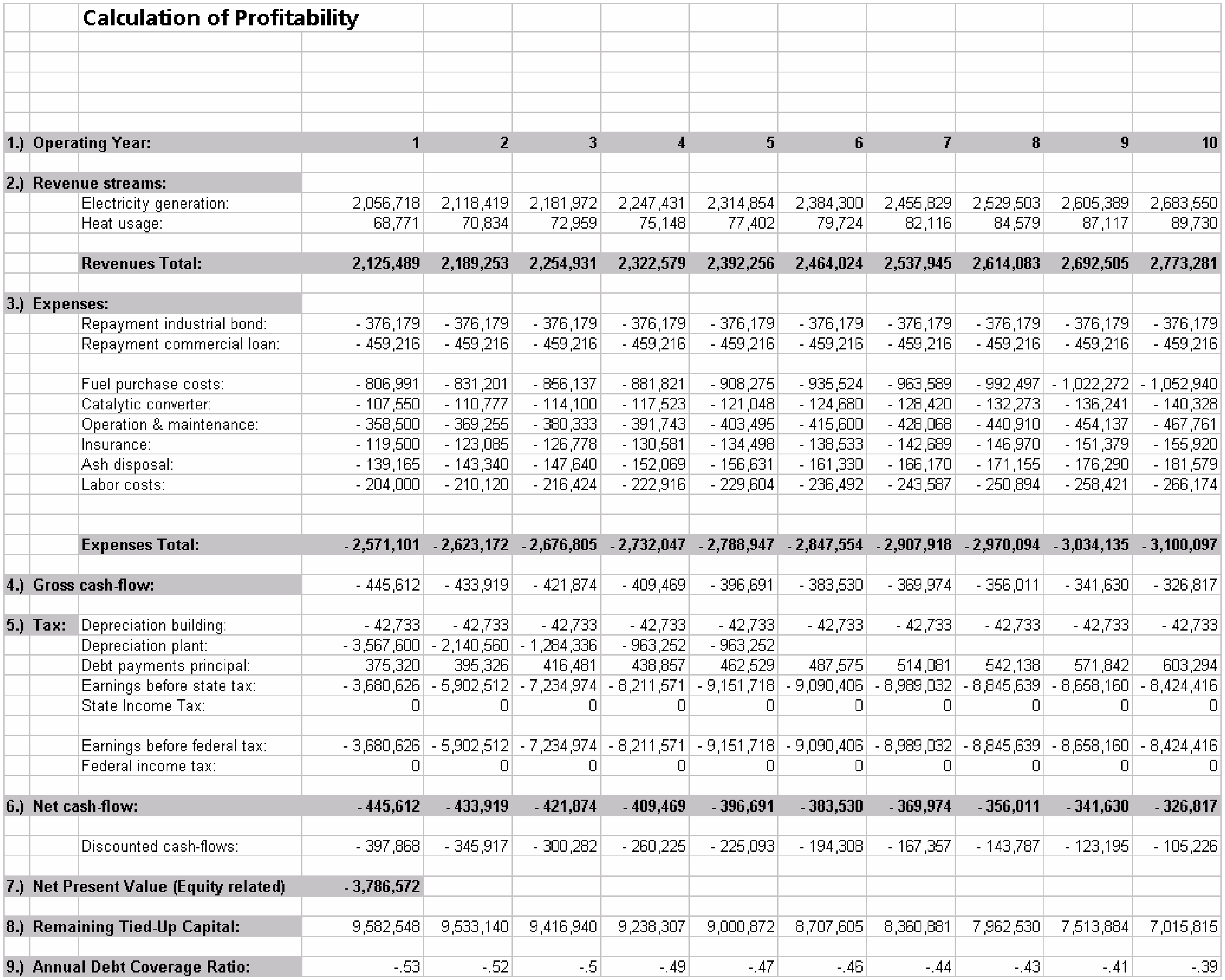
Table 7-4 shows the profitability calculations for the project outlined above. Additional assumptions that had to be made for theses calculation are the same as for the first scenario.

7.5.1 Net Present Value

The 5 MW_{el} plant scenario for the lumber mill has a negative net present value of $-3,786,572 over a ten-year period. Similarly to the simple payback period assessment, this economic indicator suggests that this scenario would not be a sensible investment based on current assumptions and conditions.

