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.

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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.

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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.

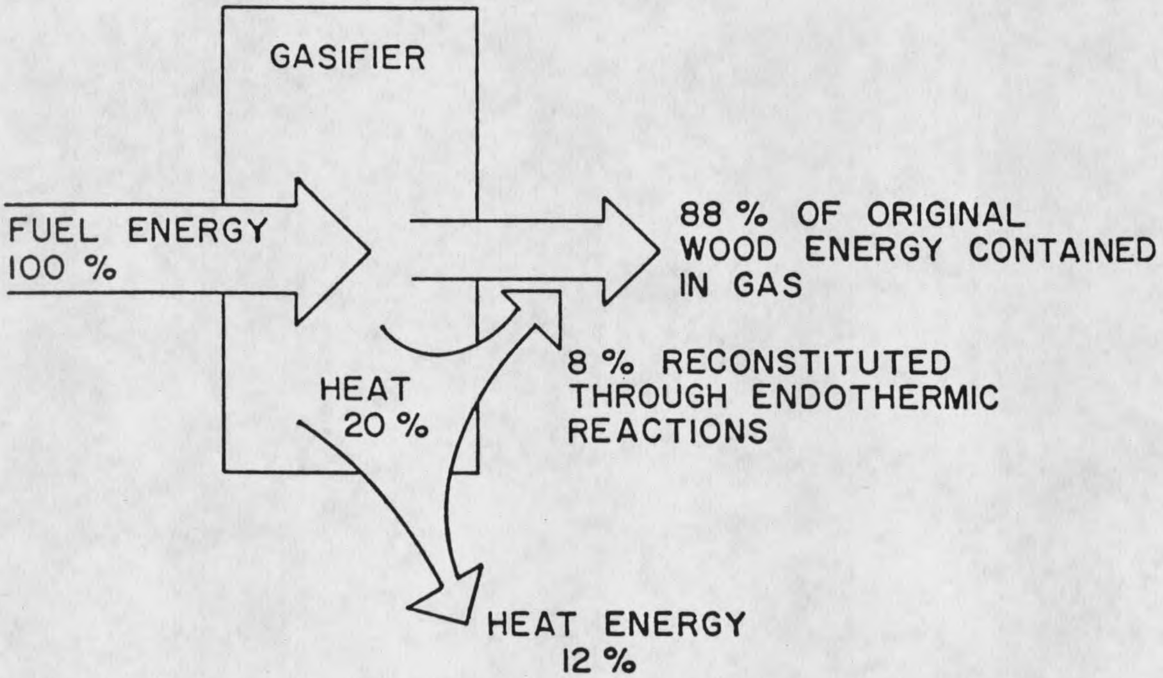

Figure 1. Gasification energy balance.
Boyette and McKusick, 1986.

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.

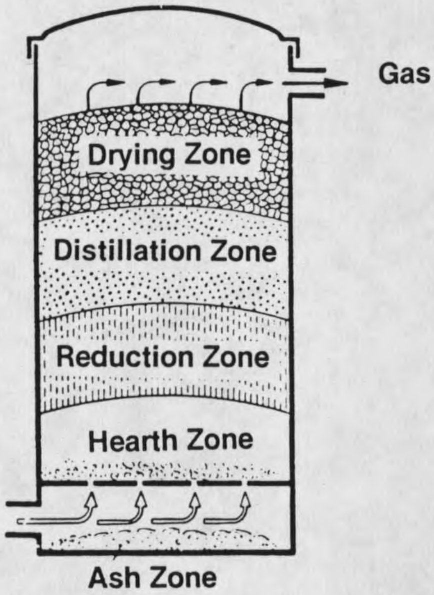

Figure 2. Fixed-bed updraft gasifier.
Skov and Papworth, 1980.

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