Potential for on-farm biomass gasification in Montana
by Clinton Wade Molde

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Engineering MONTANA STATE UNIVERSITY Bozeman, Montana June 1987
Montana State University

Abstract:
The feasibility of using biomass gasification systems on Montana farms was investigated for both technical and economic merit. Large volumes of biomass are available and they have the potential to replace conventional fuels. Technically biomass can be used to replace conventional fuels through gasification. Each gasification system must be specifically designed for the site and the energy end-use requirements. Ultimately a system's feasibility is determined by its economics. The economic feasibility of a gasification system is greatly controlled by the initial expenditure, current fuel costs, feedstock costs, and yearly usage. Most agricultural applications do not have enough use per year to justify the capital expenditure. Also current fuel prices would have to increase greatly for a system to become economically feasible. Cogeneration shows the best economic potential, although the current electricity buyback rate would have to increase and a long term use for the generated heat would also be needed. These requirements are not typical of most farming operations. The results of this study shows that gasification systems are very site specific with even the most ideal scenarios being noneconomical.

POTENTIAL FOR ON-FARM BIOMASS GASIFICATION IN MONTANA

by

Clinton Wade Molde

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Agricultural Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

June 1987

APPROVAL

of a thesis submitted by

Clinton Wade Molde

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style and consistency, and is ready for submission to the College of Graduate Studies.

May 19, 1987 — William E Larsen
Date — Chairperson, Graduate Committee

Approved for the Major Department

20 May '87 — Theodore E. L
Date — Head, Major Department

Approved for the College of Graduate Studies

5-29-87 — M P Malone
Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material for financial gain shall not be allowed without my written permission.

Signature Clinton W. Molde

Date May 19th, 1987

TABLE OF CONTENTS

CHAPTER

TABLE OF CONTENTS Continued

TABLE OF CONTENTS Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES Continued

LIST OF FIGURES Continued

ABSTRACT

The feasibility of using biomass gasification systems on Montana farms was investigated for both technical and economic merit. Large volumes of biomass are available and they have the potential to replace conventional fuels. Technically biomass can be used to replace conventional fuels through gasification. Each gasification system must be specifically designed for the site and the energy end-use requirements. Ultimately a system's feasibility is determined by its economics. The economic feasibility of a gasification system is greatly controlled by the initial expenditure, current fuel costs, feedstock costs, and yearly usage. Most agricultural applications do not have enough use per year to justify the capital expenditure. Also current fuel prices would have to increase greatly for a system to become economically feasible. Cogeneration shows the best economic potential, although the current electricity buyback rate would have to increase and a long term use for the generated heat would also be needed. These requirements are not typical of most farming operations. The results of this study shows that gasification systems are very site specific with even the most ideal scenarios being noneconomical.

CHAPTER 1

BACKGROUND INFORMATION

Introduction

Today's agricultural community is very dependent on energy, in one form or another. Conventional fossil fuels and electricity are used to power all types of farm machinery, heat buildings, heat water, pump irrigation water, and dry crops. To help lower energy costs and to reduce the farmer's dependency on non-renewable forms of energy, safe, efficient and reliable forms of renewable energy need to be developed.

Many researchers have considered the possible use of gasification systems for on-farm applications in an attempt to use the renewable supply of biomass feedstocks. This thesis examines the technical and economic feasibility of gasification systems for use on Montana farms and ranches. The evaluation considers potential harvest techniques, handling, processing and storage practices of biomass feedstocks as well as gasification and end-use applications suitable for Montana. The base knowledge for evaluating the total biomass gasification system from the collection process to the end-use application was accomplished through an extensive literature review. The technical and economic concepts used in the analysis of on-farm gasification systems were obtained from this review. As a result this thesis contains many references from authors with expertise in the different areas of a biomass gasification system.

Several gasification techniques and gas filtering systems were evaluated along with possible end-use applications. The reason for evaluating these different components was to understand the advantages and disadvantages of each component and to piece together a system that would accomplish different on-farm tasks.

The requirements for gasification systems were determined for different applications along with possible system modifications. For example, a gasifier's feeding system often has to be modified to suit the physical properties of a feedstock and internal combustion engines have to undergo certain modifications in order to be fueled with producer gas. Pollution control and electrical generation regulations that could possibly effect gasification systems in Montana were also reviewed.

An extensive study was conducted to determine the possible biomass feedstocks available for gasification. Wheat straw, barley straw, cattle manure and wood showed the most promise for Montana. The harvest, handling, processing and storage methods required by these feedstocks were then determined.

Several on-farm gasification scenarios were modeled to establish the economical feasibility of potential gasification systems. The scenarios were hypothetical cases dealing with irrigation pumping, grain drying, dairy barn heating and cogeneration as end-use applications. Mobile applications, such as tractor/gasifier systems were not considered due to difficulty of using producer gas in this manner. Collection, transportation, processing, and storage costs were calculated to determine the cost ranges for each type of feedstock. The systems were then sized according to energy requirements and end-use application. The initial system costs, supply costs, repair and maintenance costs and labor costs, etc. were determined and entered into a spreadsheet program to evaluate a given system's economic feasibility.

Survey of Different Biomass Conversion Alternatives

Different conversion technologies are available for using biomass for on-farm energy production. Among these are the production of methane through anaerobic digestion, fermentation of biomass to produce fuel alcohol, direct combustion to produce heat energy, and gasification to produce a combustible gas.

Anaerobic digestion is the process of breaking down organic biomass in the absence of oxygen, producing a gas composed primarily of methane and carbon dioxide. Livestock manure is an ideal biomass feedstock for anaerobic digestion. A large amount of manure is required to produce gas, making anaerobic digestion suitable only for areas with large concentrations of manure. Possible sources would be dairy and feedlot operations. Unfortunately, anaerobic digesters are expensive to build and operate, therefore this technology may not have a large overall impact on on-farm energy generation (Boyette and McKusick, 1986).

Alcohol production also appears to be uneconomical because of the large initial expense, operation costs, and feedstock costs (Boyette and McKusick, 1986). Only in ideal cases where the grain feedstock is free (spoiled grain) is produced alcohol competitive with conventional fuels. Alcohol is finding some application as a gasoline octane improver but it depends on tax refunds to be economical.

Direct combustion of wood or agricultural biomass to produce heat is an on-farm energy alternative. The heat energy can be used in a boiler/generator set to produce electricity or for direct heating applications. Direct combustion has the disadvantage of being limited to heat production. It also must be managed carefully to prevent the production of large amounts of air polluting emissions.

Gasification appears to be the only conversion technology that can convert various types of feedstocks into a combustible gas suitable for either direct combustion or for fueling an internal combustion engine. Gasification also has the advantage of producing a clean burning fuel that produces fewer emissions than direct combustion. The ability of gasification technology to accept various feedstocks and to produce a gas suitable for various applications may make it acceptable for wide spread on-farm use.

Brief History of Gasification

The gasification process has been known for at least 200 years. The application of gasification for gasifying peat and coal for steel making is documented as early as 1843. At the turn of the century, gasification of coal was extensively used to produce gas for cooking and lighting. Around 1880 gas produced from gasifying coal was starting to be used in internal combustion engines (Boyette and McKusick, 1986).

Very little research on gasification was conducted until World War II. In Europe, during World War II, the shortage of gasoline and diesel fuel triggered extensive research and use of gasification for fueling vehicles. Charcoal and wood gasifying units were used to fuel automobiles, heavy trucks, boats and stationary engines.

In the 1970's, the energy crisis again prompted researchers to turn to gasification. Gasification showed a way to provide a potential renewable energy source. Many agricultural research groups began to explore the feasibility of gasifying wood, wood wastes, and agricultural residues for use on farms. On-farm applications include grain drying, heating of livestock buildings and greenhouses, irrigation pumping, and electrical generation.

Today, research on gasification is still continuing with systems becoming more convenient, reliable, and the conversion efficiency is increasing. Research is also being directed towards creating small, simple, and rugged systems for use by third world countries. The reason for this is the potentially large market due to the high cost of fossil fuels.

CHAPTER 2

GASIFICATION TECHNOLOGY INFORMATION

Gasification Process

The aim of the gasification process is to transfer the energy of biomass feedstock to a gaseous fuel to be used in a variety of applications. This conversion process involves the combustion of the feedstock in a controlled environment that limits the amount of oxygen. In the gasification process the feedstock is heated, dried and pyrolyzed to produce various gases, tars, and char. There are numerous reactions possible in biomass gasification, many of which are coupled. An extensive kinetic framework for carbon reactions in coal gasification was presented by Von Fredersdorff and Elliot (1963). Many of these reactions can also be applied to biomass feedstocks (Table 1). By controlling the direction of gas flow, or the number of gasifying stages, a specific gasifier system can attempt to exploit some of the following reactions.

The composition of the produced gas is determined by the feedstock, oxygen supply, and process conditions such as pressure, temperature, residence time, and heat loss or heat input.

Table 1. Gasification reactions.

Endothermic Carbon Reactions	
Devolatilization	$C + heat -- CH_4$ + condensible hydrocarbons + char
Steam-carbon	$C + H_2O + heat -- CO + H_2$
Reverse Boudouard	$C + CO_2 + heat -- 2CO$
Exothermic Reactions	
Oxidation	$C + O_2 -- CO_2 + heat$
Hydrogasification	$C + 2H_2 -- CH_4 + heat$
Water Gas Shift	$H_2O + CO -- CO_2 + H_2 + heat$
Methanation	$3H_2 + CO -- CH_4 + H_2O + heat$
	$4H_2 + CO_2 -- CH_4 + 2H_2O + heat$

A possible analysis of the gas obtained from a downdraft gasifier using air for gasification and wood as a feedstock would be as shown in Table 2.

Table 2. Gas analysis.
Boyette and McKusick, 1986.

Constituent	Mole Percentage
H_2	16.63
CO	17.99
CH_4 (Methane)	1.94
C_2H_4 (Ethylene)	0.35
CO_2	12.86
N_2	50.19
Bal.	0.04

Carbon dioxide and oxygen are present in the end gas product because the chemical reactions are not being completed and also because nitrogen is introduced through the use of air as an oxygen supply. Steam may be a component of the gas depending on the moisture content of the feedstock. Although this example of producer gas composition is for a specific method of gasification and feedstock, the volume of each component is usually similar in proportion. The energy balance for this same gasifier is shown in Figure 1.

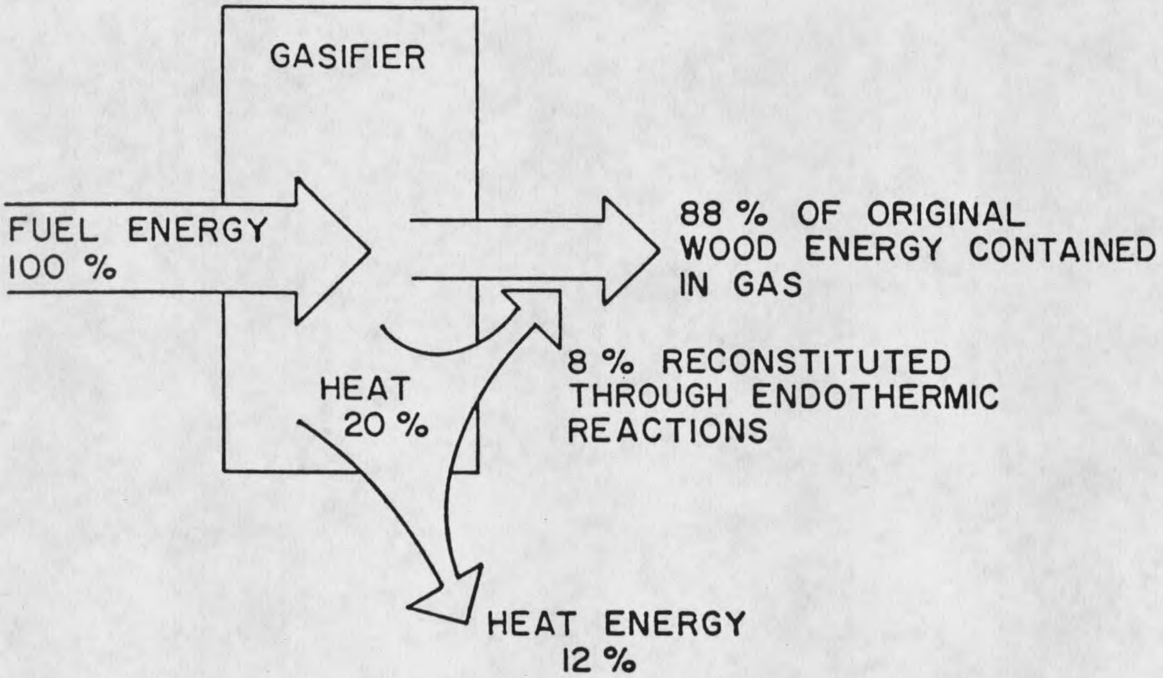


Figure 1. Gasification energy balance.
Boyette and McKusick, 1986.

One basic distinction that can be found between different methods of gasification is the source of oxygen.

Using air as a source of oxygen in the gasification process is the simplest method but produces a low energy gas (3.5-7 MJ/m^3) due to the presence of nitrogen in the air. Oxygen gasification on the other hand uses pure oxygen and produces a gas with a higher heating value (9-15 MJ/m^3). The use of pure oxygen produces a gas much higher in carbon monoxide and hydrogen and in addition to heating and power applications, it can be used in the synthesis of methanol, ammonia and other chemicals. Steam can also be used in combination with oxygen or by itself to produce a medium-heat-value gas.

Gasifier Designs

A wide variety of gasification methods are available, ranging in size and sophistication from simple units suitable for running small engines or boilers to large systems linked to plants for the manufacture of liquid fuels and chemicals.

The main component of a gasification system is the vertical closed tank or vessel referred to as the "gas generator", "gasifier", or "reactor". In this vessel, feedstock undergoes combustion and other chemical reactions involved in gasification. Openings are provided for feedstock loading, ash removal, ignition, introducing air for combustion, and gas discharge. Designs of different gas producers vary mainly by the method of introducing the combustion air and to the direction of the gas flow through the reactor relative to the direction of fuel flow. Five common categories which most gasifiers fall into are:

1. Fixed-bed updraft gasifiers;
2. Fixed-bed downdraft gasifiers;
3. Fixed-bed crossdraft gasifiers;
4. Moving-bed gasifiers; and
5. Fluidized-bed gasifiers.

Fixed-bed Updraft Gasifiers

In a updraft gasifier (Figure 2) feedstock is introduced at the top of the gasifier and moves down through the vessel under the force of gravity. Air inlets are placed near the bottom where the combustion takes place and the gas is produced. The gas leaves the gasifier by passing up through the bed and exiting near the top of the reactor. Because the gas flow is up through the pyrolysis zone, tars are gasified and drawn off in the gas stream. This is not a problem if the producer gas is going to be burned close to the producer, but if it is to be piped any distance the gas will cool and the tars will condense on the inside of the pipe. If an updraft gas producer is used to produce gas for an internal combustion engine, considerable care must be taken to clean the gas.

Updraft gasification is characterized by the enlarged hearth zone, which allows numerous ignition points for the gasification process. This type of gasification is therefore not sensitive to the choice of feedstock and is particularly suitable to feedstocks with a low reaction response. The large volume of the gasification zone offers a certain delay in response to the flunctuations in gas demand. It also requires a longer time for gasifier start-up and an initial higher fuel consumption.

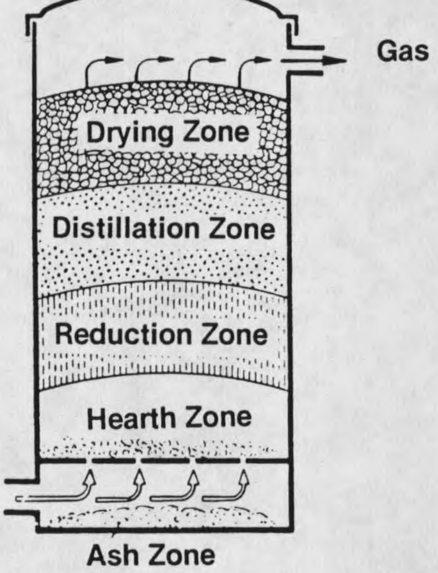


Figure 2. Fixed-bed updraft gasifier.
Skov and Papworth, 1980.

In the updraft gasifier air is introduced below or from inside the grate causing the grate to be cooled. The cool grate helps to deter slag formation. Heat from the grate also preheats the air thus improving gasification.

Updraft gasifiers have a limit on the maximum size of the reactor vessel which restricts the maximum output to about 50 GJ/h. Diameters much larger than 3 m may have difficulty in sustaining a uniform bed which is essential for quality gas production.

Fixed-bed Downdraft Gasifiers

In a downdraft gasifier design (Figure 3), the feedstock enters at the top, and air is introduced circumferentially through nozzles just above the reduction zone. The air draws all the gaseous feedstock components down into the hearth zone where they are exposed to high temperatures and to carbon where they undergo partial oxidization and partial dissociation. Therefore it is nearly impossible for steam, condensates, tars and other volatiles to enter directly into the gas as in the updraft system.

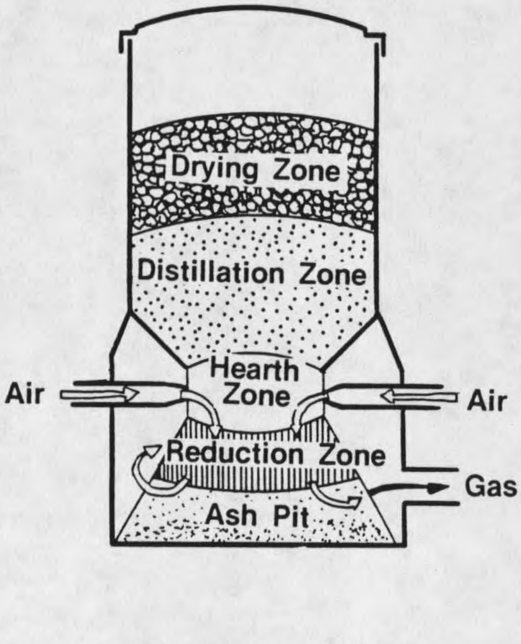


Figure 3. Fixed-bed downdraft gasifier.
Skov and Papworth, 1980.

Because downdraft gas producers have the potential to eliminate tars from the gas they are considered the best gas producers for making engine quality gas, even when high tar feedstocks are used. This makes downdraft gas producers attractive for gasification of biomass feedstocks that tend to produce gas high in tars.

Downdraft systems have developed a characteristic venturi constriction of the hearth near the entry of the air stream. This constriction causes an increase in air velocity causing an increase in temperature. This increase in temperature allows for a more complete conversion of tars into gaseous components. On the other hand the constriction causes the walls of the hearth zone to heat up and the narrowed cross-section increases the resistance to air passage (Skov and Papworth, 1980). This system is usually unsuitable for feedstocks with high ash content because the increased temperatures of the hearth zone will cause the ash to form slag and cause fouling.

Compared to the updraft method of gasification, the downdraft method uses a substantially smaller space for reactions and consequently is more able to swiftly accommodate flunctuations in gas demand. The start-up time is thereby minimized. But the smaller reaction space requires uniform feedstock feeding and if irregularities occur, such as bridging the already modest sized reactive surface will be further diminished. Although the downdraft design may have some advantages over the updraft design, it usually is more complex thus having a higher initial, operation, and maintenance costs.

Fixed-bed Crossdraft Gasifiers

In the crossdraft gasifier (Figure 4) the feedstock enters through the top and the air enters through a small diameter nozzle at the side of the vessel. In this system the goal is to achieve a hearth zone of small volume but very high temperature, causing the tar components of the feedstock to completely gasify and the entire ash content to convert to slag. Using the small air nozzle, air velocities of up to 80 m/s raise the temperature of the hearth zone core to about 2,000°C. The produced gases pass through a grate and out of the reactor.

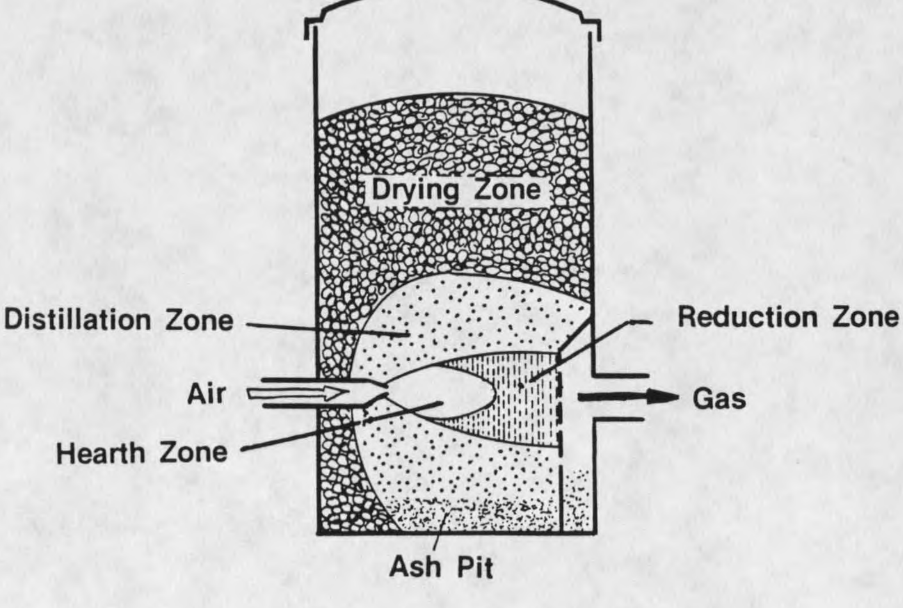


Figure 4. Fixed-bed crossdraft gasifier.
Skov and Papworth, 1980.

This gasifier's central hearth zone causes a different arrangement of zones. The distillation zone or the pyrolysis zone is a spherical shape, with the drying zone around the outside serving as a heat shield for the reactor walls.

The small hearth zone enables the crossdraft system to quickly adjust to any fluctuations in gas demand. The system is flexible and needs little start-up time. But the system, because of the small hearth zone requires smooth and uninterrupted feed of feedstock. Problems do arise with the formation of slag affecting gas quality and quantity.

Because tar dissociation is limited to the small hearth zone, the system is confined to feedstocks with low tar content. It is also desirable to use feedstocks with low ash content in order to keep the slag accumulation down. It is apparent that long-term, trouble free operation of the crossdraft gasifiers limits the compatible feedstocks types to a minimum.

Moving-bed Gasifiers

The moving-bed gasifier design (Figure 5) is similar to a furnace design used to burn coal. In this gasifier design the feedstock is fed through an airlock onto a moving grate. The combustion and gasification of the feedstock proceeds in proportions based on the process air flow. The produced gas is drawn off by an induced-draft fan.

The basic advantage of the moving-bed design is its ability to be scaled up to large sizes because output is not limited by the structural dynamics of the bed. The major drawbacks of the moving-bed gasifier is its added complexity, the horsepower associated with the moving grate and the limitation on feedstock caused by the grate design. Fine feedstocks such as sawdust, and stringy fuels such as straw are not suitable with the moving grate design. Because of this limitation on the fuel type, the design is severely restricted to one type of feedstock.

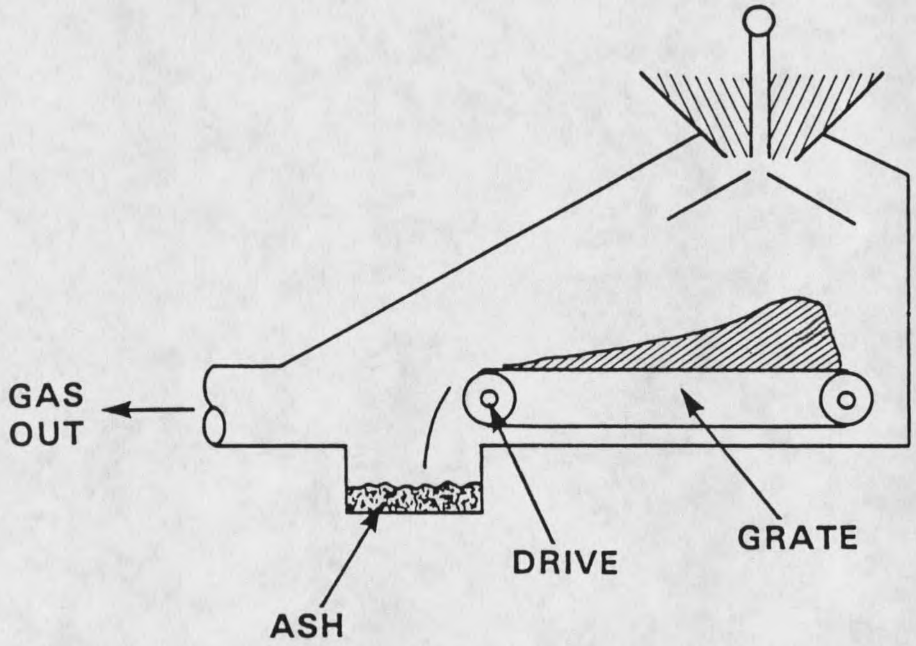


Figure 5. Moving-bed gasifier.
F. C. Hart Associates Inc., 1983.

Fluidized-bed Gasifiers

Of all the types of gasifier systems the fluidized-bed technology (Figure 6) is the most recent development. In a fluidized-bed gasifier the combustion and gasification of the feedstock takes place in a heated sand bed which is agitated by an upward stream of air. The feedstock can be injected into the gasifier using various methods, all of which influence its residence time in the bed. There are both top and bottom feed systems. Bottom feed systems in fluidized-beds are more analogous to downdraft systems, because of low tar production. Feeding the feedstock in at the bottom allows it to travel the full length of the bed thus increasing its residence time. Tars are therefore decomposed into other hydrocarbons to increase the carbon conversion efficiency and the heating value of the produced gas. The ash and unconverted carbon are removed from the gasifier by the gas stream or withdrawn at the bottom of the bed. If the ash is removed by the gas stream the filtering system must be improved for any end-use application.

A broad range of operating conditions can be obtained in a fluidized-bed unit. Some of the parameters that can easily be changed include air velocity, operating pressure, type of bed material, and size of bed material. By controlling the air velocity, turbulence in the bed is varied to provide an accurate control of reaction temperatures. This agitation of the bed improves the efficiency of the conversion reactions and allows feedstocks having wide variations in composition and particle size to be used. The upper bed temperature limit is controlled by the feedstock's slag temperature. The basic advantages of the fluidized-bed is its ability to accept many types of feedstocks, due to control of operating conditions and its ability to be scaled up to large sizes (eg. 200 GJ/h) without much modification.