Table 7-4

Calculation of profitability for Georgia Pacific gasifier



Calculation of Profitability

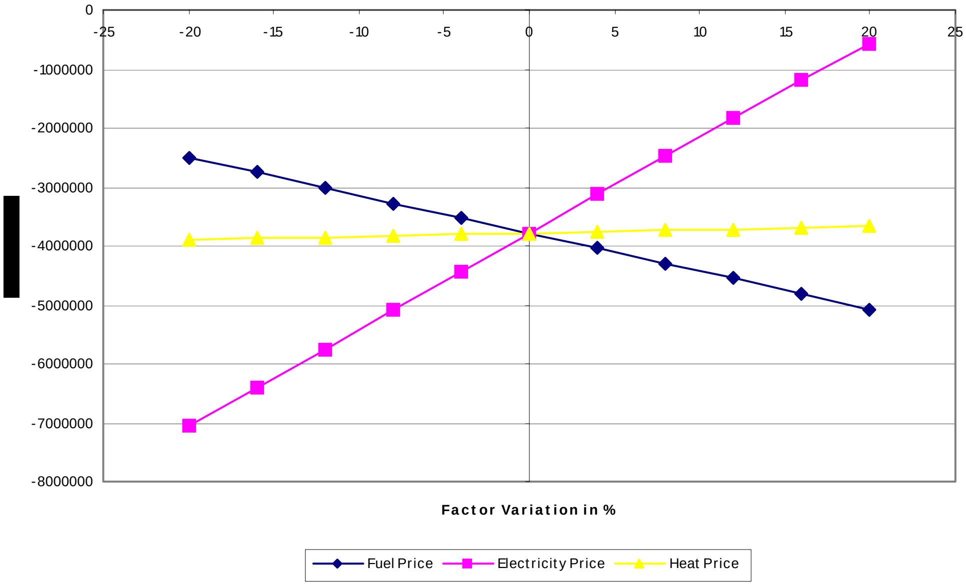
1.)	**Operating Year:**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2.)	**Revenue streams:**											
		Electricity generation:	2,056,718	2,118,419	2,181,972	2,247,431	2,314,854	2,384,300	2,455,829	2,529,503	2,605,389	2,683,550
		Heat usage:	68,771	70,834	72,959	75,148	77,402	79,724	82,116	84,579	87,117	89,730
		Revenues Total:	**2,125,489**	**2,189,253**	**2,254,931**	**2,322,579**	**2,392,256**	**2,464,024**	**2,537,945**	**2,614,083**	**2,692,505**	**2,773,281**
3.)	**Expenses:**											
		Repayment industrial bond:	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179
		Repayment commercial loan:	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216
		Fuel purchase costs:	- 806,991	- 831,201	- 856,137	- 881,821	- 908,275	- 935,524	- 963,589	- 992,497	- 1,022,272	- 1,052,940
		Catalytic converter:	- 107,550	- 110,777	- 114,100	- 117,523	- 121,048	- 124,680	- 128,420	- 132,273	- 136,241	- 140,328
		Operation & maintenance:	- 358,500	- 369,255	- 380,333	- 391,743	- 403,495	- 415,600	- 428,068	- 440,910	- 454,137	- 467,761
		Insurance:	- 119,500	- 123,085	- 126,778	- 130,581	- 134,498	- 138,533	- 142,689	- 146,970	- 151,379	- 155,920
		Ash disposal:	- 139,165	- 143,340	- 147,640	- 152,069	- 156,631	- 161,330	- 166,170	- 171,155	- 176,290	- 181,579
		Labor costs:	- 204,000	- 210,120	- 216,424	- 222,916	- 229,604	- 236,492	- 243,587	- 250,894	- 258,421	- 266,174
		Expenses Total:	**- 2,571,101**	**- 2,623,172**	**- 2,676,805**	**- 2,732,047**	**- 2,788,947**	**- 2,847,554**	**- 2,907,918**	**- 2,970,094**	**- 3,034,135**	**- 3,100,097**
4.)	**Gross cash-flow:**		- 445,612	- 433,919	- 421,874	- 409,469	- 396,691	- 383,530	- 369,974	- 356,011	- 341,630	- 326,817
5.)	**Tax:**	Depreciation building:	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733
		Depreciation plant:	- 3,567,600	- 2,140,560	- 1,284,336	- 963,252	- 963,252					
		Debt payments principal:	375,320	395,326	416,481	438,857	462,529	487,575	514,081	542,138	571,842	603,294
		Earnings before state tax:	- 3,680,626	- 5,902,512	- 7,234,974	- 8,211,571	- 9,151,718	- 9,090,406	- 8,989,032	- 8,845,639	- 8,658,160	- 8,424,416
		State Income Tax:	0	0	0	0	0	0	0	0	0	0
		Earnings before federal tax:	- 3,680,626	- 5,902,512	- 7,234,974	- 8,211,571	- 9,151,718	- 9,090,406	- 8,989,032	- 8,845,639	- 8,658,160	- 8,424,416
		Federal income tax:	0	0	0	0	0	0	0	0	0	0
6.)	**Net cash-flow:**		**- 445,612**	**- 433,919**	**- 421,874**	**- 409,469**	**- 396,691**	**- 383,530**	**- 369,974**	**- 356,011**	**- 341,630**	**- 326,817**
		Discounted cash-flows:	- 397,868	- 345,917	- 300,282	- 260,225	- 225,093	- 194,308	- 167,357	- 143,787	- 123,195	- 105,226
7.)	**Net Present Value (Equity related)**		**- 3,786,572**									
8.)	**Remaining Tied-Up Capital:**		9,582,548	9,533,140	9,416,940	9,238,307	9,000,872	8,707,605	8,360,881	7,962,530	7,513,884	7,015,815
9.)	**Annual Debt Coverage Ratio:**		-.53	-.52	-.5	-.49	-.47	-.46	-.44	-.43	-.41	-.39

