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The Economic Potential of On-Farm Biomass
Gasification for Corn Drying

presented by

Otto John Loewer

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J Roy Black
Major professor

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THE ECONOMIC POTENTIAL OF ON-FARM BIOMASS GASIFICATION FOR CORN DRYING

By

Otto John Loewer

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ABSTRACT

THE ECONOMIC POTENTIAL OF ON-FARM BIOMASS

GASIFICATION FOR CORN DRYING

By

Otto John Loewer

Computations indicate that sufficient energy exists in grain, cobs and stover so that the gasification process may be used to dry corn over the range of moisture contents typical at harvest. It was found that as much as 38.9¢ and 23.5¢ per U.S. No. 2 bushel could be invested in gasification equipment when using cobs and stover, respectively, as sources of energy when removing 10 points of moisture and using representative values for essential physical and economic parameters. Grain could be used as an economical fuel source only if it were subsidized by the equivalent of 37.6¢ per bushel dried. This analysis indicated that cobs would be the best source of biomass fuel for grain drying followed by stover and grain. However, it is unlikely that grain could ever compete with cobs or stover as an energy source.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Early harvesting of corn reduces the field losses associated with adverse weather and insects, and may enhance the price received at harvest time. In most areas of the country, early harvested corn must be dried if it is to be stored safely. The primary fuel sources for corn drying are liquid petroleum (LP) gas and natural gas, both of which burn cleanly and are utilized in directly fired systems. The returns to heated air drying are inversely proportional to the cost of LP and natural gas. Should the prices of these fuels become sufficiently high, substitute energy sources and technologies may develop. One such alternative is the gasification of crop residue.

Gasification is the process by which biomass is burned while controlling the air supply to the material. This process results in a combustible gas that may be ignited and mixed with ambient air to provide the heated air necessary for grain drying.

Biomass gasification equipment is not currently being manufactured for use in crop drying. How much can manufacturers charge or farmers afford to pay for this equipment? The primary objective of this study is to answer this question by determining the breakeven investment for biomass gasification equipment used in corn drying. For this study only corn grain, stover and cobs will be evaluated as sources of energy, and uses of the gasification equipment for purposes other than grain drying will not be considered. The break-even investment will be determined for one bushel of U.S. No. 2 corn defined as 56 pounds of grain at 15.5 percent moisture content. Storage of biomass will not be evaluated.

The study begins by presenting an overview of the economic and energy considerations associated with corn drying followed by a discussion of biomass gasification technology. The break-even investment for gasification equipment is partially a function of biomass and energy availability; thus, Chapters III and IV investigate the technical feasibility of using biomass as an energy source for corn drying. This portion of the analysis is structured so as to determine the quantities of biomass and energy available and required for drying one bushel of corn over a range of moisture contents and energy conversion efficiencies. Chapter V addresses the economic considerations associated with gasification of corn biomass including gross return, harvesting and transportation costs, soil productivity, alternative uses for biomass, gasification equipment costs and break-even investment determination. In Chapter VI the sensitivity of break-even investment to changes in technology and prices is computed. The summary and conclusions from the study are given in Chapter VII. An example drying situation is periodically used in Chapters IV-VI to demonstrate the procedures used for determining the break-even investments reported in Chapter VII.

CHAPTER II

CORN DRYING: ECONOMIC AND ENERGY CONSIDERATIONS

The drying of corn enables the farmer to significantly reduce his harvest and storage losses. This gain in physical production efficiency is obtained by extensive use of fossil energy, primarily liquid petroleum (LP) gas.

In 1974, the United States produced approximately 4.7 billion bushels of corn (Statistical Reporting Service, USDA). Nelson (1975) reported that nearly one billion gallons of LP gas were used that year in drying feed and food grains, primarily corn. This translates to approximately 0.2 gallons of LP gas to dry each bushel, and would be sufficient to remove 10 points of moisture. Using 1977 corn production levels (6.4 billion bu), and assuming the same energy usage per bushel, LP gas consumption for drying would have increased to 1.27 billion gallons.

Although agricultural production accounts for only 2.2 percent of the total fossil energy used in the United States (Hirst, 1974), it uses 17 percent of the LP gas that is consumed (Walker, 1975). Drying accounts for 6.5 percent of the total energy used in all U.S. agricultural production (Nelson, 1975). However, drying would account for 22 percent of the energy required in a non-irrigated no-tillage corn production system where 10 points of moisture are removed, second only to the energy input in fertilization (Walker, 1975).

Drying allows for earlier harvesting of corn, thus significantly reducing harvest losses. Byg et al. (1966) reported that for harvesting conditions in Ohio, total machine losses for combines averaged 6.4, 6.5 and 9.3 bushels per acre in 1964, 1965 and 1966, respectively. The losses over all samples ranged from a low observation of 2.3 to a high of 29.4 bushels per acre in 1964. Similar but somewhat less extreme conditions were reported for 1965 and 1966. Data compiled by Johnson and Lamp (1966) for picker-shellers indicated a range of 7 to 26 percent for harvest losses depending on harvester speed, number of calendar days required for harvesting, moisture content at the beginning of harvest, and weather. If drying could account for a 5 percent saving in total yield by permitting earlier harvesting, the gross dollar gain would $12.50 per acre assuming 100 bushels per acre corn at a price of $2.50 per bushel.

Grain must also be dried if it is to be safely stored for future sale, the final moisture content depending primarily on average outside temperature and relative humidity (Ross et al., 1973; Loewer et al., 1979). This is especially important when there is a possibility of aflatoxin contamination (Ross et al., 1978).

Another consideration is that farmers can avoid discounts for excess moisture by drying the grain before delivering it to a commercial elevator. Using a "2 percent of selling price per point of moisture above 15.5 percent" dockage method for 25.5 percent moisture corn, the gross returns for on-farm drying would be 8.74¢ per dollar of selling price less expenses for fuel, labor and equipment (Loewer and Hamilton, 1974).

Electricity is used as a source of heat in most low temperature drying processes. This drying method is very slow and in some geographic areas may lead to unacceptable storage risk (Ross et al., 1978). If the price of LP or natural gas is sufficiently high or if these fuel sources are not available for drying because of allocation policies, electricity would presently be the primary substitute. In all likelihood, a shift to electrical drying would result in a greatly increased demand for peak load power, not a situation welcomed by utility companies. There would be production pattern shifts in corn production away from the warmer areas of the United States, because of storage risks, accompanied by an increase in ear corn production. Harvest losses would increase dramatically because of additional field drying required when using low temperature drying, and there would be a shift in the types of equipment and structures used for harvesting, handling and storing the corn. In essence, the elimination of an economical energy source for medium to high temperature grain drying could result in a corn production system similar to that of 30-40 years ago.

From the above discussion, the drying of corn is an important energy and economic consideration for both the grain farmer and consumer. The thrust of this analysis is directed toward the economic examination of a new energy technology for grain drying, the gasification of biomass.

CHAPTER III

THE GASIFICATION PROCESS

A. Historical Perspective

The gasification process is not a new technology. Horsfield and Williams (1976), Horsfield (1977), Goss and Williams (1977b) and Payne (1978) have traced the development of gasification. The first record of a gasification process was in 1839 when Bischaf patented a simple process for gasifying coke. Since that time many different types of cellulosic material have been used including rice hulls, olive pits, corn cobs, straw, walnut shells and animal manure.

The gasification process has been used for both stationary and mobile sources of energy, the most common sources of fuel being either coal or coke. Research into the use of portable gas generators increased into the war years of the 1940's and nearly 700,000 vehicles in Europe were powered by "producer" gas (the term used for the gas output). However, development of the process ceased after World War II when plentiful supplies of petroleum became available. In fact, gasification never attracted wide attention in the United States.

The Suez crisis in 1957 triggered a long term research program in producer gas systems in Sweden, as they realized their total dependence on foreign oil. Presently, Duvant Motors in France manufactures diesel engines that can operate in the dual fuel mode with producer gas.

In the early 1970's, as petroleum became more expensive and supplies less certain, the United States became more involved in evaluating alternative fuel sources. Initially, the agricultural research community focused on the technology for direct collection of solar energy. More recently, the potential of biomass utilization, especially in the production of alcohol, has received attention. Much of the interest in gasification and direct combustion has been directed toward large scale systems such as the substitution of agricultural biomass for coal in electrical power generating stations (Bailie and Richmond, 1976; Emrri-Ames Laboratory, 1976; Horsfield, Jenkins and Becker, 1977).

There are several companies that are presently involved in biomass gasification projects. Likewise, agricultural engineering departments at several universities are conducting research in the area of converting biomass to a heat source suitable for drying. These include projects at the University of California at Davis (Goss, 1978), Iowa State University (Buchele et al., 1977), Purdue University (Peart et al., 1979) and the University of Kentucky (Payne et al., 1979).

B. Biomass Conversion Processes

There are three thermochemical processes that may be used to convert dry biomass into an energy form suitable for grain drying: pyrolysis, combustion and gasification (Payne, 1978). In an actual thermochemical conversion process, a combination of all three processes may occur. The energy source and by-products of each process are shown in Figure 1.

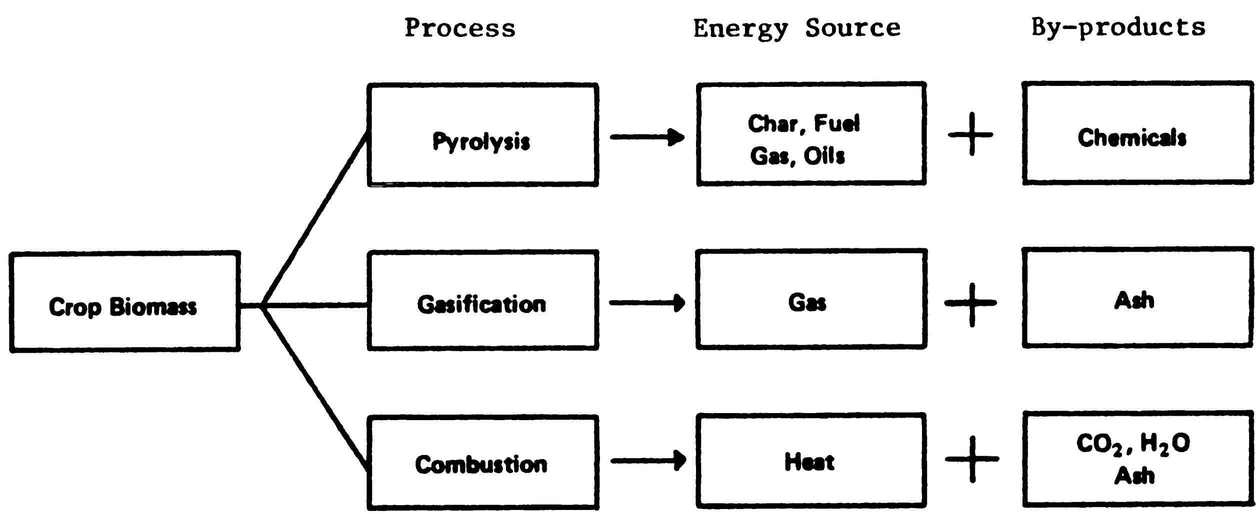

Figure 1. Thermochemical process for biomass conversion (Payne, 1979).

Pyrolysis is destructive distillation in the absence of oxygen in which the biomass is decomposed to yield char, organic liquids and gas. The char is composed primarily of mineral ash and fixed carbon. The organic liquids include resin oils, turpentine, creosote oils, etc. The gas is of relatively low energy value, 20 to 40 percent the energy content of natural gas. The major U.S. research on this process has been conducted at Georgia Tech (Knight et al., 1974).

Combustion is the most direct method of obtaining thermal energy from biomass and has been used extensively by man since his beginning. In the combustion process, the moisture is first evaporated from the biomass. Then the volatile matter is distilled and burned. Lastly, the fixed carbon is burned. If sufficient oxygen is available, the resulting product is composed mainly of heat, carbon dioxide and water vapor.

Gasification is the conversion of the carbonaceous solids in biomass into a combustible gas by controlling or limiting the rate of oxygen or air admitted to the fuel bed. The combustible components in the gas are primarily carbon monoxide and hydrogen with traces of methane. The energy value of this gas is 15 percent of natural gas.

Of the three techniques mentioned above, the concensus of past research is that for grain drying a combination of gasification-combustion offers the best biomass energy alternative to LP gas. The advantages are that the exhaust gases from the combination are free from odor and smoke and require no pollution control equipment.

This may allow the heated exhaust to be passed directly into the grain mass just as occurs with present day LP gas burner units. University of Kentucky researchers are currently investigating the properties of the exhaust gases to determine if pollution hazards exist. The direct application of heat would eliminate the need for a heat exchanger, thus reducing equipment costs. Estimated efficiencies of the gasification process range from 60 to 80 percent.

The disadvantages of this technique are that a closed air-tight mechanical system is required, and the gasification of loose biomass such as corn fodder and straw is not a proven technology. Possible contamination of grain by the exhaust gas may also prove to be a disadvantage (Payne et al., 1979).

For grain drying, Payne et al. (1979) states "The combustion takes place in two stages (Figure 2). The first stage is gasification, in which the volatiles are driven off and the char is oxidized primarily to carbon monoxide. In the second stage, the gas is transferred into the secondary combustion chamber where additional air is used to complete the combustion of the gas. The products of combustion (exhaust) are then mixed with air in roughly one part by weight of exhaust to 20 parts by weight of outside air. .... Two major factors distinguish this type of burning from ordinary combustion. First, only 30 percent of the air required to complete the combustion passes through the fire zone. This reduces the amount of particulates that are carried into the exhaust. And second, the gases are burned, before any heat is removed, in an insulated secondary combustion chamber with sufficient time, temperature, turbulence and oxygen to complete the burning reactions".

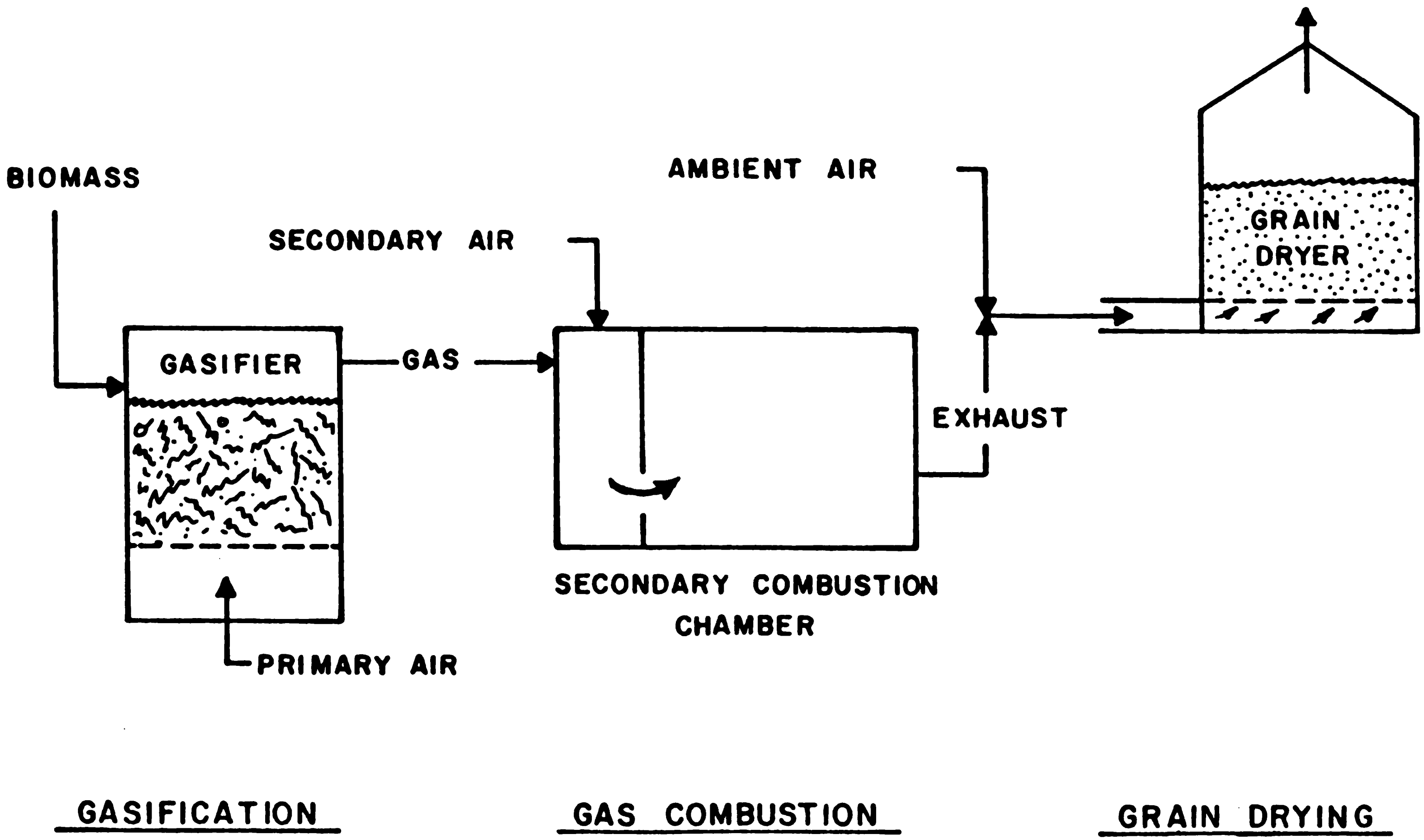

Figure 2. Schematic of the biomass gasification-combustion process for grain drying (Payne, et al., 1979).

Mobile gas producers are usually classified as one of three types: updraft, downdraft and crossdraft (Figure 3). The differences in the types lie in the relative directions of fuel and air flow. The fuel and gases flow counter current to each other in the updraft gasifier. The products of combustion and air move concurrently through the restricted fire zone in the updraft gasifier. The crossdraft producers are characterized by small fire zone volumes and require high temperatures to produce a high quality gas. Payne et al. (1979) carefully evaluated the relative advantages and disadvantages of each of these types and concluded that the updraft gasification process was best suited for corn drying. A schematic of his design, currently in operation, is shown in Figure 4.

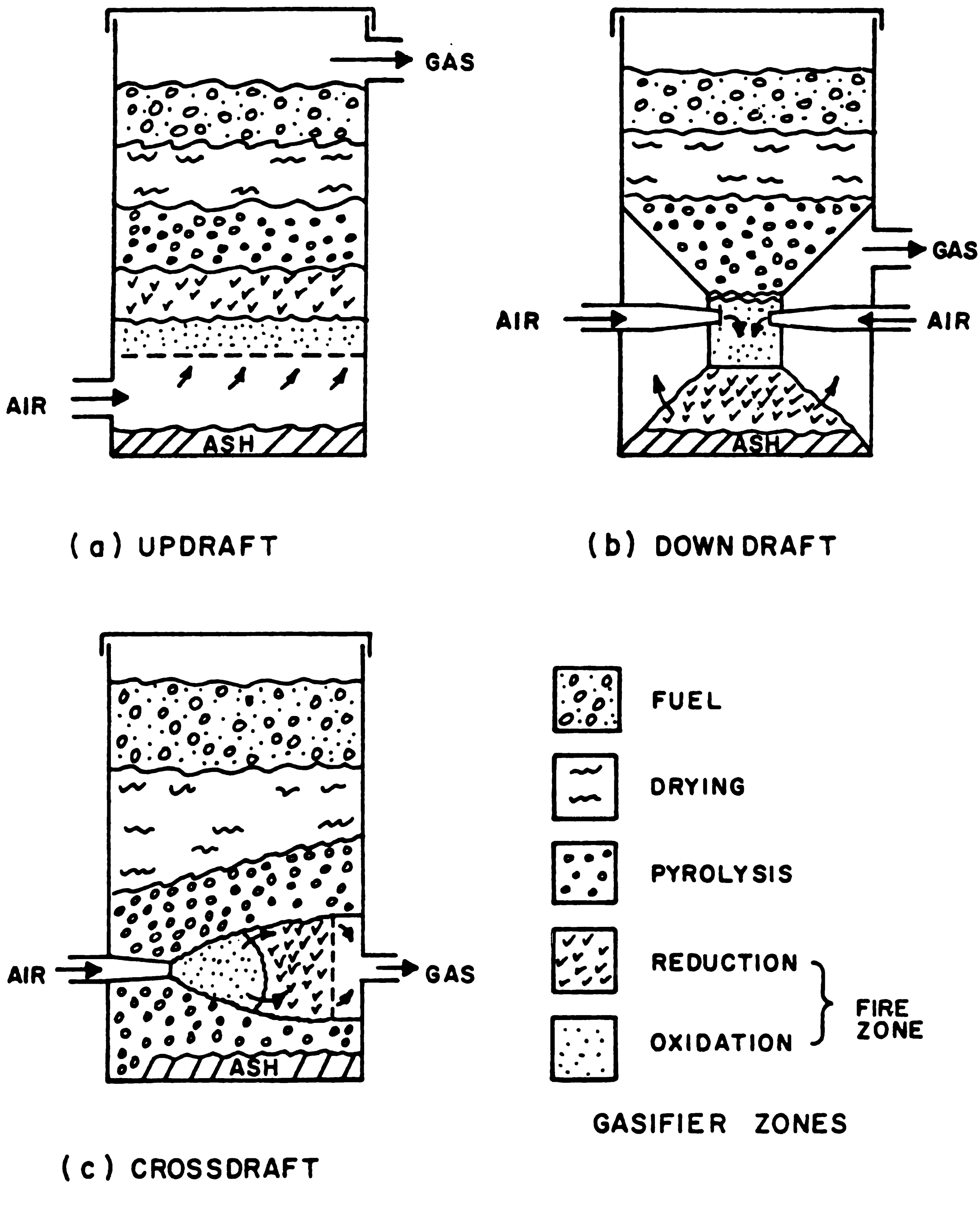

Figure 3. Schematic of the three basic types of mobile gasifiers (Payne, et al., 1979).

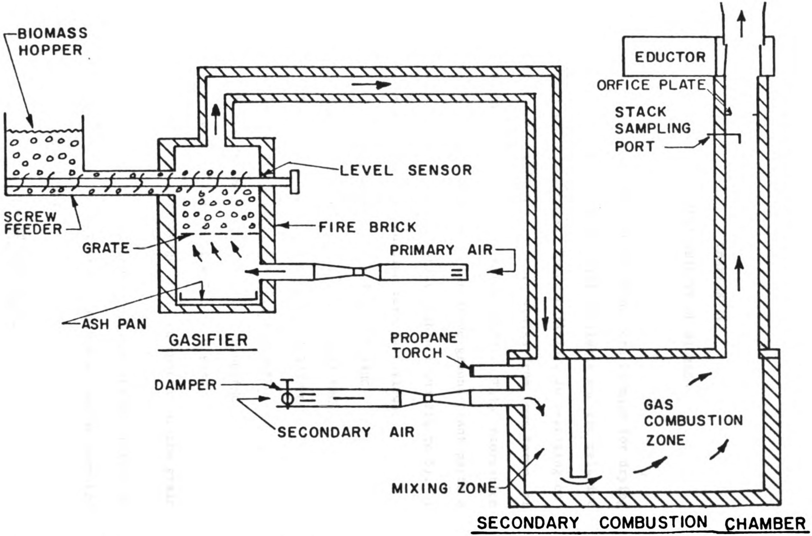

Figure 4. Schematic of the gasification combustion equipment used at the University of Kentucky (Payne et al., 1979).

CHAPTER IV

THE AVAILABILITY OF BIOMASS

The first consideration in using corn biomass for drying is to determine the quantity of material available and the relative proportions of the components. Buchele (1975), in reporting on the harvesting and utilization of corn stalks from Iowa farms, presented data from an earlier study by Ayres (1973). This information relates the dry matter distribution of the above ground plant parts as a function of grain moisture content (Table 1 and Figure 5). The data may also be expressed in equation form as follows:

$$\text{Grain dry matter, \%} = 70.4 - 0.8*MC \tag{1}$$

$$\text{Cobs dry matter, \%} = 12.4 - 0.035*MC \tag{2}$$

$$\text{Stalks dry matter, \%} = 6.7 + 0.525*MC \tag{3}$$

$$\text{Leaves dry matter, \%} = -0.1 + 0.38*MC \tag{4}$$

$$\text{Husks dry matter, \%} = 10.4 - 0.065*MC \tag{5}$$

$$\text{Stover dry matter, \%} = 17.0 + 0.84*MC \tag{6}$$

where MC = percentage moisture content of the grain, wet basis.

For purposes of this study, stover includes stalks, leaves and husks.

The quantity of dry matter per unit area may be computed using the following equations:

$$F = \frac{YWB\ (100-MC)}{(70.4-0.8*MC)} \tag{7}$$

Table 1. Dry matter distribution (% of total dry matter) within corn plant (Ayres, 1973).

Plant Part	Kernel Moisture (%) 40	35	30	25	20
Grain	38.4	42.4	46.4	50.5	54.4
Cobs	11.0	11.1	11.3	11.5	11.7
Stalk	27.7	25.1	22.5	19.9	17.2
Leaf	15.1	13.2	11.3	9.4	7.5
Husk	7.8	8.1	8.5	8.8	9.1

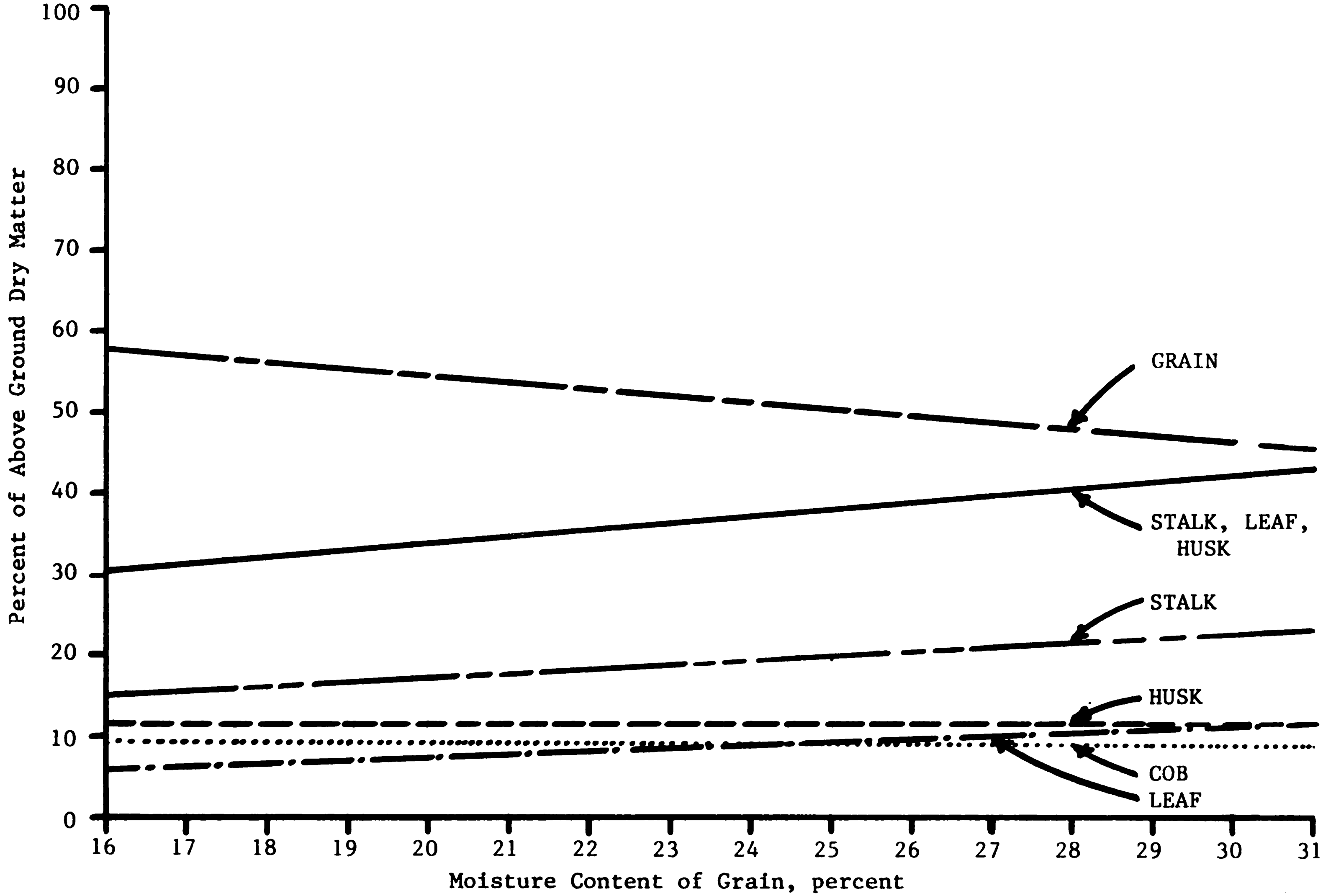

Figure 5. Relative percentage of above ground biomass as a function of grain moisture content (Ayres, 1973).

$$\text{Dry weight of grain/unit area} = YWB*\frac{100-MC}{100} \tag{8}$$

$$\text{Dry weight of cobs/unit area} = F*(12.4-0.035*MC)/100 \tag{9}$$

$$\text{Dry weight of stalks/unit area} = F*(6.7+0.525*MC)/100 \tag{10}$$

$$\text{Dry weight of leaves/unit area} = F*(-0.1+0.38*MC)/100 \tag{11}$$

$$\text{Dry weight of husks/unit area} = F*(10.4-0.065*MC)/100 \tag{12}$$

$$\text{Dry weight of stover/unit area} = F*(17.0+0.84*MC)/100 \tag{13}$$

where F = total above ground dry matter yield/unit area

MC = percent moisture content of the grain, wet basis

YWB = yield of grain per unit area at MC, and computed dry weights are measured in the same units as YWB.