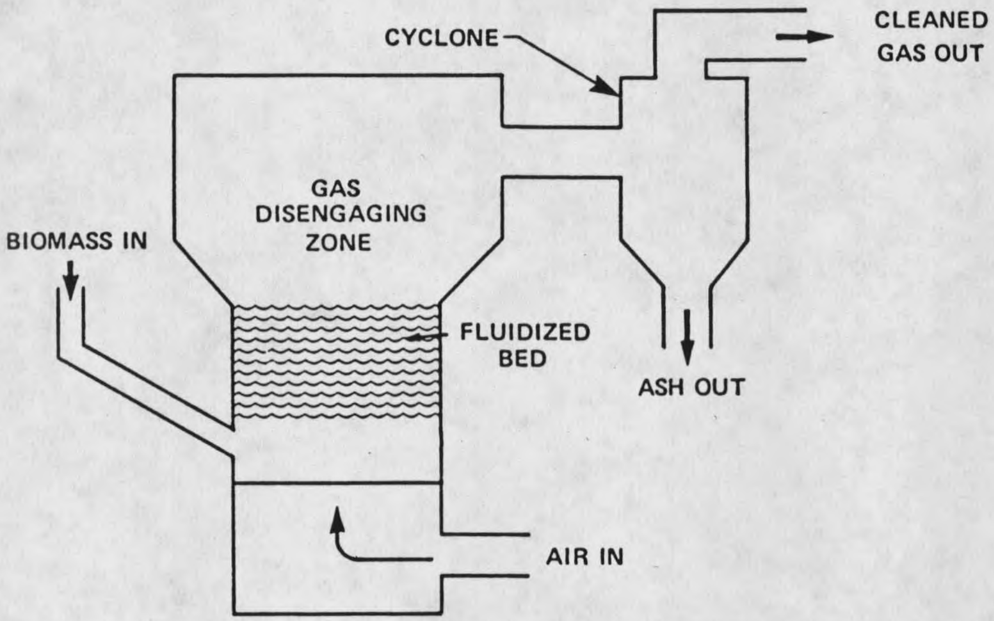


Figure 6. Fluidized-bed gasifier.
F. C. Hart Associates Inc., 1983.

Fluidized-beds have been used in a number of gasification studies involving biomass fuels. Some systems use a mixture of steam and air, or oxygen to fluidize the bed and give a gas with a higher heating value. Most systems just use air because it is the least expensive and the simplest to use.

Gas Cleaning and Cooling

The gas stream contains: gaseous components such as hydrogen, nitrogen, and water vapor; solid particles such as ash, soot, and char; and semi-solids such as tars and pyrolitic oils. The gas stream exits the gasifier at temperatures ranging from 400 to 600°C.

Often the gas produced by the gasifier has to undergo some degree of cleaning and cooling, depending on the end-use application. Direct combustion of the producer gas in a secondary chamber or boiler needs little or no cleaning, while fueling an internal combustion engine requires intense cleaning and cooling. Using the producer gas in a boiler requires that only solid particles need to be removed from the gas stream.

The use of producer gas in an engine requires the removal of all the solid and semi-solid constituents of the gas stream. Solid particles such as soot and ash are hard and abrasive and can cause excessive wear within an engine. The semi-solid components such as tars tend to condense out of the gas steam onto valve stems causing them to stick resulting in bent push rods and engine power loss. Cooling the produced gas is also important when using it in an engine. Cooled gas improves the volumetric efficiency of the engine. Generally a 10°C drop in gas temperature results in a 3% increase in power output (Boyette and McKusick, 1986).

Removal of the harmful materials in the gas stream at first glance seems to be a very simple process but it actually constitutes one of the most difficult tasks in gasification. The main reason for this is that the impurities in the gas stream are many and varied and change from one system and feedstock to another. Filtering systems should be designed to remove the larger particles first, then the smaller particles and lastly the tars and oils.

Most filtration devices can be classified as either in-line or off-line devices. Baghouse filters and packed beds are examples of in-line filters. These filters remove the impurities from the gas stream quite well but over time the contaminants build up on the face of the filter blocking gas flow. For this reason, in-line filters require constant maintenance and are usually unacceptable for use in automated gasification systems. The main advantage to in-line filters is that they are easy to construct and relatively inexpensive.

Off-line devices are filters that trap the impurities from the gas stream and carry them out of the gas flow. Filters such as cyclones, drop boxes and liquid scrubbers may be classified as off-line devices. The advantage to these devices is that they can not be easily plugged and therefore can be left unattended for extended periods. The down side is that these filters can be expensive and add greatly to the cost of the system.

In the design and implementation of a filtering system the pressure drop through the filtering system should be kept to a minimum. Limiting pressure drop can be overdone since the degree of gas cleanup is proportional to the pressure drop through the filtration system. If the resistance to gas flow is too great it may be impossible to start and operate the gasifier. The best approach is to filter the gas to the highest acceptable level without driving the pressure drop too high.

In summary the design of a filtration system is dependent on the gasification system, feedstock, end-use application, and cost. The optimum filtration system balances both cleaning ability and system cost.

Producer Gas Use

The gas produced from a gasification process may be used in a variety of ways to produce energy for an application (Figure 7). Basically the gas is used to provide heat energy and/or mechanical shaft power.

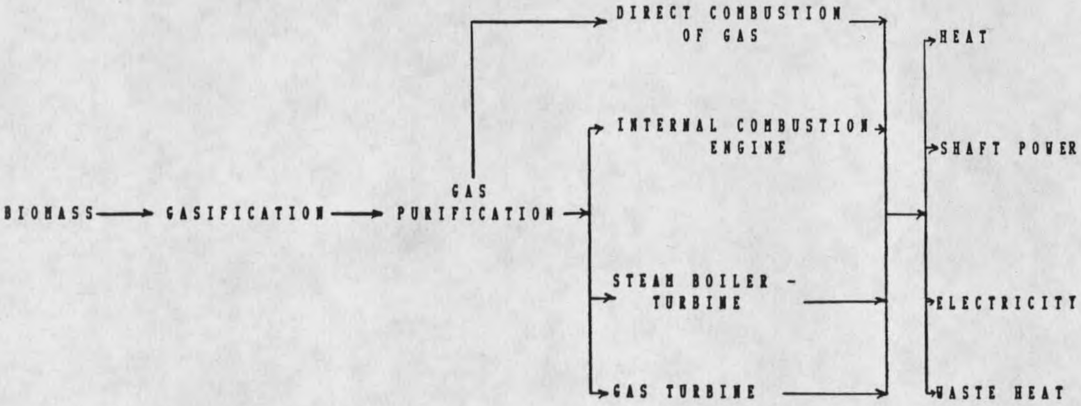


Figure 7. Alternate methods of producing energy from biomass gasification.
Adapted from LePori et al., 1983.

Direct Combustion of Producer Gas

The producer gas is often burned directly in a secondary chamber in order to obtain heat energy. This method provides a much cleaner combustion than does the direct combustion of the feedstock. Even if the gas contains tars, it is still a very clean burning fuel. This technique has been exploited by Payne et al. (1979) to provide heat directly through an air and exhaust-gas mixture for drying grain. Direct combustion of the producer gas has also been used through heat exchangers to heat greenhouses (Shaw et al. 1982).

Boilers

The gasifier can be directly coupled to a boiler to produce steam for use in manufacturing processes, heating, and to turn a steam turbine. The boiler must be close enough to the gasifier so that the tars do not condense out of the gas. The gas must be burned in properly designed burner nozzles because of the ash and tar content.

Internal Combustion Engines

The gas can be used in both spark ignition and diesel engines to produce mechanical shaft power without major modifications. To avoid engine wear and damage. tars, ash and soot must be removed from the gas. The extent of the filtering system depends on the type of gasifier used and the type of feedstock gasified. A gas cooler is usually used to cool the gas inorder to increase the volumetric effiency of the engine. Many gasification/engine systems are being tested because internal combustion engines at the present time offer a potentially economical and available power source suitable for on-farm applications. These include stationary applications such as irrigation pumping and electricity generation or for mobile applications such as tractors and trucks. Stationary gas producers have the advantage that bulky, wet cleaners are not the drawback that they are with portable producers.

Gas Turbines

A gas turbine or combustion turbine consists of a compressor, combustor, and a turbine connected by a common shaft. Air is compressed, heated to high temperatures in the combustor, and then expanded in the turbine. The energy extracted from the gases by the turbine is used to drive the compressor and produce shaft power.

Gas turbines can use low Btu producer gas at the temperatures and pressures that exist when the gas flow exits the gasifier. This ability allows the turbine to obtain high conversion efficiencies. A gas turbine must be carefully selected to obtain optimum performance.

Steam Turbines

There are various steam turbine systems and configurations available to connect to a boiler-gasifier arrangement. The steam turbines require high pressure steam from the boiler to be expanded in the turbine. Steam turbine systems are relatively more complex than other producer gas applications. The fact that the technology is not known by the farmer makes the system impractical for most farm use.

Cogeneration

Combinations of the above methods for converting the producer gas into usable energy are often used. These combinations are termed cogeneration systems. Cogeneration is defined as the sequential production of two or more forms of output energy from the same input (Synergic Resources Corporation 1983). Typically, cogeneration systems produce electricity and thermal energy. The thermal energy may be in the form of steam, hot water, or hot air. Mechanical cogeneration systems are similar to electrical ones except that a compressor, pump, or fan etc. is connected to a rotating shaft instead of an electrical generator. Cogeneration systems tend to have high energy conversion efficiencies because the waste heat lost in gasification, combustion, and filtering etc. is collected and used.

CHAPTER 3

BIOMASS SYSTEM REQUIREMENTS

Gasifier System Requirements

The successful development of a gasification system is a site-specific process involving the use of many components. An entire system can include feedstock collection, feedstock transportation, feedstock handling and preparation, gasification, gas clean-up and use. In order for a gasification system to replace or compete with a conventional system it must satisfy two major requirements; reliability and economics.

A gasification system that is to be successfully operated on the farm must be reliable. During planting or harvest a farmer cannot afford to be troubled with a complicated and labor intensive gasification system. Secondly the system must be economically attractive and not require a large initial investment by the farmer and have a relatively short pay back period. The final system should increase the overall efficiency of the farmer's operation in terms of time and economics.

There is a lot of flexibility in the types of systems available because various parts can be interchanged, to achieve the designed goals for a specific application. Thus the key is to analyze the technical and economical aspects of each component before selecting and adding it to the system.

A gasification system's design must satisfy the user's needs. The choice of a gasifier will depend on (F. C. Hart Associates Inc., 1983):

1. the total amount of energy required;
2. the energy use profile;
3. the energy's end-use; and
4. the type of feedstock available.

The total amount of energy required to meet the needs of an application should be determined, with some allowances made for end-use inefficiencies and future expansion. The design energy output from a gasifier is dependent on the feedstock throughput and the heating value of the produced gas. The ultimate selection of a gasifier may depend on engineering and bed dynamic problems. The following table can be used as an approximate example for scaling gasifier sizes using wood. Table 3 does not include information for crossdraft or moving-bed gasifiers because they are not a common gasifier for biomass feedstocks.

The fluidized-bed shows a very high throughput, because of the improved contact between the gas flow and the feedstock. In the updraft gasifier the gas flow rate is limited because ash and feedstock particles will blow out and channeling in the bed will occur. In the downdraft gasifier the gas flow moves in the same direction as gravity therefore higher flow rates can be achieved. But if the flow is too high the pressure drop becomes too great and will result in channeling, and unreacted gases and feedstock passing through the grate.

Table 3. Relative gasifier throughput.
R. Overend, 1979.

REACTOR	THROUGHPUT OF DRY WOOD (kg/m^2/h)
Updraft	100 - 200
Downdraft	290 - 490
Fluidized-bed	1500+

The energy use profile of a producer gas application should be considered when sizing a gasifier. The gas output from a gasifier is very slow to react to any throttling by limiting the feedstock input. By limiting the biomass input, the conversion efficiency and gas quality decrease. Therefore the end-use application's energy needs should be matched as close as possible to the rated output of the gasifier in order to obtain optimum performance.

The quality of producer gas needed for different end-use applications varies for each application. When producer gas is used to fuel internal combustion engines the gas must be very clean in order to avoid excessive engine wear. Ideally feedstocks low in tar and ash content should be used with a low tar producing gasifier (downdraft or fluidized-bed). The more tar and ash in the gas stream the greater the need for an efficient filtering system. If the produced gas is to be used in a boiler or for direct combustion the quality of the gas becomes less important.

System Modifications

All the different types of gasifiers have available various modifications that can be used to solve problems arising from use of a specific fuel or to adapt the produced gas to a certain application. These problems can include difficulties with feeding systems, slag formation, and the cleaning and cooling for fueling internal combustion engines.

Gasifiers can be operated in a batch or a continuous mode of operation. No continuous feeding system is used with batch operated gasifiers. When the gasifier needs to be replenished the gasifier is opened and biomass is added. This interferes with the controlled oxygen environment and disturbs the gasification process which effects the quality of the produced gas momentarily. Batch gasification thus requires an operator to monitor and add the feedstock, adding to the cost of operation.

Many systems operate on a continuous basis for convenience, cost savings and the need for an uninterrupted supply of quality gas. The feedstock is fed into the gasifier, usually by an auger type feeder controlled by level sensors within the gasifier. Other feeders may be pneumatic, hydraulic ram or a vibratory conveyer. The feeder is fed through an airlock feeder from a feedstock hopper. The airlock feeder is used to lessen air entry into the gasifier and also acts as a measuring device. An auger feeder can act as an airlock for a moderately-pressurized gasifier using fine material (Richey et al. 1983). Care has to be taken with an airlock not to jam the doors when wood and other course feedstocks are used.

A continuous feed system limits the problem of incomplete conversion and smoke entering the gas stream when the gasifier is opened for batch feeding. When a feeding system is properly adjusted for the gasifier, little monitoring is needed.

Slag formation is a problem when biomass fuels are used, especially with wheat straw and other agricultural biomass. Several methods have been used to discourage slag formation within the gasifier. Slag tends to form on areas of high temperature, like the grate of an updraft gasifier. Richey et al. (1982) solved this problem by using a hollow grate to feed air into his channel gasifier. This technique cooled the grate and greatly decreased slag formation on the grate and the preheated air helped the gasification process. Controlling the temperature on areas receiving high levels of heat (air nozzles etc.) with water cooling is also helpful.

Problems are encountered with power loss and a need for machinery modifications when internal combustion engines are fueled with producer gas. When a spark ignition engine is converted to burn producer gas, the only major change is the replacement of the carburetor with a producer gas carburetor. The producer gas carburetor is used to mix the correct amount of air with the producer gas for proper combustion and consists of simple arrangements of butterfly valves. Because the energy content of the producer gas is lower than that of gasoline, the power produced by a spark ignition engine fueled with producer gas is 40 to 50% lower. A small increase in power can be gained by increasing the compression ratio and advancing the ignition timing by up to 20 degrees. Both of these adjustments are possible because the producer gas has a higher octane rating than gasoline. The power output of a diesel engine is also reduced when it is fueled with producer gas, and no simple adjustments can be made to overcome this problem.

To conserve diesel fuel and to improve the performance of an IC engine using producer gas, compression ignition engines can be converted to dual fuel operation. In this manner they will require about 15 to 20% of the normal amount of diesel fuel. This arrangement allows for the operation of IC engines without any major modifications. The producer gas is introduced with the combustion air into the intake manifold. The fuel injection pump introduces only a small amount of diesel fuel into the engine to ignite the producer gas in the combustion chamber.

Studies have been conducted by Parke et al. (1981) and Ogunlowo et al. (1981) in the use of turbocharging and supercharging to increase the power of producer gas burning engines. Their investigations show that the power output of an internal combustion engine can be improved through the use of a turbocharger or supercharger.

Pollution Control Regulations

The gasification process involves the controlled combustion of a biomass feedstock yielding methane, carbon monoxide, hydrogen, nitric oxides and particulates. Gasification has the potential to affect the environment through:

1. Water pollution;
2. Air pollution;
    - Sulfur Oxides
    - Nitrogen Oxides
    - Hydrocarbons
    - Particulates
    - Odor
    - Carbon Monoxide
3. Solid Waste Disposal; and
4. Hazardous Waste.

The Montana state government has implemented many regulations to minimize pollution. A permit from the Department of Health and Environmental Sciences (DHES), Air Quality Bureau is required for construction, installation and operation of a gasification facility. Biomass facilities must acquire an air quality permit for fuel burning equipment that has a heat input greater than 10.6 GJ/h (liquid or gaseous fuel) or 5.3 GJ/h (solid fuel). Other biomass facilities that can emit more than 22.7 t/yr of any pollutant not regulated by the government must apply for an Air Quality Permit.

Table 4. Montana emission standards.
Renewable Technologies, Inc.

Pollutant	Emission Rate (tonnes/year)
Carbon Monoxide	90.6
Nitrogen Oxides	36.3
Sulfur Dioxide	36.3
Hydrogen Sulfide	9.1
Sulfuric Acid Mist	6.4
Reduced Sulfur Compounds	9.1
Total Reduced Sulfur	9.1
Particulate Matter	22.7
Ozone	36.3 (of volatile organic matter)
Trace Metals	
Lead	0.54
Beryllium	0.0004
Mercury	0.09
Asbestos	0.007
Vinyl Chloride	0.91
Fluorides	2.7

Table 4 shows air pollutants that are regulated by the Montana state government when their minimum emission rates are exceeded.

The city or county where a biomass gasification facility is located may administer more stringent air pollution standards than those set forth by the DHES. The maximum allowable emission rate (lbs/MBtu) of particulate matter for new biomass facilities is shown in Figure 8.

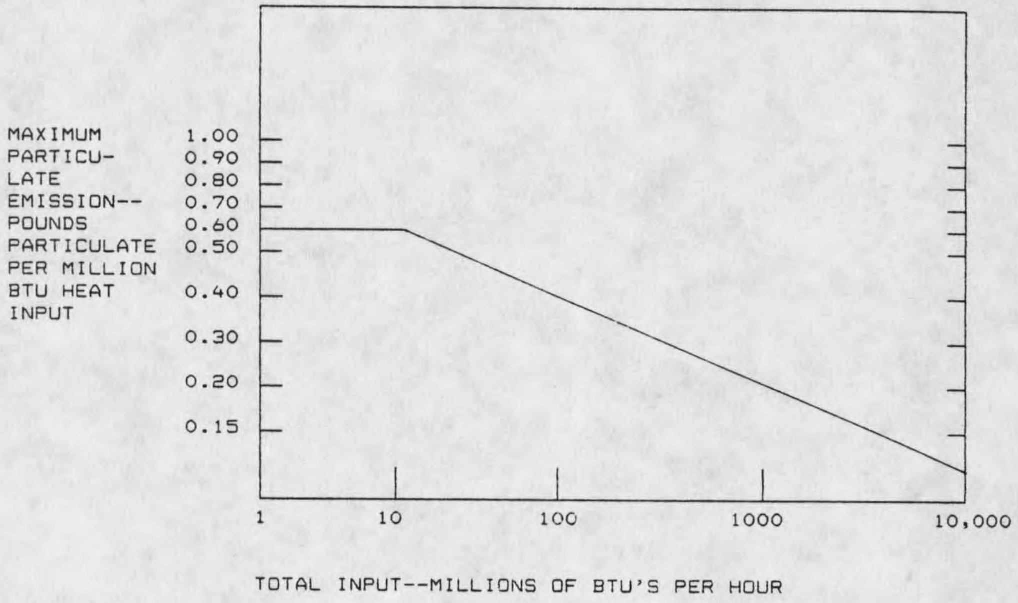


Figure 8. Maximum emission of particulates.
Renewable Technologies, Inc.

All biomass energy projects that discharge liquid or solid pollutants into surface or ground waters must obtain a permit to do so from the DHES. There are no exceptions for quality and quantity of the discharge. Biomass facilities are subject to the state's effluent standards to ensure water quality.

The subject of waste management covers both solid waste (non-hazardous) and hazardous waste disposal. Solid wastes include garbage, hazardous wastes, ashes and industrial by-product. Generators of solid waste must dispose of that waste at a licensed disposal facility or if the generating facility owns or leases 2 ha or more of land a private site can be set up. Hazardous waste is a waste that can contribute to mortality or serious illness. A waste is classified as hazardous if it is listed by the Environmental Protection Agencies as such. The storage and transportation of hazardous wastes is strictly monitored by the DHES. Violators of hazardous waste laws may be subject to civil and criminal penalties.

Under normal conditions, biomass facilities should not generate any hazardous wastes. However products such as solvents used in operation and maintenance can be classified as hazardous. For more information on pollution standards and obtaining permits refer to "Montana's Bioenergy Project Permitting Guide" obtainable from the Montana Department of Natural Resources and Conservation.

Federal Small Power Producers Regulations

On November 9, 1978, the Carter Administration signed into law the National Energy Act. The National Energy Act included three major parts, the Public Utility Regulatory

Policies Act, the Fuel Use Act and the Natural Gas Policy Act. These parts cover restrictions on fuel use, tax incentives for project development and incentives for small power producers and cogenerators.

The Public Utility Regulatory Policies Act of 1978 (PURPA) basically allowed the Federal Energy Regulatory Commission (FERC) to remove both regulatory and economic obstacles for small power production and cogeneration facilities using renewable fuels. The FERC was authorized to require electric utilities to pay reasonable rates to cogeneration and small power facilities for generated power. The buy-back rates paid by the utilities are based on the avoided costs and not the cost of service. The avoided costs are defined as all the expenditures that the utility would save by not generating or purchasing the equivalent amount of power. The avoidance cost is set by each state's regulatory commission and the buy-back rate must not exceed this set cost. Power utilities that existed before the enactment of PURPA can pay a lower rate, as long as the rate encourages cogeneration. The PURPA also required electric utilities to provide non-discriminatory electric service to small power and cogeneration facilities. Finally, PURPA exempted all cogeneration and certain small power producing facilities from state regulations regarding utility rates and most federal regulations under the Federal Power Act and the Public Utility Holding Act.

The PURPA defines a cogeneration facility as a facility that produces electrical energy and other forms of useful energy. Small power production facilities are defined as facilities having a capacity of 80 MW or less and fueled by biomass, wastes or other renewable sources to produce electricity.

The following is a summary of PURPA regulations (Synergic Resources Corporation):

1. New qualifying facilities are to be paid full avoided cost for buy-back rates.
2. The state regulatory commission and non-regulated utilities are to establish the rates.
3. The simultaneous purchase and sale of power between the utility and facility is allowed.
4. Stand-by power must be provided at non-discriminatory rates.
5. All qualifying facilities are exempt from federal and state regulations concerning rates and financial organization.

CHAPTER 4

POTENTIAL FOR GASIFICATION IN MONTANA

Montana's Agricultural Energy Consumption

In 1985, there were 23,600 farms and ranches in Montana covering approximately 25,000,000 ha. Cattle were raised on 21,000,000 of these hectares with the balance being used to grow crops. A breakdown of Montana's agricultural receipts is shown in Figure 9.

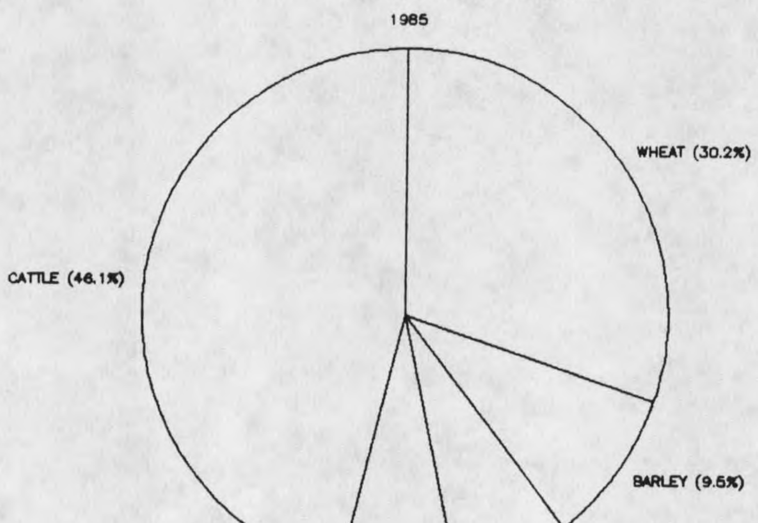


Figure 9. Montana's agricultural income, 1985.
Montana Agricultural Statistics Service.

The cost to produce these crops and livestock vary significantly from farm to farm, but in general the cost is high. A major contributing factor to the high cost of production is energy costs. During 1982 Montana farmers and ranchers spent $157,696,000 on energy. The energy was used to operate vehicles, equipment, homes, buildings and irrigation systems. A general breakdown on how conventional fuels were used on the farm in 1982, is shown in Figure 10.

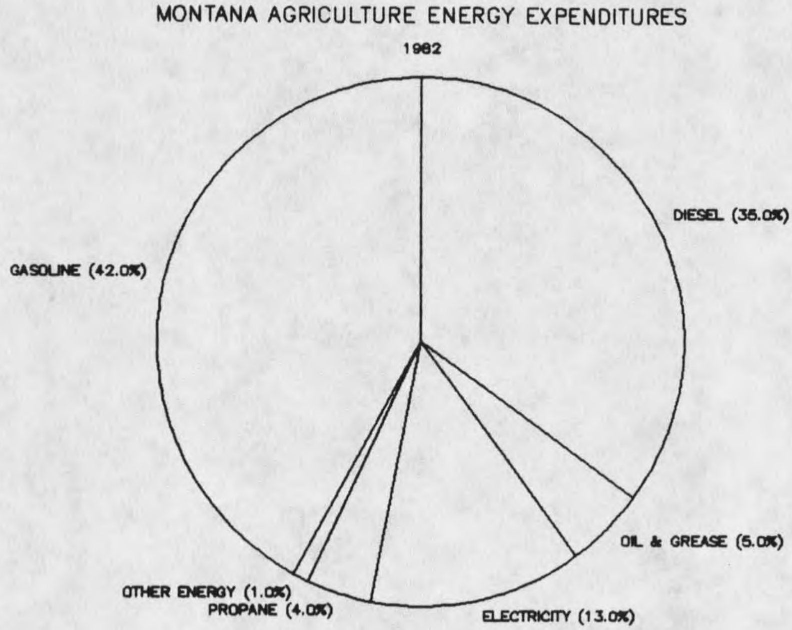


Figure 10. Montana's 1982 agricultural energy expenditures. Source: Saving Energy on Montana Farms and Ranches, 1987.

Agriculture in Montana uses a large amount of energy for farming operations. Figure 10 shows that the majority of energy expenditures involve gasoline and diesel fuel for vehicle operation. The remaining energy expenditures, except for motor oil and grease, could potentially be replaced by gasification of agricultural and wood residues.

Possible End-Use Applications In Montana

The gas produced from a gasification process may be used to provide heat energy and/or mechanical shaft power. In agriculture, gasification systems would be ideal for both the small grain and livestock sectors. The possible end-use applications in the agriculture industry are:

1. irrigation pumping;
2. grain drying;
3. heating of livestock buildings;
4. electrical power generation; and
5. cogeneration.

Crop drying is a very energy intensive agricultural operation. Large amounts of propane (LPG) are used annually in the United States for this purpose. A gasifier could be used to provide all the heat requirements of a grain drying system. Approximately 4.65 MJ of heat are required to remove 1 kg of water from the grain. Drying 33 t (1200 bu) of grain in a 10 hour day with an initial moisture content of 18% (w.b.) to 13% requires approximately 1 GJ/h of heat. The produced gas can be burned and fed directly into the drying system with minimal contamination of the grain. This type of end-use application may only need a filtering system capable of filtering out particulates. The tars contained in the gas stream are burned along with the producer gas producing few emissions.

Using internal combustion engines for generating mechanical power for irrigation pumping or electrical generation is a possible on-farm end-use application.