7.5.2 Sensitivity Analysis

A sensitivity analysis was performed for the 5 MW_{el} scenario at the lumber mill. For this scenario, only the three most influential variables were incorporated. These variables are the price of wood, the price of electricity, and the price of heat. As can be seen in Figure 7-1, the price of heat does not have a very large influence on the NPV due to the small amount of off-heat utilized from the plant. The wood price and electricity price both have a very strong effect on the profitability of the gasification plant. For example, a 20% increase in the electricity price would result in the NPV changing from \$-3,786,572 to \$-587,078.

Figure 7-1

Sensitivity analysis, variation for Georgia Pacific site gasifier



7.5.3 Conclusion

In conclusion, the 5 MW_{el} and the 10 MW_{el} scenarios at the lumber mill or the power plant are not very promising. The simple payback times of 30 years for the 5 MW_{el} plant and 27.7 years for the 10 MW_{el} plant are far too long for any reasonable investment, which was only reaffirmed by the net present value investigations. The unfavorable outcome of these scenarios can be attributed to the low electricity reimbursement but foremost to the low potential for heat utilization from the plants.

8 Feasibility of a Wood Gasification Plant for a Hypothetical Scenario

8.1 Description of a Hypothetical Scenario

The poor payback periods of the scenarios for the lumber mill and the power plant demonstrated the importance of identifying sites where the majority of off-heat from a gasification plant can replace purchased natural gas or heat generated in other ways. One additional scenario was investigated for a 5 MW_{el} plant identical to the plant at the lumber mill only with a higher heat demand of 76.24 billion Btu per year compared to the 52 billion Btu/year. The heat generated from the plant will replace natural gas purchased at $5.1/Mcf, which is significantly higher than the heat income assumed for the lumber mill, and electricity revenue was again estimated to be 6 cents/kWh.

8.2 Simple Payback Period

This option would have the same investment costs as the option investigated for the lumber mill of $1,914,000. The annual operating costs would be slightly higher at $1,930,360 because it was not assumed that personnel would already be available at this site. Due to a significantly higher heat income of $310,890 compared to the $73,240 of the lumber mill scenario, the annual revenue increases to $2,544,690, which results in the shortened payback period of 19 years. This payback period is still unacceptable. Thus, unless some of the circumstances are different than assumed or will change in the future, this option is not acceptable from an investment potential point of view.

8.3 Profitability Calculations

The profitability calculations were also carried out for this option, as shown in Table 8-1, with the following results.

8.3.1 Net Present Value

The net present value of this option was calculated to be $-1,749,537. While not as negative as in the previous scenario, this result still supports the findings from the simple payback calculations and suggests that an investment in this scenario would not be sensible.