See Figure 6 for a graphical presentation of Equations 8, 9 and 13.

Using Equations 1 and 2 or 8 and 9, the ratio of cobs to grain is 0.2150 at a grain moisture content of 20 percent. If Equations 1 and 2 were linearly projected to moisture contents of 10 and 0 (well beyond the range for which they were developed), the ratios of cobs to grain would be 0.193 and 0.176, respectively. This is to be compared with a ratio of 0.186 given by Horsfield, Doster and Peart (1977); thus, the difference might be explained by the relative plant part composition at different grain moisture contents. Likewise, Roller et al. (1975) gave data from several sources that compared favorably with results obtained from Equations 1 - 6.

The following equations may be used to determine the dry weight ratios of the major biomass components (Figure 7):

$$\frac{\text{COB}}{\text{GRAIN}} = \frac{(12.4 - 0.035*MC)}{(70.4 - 0.8*MC)} \tag{14}$$

$$\frac{\text{STOVER}}{\text{GRAIN}} = \frac{(17.0 + 0.84*MC)}{(70.4 - 0.8*MC)} \tag{15}$$

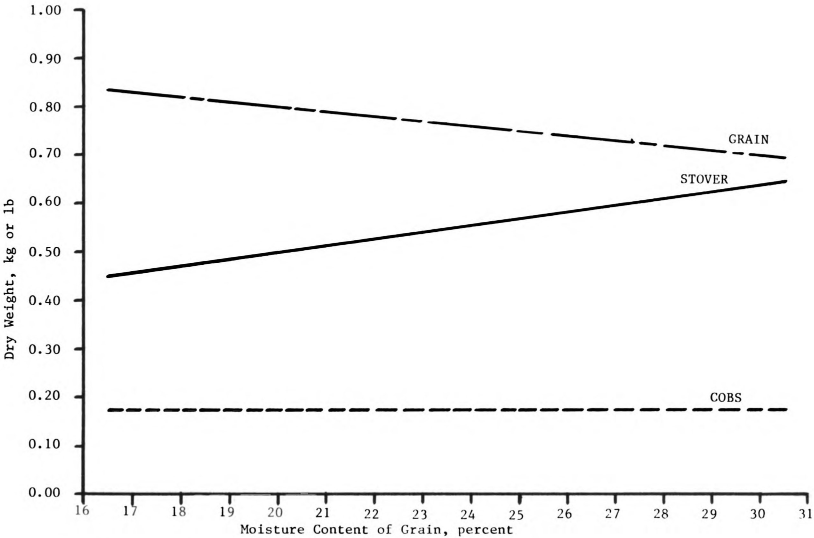

Figure 6. Relative dry weights of biomass components as a function of grain moisture content (grain, cobs and stover are measured simultaneously and in the same units).

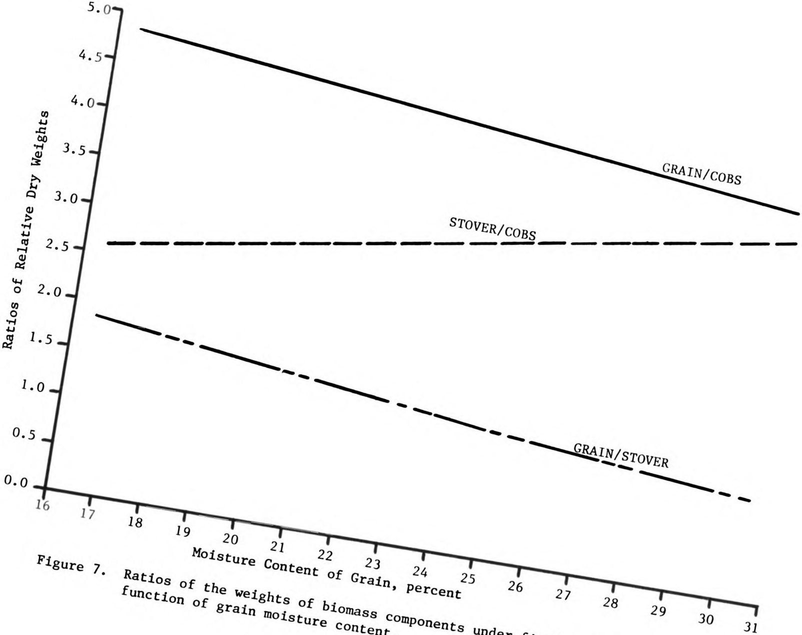

Figure 7. Ratios of the weights of biomass components under field conditions as a function of grain moisture content.

$$\frac{\text{COB}}{\text{STOVER}} = \frac{(12.4 - 0.035*\text{MC})}{(17.0 + 0.84*\text{MC})} \tag{16}$$

$$\frac{\text{GRAIN}}{\text{COB}} = \frac{(70.4 - 0.8*\text{MC})}{(12.4 - 0.035*\text{MC})} \tag{17}$$

$$\frac{\text{GRAIN}}{\text{STOVER}} = \frac{(70.4 - 0.8*\text{MC})}{(17.0 + 0.84*\text{MC})} \tag{18}$$

$$\frac{\text{STOVER}}{\text{COB}} = \frac{(17.0 + 0.84*\text{MC})}{(12.4 - 0.035*\text{MC})} \tag{19}$$

where MC = percent moisture content of the grain, wet basis.

The results shown in Figure 7 indicate that there are sufficient differences in the dry weight ratios of grain, cobs and stover over a range of moisture contents to influence the relative costs of harvesting and transporting a given quantity of energy demanded for drying. This will be explored in greater detail in the following chapter on energy availability. Note also, Equations 7-19 do not consider any production, varietal or environmental factors that might alter the relative proportions of grain, cobs and stover.

CHAPTER V

THE AVAILABILITY OF ENERGY FOR DRYING

A. Gross Energy

The National Research Council (NRC) provides information concerning the energy content of feedstuffs (Crampton and Harris, 1969). The heat of combustion of gross energy (GE) is defined as the amount of heat, measured in calories, that is released when a substance is completely oxidized in a bomb calorimeter containing 25 to 30 atmospheres of oxygen. The GE for corn kernels is given as 5553 kilogram-calories (kcal) per kilogram (kg) or 9995 British thermal units (Btu) per pound (lb) of dry weight. The GE for cobs is 4423 kcal/kg (7961 Btu/lb) dry weight. No GE value is given in the NRC tables for corn stover. Kajewski et al., (1977), reports that cornstalks contain 1.66×10^7 joules (J) per kg (3972 kcal/kg; 7150 Btu/lb) dry weight. For purposes of this study, the energy value for cornstalks will also be used for stover.

Not all of the biomass will be converted to energy; some ash will remain. However, this is considered when computing the gross energy values. The dry weight percentages of ash for kernels, cobs and stover are 1.2, 1.7 and 7.6 percent, respectively (Crampton and Harris, 1969), and there is a slight variation in these values depending on feedstuff description.

B. Bomb Calorimeter Adjustments

Only 93 percent of bomb calorimeter values should be considered as useful energy for grain drying (Payne, 1980). This is because bomb calorimeter measurements include the latent heat used to vaporize the water resulting from the combustion process which is not available for grain drying. The net energy content on a dry weight basis then becomes:

GRAIN - 5164 kcal/kg,
2.16×10^7 J/kg, or
9295 Btu/lb

COBS - 4113 kcal/kg,
1.72×10^7 J/kg, or
7404 Btu/lb

STOVER - 3694 kcal/kg,
1.54×10^7 J/kg, or
6650 Btu/lb

Similarly, the following dry weight gross energy ratios apply:

$$\frac{\text{COB}}{\text{GRAIN}} = 0.796 \tag{20}$$

$$\frac{\text{STOVER}}{\text{GRAIN}} = 0.715 \tag{21}$$

$$\frac{\text{COB}}{\text{STOVER}} = 1.113 \tag{22}$$

$$\frac{\text{GRAIN}}{\text{COB}} = 1.256 \tag{23}$$

$$\frac{\text{GRAIN}}{\text{STOVER}} = 1.399 \tag{24}$$

$$\frac{\text{STOVER}}{\text{COB}} = 0.898 \tag{25}$$

C. Moisture Content Adjustments

The energy availability computed thus far has been on a dry matter basis. However, when biomass is gasified, part of the energy must be used in removing the moisture contained within the material. The latent heat of evaporation for water is approximately 589 kcal/kg (2.46×10^6 J/kg; 1060 Btu/lb). Thus, for each kg of moisture in the biomass, 589 kcal of energy will be used for vaporization rather than as a source of energy for grain drying.

The moisture contents of each of the biomass components must be known if the net energy available for drying is to be computed. Buchele (1975) reports that the stover contains approximately twice as much moisture as the kernels during the harvest season. Bargiel et al. (1979) confirms Buchele's observation for cobs when kernel moisture content is above 25 percent. However, he states that cob moisture content rapidly approaches the grain moisture content in the range of 15 to 20 percent and is essentially the same at 12.5 percent moisture content wet basis. Using these estimates, the following relationships have been established:

$$\text{Stover moisture content} = 2.0*\text{GMC}) \tag{26}$$

For GMC greater than 25 percent,

$$\text{Cob moisture content} = 2.0*\text{GMC} \tag{27}$$

For GMC in the range of 12.5 to 25 percent,

$$\text{Cob moisture content} = -25.0 + 3.0*\text{GMC} \tag{28}$$

For GMC less than 12.5 percent,

$$\text{Cob moisture content} = \text{GMC} \tag{29}$$

where GMC = grain moisture content, and all moisture contents are measured as a percentage, wet basis.

The net energy that is available for grain drying is a function of moisture content after adjustments for the bomb calorimeter data have been made. The following general equation may be used:

$$\text{Energy available per unit weight, wet basis} = \frac{100\text{-MC}}{100} * \text{ECD} - \frac{\text{MC}}{100} * \text{HVAP} \qquad (30)$$

where MC = percentage of moisture content of biomass component, wet basis

ECD = adjusted gross energy content per unit of biomass component, dry basis

HVAP = heat of vaporization of water

Equation 30 can also be written as follows for the adjusted energy content based on the wet weight of the biomass components using values presented previously for the different biomass components:

$$\text{GRAIN (kcal/kg)} = (5164) - (57.53)*\text{MC} \qquad (31)$$

$$\text{GRAIN (J/kg)} = (2.16 \times 10^7) - (2.406 \times 10^5)*\text{MC} \qquad (32)$$

$$\text{GRAIN (Btu/lb)} = (9295) - (103.55)*\text{MC} \qquad (33)$$

$$\text{COBS (kcal/kg)} = (4113) - (47.02)*\text{MC} \qquad (34)$$

$$\text{COBS (J/kg)} = (1.72 \times 10^7) - (1.966 \times 10^5)*\text{MC} \qquad (35)$$

$$\text{COBS (Btu/lb)} = (7404) - (84.64)*\text{MC} \qquad (36)$$

$$\text{STOVER (kcal/kg)} = (3694) - (42.83)*\text{MC} \qquad (37)$$

$$\text{STOVER (J/kg)} = (1.54 \times 10^7) - (1.786 \times 10^5)*\text{MC} \qquad (38)$$

$$\text{STOVER (Btu/lb)} = (6650) - (77.1)*\text{MC} \qquad (39)$$

where MC = moisture content of the biomass component, percent wet basis, and all computed values are based on the wet basis of the material.

Equations 31-39 are presented graphically in Figure 8.

In the previous discussion, the ratios of dry weights, energy values and moisture contents were presented. It has been shown that moisture content affects the available energy for drying in two ways. First, the higher the moisture content of a given weight of biomass, the less the proportion of dry matter to provide energy. Secondly, the greater the moisture content the greater the energy requirements to vaporize the water, thus leaving less energy available for grain drying. Therefore, the field moisture content will be an important consideration if the biomass component is to be utilized directly at the time of harvest.

D. Example

The relationship between the grain moisture content and energy availability among the biomass components can be computed using the following equations:

GIVEN: 1 unit of wet grain (kg or lb), GWWT, @ GMC percent moisture content, wet basis.

Step 1. Use Equation Nos. 26, 27, 28 and 29 as appropriate to compute:

CMC - cob moisture content, percent wet basis

SMC - stover moisture content, percent wet basis

Step 2. Use Equation Nos. 7, 8, 9 and 13 to compute:

GDWT - dry weight of grain

CDWT - dry weight of cobs

SDWT - dry weight of stover

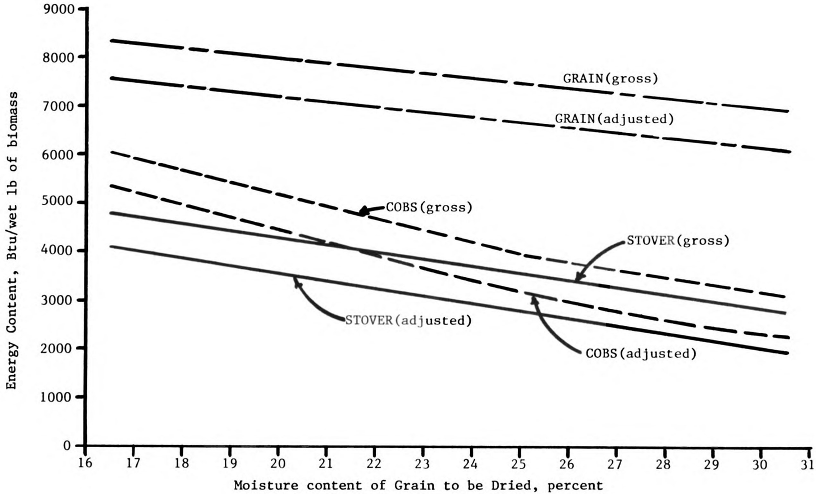

Figure 8. Gross and net energy content per wet pound of biomass as a function of the moisture content of the grain to be dried.

Step 3. Use the following equations to compute the wet weight of cobs and stover:

$$CWWT = \frac{CDWT*100}{(100-CMC)} \qquad (40)$$

$$SWWT = \frac{SDWT*100}{(100-SMC)} \qquad (41)$$

Step 4. Use Equation Nos. 31-39 as appropriate to determine:

GEPWWT = available grain energy per wet weight unit considering GMC

CEPWWT = available cob energy per wet weight unit considering CMC

SEPWWT = available stover energy per wet weight unit considering SMC.

Step 5. Compute the total energy available for drying during harvest using the following relationships:

$$TGE = GEPWWT*WTUGI \qquad (42)$$

$$TCE = CEPWWT*CWWT \qquad (43)$$

$$TSE = SEPWWT*SWWT \qquad (44)$$

where TGE = the total net energy available for drying from one wet unit of grain

TCE = the total net energy available for drying from cobs

TSE = the total net energy available for drying from stover

WTUGI = initial wet weight units of grain

Step 6. The available energy for drying ratios may then be expressed:

$$\frac{\text{cob energy}}{\text{grain energy}} = \frac{TCE}{TGE} \qquad (45)$$

$$\frac{\text{stover energy}}{\text{grain energy}} = \frac{TSE}{TGE} \qquad (46)$$

$$\frac{\text{cob energy}}{\text{stover energy}} = \frac{TCE}{TSE} \tag{47}$$

$$\frac{\text{grain energy}}{\text{cob energy}} = \frac{TGE}{TCE} \tag{48}$$

$$\frac{\text{grain energy}}{\text{stover energy}} = \frac{TGE}{TSE} \tag{49}$$

$$\frac{\text{stover energy}}{\text{cob energy}} = \frac{TSE}{TCE} \tag{50}$$

For purposes of illustration, consider at harvest 1 kg of grain at 30.5 percent moisture, wet basis. From Equations 26 and 27, the stover and cob moisture contents are:

$$SMC = 2.0*GMC = 2.0*30.5 = 61.0 \text{ percent}$$

$$CMC = 2.0*GMC = 2.0*30.5 = 61.0 \text{ percent}$$

The moisture content of the grain may be used to determine the dry weight of material that is available (Equations 7, 8, 9 and 13).

$$F = \frac{YWB(100-GMC)}{(70.4-0.8*GMC)} = \frac{(1)*(69.5)}{(70.4-0.8*30.5)} = 1.510$$

$$GDWT = YWB*\frac{100-GMC}{100} = (1)*\frac{100-30.5}{100} = 0.695 \text{ kg}$$

$$CDWT = F*(12.4-0.035*GMC)/100 = 0.171 \text{ kg}$$

$$SDWT = F*(17.0+0.84*GMC)/100 = 0.644 \text{ kg}$$

The initial wet weight of the grain, GWWT, was given as 1 kg. The wet weights for cobs and stover are computed from Equations 40 and 41.

$$CWWT = \frac{CDWT*100}{(100-CMC)} = \frac{(0.171)*(100)}{(100-61)} = 0.439 \text{ kg}$$

$$SWWT = \frac{SDWT*100}{(100-SMC)} = \frac{(0.644)*(100)}{(100-61)} = 1.651 \text{ kg}$$

At this point, the net energy available for drying per wet unit of biomass may be calculated using Equations 31, 34, and 37.

$$GEPWWT = 5164 - 57.53*GMC = 3409 \text{ kcal/kg}$$

$$CEPWWT = 4113 - 47.02*CMC = 1245 \text{ kcal/kg}$$

$$SEPWWT = 3694 - 42.83*SMC = 1081 \text{ kcal/kg}$$

The net energy per wet unit of biomass may be converted to total energy available for drying per unit of wet grain by using Equations 42, 43 and 44.

$$TGE = GEPWWT*WTUGI = (3409)*(1) = 3409 \text{ kcal}$$

$$TCE = CEPWWT*CWWT = (1245)*(0.439) = 547 \text{ kcal}$$

$$TSE = SEPWWT*SWWT = (1081)*(1.651) = 1785 \text{ kcal}$$

The energy ratios are calculated from Equations 45-50.

$$\frac{\text{cob energy}}{\text{grain energy}} = \frac{TCE}{TGE} = \frac{547}{3409} = 0.160$$

$$\frac{\text{stover energy}}{\text{grain energy}} = \frac{TSE}{TGE} = \frac{1785}{3409} = 0.524$$

$$\frac{\text{cob energy}}{\text{stover energy}} = \frac{TCE}{TSE} = \frac{547}{1785} = 0.306$$

$$\frac{\text{grain energy}}{\text{cob energy}} = \frac{TGE}{TCE} = \frac{3409}{547} = 6.232$$

$$\frac{\text{grain energy}}{\text{stover energy}} = \frac{TGE}{TSE} = \frac{3409}{1785} = 1.910$$

$$\frac{\text{stover energy}}{\text{cob energy}} = \frac{TSE}{TCE} = \frac{1785}{547} = 3.263$$

See Figures 9 and 10 for a graphical representation of the effects of kernel moisture content on energy availability.

E. Efficiency of Gasification Process

Thus far, the total energy available for drying has been computed. The previous discussion assumed complete combustion and 100 percent efficiency in removing the internal moisture from the biomass. However, in physical systems, the process of converting stored energy into thermal energy for drying will not be 100 percent efficient. There are several references to the efficiency of

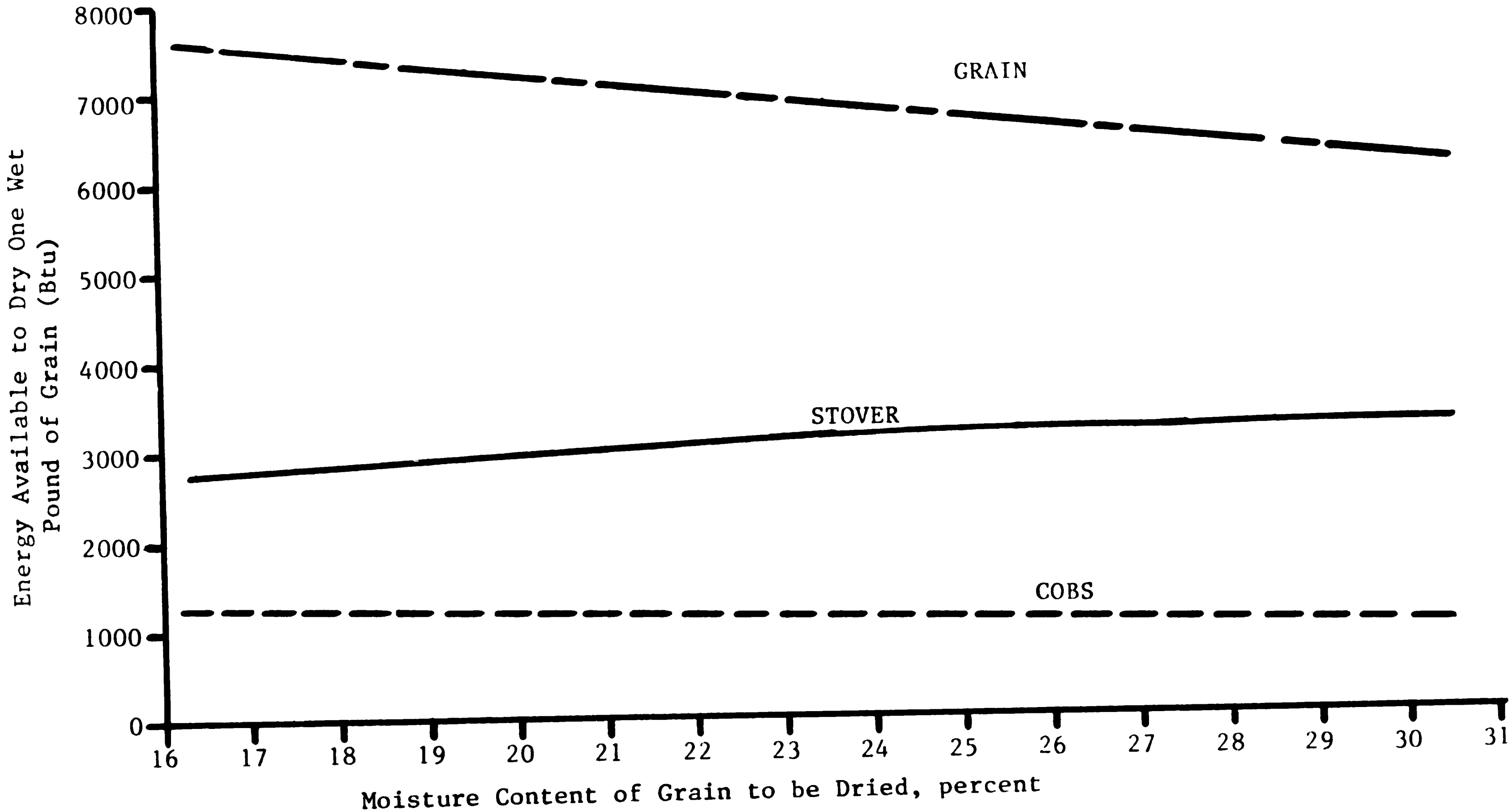

Figure 9. Net energy available for drying one pound of wet grain based on relative field quantities of biomass.

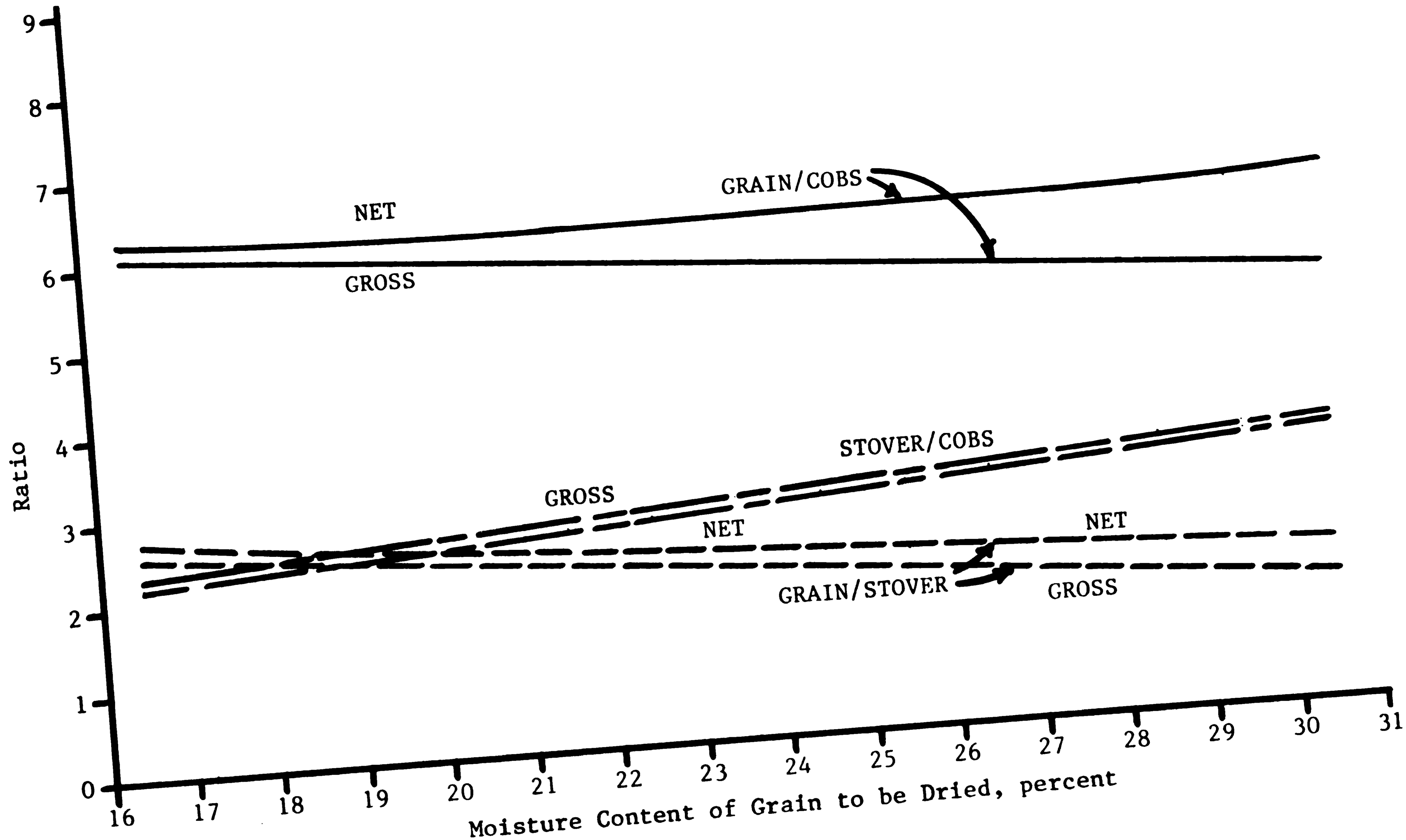

Figure 10. Ratios of gross and net energy availability based on grain moisture content.

gasifiers (Payne et al., 1079; Goss and Williams, 1977a; Horsfield and Williams, 1976; Williams and Horsfield, 1977). The efficiency values typically range from 65 to 80 percent. Williams and Horsfield (1977), in a detailed report of their efficiency calculations, included such items as initial moisture content; sensible heat in the air and dry gas; heat losses in solid refuse, condensate and the steam in the gas; and radiant losses from the gasifier. Their comments, along with that of Payne et al. (1980), would indicate that a minimum efficiency of 60 percent could be obtained. Likewise, they suggest that gasification efficiency could be much higher, perhaps 80 percent, when using a well-engineered system. This would be comparable to the 80 percent conversion efficiency of LP gas to thermal energy for drying.

Although the total energy available per unit of wet grain must be further reduced by the conversion efficiency of the gasification process, there was no mention in the literature of efficiency differences among grain, cobs and stover. If the process efficiency is assumed to be the same for each biomass component, the energy delivered to the grain is:

$$EDGRG = TGE * GEFF/100 \tag{51}$$

$$EDGRC = TCE * GEFF/100 \tag{52}$$

$$EDGRS = TSE * GEFF/100 \tag{53}$$

where EDGRG = grain energy available for each unit of wet grain to be dried

EDGRC = cob energy available for each unit of wet grain to be dried

EDGRS = stover energy available for each unit of wet grain to be dried

TGE, TCE and TSE = the total energy available per unit of wet grain from the grain, cobs and stover, respectively

GEFF = percent efficiency of the gasification process.