There are basically two types of electrical generators that can be used on the farm; induction and synchronous. Induction generators are basically electric motors that are driven faster than their rated speed or synchronous speed. When the generator is driven above the synchronous speed, it draws excitation current from the utility main, and the power generated is then fed back to the grid. The power frequency generated is not dependent on the generator's rotor speed but on the incoming frequency of the grid. This allows the induction generator output to always be synchronized with the utility's grid power. Although switching gear is required to interface the generator to the power grid, the apparatus is not as complicated and expensive as that required for a synchronous generator. The draw-back to induction generators is that without this excitation current from the utility the generating system can not serve as a back-up power supply in an emergency situation.

The synchronous generator is the type used in on-farm emergency generator sets. A synchronous generator does not require an excitation current to operate. The disadvantage to synchronous generators is that the frequency of the output is directly dependent on the rotational speed of the generator. Maintaining the RPM of the generator exactly at the required speed is nearly impossible when using a producer gas fueled engine because of the fluctuations in the gasifier's output and the governor characteristics of an internal combustion engine. If the generated electricity is to be used for resistive loads the output frequency tolerance is large. On the other hand if the electricity is to power induction motors the frequency tolerance narrows considerably. When a synchronous generator produces power for sale to the utilities extreme care must be taken to match the power frequencies. To do this expensive, complicated equipment is needed to synchronize the frequencies and to monitor the generator output in order to disconnect it if needed.

For on-farm power generation, induction generators are better suited for the sale of electricity than synchronous generators, but are not adequate for emergency or remote power production.

On-farm gasification/cogeneration systems would probably produce electrical and heat energy. The electrical power may be produced by engine/generator sets using induction or synchronous technology. The choice of generation is dependent not only on the site but also the needs of the user. The thermal energy may be in the form of steam, hot water, or hot air. The heat will be produced by heat exchangers collecting waste heat from the system increasing the conversion efficiency of the system to 50 or 60%. The size of the gasification system may be dictated by the amount of heat or by the electrical energy needed.

CHAPTER 5

BIOMASS FEEDSTOCKS

Gasification systems suitable for applications in Montana are in part limited by the biomass feedstock available in the facilities immediate area. Biomass materials can be classified into five major categories (Ebeling and Jenkins, 1983):

1. field crops;
2. orchard prunings (fruit and nut crop prunings);
3. forest residues (logging slash and mill residues);
4. food and fiber processing residues; and
5. livestock residues (confinement animal manures).

In Montana field crops and forest residues provide the bulk of biomass available for gasification, although livestock residues may be feasible in certain areas.

Small Grain Inventory

Of the solar energy incident upon the earth's atmosphere about 0.02% is transformed through photosynthesis into carbohydrates. On a global basis this amounts to an annual production of 100 Gt of plant biomass and approximately 5 times the current energy consumption of the world. Agriculture itself is a source of considerable quantities of biomass in the forms of field crop residues and crop processing wastes. In the United States the annual production of biomass from crop residues such as barley, corn, cotton, oats, rice, rye, sorghum, soybeans and wheat is estimated at 388 Mt.

In Montana, agriculture is the most important industry. Agriculture provides about one-third of the total receipts of Montana's primary industries. Of this one-third approximately 41% is contributed through the sales of small grains.

The types of small grains grown in Montana in any sizable amount include:

1. Wheat - Winter, Hard Spring, and Durum;
2. Barley; and
3. Oats.

Wheat is commonly grown in Montana, with both winter, spring, and durum varieties comprising the majority of the small grain acreage. Barley is the next small grain crop that is grown in any significant amount. The amount of barley produced in 1984 was estimated at approximately 1.3 Mt, while the total wheat production was about 3.0 Mt.

Oats was the third most commonly grown crop in Montana for the 1984 crop year, with approximately 60 kt produced. Farmers who grow oats generally do so for livestock feed. The oat straw is usually baled and also used for feed. Because of oat straw's value for feed and its lack of availability in large amounts (as compared to wheat and barley), use as a biomass feedstock for energy production is probably unlikely.

Small Grain Inventory - County by County

Each county in Montana has varying climatic, soil and terrain conditions that tend to determine the types and quantities of crops grown. Figures 11 through 15 show the distribution (bushels) and rankings by counties of the different crops for the 1984 crop year. From these figures it can be concluded that the counties in the Northcentral, Northeast, Central and Southeast districts produce the bulk of Montana's small grains. Actual data on acres seeded, acres harvested, yield per acre and the total production for each county for the 1984 crop year can be seen in Appendix A.

The amount of accessible biomass feedstock and its distribution determines in part the size of the gasification system. Estimates on crop residue yields are based on grain yield and are shown in Table 5.

The calculated amount of biomass available is said to be 95% of the plant or the above ground portion. Actual collection of all the above ground biomass may be infeasible because of equipment limitations or from the standpoint of erosion control, nutrient loss and moisture trapping.

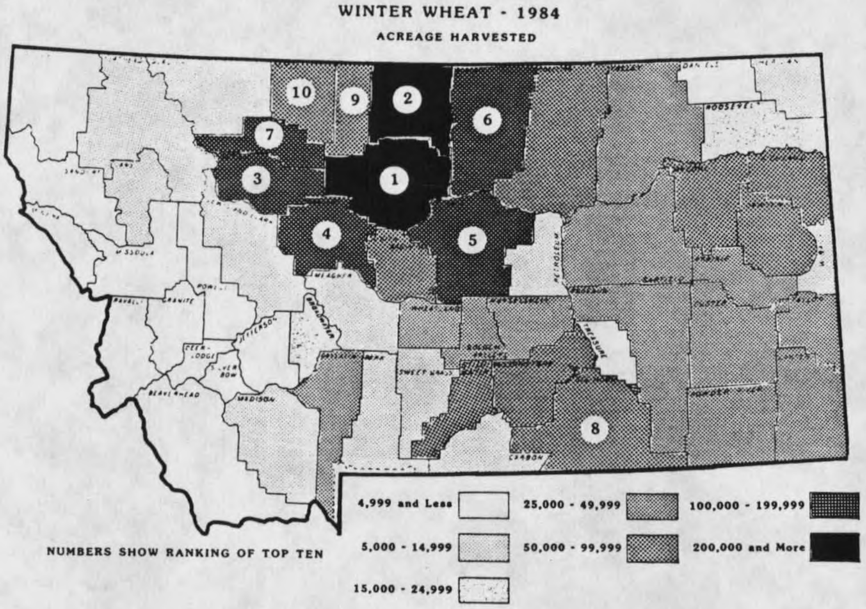


Figure 11. Winter wheat, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

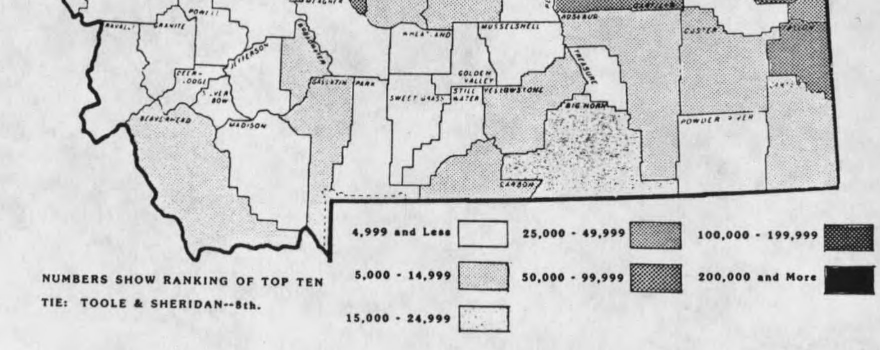


Figure 12. Spring wheat, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

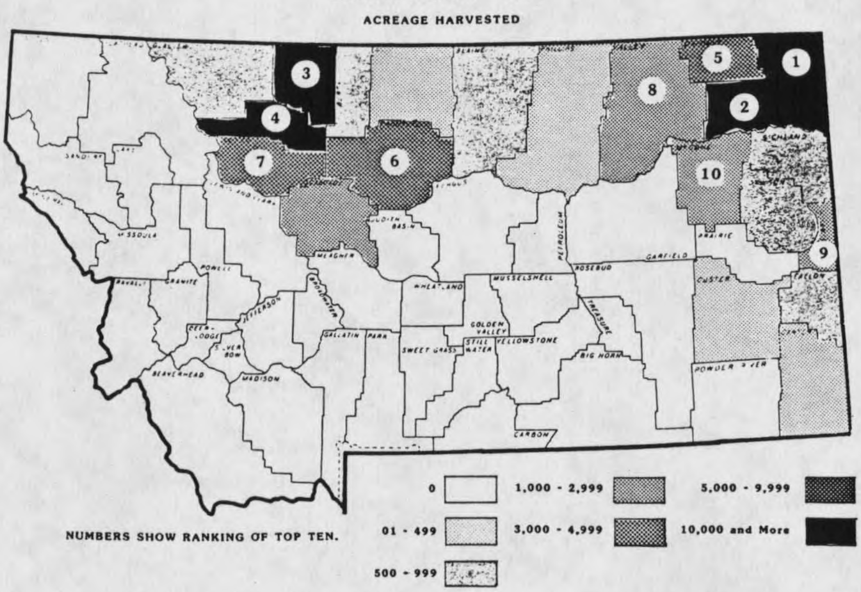


Figure 13. Durum wheat, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

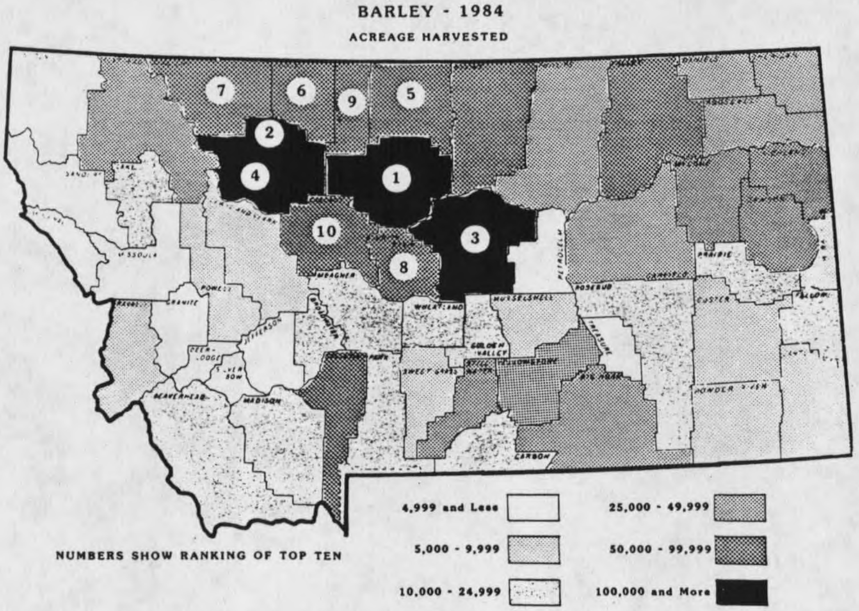
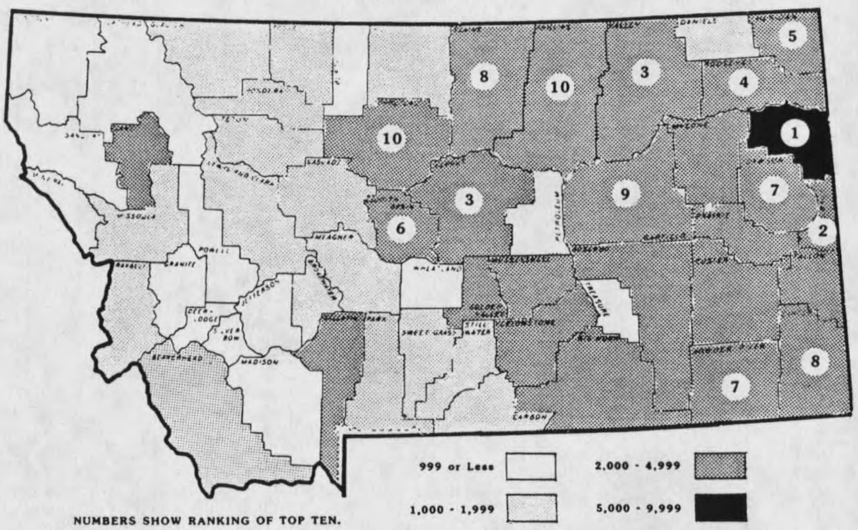


Figure 14. Barley, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

OATS - 1984

ACREAGE HARVESTED



NUMBERS SHOW RANKING OF TOP TEN.

TIE: VALLEY & FERGUS--3rd
DAWSON & POWDER RIVER--7th
BLAINE & CUSTER--8th
CHOUTEAU & PHILLIPS--10th

Figure 15. Oats, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

Table 5. Montana grain crop residues conversion.
Synergic Resources Corporation, 1983.

Crop	Unit Weight (tonnes/m^3)	Straw/Grain Weight Ratio	Tonnes of Straw/ m^3 of Grain	Availability
Winter Wheat	0.77	1.3	1.00	95%
Spring Wheat	0.77	1.3	1.00	95%
Barley	0.62	1.1	0.68	95%
Oats	0.44	1.6	0.57	95%

Koelsch et al. (1977) determined in field tests that the three machines commonly used to gather straw; small square baler, large round baler and the self-loading stack-forming wagon collected respectively just 15%, 25%, and 33% of the available straw after combining. The straw was left in windrows behind the combine with the straw spreaders and choppers disconnected. The U.S. Department of Agriculture estimates that roughly 35% of the crop residues can be removed safely under conventional tillage practices without any detrimental effects.

If we assume that 3.0 Mt of wheat and 1.3 Mt of barley (1984 crop year) were grown in Montana. The potential biomass harvest could be:

```
Wheat Straw = (3,000,000 t grain)
                * (1.3 t straw/t grain)
                * (25%/100 availability)
            = 975,000 t straw

Barley Straw = (1,300,000 t grain)
                 * (1.1 t straw/t grain)
                 * (25%/100 availability)
             = 357,500 t straw
```

For on-farm use of crop residue biomass, a site specific analyses of the feedstock source can be easily done. The maximum size of a farm scale gasifier is usually determined by the amount of biomass available. When the scale of the facility increases beyond the farm scale, determination of the size and availability of the biomass resource becomes more difficult. The quantity, quality and distribution of the feedstock become very important in the size and feasibility of the overall system. Generally using county-wide analysis of the biomass supply is not good enough for large scale facilities and a more intense survey is needed (Jenkins and Sumner, 1985).

Variation in production of small grain crops is mainly due to changes in grain prices and the variation in the weather. The previous years grain prices and future forecasts are usually the factors a farmer uses to decide on the type of crop and the quantity to plant. The weather then determines the final crop yield. The farmer is said to be at the mercy of the weather. Figures 16 and 17 show the variations in crop productions over the 1975-1984 crop years. The figures give an excellent indication of the variability of production caused by grain prices. Compared with the actual prices received by the farmer (Figure 18) the general decline in prices causes a decline in production.

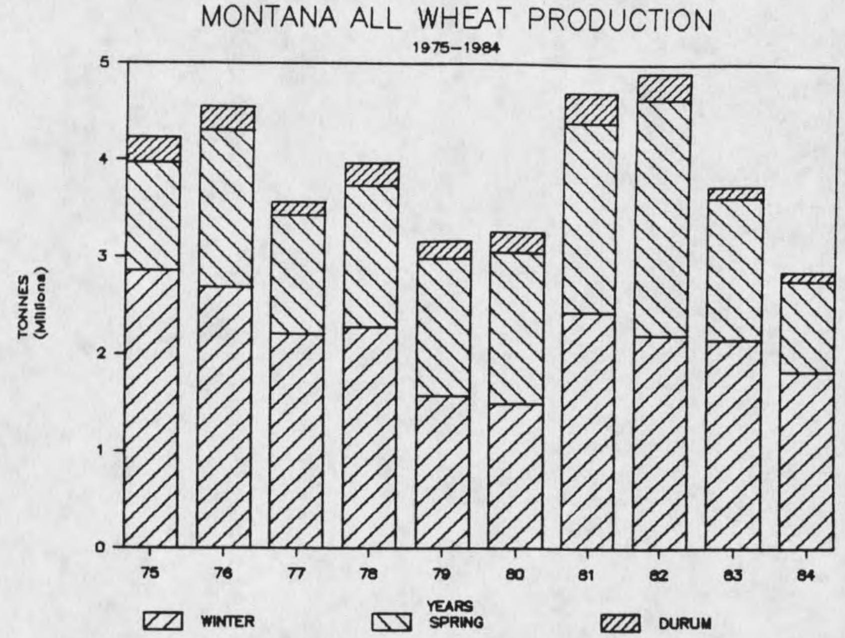


Figure 16. Montana all wheat production, 1975-1984.
Montana Agricultural Statistics Vol. XXII, 1985.

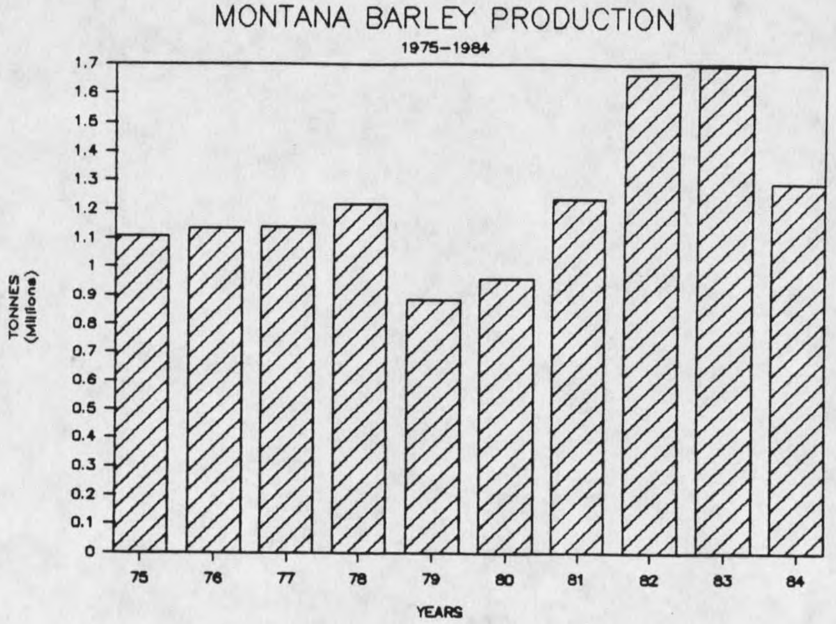


Figure 17. Montana barley production 1975-1984.
Montana Agricultural Statistics Vol. XXII, 1985.

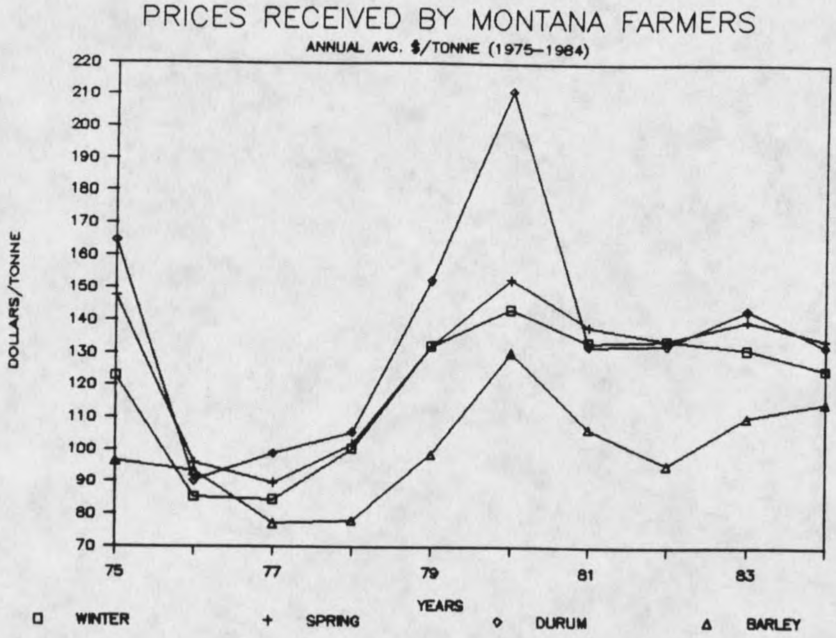


Figure 18. Prices received by Montana farmers. Data taken from Montana Agricultural Statistics Vol. XXII, 1985.

Animal Wastes Inventory

Livestock wastes, which in Montana are primarily cattle wastes, provide a potential source for energy through gasification. The value of animal wastes for use as biomass feedstock is due to their availability in substantial amounts in concentrated areas. The main requirement for using manure as a biomass source is that it must be free of contaminants such as dirt. The presence of dirt in the manure raises the ash content of the fuel. When gasified this ash can increase the chance that the gasifier will foul which will affect the quantity and quality of the producer gas. Even if the gasifier does not foul the increased ash level will be a greater burden on the filtering system, requiring increased maintenance or possibly redesign.

Another requirement to make manure available as a feedstock is that cattle need to be confined in areas such as feedlots and dairy barns. This is necessary in order to concentrate wastes and keep collection costs low. Dairy barns are an ideal location for collection of dirt free wastes. Dairy barns use various manure collection schemes such as drag chain gutter cleaners or slatted floors. The collected manure is usually stored in a pit or pile for disposal on fields or alternatively for use in a gasifier.

The main problem with the use of manure as a biomass feedstock is the fact that fresh manure contains approximately 88% moisture. The manure must be dried before it can be gasified. This process requires a large amount of heat energy which decreases the net energy production of the system.

In 1985, Montana had a total of 2,960,000 head of cattle and calves. Approximately 1,513,000 were beef cows and 27,000 dairy cows. Assuming that dairy farms provide an ideal situation for the collection of manure, the potential amount of dried biomass could be:

Manure = (27,000 cows) * (4.5 kg dry manure/day/cow) *
(365 day/yr) * (50%/100 availability) /
(1,000 kg/t)
= 22,174 t/yr

Note: This assumes that the average dairy cow weighs a 454 kg, produces 4.5 kg of dry matter per day (Table 6), and that only 50% of the manure can be collected.

Table 6. Cattle waste production per day.
Pennsylvania State University.

Animal	Kilograms of Waste[1] Wet	Dry
Dairy Cow	38.6	4.5
Beef Cow	27.2	3.2

[1] kg of waste / 454 kg of animal weight.

The variation in manure production is dependent on the cattle population. The cattle population, especially beef cattle, in turn depends on both market value and feed supply. Figure 19 shows directly the relation between the number of cattle and their market price. Dairy cattle numbers are also dependent on milk prices and production quotas.

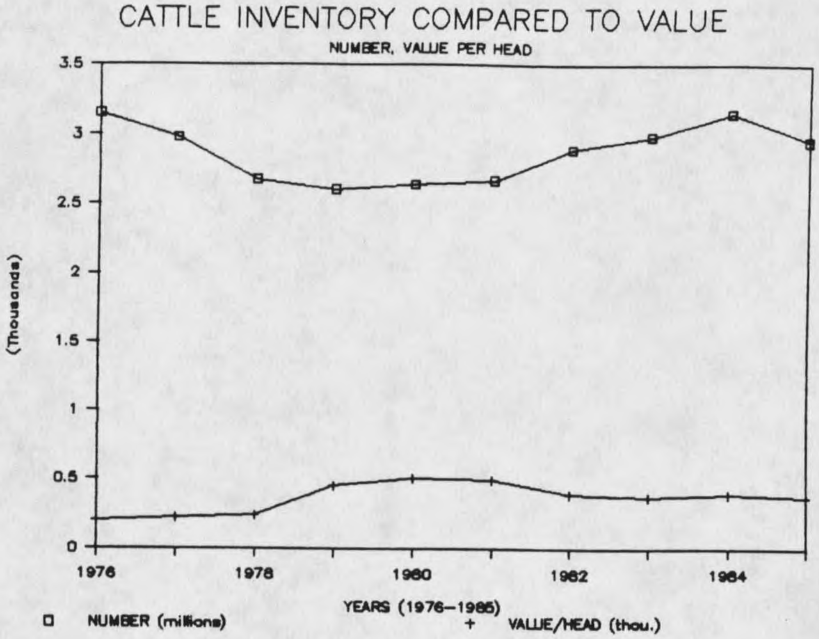


Figure 19. Cattle inventory in Montana compared with market value.
Data taken from Montana Agricultural Statistics Vol. XXII, 1985.

Wood and Wood Wastes Inventory

The forests of Montana cover approximately 22% of the state's land area, amounting to 8,200,000 ha. Of this 8.200,000 ha only 5,800,000 ha are considered to be productive timber land. Using the Continental Divide as a reference point, over one-half of the forest area lies to the west. West of the Divide, the land base is 80% forested, while the area east of the Divide comprises 83% of Montana's land base but is only 13% forested.

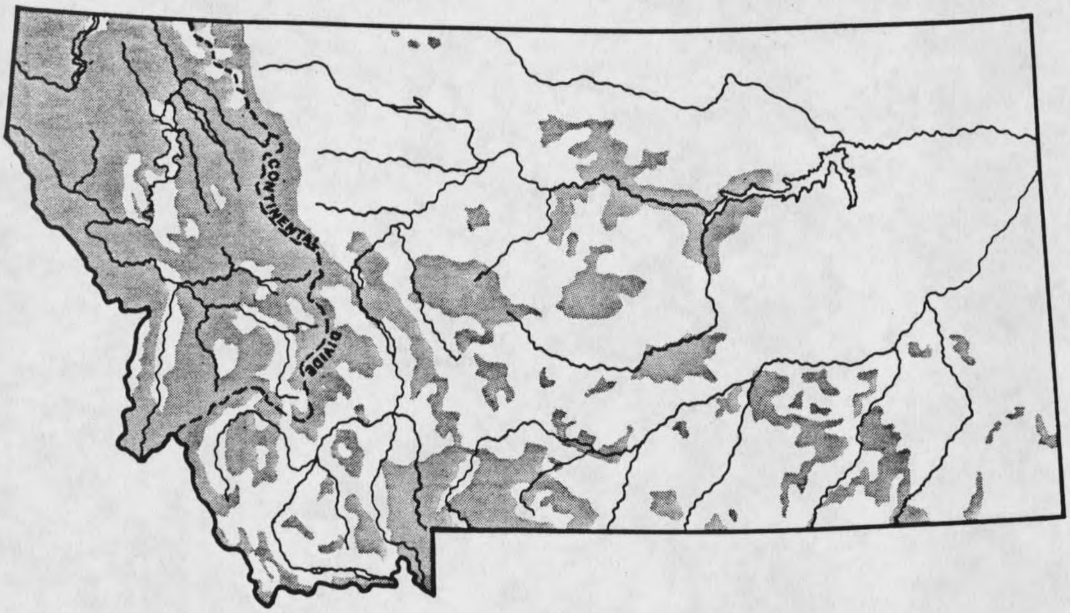


Figure 20. Forest distribution in Montana.
A. W. Green et al., 1985.

The western side of the Divide is heavily forested because the high mountain ranges trigger the release of moisture from the westerly air flows. The drier climate east of the Divide limits the forests to higher elevations. This causes the forests to be fairly patchy and widely scattered.