Table 8-1

Calculation of profitability for hypothetical gasifier

Calculation of Profitability

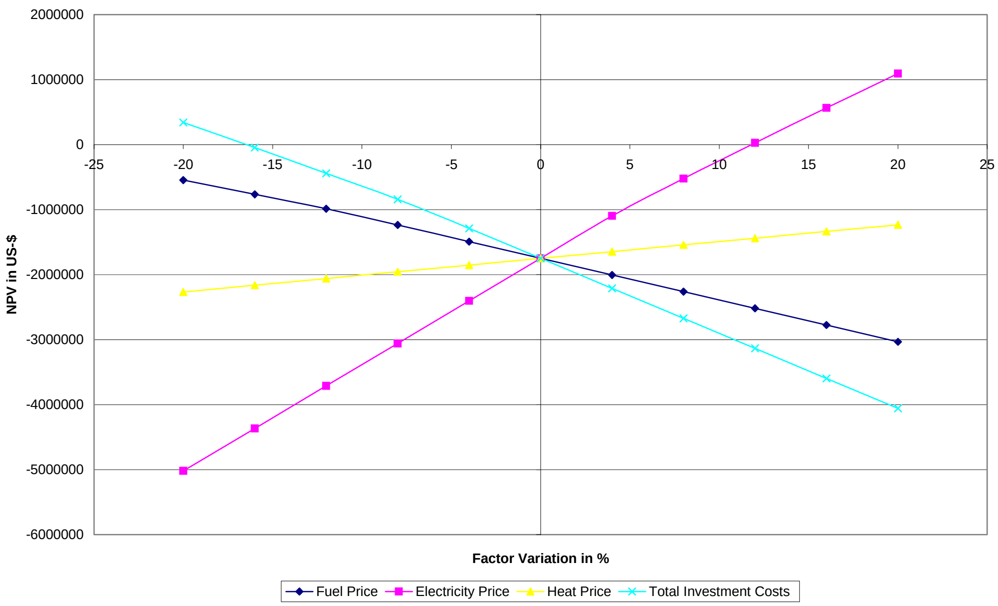
1.)	**Operating Year:**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2.)	**Revenue streams:**											
		Electricity generation:	2,056,718	2,118,419	2,181,972	2,247,431	2,314,854	2,384,300	2,455,829	2,529,503	2,605,389	2,683,550
		Heat usage:	325,050	334,802	344,846	355,191	365,847	376,822	388,127	399,770	411,764	424,117
		Revenues Total:	**2,381,768**	**2,453,221**	**2,526,817**	**2,602,622**	**2,680,701**	**2,761,122**	**2,843,955**	**2,929,274**	**3,017,152**	**3,107,667**
3.)	**Expenses:**											
		Repayment industrial bond:	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179	- 376,179
		Repayment commercial loan:	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216	- 459,216
		Fuel purchase costs:	- 806,991	- 831,201	- 856,137	- 881,821	- 908,275	- 935,524	- 963,589	- 992,497	- 1,022,272	- 1,052,940
		Catalytic converter:	- 107,550	- 110,777	- 114,100	- 117,523	- 121,048	- 124,680	- 128,420	- 132,273	- 136,241	- 140,328
		Operation & maintenance:	- 358,500	- 369,255	- 380,333	- 391,743	- 403,495	- 415,600	- 428,068	- 440,910	- 454,137	- 467,761
		Insurance:	- 119,500	- 123,085	- 126,778	- 130,581	- 134,498	- 138,533	- 142,689	- 146,970	- 151,379	- 155,920
		Ash disposal:	- 139,165	- 143,340	- 147,640	- 152,069	- 156,631	- 161,330	- 166,170	- 171,155	- 176,290	- 181,579
		Labor costs:	- 204,000	- 210,120	- 216,424	- 222,916	- 229,604	- 236,492	- 243,587	- 250,894	- 258,421	- 266,174
		Expenses Total:	**- 2,571,101**	**- 2,623,172**	**- 2,676,805**	**- 2,732,047**	**- 2,788,947**	**- 2,847,554**	**- 2,907,918**	**- 2,970,094**	**- 3,034,135**	**- 3,100,097**
4.)	**Gross cash-flow:**		- 189,333	- 169,951	- 149,988	- 129,426	- 108,246	- 86,432	- 63,963	- 40,820	- 16,983	7,569
5.)	**Tax:**	Depreciation building:	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733	- 42,733
		Depreciation plant:	- 3,567,600	- 2,140,560	- 1,284,336	- 963,252	- 963,252					
		Debt payments principal:	375,320	395,326	416,481	438,857	462,529	487,575	514,081	542,138	571,842	603,294
		Earnings before state tax:	- 3,424,347	- 5,382,265	- 6,442,841	- 7,139,394	- 7,791,097	- 7,432,688	- 7,025,303	- 6,566,719	- 6,054,593	- 5,486,463
		State Income Tax:	0	0	0	0	0	0	0	0	0	0
		Earnings before federal tax:	- 3,424,347	- 5,382,265	- 6,442,841	- 7,139,394	- 7,791,097	- 7,432,688	- 7,025,303	- 6,566,719	- 6,054,593	- 5,486,463
		Federal income tax:	0	0	0	0	0	0	0	0	0	0
6.)	**Net cash-flow:**		**- 189,333**	**- 169,951**	**- 149,988**	**- 129,426**	**- 108,246**	**- 86,432**	**- 63,963**	**- 40,820**	**- 16,983**	**7,569**
		Discounted cash-flows:	- 169,047	- 135,484	- 106,758	- 82,252	- 61,422	- 43,789	- 28,934	- 16,487	- 6,124	2,437
7.)	**Net Present Value (Equity related)**		**- 1,749,537**									
8.)	**Remaining Tied-Up Capital:**		9,353,728	9,093,886	8,784,163	8,427,557	8,026,451	7,582,665	7,097,517	6,571,866	6,006,149	5,400,417
9.)	**Annual Debt Coverage Ratio:**		-.23	-.2	-.18	-.15	-.13	-.1	-.08	-.05	-.02	.01