Using the example in the previous chapter, the total energy available for drying one wet unit of grain, when adjusted for a 60 percent gasification efficiency, would be 2045, 328 and 1071 kcal respectively for grain, cobs and stover, when beginning with 1 kg of grain at 30.5 percent moisture, wet basis.

F. Efficiency of Drying

There are many factors that influence the efficiency of evaporating and removing moisture during the drying process. However, these items all involve the utilization of available thermal energy and would be indifferent as to whether the heat source was biomass or LP gas. The typical values used in estimating drying fuel efficiency is the units of energy required to remove a unit weight of moisture from the grain. The theoretical lower limits are 589 kcal/kg of water (2.46×10^6 J/kg; 1060 Btu/lb). The lower limit expected in on-the-farm drying systems would be approximately 778 kcal/kg of water (3.25×10^6 J/kg; 1400 Btu/lb). Likewise, the expected upper limit would approach 1945 kcal/kg of water (8.14×10^6 J/kg; 3500 Btu/lb). This would indicate a drying efficiency range of from 30 to 76 percent. It should be noted that overall harvesting efficiency may be lowered by a high drying fuel efficiency. For example, the farmer may have a very fuel efficient dryer that creates a bottleneck in his harvesting operation. This may result in excessive field and hence economic losses, greater than his fuel savings.

A typical drying efficiency that will be used in this study as a basis for comparison is 45 percent (1308 kcal/kg of water; 5.46 x 10^6 J/kg; 2356 Btu/lb). Equations for relating the energy and the quantity of wet biomass needed for drying are:

$$\text{WATERU} = \frac{(\text{GRAINU})*(\text{GIMC}-\text{GFMC})}{(100-\text{GIMC})} \tag{54}$$

where WATERU = the units of water to be removed during drying per unit of grain, GFMC base

GIMC = initial moisture content of the grain, percent wet basis

GFMC = final (or desired) moisture content of the grain after drying, percent wet basis

GRAINU = units of grain to be dried, GFMC base

NOTE: GRAINU and WATERU are measured in the same units.

$$\text{ENERNU} = \frac{\text{WATERU} * \text{HVAP} * 100}{\text{DEFF}} \tag{55}$$

where ENERNU = energy required per unit of grain dried, GFMC base

HVAP = heat of vaporization of water

DEFF = drying efficiency, percent

NOTE: (a) If WATERU is measured in kg and HVAP equals 589 kcal/kg, then ENERNU will be measured in kcal.

(b) If WATERU is measured in kg and HVAP equals 2.46×10^6 J/kg, then ENERNU will be measured in J.

(c) If WATERU is measured in pounds and HVAP equals 1060 Btu/lb, then ENERNU will be measured in Btu's.

Equations 56, 57 and 58 may be used to determine the percentage of the available energy required for drying one unit of grain, measured at the final moisture content, GFMC.

$$PCWTGU = \frac{ENERNU}{EDGRG} * 100 \tag{56}$$

$$PCWTCU = \frac{ENERNU}{EDGRC} * 100 \tag{57}$$

$$PCWTSU = \frac{ENERNU}{EDGRS} * 100 \tag{58}$$

where PCWTGU, PCWTCU, PCWTSU = the percent of the wet grain, cobs and stover, respectively, required to dry the grain unit, GRAINU.

EDGRG, EDGRC, EDGRS = the energy available for each unit of grain (at the final moisture content) to be dried from grain, cobs and stover, respectively.

Referring back to the previous example, what fraction of the biomass units must be utilized in drying 1 kg of 15.5 percent moisture grain (U.S. No. 2) from 30.5 to 15.5 percent? The quantity of water that must be removed is computed using Equation 54:

$$WATERU = \frac{(1\ kg)*(30.5-15.5)}{(100-30.5)} = 0.216\ kg$$

The energy requirements for one unit of 15.5 percent moisture grain may be estimated from Equation 55 using a drying efficiency of 45 percent.

$$ENERNU = \frac{(0.216\ kg)*(589\ kcal/kg)*(100)}{45} = 283\ kcal$$

In the previous example for grain at 30.5 percent moisture content, the energy to the dryer from each wet biomass component was 2045, 328 and 1071 kcal/kg for grain, cobs and stover, respectively. The percentage of the wet biomass components needed for drying is the ratio of energy requirements to energy availability. Using Equations 56, 57 and 58:

$$PCWTGU = \frac{283\ kcal}{2045\ kcal} * 100 = 13.8\ percent$$

$$PCWTCU = \frac{283\ kcal}{328\ kcal} * 100 = 86.3\ percent$$

$$PCWTSU = \frac{283\ \text{kcal}}{1071\ \text{kcal}} * 100 = 26.4\ \text{percent}$$

In other words, for the conditions given, either 13.8 percent of the grain, 86.3 percent of the cobs, or 26.4 percent of the stover would be required to dry one unit of 15.5 percent moisture grain from 30.5 percent. This would be equivalent to 11.4 percent of the grain, 70.8 percent of the cobs, and 21.7 percent of the stover based on 30.5 percent moisture grain rather than the 15.5 percent base. The relationships between moisture content of the grain and the proportion of biomass needed for drying are shown in Figure 11.

To this point, an engineering analysis of biomass energy availability has been completed. The example problem indicates that sufficient energy exists in each category of biomass to dry the grain when using conservative estimates of system performance. The next question involves the economic feasibility of gasification. The following chapter addresses this topic by examining gross return as determined by LP gas replacement cost, harvesting and transportation costs, soil productivity changes, alternative uses of biomass, and gasification equipment cost estimates. The chapter concludes by presenting the procedure used for determining break-even investment.

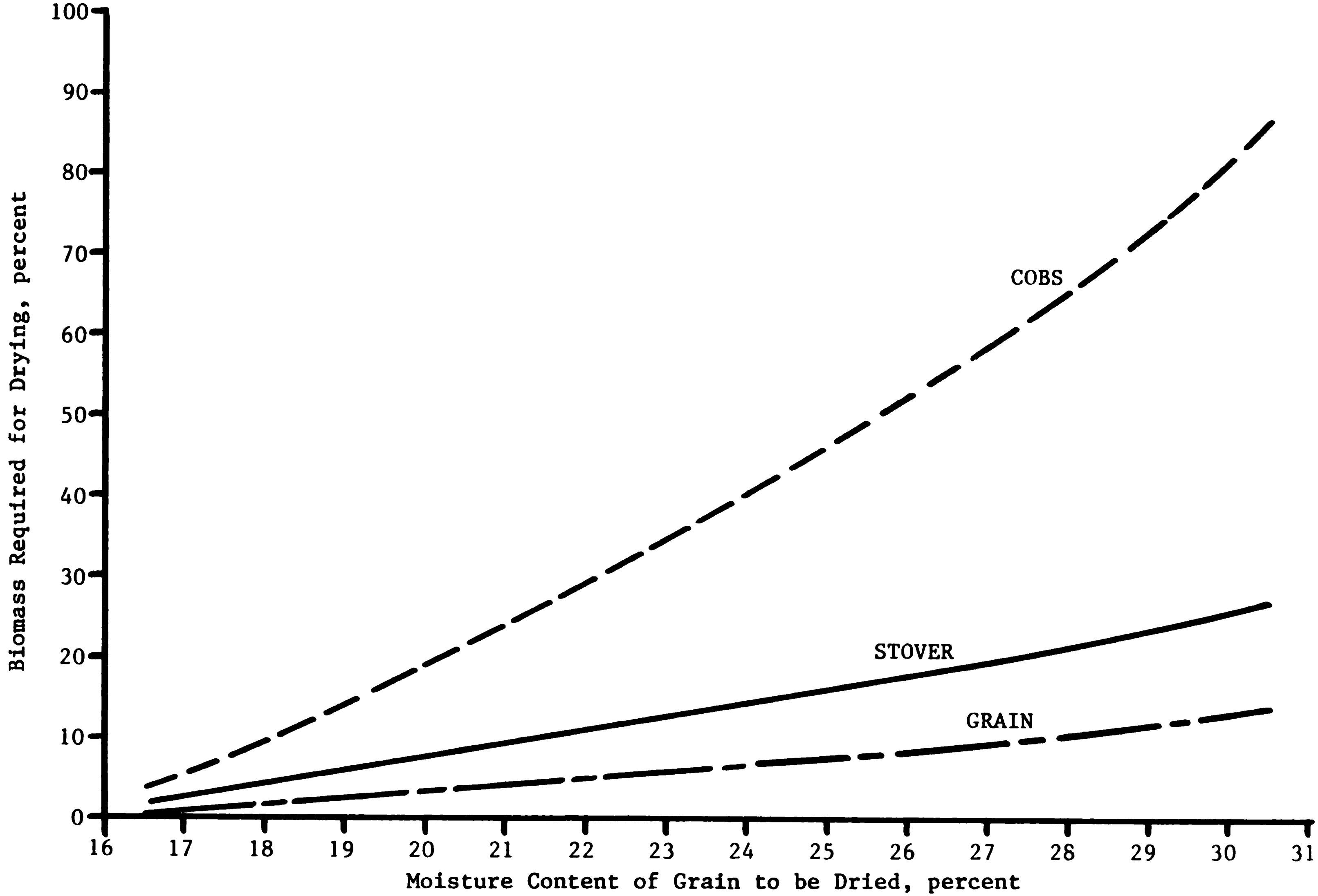

Figure 11. The percentage of the available biomass required to dry one bushel of U.S.No.2 wet grain (gasification efficiency = 60%; drying efficiency = 45%).

CHAPTER VI

ECONOMIC CONSIDERATIONS

At this point in the analysis, the economic question becomes one of determining if biomass can be used as a fuel source for grain drying for less money than the value of the LP gas saved. Initially, gross return from LP gas savings will be presented followed by a discussion of biomass cost considerations.

A. <u>Gross Return from Savings of LP Gas</u>

The dominant fuel used from grain drying in the U.S. is LP gas. LP gas prices have increased rapidly following the upward spiral of energy costs in general. Presently, U.S. farmers are paying 50 to 60 cents per gallon of LP gas, which contains approximately 6125 kcal/l (2.56×10^7J/l; 92,000 Btu/gal).

Referring back to the example in Chapter V, Section F, the drying efficiency assumed was 45 percent. When using LP gas, the efficiency of converting the gas to thermal energy available for drying must also be considered. The usual value given for this efficiency is 80 percent. The quantity of energy in LP gas needed to remove the specified quantity of water from the grain is obtained using Equation 54, repeated below, and a modified version of Equation 55.

$$\text{WATERU} = \frac{(\text{GRAINU})*(\text{GIMC}-\text{GFMC})}{(100-\text{GIMC})} \tag{54}$$

where WATERU = the units of water to be removed during drying per unit of grain, GFMC base

GIMC = initial moisture content of the grain, percent wet basis

GFMC = final (or desired) moisture content of the grain after drying, percent wet basis

GRAINU = units of grain to be dried, GFMC base

NOTE: GRAINU and WATERU are measured in the same units.

$$ENERNU = \frac{WATERU * HVAP * 10000}{THEFF * DEFF} \tag{59}$$

where ENERNU = energy required per unit of grain dried, GFMC base

HVAP = heat of vaporization of water

DEFF = drying efficiency, percent

THEFF = thermal conversion efficiency for LP gas burners, percent

The quantity of LP gas needed is:

$$QLPG = \frac{ENERNU}{EPQLPG} \tag{60}$$

where QLPG = quantity of LP gas needed per unit of grain to be dried, GFMC base

EPQLPG = energy per quantity of LP gas

The cost for this quantity of gas is:

$$COSTLP = QLPG * PPULPG \tag{61}$$

where COSTLP = cost of LP gas per unit of grain dried, GFMC base

PPULPG = price per unit of LP gas

In the example problem, the water to be removed from 1 kg of 15.5 percent moisture grain being dried from 30.5 to 15.5 percent moisture content was computed to be 0.216 kg. Using Equation 59:

$$ENERNU = \frac{(0.216\ kg) * (589\ kcal/kg) * (10000)}{(80) * (45)}$$

$$= 353\ kcal/kg \text{ of grain, 15.5 percent base}$$

The quantity of LP gas needed for drying one kg of 15.5 percent moisture grain is computed from Equation 60:

$$QLPG = \frac{353\ \text{kcal/kg}}{6125\ \text{kcal/l}} = 0.057\ \text{l/kg}$$

The cost equivalent of \$0.50/gallon LP gas is approximately \$0.132 per liter. Therefore from Equation 61, the total cost of drying per kg of 15.5 percent moisture grain is:

$$COSTLP = (0.057\ \text{l/kg grain}) * (\$0.132/\text{l}) = \$0.00752$$

This would be equivalent to a cost of \$0.192 per 15.5 percent moisture bushel for 15 points of moisture removal, and represents the gross return for using biomass gasification equipment.

B. Harvesting and Transportation Costs

Grain

The form of biomass most often collected on grain farms is grain itself. The primary advantages of using grain as a source of fuel are (1) no additional machinery is required for gathering and handling, (2) the material is easily transported, marketed and stored for future use, (3) the material is flowable, and (4) the grain contains relatively high levels of energy per unit weight when compared to cobs and stover.

The cost of harvesting might be considered either the custom charge or the average ownership cost. Schwab (1975) stated that the average custom charge for a combine-sheller in Michigan was \$13.03 per acre. The average yield in Michigan that year was 80 U.S. No. 2 bushels per acre which would correspond to \$0.163 per bushel for harvesting. Custom rates for delivery to the grain facility would cost approximately \$0.02 per bushel based on delivering 400 bushels per hour and an $8.00 rental charge for the truck bringing the total custom charge to $0.183 per bushel. Hinton and Walker (1971) reported on custom rates in Illinois. When adjusted to 1975 prices by the Consumer Price Index (CPI), the cost for combining and hauling corn was $0.173 per bushel which would compare favorably with the value computed previously. Schlender and Figurski (1975) reported an average custom harvesting rate of $0.18 per bushel for Kansas, not including hauling. From these studies, a custom combining charge for corn of $0.18 per bushel, including hauling, seemed to be representative for 1975. If the CPI were 224, somewhat representative of 1980, the custom rate would be $0.25 per bushel ($0.00446/lb; $0.00984/kg). The moisture content of the bushel was not specified in any of the above studies.

The cost of combine ownership may be approximated using the following parameters (Campbell, 1978):

Average annual interest	- 7.5% of purchase price (PP)
Annual depreciation (7 yr life, zero salvage, straight line method)	- 14.3% of PP
Repair and maintenance	- 8.6% of PP
Taxes, insurance, housing	- 2.0% of PP
Estimated fixed cost	= 32.4% of PP
Estimated life, total in 7 yr	- 2000 hours
Estimated purchase price	- $60,000
Harvesting rate	- 400 bu/hr
Operator labor	- $5.00 per hour
Fuel and lube cost (diesel @ $1.25/gal)	- $6.25 per hour

These figures indicate an annual cummulative charge of 32.4 percent of purchase price or $19,440. This equals $68.04 per hour of machine life. The fixed cost per bushel is $0.17. To this is added the total variable cost of \$11.25 or \$0.028 per bushel for a total ownership cost of approximately \$0.20 per bushel.

The same assumptions apply for a farm delivery truck except for the following:

Purchase price	- \$14,000.00
Fuel and lube (operating 25% of time)	- \$ 1.56 per hour
Hauling rate	- 400 bu/hr

The fixed cost is \$15.88 per hour and the variable cost is \$6.56 per hour for a total of \$22.44 per hour or \$0.0561 per bushel.

From these calculations, the total per bushel cost of combining and hauling the grain is about \$0.26 per bushel or essentially the same as the custom rate computed previously. Of course, the computed cost could vary considerably with changes of the input assumptions. Likewise, the present interest rate and fuel charges have risen considerably faster than the general CPI.

Cobs

Cobs may be gathered in several ways including:

1. Harvesting the cobs in broken form and mixing the material with the grain during harvesting (Horsfield, Doster and Peart, 1977).
2. Collecting cobs in a separate wagon during the harvesting operation (Bargiel et al., 1979).
3. Harvesting ear corn and separating the cobs from the corn at the drying site.

The first method would involve some modification of present-day harvesting machinery with regard to the mechanisms involving separation of cob and grain after shelling occurs. This would probably not be a major problem. The addition of broken cob to the grain was estimated by Horsfield et al. (1977) to require an increase in harvesting volume of 15 percent. Using this figure, the estimated total cost of harvesting and transportation would also increase to $0.30 from $0.26 per bushel of grain. This would translate to an additional charge of $0.04 per harvested bushel if cobs were collected with grain.

The method presented by Bargiel et al. (1979) utilized an attachment much like a straw spreader to direct cobs to a wagon being pulled by the combine. No estimates of cost were given, but the power requirements were similar to a straw spreader and the device was reasonably simple in design. The additional cost would be for combine design modifications, a forage wagon, transportation, and the added fuel needed for the combine. This cost should be no greater than the cost of transporting the grain, $0.06 per bushel equivalent. Another cost estimate is $13.33/dry ton of cobs collected behind a combine (Williams, McAniff and Larson, 1979). This assumes a 25 percent moisture content and is equivalent to $0.85 per million Btu's of cob energy value.

All of the equipment needed to harvest ear corn is available. The question is whether it is more economic to do the shelling at a central location where drying occurs, or separate the grain from the cob in the field using the present technology. Custom rates given by Schwab and Gruenwald (1978) indicated that rates for harvesting ear corn were $3.12 per acre less than combine harvesting.

The custom rate for shelling ear corn from the crib averaged \$0.09 per bushel. For a yield of 90 bushels per acre, the ear corn harvesting system would cost nearly \$0.06 per bushel more than the conventional combine system.

Stover

Stover may be collected from the field using standard baling equipment. Schwab and Gruenwald (1978) stated that the average custom charge per bale for hauling and baling straw was \$0.27, the bales weighing 40-55 pounds each. The custom rate for big bale balers was \$5.79 for straw bales, each weighing 1000 to 1500 pounds. When using mechanical long hay stackers, the custom rate for straw stacks weighing not over 2 tons was \$20.00. If over 2 tons, the charge was \$25.00.

Hillman and Logan (1979) estimated the total harvesting and feeding cost per ton for several different forage systems over a range of yearly capacities. The cost per ton varied from \$9.77 to \$14.68 per ton, the average being \$11.82 for an annual capacity of 500 tons. The average was \$8.91 per ton when 1000 tons per year were harvested. These values would compare favorably with those presented in other studies (Fairbanks et al., 1977; Stout, 1979). Stout gives the average cost per ton in the mid-west to be \$16.01 but this includes a uniform haul distance of 15 miles.

Stout (1979) provides a rather detailed analysis of cost computations involving labor, diesel fuel and equipment costs. The following equations apply:

For large round bales,

$$TCPTNR = 6.30 + \frac{10.85}{RESIDU} + 0.182*DIST \qquad (62)$$

For large stacks,

$$TCPTNS = 2.61 + \frac{9.72}{RESIDU} + 0.276*DIST \qquad (63)$$

where TCPTNR = total cost per ton (dry) for large round bales

TCPTNS = total cost per ton (dry) for large stacks

RESIDU = harvestable residue, tons (dry) per acre

DIST = one-way haul distance, miles.

For example, if the grain is a 30 percent moisture, there would be 42.3 percent stover per acre (Equation 6). Assuming a dry weight yield of 100 bushels per acre, the dry stover present is 5105 pounds, or 2.55 tons. If the one-way hauling distance is 1 mile, the cost per dry ton for large round bales is:

$$TCPTNR = 6.30 + \frac{10.85}{2.55} + 0.182*1 = \$10.74$$

For large stacks, the cost per dry ton is:

$$TCPTNS = 2.61 + \frac{9.72}{2.55} + 0.276*1 = \$6.70$$

When converted to a 60 percent wet basis, the cost per wet ton is \$6.72 and \$4.20 for large round bales and large stacks, respectively.

C. Soil Productivity

There are many arguments to be made both against and in favor of biomass removal (Robertson and Mokma, 1978). First, it should be remembered that approximately half of the biomass, in terms of dry matter, is already removed in the form of grain. The remaining cobs and stover are the primary source of organic matter which aids in the formation of a stable soil structure. In addition, the stover and cobs add to soil fertility levels and help reduce soil erosion.

How are important are these factors? Soil organic matter levels influence the physical condition of the soil and in turn are associated with power requirements for tillage, water infiltration levels, and oxygen diffusion rates. However, the effects would appear to be more long-run, hence part of the difficulty in assigning short term economic costs. For example, Robertson and Mokma (1978) stated that root growth rates were slow and crop yields were less than optimum when bulk density values were less than 1.3 gms/cc, a condition already prevalent on most of Michigan's soils. This bulk density is approximately equivalent to a 3 percent organic matter level. The upper 6 inches of soil weighs approximately 2 million pounds per acre. If 9000 pounds of residue from 150 bushel per acre corn are incorporated into the soil and if all of it were converted to organic matter with no losses, this would change the organic matter level by 0.45 percent. If only 25 percent of the residue was used for drying, the difference would be approximately 0.11 percent per year in organic matter. This says nothing about the normal disappearance of organic matter from the soil.

The nutrient contents of the biomass components are presented in Table 2. Of these items, only nitrogen is really affected in that the remaining nutrients may be recovered after the gasification process and again applied to the soil as with fertilizer. Even with nitrogen, the situation is not clearly stated because over the winter the losses from the stover and cobs to the air, through

Table 2. Nutrient content of corn biomass (Crampton and Harris, 1969).

	Percent Nitrogen	Percent Calcium	Percent Magnesium	Percent Phosphorus	Percent Potassium
Corn Grain *(Ref. No. 4-02-931 and 4-02-935	1.60	0.02	0.17	0.35	0.38
Corn Cobs *(Ref. No. 1-02-783)	0.45	0.12	0.07	0.04	0.84
Corn Stover *(Ref. No. 3-02-836)	1.15	0.38	0.31	0.19	1.43

*Refers to NRC identification.

the soil, and from run-off may totally negate any benefits from this source of nitrogen.

Crop residue reduces soil losses from both wind and water erosion. The relative importance of erosion varies with climate and soil type. For Michigan conditions, water erosion is the more important. Data presented by Robertson and Mokma (1978) showed that the potential soil loss was greatest when fall plowing with a moldboard plow. The second greatest soil losses occurred on land used for silage and plowed in the spring. Chisel plowing in the fall resulted in the third greatest soil loss. The best practice to follow in terms of reducing water erosion was to leave the residue standing in the field and spring plow. However, in all instances the expected soil losses exceeded the tolerable loss, the magnitude of the difference being primarily a function of soil type and the length of the slope. In the case of spring plowing, there was no differentiation as to the proportion of losses that occurred before plowing as compared to afterwards.

A study by Mannering and Meyer (1963) suggested that one ton of uniformly distributed crop residue per acre would be sufficient to control water erosion. Buchele (1975) reported that 1 to 1.5 tons of cornstalk residue per acre could control erosion under Iowa conditions if the material were managed correctly. In addition, he suggested that the removal of some of the residue might reduce the need for tillage operations specifically geared to incorporating the cornstalks into the soil. When considering the cost for nitrogen replacement and harvesting, and the savings associated with reduced tillage requirements, Buchele's cost estimates showed only an increased cost of \$1.07 per acre for removing one ton of material per acre, not considering transportation. For a yield of 100 bushels per acre, the equivalent cost would be approximately \$0.01 per bushel.

Considering all factors, it would appear that soil erosion can be minimized using currently available cultural practices so long as 1 to 1.5 tons of the crop residue remain. For the earlier example of drying 30.5 percent moisture corn to 15.5 percent, only 26.4 percent of the available stover was used, much less than the minimum needed for erosion control. Therefore, the cost of reduced erosion control will be neglected in so far as this study is concerned.

The value of the nutrients lost due to gasification may be ignored, except for nitrogen, assuming they will be replaced in the soil after gasification. The value of the lost nitrogen may be estimated using the following equations:

$$CSTNRG = 1.6*GDWT*RNSPC*CSTUN*GUGPC*10^{-6} \tag{64}$$

$$CSTNRC = 0.45*CDWT*RNSPC*CSTUN*CUGPC*10^{-6} \tag{65}$$

$$CSTNRS = 1.15*SDWT*RNSPC*CSTUN*SUGPC*10^{-6} \tag{66}$$

where CSTNRG, CSTNRC, CSTNRS = cost of nitrogen replacement because of biomass removal, for grain, cobs and stover, respectively

GDWT, CDWT and SDWT = dry weight units per unit of wet grain for grain, cobs and stover, respectively, in relative proportion to each other (Equations 7, 8, 9, 13)

RNSPC = percentage of nitrogen retained by the soil and available for crops the following year

CSTUN = cost of nitrogen per unit

GUGPC, CUGPC, SUGPC = the percentage of grain, cobs and stover, respectively, that are utilized in drying

In the example used previously, corn was to be dried from 30.5 to 15.5 percent moisture. The moisture contents of both the cobs and stover was computed to be 61 percent. The proportional dry weights for grain, cobs and stover were 0.695,0.171 and 0.637 kg, respectively. Likewise, the percentages of grain, cobs and stover required to dry the grain were 13.8, 86.3 and 26.4 percent, respectively. A representative cost for nitrogen is $.44/kg ($0.20/lb), and expected losses over the winter would be approximately 20 percent, or an 80 percent retention factor (Vitosh, Lucas and Black, 1979). Using these values in Equations 64, 65 and 66:

$$\begin{aligned} CSTNRG &= 1.6*0.70kg*80\%*\$0.44/kg*13.8*10^{-6} \\ &= \$0.00054/kg \text{ or } \$0.0137/bu \\ CSTNRC &= 0.45*0.171kg*80\%*\$0.44/kg*86.3\%*10^{-6} \\ &= \$0.00023/kg \text{ or } \$0.0058/bu \\ CSTNRS &= 1.15*0.637kg*80\%*\$0.44/kg*26.4\%*10^{-6} \\ &= \$0.00068/kg \text{ or } \$0.0173/bu \end{aligned}$$

From these calculations, the removal of biomass from the soil for purposes of grain drying would have sufficient economic impact with regard to nitrogen replacement to be included in the study.

In summary, the effects of biomass removal in the quantities required for drying do not seem to have significant short term costs for erosion control. Instead, it appears that management practices, such as plowing and residue distribution are more important considerations than residue removal alone. From this analysis, no opportunity costs will be assigned to gasification in this study based on erosion control. This is not to say, however, that the long term effects under improper management might not be important. Only nitrogen loss will be considered with regard to nutrient loss and then only for cobs and stover for reasons stated in the following section.

D. Alternative Uses

In the previous section, the opportunity cost of biomass was defined in terms of soil productivity. However, greater opportunity cost would typically be reflected in the market value of the material. In the case of grain, the market value is approximately \$2.50 per bushel. However, for the grain farmer, cobs and stover have traditionally had no market value, except in those cases where individuals were able to use this material for animal feed. Therefore, for the boundaries of this study, only the grain will be considered to have a non-zero opportunity cost, recognizing that in the longer run stover and cobs may develop into valuable energy sources that may compete with gasification for grain drying.

Using the previous example and corn at \$2.50 per bushel (\$0.10/kg) the opportunity costs for grain, cobs and stover may be computed using the following general equation:

$$OPCST = MVBU*PCBUGA/100 \tag{67}$$

where OPCST = opportunity cost per unit of grain dried

MVBU = market value of the biomass per unit of material

PCBUGA = percent of biomass used per unit of grain dried

For our example, the opportunity cost of gasification when 13.8 percent of the grain is required to dry the remaining portion is:

$$OPCST = \$0.10/kg*13.8\%/100 = \$0.0138/kg$$

This would be equivalent to $0.35 per bushel, or nearly twice as much as the cost of LP gas computed earlier for 15 points of moisture removal.

E. <u>Gasification Equipment Costs</u>

There is little data on which to estimate the capital cost of a farm size gasification unit in that they are not produced on a large scale. Goss and Williams (1977a) estimated the cost of a commercial gasification unit to be $3000/(ton-day) plus additional cost for piping, burners and controls, bringing the capital cost to approximately $4400/(ton-day). Typical burners for farm dryers range from approximately 2 to 5 million Btu/hr capacity (0.5-12.6 kcal/hr; $2.1 \times 10^3 - 5.3 \times 10^3$ J/hr). In the example problem, the quantities of wet biomass needed to dry 1 kg of grain was found to be 13.8 percent of the grain, 86.3 percent of the cobs and 26.4 percent of the stover. For each kg of 30.5 percent moisture grain, there is 0.439 kg of wet cobs and 1.651 kg of wet stover. Therefore, the drying of 1 kg of 30.5 percent grain each day requires approximately 0.14 kg of grain or 0.36 kg of cobs or 0.42 kg of stover. This would translate to an estimated capital cost per kg of wet grain of $0.68, $1.74 and $2.04 for a gasification unit processing grain, cobs and stover, respectively. On a per wet bushel basis, the corresponding capital costs are $17.25, $44.35 and $51.74.