Montana forests contain 27 species of trees with 17 being conifers and 10 being hardwoods (see Appendix B). These species may grow intermixed or in pure stands. The type of species growing in an environment greatly depends on the sites elevation, yearly moisture, and soil characteristics. The major tree species grow over a range of environmental conditions, and some become the climax vegetation for a specific environment.

Montana is divided into five major climax forest zones as shown in Figure 20. The dominant species in each zone are shown and include; larch, lodgepole pine, ponderosa pine, douglas-fir, white pine, and spruce-fir. Figure 21 associates the general land type and elevation with the forest zone. About 64% of the forests in Montana have the dominant species in douglas-fir and lodgepole pine. Adding ponderosa pine and fir-spruce zones brings the total to 93% of the forest area.

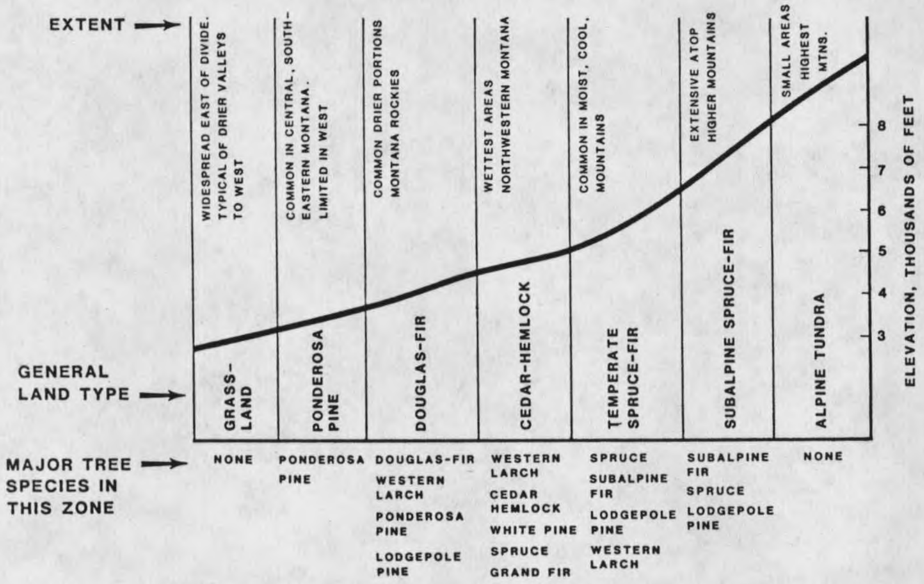


Figure 21. Forest zones of Montana.
A. W. Green et al., 1985.

Approximately 74% of Montana's forest land is publicly owned, with 68% federally regulated while the remaining is owned privately or by the forest industry (Table 7).

Table 7. Forest ownership in Montana.
Green et al., 1985.

Owner Group	Area (1000 hectares)	Percent of Total
Public		
Forest Service	5591.8	68
Other Public	426.3	6
Total	6018.1	74
Private	2167.3	26
Total	8185.4	100

The net volume of growing stock and sawtimber in Montana during 1980 is summarized in Table 8.

Table 8. Net volume of growing stock and sawtimber on commercial timberland in Montana, 1980.
A. W. Green et al., 1985.

Growing Stock (million cubic meters)

Owner Group	Softwood	Hardwood	Total
Public			
Forest Service	512.3	1.3	513.6
Other Public	34.6	1.3	35.9
Total	546.9	2.6	549.5
Private	182.3	9.3	191.6
Total	729.2	11.9	741.1

Forest residue is a possible source of biomass feedstock for gasification. These residues include logging residues, thinning residues, standing residues, and clearing residues. Logging residues are made up of the unused tops, limbs, poor quality logs and brush left over from the harvest operation. The amount of logging residue may range from 10 to 20% of the standing tree with hardwoods generally producing more residue than softwoods. Standing residues are trees that are unsuitable for timber or dead trees that are dried and cracked. The forest residue is generally left in the forest to decay and if collection costs are minimal, it may be a valuable feedstock.

An average of 2,714,000 m^3 of timber is harvested annually in Montana. The total volume of logging residues generated from harvesting the timber is estimated at 760,000 bone dry tonnes. Due to economics only an estimated 209,000 dry tonnes of logging residue is suitable for fuel usage annually in Montana (Combes, 1983).

The total residue available for biomass and other products from pole timber, cull trees, dead trees and down trees on commercial forest land of the National Forests is estimated at 292,000,000 m^3. At the present time, due to poor collection economics only about 45% of this residue is accessible, amounting to a total of 50,500,000 tonnes of dry wood (Combes, 1983).

Another important source of wood for gasification is wood wastes left over from both primary and secondary processing. Over one-half the volume in logs delivered to sawmills ends up as wood wastes. Mill wastes are in several forms; coarse, fines and bark. The course materials are in the form of slabs, edgings and trimmings, and peeler cores. While the fines are made up of sawdust and shavings.

Generally the waste wood creates a disposal problem at a mill. It is usually burned in tepee burners or just piled up. In some cases the wood wastes are utilized in the pulp and paper industry for feedstock or fuel. Most of the smaller mills have no market for the wastes and thus the wastes are a disposal problem.

The amount of forest residue available is fairly variable in Montana. It is directly connected to the amount of timber harvested, which in turn is dependent on lumber demand and the interest rate charged on home mortgages.

Properties of Biomass

Biomass includes a wide variety of organic material different in both chemical and physical properties. Defining these properties for each type of biomass is essential for the development and evaluation of a gasification system.

Wood gasification systems have been in use since World War II and as a result the technology is well known for wood. As compared to wood very little research on gasifying crop and livestock residues has been conducted. An assumption that is usually made is that the thermochemical reactions of crop residue is the same as wood or fossil fuels. This assumption is wrong because of the differences in chemical and physical composition. Crops and livestock residues are high in ash and silica which can cause problems in gasification. Residues such as straw often require the feeding system to be modified to allow for proper operation.

Chemical Properties

The chemical properties of a feedstock can be determined through proximate or ultimate analysis. Proximate analysis can identify the amount of moisture, fixed carbon, ash and other components in a fuel. Thus general gasification characteristics can be determined from this analysis. The ash content of the feedstock is important because it affects the reaction temperature and the level of particulate emissions from the gasification process. Thus the ash content of a feedstock determines the complexity of a gasification systems filtering system in relation to the end-use application. Handling of high ash feedstocks can also pose a problem due to high abrasion and erosion characteristics.

The ultimate analysis method is a more complex technique used to determine the percent by weight of the individual components of a feedstock. Through the ultimate analysis a better understanding of a feedstocks gasification process can be obtained. The extent of air emissions of nitrates, sulfates and heavy metals can also be estimated.

Probably the most important property of a feedstock is its heating value. Normally the higher heating value (HHV), is reported from tests using an adiabatic bomb calorimeter. The lower heating value (LHV) is then calculated by subtracting from the HHV the energy required to vaporize the water in the fuel and the water formed in the combustion process.

Ash composition and fusion temperatures are important considerations in thermochemical conversions of biomass feedstocks. Ash composition indicates the potential for the formation of slag deposits on combustor surfaces and possible disposal problems of the ash. Slag is formed when the temperature rises above the liquid point of the eutectic mixtures in the ash. Slagging and the formation of clinkers can greatly reduce the quantity and the quality of the produced gas effecting the gasifiers overall performance.

Approximations of chemical properties of wheat and barley straw, ponderosa pine and livestock manure are shown in Tables 9 through 11, along with traditional fuels for comparison.

Ebeling and Jenkins found that with the exception of ash content, the variations between fields of small grain residues is small. The volatile carbon matter (VCM) and the fixed carbon (FC) varied about 3% while the ash varied as much as 20%. The ash variability is due to dirt contamination caused by such factors as harvesting method, transportation of residues, weather conditions, soil conditions, and soil type.

Manure like straw also shows a wide variation in ash content between samples. Again this can be attributed to the amount of dirt contaminating the samples.

Table 9. Chemical analysis of biomass and traditional fuels. Jenkins and Ebeling, 1985 and Ebeling and Jenkins, 1983.

Chemical Analysis Fuels	HHV (MJ/kg d.b.)	LHV
Biomass		
Barley Straw	17.31	16.24
Wheat Straw	17.51	16.49
Ponderosa Pine	20.02	18.80
Livestock Manure	16.50	-----
Traditional Fuels		
Coal	29.56	-----
Fuel Oil	43.81	-----
Natural Gas	56.06	-----

Table 10. Proximate analysis of biomass and traditional fuels. Jenkins and Ebeling, 1985 and Ebeling and Jenkins, 1983.

Proximate Analysis Fuels	VCM[1]	ASH (% by weight d.b.)	FC[2]
Biomass			
Barley Straw	68.8	10.3	20.9
Wheat Straw	71.3	8.9	19.8
Ponderosa Pine	82.5	0.3	17.2
Livestock Manure	50.5	41.3	8.2
Traditional Fuels			
Coal	44.4	4.2	51.4
Fuel Oil	-----	1.8	----
Natural Gas	100.0	---	----

1. Volatile Carbon Matter
2. Fixed Carbon

Table 11. Ultimate analysis of biomass and traditional fuels.
Jenkins and Ebeling, 1985 and Ebeling and Jenkins, 1983.

Ultimate Analysis Fuels	C	H	N	S	Cl	ASH	O
				(% by weight d.b.)			
Biomass							
Barley Straw	39.92	5.27	1.25	----	----	9.75	43.81
Wheat Straw	43.20	5.00	0.61	0.11	0.28	11.40	39.40
Ponderosa Pine	49.30	6.00	0.06	0.01	0.01	0.30	44.36
Livestock Manure	37.40	5.60	2.80	0.05	----	26.30	27.40
Traditional Fuels							
Coal	71.50	5.30	1.20	0.90	----	4.60	16.90
Fuel Oil	84.67	12.40	----	1.16	----	1.81	-----
Natural Gas	72.00	23.00	----	----	----	----	5.00

Physical Properties

The physical properties of biomass are important factors that can affect its use as a feedstock. Three critical physical properties include:

1. particle size;
2. bulk density; and
3. moisture content.

The particle size directly affects the bulk density of the fuel and also the type of gasifier to be used. The bulk density of the feedstock is dependent not only on the material but also on the harvesting method, moisture content, handling method and on any densification process that may be used. Moisture content directly affects the available energy in the feedstock. The moisture acts as a heat sink in the fuel and therefore lowers the combustion efficiency. This results in a lower reactor temperature and thus there is an increase in tar content of the producer gas. High moisture feedstocks are difficult to store because of the dangers of spontaneous ignition and bacterial build-up.

The following list shows desirable properties for gasifying biomass feedstocks (Sofer and Zaborsky, 1981):

1. Average moisture content of less than 50%;
2. Average heating value (HHV) of not less than 9.8 MJ/kg;
3. Average feedstock size range > 1.27 and < 7.62 cm;
4. Ash fusion temperature of not less than 1149 °C;
5. Low ash content (6 - 10%);
6. Easy ignition characteristics; and
7. Uniform chemical composition.

Harvesting and Handling of Biomass Feedstock

The operations of harvesting and handling of biomass feedstocks may be influenced by the type of delivery system, the impact of biomass harvesting on the environment, and the integration of the system into farming practices. The delivery systems generally include collection, transportation, processing and storage of the feedstock. Many factors influence the design of a delivery system other than just the type of gasification system. These factors include (Jenkins and Sumner, 1985):

1. Physical and chemical properties of the biomass;
2. The season of the biomass production;
3. Harvest and terrain conditions;
4. The scale of the biomass conversion system;
5. The types and yields of biomass within the region;
6. The type of conversion technology;
7. Economic and financial constraints;
8. Political regulations and incentives; and
9. Environmental and social impacts.

These factors affect the design and operation of collection and processing equipment, transportation cost, and storage characteristics. Furthermore, the design of the conversion system will in turn be affected by the design of the delivery system (Jenkins, et al., 1983).

Biomass feedstocks generally require some method of collection at the region of production. Collection may be as simple as gathering the feedstock and packaging it for transport or it may entail some processing such as baling, cubing or chipping.

The term processing of biomass residues can include drying, grinding, densification, or screening. The reason for processing biomass feedstocks is to meet the fuel specifications of the gasifier by adjusting moisture content, bulk density and/or particle size distribution. Any combination may be required before collection, transportation, storage or gasification of the feedstock.

The extent of feedstock processing is dependent on the type of conversion and material handling system in order to optimize the performance and the economics.

Transportation of biomass can be very costly and it is dependent on both the distribution of the source, ease of access, and bulk density. In cases where the feedstock has a low bulk density, a densification process may decrease transportation costs. Often the cost of transportation is the limiting factor in the development of large scale gasification facilities (Jenkins and Sumner, 1985). For this reason a careful study on the distribution of the feedstock, the residues package type, and the mode of transportation should be completed for a proposed facility. On a farm scale, the cost of transportation is often less important because the supply is usually close at hand.

Storage is another important factor in the handling of biomass. Biomass feedstocks should be protected from the weather in order to maintain their quality. Weathering causes a general deterioration of the feedstock and as a result increases the ash content and decreases the energy content. Generally biomass feedstocks are seasonal in nature and require storage for a facility that operates through out the year, either continuously or periodically. For both large and small scale conversion systems the amount of required storage can be quite large. Therefore a further densification may be economically justified.

Crop Residues

All of Montana's small grain crops are harvested by one of two methods:

1. Swathing and then combining; and
2. Direct combining.

Costs for both methods of harvesting are tied to primary production costs and not residue collection. The method of swathing and combining, without spreading the straw, leaves the straw residue in an ideal position for collection. The harvesting operation of direct combining processes a smaller portion of the crop. Most of the straw is left standing and it often would require swathing before it could be collected. This additional operation adds to collection costs and may cause the system to become infeasible.

The use of crop residues as a source of biomass lends itself ideally to the use of existing forage harvesting equipment for collection. Several methods of collection could be utilized and these include:

1. Baling (small or large square and round bales);
2. Cubing; and
3. Stacks.

Baling of the crop residues can give several package forms. The large square bales and round bales have a higher bulk density than small square bales. Also the large bales require less labor and energy input to collect and handle in the field and gasification site.

Cubing of the straw gives it the highest bulk density of all the three possible operations. This could be very important in lowering costs if the transportation distance is quite long. Cubing also produces uniformly sized feedstock that can ease handling and reduce bridging during gasification. The problem with cubing is that it is a very energy and labor intensive job and the resulting cubes are of low quality.

The last type of collection indicated is stacks of straw. This method has the lowest bulk density of the three and therefore is the most costly to transport. These stacks can be hard to handle and haul long distances.

In Montana a swathing-combining-large bale system would probably be the best choice for the collection of crop residues from a economic and practical standpoint. For on-farm conversion systems the farmer would probably use his own forage harvesting equipment configuration rather than use addition capital to obtain the optimum collection system.

Storage of crop residues can be a problem for a gasification facility. Crop residues are seasonal in nature and require storage for a facility that operates through out the year, either continuously or periodically. For both large and small scale conversion systems the use of land for storage may be a problem. Jenkins and Knutson (1984) estimated that about 16 ha of land would be required to store a years supply of big round straw bales to power a 25 MW facility. One solution to on-site storage is field storage but this could be a problem for continuous cropping and irrigation practices. A further densification process may be profitable if the cost of the process is less than the cost of saved storage.

Weathering of the crop residues results in loss of fuel value. Dobie and Haq (1980) evaluated the storage of uncovered big round bales of rice straw of varying moisture contents. Their findings showed that the heating value declined and the ash content increased with the higher initial moisture content. As a result, covered storage could be used to stop weathering but again the costs increase. Sumner, et al. (1984) performed storage experiments with wheat straw and other types of biomass. They found that spraying wheat straw bales with asphalt, tar and motor oil did not reduce water absorption compared to the bales with no covers. The bales with the polyethylene covers prevented most of the water build up from rainfall. Placing the bales on coarse drained soil reduced moisture transfer from the ground.

Animal Wastes

Animal wastes provide a potential source as a gasification feedstock in areas where they are available in large amounts. As mentioned earlier feedlots and dairy farms would probably be the best locations for collecting manure because of the confined areas. This is necessary in order to concentrate wastes and keep collection costs down. Dairy barns are an ideal location for collection of dirt free wastes for they use paved floors and various manure collection schemes such as drag chain gutter cleaners or slatted floors. The collected manure can then be stored in a pit or pile for use in a gasifier.

The main problem with the use of manure as a biomass feedstock is the fact that fresh manure contains approximately 88% moisture. The manure must be dried before it can be gasified. The manure may be sun dried but problems in weather variation may interrupt the gasification schedule. Usually the manure is dried using exhaust heat from the gasifier. This process requires a large amount of heat energy which decreases the net energy production of the system. Dried manure can contain different sized particles ranging in sizes from fines to sizable clods. Manures are gasified in fluidized bed gasifiers because of their high ash content and the clod sized feedstock may have to be broken up if it is not accomplished by the handling system.

Wood and Wood Wastes

Wood in the form of chips or sawdust is an excellent biomass feedstock. A farmer contemplating using wood for on farm gasification must decide whether to produce his own feedstock or obtain it from a mill. There are advantages and disadvantages to each source, therefore a combination may be more suitable. Harvesting, wood for gasification is a possibility for a site that is located near large timber stands. For small conversion systems a portable wood chipper can be used to process the wood at the harvesting location. Larger systems may use tub grinders to chip large amounts of wood at the gasification site (Arthur et al., 1982).

Approximately 1.7 kg of green wood are required to produce one kWh of electricity. Therefore, even small scale conversion systems require large amounts of wood. With all the handling of the feedstock, an on-farm handling system should be designed to be reliable, minimize labor requirements and make use of existing equipment. Handling equipment can include chain and belt conveyers, well built augers, and tractor mounted front-end loaders.

Often wood obtained from harvest or sawmills contains a moisture content of 50% by weight. The water is held by the wood in two ways. In green wood, water is held by capillary action between cell walls giving green wood its characteristically wet feel. The second method for holding water in wood, is by weak molecular bonds. This water exists in the cell walls and cannot be seen or felt. Water is held by both methods in wood with a moisture content above 30% (d.b.) while below 30% the water is held by the molecular bonds.

Wood to be used as a feedstock for gasification must have a moisture content below 20% in order to maintain the quality of the produced gas. Drying wood with unheated air can lower the moisture content to 14%, but this is dependent on the species of wood, the air temperature and the humidity. The use of heated air can lower the moisture content of the wood even further to approximately 0%. Supplement heat may have to be added to the drying air during cold days with high humidity. In an actual on-farm situation the feedstock handling system would need a building for both storage and drying of large quantities of wood. A team of researchers at North Carolina State University suggest that a grain bin equipped with fans and a drying floor would make an ideal storage and drying facility.

A dry, well ventilated storage area is not only a necessity from a gasification stand point but also for health reasons. Wood chips allowed to sit in a damp storage area for an extended period of time can become diseased with fungi and bacteria. Eventually the fungi will develop spores that can cause allergic reactions in humans.

Environmental Problems of Residue Collection

Crop and forest residues when left on the surface or incorporated into the soil assist in the prevention of soil erosion by rain and wind, retain moisture by trapping snow and allow for penetration of rainfall, and for enriching the soil with organic matter. Rainfall and wind erosion can be a serious problem in Montana. Sudden thunderstorms and gusting winds can remove large amounts of top soil from barren ground. The effects of soil loss can have detrimental effects on crop yields and tree growth for many years. Residues helps to trap snow in the winter and improve soil moisture for spring growth. Crop residues incorporated into the soil help to prevent the soil from compacting allowing for better moisture penetration. Biomass residue helps to replace nutrients and organic matter in the soil. The effects of continuous residue removal on the nutrient and organic matter content of the soil depends on the type of soil and its reserves.

Matching Gasifiers With Feedstocks

The type of gasifier used in a gasification system is determined by the type of feedstock used and the end-use application intended for the produced gas. The properties of feedstock in part control the method of gasification. Small grain straw and manure have a very high ash content when compared to wood (Table 10). Therefore these high ash feedstocks are best suited for gasifiers able to handle the high ash content. From Chapter 2, fixed-bed updraft gasifiers and fluidized-bed gasifiers are best suited to handle these high ash feedstocks. Particle size is also an important feedstock property that affects the method of gasification. Fixed-bed gasifiers require feedstocks the size of wood chips. Therefore manure would be unsuitable for fixed-bed gasification. Unprocessed straw is stringy and must be cubed or ground to meet gasification requirements for fixed-bed and fluidized-bed gasifiers respectively.

The end-use application also dictates the type of gasifier to be used in a system. Applications using producer gas to fuel internal combustion engines require low tar content gas. Fixed-bed downdraft and fluidized-bed gasifiers are best suited to produce low tar content gas.

In conclusion, fixed-bed downdraft gasifiers fueled with wood and fluidized-bed gasifiers fueled with manure or ground small grain straw give the best gasifier to feedstock matches.

CHAPTER 6

ECONOMIC ANALYSIS

The major factors influencing a farmer's decision to build a gasification system are the economics of this energy source when applied to his specific end-use applications. The system economics are different for each site because of feedstock type and distribution, system size, end-use application, and the biomass collection equipment. The economic analysis of a gasification system is therefore site specific and must include analysis of equipment costs, feedstock costs, and operating costs.

Equipment Costs

Biomass harvesting and handling systems vary from site to site. The type of harvest and handling system is dependent on the size of the conversion system, type of conversion system, feedstock type and feedstock specifications. The three feedstocks considered in this analysis, each require a different harvesting and handling system. A crop residue harvesting and handling system consisting of a tractor with front-end loader, large round baler, a hauling wagon or truck, and a tubgrinder is assumed to be the most common or standard crop residue collection system available to the Montana farmer. A manure handling system would make use of existing collection equipment and require the addition of drying and storage facilities. While wood harvesting and handling systems will need hauling, chipping, drying, and storage equipment. In cases where dry wood residues are purchased from a sawmill or a secondary mill the chipping and drying equipment may be eliminated.

The following scenario is used to demonstrate the methodology for calculating equipment costs for the harvest and handling equipment (Kinzey, 1986).

Typical procedure for calculating tractor cost:

> A 45 kW diesel tractor with front-end loader operating at an average of 40% of rated power is used by the farmer. The purchase price of the tractor is $15,000 and the annual use is approximately 500 hours.
>
> Annual Cost = (Fixed Cost%) * P/100 + (Annual Use) * Variable Costs
>
> P = Purchase Price of Equipment ($15,000)
>
> Fixed Costs (as a % of purchase cost):
>
> Depreciation = (P-S)/L = (P-0.1P)/10 = 0.09P/yr
>
> Int. on Invest. = (P+S)*i/2 = (P+0.1P)*(0.08)/2 = 0.044P/yr
>
> Taxes = 0.015P/yr
>
> Insurance = 0.0025P/yr
>
> Shelter = 0.01P/yr

S = Salvage Value of Equipment (10%)

L = Depreciation Life of Equipment (10 years)

i = Interest Rate (8%)

Total fixed Costs = (0.09 + 0.044 + 0.015 + 0.0025
+ 0.01)P/yr
= (0.1615)P/yr
= $2422.50/yr

Variable Costs:

Repair and Maintenance = 0.012P/100 h

Labor = $10.00/h

Diesel Fuel = (45 kW) * (1 L / 1.72 kwh)
* ($0.26/L)
= $6.80/h

Oil = (0.045 L/h) * ($0.92/L) = $0.042/h

Total Variable costs = (500 h/yr) * (0.012 / 100 h)
* ($15,000) + (10.00 + 6.80
+ 0.042)$/h * (500 h/yr)
= $9321.00/yr

Total Tractor Costs:

Total Annual Tractor Costs = ($2422.50/yr)
+ ($9321.00/yr)
= $11743.50/yr

Total Hourly Tractor Costs = $23.49/h

Typical equipment costs for harvesting and handling systems are summarized in Table 12.

Table 12. Equipment costs.

Machine	Fixed Cost ($/yr)	Variable Cost ($/yr)	Total Cost ($/yr)	Annual Use (hr/yr)	Total Cost ($/hr)
Tractor (45 kW)	2422.50	9321.00	11743.50	500	23.49
Tractor (90 kW)	4845.00	13686.00	18531.00	500	37.06
Round Baler	1292.00	248.00	1540.00	100	15.40
Hauling Wagon	127.80	21.60	149.40	100	1.49
Tub Grinder	1650.00	125.00	1775.00	200	8.88
Drier[1]	-------	-------	--------	---	----

[1] The drier cost varies considerably for each site and is included in the cost of the system.

Biomass Feedstock Costs

In some cases biomass feedstocks are assumed to be free sources of energy. However, there are extra costs associated with the use of biomass feedstocks. These costs include collection, transportation, storage, processing, and opportunity costs and must be evaluated in order to determine the true cost of the feedstock.

Collection costs are the first costs incurred in the use of biomass residues. The collection process includes removing the biomass from its growing environment and packaging or processing it into a transportable form.

Transportation costs are incurred with the movement of the biomass from the field to the storage site and from storage to the gasifier. Transportation costs are a function of the feedstock's bulk density and travel distance. Usually the bulk density of the feedstock is too low to utilize the available load carrying capacity of the transport vehicle without surpassing their volumetric capacity. A densification process may be economically justified if the hauling distance is quite long. Handling costs are often included in the transportation costs. Handling costs include loading and unloading vehicles, and moving of the feedstock at the gasification site.

Processing costs are the costs incurred to convert the feedstock into material that will meet fuel specifications for the gasifier. Processing can include grinding, cubing, chipping, and/or drying of the feedstock.

Storage costs are site specific, because they depend on the seasonal use of the feedstock and the method of storage. The feedstock should be protected from the weather as much as possible to prevent deterioration and subsequent loss in heating value.

Often feedstocks have hidden or opportunity costs due to alternative uses. These alternate uses are usually not included in feedstock cost estimates. Alternate feedstock uses can include livestock feed, livestock bedding, fertilizer replacement and the prevention of soil erosion. In some instances biomass is considered to be a waste product and has to be removed from the site. In these cases a portion of the disposal cost may be recovered through gasification. The amount of opportunity costs present in the feedstock cost is very site specific and putting a value on the opportunity cost often is based only on the judgment of the system operator.

Crop Residues

In the collection of small grain residue, the costs of production, swathing and combining are considered to be part of the crop production costs, therefore lowering the overall feedstock cost. A large round baler should have a capacity of 5 to 9 t/h when baling straw. The exact capacity depends on the size and uniformity of the swath and the roughness of the field. Using a capacity of 7 t/h and combining the hourly cost of the tractor and baler, the packaging cost is $5.56/t.

The bale wagon has a 9 t weight capacity but due to the low bulk density of the straw approximately 4 t of straw are carried per load. The tractor can pull the wagon at a road speed of 25 km/h. With a combined tractor-wagon cost of $24.98/h the cost for transportation is represented by the following equation:

$$\begin{aligned}\text{Transport Cost} &= (X\ \text{km}) * (\$24.98/\text{h}) / \\ &\quad (25\ \text{km/h}) / (4\ \text{t}) \\ &= (0.25 * X)\$/\text{t}\end{aligned}$$

X = Round-trip Distance, km.