8.3.2 Sensitivity Analysis

A sensitivity analysis was performed for this scenario to demonstrate the effect on the NPV of individually changing economic variables. The variables used in this analysis are the fuel price, the heat price, the electricity price, and the total investment costs. The results of the analysis are visualized in Figure 8-1. As shown, the strongest influencing factor is the electricity price. For example, an increase in the electricity price of 20% (7.2 c/kWh) would result in a NPV of $1,092,778 compared to the initial $-1,749,537, and the plant would be economically feasible.

Figure 8-1

Sensitivity analysis chart for hypothetical gasifier



8.4 Conclusion

The hypothetical option analyzed above showed some improvement compared to the scenarios investigated for the lumber mill and the power plant. However, the payback period of 19 years and the NPV of $-1,749,537 still demonstrate that this option is not economically feasible under the current conditions and assumptions. Nevertheless, assuming a scenario where, for example, 10% funding is available and a reasonable amount of heat as well as electricity could be sold at consumer prices, a gasification plant may well be feasible. This would be even more so, if emission credits or renewable energy credits could be obtained.

9 Environmental Aspects and Emissions

Many people associate energy generation facilities with the image of smoking stacks and non-environmentally sound technology, especially those using solid fuels such as wood. This picture does not adequately represent today's advanced and sophisticated wood or other solid biomass burning facilities.

In contrast to the old images of smoky, coal-fired, industrial plants, the utilization of biomass offers various environmental benefits starting with the production of the fuel, the growth of biomass. During the growth of the fuel plant, the greenhouse gas carbon dioxide is removed from the atmosphere. Furthermore, forests humidify and filter dust from the air, create the local micro and macroclimate, prevent erosion and present a biotope for a great variety of animals, plants, insects and other organisms.

The consequence of increased utilization of biomass, especially wood, will not result in clear-cutting of existing forests. Instead, only the utilization of byproducts from the forest and lumber industry is envisioned. The use of this 'low cost/low quality' wood will support sustainable forestry and enable successful use of this energy source. Thinning and the collection of low quality wood out of forest stocks containing high quality wood significantly reduces the risk of wild fires and increases the growth of high quality wood. This strengthens the local, rural economy, which consequently prevents emigration of the rural population towards the cities and enables maintaining the historical use of the landscape and historical social appearance of the countryside.

The local utilization of fuel for power generation further leads to shorter transportation distances of fuels, resulting in lower emissions. Furthermore, transportation of biomass does not present the inherent risks and consequences to the environment associated with the transportation of fuels such as gas or oil via pipeline, truck or ship.

The existing biomass conversion technologies guarantee emissions significantly below the strictest limits. In the majority of cases, the water content of residues from the lumber industry will be lower compared to that of forest wood. Due to this, higher yields of power and heat per weight of fuel input and even lower emissions can be achieved.

Especially for power production, the combination of CFB gasifier, catalytic tar reformer, and gas engine offers new possibilities for environmentally and economically sound projects. Including simultaneous heat utilization, electric efficiencies of 30% or more, even for relatively small sized plants, guarantee an efficient use of the valuable biomass resources. Although the carbon monoxide emissions of wood gas fueled IC engines are slightly higher than those of oil or natural gas engines, generally the emissions of the environmentally more problematic pollutant nitrogen oxide are significantly lower.

Optimal combustion control technology ensures nearly 100% fuel conversion to water and carbon dioxide, which has been extracted from the atmosphere during plant growth. Grey or even black soot emissions from stacks are a part of history but not of today's power and heating plants. Ash dust is removed from flue gases. The ash can be used as a component for concrete and road construction. Furthermore, the benefits of using these ashes as a soil amendment have been proven and put into practice in Austria and Scandinavian countries (Deimling et al., 2000). The ash contains nutrients, which have been extracted by the trees out of the soil and can be made available to other plants.

The ash recycling completely closes the cycle of heat and/or power generation which starts using solar energy for the growth of biomass by extracting carbon dioxide, water and nutrients from the biosphere and ends with the combustion of the wood releasing carbon dioxide and water and recycling the nutrients back to the forests.

There are no emission limits prescribed for wood gasifiers in Pennsylvania. In order to obtain permits it has to be shown that emissions are at least as low as those of other comparable power and heat generation plants. As there are currently no plants of this kind in operation, a comparison would have to be made with gasifiers fueled with e.g. coal or with wood incineration plants of comparable size.