Perhaps the closest comparison to a gasification unit would be an incinerator (Rubel, 1974). Using the same basic information as above, the 1969 incinerator cost for a unit that could dispose of 1 kg of grain, 0.36 kg of cobs and 0.42 kg of stover each day would be \$0.31, \$0.80, and \$0.91, respectively, when adjusted to 1977 prices. On a per wet bushel dried basis, the corresponding costs would be \$7.87, \$20.32 and \$23.12.

The above two references do give some range of prices that one might expect for a gasification unit. Both sets of prices are based on 24 hours of operation. In grain drying, the time of operation per day may be considerably less than 24 hours. If, for example, the dryer was to operate only 12 hours per day, the cost of the unit would double due to the doubling of the required hourly capacity.

In that there is no exact cost information, the maximum amount of money that may be invested in a gasification unit will be calculated using present value analysis. This requires that certain annual costs be considered including interest, taxes, insurance, maintenance, repair and depreciation.

The following annual costs would be typical for a machine of this type:

1. Interest: 15 percent of purchase price compounded yearly for an average annual rate of 7.5 percent considering no salvage value.

2. Taxes and Insurance: 1 percent of purchase price per year.

3. Maintenance and Repair: 4 percent of purchase price per year.

4. Depreciation: 10 percent of purchase price per year based on straight line depreciation and a 10-year machine life.

Other items of consideration are investment credit and the tax bracket of the particular individual. Investment credit would be nearly equivalent to a 10 percent reduction in purchase price assuming present law and a 10-year life for the gasification unit. The income tax bracket tends to reduce both the profits and the losses associated with the investment.

F. Break-even Investment

The major objective of this study is to determine the break-even capital investment in gasification equipment for grain drying. For purposes of this analysis, cost considerations that may be unique to an individual will not be considered, i.e. tax bracket, investment credit, and depreciation. In that way, the results apply more readily to all individuals although each would have to make modifications to reflect his unique situation.

Break-even capital investment is defined as the amount of money that may be invested in equipment so that the gross return will equal the gross expenses. Gross return is defined as the annual equivalent cost of LP gas if used as a source of energy for drying. Annual gross expenses include the cost of harvesting and transportation; replacement value of nitrogen lost due to gasification; opportunity costs of the biomass as a function of market price; and repair, operation and maintenance costs of the gasification equipment.

The following equations are used to determine the break-even investment cost per unit of wet grain dried where "wet" grain is referenced to either its initial or final moisture content.

$$CQLPQ = \frac{ENERNU*PPULPG}{EPQLPG} \tag{68}$$

where CQLPQ = cost of the quantity of LP gas needed per unit of wet grain to be dried

ENERNU = efficiency adjusted energy requirements per unit of wet grain dried by LP gas (determined using Equation 59)

PPULPG = price per unit of LP gas

EPQLPG = energy per quantity of LP gas

$$QWWT = \frac{ENERNX*100}{ENPWTU*GEFF} \quad (69)$$

where QWWT = quantity of wet biomass needed to dry one wet unit of grain

ENERNX = adjusted energy requirements per unit of wet grain dried by biomass (determined from Equation 55)

ENPWTU = energy available for drying one wet unit of grain after adjusting for internal moisture (determined by Equations 31-39)

GEFF = efficiency of the gasification process, percent

$$HTCST = HTCPU*QWWT \quad (70)$$

where HTCST = harvesting and transportation cost per unit of wet grain dried

HTCPU = harvesting and transportation cost per unit of wet biomass

$$VNREM = PCN*QDRYB*RNSPC*QUGPC*10^{-6} \quad (71)$$

where VNREM = value of the nitrogen removed per unit of wet grain dried (see Equations 64-66)

PCN = percent of the dry biomass composed of nitrogen

QDRYB = dry weight of biomass available for gasification per unit of wet grain (see Equations 7, 8, 9 and 13)

RNSPC = percentage of nitrogen retained by the soil and available for crops the next year

QUGPC = percentage of biomass available that is utilized in drying one wet unit of grain (see Equations 56, 57 and 58)

$$MARVAL = MPRICU*QUGPC/100 \tag{72}$$

where MARVAL = market value of biomass per unit of wet grain dried

MPRICU = market price per unit of biomass

$$GROSAV = CQLPQ-HTCST-MAX(VNREM,MARVAL) \tag{73}$$

where GROSAV = gross savings per year associated with using the gasification process, on a per wet unit of grain dried basis

$$PWF = 1.0/(1.0+I)**n \tag{74}$$

where PWF = present worth factor for a given year that when multiplied times a future return will give its present value

I = annual interest rate, decimal

n = years from present

$$SPWF = ((1.0+I)**L-1.0)/(I*(1.0+I)**L) \tag{75}$$

where SPWF = present worth factor that will give the present value of a uniform series of payments when multiplied by the annual return

L = life of the gasification equipment in years

$$GPVAL = \sum_{j=1}^{n} PWF(j)GROSAV(j) \tag{76}$$

where GPVAL = gross present value of the annual stream of gross savings

$$BEGASE = GPVAL/(1.0+(AMAIN/100.0)*SPWF) \tag{77}$$

where BEGASE = break-even investment cost per wet unit of grain dried for gasification equipment

AMAIN = annual charge for maintenance, repair operation of gasification equipment, percent

$$AMGASE = BEGASE*AMAIN/100.0 \tag{78}$$

where AMGASE = annual charge per wet unit of grain dried for maintenance, repair and operation of gasification equipment

However, if "BEGASE" is negative, another alteration is required to show that if the gasification equipment is purchased, the maintenance and operation expense decreases the break-even investment even more. This is discussed in greater detail later in this section.

$$\underset{\text{(new value)}}{\text{BEGASE}} = \underset{\text{(Equation 77 value)}}{\text{BEGASE}} + \text{SPWF} * \text{AMGASE} \tag{79}$$

Using Equations 68-78, the break-even investment cost for gasification equipment may be calculated for the previous example. The cost of LP gas is calculated using the value obtained in Equation 59 for ENERNU and converted to Btu's per dry bushel. An LP gas price of $.50 per gallon is used and a fuel energy content of 92,000 Btu/gal is assumed. A dry bushel is defined as 56 pounds of corn that is at 15.5 percent moisture content after drying (U.S. No. 2).

$$\begin{aligned}\text{CQLPQ} &= \frac{\text{ENERNU*PPULPG}}{\text{EPQLPG}} \\ &= \frac{35280 \text{ Btu/bu*\$.50/gal}}{92000 \text{ Btu/gal}} \\ &= \$0.1917 \text{ per dry bushel dried}\end{aligned}$$

The quantity of wet grain, cobs and stover needed to dry one dry bushel of grain are computed using values determined previously and converted to a Btu per dry bushel dried basis.

$$\text{QWWT} = \frac{\text{ENERNX*100}}{\text{ENPWTU*GEFF}}$$

$$\text{For grain:} \quad \text{QWWT} = \frac{28224 \text{ Btu/bu*100}}{6188 \text{ Btu/lb*60}} = 7.60 \text{ wet pounds per dry bushel dried}$$

$$\text{For cobs:} \quad \text{QWWT} = \frac{28114 \text{ Btu/bu*100}}{2326 \text{ Btu/bl*60}} = 20.22 \text{ wet pounds per dry bushel dried}$$

For stover: $QWWT = \frac{28224Btu/bu*100}{2023Btu/lb*60} = 23.25$ wet pounds per dry bushel dried

The cost of harvesting and transporting the biomass can be calculated using Equation 70. Assume that a 56 lb bushel may be harvested for $0.26 and that similar costs are $5.00 and $10.00 per ton of wet material for cobs and stover, respectively.

For grain: HTCST = 26¢/bu*7.60lb/56lb/bu

= 3.53¢ per dry bushel dried

For cobs: HTCST = 500¢/ton*20.22lb/2000lb/ton

= 5.06¢ per dry bushel dried

For stover: HTCST = 1000¢/ton*23.25lb/2000lb/ton

= 11.63¢ per dry bushel dried

The value of the nitrogen lost from the field has previously been calculated using Equations 64, 65 and 66.

For grain: VNREM = 1.37¢ per dry bushel dried

For cobs: VNREM = 0.58¢ per dry bushel dried

For stover: VNREM = 1.70¢ per dry bushel dried

A typical market value for grain would be $2.50 per bushel based on 15.5 percent moisture content. This would be equivalent to $2.07 per bushel for 30.5 percent moisture grain. For purposes of this study, cobs and stover have no market value.

For grain: MARVAL = 207¢/bu*7.60lb/56lb/bu = 28.09¢ per dry bushel dried

For cobs: MARVAL = 0

For stover: MARVAL = 0

There is now sufficient information to compute the gross savings using Equation 73. Note that the maximum cost of either the nitrogen removed or the market value will be considered but not both. This is to say that the market value reflects the total worth of the biomass including the nitrogen removed from the soil. One would usually expect the market price to exceed the nitrogen value contained with the material. If not, as is the case assumed for cobs and stover, the nitrogen loss is the opportunity cost considered. In the example problem:

For grain: GROSAS = 19.17¢-3.53¢-MAX(1.37¢, 28.09¢)

= -12.45¢ per dry bushel dried

For cobs: GROSAS = 19.17¢-5.06¢-MAX(0.58¢, 0)

= 13.53¢ per dry bushel dried

For stover: GROSAS = 19.17¢-11.63¢-MAX(1.73¢, 0)

= 5.82¢ per dry bushel dried

For purposes of this example, the life of the gasification equipment will be 10 years and the interest rate 15 percent per year. From Equation 74, PWF may be determined for each year.

Year 1: PWF = 0.8696
Year 2: PWF = 0.7561
Year 3: PWF = 0.6575
Year 4: PWF = 0.5718
Year 5: PWF = 0.4972
Year 6: PWF = 0.4323
Year 7: PWF = 0.3759
Year 8: PWF = 0.3269
Year 9: PWF = 0.2843
Year 10: PWF = 0.2474

From Equation 75:

SPWF = ((1.0+0.15)**10-1.0)/(0.15*(1.0+0.15)**10)

= 5.019

The gross present value is computed using Equation 76.

For grain: GPVAL = 0.8696*(-12.45¢)+0.7561*(-12.45¢)+0.6575 *(-12.45¢)+0.5718*(-12.45¢)+0.4972*(-12.45¢) +0.4323*(-12.45¢)+0.3759*(-12.45¢)+0.3269 *(-12.45¢)+0.2843*(-12.45¢)+0.02474*(-12.45¢)

= -62.49¢ per dry bushel

Similarly,

For cobs: GPVAL = 67.90¢ per dry bushel dried

For stover: GPVAL = 29.16¢ per dry bushel dried

These values can be calculated somewhat easier than in the above example for situations where the annual return is constant over the life of the equipment. However, this will not always be the case as with escalating real energy prices.

Part of the gross present value must be used to maintain and operate the gasification equipment if it is purchased. For this example, 4 percent of the purchase price will be charged each year for maintenance and operation. The break-even investment can be calculated using Equation 77:

For grain: BEGASE = -62.49¢/(1.0+(4.0/100)*5.019)

= -52.04¢ per dry bushel dried

For cobs: BEGASE = 67.90¢/(1.0+(4.0/100)*5.019)

= 56.55¢ per dry bushel dried

For stover: BEGASE = 29.16¢/(1.0+(4.0/100)*5.019)

= 24.28¢ per dry bushel dried

The annual charge for maintenance and operation may now be computed using Equation 78:

For grain: AMGASE = -52.04¢*4.0/100

= -2.08¢ per dry bushel dried

For cobs: AMGASE = 56.55¢*4.0/100

= 2.26¢ per dry bushel dried

For stover: AMGASE = 24.28¢*4.0/100

= 0.97¢ per dry bushel dried

Because BEGASE has a negative value, an adjustment must be made by using Equation 79.

For grain: BEGASE = -52.04+(5.019)*(-2.08)

= -62.49¢ per dry bushel dried

Notice that this value is actually the same as the gross present value calculated previously using Equation 76.

For our example, there is a negative break-even investment for using grain as a source of fuel for grain drying. There are several ways in which the negative value should be interpreted. First, a negative investment simply reflects a negative annual return which means the machine will not pay for itself. Another interpretation is that the negative investment is the present value of the annual losses. The annual losses include the gross savings (actually gross losses) and the maintenance and operation charges for the equipment. The annual losses per dry bushel times the number of dry bushels dried yield the total value per year that must be returned by other uses of the equipment besides grain drying if the investment is to break even.

G. Concluding Remarks

At this point in the analysis, both the technological and economic implications have been examined. The following represents a descriptive summary of the evaluation:

1. The relative and absolute quantities of grain, cobs and stover may be determined based on the grain moisture contents for which the grain is considered mature enough for harvesting.
2. The energy available for drying can be estimated based on biomass moisture content, and gasification and drying efficiency.
3. The present value of the annual gross return to gasification is defined as the present value of the cost savings from not using LP gas in grain drying.
4. The annual net return available for purchase of gasification equipment may be determined by subtracting from the annual gross return the following items:
   (a) harvesting and transportation costs of the biomass;
   (b) opportunity costs, i.e. market value of the biomass, or the value of the nitrogen losses, whichever is greater; and
   (c) maintenance, insurance and operational costs for gasification equipment.
5. The cost for harvesting grain, cobs and stover is usually based on the weight of wet material rather than dry material. In fact, moisture content is not usually considered at all when establishing custom rates.
6. The effects of biomass removal on soil productivity are somewhat site specific; that is, nutrient removal may be calculated easily but the effects of erosion and losses

in organic matter will not have the same effect on yield in every location.

The same example problem has been presented through the text. How representative is this example? The initial moisture content of the grain, 30.5 percent wet basis, would be considered close to the upper bound for normal grain harvesting operations. The drying efficiency of 45 percent would be typical of a high temperature (180-220° F) drying system. The energy supplied by LP gas would represent over 95 percent of the energy required for drying, the remainder being for electricity to power the fans. However, fan operation would be required regardless of the energy source for heating the air.

The problem now becomes one of determining the influence of the various physical and economic factors on break-even investment.

CHAPTER VII

ECONOMIC FEASIBILITY OF GASIFICATION

A. Introduction

In the preceding chapters, a series of equations have been presented that may be used to determine the physical and economic feasibility of gasifying corn grain, cobs and stover for purposes of drying grain. Either single or a range of values have been given for the physical and economic parameters considered. In this chapter, the sensitivity of the gasification system to changes in certain physical and economic conditions will be explored. The mechanism for doing this is a computer program which incorporates the equations and concepts presented in previous chapters. (See Appendix.)

B. Base Condition

A base condition is defined as the set of parameters considered most representative for determining the break-even investment cost for gasification equipment. For this study, the base conditions are given in Table 3. All values presented in the following analyses are determined by changing one of the base conditions while holding the remaining values constant. This is commonly referred to as a sensitivity analysis. Again, a dry bushel is defined as 56 pounds of corn at 15.5 percent moisture (U.S. No. 2).

Table 3. Base values of inputs used in sensitivity analysis.

No.	Input Description	New Value
1	Initial grain moisture, percent	25.50
2	Desired final grain moisture, percent	15.50
3	Gross energy in grain, Btu/dry lb	9995.00
4	Gross energy in cobs, Btu/dry lb	7961.00
5	Gross energy in stover, Btu/dry lb	7150.00
6	Percent adjustment for bomb calorimeter	93.00
7	Percent efficiency of LP gas burner	80.00
8	Percent efficiency of drying process	45.00
9	Percent efficiency of gasification process	60.00
10	Nitrogen content in grain, percent of dry weight	1.60
11	Nitrogen content in cobs, percent of dry weight	0.45
12	Nitrogen content in stover, percent of dry weight	1.15
13	Heat of vaporization of water, Btu/lb	1060.00
14	Price of LP gas in year No. 1, ¢/gal	50.00
15	Constant change per year in LP gas price, ¢/gal	0.00
16	Change in LP gas price, percent from previous year	0.00
17	Price of nitrogen, ¢/lb	20.00
18	Percent/year for maintenance of gasification equipment based on purchase price	4.00
19	Annual interest rate, percent	15.00
20	Economic life of gasification equipment, years	10.00
21	Harvest-transport cost for grain, ¢/bu @ 56lb/bu	26.00
22	Harvest-transport cost for cobs in field, $/ton of wet material	5.00
23	Harvest-transport cost for stover in field, $/ton of wet material	10.00
24	Market value of grain at 15.5 percent moisture, $/bu	2.50
25	Market value of cobs in field, $/wet ton	0.00
26	Market value of stover in field, $/ wet ton	0.00
27	Retention rate of biomass nitrogen by soil, percent	80.00

Computed base break-even investment costs, ¢/dry bushel (U.S. No.2)

Grain	-37.56
Cobs	38.88
Stover	23.49

C. Sensitivity Analysis

The objective of the sensitivity analysis is to determine the relative importance of an exogenous variable with respect to endogenous variables. For this study, the sensitivity analysis is used primarily to determine the effects of changing a "base condition" variable with regard to the break-even investment for gasification equipment. Generally, the base condition changes are broad and are not intended to reflect normally expected input values but rather extreme input differences. Radical changes permit the vigorous testing of equation logic and tend to expose errors more readily than when using "typical" input values.

The base conditions may be categorized into two broad categories of factors: physical and economic. An estimate of the net effects of simultaneously changing more than one base condition may be obtained by summing the effects of each separate change.

D. Physical Factors

Gasification Efficiency (Figure 12)

The efficiency of the gasification process has moderate economic implications. References cited previously indicate that gasification efficiency may reach 80 percent. An 80 percent efficiency, as compared to the base condition efficiency of 60 percent, increases the break-even investment for cobs, stover and grain by approximately 3, 7 and 14¢, respectively. The effect is more pronounced when using grain as a fuel source because it has a relatively high market value. Note, as the efficiency of the gasification process nears 100 percent, the break-even investment cost becomes positive for using grain as fuel.

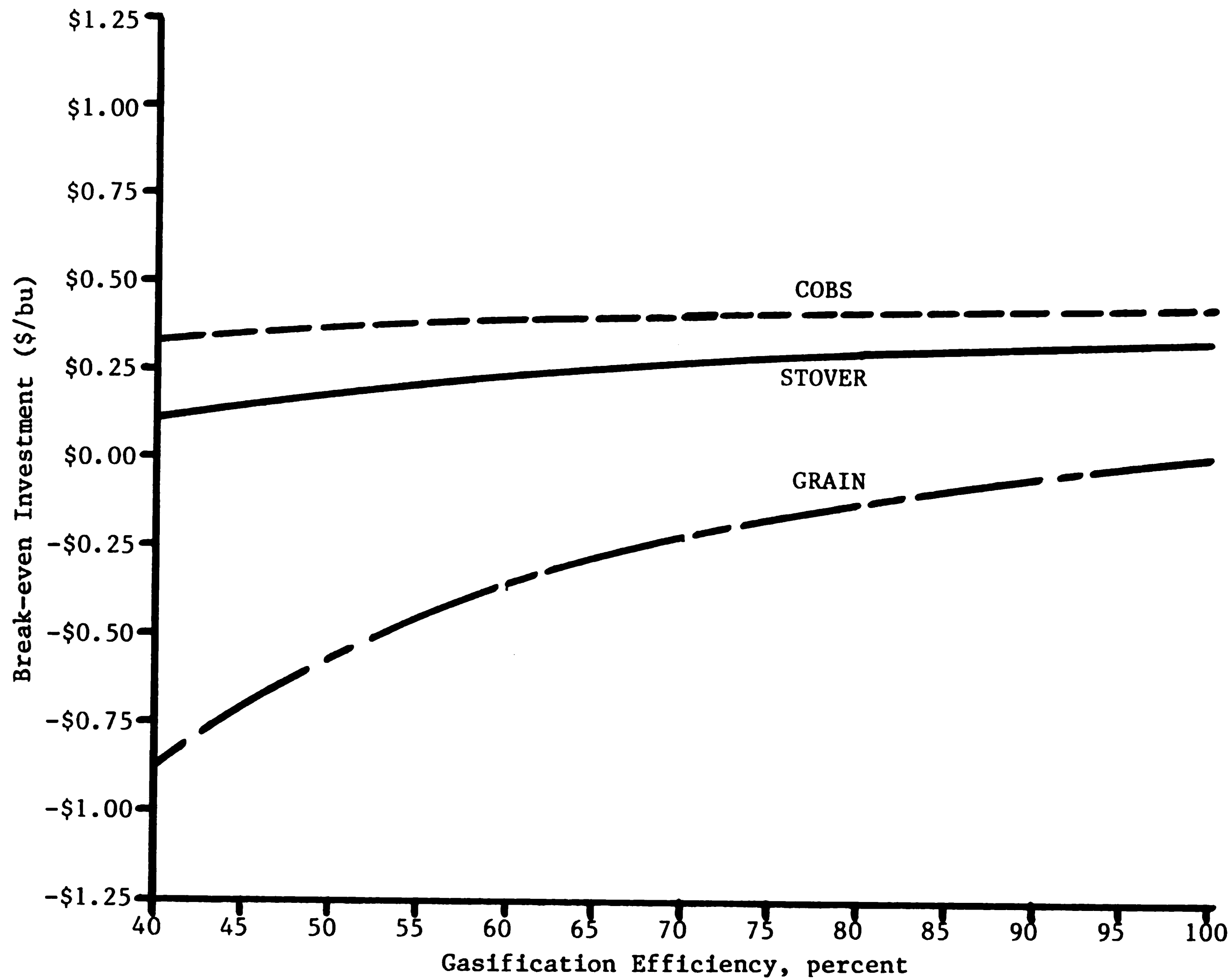

Figure 12. Effects of gasification efficiency on break-even investment per bushel of dry grain (U.S.No.2).

LP Gas Burner Efficiency (Figure 13)

The efficiency of converting LP gas to heat energy through a conventional burner is usually estimated to be 80 percent and it is unlikely that it deviates greatly from that value. However, it does have significant economic implications in that it directly influences the quantity of LP gas required for drying. In fact, the break-even investment cost for using grain as a fuel source nears a positive value when the burner conversion efficiency apporaches 50 percent.

Drying Efficiency (Figure 14)

As drying efficiency increases, the break-even investment cost narrows between using LP gas and biomass. The narrowing occurs because the relative quantities of fuel needed for drying increase with a decrease in drying efficiency. Thus, the relative break-even investments for using cobs or stover tend to decrease with an increase in drying efficiency. If the fuel source is grain, the break-even investment tends to increase.

Adjustment to Bomb Calorimeter Data (Figure 15)

The base condition for adjustment of the biomass energy content is 93 percent of the gross energy reported from bomb calorimeter data. In reality, this percentage is assumed to vary very little. However, a reduction in the value of this parameter is effectively the same as reducing the energy content of the biomass. In this context, the break-even investment cost for stover remains positive so long as approximately 58 percent of the gross energy content is available

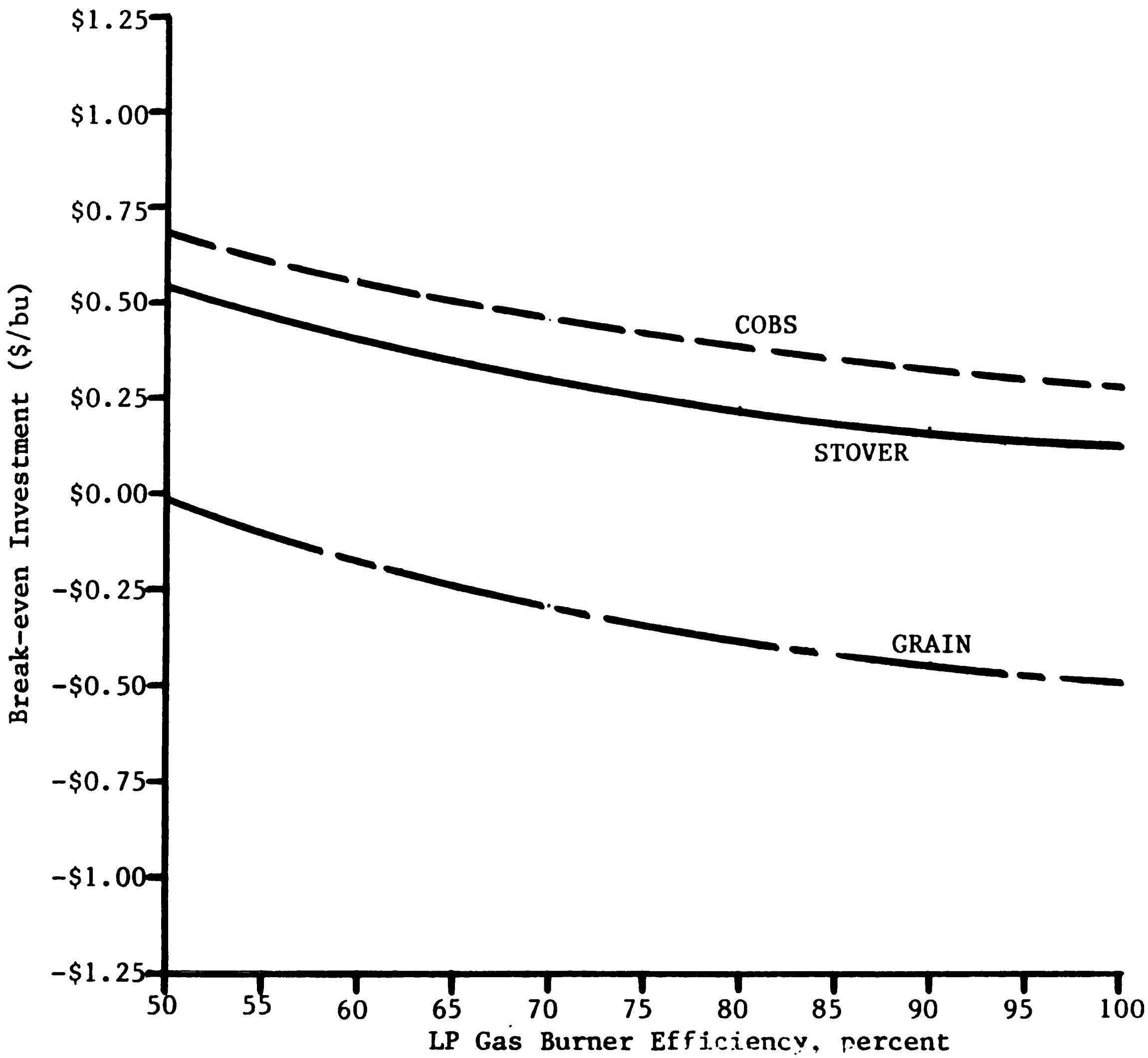

Figure 13. Effects of LP gas burner efficiency on break-even investment per bushel of dry grain (U.S.No.2).

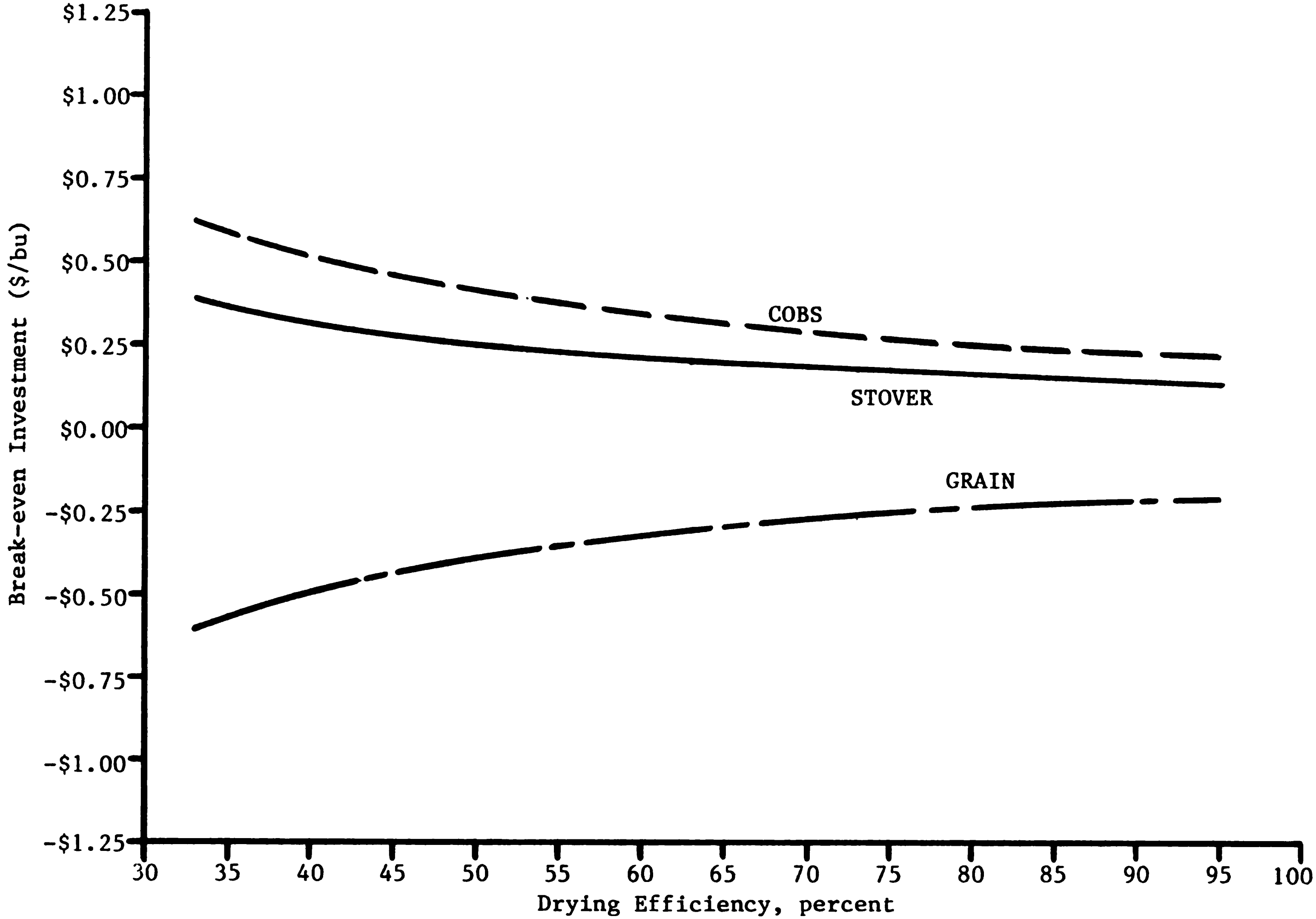

Figure 14. Effects of drying efficiency on break-even investment per bushel of dry grain (U.S.No.2).