The handling costs include loading and unloading the wagon and moving straw at the gasifier site. The bales are handled by a front-end loader equipped tractor. The tractor can handle only one bale (300 kg) at one time with approximately 10 min. handling time per bale. This translates into a handling cost of $13.05/t giving a total transportation and handling cost:

Total Trans. and Handling Cost = (0.25X + 13.05)$/t

When a fluidized bed gasifier system is used in a facility using straw as a feedstock, the straw should be ground to meet the specifications of the gasifier. Grinding the straw gives the feedstock uniformity and lessens the chances of bed channeling. The easiest way to grind large round bales is in a tub grinder. A tub grinder with a 11 t/h of straw capacity will require approximately a 90 kW tractor for power. The cost of a tractor and grinder is estimated at $4.18/t.

The calculation of the opportunity cost for crop residues includes many factors relative to the region. Wheat and barley straw, in some situations, are left in the field and at other times are harvested for livestock feed and bedding or for disposal in continuous cropping situations. In areas of light soils, special soil conservation methods are needed. Often crop residue is needed to prevent soil erosion and to build up soil humus. If the straw is removed replacement fertilizer and erosion damages can be added to fuel costs. The dollar value of straw when left in the field is difficult to determine. Alternate uses of wheat and barley straw such as livestock bedding and feed give it a market value and must be considered when utilizing it for gasification.

Often farmers find it advantageous to remove crop residues from the field to control diseases or regulate the trash cover. Utilizing the straw for gasification in these cases provides a way to recover part of the disposal costs.

The following is a summary of small grain feedstock costs;

Collection = \$5.56/t

Transportation and Handling = (0.25* X km +13.05)\$/t

Processing = \$4.18/t

Storage = \$0 - ?

Opportunity = \$0 - ?

Total Fuel Cost = (0.25 * X km + 22.79
+ Storage & Oppor.)\$/t

A total fuel cost of \$40.00/t or \$2.29/GJ (HHV = 17.5 MJ/kg) is probably a maximum cost estimate for straw.

Animal Wastes

As previously discussed the value of animal wastes as a biomass feedstock depends on its being available in substantial amounts in relatively confined areas. The ideal case would be a dairy farm where the cattle are kept indoors for part of the day. Modern dairy barns are equipped with manure removal systems. These removal systems include self-cleaning gutters or slatted floors and a storage pit or pile. Since the collection of the manure makes use of the existing disposal system, collection costs are usually non-existent.

A major cost for manure usage is the drying of the manure. Raw manure is approximately 88% water, therefore to dry the manure in a relatively short time will require the use of heated air. The best way to dry the manure would probably be in a small rotary kiln using heat generated from the gasification system. The manure will have to be dried from 88% moisture content to about 10% requiring:

Total Heat Required = (0.78 kg water/kg wet manure) *
(4.65 MJ/kg water) *
(1000 kg/t) * (7.5 t
wet manure/t 10% m.c.)
= 27,200 MJ/t 10% m.c. manure

Note: Using 4.65 MJ/kg water allows for heat absorbed by the manure and exhausted heat from the drier.

The total heat required to dry the wet manure to a 10% moisture content is calculated to be 27,200 MJ/t. If waste heat and the heat provided from the direct combustion of the producer gas were used to dry the wet manure (assuming 100% conversion and collection efficiency), only 16,500 MJ/t of heat could be collected. Therefore waste heat from gasification could only be used to supplement another drying method.

Using natural gas at $\$0.107/m^3$ for comparison purposes the cost of the heat required for drying is:

Drying Cost = (27,200 MJ/t 10% m.c.) * ($\$0.107/m^3$)
/ (33.0 MJ/m^3)
= \$88.19/t 10% m.c. manure

Because of possible collection problems, enough manure should be dried to maintain a two or three day fuel supply. The storage area size for dried manure is dependent on the size of the conversion system and the required reserve. Small systems using a short leeway could possibly use the feedstock hopper for storage.

Another important cost is the opportunity cost of using manure as fertilizer. The opportunity cost depends on the local market for manure as fertilizer. The cost can vary from $0.00 upwards. In this cost estimate the opportunity cost is assumed to be $5.00/t of 10% m.c. manure.

The following is a summary of animal waste feedstock costs;

Collection = $0

Transportation = $0

Processing (drying) = $88.19/ t (10% m.c.)

Storage = $0

Opportunity = $5.00/ t (10% m.c.)

Total Animal Waste Cost = $93.19/t (10% m.c.)

Assuming livestock manure has a heating value of 16.5 MJ/kg d.b., the total cost of $93.19/t translates into $5.65/GJ. The total cost for a dry ton of manure is quite large with the majority of the cost being drying costs. A site considering using manure as a possible feedstock source should look at alternative drying methods as it would not be practical to use natural gas for drying manure. These methods could include solar drying or techniques of draining away excess water.

Wood and Wood Wastes

The cost of wood for biomass feedstock depends on the source of supply. The wood can be purchased from a mill or harvested directly from the forest.

Wood residue that is purchased from a mill can be in the form of chips or sawdust. In the case of a primary mill the chips are green thus requiring drying before gasification. Sawdust produced from cutting dried lumber is suitable for gasification in a fluidized bed without drying. Residues from a secondary mill consist of both small blocks and sawdust in a dried state. Wood residue generally becomes a disposal problem for a mill and the cost of the wood for fuel use is usually the cost of transportation and drying when needed.

The harvesting of logs and forest residues involves the cost of collection, processing and transportation. The collection of the residues can include falling and bunching, skidding and/or processing. The collection process can require a lot of labor and equipment usage on difficult terrain. In addition forest residues are bulky and contain about 50% moisture which requires chipping and drying thus increasing the feedstock cost.

Combe (1983), estimated the cost of harvesting logging residues to be $52.00/dry t while the costs to harvest other forest residues to be as high as $101.00/dry t of wood in Montana. These costs assume that the harvesting is done by a commercial logging company. The costs may be lower for a farmer to harvest the residue for his own system. If a mill is close by, mill residues would be the best source of supply.

Since there is a large degree of uncertainty in the cost of wood feedstock and the requirements of each gasification site the cost of wood is assumed to range from $0.00 to $80.00/dry t. Assuming wood has a heating value of 20.02 MJ/kg (d.b.), the cost of wood energy ranges from $0.00 to $4.00/GJ.

Operating Costs

The operating cost for any piece of equipment includes costs such as those for repair and maintenance, fuel, supplies important to the operation, insurance and labor. In this case, the operational costs for a gasifier are assumed to include repair and maintenance, supplies, insurance and labor costs with the exclusion of fuel or feedstock costs. The development of feedstock costs in this economic analysis is assumed to warrant its own separate analysis. The operating cost for a gasifier is very specific to the type of gasifier system used and the type of feedstock utilized.

The size of a gasification facility and the extent of automation is a factor in considering the magnitude of labor and maintenance costs. Also one type of gasification technology may require more maintenance than if another method were used. A fluidized bed gasifier usually requires an extensive filtering system requiring extra monitoring and maintenance. Fixed bed systems are prone to slag build up which should be periodically removed to allow for optimum performance of the gasifier. Also different gasification systems require different start up and shut down procedures that vary labor demand.

A general rule of thumb is that operating costs are approximately 5% of the gasification system cost (Curtis et al., 1982). The costs for repair/maintenance and labor, insurance, and supplies are assumed to be 3%, 1%, and 1% respectively of the installed system cost. This analysis divides the operating cost into repair and maintenance (2%), insurance (1%), and supplies (1%) totaling 4% of the installed cost of the system. Labor costs are treated separate from maintenance costs due to the possibility of large variations of system use per year from one system to another. Each gasification system is assumed to require 2 man hours per 10 hour day and at a hourly rate of $10.00/h.

Gasification System Models

In this section, four site specific scenarios with different end-use applications are modeled. The four models cover the possible agricultural end-use applications mentioned in Chapter Four:

1. irrigation pumping;
2. grain drying;
3. heating of livestock buildings; and
4. cogeneration.

The method used for assessing the economics of each model is described by the following steps:

1. Each hypothetical system is sized according to the scenario requirements.
2. The amount of needed feedstock energy is determined.
3. The installed cost of the system is estimated.
4. The yearly fuel displacement credit is calculated using the least expensive conventional energy alternative.
5. Operation costs that include; labor, insurance, and repair and maintenance costs are calculated.
6. The calculated system parameters are then entered into an economic spreadsheet program (Appendix C). The economic spreadsheet program is used to evaluate the economic performance of the modeled system.
7. The economic feasibility of the base case is then analyzed and a sensitivity analysis is performed on assumed parameters. The assumed parameters that are varied include; interest rates, feedstock costs, estimated fuel displacement, and electricity buy-back rates if electricity is produced.

Model 1. Irrigation Pumping

The following hypothetical scenario is used to demonstrate the sizing and economics of an irrigation/gasification system.

A farmer irrigates 260 ha of wheat against a total head of 50 m over approximately 1,000 h. The efficiency of the pump is assumed to be 80%. Wheat has a peak water requirement of 0.69 cm/day. The required engine pto power to drive the pump or pumps is:

$$\begin{aligned}\text{Engine pto} &= (0.69\ \text{cm/day}) / (10\ \text{h/day}) / (3{,}600\ \text{s/h}) * \\ &\quad (260\ \text{ha}) * (10{,}000\ \text{m}^2/\text{ha}) / (100\ \text{cm/m}) \\ &\quad * (1{,}000\ \text{kg/m}^3) * (50\ \text{m}) / (80\%/100) * \\ &\quad (9.81\ \text{m/s}^2) \\ &= 305{,}541\ \text{kg m}^2/\text{s}^3 \\ &= 306\ \text{kW}\end{aligned}$$

The producer gas fueled engine and gasifier are assumed to have conversion efficiencies of 20% and 65%, respectively. The energy requirements are:

$$\begin{aligned}\text{Engine fuel energy} &= (306\ \text{kW}) / (20\%/100) \\ &= 1{,}530\ \text{kW} \\ &= (1{,}530\ \text{kW}) * (3{,}600\ \text{s/h}) \\ &= 5.51\ \text{GJ/h}\end{aligned}$$

$$\begin{aligned}\text{Feedstock energy} &= (5.51\ \text{GJ/h}) / (65\%/100) \\ &= 8.47\ \text{GJ/h}\end{aligned}$$

The possible feedstock types for the irrigation/gasification model use include straw, wood and wood wastes, and manure. A fixed-bed downdraft gasifier fueled with wood chips and a fluidized-bed gasifier using any of the three fuels could be used at this site. The approximate installed costs for the fixed-bed downdraft and fluidized bed gasifiers are $100,000 and $140,000 respectively (Sure-Lite

Manufacturing). The estimated installed cost includes the feeding system, gasifier, cleaning and cooling system, irrigation motor, and miscellaneous (housing, controls etc.).

Using electricity as the least expensive alternative energy for irrigation pumping at a cost of \$0.031/kWh with a electrical motor efficiency of 90%, the estimated fuel displacement is:

Est. Fuel Displ. = (306 kW) / (90%/100) * (1000 h/yr)
* (\$0.031/kWh)
= \$10,540/yr

A reasonable estimate of repair and maintenance, insurance, supplies and labor costs installed costs are calculated:

Repair and Maint. Costs = (\$100,000) * (2%/100)
= \$2,000

Insurance Costs = (\$100,000) * (1%/100)
= \$1,000

Supply Costs = (\$100,000) * (1%/100)
= \$1,000

Labor Costs = (1,000 h/yr) * (\$20/10 h/day)
= \$2,000/yr

A base case is developed in order to establish a benchmark to determine whether a gasification system would be economically feasible. The base case represents realistic economic system parameters and assumptions such as taxes, and other fixed costs.

Base case assumptions:

1. System cost (Downdraft)	\$100,000

2. Initial Investment	20%
3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day. 5 day/wk. 20 wk/yr)	1,000 h
6. System Life	10 yr
7. Tax Rate: Federal State	30% 7%
8. Feedstock Cost	$2.00/GJ
9. Fuel Displacement Credit	$10,540/yr
10. Discount Rate	12%

Figure 22, is the output of the economic spreadsheet program displaying the net present value versus years for the base case. The zero net present value line represents the break even line. The output shows a steady decline after the first year of operation. The discontinuity of the first year is due to the affect of the investment tax credit.

Figures 23 through 25 show present net value versus years for variations in interest rates, feedstock costs and estimated fuel displacement credit respectively. The base case interest rate of 8% was varied from 4% to 12% to study its effect on the analysis. The feedstock cost was varied from $0/GJ to $5/GJ and the fuel displacement credit was varied from 0 to 4 times the estimate.

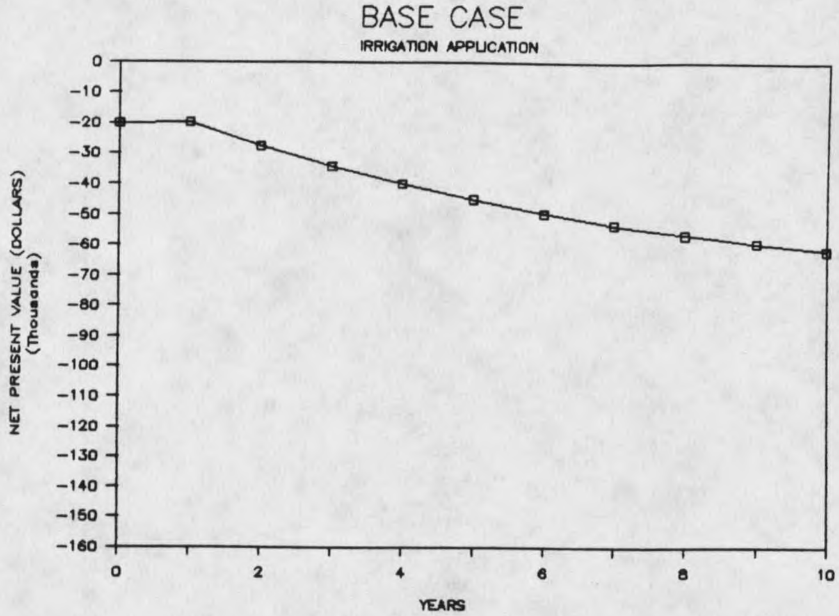


Figure 22. Base case - irrigation model.

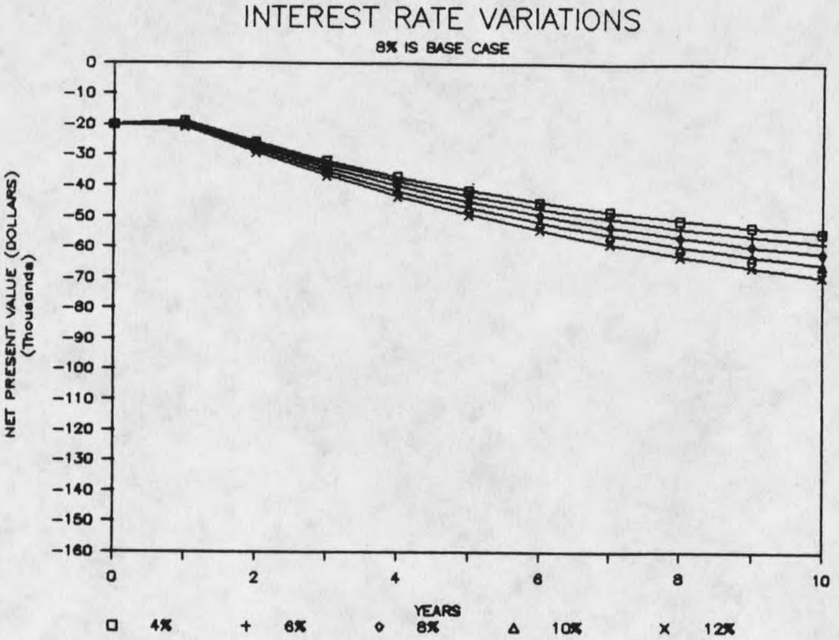


Figure 23. Interest rate variations - irrigation model.

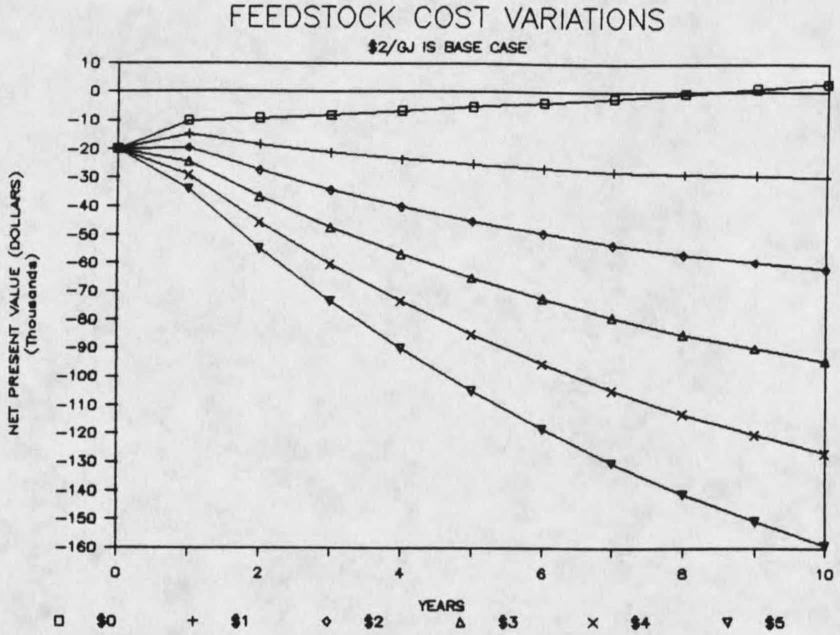


Figure 24. Feedstock cost variations - irrigation model.

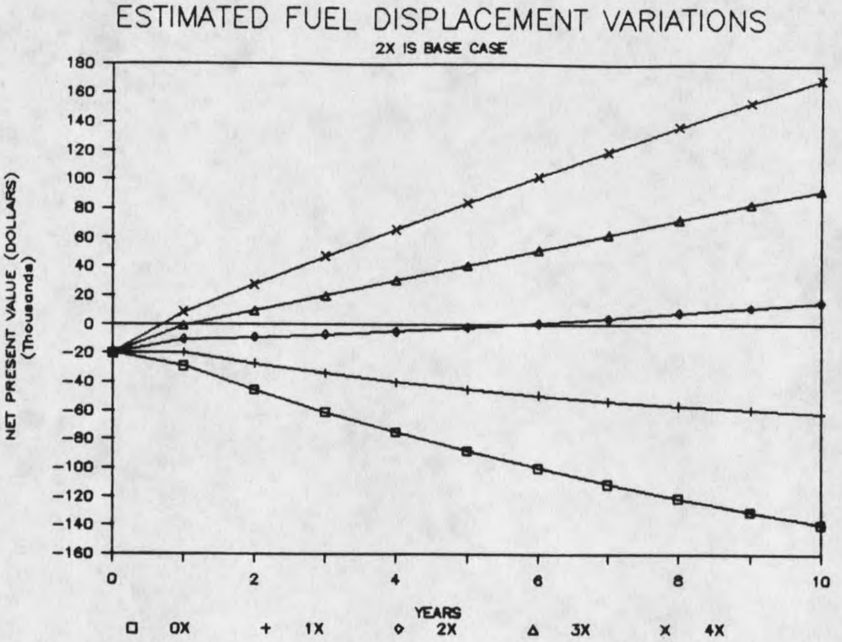


Figure 25. Estimated fuel displacement variations - irrigation model.

The base case graph and the sensitivity graphs show that at this hypothetical site the gasification system used to pump irrigation water is uneconomical. Ideal situations with zero feedstock cost and conventional fuel costs at 2 times the present cost of electricity proved to be economical. Since situations with zero fuel cost and high conventional fuel prices are deemed unrealistic at the present time the site was considered uneconomical. Therefore the main reasons for this sites economic failure is due to the high installed cost and low annual use.

The use of the lower cost fixed-bed downdraft gasification proved uneconomical therefore the higher cost fluidized bed system is also assumed to be uneconomical. To increase the usage of the system, the designer may consider multiple tasks for the system.

Model 2. Grain Drying

The following hypothetical scenario is used to demonstrate the sizing and economics of a grain drying /gasification system.

The farmer wishes to dry the wheat harvested from 260 hectares of irrigated crop yielding 3.026 t/ha (45 bu/acre). The grain is harvested at 18% moisture content and is to be dried to 13% for storage.

$$\begin{aligned}\text{Total Heat Required} &= (3.026\ \text{t wheat/ha}) * (260\ \text{ha}) * \\ &\quad (0.0575\ \text{t water/t wheat}) * \\ &\quad (4.65\ \text{GJ/t water}) \\ &= 210.38\ \text{GJ}\end{aligned}$$

Note: Using 4.65 GJ/t water allows for heat absorbed by the wheat and not used in evaporating water and also the heat remaining in the air that is exhausted from the drier.

Assuming that the drier can dry 54.4 t (2,000 bu) batches, in a 10 h/day drying cycle a total of 144 h or 15 days are needed. The gasifier is assumed to have a thermal efficiency of 80% when used in a direct combustion process. The gasifier size and feedstock energy required is:

Gasifier Size = (210.38 GJ) / (144 h)
= 1.46 GJ/h

Feedstock Energy = (1.46 GJ/h) / (80%/100)
= 1.83 GJ/h

The approximate installed cost for the fixed-bed downdraft and fluidized bed gasifiers to supply heat for the drier are $60,000 and $100,000 respectively (Sure-Lite Manufacturing). Using natural gas as the least expensive alternative energy for drying grain at a cost of $\$0.107/m^3$ and burning efficiency of 80% the estimated fuel displacement is:

Est. Fuel Displ.= (210.38 GJ/yr) / (80%/100) /
$(33\ MJ/m^3)$ * $(\$0.107/m^3)$
= $853/yr

A reasonable estimate of operational supplies, repair and maintenance, and insurance is:

Operational Supplies = ($60,000) * (1%/100)
= $600

Repair and Maintenance = ($60,000) * (2%/100)
= $1,200

Insurance Cost = ($60,000) * (1%/100)
= $600

Base case assumptions:

1. System Cost (downdraft)	$60,000
2. Initial Investment	20%
3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day, 5 day/wk, 3 wk/yr)	144 h
6. System Life	10 yr
7. Tax Rate: Federal	30%
State	7%
8. Feedstock Cost	$2.00/GJ
9. Fuel Displacement Credit	$853
10. Discount Rate	12%

Figure 25, is the output from the economic spreadsheet program using the above base case input parameters. The results are similar to those of the first model except for a lower debt after ten years.

Figures 27 through 29 show present net value versus years for variations in interest rates and feedstock costs respectively. The base case interest rate of 8% was varied from 4% to 12%, the feedstock cost from $0/GJ to $5/GJ and the estimated fuel displacement credit from 0 to 4 times the base case.

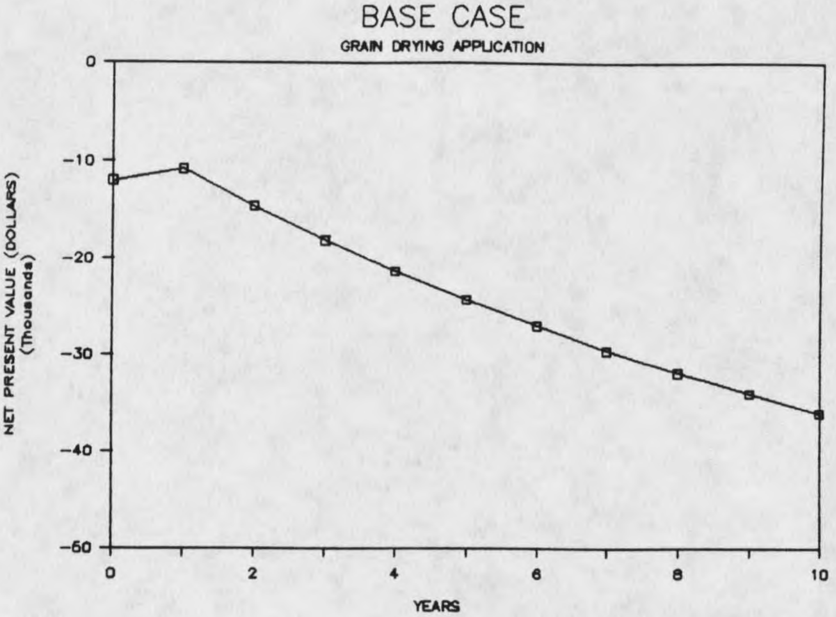


Figure 26. Base case - grain drying model.

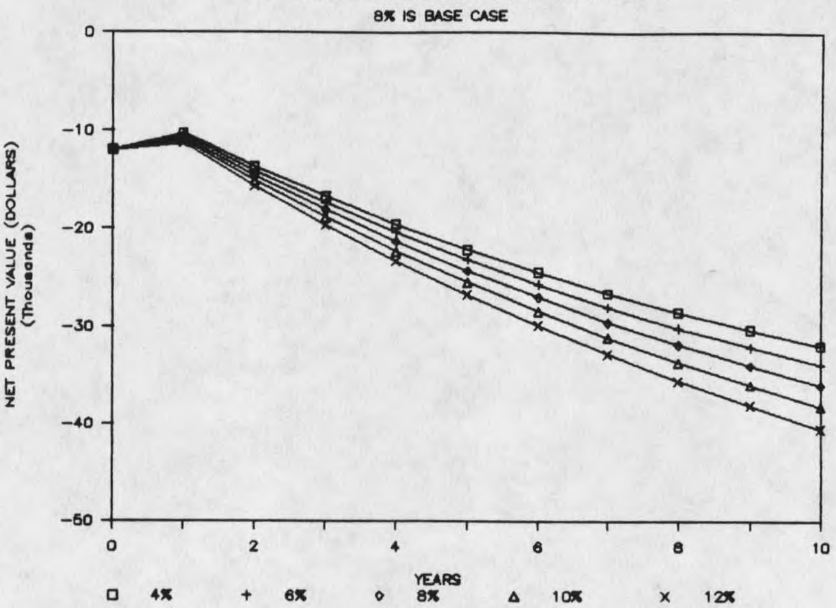


Figure 27. Interest rate variations - grain drying model.

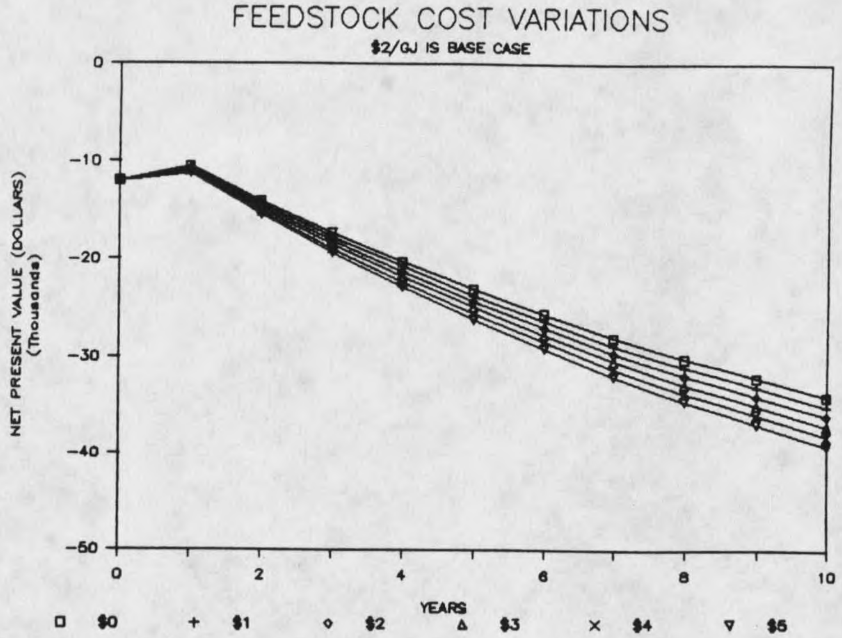


Figure 28. Feedstock cost variations - grain drying model.