A great deal of difficulty was encountered in obtaining information on emissions from various point sources. Data were often not publicly available. Owners and operators did not want specific details of their plant to be published. Another problem was that even publicly available information was in various units, which often couldn't be converted without further information such as the concentration of oxygen in the flue gas. Some published data are given in units of parts per million by weight (ppm) or parts per million by volume (ppm_v), while others are in pounds per mmBtu (lb/mmBtu), milligram per standard cubic meter (mg/sdm^3), or others. Units in this report will be limited to ppm, lb/mmBtu and lb/ton burned.

Emissions from combustion depend on various parameters: the source and composition of the fuel, the type and size of the boiler, firing conditions, load, type of control technologies, and the level of equipment maintenance. Particulate matter composition and emission levels are a complex function of boiler firing configuration, boiler operation, pollution control equipment, and coal properties. Formation of sulfur oxides is related to the sulfur content of the fuel and the pH value of the ash. The nitrogen oxide concentration in the combustion gas is dependent on the oxygen and the nitrogen concentration in the flame, the nitrogen source (fuel or combustion air), and the gas residence time at a specific combustion temperature. Carbon monoxide emissions depend on the fuel oxidation efficiency. Smaller boilers, heaters, and furnaces will emit more carbon monoxide due to the fact that they have a shorter high-temperature residence time, which does not enable them to achieve complete combustion (ELAW, 1998).

Table 9-1 compares a potential wood gasifier with gas utilization in a reciprocating engine to wood and coal fired boilers. Residential fireplaces were also placed on the list for comparison. The values listed for the gasifier are estimates based on data obtained from the operation of a demonstration plant at the Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT in Oberhausen, Germany. The gasifier coupled with a gas engine produces the least amount of carbon monoxide and particulate matter. Nitrous oxides are low and in the range of those from other sources. Sulfur oxide levels are very low because wood doesn't contain much sulfur (SO_2 is one component of SO_x; data given for SO_2 often represent total SO_x). An interesting comparison can be made between a residential fireplace and the gasifier. The amount of carbon monoxide emitted by fireplace A is 41 times higher than the amount produced by the gasifier.

Table 9-1

Comparison of emissions in (lb/mmBtu) from various thermal conversion units (Cobb, 2001; Houck & Crouch, 2002; Resource Systems Group, 2001).

SOURCE	TYPE	FUEL	CO	NOx	SOx	SO_2	PM
Gasifier with engine and thermal flue gas treatment	Wood Gasifier	Clean Wood	<0.06	<0.28	<0.06	N/A	<0.01
Messerismith	Wood Boiler	Clean Wood	2.123	0.146	N/A	N/A	0.12
Chiptec 85-90T	Wood Boiler	Clean Wood	0.902	0.211	N/A	N/A	0.097
AP-42	Wood Boiler	Clean Wood	1.496	0.165	N/A	0.00825	0.968
NIOSH II	Coal Boiler	Coal	N/A	0.426	N/A	0.925	2.31
NIOSH II	Boiler	33% Demolition Wood/66% coal	N/A	0.4	N/A	0.856	2.92
Fireplace A	Residential	Wood	14.6	0.1503	0.0231	N/A	2
Fireplace B	Residential	Firelog	6.76	0.23	N/A	N/A	2.46
Fireplace C	Residential	Cordwood	8.45	0.185	N/A	N/A	1.28

Comparing the wood gasifier with gas engine to other gasifiers wasn't easy. As previously stated, obtaining information regarding emissions is extremely difficult. Nevertheless, Table 9-2 was prepared based on information that was collected. It has to be mentioned that the capacity of the coal gasifiers is significantly higher. If a wood gasifier of similar capacity was built, the same or even lower NO_x-concentrations in the flue gas could be achieved.

Table 9-2

Comparison of the wood gasifier emissions in (lb/mmBtu) to those of other gasifiers (Hornick, 2002).

SOURCE	TYPE	FUEL	CO	NOx	SOx	SO_2	PM
Wood Gasifier with Gas Engine	Wood Gasifier	Wood	<0.06	<0.28	<0.06	N/A	<0.01
Wabash River Coal	Coal Gasifier	Coal Slurry	0.05	0.15	N/A	0.1	0
Tampa Electric	Coal Gasifier-IGCC	Coal		0.27	N/A	0.15	N/A

In order to provide the most information possible, an additional table (Table 9-3) with data from different sources is included. Data are given in parts per million by weight (ppm) unless stated otherwise (ppmv = part per million volume). As described before, ppm cannot be easily converted into lb/mmBtu without additional information. Emission factors are used as a tool to estimate air pollutant emissions to the atmosphere. They relate the quantity of pollutants released from a source to some activity associated with those emissions. Emission factors are usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (EPA, 2001).