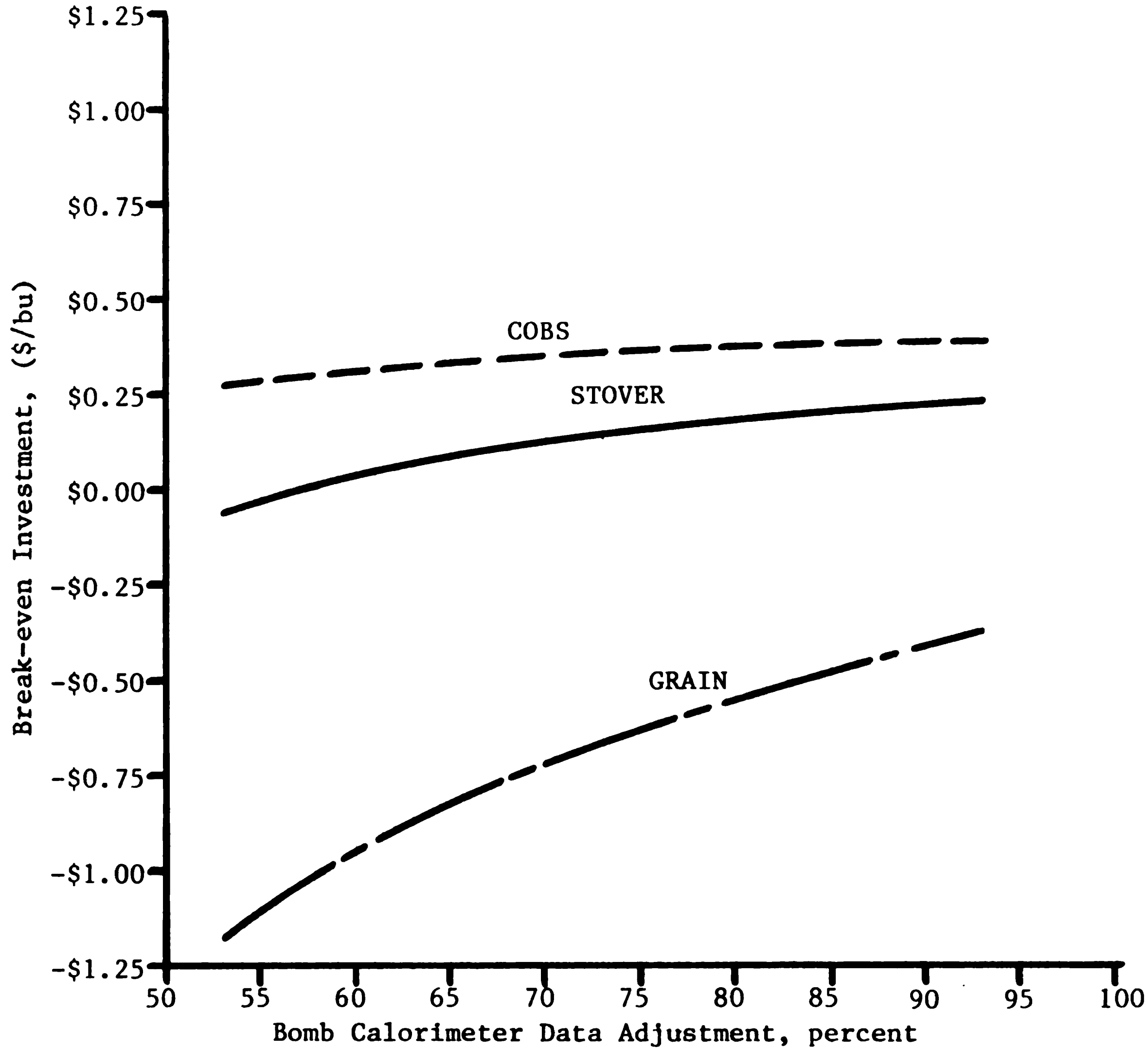

Figure 15. Effects of adjusting bomb calorimeter data on break-even investment per bushel of dry grain (U.S.No.2).

for gasification. At approximately 53 percent of the gross energy value, all the available cobs are required to dry the corn from 25.5 to 15.5 percent.

Nitrogen Retention Rate (Figure 16)

The percentage of nitrogen retained by the soil from biomass has no effect on the economics of using grain as a fuel. This is because the market value of the grain exceeds its value as a source of nitrogen. Cobs contain less than half the percentage of nitrogen found in stover, the nitrogen content being low in both instances. Hence, the break-even investment cost when using stover is somewhat more sensitive to the nitrogen retention rate than when using cobs. Regardless, the nitrogen retention rate does not appear to be overwhelmingly important.

E. Economic Factors

Life of the Gasification Equipment (Figure 17)

As the economic life (assumed to be the same as the physical life) increases, the potential for using either cobs or stover increases at a moderate but diminishing rate as would be expected. Likewise, the potential for using grain decreases. This really says that for the base conditions selected, using grain for fuel to dry grain is a bad investment and the longer the life of the investment, the worse it becomes but at a decreasing rate.

Moisture Content of Grain to be Dried
(Figure 18)

As initial moisture content increases, the break-even investment cost also increases when using cobs or stover. However, the rate of

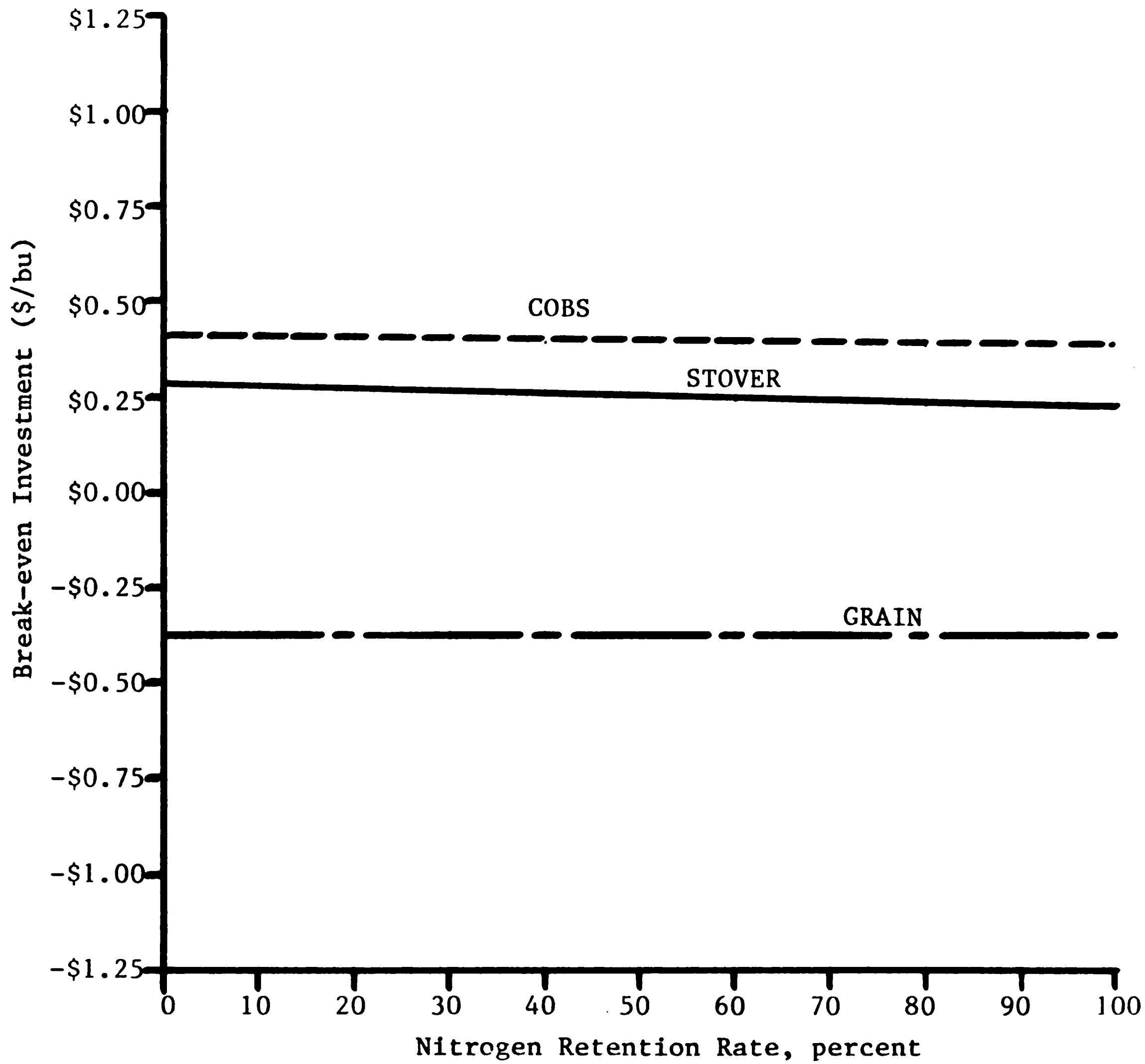

Figure 16. Effects of the nitrogen retention rate on break-even investment per bushel of dry grain (U.S.No.2).

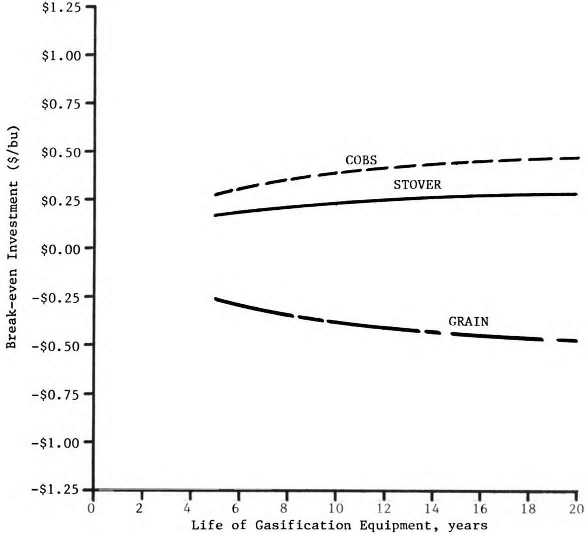

Figure 17. Effects of gasification equipment life on break-even investment per bushel of dry grain (U.S.No.2).

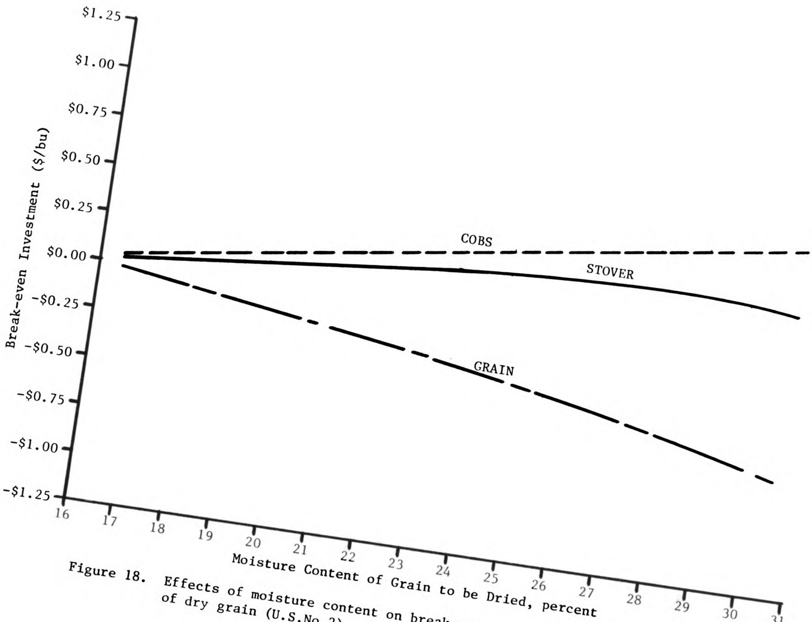

Figure 18. Effects of moisture content on break-even investment per bushel of dry grain (U.S.No.2).

increase decreases and in fact becomes negative in the case of stover. The reduction in increase is because both cobs and stover collection costs are based on wet rather than dry material. Thus, the cost of collection (harvesting and transportation) increases faster than the savings associated with expanded use of LP gas at the higher moisture content. This effect is compounded when using grain as a fuel source in that it becomes a progressively poorer investment as moisture content increases. Note that drying efficiency is held constant over the entire range of moisture contents.

Interest Rate (Figure 19)

The break-even investment cost for cobs and stover decreases as the interest rate increases. However, the effects are less when moving from the base condition to higher values than when moving to lower values. In other words, future increases will have a relatively lower effect than past increases. In the case of grain, the higher interest rates reduce the return that must be obtained from other sources to subsidize the losses resulting from using grain as a fuel source.

Annual Operation and Maintenance (Figure 20)

Annual operation and maintenance are expressed as a constant annual percentage of purchase price. It has no effect on situations where the expected return is negative as when using grain as a source of fuel. It has a moderate effect on break-even investment when using cobs and stover.

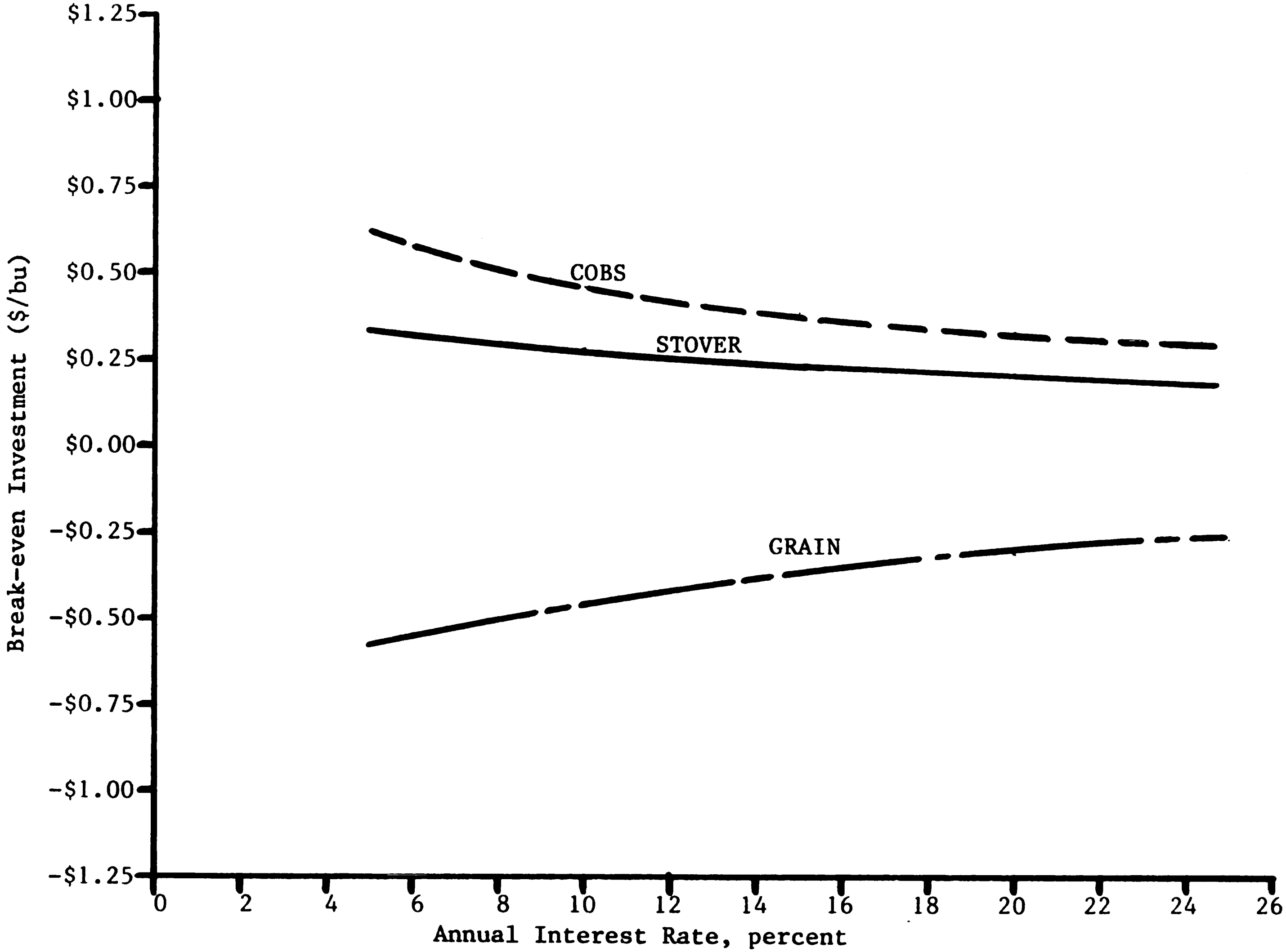

Figure 19. Effects of interest rate on break-even investment per bushel of dry grain (U.S.No.2).

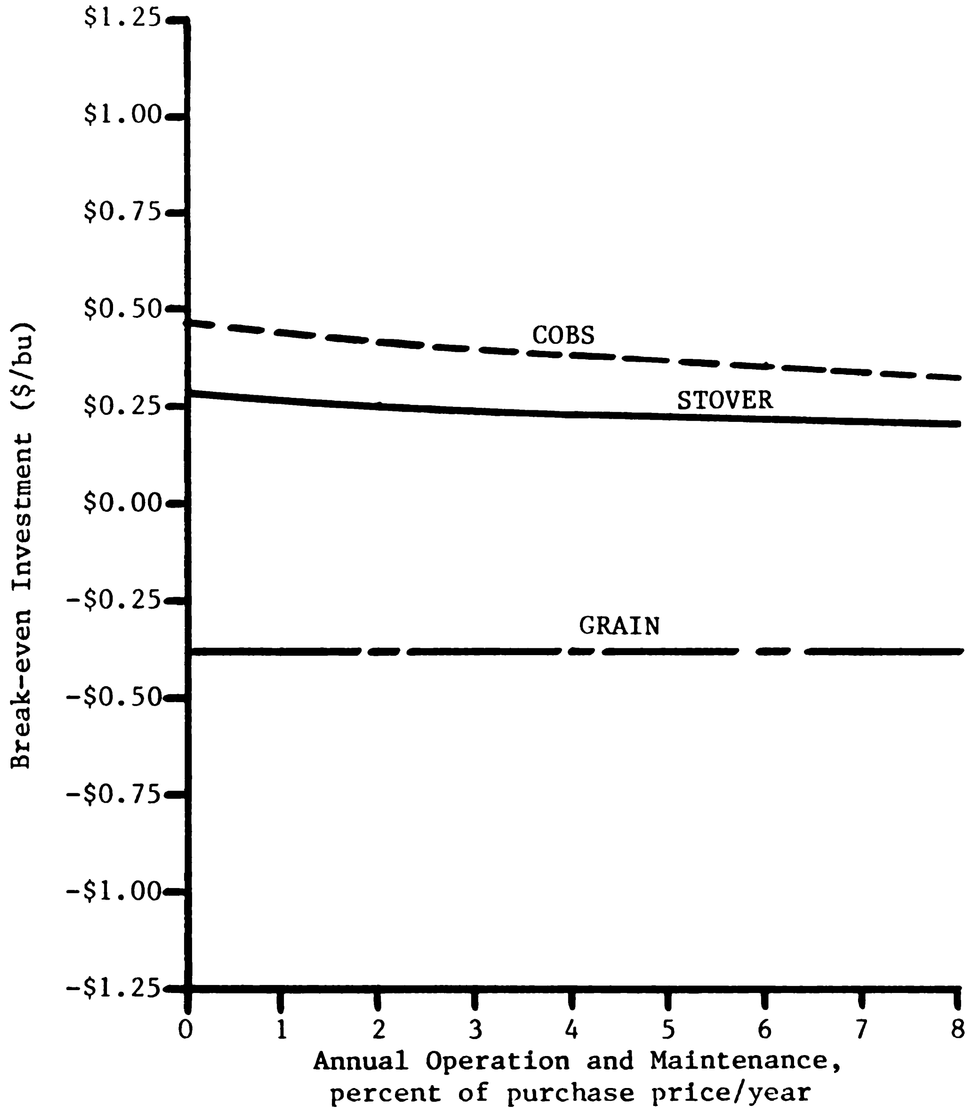

Figure 20. Effects of annual operation and maintenance on break-even investment per bushel of dry grain (U.S.No.2).

Harvesting Costs (Figures 21 and 22)

Large changes in the cost of harvesting grain have only a moderate effect on break-even investment cost. Certainly the changes are not sufficient to make grain a viable source of fuel. However, the costs of harvesting cobs and stover are very important factors to consider when computing the break-even investment cost of gasification equipment. In fact, harvesting costs of approximately $20 and $25 per ton of wet material for stover and cobs, respectively, would result in a zero break-even investment.

Market Value of Biomass (Figures 23 and 24)

The primary reason that grain is not an economic source of fuel is its high opportunity cost; that is, grain can be sold and the resulting funds used to buy more energy in the form of LP gas than the grain itself contains. However, if grain were to sell for approximately $1.45 per bushel (15.5 percent moisture), it would be competitive with LP gas as a fuel source for the values used in the base conditions.

The same logic applies to the use of cobs and stover for energy. The higher the market value, the less desirable they are as sources of energy, all other things constant. The base conditions assume a market value of zero. However, a positive market value could reflect the equivalent worth of cobs or stover as animal feed or as a source of erosion control. For this analysis, a zero value for break-even investment would be obtained if the market value of cobs and stover were approximately $20 and $11 per ton of wet material, respectively.

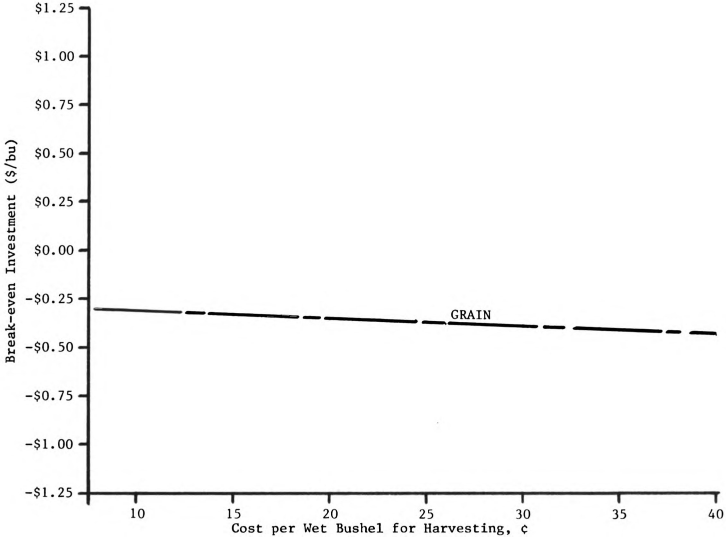

Figure 21. Effects of grain harvesting cost on break-even investment per bushel of dry grain when using grain as a fuel source (U.S.No.2).

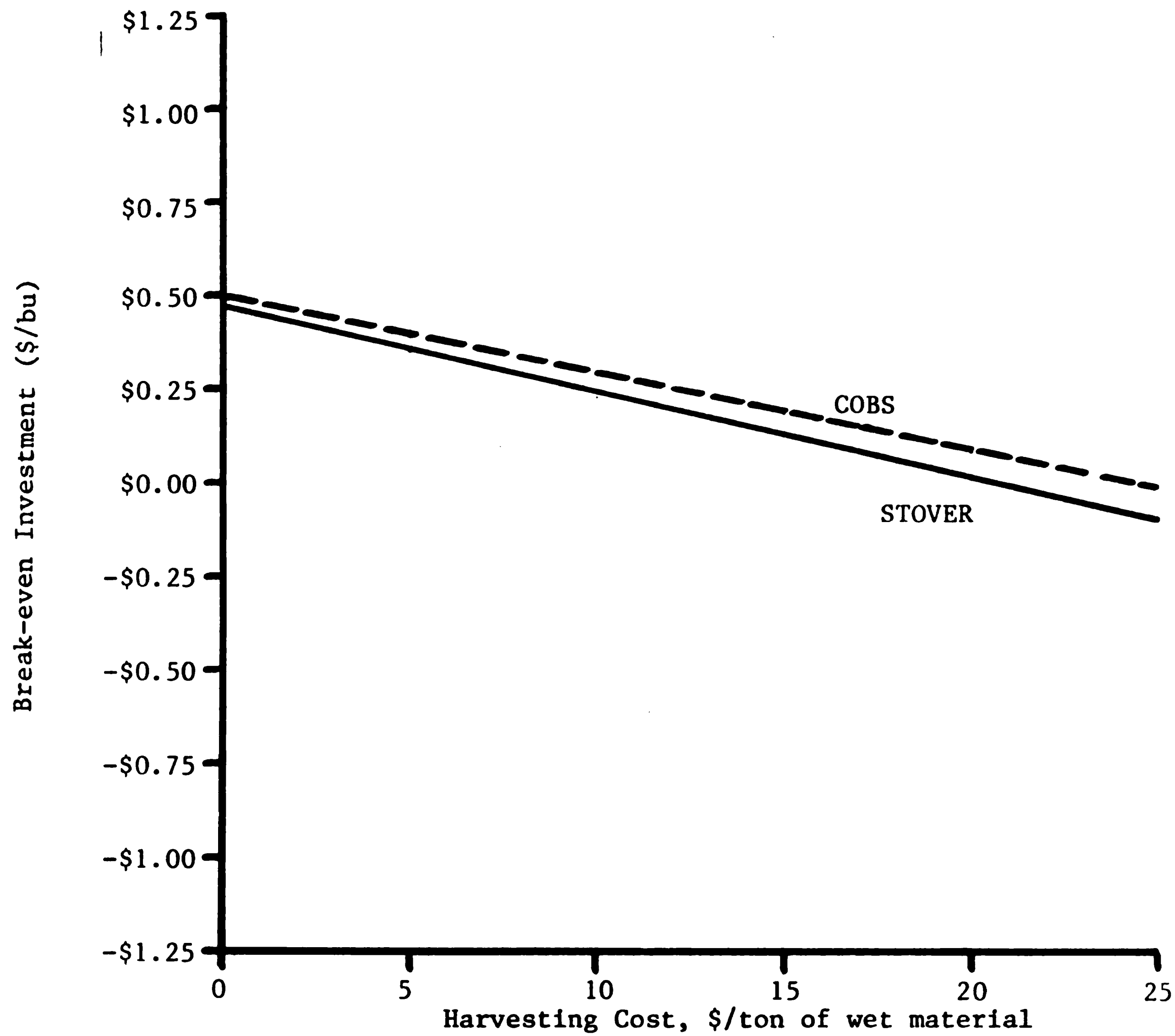

Figure 22. Effects of cob and stover harvesting costs on break-even investment per bushel of dry grain when using cobs and stover as a fuel source (U.S.No.2 grain).