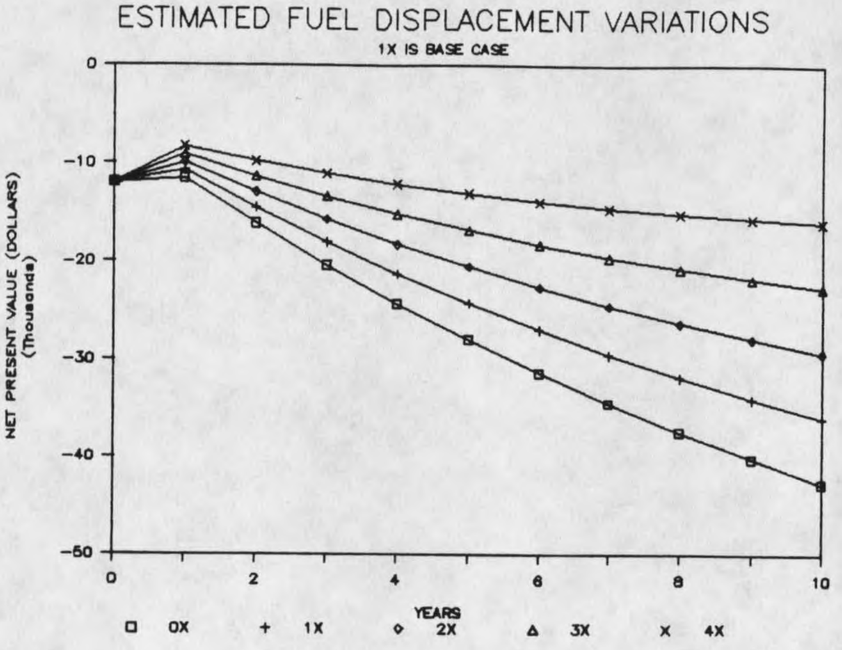


Figure 29. Estimated fuel displacement variations - grain drying model.

The base case graph and sensitivity graphs show that the gasification system used to provide heat for drying grain is uneconomical. Again the reason for economic failure is due to the high initial cost, low annual use and low conventional fuel costs.

Ideally, to increase annual system use the gasifier could be used to pump irrigation water and dry the grain for the same 260 ha of land. But as shown in models one and two the required gasifier size for irrigating pumping and grain drying is quite different. Irrigation pumping required 5.51 GJ/h of gas energy, while grain drying required 1.46 GJ/h of heat energy. To size the gasifier to operate both systems would require a compromise of efficiency or size.

Model 3. Heating Livestock Buildings

The following hypothetical scenario is used to demonstrate the sizing and economics of an livestock heating/gasification system. A dairy operation scenario is used because it has a good potential for using the generated heat.

The system design parameters are for a hypothetical dairy operation and are taken from the "Midwest Plan Service Structures and Environment Handbook", 1980. A hypothetical dairy operation is used rather than an actual case because each design is site specific and the data from the Midwest Plan Service describes a more average operation.

A dairy farmer is considering using a gasification system to help supplement the heating requirements of his operation. The system design parameters used in the scenario are as follows:

Typical herd size:

Milking cows	100
Dry cows	22
Heifer (10 mon. to freshening)	53
Calves (1.5 to 10 mon.)	29
Calves (up to 1.5 mon.)	18
Total animals in herd	222

Space heating:

Milking parlor	74 MJ/h
Milkhouse	11 MJ/h
Calf housing (1,000 Btu/hr/calf)	19 MJ/h
	104 MJ/h

Water heating (cleaning):

Bulktank[1] (208 L/day)	55 MJ/day
Pipelines[1] (200 L/milking)	50 MJ/milking
Miscellaneous[1] (114 L/day)	30 MJ/day
Parlor[1] (208 L/milking)	55 MJ/milking
Milkhouse floor[1] (76 L/day)	20 MJ/day
Cow prep.[2] (8 L/cow/milking)	114 MJ/milking

[1] Water temperature of 74°C.
[2] Water temperature of 46°C.

Note: The water inlet temperature is assumed to be 10°C.

The farmer plans to milk twice daily and meet all the space and water heating requirements with the gasification system. Since the gasifier will only operate for 10 h/day a heat storage tank will be incorporated into the heating system. The storage system will be designed to meet the following heat usage schedule during the winter.

Table 13. Heat load schedule.

Hour	Gasifier On/Off	Heating Load (MJ) Space		Heating Load (MJ) Water
1	on	103.4		0
2	on	103.4		0
3	on	103.4		0
4	on	103.4	Cow Prep.	114
5	on	103.4	Cow Prep.	114
6	on	103.4	Cleaning	126
7	on	103.4		0
8	on	103.4		0
9	on	103.4		0
10	on	103.4	Cleaning	75
11	off	103.4		0
12	off	103.4		0
13	off	103.4		0
14	off	103.4		0
15	off	103.4	Cow prep.	114
16	off	103.4	Cow prep.	114
17	off	103.4	Cleaning	126
18	off	103.4		0
19	off	103.4		0
20	off	103.4		0
21	off	103.4		0
22	off	103.4		0
23	off	103.4		0
24	off	103.4		0
		2,481.6		743

Water is an ideal material in which to transport and store usable heat. Heat energy can be added and removed from a water medium without an energy loss between the transport fluid and the water. The energy balance on a nonstratified storage tank is (Duffie and Beckman, 1980):

$$(mC_p)_s dT_s/dt = Q_u - L - (UA)_s(T_s - T_a)$$

m = mass of water in storage.
C_p = specific heat of water.
T_s = temperature of the water in storage.
T_a = temperature of the ambient air.
t = time.
Q_u = energy supply.
L = energy load.
$(UA)_s$ = loss coefficient-area product of the tank.

With the above equation rewritten in finite difference form, the heat energy supply from the gasifier can be solved for by maintaining the appropriate water temperature, and heating schedule.

$$Q_u = L + (UA)_s(T_s - T_a) + (mC_p)_s/t(T_{sn} - T_{so})$$

T_{sn} = new temperature of water in storage.
T_{so} = old temperature of water in storage.
m = 4,500 kg
C_p = 4190 J/kg/^{o}C
T_a = 4^{o}C
t = 1 h
$(UA)_s$ = 11.1 W/^{o}C

Using the above assumptions and the heating schedule a gasifier producing approximately 422 MJ/h will meet the winter heating requirements. The system will only have to heat water during the summer months or 35% of the year.

A heating load of 422 MJ/h is below the minimum capacity of fluidized bed gasifiers, therefore a fixed-bed system will have be used. Of the available feedstocks, woodchips are best suited for gasification in a fixed-bed downdraft gasifier.

The direct combustion of producer gas is assumed to have a thermal efficiency of 80%.

Feedstock Energy = (422 MJ) / (80%/100)
= 527.5 MJ/h

The purchase price of the gasification system is assumed to be $40,000 (Boyette and McKusick, 1983). This includes feedstock feeding, solid waste removal, gas filtering and producer gas burning equipment. Using natural gas as the least expensive conventional fuel alternative (\$0.107/m^3) the estimated fuel displacement is:

Est. Fuel Displ. = (((3,500 h/yr) / (10 h/day) *
(65%/100) * (3,264.6 MJ/day)) +
((3,500 h/yr) / (10 h/day) *
(35%/100) * (783 MJ/day))) /
(33 MJ/m^3) * (\$0.107/m^3)
= $2,719

The estimated supply costs, repair and maintenance, insurance, and labor costs are:

Supply Costs = ($40,000) * (1%/100)
= $400

Repair and Maintenance = ($40,000) * (2%/100)
= $800

Insurance Cost = ($40,000) * (1%/100)
= $400

Labor Cost =($10/h) * (2 h/10h-day) * (3,500 h/yr)
= $7,000/yr

Base case assumptions:

1. System Cost (downdraft)	$40,000
2. Initial Investment	20%

3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day, 7 day/wk, 50 wk/yr)	3,500 h
6. System Life	10 yr
7. Tax Rate: Federal	30%
State	7%
8. Feedstock Cost	\$2.00/GJ
9. Fuel Displacement Credit	\$2,719
10. Discount Rate	12%

The results for the base case assumptions are shown in Figure 30. The graphical output shows a steady decline in the net present value of the system over the ten years. Again a sensitivity analysis was performed for the assumptions made on current interest rates, feedstock costs, and fuel displacement credit. The results of the sensitivity analysis are displayed in Figures 31 through 33.

Even with low interest rates and feedstock costs the system still proved to be uneconomical. Variations of the estimated fuel displacement (Figure 33) show the system will break even after 4 years if the current price of natural gas (\$0.107 m^3) quadruples.

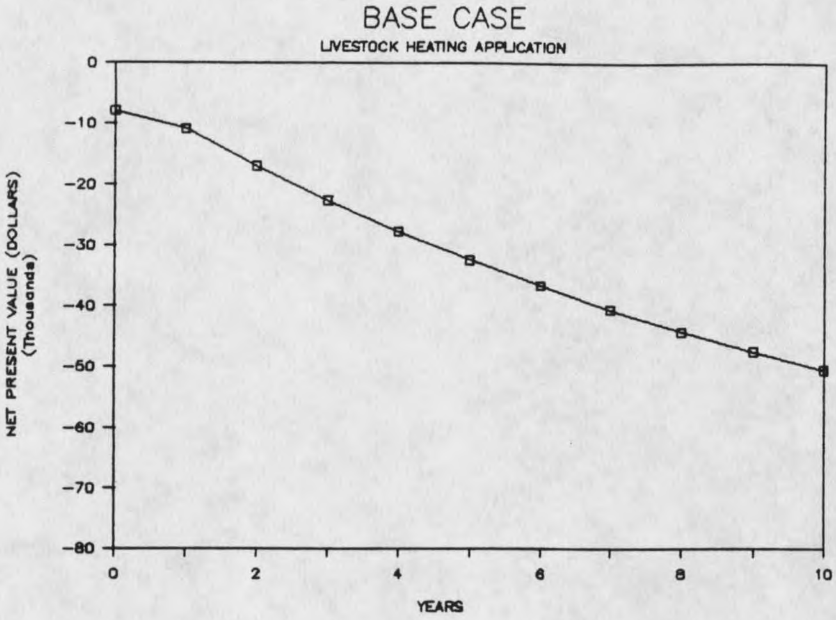


Figure 30. Base case - heating livestock buildings model.

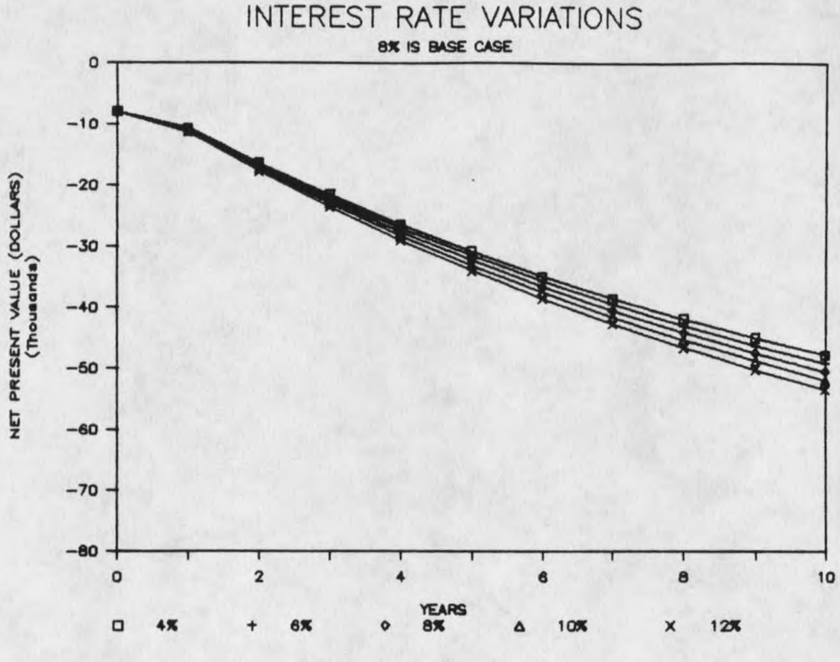


Figure 31. Interest rate variations - heating livestock buildings model.

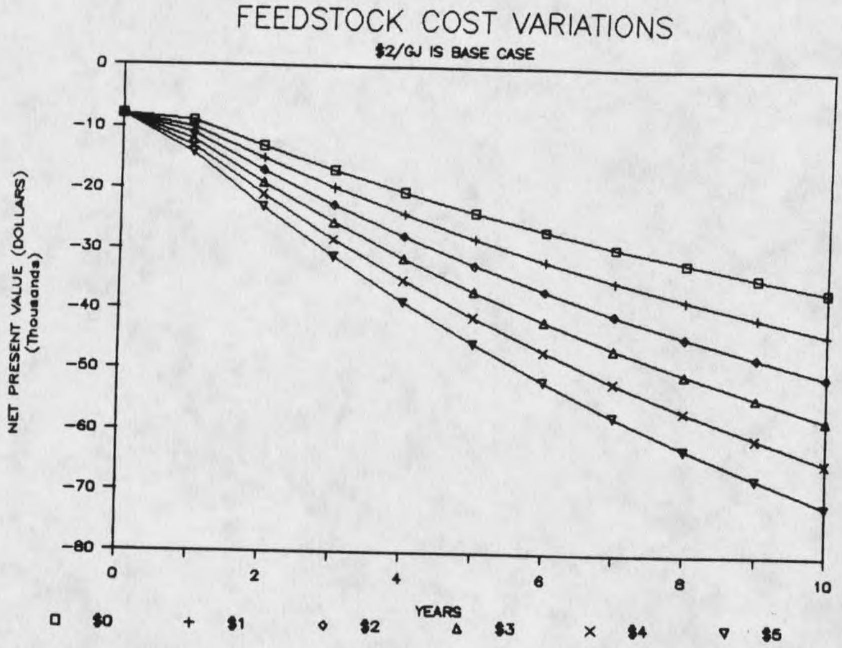


Figure 32. Feedstock cost variations - heating livestock buildings model.

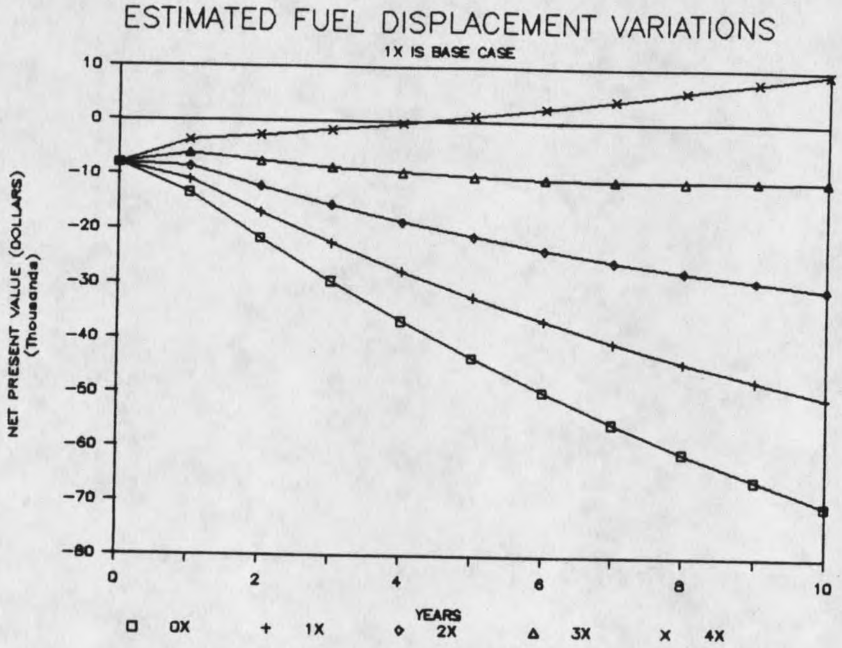


Figure 33. Estimated fuel displacement variations - heating livestock buildings model.

Model 4. Cogeneration

The following hypothetical scenario is used to demonstrate the general sizing and economics for an on-farm cogeneration system.

The farmer is considering using cogeneration to satisfy both heating (422 MJ/h) and electrical requirements of the dairy operation. The electrical energy will be produced by an engine/generator set and the heat energy supplied by waste heat. Sizing a system can depend either on the heating load or the electrical requirements of the site. If electrical generation is the primary criteria for the system, sizing is dependent on the electrical needs. The same is true for heating requirements. Often at cogeneration sites the generation of electricity is the primary requirement due to isolation of the site or from prospects of selling electricity to the local utility.

Assuming a 75 kWh electrical load, a 95% generator, 20% engine and 65% gasifier efficiencies, the calculated gasifier size and feedstock energy required are:

$$\text{System Size} = (75\ \text{kWh}/1\ \text{h}) * (3600\ \text{s/h}) / (95\%/100) / (20\%/100) = 1.42\ \text{GJ/h}$$

$$\text{Feedstock Energy} = (1.42\ \text{GJ/hr}) / (65\%/100) = 2.19\ \text{GJ/h}$$

Approximately 40% of the feedstock energy can be recovered (Boyette and McKusick, 1986), resulting in a possible recovery of 876 MJ/h of heat energy. Only 422 MJ is needed to meet the present dairy winter heating load.

The approximate installed cost for an appropriate fixed-bed downdraft gasifier and fluidized-bed gasifier systems are $60,000 and $100,000 respectively. Again using natural gas as the least expensive conventional alternative energy the estimated fuel displacement credit is $2,719 (model 3).

The estimated supply costs, repair and maintenance, insurance, and labor costs for the less expensive fixed-bed downdraft system are:

Supply Costs = ($60,000) * (1%/100)
= $600

Repair and maintenance = ($60,000) * (2%/100)
= $1,200

Insurance = ($60,000) * (1%/100)
= $600

Labor = ($10/h) * (2 h/10 h-day) * ($3,500 h/yr)
= $7,000

Base case assumptions:

1. System Cost (downdraft)	$60,000
2. Initial Investment	20%
3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day, 7 day/wk. 50 wk/yr)	3,500 h
6. System Life	10 yr
7. Tax Rate: Federal	30%
State	7%
8. Feedstock Cost	$2.00/GJ

9. Fuel Displacement Credit	\$2,719
10. Generation Capacity	75 kWh
11. Electrical Rate	\$0.013/kWh
12. Discount Rate	12%

The results for the base case assumptions again show the hypothetical model to be uneconomical (Figure 34). The graphical output shows a steady decline in the net present value over the life of the system. The 10% investment tax credit shows little affect in countering the high system costs.

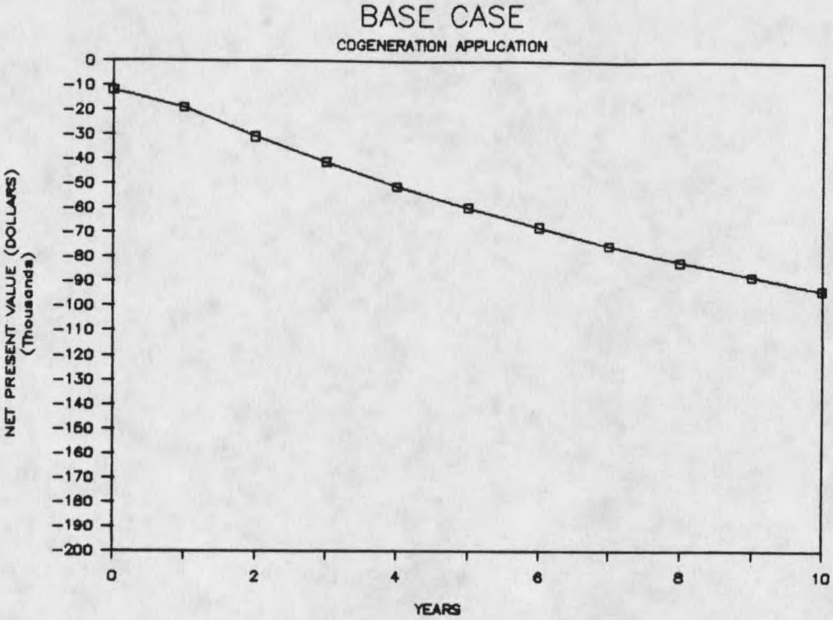


Figure 34. Base case - cogeneration model.

Figures 35 through 38 display the sensitivity of various base case assumptions for this model. The assumptions varied include interest rates, feedstock cost, estimated fuel displacement and electricity rates.

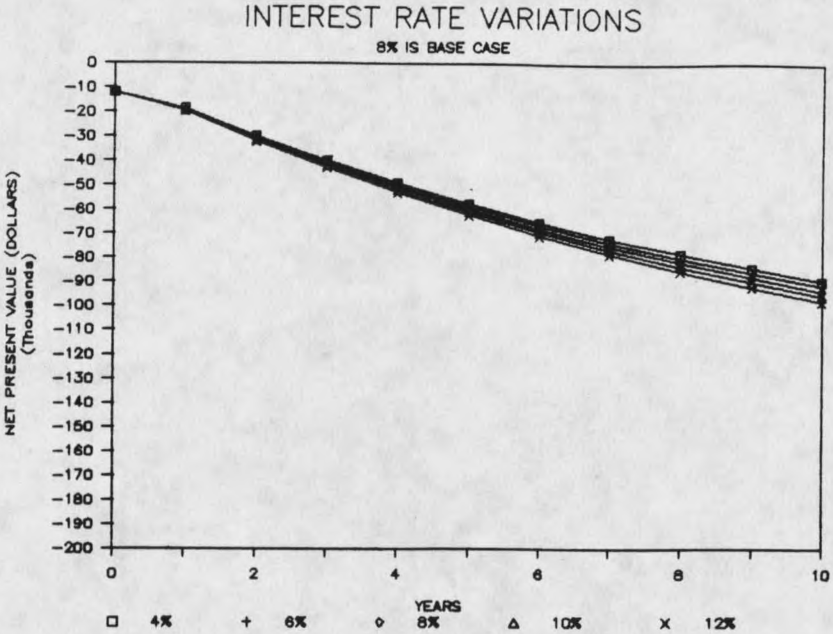


Figure 35. Interest rate variations - cogeneration model.

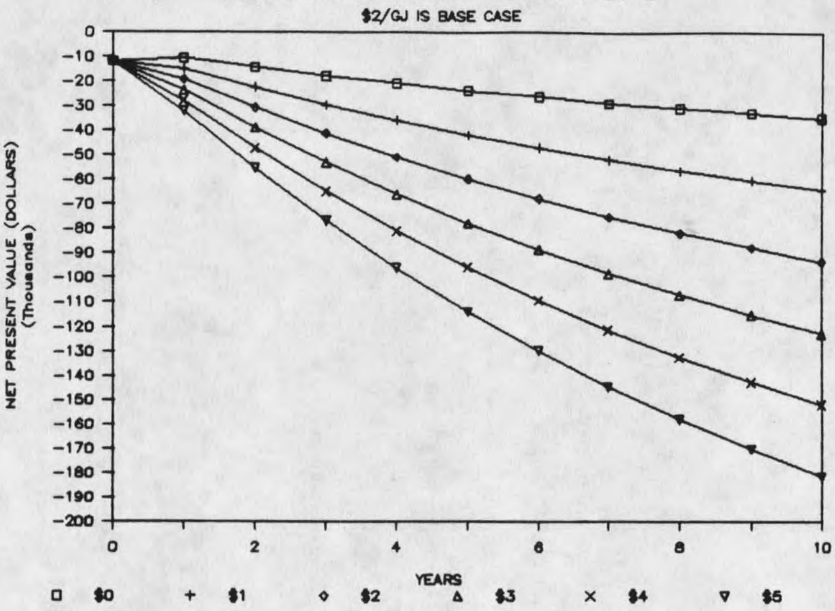


Figure 36. Feedstock cost variations - cogeneration model.

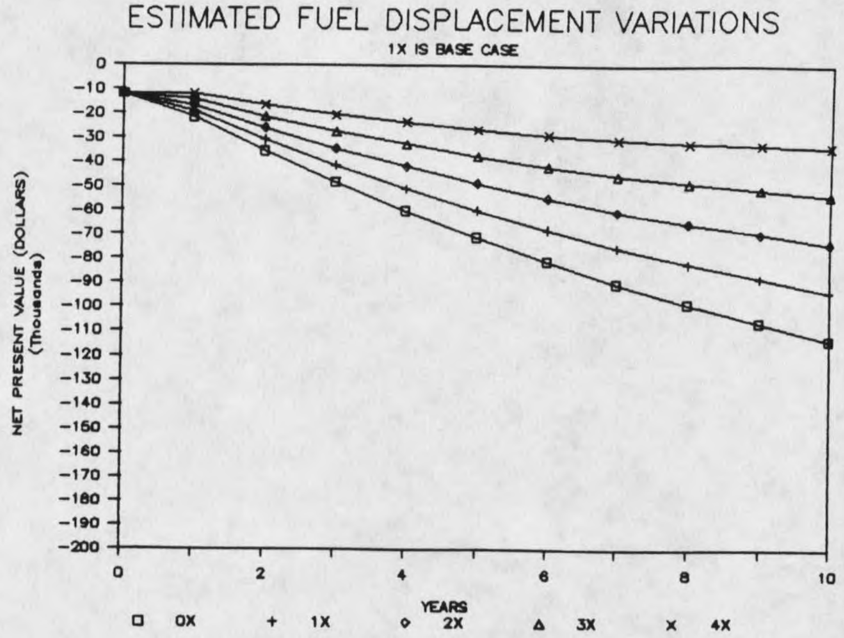


Figure 37. Estimate fuel displacement variations - cogeneration model.

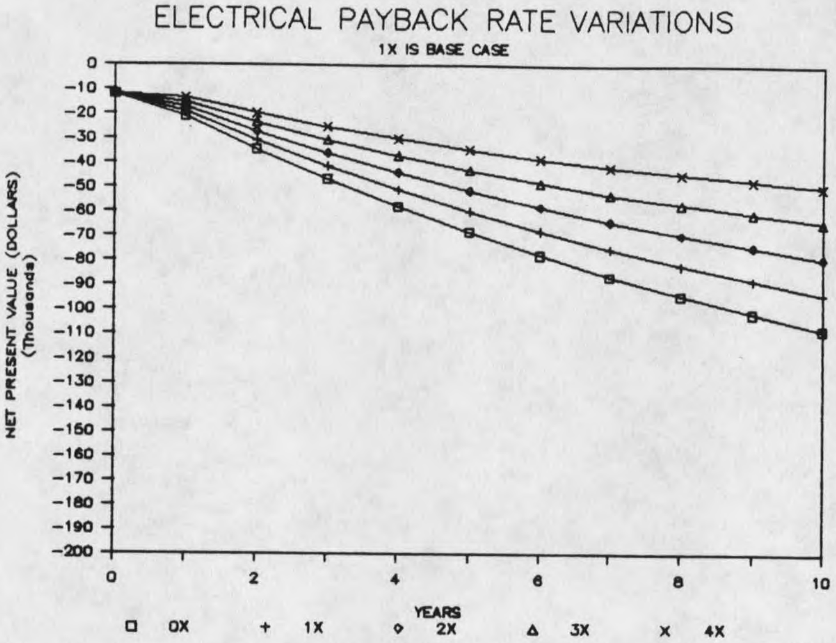


Figure 38. Electricity payback rate variations - cogeneration model.