The advantage of using a unit related to actual generation of usable energy such as lb/mmBtu lies in the fact that emissions from different plants associated with the generation of a certain amount of energy can be compared better. If only the pollutant concentration in the flue gas is given, a plant that appears to be cleaner may actually have higher emissions per unit of energy produced because its efficiency is lower compared to that of another plant with a potentially higher pollutant emission in ppm.

Table 9-3

Emission factors in ppm (unless stated otherwise) for various thermal units (Paisley, et al., 2001; Freeman, et al., 2001; Steinfeld, 2003; Western Regional Air Partnership, 2003; Capstone Turbine Corporation, 2000)

SOURCE	TYPE	FUEL	CO	NOX	SO2	PM
Burlington Gasifier	Silagas Biomass Gasifier	Natural Gas	457	20		
Burlington Gasifier	Silagas Biomass Gasifier	Natural gas and biomass derived gas	500	7		
NETL In-House Biomass	Co-Firing	coal	92	574	1209	3.9 g/dscf
NETL In-House Biomass	Co-Firing	10% Creosote Wood/90% coal	75	474	1120	2.4 g/dscf
NETL In-House Biomass	Co-Firing	10% Pentachlorophenol /90%coal	69	496	1102	3.0 g/dscf
CCT Fuel Cell Demo	Fuel Cell	Natural Gas	0.2 ppmv	0.267 ppmv	0.026 ppmv	249 µg/scm
Mobile Source	ON Road	Gasoline	45	35	25	40
Capstone Microturbine	Capstone	Natural Gas	40 ppmv	9 ppmv		

Efforts are currently being made to reduce the amount of emissions produced. In 2001, the Department of Energy placed new restrictions on permitted emissions. Pennsylvania also monitors emissions from thousands of air contamination sources. The goal of Pennsylvania's ambient air monitoring program is to evaluate compliance with federal and state air quality standards, provide real-time monitoring of air pollution, develop data for trend analysis, support the development and implementation of air quality regulations, and provide information to the public on daily air quality conditions (DEP, 2001). Table 9-4 shows the key information in Pennsylvania's Air Quality Monitoring in 2001.

Table 9-4

Air Quality Standards in Pennsylvania (DEP, 2001).

Pollutant	Primary (Health Related)	
	Type of Average	Concentration
Carbon monoxide	1 hour	35 ppm
Nitrogen dioxide	Annual Arithmetic Mean	0.053 ppm
Ozone	Max. Daily 1-hour Average	0.12 ppm
Particulate matter PM_{10}	Annual Arithmetic Mean	50 $\mu g/m^3$
Particulate matter $PM_{2.5}$	Annual Arithmetic Mean	15 $\mu g/m^3$
Sulfur dioxide	Annual Arithmetic Mean	0.03 ppm

Since gas generated in a wood gasifier cannot only be used in gas engines but also in boilers or other energy generation equipment, a few general remarks will follow on emission related to wood gasification.

The gasifier itself has no gaseous emissions. The wood is completely converted into product gas and ash. Any emissions to be considered are derived from utilization of the product gas. For example, if it is used in a gas engine or a boiler, exhaust gases of the engine or the boiler are the emissions to be evaluated.

Regarding NO_x formation, two effects have to be considered separately. Significant amounts of thermal NO_x are formed at temperatures above approximately 2,400 °F. Due to the lower heating value of wood gas, the combustion temperature is considerably lower compared to that of natural gas and thermal NO_x formation can be neglected. The second effect is the conversion of nitrogen contained in the fuel into nitrogen oxides. Wood (without bark) contains only a very small amount of nitrogen. Therefore, if clean wood is used for gasification and a state of the art gas engine or boiler is fueled with the produced gas, NO_x emissions are relatively low and additional NO_x removal is not necessary. However, nitrogen contents of bark are higher. If NO_x emissions should be reduced to even lower levels or if a fuel with more nitrogen (e.g. bark) is used, readily available technologies such as adding NH_3 to the flue gas of boilers can be applied. In fact, it is technically easier to achieve low NO_x emissions using wood gas instead of natural gas or direct combustion of solid wood. In the gasifier itself or via a side reaction in the tar removal catalyst, a significant part of the nitrogen contained in the fuel is directly converted into nitrogen gas N_2. As mentioned before, when using state of the art gas combustion technology, the downstream formation of NO_x from N_2 can be neglected.

Carbon monoxide is one important component of the wood gas adding to its heating value. In boilers, complete conversion of CO to CO_2 is usually achieved.

Due to the lower combustion speed of CO compared to natural gas (methane), very small amounts of CO can be found in the exhaust gas. If necessary, these small amounts can be reduced to below 0.06 lb/MMBtu using thermal flue gas treatment (with or without heat recovery).