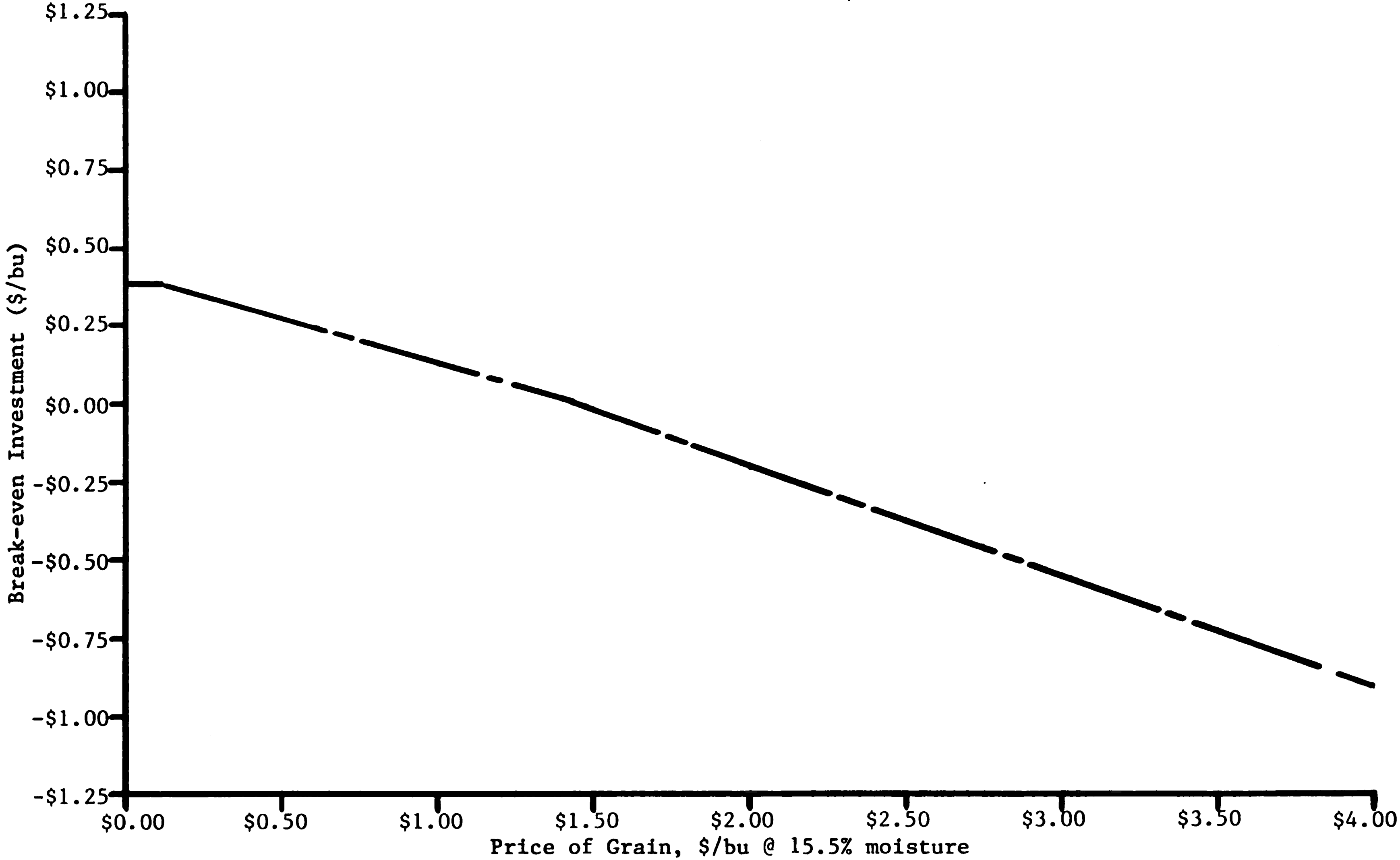

Figure 23. Effects of the market price of grain on break-even investment per bushel of dry grain when using grain as a fuel source (U.S.No.2 grain).

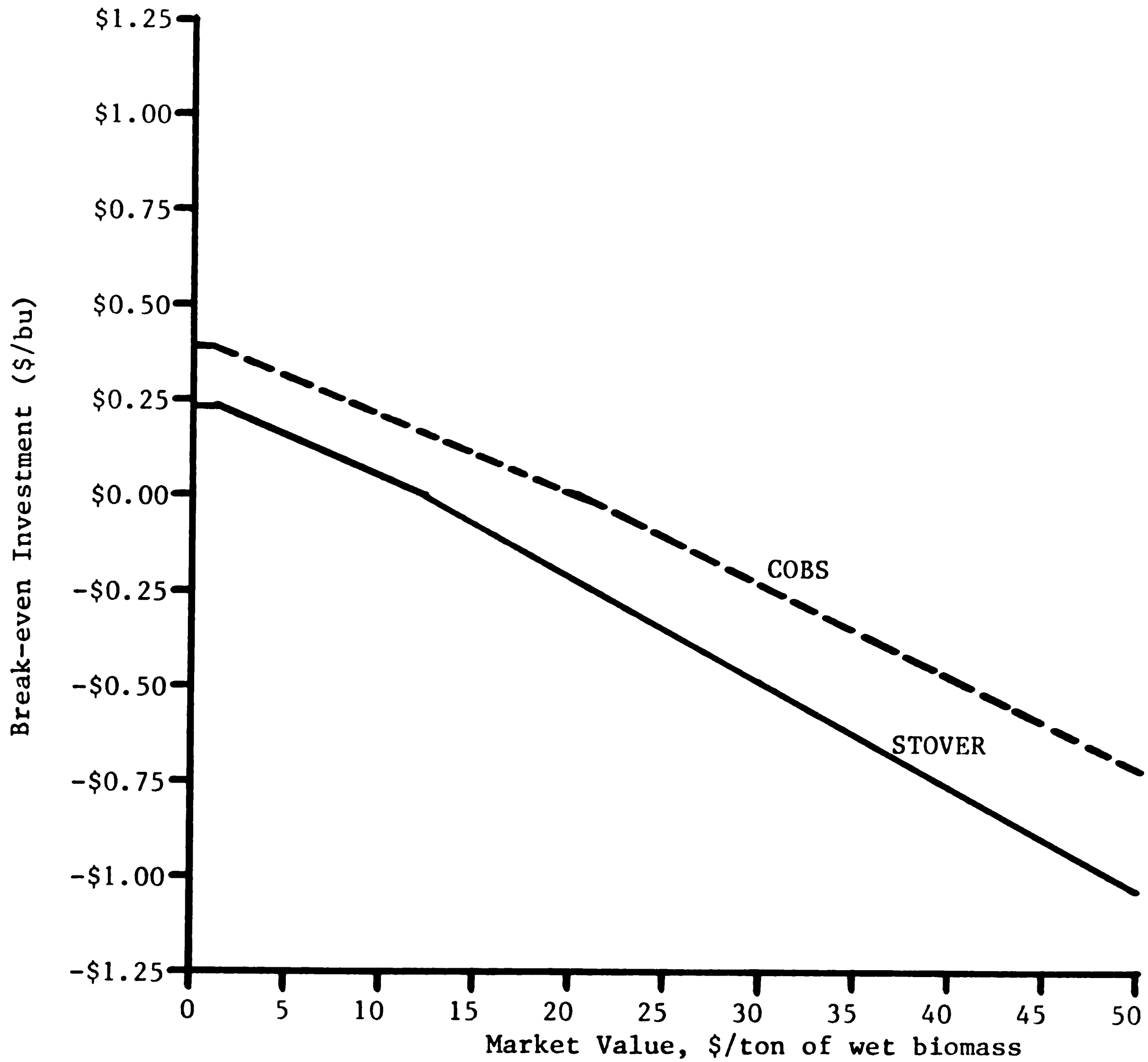

Figure 24. Effects of the cob and stover market value on break-even investment per bushel of dry grain when using cobs or stover as sources of fuel (U.S.No.2).

Cost of Nitrogen (Figure 25)

The cost of nitrogen is not important when considering grain as a fuel source. It is relatively more important when using stover as compared to cobs because stover contains a larger percentage of nitrogen, hence having a larger opportunity cost. Regardless, the price of nitrogen is not an extremely important factor.

Increases in LP Gas Price (Figures 26-34)

The break-even investment cost increases as the base price of LP gas increases. In fact, a base price greater than approximately 84¢ per gallon would result in a positive break-even investment cost when using grain as a fuel source. Likewise, increases in the amount of drying amplifies the gains or losses in break-even investment.

All increases in LP gas prices are considered real; that is, the price increase is relative to all other costs which are assumed to remain constant. This is especially important when considering that investment in capital goods occur at one point in time with proposed returns being prorated over the life of the investment. This may result in losses during the early years of the investment only to be offset by gains in the later years.

From the figures, a real increase in LP gas prices of approximately 15 percent over each previous year would result in a positive break-even investment for grain as a fuel source. It would also approximately double the break-even investment for cobs and stover for 10 points of moisture removal.

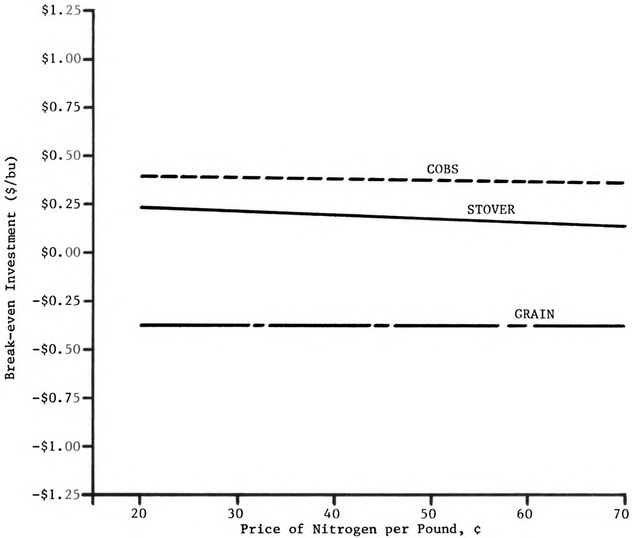

Figure 25. Effects of nitrogen cost on break-even investment per bushel of dry grain (U.S.No.2).

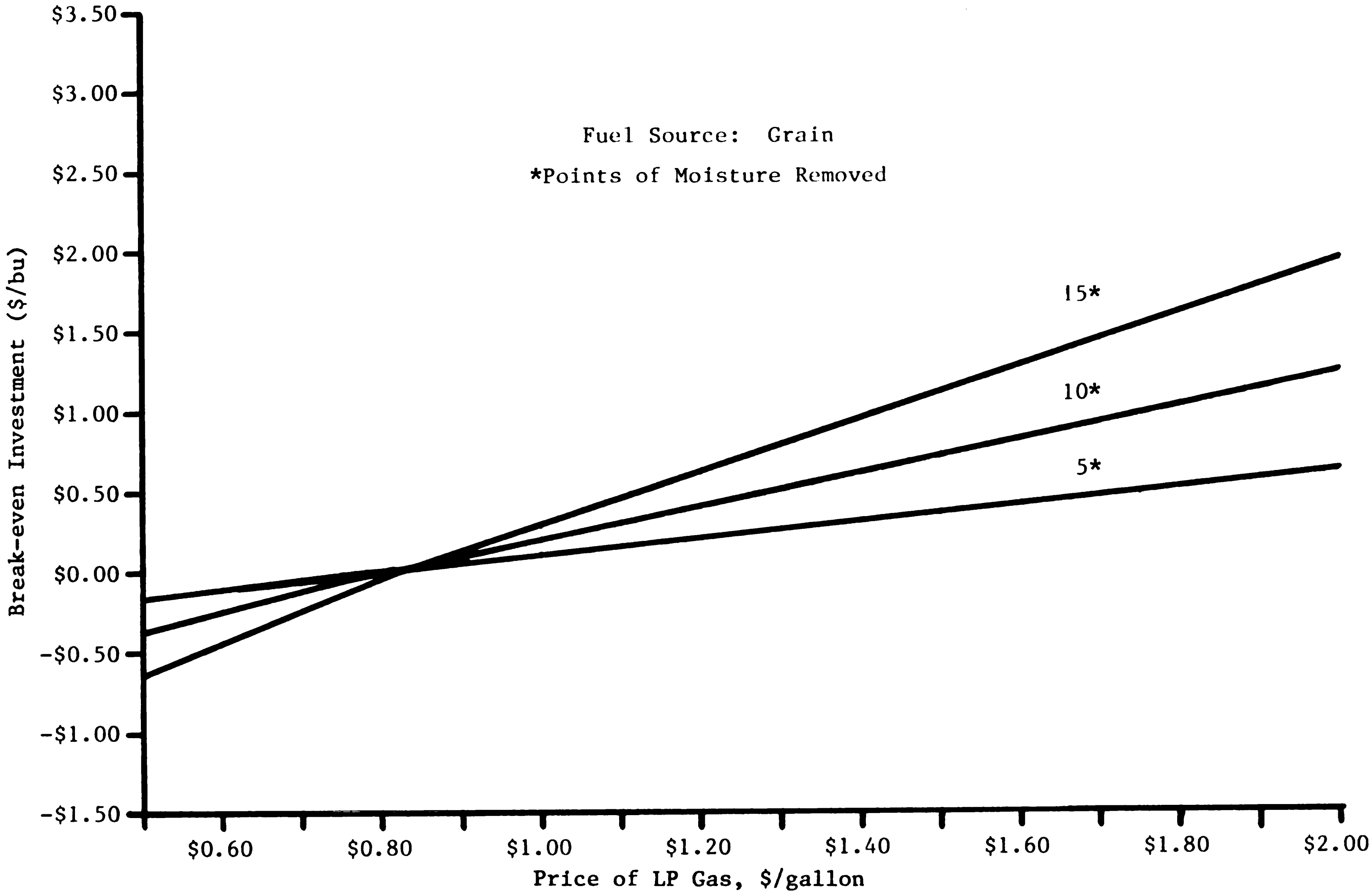

Figure 26. Effects of a constant LP gas price on the break-even investment per bushel of dry grain when grain is the fuel source (U.S.No.2).

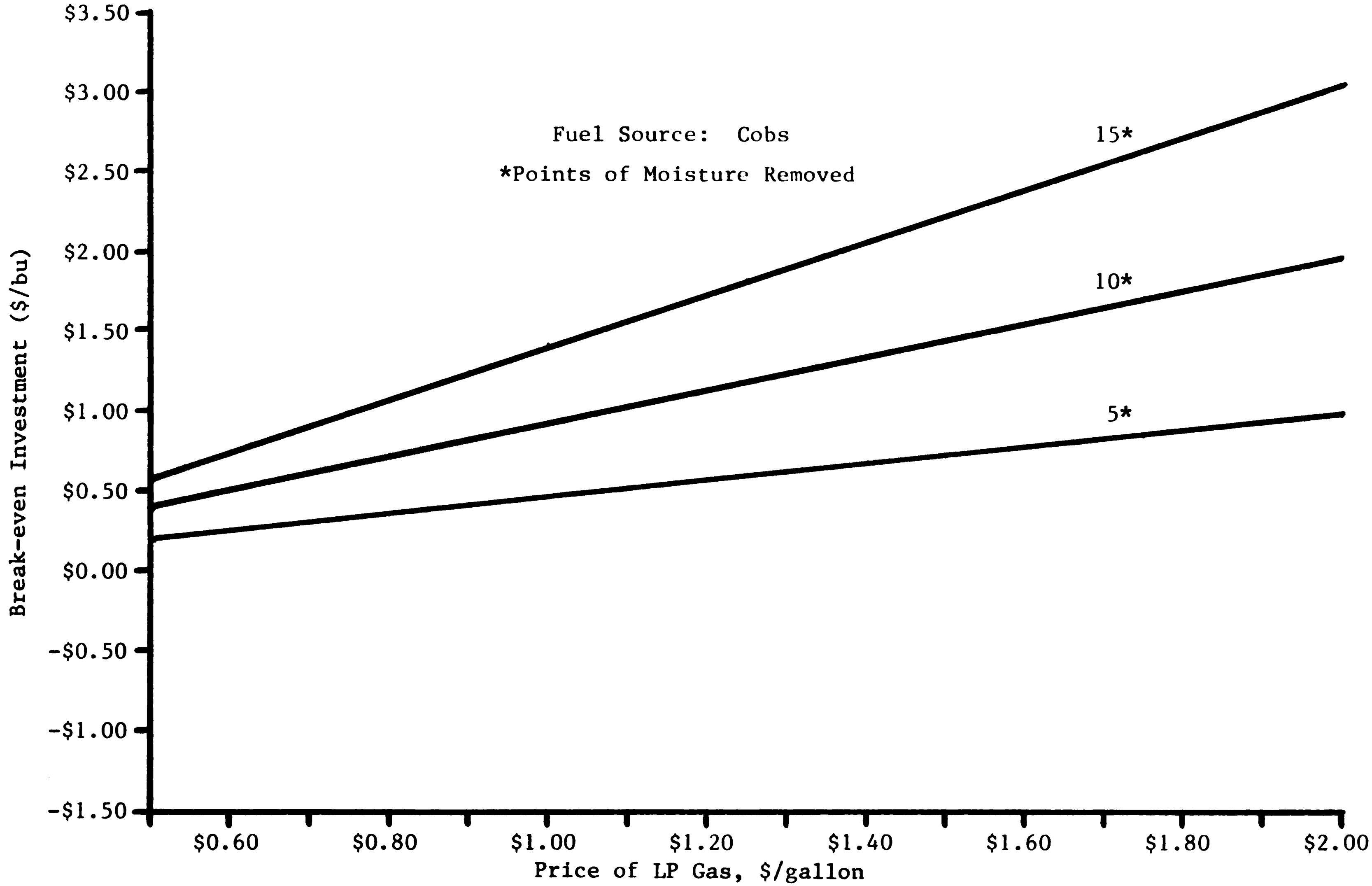

Figure 27. Effects of a constant LP gas price on the break-even investment per bushel of dry grain when cobs are the fuel source (U.S.No.2).

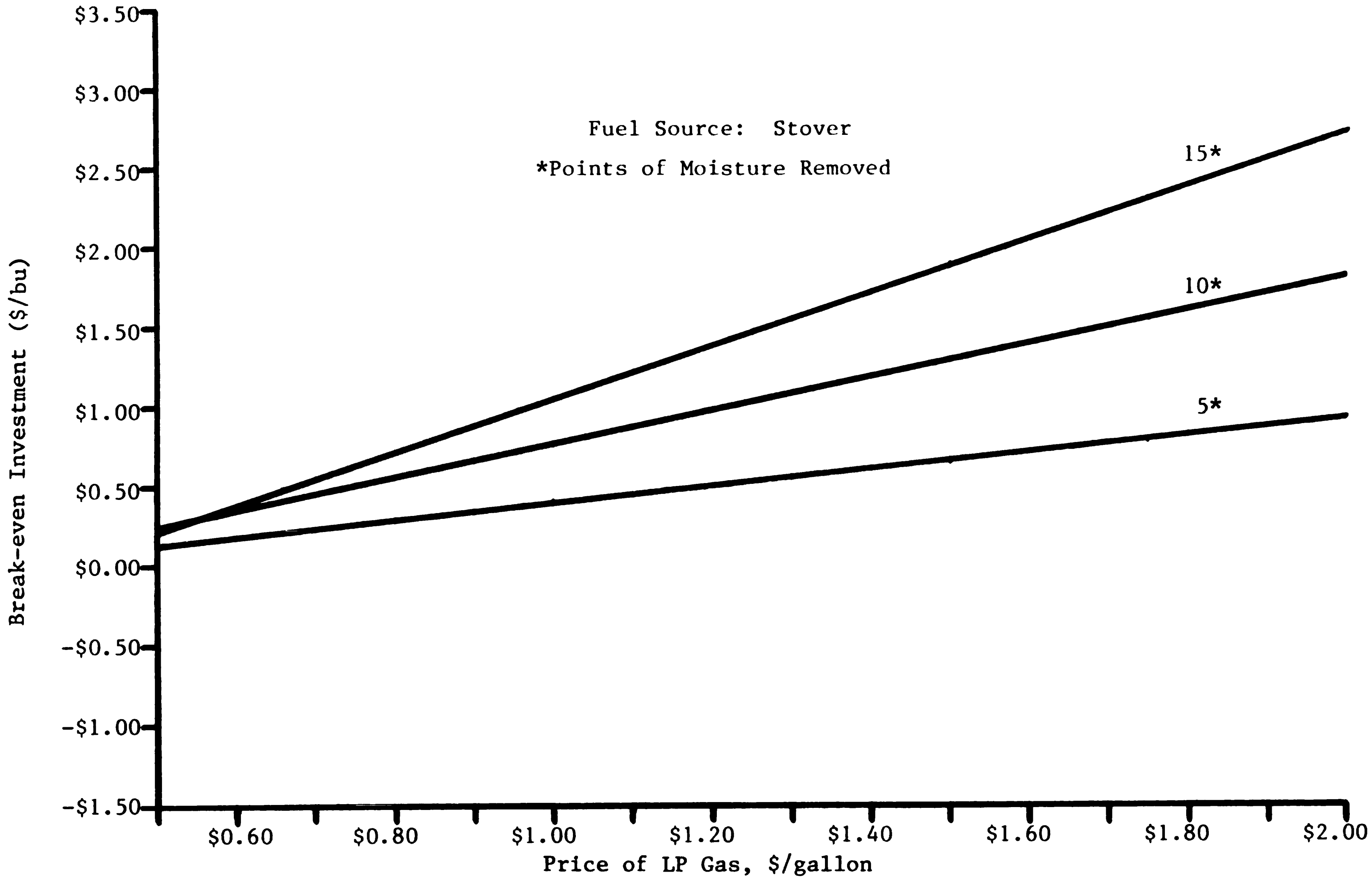

Figure 28. Effects of a constant LP gas price on the break-even investment per bushel of dry grain when stover is the fuel source (U.S.No.2).

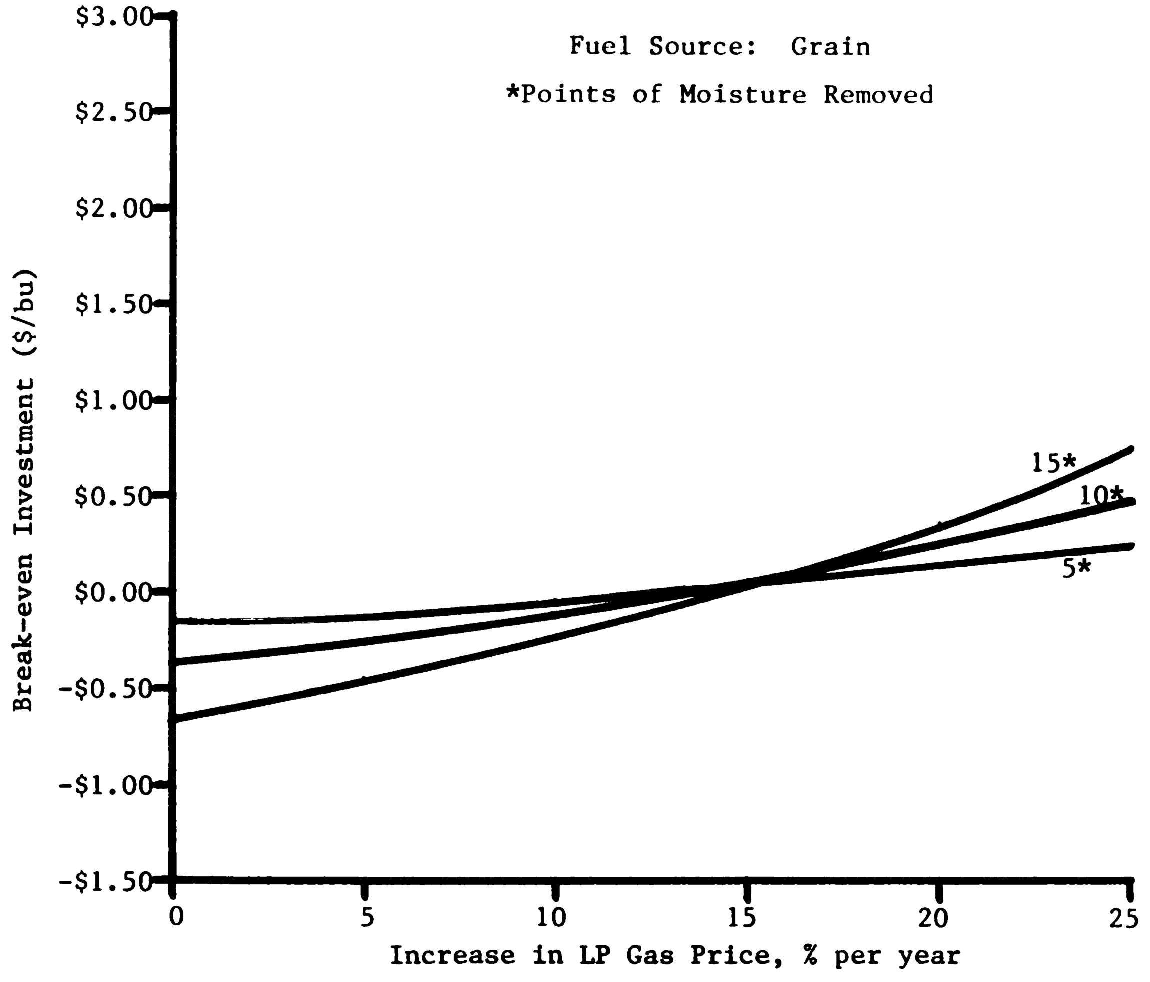

Figure 29. **Effects of annual percentage increase in LP gas price on break-even investment per bushel of dry grain when using grain as a fuel source (U.S.No.2).**

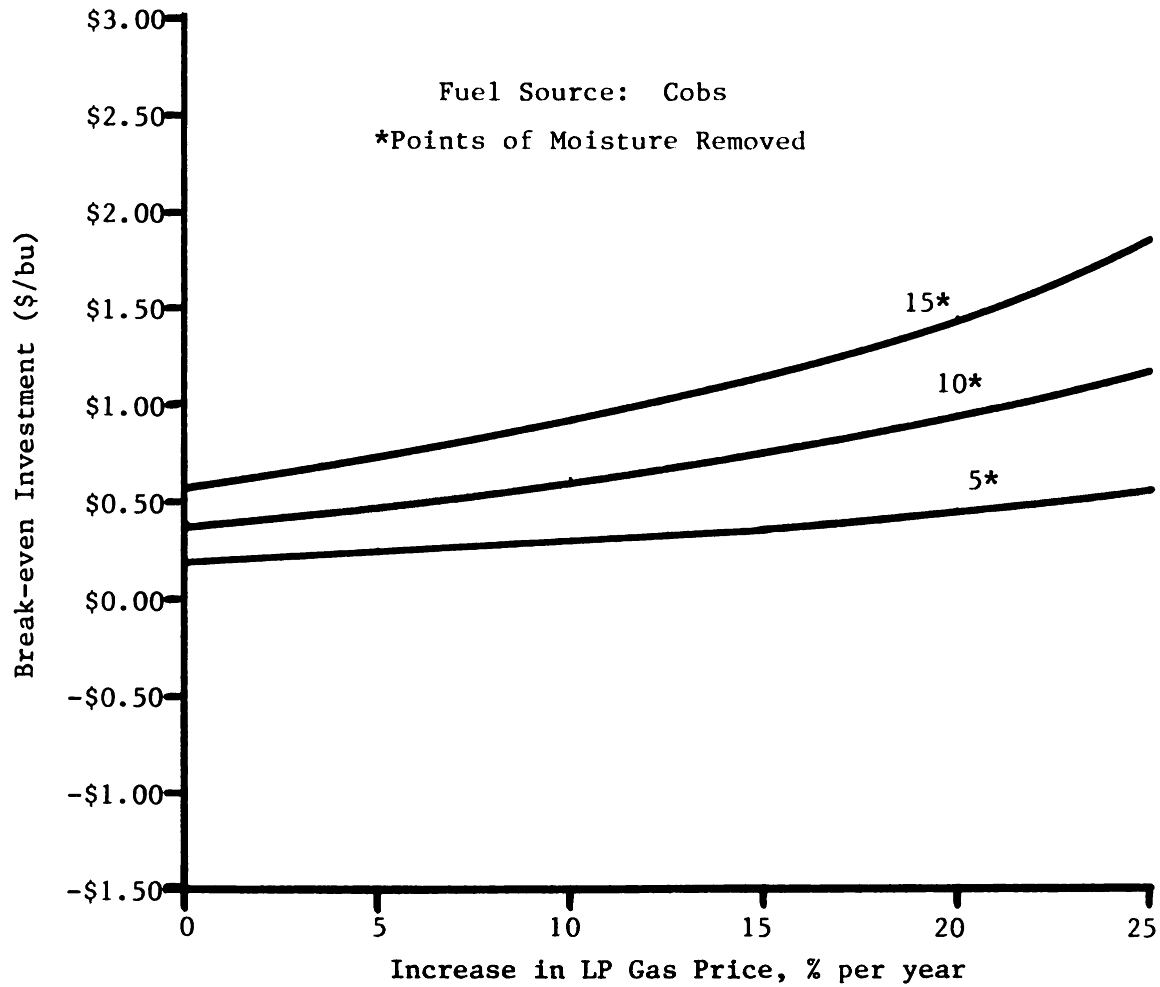

Figure 30. **Effects of annual percentage increase in LP gas price on break-even investment per bushel of dry grain when using cobs as a fuel source (U.S.No.2).**

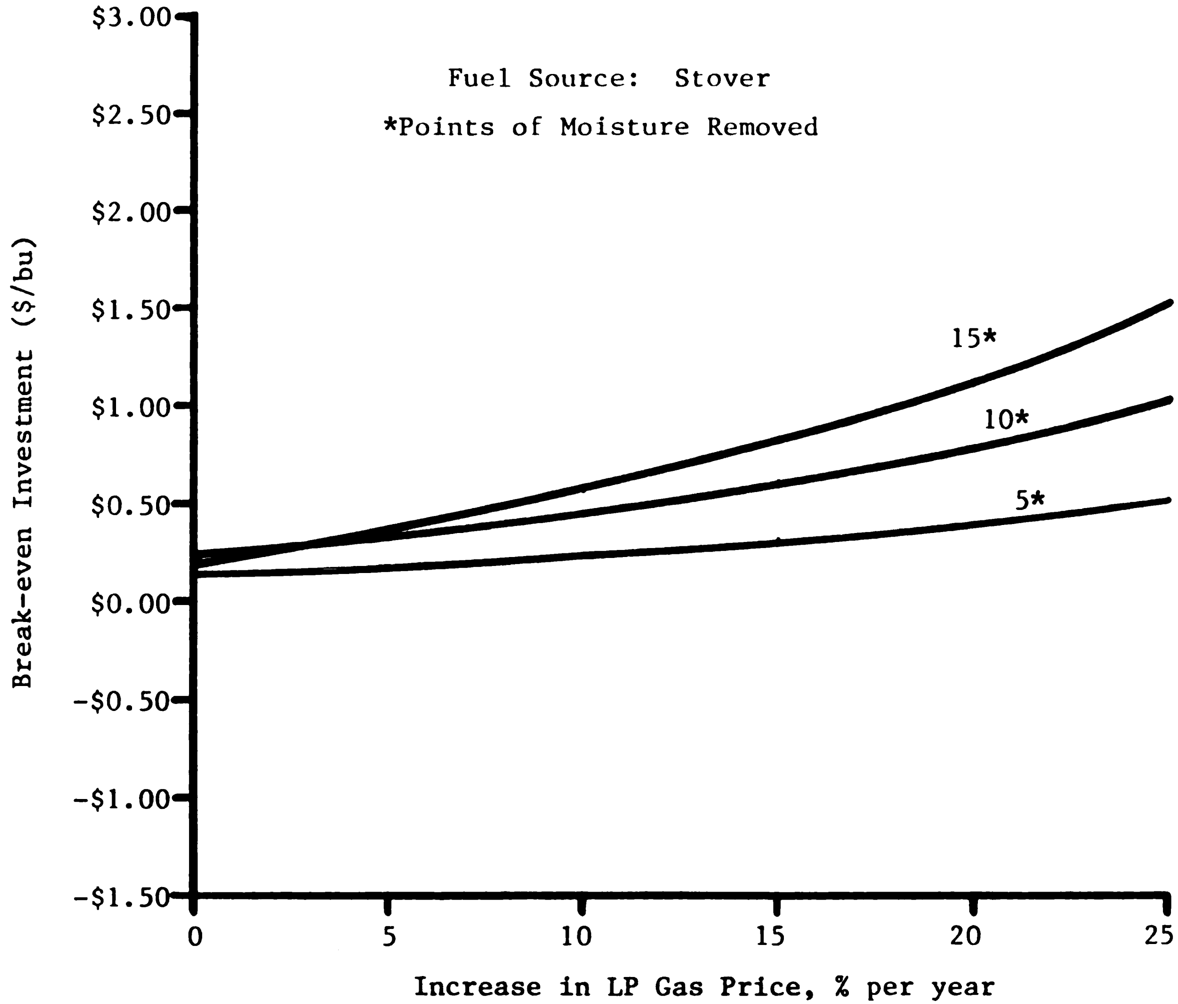

Figure 31. Effects of annual percentage increase in LP gas price on break-even investment per bushel of dry grain when using stover as a fuel source (U.S.No.2).