The base case and sensitivity plots show that this model of an on-farm cogeneration system is uneconomical. Possible parameters causing the economic failure of this model include high feedstock costs, high labor costs, low conventional energy costs, low electrical payback rates.

Summary of Model Results

An economic analysis was performed on each model's base case assumptions using the spreadsheet program. The assumed base case values were an attempt to reflect realistic values for today's economic parameters. The results of all four hypothetical models showed the systems to be economically infeasible for their respective base case assumptions.

The base case assumptions for each model were varied to allow for future realistic assumptions or for errors made in the original assumptions. The sensitivity analyses varied interest rates, feedstock costs, estimated fuel displacement credits, and electricity payback rates. The most sensitive parameters were found to be feedstock costs, estimated fuel displacement, and electricity payback rates. Varying interest rates showed little affect in changing the economic feasibility of the models.

The analyses largest sensitivity was displayed by varying the estimated fuel displacement credit. The irrigation and heating of livestock buildings models actually became feasible when the price of electricity and natural gas was varied to two and four times the current prices respectively. The irrigation model also became economical feasible when the base case feedstock cost of \$2/GJ was lowered to \$0/GJ. These variations of the base case with zero feedstock costs and double the current convention fuel prices are not realistic in today's economy, therefore they are considered to be noneconomical. Ideal situations with zero feedstock costs, low interest rates and high conventional fuel costs generally proved to be uneconomical. In conclusion, the main reason for the models economic failures are due to the high installed cost of the system.

Cost To Produce Electricity

The cost to produce energy can also be used to determine how well on-site generated energy can compete with conventional forms. Energy in the form of electricity was chosen in this case for comparison because the utility provides a market that will buy all the electricity a system can produce.

Figure 39 shows the cost of producing electricity versus the amount of straw available, for a fluidized-bed gasifier and 70 kW capacity engine/generator set. The cost of the system was estimated at \$100,000. The rest of the economic parameters were assumed to be the same as in the models, except that the gasifier was assumed to operate 24 hours/day until the straw supply was used up.

Figure 40 shows the cost of producing electricity versus the percent of time used throughout the year, for a wood fueled fixed-bed downdraft gasifier and a 50 kW capacity engine/generator set. The cost of the fixed-bed downdraft system was estimated at $40,000. Again the economic parameters were assumed to be the same as those for the previous case except that an unlimited supply of wood feedstock was assumed.

Both figures show that at low yearly usage the cost to produce one kilowatt hour is affected mostly by the initial system cost and as the yearly usage increases the cost per kilowatt hour decreases. The lower limit on the cost per kilowatt hour is controlled by the system's operational and feedstock costs.

Both figures show that even with a feedstock cost of $0/GJ that current buyback rates of $0.013/kWh would have to increase many times before becoming competitive.

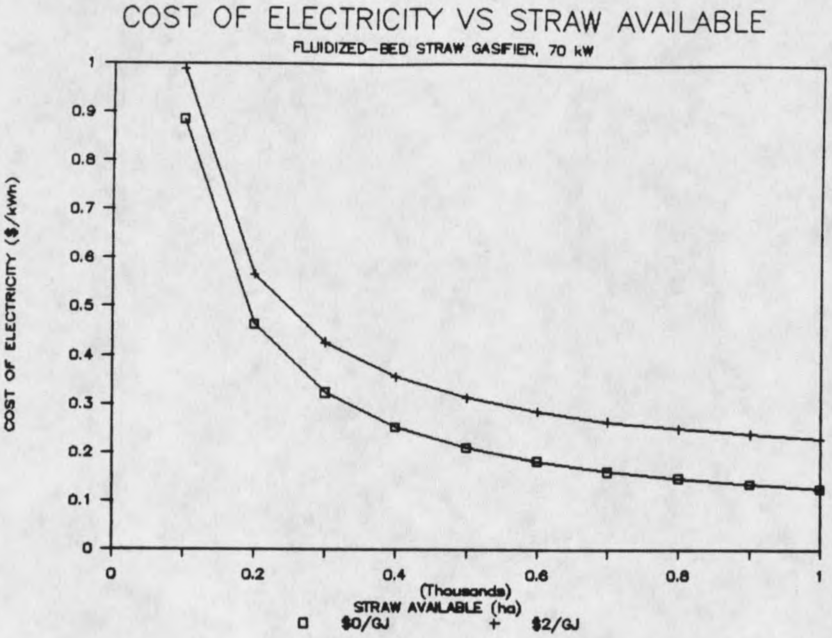


Figure 39. Cost of electricity versus straw available.

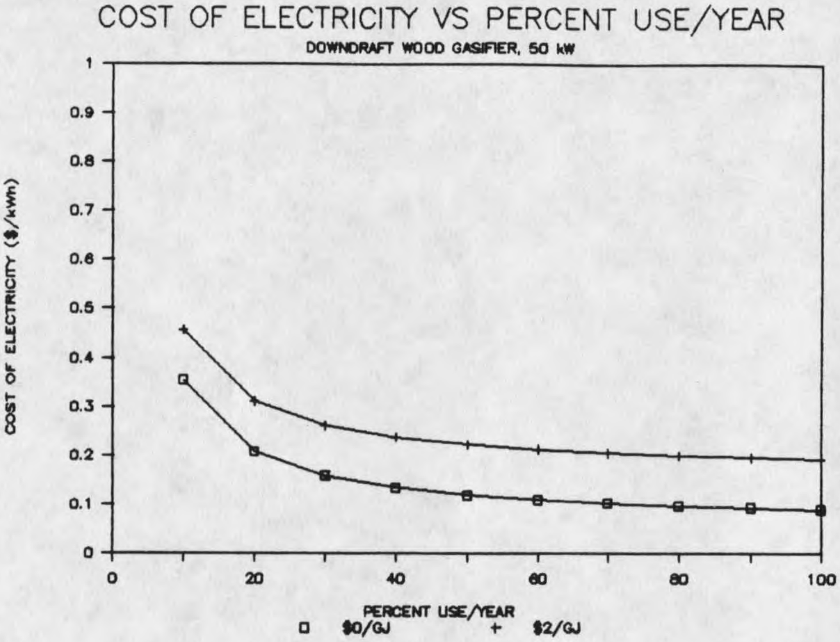


Figure 40. Cost of electricity versus percent use/year.

CHAPTER 7

CONCLUSION

Montana has large amounts of biomass feedstocks that have the potential to alleviate the agricultural industry's dependency on fossil fuels. These biomass feedstocks include small grain crop residues, animal wastes, wood, and wood wastes. Crop and wood residues are the most abundant forms of biomass in Montana. Animal wastes are also a possible gasification feedstock but only in concentrated areas.

The amount of feedstock available. the type of handling system, the type and size of gasifier, and the end-use applications were found to be very site dependent. The sites energy requirements, feedstock type, and end-use application are the major factors determining the type of gasification system. When an application requires a high quality, low tar content producer gas, such as an internal combustion engine, a downdraft gasifier or a fluidized-bed with a improved filtering system could be used. Feedstocks such as straw, manure and sawdust are best suited for a fluidized bed gasifier because of their high ash content and small particle size. Wood chips are best suited for gasification in a downdraft fixed bed gasifier.

The most beneficial energy conversion processes for farm use is space heating and powering of internal combustion engines. The energy produced by these methods can be used to heat livestock buildings, dry grain, generate electricity, and pump irrigation water. System designers should seriously consider cogeneration applications because of their high energy conversion efficiencies. The gasification feeding system should be a continuous feeding type, for convenience, reliability and cost effectiveness.

Based on literature reviewed concerning biomass gasification and the four system economic models, on-farm biomass gasification is not recommended in Montana. There are several major factors that influence this recommendation. Although biomass feedstocks are seen as a renewable and free source of energy, this study has shown that the cost to convert biomass into usable forms of energy through gasification is quite high. The high installed system cost and the low cost of electricity and fossil fuels in Montana, make gasification systems economically infeasible under current economic conditions. Small gasification systems suitable for on-farm applications are still mainly in the development and testing stages making the implementation of gasification systems on Montana farms risky.

Future developments and cost reductions in gasification designs and/or changes in economic conditions will be required to make on-farm biomass gasification economical in Montana.

BIBLIOGRAPHY

Bibliography

Arthur J. F., Kepner R. A., Dobie J. B., Miller G. E., and Parsons P. S. 1982. Tub Grinder Performance with Crop and Forest Residues. ASAE Transactions Vol. 25, No. 6, pp 1488-1494, 1982.

Boyette M. D., and McKusick K. 1986. Biomass Gasification for Electrical Cogeneration in North Carolina: Volume I: Technical Report. The North Carolina Alternate Energy Corporation.

Curtis A. B. Jr., Ragus C., and Delaski D. 1982. A Preliminary Economic Analysis for a Wood Energy System. USDA Forest Service, Atlanta, Michigan.

Dobie, J. B., and Haq A. 1983. Outside Storage of Baled Rice Straw. ASAE Transactions Vol. 23, No. 4, pp 990-993, 1983.

Duffie J. A., and Beckman W. A. 1980. Solar Engineering of Thermal Processes. Wiley-Interscience Publications.

Ebeling J. M., and Jenkins B. M. 1983. Physical and Chemical Properties of Biomass Fuels. ASAE Paper No. 83-3546.

F. C. Hart Associates, Inc 1983. Commercial Potential of Wood Gasification and its Application in New York State. New York State Energy Research and Development Authority, Report 83-24.

Green A. W., O'Brien R. A., and Schaefer J. C. 1985. Montana's Forests. USDA and Forest Service, Resource Bulletin INT-38.

Jenkins B. M., and Sumner H. R. 1985. Research Needs and Priorities For Harvest and Handling of Agricultural Residues. ASAE Paper No. 85-3066.

Jenkins B. M., and Ebeling J. M. 1985. Correlation of Physical and Chemical Properties of Terrestrial Biomass With Conversion. Proceedings of Energy From Biomass and Wastes IX Conference 1985.

Jenkins B. M., and Knutson G. 1984. Energy Balances in Biomass Handling Systems: Net Energy Analysis of Electricity From Straw. ASAE Paper No. 84-3593.

Jenkins B. M., Authur J. F., Miller G. E., and Parsons P. S. 1983. Logistics and Economics of Biomass Utilization. ASAE Paper No. 83-3020

Kinzey B. R. 1986. Direct Combustion of Biomass: Technical and Economic Feasibility. Masters Thesis Montana State University.

LePori W. A., Parnell C. B., Carney D. B., and Ling P. P. 1983. Small Scale Power Generation From Biomass-Technical Potential. ASAE Paper No. 83-3541.

Midwest Plan Service Structures and Environment Handbook, 1980. Iowa State University, Ames Iowa.

Montana Crop and Livestock Reporting Service 1985. Montana Agricultural Statistics 1983-1984. Montana Department of Agriculture.

Ogunlowo A. S., Chancellor W. J., and Goss J. R. 1981. Dual-Fueling a Small Diesel Engine with Producer Gas. ASAE Transactions, 1981.

Overend R. 1979. Wood Gasification - An Overview. Proceedings of FPRS Seattle Conference 1979.

Parke P. P., Clark S. J., and Walawender W. P. 1981. Biomass Producer Gas Fueling of Internal Combustion Engines. Kansas State University.

Payne F. A., Ross I. J., and Walker J. N. 1979. Forced Fed Biomass Gasification Combustion For Drying Grain. ASAE Paper No. 79-4546.

Pennsylvania State University, College of Agricultural Extension Service. Soil Tests, Manure Application, and Legumes, Special Circular 242.

Renewable Technologies, Inc., and Information Now 1986. Montana's Project Permitting Guide. DNRC.

Richey C. B., and Barrett J. R. 1983. Automatic Corncob Feeding Into a Gasifier Furnace. ASAE Paper No. 83-3071.

Richey C. B., Barrett J. R., and Foster G. H. 1982. Biomass Channel-Gasification Furnace. ASAE Transactions, 1982.

Saving Energy on Montana Farms and Ranches, 1987. Montana State Government, Energy Division, Department of Natural Resources and Conservation.

Shaw L. N., Post D. M., and Arnold C. E. 1982. Greenhouse Heating With A Wood Gasifier Furnace. Proc. Fla. State Hort. Soc. 95: 1982.

Skov N. A.,and Papworth M. L. 1980. The Pegasus Unit. Pegasus Publishers Inc., P.O. Box 121 Olympia, Washington 98507.

Sofer S. S., Zaborsky O. R. 1981. Biomass Conversion Process for Energy and Fuels. Plenum Press, New York.

Sumner H. R., Hellwig R. E., and Monroe G. E. 1984. Storing Biomass in Round Bales. Agricultural Engineering 64(9):968-972.

Synergic Resources Corporation and Montana Department of Natural Resources and Conservation 1983. Biomass Cogeneration Workshop. DNRC.

Von Fredersdorff C. G., and Elliot M. A. 1963. Chemistry of Coal Utilization, Supplementary Volume. John Wiley & Sons, New York.

APPENDICES

Appendix A

Small Grain Inventory

WINTER WHEAT -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Har-vested	Yield Per Acre	Pro-duction	Acres Har-vested	Yield Per Acre	Acres Har-vested	Yield Per Acre
			-----Bushels------			-Bu.-		-Bu.-
Flathead.........	6,600	6,400	38.8	248,400	1,300	62.0	5,100	32.9
Lake.............	6,900	6,500	29.6	192,700	1,000	58.0	5,500	24.5
Mineral..........	100	100	24.0	2,400	0	0	100	24.0
Missoula.........	600	500	39.6	19,800	300	50.0	200	24.0
Powell...........	200	200	23.0	4,600	0	0	200	23.0
Ravalli..........	1,100	1,100	29.4	32,300	200	58.0	900	23.0
Sanders..........	1,900	1,500	27.1	40,700	0	0	1,500	27.1
N. WEST	17,400	16,300	33.2	540,900	2,800	59.0	13,500	27.8
Blaine...........	117,500	110,800	27.0	2,991,100	0	0	110,800	27.0
Chouteau.........	336,800	322,600	34.8	11,219,300	200	60.0	322,400	34.8
Glacier..........	13,500	11,500	22.5	258,800	0	0	11,500	22.5
Hill.............	267,800	254,300	24.7	6,289,000	0	0	254,300	24.7
Liberty..........	103,600	96,500	18.7	1,806,600	0	0	96,500	18.7
Phillips.........	58,100	53,600	20.5	1,100,200	200	57.0	53,400	20.4
Pondera..........	120,000	109,700	28.3	3,102,600	2,500	58.0	107,200	27.6
Teton............	141,400	133,300	31.6	4,212,000	2,800	60.0	130,500	31.0
Toole............	92,300	86,200	23.7	2,038,800	0	0	86,200	23.7
N. CENTRAL	1,251,000	1,178,500	28.0	33,018,400	5,700	59.0	1,172,800	27.9
Daniels..........	1,500	1,300	10.8	14,000	0	0	1,300	10.8
Dawson...........	78,700	69,200	22.1	1,530,300	0	0	69,200	22.1
Garfield.........	49,200	43,200	13.2	568,100	0	0	43,200	13.2
McCone...........	93,200	81,600	22.1	1,802,700	0	0	81,600	22.1
Richland.........	67,200	52,800	22.7	1,198,000	0	0	52,800	22.7
Roosevelt........	27,100	24,600	19.8	486,800	100	34.0	24,500	19.7
Sheridan.........	6,400	5,200	21.7	112,700	0	0	5,200	21.7
Valley...........	35,200	30,500	17.4	531,800	100	36.0	30,400	17.4
N. EAST	358,500	308,400	20.2	6,244,400	200	35.0	308,200	20.2
Broadwater.......	29,100	24,500	28.1	687,300	400	52.0	24,100	27.7
Cascade..........	126,700	119,800	33.1	3,964,800	500	39.0	119,300	33.1
Fergus...........	124,400	118,100	29.5	3,479,300	0	0	118,100	29.5
Golden Valley....	37,500	34,800	20.3	706,100	400	45.0	34,400	20.0
Judith Basin.....	61,000	57,800	29.1	1,683,200	0	0	57,800	29.1
Lewis & Clark....	14,900	14,200	28.7	407,400	200	46.0	14,000	28.4
Meagher..........	11,100	10,700	24.5	262,100	0	0	10,700	24.5
Musselshell......	33,900	27,000	18.1	487,700	0	0	27,000	18.1
Petroleum........	8,800	7,800	16.7	130,500	0	0	7,800	16.7
Wheatland........	32,900	30,500	19.5	596,000	0	0	30,500	19.5
CENTRAL	480,300	445,200	27.9	12,404,400	1,500	45.0	443,700	27.8
Beaverhead.......	4,300	3,900	34.2	133,500	100	66.0	3,800	33.4
Gallatin.........	31,000	27,600	42.1	1,162,600	3,200	65.0	24,400	39.1
Jefferson........	5,500	4,800	29.7	142,700	0	0	4,800	29.7
Madison..........	5,600	5,000	28.8	144,100	100	64.0	4,900	28.1
S. WEST	46,400	41,300	38.3	1,582,900	3,400	65.0	37,900	35.9
Big Horn.........	105,800	97,400	27.9	2,721,400	800	46.0	96,600	27.8
Carbon...........	14,000	13,000	29.6	384,700	1,500	51.0	11,500	26.8
Park.............	12,800	11,700	26.5	310,600	300	53.0	11,400	25.9
Stillwater.......	59,100	56,000	22.9	1,284,200	0	0	56,000	22.9
Sweet Grass......	6,800	6,400	21.9	140,100	100	46.0	6,300	21.5
Treasure.........	4,200	4,100	29.0	118,700	300	60.0	3,800	26.5
Yellowstone......	92,800	83,600	27.0	2,256,800	1,200	59.0	82,400	26.5
S. CENTRAL	295,500	272,200	26.5	7,216,500	4,200	53.0	268,000	26.1
Carter...........	40,500	37,000	30.1	1,113,400	0	0	37,000	30.1
Custer...........	36,500	32,000	25.2	806,400	800	38.0	31,200	24.9
Fallon...........	31,600	28,000	28.2	789,600	0	0	28,000	28.2
Powder River.....	31,600	28,800	30.3	872,800	0	0	28,800	30.3
Prairie..........	41,300	34,800	27.3	949,800	200	35.0	34,600	27.2
Rosebud..........	53,500	42,900	24.3	1,040,900	200	35.0	42,700	24.2
Wibaux...........	15,900	14,600	26.0	379,600	0	0	14,600	26.0
S. EAST	250,900	218,100	27.3	5,952,500	1,200	37.0	216,900	27.2
STATE	2,700,000	2,480,000	27.0	66,960,000	19,000	56.0	2,461,000	26.8

Figure 41. Winter wheat production in Montana, 1984. Montana Crop and Livestock Reporting Service, 1985.

SPRING WHEAT OTHER THAN DURUM -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES – IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested	Yield Per Acre	Production	Acres Harvested	Yield Per Acre	Acres Harvested	Yield Per Acre
			-----Bushels-----			-Bu.-		-Bu.-
Deerlodge.......	300	300	26.0	7,800	0	0	300	26.0
Flathead........	900	900	62.0	55,800	900	62.0	0	0
Granite.........	300	300	25.0	7,500	0	0	300	25.0
Lake............	3,100	3,000	49.6	148,700	2,400	56.0	600	23.7
Missoula........	500	500	57.2	28,600	400	64.0	100	30.0
Powell..........	500	500	28.0	14,000	0	0	500	28.0
Ravalli.........	1,300	1,300	57.0	74,100	1,300	57.0	0	0
Sanders.........	500	300	27.0	8,100	0	0	300	27.0
N. WEST	7,400	7,100	48.5	344,600	5,000	58.0	2,100	26.0
Blaine..........	71,400	65,500	19.0	1,245,400	3,500	38.0	62,000	17.9
Chouteau........	123,300	115,000	24.1	2,776,400	5,000	51.0	110,000	22.9
Glacier.........	115,200	91,500	10.3	938,900	1,300	37.0	90,200	9.9
Hill............	187,300	159,100	14.8	2,357,400	2,400	52.0	156,700	14.2
Liberty.........	118,700	112,200	12.1	1,358,600	500	38.0	111,700	12.0
Phillips........	84,600	78,400	16.5	1,291,900	3,100	36.0	75,300	15.7
Pondera.........	37,500	35,700	17.0	606,300	4,200	42.0	31,500	13.7
Teton...........	32,700	30,300	23.2	702,800	6,500	50.0	23,800	15.9
Toole...........	92,600	88,400	10.9	965,600	0	0	88,400	10.9
N. CENTRAL	863,300	776,100	15.8	12,243,300	26,500	45.0	749,600	14.7
Daniels.........	172,700	167,100	10.9	1,819,800	0	0	167,100	10.9
Dawson..........	65,000	61,900	18.9	1,168,100	0	0	61,900	18.9
Garfield........	40,000	34,000	12.4	421,700	400	50.0	33,600	12.0
McCone..........	90,900	88,200	22.0	1,938,800	3,100	53.0	85,100	20.9
Richland........	83,700	80,600	20.4	1,644,500	3,300	63.0	77,300	18.6
Roosevelt.......	201,300	193,400	14.9	2,888,400	4,200	58.0	189,200	14.0
Sheridan........	95,000	88,400	18.4	1,625,500	1,400	55.0	87,000	17.8
Valley..........	208,000	200,700	16.2	3,255,900	5,200	66.0	195,500	14.9
N. EAST	956,600	914,300	16.1	14,762,700	17,600	60.0	896,700	15.3
Broadwater......	11,300	10,800	47.4	512,000	6,600	63.0	4,200	22.9
Cascade.........	53,400	42,400	21.4	906,500	4,200	51.0	38,200	18.1
Fergus..........	14,600	12,500	14.4	180,100	300	53.0	12,200	13.5
Golden Valley...	900	900	24.4	22,000	300	48.0	600	12.7
Judith Basin....	11,100	10,700	17.7	189,100	100	57.0	10,600	17.3
Lewis & Clark...	1,600	1,600	38.3	61,200	800	60.0	800	16.5
Meagher.........	800	800	14.5	11,600	0	0	800	14.5
Musselshell.....	800	800	8.0	6,400	0	0	800	8.0
Petroleum.......	800	700	8.0	5,600	0	0	700	8.0
Wheatland.......	3,600	2,500	16.2	40,600	100	52.0	2,400	14.8
CENTRAL	98,900	83,700	23.1	1,935,100	12,400	58.0	71,300	17.1
Beaverhead......	6,000	5,900	54.5	321,800	5,100	59.0	800	26.1
Gallatin........	12,900	12,600	43.4	547,300	5,200	62.0	7,400	30.4
Jefferson.......	1,400	1,400	36.3	50,800	200	56.0	1,200	33.0
Madison.........	4,200	3,900	42.2	164,700	2,500	53.0	1,400	23.0
S. WEST	24,500	23,800	45.6	1,084,600	13,000	59.0	10,800	29.4
Big Horn........	20,200	19,800	31.8	630,100	5,100	62.0	14,700	21.4
Carbon..........	6,700	6,700	42.9	287,300	4,200	55.0	2,500	22.5
Park............	1,500	1,500	32.3	48,400	500	52.0	1,000	22.4
Stillwater......	3,900	3,900	19.1	74,500	100	59.0	3,800	18.1
Sweet Grass.....	300	300	30.3	9,100	100	52.0	200	19.5
Treasure........	3,000	3,000	50.3	150,900	2,100	65.0	900	16.0
Yellowstone.....	6,200	6,000	36.4	218,200	2,600	62.0	3,400	16.8
S. CENTRAL	41,800	41,200	34.4	1,418,500	14,700	60.0	26,500	20.2
Carter..........	5,600	5,200	17.7	91,800	0	0	5,200	17.7
Custer..........	10,500	10,300	31.4	323,000	1,700	59.0	8,600	25.9
Fallon..........	38,600	37,700	21.9	826,100	800	39.0	36,900	21.5
Powder River....	2,400	2,100	23.5	49,300	100	43.0	2,000	22.5
Prairie.........	2,300	2,200	18.1	39,800	0	0	2,200	18.1
Rosebud.........	8,700	8,400	24.7	207,600	1,200	61.0	7,200	18.7
Wibaux..........	39,400	37,900	21.1	798,600	0	0	37,900	21.1
S. EAST	107,500	103,800	22.5	2,336,200	3,800	55.0	100,000	21.3
STATE	2,100,000	1,950,000	17.5	34,125,000	93,000	55.0	1,857,000	15.6

Figure 42. Spring wheat production in Montana, 1984. Montana Crop and Livestock Reporting Service, 1985.

DURUM WHEAT -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested	Yield Per Acre -----Bushels-----	Production -----Bushels-----	Acres Harvested	Yield Per Acre -Bu.-	Acres Harvested	Yield Per Acre -Bu.-
Blaine...........	600	600	23.0	13,800	0	0	600	23.0
Chouteau.........	3,600	3,500	25.4	89,000	0	0	3,500	25.4
Glacier..........	800	800	18.0	14,400	0	0	800	18.0
Hill.............	400	400	16.0	6,400	0	0	400	16.0
Liberty..........	600	600	14.0	8,400	0	0	600	14.0
Phillips.........	100	100	15.0	1,500	0	0	100	15.0
Pondera..........	19,400	18,800	19.9	373,200	1,200	67.0	17,600	16.6
Teton............	3,300	3,300	28.9	95,500	800	62.0	2,500	18.4
Toole............	22,100	21,300	17.8	379,400	0	0	21,300	17.8
N. CENTRAL	50,900	49,400	19.9	981,600	2,000	65.0	47,400	18.0
Daniels..........	4,300	3,900	15.8	61,600	0	0	3,900	15.8
Dawson...........	900	900	19.0	17,100	0	0	900	19.0
McCone...........	1,500	1,500	13.0	19,500	0	0	1,500	13.0
Richland.........	900	900	18.0	16,200	0	0	900	18.0
Roosevelt........	27,400	26,500	16.0	423,500	0	0	26,500	16.0
Sheridan.........	123,300	121,300	16.1	1,949,200	600	52.0	120,700	15.9
Valley...........	2,100	2,000	16.0	32,000	0	0	2,000	16.0
N. EAST	160,400	157,000	16.0	2,519,100	600	52.0	156,400	15.9
Cascade..........	1,100	1,100	18.6	20,500	0	0	1,100	18.6
CENTRAL	1,100	1,100	18.6	20,500	0	0	1,100	18.6
Carter...........	100	100	19.0	1,900	0	0	100	19.0
Custer...........	100	100	20.0	2,000	0	0	100	20.0
Fallon...........	500	500	17.0	8,500	0	0	500	17.0
Wibaux...........	1,900	1,800	20.2	36,400	0	0	1,800	20.2
S. EAST	2,600	2,500	19.5	48,800	0	0	2,500	19.5
STATE	215,000	210,000	17.0	3,570,000	2,600	62.0	207,400	16.4

Figure 43. Durum production in Montana, 1984.
Montana Crop and Livestock Reporting Service, 1985.