SO_x generally are no problem due to the very low sulfur contents of wood.

Dust emissions (particulate matter) are very low because the product gas is filtered before entering the gas engine. If a boiler is used, the filter can also be installed in the exhaust of the boiler.

Generally, it can be said that emissions of energy generation plants fueled by wood gas are similar to those of plants fired with natural gas. Gasification is the cleanest way of using wood for energy generation because gas burners can be controlled and operated at the optimum much better than burners for solid fuels such as wood chips or saw dust.

10 Conclusion and Recommendations

10.1 Conclusion

In conclusion, this study explored the feasibility of generating energy through gasification of wood in Clarion County, Pennsylvania. The underlying objectives of the project were to establish the wood supply potential, the energy demand, and potential sites for a biomass power plant. Based on that information the economic feasibility of various energy generation scenarios was assessed.

The wood supply in Clarion County and the surrounding areas was investigated. Local businesses were surveyed to determine the type, quantity, and quality of various wood sources. Residual wood suitable for gasification is largely available. The total amount identified was over 258,000 tons/year with an average price of $23/ton and an average energy potential of approximately 6,320 mmBtu/day. Therefore, an adequate amount of biomass is available in Clarion County to supply one or more small-scale gasifiers.

During the site selection process it was determined that the site with the highest potential for on site energy generation from residual wood was an industrial company with a constant, high gas demand. A scenario where gas is produced to replace natural gas turned out to be very favorable with a simple payback time below 4 years. Aside from other advantages, in this case wood gasification can provide the energy needed with less technical effort than wood combustion. Increasing prices of natural gas will further improve the economics for this site. This pant would save over 19,000 tons of CO_2-emissions annually.

The economic evaluation of scenarios based on gasification to generate electricity showed that this option is not economically feasible under the current assumptions and boundary conditions. This was largely due to the low reimbursement of electricity fed into the grid. However, no grants or tax incentives were assumed for the scenarios, which could be available for renewable energy projects as envisioned in this study. If energy prices will rise in the future, if emission credits can be sold or if public funding would be available, combined power and heat generation through gasification of residual wood could become feasible in the future.

Although the study was carried out for Clarion County, results are also valid for other areas in Pennsylvania with similar energy prices, prices for residual wood and energy consumers that have a constant and high demand for gas.

10.2 Recommendations and Final Remarks

Based on the results of this study, it is recommended to further investigate the potential of wood gasification at other industrial sites in Pennsylvania where a sufficient amount of residual wood is available.

If the company owning the most promising site investigated in this project is interested in further pursuing wood gasification, they should form a team of site representatives, potential plant owners and operators (if they don't want to do it themselves), a plant designer etc. to develop a final concept and detail design. Following, accurate quotes from potential suppliers and manufacturers of plant components should be obtained and negotiations for contractual agreements with potential biomass suppliers have to be carried out. Permitting for the plant and land use should be investigated/initiated to ensure that these won't become prohibitive to the proposed project.

This study should not be taken as a final vote on the economic feasibility of gasification projects. Many of the assumptions made for the variables such as the prices for fuel and replaced energy of the economic evaluations are constantly changing. This could work in favor or against a project and should be kept in mind. Furthermore, the energy bill currently under review could also have several positive impacts. For example, the introduction of renewable portfolio standards would mandate local utilities to have a certain amount of renewable energy in their generation portfolio. This would enable independent power producers to sell their renewable electricity at a much higher premium, which would then make projects that incorporate electricity generation much more competitive.

Although this project was carried out in order to take advantage of the environmental benefits of energy generation from clean residual wood and to support local economy, several local environmental groups would oppose the construction of a wood gasifier in Clarion County. They are afraid that such a plant could be used to gasify other material such as treated waste wood or sewage sludge and would also be a driving force for increased cutting of trees in the Allegheny National Forest. As described before, the authors of this study do not intend to support increased clear cuts, and it wouldn't make sense economically to cut trees just for energy generation. Wood gasification should only be considered where an abundant supply of clean, residual wood is available. Operating a plant with different fuels usually is not possible without significant changes in plant design, associated with respective costs. Furthermore, this would require additional permits from the Pennsylvania Department of Environmental Protection.

However, these concerns have to be taken seriously, and fair and open discussions should be held if a decision should be made to actually build a plant. It has to be made clear that a permit should only be given for use of clean wood as fuel. Emission data should be presented frankly by the potential plant owner and operator. Concerned environmentalists should not present significant emission data out of context (from very different plants based on other technologies and fuels) in order to increase opposition.

If a wood gasification plant is built using best available technologies and fueled only with clean, residual wood, it can be advantageous for the environment as well as for the local economy.

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