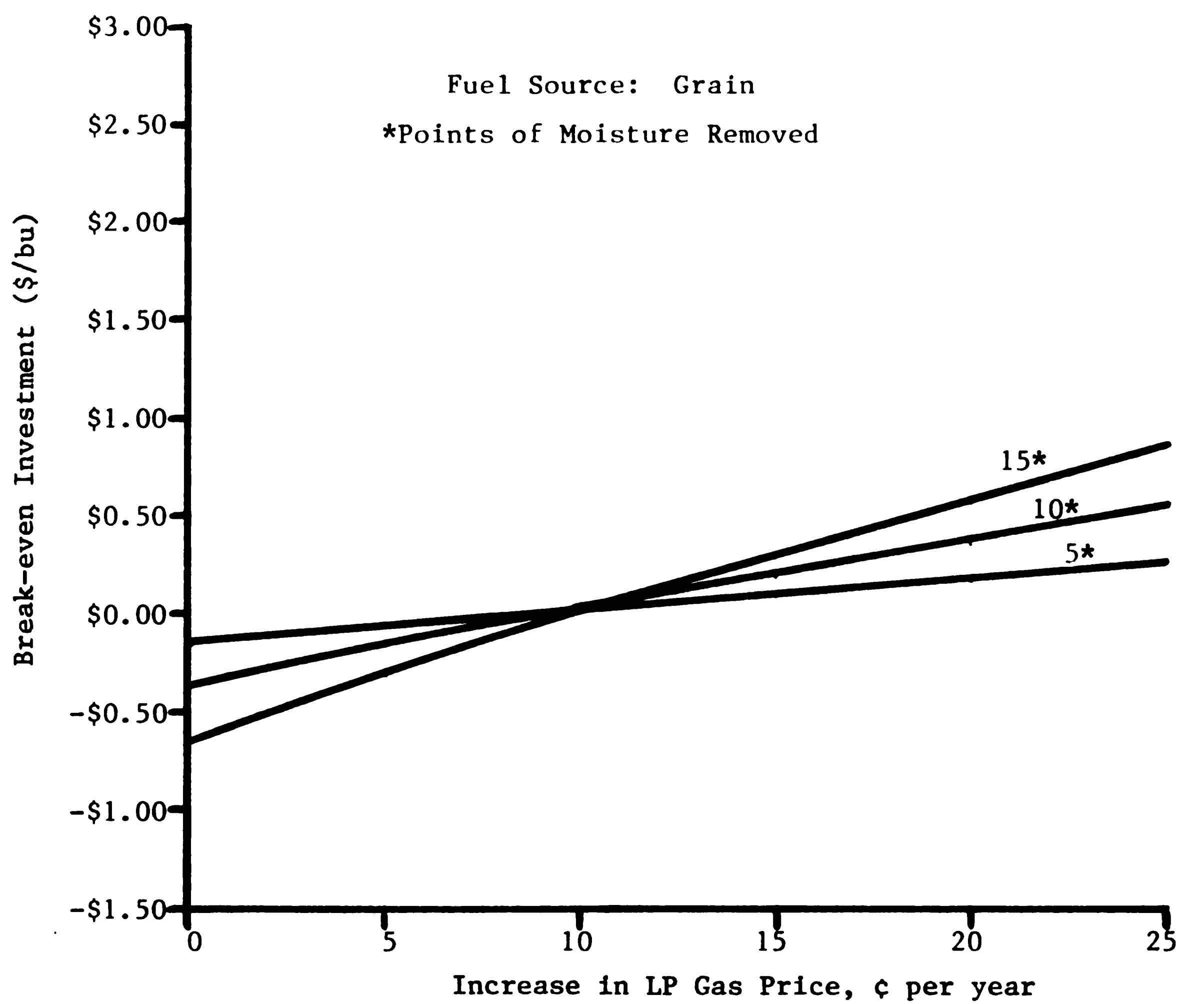

Figure 32. Effects of a constant increase per year in LP gas prices on break-even investment per bushel of grain dried when using grain as a fuel source (U.S.No.2).

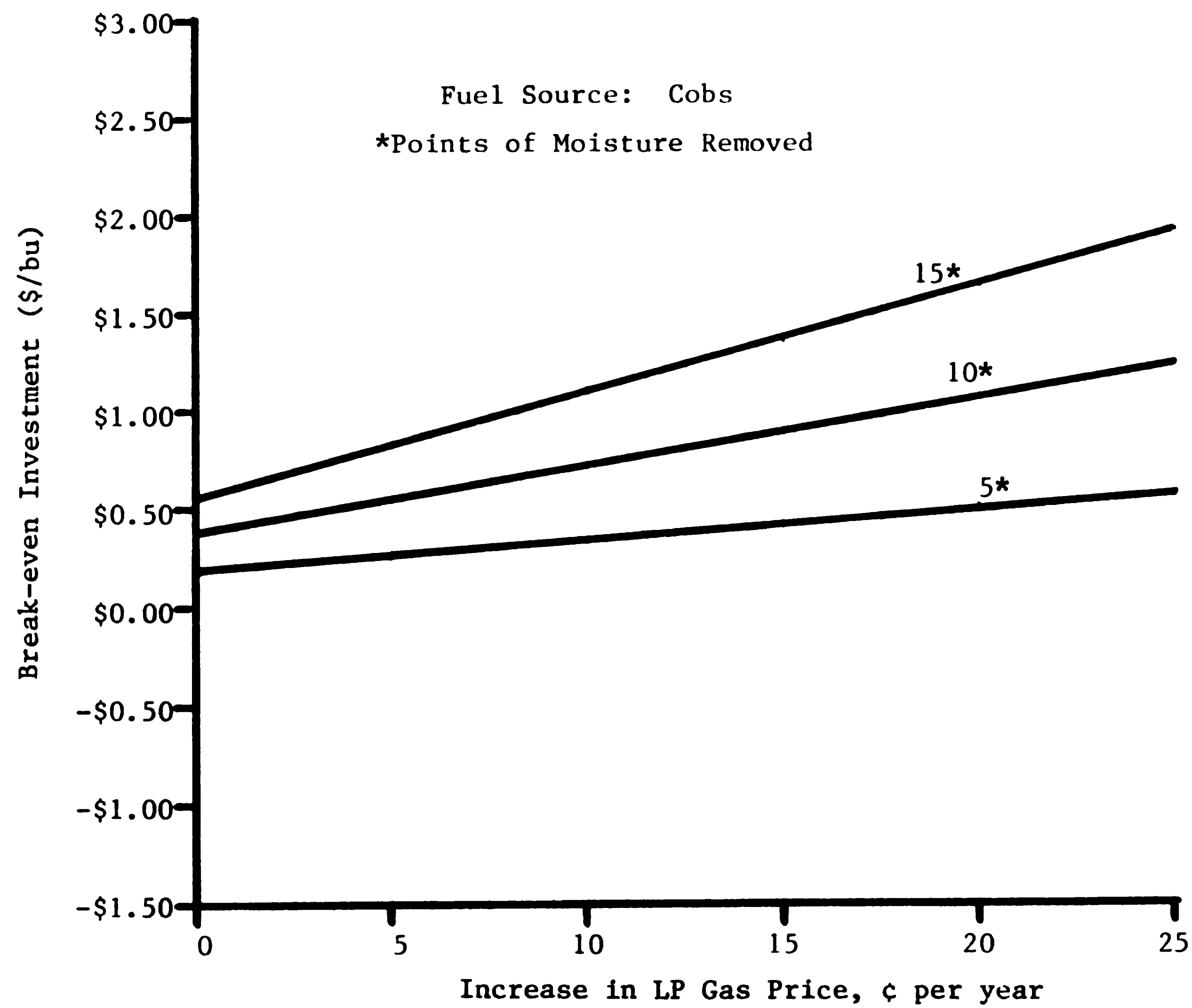

Figure 33. **Effects of a constant increase per year in LP gas prices on break-even investment per bushel of grain dried when using cobs as a fuel source (U.S.No.2).**

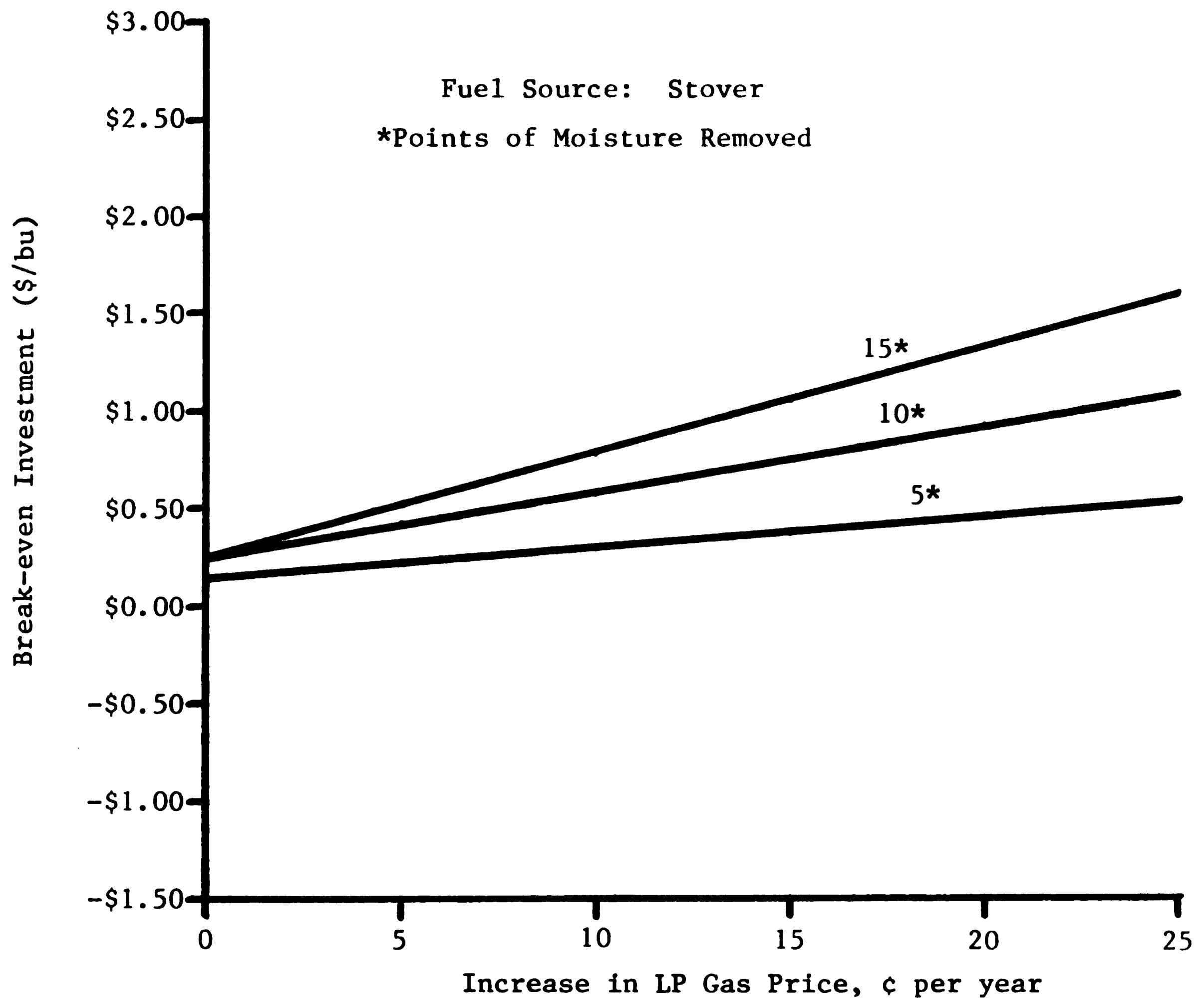

Figure 34. Effects of a constant increase per year in LP gas prices on break-even investment per bushel of grain dried when using stover as a fuel source (U.S.No.2).

Constant real increases in LP gas prices would be equivalent to diminishing percentage increases. A constant real price increase of approximately 10 cents per year would result in positive break-even costs for grain as a fuel source. It would also approximately double the break-even investment for using cobs and stover at 10 points of moisture removal.

F. Summary

Thus far, the sensitivity analysis has shown the effects of altering one variable while holding the remaining base conditions constant. In order to gain some insight into the relative importance of changing a parameter, the average effects were computed as shown in Table 4. In this analysis, the break-even investment was determined for the low and high values of the parameter used in the sensitivity analysis. The average change in the break-even investment was then computed over this range using only the end point values. Within the limits of the linearity assumption, certain comparisons may be made concerning the relative importance of certain parameters.

For the set of physical factors when using grain as a fuel source, the most important factor was the bomb calorimeter adjustment followed in descending order by the efficiencies of gasification, LP gas burner and drying. The least important factor was the soil retention rate for nitrogen. For cobs, the most important physical factor was LP gas burner efficiency followed by the efficiencies for drying, bomb calorimeter adjustments and gasification. Of least importance was the soil retention rate for nitrogen. For stover, the

Table 4. Linear sensitivity of break-even investment to changes in physical and economic parameters.

Parameter	Fuel Source	Range of Values: Parameter Low	Parameter High	Parameter Difference	Corresponding Break-even investment Low	High	Difference	Break-even investment per unit change in parameter value
1. Gasification	Grain	40	100	60	-86.9	1.3	88.2	1.470¢/%
Efficiency	Cobs				33.3	43.6	10.3	0.172¢/%
(percent)	Stover				10.1	34.4	24.3	0.405¢/%
2. LP Gas Burner	Grain	50	100	50	- 1.3	49.9	51.2	1.024¢/%
Efficiency	Cobs				69.4	29.0	-40.4	-0.808¢/%
(percent)	Stover				53.9	13.5	-40.4	-0.808¢/%
3. Drying	Grain	33	93	60	-60.6	-21.5	39.1	0.652¢/%
Efficiency	Cobs				62.7	22.3	-40.4	-0.673¢/%
(percent)	Stover				37.9	13.5	-24.4	-0.407¢/%
4. Bomb Calorimeter	Grain	53	93	40	-117.5	-37.7	79.8	1.995¢/%
Adjustment	Cobs				27.4	39.1	11.7	0.293¢/%
(percent)	Stover				- 6.1	23.6	29.7	0.743¢/%
5. Soil Retention	Grain	0	80	80	-37.7	-37.7	0	0.000¢/%
Rate for	Cobs				40.5	39.1	- 1.4	-0.018¢/%
Nitrogen	Stover				27.7	23.6	- 4.1	-0.051¢/%
(percent)								
6. Life of	Grain	5	20	15	-25.2	-47.1	-21.9	-1.460¢/yr
Gasification	Cobs				27.6	46.8	19.2	1.280¢/yr
Equipment	Stover				16.7	28.3	11.6	0.773¢/yr
(years)								

Table 4 (cont'd.).

Parameter	Fuel Source	Range of Values: Parameter Low	Parameter High	Parameter Difference	Corresponding Break-even investment Low	High	Difference	Break-even investment per unit change in parameter value
7. Moisture Content of Grain to be Dried (percent)	Grain	16.5	30.5	15	- 3.1	-63.7	-60.6	-4.040¢/%
	Cobs				3.9	56.5	52.6	3.507¢/%
	Stover				2.8	22.7	19.9	1.327¢/%
8. Annual Interest Rate (percent)	Grain	5	25	20	-58.1	-26.9	31.2	1.560¢/%
	Cobs				55.2	29.2	-26.0	-1.300¢/%
	Stover				33.3	17.6	-15.7	-0.785¢/%
9. Annual Charge for Operation & Maintenance (percent)	Grain	0	8	8	-37.7	-37.7	0	0 ¢/%
	Cobs				46.9	33.5	-13.4	-1.675¢/%
	Stover				28.3	20.2	- 8.1	-1.013¢/%
10. Harvesting Cost (¢/bu-$/ton)	Grain	13	39	26	-32.6	-42.9	-10.3	-0.396¢/(¢/bu)
	Cobs	0	20	20	49.1	9.0	-40.1	-2.005¢/($/t)
	Stover	0	20	20	46.4	0.8	-45.6	-2.280¢/($/t)
11. Market Price ($/bu@15.5%) ($/ton, wet)	Grain	0	4	4	38.3	-90.6	-128.9	-32.225¢/($/bu)
	Cobs	10	50	40	20.4	-71.9	-92.3	- 2.308¢/($/t)
	Stover	10	50	40	4.9	-103.6	-108.5	- 2.713¢/($/t)
12. Price of Nitrogen (¢/lb)	Grain	20	60	40	-37.7	-37.7	0	0 ¢/(¢/lb)
	Cobs				39.1	36.2	- 2.9	-0.073¢/(¢/lb)
	Stover				23.6	15.4	- 8.2	-0.205¢/(¢/lb)

Table 4 (cont'd.).

	Parameter	Fuel Source	Range of Values: Parameter Low	Parameter High	Parameter Difference	Corresponding Break-even investment Low	High	Difference	Break-even investment per unit change in parameter value
13.	Base Price of LP GAS (¢/gal)	Grain	50	225	175	-37.7	151.8	189.5	1.083¢/(¢/gal)
		Cobs				39.1	225.3	186.2	1.064¢/(¢/gal)
		Stover				23.6	209.2	185.6	1.061¢/(¢/gal)
14.	Change in LP Gas Price (%/yr)	Grain	0	25	25	-37.7	49.1	86.8	3.472¢/(%/yr)
		Cobs				39.1	119.6	80.5	3.220¢/(%/yr)
		Stover				23.6	104.2	80.6	3.224¢/(%/yr)
15.	Change in LP Gas Price (¢/yr)	Grain	0	25	25	-37.7	54.0	91.7	3.668¢/(¢/yr)
		Cobs				39.1	124.5	85.4	3.416¢/(¢/yr)
		Stover				23.6	109.1	85.5	3.420¢/(¢/yr)

most important physical factor was the LP gas burner efficiency followed by the efficiencies for the bomb calorimeter adjustment, drying and gasification. Again, the rate of nitrogen retention by the soil was the least important factor.

When considering the influence of these physical factors, note that the bomb calorimeter adjustment efficiency and the LP gas burner efficiency are not subject to great change. The drying efficiency could approach 100 percent if the bed of grain were very deep with very low air flow rates. However, an 80 percent drying efficiency would be near the maximum for farm drying systems. Likewise, the upper limit for gasification efficiency is approximately 80 percent. Note also that the direction of change associated with an increase in the physical factor was always the same for cobs and stover but not for grain.

It is somewhat more difficult to compare the remaining factors because the units and/or functions are completely different. For example, wet grain moisture content and interest rate are both measured in percent and are important parameters but have little else in common. An increase in the moisture content of the grain amplified the break-even investment costs; that is, the break-even investment for cobs and stovers increases while there is a decrease in the break-even value for using grain as a fuel source. An increase in interest rates tends to have the opposite effect with break-even investment converging toward a zero value for grain, cobs and stover. This is equivalent to saying that the opportunity costs for investment limits what can be spent for gasification equipment when using cobs or stover. In the case of grain which initially has a negative break-even value, the convergence means that it's easier to subsidize a bad investment with other funds when interest rates are high.

Factors of moderate importance considering the probable range of values are the life of the gasification equipment and the annual charge for operation and maintenance. The price of nitrogen is of little importance as is the cost of harvesting grain. However, the cost of harvesting cobs and stover are very important considerations as are the market values of the biomass components.

The high market value for grain is primarily responsible for the negative break-even investment. If cob and stover had similar market value in terms of erosion control, future productivity of the soil, cattle feed, other energy uses, etc., their break-even market values could also become negative.

Much of the economics of using biomass as a fuel source lies with the real increase in the price of the price of the primary fuel substitute LP gas, as compared to the other price of other factors. Even under today's prices, cobs and stover have a positive break-even investment. As can be seen from Table 4 and Figures 26-34, it would not take great changes in the real price of LP gas for grain to also have a positive break-even investment cost.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

In this study, it has been shown that there is sufficient energy in the form of grain, cobs and stover so that the gasification process may be used to dry corn over the range of moisture contents typical of harvest. Certain physical and economic parameters were determined to be essential in computing the economic feasibility of gasification. When using representative values for these factors, it was found that as much as 38.9¢ and 23.5¢ per U.S. No. 2 bushel dried could be invested in gasification equipment when using cobs and stover, respectively, as sources of energy for 10 points of moisture removal. However, grain itself could be used as a fuel source only if it were subsidized by the equivalent of 37.6¢ per bushel dired. Therefore, it would be extremely doubtful that grain would ever be economically competitive with cobs or stover as a source of fuel for grain drying.

The economic feasibility of using cobs and stover would be enhanced under the following conditions:

1. Increases in the efficiency of the gasification process.
2. Increases in the economic life of the gasification equipment.
3. Employment of high temperature drying methods that typically have lower drying efficiencies.

4. Increases in the quantity of moisture to be removed from the grain.
5. Reductions in the interest rate.
6. Reductions in the annual charge for operation and maintenance.
7. Reductions in harvesting costs.
8. Limited market value of cobs and stover.
9. Low prices of nitrogen.
10. Real increases in the price of LP gas.

The altering of these factors can have significant additive effects on the break-even investment cost. For example, if the base conditions given in Table 3 were altered to reflect the conditions shown in Table 5, the break-even investment would be \$1.59, \$2.63 and \$2.42 for grain, cobs and stover, respectively. This would represent a change in the base values of break-even investment of approximately \$1.97, \$2.00 and \$2.18, respectively, for grain, cobs and stover.

It would appear that the use of cobs is the best gasification alternative. Cobs are presently passed through the combine and could be most easily gathered with existing grain harvesting machinery. This could be accomplished by either blending the cobs and the grain and separating them later, or by collecting the cobs as they exit the combine. It would also be possible to use ear corn harvesters and stationary shellers. In addition, cobs are more flowable than stover and thus offer advantages in terms of materials handling. Likewise, nitrogen removal is less with cobs than with stover, and stover is more effective in erosion control. The net effect of these advantages is that the break-even investment cost will probably

Table 5. Modification to the base condition values given in Table 3.

No.	Input Description	New Value
1.	Initial grain moisture, percent	30.50
8.	Percent efficiency of drying process	40.00
9.	Percent efficiency of gasification process	80.00
16.	Change in LP gas price, percent increase from previous year	15.00
19.	Annual interest rate, percent	12.00
20.	Economic life of gasification equipment, years	15.00
22.	Harvest-transport cost for cobs in field, dollars per ton of wet material	2.50
23.	Harvest-transport cost for stover in field, dollars per ton of wet material	5.00
24.	Market value of grain at 15.5 percent moisture dollars per bushel	2.00

Computed break-even investment costs using the above values, ¢ per dry bushel (U.S. No.2):

Grain	158.58
Cobs	262.73
Stover	241.95

be greater when using cobs than with stover. The costs of gasification equipment may also be influenced by the type of biomass used as fuel, thus altering the relative economics concerning the choice of biomass.

In conclusion, the break-even investment cost for gasification equipment is positive under existing technology and prices when using either cobs or stover as a fuel source for drying. This indicates that cobs or stover can compete with LP gas under present economic conditions so long as investment in gasification equipment does not exceed the break-even values. Cobs appear to be a more economical source of fuel than stover, and grain is not presently an economical energy substitute for LP gas.