BARLEY -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Har-vested	Yield Per Acre	Production	Acres Har-vested	Yield Per Acre	Acres Har-vested	Yield Per Acre
			------Bushels------			-Bu.-		-Bu.-
Deer Lodge......	2,400	2,400	54.3	130,200	1,500	67.0	900	33.0
Flathead........	31,300	30,500	59.5	1,814,700	20,000	69.0	10,500	41.4
Granite.........	600	500	68.0	34,000	500	68.0	0	0
Lake............	12,500	12,200	48.6	593,400	5,000	63.0	7,200	38.7
Lincoln.........	100	100	68.0	6,800	100	68.0	0	0
Mineral.........	100	100	34.0	3,400	0	0	100	34.0
Missoula........	3,600	3,500	51.5	180,400	2,500	60.0	1,000	30.4
Powell..........	6,200	6,100	54.4	332,000	3,200	70.0	2,900	37.2
Ravalli.........	6,100	5,800	60.6	351,600	4,200	73.0	1,600	28.1
Sanders.........	2,100	1,500	33.4	50,100	300	65.0	1,200	25.5
N.WEST	65,000	62,700	55.8	3,496,600	37,300	68.0	25,400	37.8
Blaine..........	67,000	57,200	25.8	1,475,700	3,100	50.0	54,100	24.4
Chouteau........	290,700	260,100	28.6	7,433,300	1,200	50.0	258,900	28.5
Glacier.........	123,000	91,500	19.3	1,769,400	7,500	54.0	84,000	16.2
Hill............	109,700	96,300	19.5	1,877,500	2,000	62.0	94,300	18.6
Liberty.........	103,000	85,000	14.4	1,225,800	0	0	85,000	14.4
Phillips........	50,400	45,400	22.8	1,035,200	2,000	51.0	43,400	21.5
Pondera.........	156,700	145,700	29.1	4,233,500	21,600	61.0	124,100	23.5
Teton...........	139,800	136,100	36.3	4,938,000	41,500	62.0	94,600	25.0
Toole...........	101,500	91,700	17.4	1,591,200	300	52.0	91,400	17.2
N. CENTRAL	1,141,800	1,009,000	25.4	25,579,600	79,200	60.0	929,800	22.4
Daniels.........	42,000	34,700	14.6	506,400	0	0	34,700	14.6
Dawson..........	39,200	34,700	26.3	911,600	400	52.0	34,300	26.0
Garfield........	28,400	25,000	17.6	439,300	100	63.0	24,900	17.4
McCone..........	36,000	32,900	26.6	874,200	300	56.0	32,600	26.3
Richland........	31,700	28,700	27.4	785,800	1,100	69.0	27,600	25.7
Roosevelt.......	44,400	39,600	17.9	710,000	700	54.0	38,900	17.3
Sheridan........	47,100	42,400	18.0	764,100	0	0	42,400	18.0
Valley..........	86,800	81,200	18.8	1,525,400	1,400	56.0	79,800	18.1
N. EAST	355,600	319,200	20.4	6,516,800	4,000	59.0	315,200	19.9
Broadwater......	19,500	19,000	43.7	831,100	7,400	62.0	11,600	32.1
Cascade.........	84,300	82,700	30.0	2,480,800	11,300	61.0	71,400	25.1
Fergus..........	148,800	143,400	24.3	3,487,500	1,200	46.0	142,200	24.1
Golden Valley...	13,800	13,300	17.3	229,800	700	54.0	12,600	15.2
Judith Basin....	89,800	86,500	28.3	2,451,700	2,400	43.0	84,100	27.9
Lewis & Clark...	11,400	9,900	43.2	427,300	5,000	58.0	4,900	28.0
Meagher.........	20,400	20,400	25.1	511,700	1,800	49.0	18,600	22.8
Musselshell.....	12,000	9,500	18.2	173,100	700	47.0	8,800	15.9
Petroleum.......	5,000	4,200	17.2	72,400	300	57.0	3,900	14.2
Wheatland.......	17,300	15,600	16.2	253,200	1,200	43.0	14,400	14.0
CENTRAL	422,300	404,500	27.0	10,918,600	32,000	57.0	372,500	24.4
Beaverhead......	15,400	13,900	44.6	620,100	7,700	63.0	6,200	21.8
Gallatin........	65,200	62,600	55.0	3,444,800	22,800	75.0	39,800	43.6
Jefferson.......	2,700	2,300	46.9	107,900	900	67.0	1,400	34.0
Madison.........	11,300	10,300	62.6	644,300	7,500	73.0	2,800	34.6
Silver Bow......	300	300	65.0	19,500	300	65.0	0	0
S. WEST	94,900	89,400	54.1	4,836,600	39,200	72.0	50,200	40.1
Big Horn........	40,900	40,600	32.9	1,335,800	4,100	72.0	36,500	28.5
Carbon..........	15,900	15,500	50.1	776,100	6,900	79.0	8,600	26.9
Park............	16,300	15,700	36.3	569,400	2,900	69.0	12,800	28.9
Stillwater......	26,400	25,900	30.0	777,700	1,300	77.0	24,600	27.5
Sweet Grass.....	6,200	5,000	32.9	164,400	1,000	66.0	4,000	24.6
Treasure........	2,800	2,800	68.9	192,900	2,300	78.0	500	27.0
Yellowstone.....	50,700	48,700	36.5	1,777,700	10,000	78.0	38,700	25.8
S. CENTRAL	159,200	154,200	36.3	5,594,000	28,500	76.0	125,700	27.3
Carter..........	9,500	8,300	32.8	272,500	0	0	8,300	32.8
Custer..........	7,700	6,500	29.8	193,900	800	73.0	5,700	23.8
Fallon..........	13,800	12,600	34.7	437,500	0	0	12,600	34.7
Powder River....	8,600	7,900	26.2	207,100	0	0	7,900	26.2
Prairie.........	15,500	13,700	25.6	351,200	1,300	52.0	12,400	22.9
Rosebud.........	17,600	15,900	29.9	476,100	2,700	60.0	13,200	23.8
Wibaux..........	8,500	6,100	32.7	199,500	0	0	6,100	32.7
S. EAST	81,200	71,000	30.1	2,137,800	4,800	60.0	66,200	27.9
STATE	2,320,000	2,110,000	28.0	59,080,000	225,000	65.0	1,885,000	23.6

Figure 44. Barley production in Montana, 1984.
Montana Crop and Livestock Reporting Service, 1985.

OATS -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested For Grain	Yield Per Acre	Production	Acres Har-vested	Yield Per Acre	Acres Har-vested	Yield Per Acre
			---------Bu.---------			-Bu.-		-Bu.-
Deer Lodge......	0	0	0	0	0	0	0	0
Flathead........	1,800	900	36.9	33,200	500	48.0	400	23.0
Granite.........	300	200	45.0	9,000	200	45.0	0	0
Lake............	2,800	2,400	54.3	130,400	2,000	60.0	400	26.0
Lincoln.........	400	200	43.0	8,600	200	43.0	0	0
Mineral.........	400	100	34.0	3,400	0	0	100	34.0
Missoula........	1,300	1,000	46.0	46,000	600	60.0	400	25.0
Powell..........	1,000	800	40.0	32,000	400	55.0	400	25.0
Ravalli.........	1,700	1,200	56.5	67,800	1,000	63.0	200	24.0
Sanders.........	1,800	800	40.3	32,200	500	50.0	300	24.0
N.WEST	11,500	7,600	47.7	362,600	5,400	57.0	2,200	25.0
Blaine..........	8,800	3,100	34.0	105,300	1,000	57.0	2,100	23.0
Chouteau........	5,500	2,900	23.0	66,800	100	52.0	2,800	22.0
Glacier.........	2,500	1,000	31.2	31,200	200	56.0	800	25.0
Hill............	9,200	1,700	30.9	52,600	400	47.0	1,300	26.0
Liberty.........	2,300	500	22.0	11,000	0	0	500	22.0
Phillips........	15,000	2,900	30.8	89,300	700	49.0	2,200	25.0
Pondera.........	1,700	1,300	32.5	42,300	300	51.0	1,000	27.0
Teton...........	2,200	1,500	26.2	39,300	200	47.0	1,300	23.0
Toole...........	2,300	1,500	26.5	39,800	100	48.0	1,400	25.0
N. CENTRAL	49,500	16,400	29.1	477,600	3,000	52.0	13,400	24.0
Daniels.........	6,100	1,200	23.0	27,600	0	0	1,200	23.0
Dawson..........	5,800	3,200	31.5	100,800	200	69.0	3,000	29.0
Garfield........	8,100	3,000	20.0	60,000	0	0	3,000	20.0
McCone..........	6,000	2,600	22.4	58,200	100	57.0	2,500	21.0
Richland........	10,700	6,300	37.2	234,100	1,000	70.0	5,300	31.0
Roosevelt.......	11,700	3,900	26.2	102,300	500	55.0	3,400	22.0
Sheridan........	10,900	3,500	26.1	91,300	400	50.0	3,100	23.0
Valley..........	9,400	4,000	25.8	103,100	100	56.0	3,900	25.0
N.EAST	68,700	27,700	28.1	777,400	2,300	62.0	25,400	25.0
Broadwater......	1,500	1,200	61.5	73,800	1,000	68.0	200	29.0
Cascade.........	3,800	1,900	29.8	56,600	400	44.0	1,500	26.0
Fergus..........	8,600	4,000	31.7	126,600	200	44.0	3,800	31.0
Golden Valley...	3,700	2,100	29.3	61,500	400	56.0	1,700	23.0
Judith Basin....	5,000	3,300	31.4	103,600	100	44.0	3,200	31.0
Lewis & Clark...	2,000	1,400	58.0	81,200	1,400	58.0	0	0
Meagher.........	2,500	1,200	36.0	43,200	600	45.0	600	27.0
Musselshell.....	3,600	2,000	37.3	74,600	900	56.0	1,100	22.0
Petroleum.......	1,200	400	41.3	16,500	300	47.0	100	24.0
Wheatland.......	1,400	900	29.0	26,100	200	43.0	700	25.0
CENTRAL	33,300	18,400	36.1	663,700	5,500	55.0	12,900	28.0
						0	0	0
Beaverhead......	1,800	1,000	69.5	69,500	700	80.0	300	45.0
Gallatin........	2,800	2,200	61.5	135,300	1,300	75.0	900	42.0
Jefferson.......	2,400	800	49.3	39,400	600	56.0	200	29.0
Madison.........	3,800	800	63.1	50,500	700	68.0	100	29.0
Silver Bow......	200	100	67.0	6,700	100	67.0	0	0
S.WEST	11,000	4,900	61.5	301,400	3,400	71.0	1,500	40.0
Big Horn........	2,300	2,000	46.0	92,000	200	82.0	1,800	42.0
Carbon..........	1,900	1,300	56.2	73,100	800	72.0	500	31.0
Park............	1,500	1,100	62.6	68,900	900	69.0	200	34.0
Stillwater......	1,500	1,200	38.5	46,200	200	76.0	1,000	31.0
Sweet Grass.....	3,000	1,500	53.5	80,200	800	67.0	700	38.0
Treasure........	500	500	74.6	37,300	400	82.0	100	45.0
Yellowstone.....	2,800	2,700	35.9	96,800	400	81.0	2,300	28.0
S.CENTRAL	13,500	10,300	48.0	494,500	3,700	73.0	6,600	34.0
Carter..........	4,500	2,500	35.0	87,500	0	0	2,500	35.0
Custer..........	4,600	3,100	46.9	145,400	1,300	62.0	1,800	36.0
Fallon..........	4,800	2,400	39.9	95,800	200	50.0	2,200	39.0
Powder River....	3,700	3,200	41.0	131,300	300	51.0	2,900	40.0
Prairie.........	4,200	2,000	39.5	79,000	300	65.0	1,700	35.0
Rosebud.........	2,500	2,300	43.2	99,400	1,500	46.0	800	38.0
Wibaux..........	8,200	4,200	40.3	169,400	100	54.0	4,100	40.0
S.EAST	32,500	19,700	41.0	807,800	3,700	54.0	16,000	38.0
STATE	220,000	105000	37.0	3,885,000	27,000	60.0	78,000	29.0

Figure 45. Oats production in Montana, 1984.
Montana Crop and Livestock Reporting Service, 1985.

Appendix B

Wood Inventory

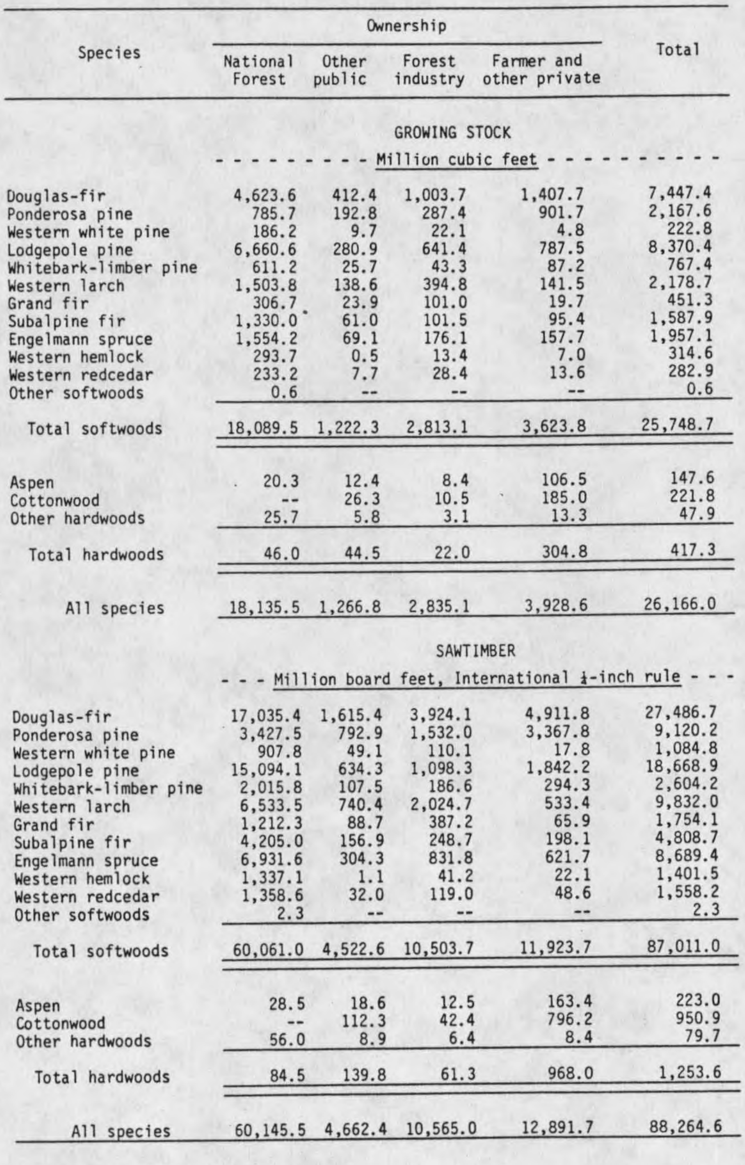
Tree Species Native To Montana

Coniferous

- Grand fir
- Subalpine fir
- Utah juniper
- Rocky Mountain juniper
- Subalpine larch
- Western larch
- Engelmann spruce
- White spruce
- Whitebark pine
- Lodgepole pine
- Limber pine
- Western white pine
- Ponderosa pine
- Douglas-fir
- Western red cedar
- Western hemlock
- Mountain hemlock

Deciduous

- Boxelder
- Paper birch
- Green ash
- Balsam popular
- Eastern cottonwood
- Black cotton wood
- Quaking aspen
- Casara buckthorn
- Peachleaf willow
- American elm



Species	Ownership				Total
	National Forest	Other public	Forest industry	Farmer and other private	
	GROWING STOCK				
	Million cubic feet				
Douglas-fir	4,623.6	412.4	1,003.7	1,407.7	7,447.4
Ponderosa pine	785.7	192.8	287.4	901.7	2,167.6
Western white pine	186.2	9.7	22.1	4.8	222.8
Lodgepole pine	6,660.6	280.9	641.4	787.5	8,370.4
Whitebark-limber pine	611.2	25.7	43.3	87.2	767.4
Western larch	1,503.8	138.6	394.8	141.5	2,178.7
Grand fir	306.7	23.9	101.0	19.7	451.3
Subalpine fir	1,330.0	61.0	101.5	95.4	1,587.9
Engelmann spruce	1,554.2	69.1	176.1	157.7	1,957.1
Western hemlock	293.7	0.5	13.4	7.0	314.6
Western redcedar	233.2	7.7	28.4	13.6	282.9
Other softwoods	0.6	--	--	--	0.6
Total softwoods	18,089.5	1,222.3	2,813.1	3,623.8	25,748.7
Aspen	20.3	12.4	8.4	106.5	147.6
Cottonwood	--	26.3	10.5	185.0	221.8
Other hardwoods	25.7	5.8	3.1	13.3	47.9
Total hardwoods	46.0	44.5	22.0	304.8	417.3
All species	18,135.5	1,266.8	2,835.1	3,928.6	26,166.0
	SAWTIMBER				
	Million board feet, International ¼-inch rule				
Douglas-fir	17,035.4	1,615.4	3,924.1	4,911.8	27,486.7
Ponderosa pine	3,427.5	792.9	1,532.0	3,367.8	9,120.2
Western white pine	907.8	49.1	110.1	17.8	1,084.8
Lodgepole pine	15,094.1	634.3	1,098.3	1,842.2	18,668.9
Whitebark-limber pine	2,015.8	107.5	186.6	294.3	2,604.2
Western larch	6,533.5	740.4	2,024.7	533.4	9,832.0
Grand fir	1,212.3	88.7	387.2	65.9	1,754.1
Subalpine fir	4,205.0	156.9	248.7	198.1	4,808.7
Engelmann spruce	6,931.6	304.3	831.8	621.7	8,689.4
Western hemlock	1,337.1	1.1	41.2	22.1	1,401.5
Western redcedar	1,358.6	32.0	119.0	48.6	1,558.2
Other softwoods	2.3	--	--	--	2.3
Total softwoods	60,061.0	4,522.6	10,503.7	11,923.7	87,011.0
Aspen	28.5	18.6	12.5	163.4	223.0
Cottonwood	--	112.3	42.4	796.2	950.9
Other hardwoods	56.0	8.9	6.4	8.4	79.7
Total hardwoods	84.5	139.8	61.3	968.0	1,253.6
All species	60,145.5	4,662.4	10,565.0	12,891.7	88,264.6

Figure. 46 Net volume of growing stock and sawtimber on commercial timberland in Montana, 1980. A. W. Green et al., 1985.

Appendix C

Economic Spreadsheet Program

```
*****************************************************************************************************
                              BIOMASS GASIFICATION ECONOMIC SPREADSHEET
                                    BY CLINTON MOLDE    1/29/87
*****************************************************************************************************

          SYSTEM:                   DOWNDRAFT GASIFIER/ENGINE SYSTEM
          APPLICATION:              IRRIGATION PUMPING
          SYSTEM VARIATION:         BASE CASE

          SYSTEM HOURS:                  1000 HOURS/YEAR
          ELECTRIC CAPACITY:                0 kW
          COST PER UNIT:                 0.00 DOLLARS/kW
            COST INCREASE:                  5 PRECENT/YEAR

          INSTALLED COST:              100000 DOLLARS
          INT. INVEST.:                    20 PERCENT
          SYSTEM LIFE:                     10 YEARS
          SALVAGE VALUE:                    0 DOLLARS
          LOAN RATE:                        8 PERCENT/YEAR
          LOAN SCHEDULE:                   10 YEARS
          TAXES FEDERAL:                   30 PERCENT
          TAXES STATE:                      7 PERCENT
          DISCOUNT RATE:                   12 PERCENT

          SUPPLY COST:                   1000 DOLLARS
            COST INCREASE:                  5 PRECENT/YEAR
          REPAIR & MAINT.:               2000 DOLLARS
            COST INCREASE:                  6 PRECENT/YEAR
          INSURANCE:                     1000 DOLLARS
            COST INCREASE:                  6 PRECENT/YEAR
          PROPERTY TAXES:                   0 PERCENT
          FEEDSTOCK COST:               16940 DOLLARS
            COST INCREASE:                  2 PRECENT/YEAR
          LABOR COST:                    2000 DOLLARS
            COST INCREASE:                  5 PRECENT/YEAR

          EST. FUEL DISPL.:             10540 DOLLARS
            COST INCREASE:                  7 PRECENT/YEAR

          FED. INVEST TAX CREDIT:          10 PERCENT
            NUMBER OF YEARS:                1 YEARS
          FED. ENERGY CREDIT:               0 PRECENT
            NUMBER OF YEARS:                0 YEARS
          STATE ENERGY CREDIT:              0 PRECENT
            NUMBER OF YEARS:                0 YEARS

*****************************************************************************************************

                       % YEARLY
                       INCREASE YEAR 0  YEAR 1  YEAR 2  YEAR 3  YEAR 4  YEAR 5  YEAR 6  YEAR 7  YEAR 8  YEAR 9  YEAR 10
                       -------- -----------------------------------------------------------------------------------
PROJECTED INCOME
  ELECTRICITY                 5       0       0       0       0       0       0       0       0       0       0       0
                                -------  ------  ------  ------  ------  ------  ------  ------  ------  ------  ------
  TOTAL INCOME                        0       0       0       0       0       0       0       0       0       0       0


PROJECTED EXPENSES:
  DEDUCTABLE ITEMS:
      DEPRECIATION          ---       0   10000   10000   10000   10000   10000   10000   10000   10000   10000   10000
      INTEREST              ---       0    6400    5958    5481    4966    4409    3808    3159    2458    1701     883
      OPERATING COSTS         5       0    1000    1050    1103    1158    1216    1276    1340    1407    1477    1551
      REPAIR & MAINT.         6       0    2000    2120    2247    2382    2525    2676    2837    3007    3188    3379
      INSURANCE               6       0    1000    1060    1124    1191    1262    1338    1419    1504    1594    1689
      PROPERTY TAXES        ---       0
      FEEDSTOCK               2       0   16940   17279   17624   17977   18336   18703   19077   19459   19848   20245
      LABOR                   5       0    2000    2100    2205    2315    2431    2553    2680    2814    2955    3103
                                -------  ------  ------  ------  ------  ------  ------  ------  ------  ------  ------
  SUM OF DEDUCTABLE ITEMS             0   39340   39567   39784   39989   40180   40355   40512   40649   40763   40850

  NONDEDUCTABLE ITEMS:
      INITIAL INVEST        ---   20000     ---     ---     ---     ---     ---     ---     ---     ---     ---     ---
      PRINCIPAL ON LOAN     ---       0    5522    5964    6441    6957    7513    8114    8763    9464   10222   11039
                                -------  ------  ------  ------  ------  ------  ------  ------  ------  ------  ------
  SUM OF NONDEDUCTABLE ITEMS      20000    5522    5964    6441    6957    7513    8114    8763    9464   10222   11039


  SUM OF DEDUCTABLE ITEMS             0   39340   39567   39784   39989   40180   40355   40512   40649   40763   40850
  SUM OF NONDEDUCTABLE ITEMS      20000    5522    5964    6441    6957    7513    8114    8763    9464   10222   11039
                                -------  ------  ------  ------  ------  ------  ------  ------  ------  ------  ------
  TOTAL EXPENSES                  20000   44862   45531   46225   46945   47693   48469   49275   50113   50984   51890

  TOTAL CASH OUTLAYS              20000   34862   35531   36225   36945   37693   38469   39275   40113   40984   41890


  EST. FUEL DISPLACEMENT      7       0   10540   11278   12067   12912   13816   14783   15818   16925   18110   19377
  ACT. DISPLACEMENT CREDIT  ---       0   10540   11278   12067   12912   13816   14783   15818   16925   18110   19377
```

Figure 47. Economic spreadsheet program.
Formatted after Boyette and McKusick, 1986.

```
*****************************************************************************************************************************

                                       YEAR 0  YEAR 1  YEAR 2  YEAR 3  YEAR 4  YEAR 5  YEAR 6  YEAR 7  YEAR 8  YEAR 9 YEAR 10
                                     ----------------------------------------------------------------------------------------
PROJECTED TAXES:
   NET TAXABLE INCOME                       0  -39340  -39567  -39784  -39989  -40180  -40355  -40512  -40649  -40763  -40850

   NET FED. TAX (- SAVING)                  0  -11802  -11870  -11935  -11997  -12054  -12106  -12154  -12195  -12229  -12255
   NET STATE TAX (- SAVING)                 0   -2754   -2770   -2785   -2799   -2813   -2825   -2836   -2845   -2853   -2860
   FED. INVEST TAX CREDIT                   0  -10000       0       0       0       0       0       0       0       0       0
   FED. ENERGY CREDIT                       0       0       0       0       0       0       0       0       0       0       0
   STATE ENERGY CREDIT                      0       0       0       0       0       0       0       0       0       0       0
                                      ------- ------- ------- ------- ------- ------- ------- ------- ------- ------- -------
   TOTAL TAX                                0  -24556  -14640  -14720  -14796  -14866  -14931  -14989  -15040  -15082  -15115
*****************************************************************************************************************************

                                       YEAR 0  YEAR 1  YEAR 2  YEAR 3  YEAR 4  YEAR 5  YEAR 6  YEAR 7  YEAR 8  YEAR 9 YEAR 10
                                     ----------------------------------------------------------------------------------------
CASH FLOW PROJECTION:
   CASH SALES                               0       0       0       0       0       0       0       0       0       0       0
   FUEL DISPLACEMENT CREDIT                 0   10540   11278   12067   12912   13816   14783   15818   16925   18110   19377
   INCOME TAX (+ CREDIT)                    0   24556   14640   14720   14796   14866   14931   14989   15040   15082   15115
                                      ------- ------- ------- ------- ------- ------- ------- ------- ------- ------- -------
   TOTAL RECEIPTS                           0   35096   25918   26787   27708   28682   29714   30807   31965   33192   34492
   TOTAL EXPENSES                       20000   34862   35531   36225   36945   37693   38469   39275   40113   40984   41890
                                      ------- ------- ------- ------- ------- ------- ------- ------- ------- ------- -------
   NET YEARLY CASH FLOW                -20000     233   -9614   -9438   -9237   -9010   -8755   -8468   -8148   -7792   -7398
   CUMM. CASH FLOW W/O INIT. INVEST.      ---     233   -9380  -18818  -28055  -37066  -45821  -54289  -62437  -70229  -77627
   CUMM. CASH FLOW WITH INIT. INVEST   -20000  -19767  -29380  -38818  -48055  -57066  -65821  -74289  -82437  -90229  -97627
   NET PRESENT VALUE                   -20000  -19792  -27455  -34173  -40044  -45156  -49592  -53422  -56713  -59523  -61905

*****************************************************************************************************************************
*****************************************************************************************************************************
```