APPENDIX

APPENDIX

BIOMASS COMPUTER PROGRAM LISTING, DATA AND SAMPLE OUTPUT

```
*POS
LOEWER, L90, JC500, RG2.
PW=0110
FTN, OPT=2.
LGO
*EOR
      PROGRAM BIOMASS (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
      DIMENSION COSTLP(20), XLPGSA(20), RG(20), RC(20), RS(20), AG(6), AC(6),
     2AS(6), RATIO(6, 6), GPVG(20), GPVC(20), GPVS(20)
      L=1
      IR=5
      IW=6
      WRITE(IW, 500)L
  500 FORMAT(2X, "********** AT STEP ", I2, "***********")
    1 FORMAT(F5.0)
C READ IN PHYSICAL PARAMETERS
C GIMC   -GRAIN MOISTURE CONTENT, PERCENT, INITIAL
C GFMC   -GRAIN MOISTURE CONTENT, PERCENT, FINAL
C GECORN-GROSS ENERGY AVAILABLE, BTU/LB., GRAIN
C GECOBS-GROSS ENERGY AVAILABLE, BTU/LB., COBS
C GESTOV-GROSS ENERGY AVAILABLE, BTU/LB., STOVER
C BOMBPC-PERCENT ADJUSTMENT FOR BOMB CALORIMETER
C
      READ(IR, 1)GIMC, GFMC, GECORN, GECOBS, GESTOV, BOMBPC
C
C THEFF  -EFFICIENCY OF LP GAS BURNERS, PERCENT
C DEFF   -EFFICIENCY OF DRYING PROCESS, PERCENT
C GEFF   -EFFICIENCY OF GASIFICATION PROCESS, PERCENT
C PCNG   -NITROGEN CONTENT IN GRAIN,    PERCENT OF DRY WT.
C PCNC   -NITROGEN CONTENT IN COBS,     PERCENT OF DRY WT.
C PCNS   -NITROGEN CONTENT IN STOVER,   PERCENT OF DRY WT.
C HVAP   -HEAT OF VAPROIZATION
C
      READ(IR, 1)THEFF, DEFF, GEFF, PCNG, PCNC, PCNS, HVAP
C READ IN ECONOMIC PARAMETERS
C
C PLPBAS-PRICE OF LP GAS, C/GAL., THIS YEAR.
C PPYRLP-PROJECTED INCREASE IN LP GAS, CONSTANT CHANGE PER, YEAR, C/GAL.
C PCYRLP-PROJECTED INCREASE IN LP GAS, PERCENT INCREASE FROM PREVIOUS YR.
C PNPLB -PRICE OF NITROGEN, CENTS PER POUND
C
      READ(IR, 1)PLPBAS, PPYRLP, PCYRLP, PNPLB
C
C AUPKEP-ANNUAL UPKEEP FOR GASIFICATION UNIT, PERCENT
C AINTPC-ANNUAL INTEREST RATE, PERCENT
C YEARS -ECONOMIC LIFE OF GASIFICATION UNITY, YEARS
C HCPBUG-HARVESTING AND TRANSPORTATION COSTS FOR GRAIN, C/HARVESTED BU.
C HCPTNC-HARVESTING AND TRANSPORTATION COSTS FOR COBS, $/HARVESTED TON
C HCPTNS-HARVESTING AND TRANSPORTATION COSTS FOR STOVER, $/HARVESTED TON
C
      READ(IR, 1)AUPKEP, AINTPC, YEARS, XCPBUG, HCPTNC, HCPTNS
C
C VMRKG -MARKET VALUE OF GRAIN AT 15.5 PERCENT MC, $/BU.
C VMRKC -MARKET VALUE OF COBS AT EXISTING FIELD MOISTURE, $/TON
C VMRKS -MARKET VALUE OF STOVER AT EXISTING FIELD MOISTURE, $/TON
C RRN    -PERCENT OF NITROGEN RETAINED BY SOIL OF BIOMASS
      READ(IR, 1)VMRKG, VMRKC, VMRKS, RRN
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DO 1000 LOOP=1, 1
      WRITE(IW, 803)LOOP, GIMC, PCYRLP, PPYRLP, PLPBAS
  803 FORMAT(72("$")/72("$")//
     XT27, "LOOP NO. ", I3/
     XT27, "GIMC   =", F6.2//
     1T27, "PCYRLP=", F6.2//
     1T27, "PPYRLP=", F6.2//
     1T27, "PLPBAS=", F6.2//
     X72("$")/72("$")//)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
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C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      WRITE(IW,50)
   50 FORMAT(72("*")/72("*")//T27,"DATA INPUT"//72("*")/1X,"ITEM",
     1T27,"DESCRIPTION"/72("*")/)
C
      WRITE(IW,51)GIMC,GFMC,GECORN,GECOBS,GESTOV,BOMBPC,THEFF
C
   51 FORMAT(
     13X,"1  INITIAL GRAIN MOISTURE,PERCENT",                      T64,F9.3/
     13X,"2  BASE AND DESIRED FINAL GRAIN MOISTURE,PERCENT",       T64,F9.3/
     13X,"3  GROSS ENERGY IN GRAIN,BTU/DRY LB.",                   T64,F9.3//
     13X,"4  GROSS ENERGY IN COBS, BTU/DRY LB.",                   T64,F9.3/
     13X,"5  GROSS ENERGY IN STOVER,BTU/DRY LB.",                  T64,F9.3/
     63X,"6  PERCENT ADJUSTMENT FOR BOMB CALORIMETER",             T64,F9.3//
     73X,"7  PERCENT EFFICIENCY OF L.P. GAS BURNER",               T64,F9.3
     8)
C
      WRITE(IW,52)DEFF,GEFF,PCNG,PCNC,PCNS,HVAP,PLPGAS
C
   52 FORMAT(
     83X,  "8 PERCENT EFFICIENCY OF DRYING PROCESS",               T64,F9.3/
     93X,  "9 PERCENT EFFICIENCY OF GASIFICATION PROCESS",         T64,F9.3//
     X2X, "10 NITROGEN CONTENT IN GRAIN,PERCENT OF DRY WT." ,      T64,F9.3/
     12X, "11 NITROGEN CONTENT IN COBS, PERCENT OF DRY WT." ,      T64,F9.3/
     22X, "12 NITROGEN CONTENT IN STOVER,PERCENT OF DRY WT.",      T64,F9.3//
     32X, "13 HEAT OF VAPROIZATION OF WATER,BTU PER LB.",          T64,F9.3/
     42X, "14 PRICE OF L.P.GAS IN YEAR NO.1,C/GAL.",               T64,F9.3
     X)
C
      WRITE(IW,53)PPYRLP,PCYRLP,PNPLB,AUPKEP,AINTPC,YEARS,XCPBUG
C
   53 FORMAT(
     52X, "15 CONSTANT CHANGE PER YEAR IN L.P.GAS PRICE,C/GAL",T64,F9.3//
     62X, "16 CHANGE IN L.P.GAS PRICE,PERCENT FROM PREVIOUS YEAR",T64,
     XF9.3/
     72X, "17 PRICE OF NITROGEN,C/LB.",                            T64,F9.3/
     82X, "18 PERCENT/YR FOR MAINTENANCE OF GASIFICATION EQUIPMENT"/
     82X, "   BASED ON PURCHASE PRICE",                            T64,F9.3//
     92X, "19 ANNUAL INTEREST RATE,PERCENT",                       T64,F9.3/
     X2X, "20 ECONOMIC LIFE OF GASIFICATION EQUIPMENT,YEARS",      T64,F9.3/
     12X, "21 HARVEST-TRANSPORT COST FOR GRAIN,C/BU AT 56LB/BU",T64,
     XF9.3/)
C
      WRITE(IW,54)HCPTNC,HCPTNS,VMRKG,VMRKC,VMRKS,RRN
C
   54 FORMAT(
     22X, "22 HARVEST-TRANSPORT COST FOR COBS IN FIELD,$/TON",     T64,F9.3/
     32X, "23 HARVEST-TRANSPORT COST FOR STOVER IN FIELD,$/TON",T64,
     XF9.3/
     42X, "24 MARKET VALUE OF GRAIN AT 15.5 PERCENT MC,$/BU.",     T64,F9.3//
     52X, "25 MARKET VALUE OF COBS IN FIELD,$/WET TON",            T64,F9.3/
     62X, "26 MARKET VALUE OF STOVER IN FIELD,$/WET TON",          T64,F9.3/
     62X, "27 RETENTION RATE OF BIOMASS NITROGEN BY SOIL,PC",      T64,F9.3//
     772("*")//)
C
C DETERMINE THE PERCENTAGE OF GRAIN,COBS AND STOVER PRESENT ON A DRY BASIS
C THEN CALCULATE THE RELATIVE DRY WEIGHTS OF EACH COMPONENT
C
      PCGDB=70.4 - 0.8*GIMC
      PCCDB=12.4 - 0.035*GIMC
      PCSDB=17.0 + 0.84*GIMC
      YWB=1.0
      F=YWB*(100.0-GIMC)/(7040.0-80.0*GIMC)
C
      DRYWTG=YWB*(100.0-GIMC)/100.0
      DRYWTC=F*PCCDB
      DRYWTS=F*PCSDB
```

```
C
C ADJUST THE GROSS ENERGY AVAILABLE BY THE BOMB CALORIMETER FACTOR
C
      AECORN=BOMBPC*GECORN/100.0
      AECOBS=BOMBPC*GECOBS/100.0
      AESTOV=BOMBPC*GESTOV/100.0
C
C ESTABLISH THE MOISTURE CONTENTS OF THE COBS AND STOVER
C
      CMC=2.0*GIMC
      IF(GIMC.LT.25.0)CMC=-25.0+3.0*GIMC
      IF(GIMC.LT.12.5)CMC=GIMC
      SMC=2.0*GIMC
C
C ESTABLIST THE RELATIVE WET WEIGHTS FOR GRAIN,COBS AND STOVER
C
      WETWTG=DRYWTG/(1.0-GIMC/100.0)
      WETWTC=DRYWTC/(1.0-CMC/100.0)
      WETWTS=DRYWTS/(1.0-SMC/100.0)
C
C DETERMINE THE ENERGY AVAILABLE FOR DRYING AFTER THE BOMB CALORIMETER
C AND MOISTURE CONTENT ADJUSTMENTS ARE MADE,PER POUND WET WT.
C
      EAGWTG=(1.0-GIMC/100.0)*AECORN -(GIMC/100.0)*HVAP
      EAGWTC=(1.0-CMC /100.0)*AECOBS -(CMC /100.0)*HVAP
      EAGWTS=(1.0-SMC /100.0)*AESTOV -(SMC /100.0)*HVAP
C DETERMINE THE AVAILABLE ENERGY FOR DRYING CONSIDERING THE EFFICIENCY
C OF THE GASIFICATION PROCESS,PER POUND WET WT.
C
      EAAWTG=EAGWTG*GEFF/100.0
      EAAWTC=EAGWTC*GEFF/100.0
      EAAWTS=EAGWTS*GEFF/100.0
C
C DETERMINE THE AVAILABLE ENERGY FOR DRYING CONSIDERING THE EFFICIENCY OF
C THE DRYING PROCESS, PER POUND WET WT.
C
      EANWTG=EAAWTG*DEFF/100.0
      EANWTC=EAAWTC*DEFF/100.0
      EANWTS=EAAWTS*DEFF/100.0
C
C DETERMINE THE TOTAL ENERGY AVAILABLE FOR DRYING,NET,CONSIDERING THE
C RELATIVE PROPORTIONS OF WET MATERIAL
C
      TGE=EANWTG*WETWTG
      TCE=EANWTC*WETWTC
      TSE=EANWTS*WETWTS
C
C AT THIS POINT,DETERMINE THE ENERGY REQUIREMENTS FOR DRYING.
C CALCULATE THE AMOUNT OF WATER TO BE REMOVED FROME ONE LB. OF WET GRAIN.
C THEN COMPUTE THE DRYING ENERGY NEEDED ON A 100 PERCENT EFF.BASIS.
C
C**********************************************************************
C NOTE THAT THE WATER REMOVED IS FOR ONE UNIT OF GRAIN WITH FINAL
C MOISTURE CONTENT OF GFMC.  IF THIS IS U.S. NO. 2,GFMC WILL BE
C EQUAL TO 15.5 PERCENT.THUS ALL REFERENCES TO A DRY BUSHEL REFER
C TO A BASE MOISTURE CONTENT OF GFMC.
C**********************************************************************
      GRAINP=1.0
      WATERP=GRAINP*(GIMC-GFMC)/(100.0-GIMC)
      ENERGP=WATERP*HVAP
C CONVERT TO A 56 POUND BU.
      ENERGB=56.0*ENERGP
C
C DETERMINE THE QUANTITY OF L.P. GAS NEEDED,GAL. PER POUND OF DRY GRAIN.
C CONVERT TO A 56 POUND BUSHEL.
      EPGLPG=92000.0
      QLPGPP=ENERGP*10000.0/(EPGLPG*THEFF*DEFF)
      QLPGBU=QLPGPP*56.0
```

```
C
C COMPUTE THE COST FOR LP GAS FOR EACH YEAR OF THE GASIFIERS LIFE, AND
C THE POTENTIAL SAVINGS
C
      IYEAR=YEARS
      COSTLP(1)=PLPBAS
      XLPGSA(1)=QLPGBU*COSTLP(1)
C
      DO 2 I=2, IYEAR
      COSTLP(I)=COSTLP(I-1)*(1.0+PCYRLP/100.0) +PPYRLP
      XLPGSA(I)=COSTLP(I)*QLPGBU
    2 CONTINUE
C
C COMPUTE THE QUANTITY OF WET BIOMASS NEEDED FOR DRYING A 56 LB. DRY BU.
C QUANTITIES IN POUNDS
C
      QWTGD=ENERGB/EANWTG
      QWTCD=ENERGB/EANWTC
      QWTSD=ENERGB/EANWTS
C
C COMPUTE THE QUANTITY OF DRY BIOMASS NEEDED FOR DRYING A 56 LB. DRY BU.
C QUANTITIES IN POUNDS
      QDRYGD=QWTGD*(1.0-GIMC/100.0)
      QDRYCD=QWTCD*(1.0-CMC /100.0)
      QDRYSD=QWTSD*(1.0-SMC /100.0)
C
C COMPUTE THE QUANTITY AND VALUE OF NITROGEN REMOVED FROM THE FIELD,
C POUNDS OF N PER BU OF GRAIN DRIED, AND C/BU OF GRAIN DRIED
C
      PNREMG=QDRYGD*PCNG/100.0  *RRN/100.0
      PNREMC=QDRYCD*PCNC/100.0  *RRN/100.0
      PNREMS=QDRYSD*PCNS/100.0  *RRN/100.0
C
      VNREMG=PNREMG*PNPLB
      VNREMC=PNREMC*PNPLB
      VNREMS=PNREMS*PNPLB
C
C CONVERT THE COST PER 2000 LB WET TON FOR HARVESTING AND TRANSPORTING
C TO A COST PER 56 POUND DRY BU.  IN CENTS.
      HCPBUG=XCPBUG*QWTGD/56.0
      HCPBUC=HCPTNC*QWTCD/2000.0*100.0

      HCPBUS=HCPTNS*QWTSD/2000.0*100.0
C
C CONVERT THE MARKET VALUE OF GRAIN, COBS AND STOVER TO A FIELD BU BASIS
      BMC=15.5
      VMRKWG=((100.0-GIMC)/(100.0-BMC))*VMRKG*100.0*QWTGD/56.0
      VMRKSB=VMRKS*QWTSD/2000.0  *100.0
      VMRKCB=VMRKC*QWTCD/2000.0  *100.0
C
C AT THIS POINT, ALL THE COSTS ARE OR HAVE BEEN COMPUTED. THEREFORE COMPUTE
C THE YEARLY SAVINGS VIA GASIFICATION AND CONVERT TO A QUANTITY THAT
C MAY BE SPENT FOR GASIFICATION EQUIPMENT.
C
      TGPVG=0.0
      TGPVC=0.0
      TGPVS=0.0
      IY=IYEAR
      DO 3 I=1, IY
      PVTERM=(1.0+AINTPC/100.0)**I
C
C COMPUTE ANNUAL SAVINGS, R, FOR GRAIN, COBS AND STOVER
C
      RG(I)=XLPGSA(I)-HCPBUG-AMAX1(VNREMG, VMRKWG)
      RC(I)=XLPGSA(I)-HCPBUC-AMAX1(VNREMC, VMRKCB)
      RS(I)=XLPGSA(I)-HCPBUS-AMAX1(VNREMS, VMRKSB)
C
```

```
C CONVERT THE GROSS ANNUAL SAVINGS TO A PRESENT VALUE BY YEAR AND IN TOTAL
      GPVG(I)=RG(I)/PVTERM
      TGPVG=TGPVG + GPVG(I)
C
      GPVC(I)=RC(I)/PVTERM
      TGPVC=TGPVC + GPVC(I)
C
      GPVS(I)=RS(I)/PVTERM
      TGPVS=TGPVS + GPVS(I)
    3 CONTINUE
C
C A CONSTANT PERCENTAGE OF THE PURCHASE PRICE WILL BE ASSIGNED FOR
C MAINTENANCE AND UPKEEP EACH YEAR.
C COMPUTE THE PWF
      AI=AINTPC/100.0
      XPWF=((1.0+AI)**IY-1.0)/(AI*(1.0+AI)**IY)
      PWF=1.0 + XPWF*AUPKEP/100.0
C PWF FOR UPKEEP ALONE
      PWFUPK=PWF*AUPKEP/100.0
C
C COMPUTE THE AMT. THAT MAY BE SPENT ON MACHINERY CONSIDERING UPKEEP
C
      PURMG=TGPVG/PWF
      PURMC=TGPVC/PWF
      PURMS=TGPVS/PWF
C
C COMPUTE THE ANNUAL COST FOR MAINTENANCE AND UPKEEP
C
      UPKEPG=PURMG*AUPKEP/100.0
      UPKEPC=PURMC*AUPKEP/100.0
      UPKEPS=PURMS*AUPKEP/100.0
C
C
C CHECK TO SEE IF THIS IS A NEGATIVE PRESENT VALUE.
C
      IF(PURMG.LT.0.0)PURMG=PURMG + XPWF*UPKEPG
      IF(PURMC.LT.0.0)PURMC=PURMC + XPWF*UPKEPC
      IF(PURMS.LT.0.0)PURMS=PURMS + XPWF*UPKEPS
C DETERMINE THE PERCENT OF AVAILABLE DRY AND WET MATERIAL REQUIRED.
      PCAVDG=QDRYGD/DRYWTG*100.0 /56.0
      PCAVDC=QDRYCD/DRYWTC*100.0 /56.0
      PCAVDS=QDRYSD/DRYWTS*100.0 /56.0
      PCAVWG=QWTGD/WETWTG*100.0  /56.0
      PCAVWC=QWTCD/WETWTC*100.0  /56.0
      PCAVWS=QWTSD/WETWTS*100.0  /56.0
C
      WRITE(IW,70)WATERP,ENERGP,ENERGB,EPGLPG,QLPGPP,QLPGBU,XPWF,
     XPWF,PWFUPK
C
   70 FORMAT(
     13X,"1 POUNDS OF WATER PER POUND WET GRAIN",      T64,F9.3/
     23X,"2 THEORETICAL BTU/LB OF WET GRAIN",          T64,F9.3/
     33X,"3 THEORETICAL BTU/BU OF WET GRAIN",          T64,F9.3/ /
     43X,"4 ENERGY CONTENT OF LP GAS,BTU/GAL.",        T64,F9.3/
     53X,"5 LP GAS NEEDED,GAL/LB WET GRAIN",           T64,F9.3/
     63X,"6 LP GAS NEEDED,GAL/BU WET GRAIN",           T64,F9.3//
     73X,"7 PRESENT WORTH FACTOR",                     T64,F9.3/
     83X,"8 PRESENT WORTH FACTOR,ADJUSTED",            T64,F9.3/
     93X,"9 REPAIR AND OPERATION MODIFIER",            T64,F9.3/)
      WRITE(IW,55)
C
   55 FORMAT(72("*")/72("*")/
     13X,"ITEMS",
     1T13,"FIELD  RELATIVE   GROSS  ADJUSTED  AVERAGE RELATIVE  ENERGY"/
     23X,"(1-7)",
     2T13,"AVAIL.  WEIGHTS   ENERGY   ENERGY  MOISTURE WEIGHTS  AVAILABLE
     2"/
     3T12,"PERCENT IN FIELD AVAILABLE AVAIL.   CONTENT IN FIELD MC ADJUS
     3T"/
     4T14,"DRY    DRY LB.  (BTU/DLB)(BTU/DLB) PERCENT  WET LB. (BTU/WLB)"
     5/72("*")/)
```

```
C
C
      WRITE(IW,56)PCGDB,DRYWTG,GECORN,AECORN,GIMC,WETWTG,EAGWTG
   56 FORMAT(3X,"GRAIN",T11,7F9.3)
C
      WRITE(IW,57)PCCDB,DRYWTC,GECOBS,AECOBS,CMC,WETWTC,EAGWTC
   57 FORMAT(3X,"COBS",T11,7F9.3)
C
      WRITE(IW,58)PCSDB,DRYWTS,GESTOV,AESTOV,SMC,WETWTS,EAGWTS
   58 FORMAT(3X,"STOVER",T11,7F9.3//72("*")///)
      WRITE(IW,59)
   59 FORMAT(72("*")/72("*")/
     13X,"ITEMS",
     1T12,"ENERGY     NET     RELATIVE QUANTITY QUANTITY QUANTITY VALUE OF
     1"/3X,"(8-14)",
     2T11,"AVAILABLE ENERGY  ADJ.ENER.   FOR       FOR    NITROGEN NITROGE
     3N"/
     4T11,"GAS P.ADJ AVAIL.    AVAIL.   DRYING   DRYING  REMOVED  REMOVED
     4"/
     5T11,"(BTU/WLB)(BTU/WLB)(TOT.BTU)(WET LB) (DRY LB)  (LB.)      (C)"/
     6/72("*")/)
C
      WRITE(IW,56)EAAWTG,EANWTG,TGE,QWTGD,QDRYGD,PNREMG,VNREMG
C
      WRITE(IW,57)EAAWTC,EANWTC,TCE,QWTCD,QDRYCD,PNREMC,VNREMC
C
      WRITE(IW,58)EAAWTS,EANWTS,TSE,QWTSD,QDRYSD,PNREMS,VNREMS
      WRITE(IW,60)
   60 FORMAT(72("*")/72("*")/
     13X,"ITEMS",
     1T11,"GATHERING  FIELD    PERCENT  PERCENT"/
     22X,"(15-17) TRANSPORT MARKET  OF TOTAL OF TOTAL"/
     3T13,"COST      VALUE     AVAIL.    AVAIL."/
     4T11,"(C/DR BU)(C/DR.BU)  (DRY)     (WET)"/72("*")/)
C
      WRITE(IW,61)HCPBUG,VMRKWG,PCAVDG,PCAVWG,HCPBUC,VMRKCB,
     XPCAVDC,PCAVWC,HCPBUS,VMRKSB,PCAVDS,PCAVWS
C
   61 FORMAT(3X,"GRAIN",T11,4F9.3/
     23X,"COBS",T11,4F9.3/
     33X,"STOVER",T11,4F9.3//72("*")///)
C
      WRITE(IW,62)
C
   62 FORMAT(72("*")/72("*")//T29,"ECONOMIC SUMMARY *"//72("*")/
     11X,"ITEM   YR  GROSS   COLLECT- COST OF  MARKET    GROSS   ANNUAL
     2  NET AMT."/
     3T12,"LP GAS   ION COST NITROGEN VALUE,   SAVINGS, COST OF AVAIL.FO
     4R"/
     5T12,"SAVINGS",T30,"REMOVED  BIOMASS  BIOMASS EQUIPMENT PURCHASE"/
     6T12,"(C/BU)   (C/BU)   (C/BU)   (C/BU)   (C/BU)   (C/BU)   (C/BU)"
     7//72("*")/)
C
      DO 10 I=1,IY
C
      WRITE(IW,63)I,XLPGSA(I),HCPBUG,VNREMG,VMRKWG,RG(I),UPKEPG,PURMG
C
   63 FORMAT(1X,"GRAIN  ",I2,7F9.3)
C
      WRITE(IW,64)XLPGSA(I),HCPBUC,VNREMC,VMRKCB,RC(I),UPKEPC,PURMC
   64 FORMAT(1X,"COBS    ",2X,7F9.3)
C
      WRITE(IW,65)XLPGSA(I),HCPBUS,VNREMS,VMRKSB,RS(I),UPKEPS,PURMS
   65 FORMAT(1X,"STOVER ",2X,7F9.3)
C
      WRITE(IW,67)COSTLP(I)
C
   67 FORMAT(1X,"LPGAS,C/G",F9.3/)
C
      IF(I.EQ.IY)WRITE(IW,66)GFMC
C
   66 FORMAT(1X,"* ALL VALUES BASED ON A BU.  AT ",F5.2," PERCENT MOISTUR
     XE CONTENT"/72("*"))
```

```
C
   10 CONTINUE
      AG(1)=DRYWTG
      AG(2)=DRYWTG*GECORN
      AG(3)=TGE
      AG(4)=HCPBUG + VNREMG - VMRKWG
      AG(5)=TGPVG/YEARS
      AG(6)=PURMC
C
      AC(1)=DRYWTC
      AC(2)=DRYWTC*GECOBS
      AC(3)=TCE
      AC(4)=HCPBUC + VNREMC + VMRKCB
      AC(5)=TGPVC/YEARS
      AC(6)=PURMC
C
      AS(1)=DRYWTS
      AS(2)=DRYWTS*GESTOV
      AS(3)= TSE
      AS(4)=HCPBUS + VNREMS + VMRKSB
      AS(5)=TGPVS/YEARS
      AS(6)=PURMS
C
C
      DO 101 J=1,6
C
      RATIO(1,J)=AG(J)/AC(J)
      RATIO(2,J)=AG(J)/AS(J)
      RATIO(3,J)=AC(J)/AS(J)
      RATIO(4,J)=AC(J)/AG(J)
      RATIO(5,J)=AS(J)/AG(J)
      RATIO(6,J)=AS(J)/AC(J)
C
  101 CONTINUE
      WRITE(IW,68)
C
   68 FORMAT(72("*")/72("*")/3X,"RATIOS",
     2T20,"RELATIVE    GROSS       NET",T49,"TOTAL    AVERAGE    AVAIL."/
     3T20,"DRY WT.IN   ENERGY    ENERGY     GROSS     GROSS       FOR"/
     4T20,"   FIELD     AVAIL.    AVAIL.     COSTS   SAVINGS  PURCHASE"/
     572("*")/)
      WRITE(IW,69)((RATIO(I,J),J=1,6),I=1,6)
C
   69 FORMAT(3X,"GRAIN/COBS",T20,6F9.3/
     23X,"GRAIN/STOVER",T20,6F9.3/
     33X,"COBS/STOVER ",T20,6F9.3/
     33X,"COBS/GRAIN  ",T20,6F9.3/
     53X,"STOVER/GRAIN",T20,6F9.3/
     63X,"STOVER/COBS" ,T20,6F9.3/
     7/72("*")///)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 1000 CONTINUE
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      STOP
      END
```

Data Entry for Biomass

Computer Program

```
*EOR
30.5
15.5
9995.
7961.
7150.
93.
80.0
40.0
80.0
1.6
0.45
1.15
1060.
50.
0.0
15.0
20.0
4.0
12.0
15.0
26.0
2.50
5.0
2.0
0.0

0.0
80.
*EOF
```

```
*********** AT STEP  1************
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

                    LOOP NO.  1
                    GIMC   = 30.50

                    PCYRLP= 15.00

                    PPYRLP=  0.00

                    PLPBAS= 50.00

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

************************************************************************
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                    DATA INPUT

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ITEM	DESCRIPTION	
1	INITIAL GRAIN MOISTURE,PERCENT	30.500
2	BASE AND DESIRED FINAL GRAIN MOISTURE,PERCENT	15.500
3	GROSS ENERGY IN GRAIN,BTU/DRY LB.	9995.000
4	GROSS ENERGY IN COBS, BTU/DRY LB.	7961.000
5	GROSS ENERGY IN STOVER,BTU/DRY LB.	7150.000
6	PERCENT ADJUSTMENT FOR BOMB CALORIMETER	93.000
7	PERCENT EFFICIENCY OF L.P. GAS BURNER	80.000
8	PERCENT EFFICIENCY OF DRYING PROCESS	40.000
9	PERCENT EFFICIENCY OF GASIFICATION PROCESS	80.000
10	NITROGEN CONTENT IN GRAIN,PERCENT OF DRY WT.	1.600
11	NITROGEN CONTENT IN COBS, PERCENT OF DRY WT.	.450
12	NITROGEN CONTENT IN STOVER,PERCENT OF DRY WT.	1.150
13	HEAT OF VAPORIZATION OF WATER,BTU PER LB.	1060.000
14	PRICE OF L.P.GAS IN YEAR NO.1,C/GAL.	50.000
15	CONSTANT CHANGE PER YEAR IN L.P.GAS PRICE,C/GAL	0.000
16	CHANGE IN L.P.GAS PRICE,PERCENT FROM PREVIOUS YEAR	15.000
17	PRICE OF NITROGEN,C/LB.	20.000
18	PERCENT/YR FOR MAINTENANCE OF GASIFICATION EQUIPMENT BASED ON PURCHASE PRICE	4.000
19	ANNUAL INTEREST RATE,PERCENT	12.000
20	ECONOMIC LIFE OF GASIFICATION EQUIPMENT,YEARS	15.000
21	HARVEST-TRANSPORT COST FOR GRAIN,C/BU AT 56LB/BU	26.000
22	HARVEST-TRANSPORT COST FOR COBS IN FIELD,$/TON	2.500
23	HARVEST-TRANSPORT COST FOR STOVER IN FIELD,$/TON	5.000
24	MARKET VALUE OF GRAIN AT 15.5 PERCENT MC,$/BU.	2.000
25	MARKET VALUE OF COBS IN FIELD,$/WET TON	0.000
26	MARKET VALUE OF STOVER IN FIELD,$/WET TON	0.000
27	RETENTION RATE OF BIOMASS NITROGEN BY SOIL,PC	80.000

1	POUNDS OF WATER PER POUND WET GRAIN	.216
2	THEORETICAL BTU/LB OF WET GRAIN	228.777
3	THEORETICAL BTU/BU OF WET GRAIN	12811.511
4	ENERGY CONTENT OF LP GAS,BTU/GAL.	92000.000
5	LP GAS NEEDED,GAL/LB WET GRAIN	.006
6	LP GAS NEEDED,GAL/BU WET GRAIN	.435
7	PRESENT WORTH FACTOR	6.811
8	PRESENT WORTH FACTOR,ADJUSTED	1.272
9	REPAIR AND OPERATION MODIFIER	.051

ITEMS (1-7)	FIELD AVAIL. PERCENT DRY	RELATIVE WEIGHTS IN FIELD DRY LB.	GROSS ENERGY AVAILABLE (BTU/DLB)	ADJUSTED ENERGY AVAIL. (BTU/DLB)	AVERAGE MOISTURE CONTENT PERCENT	RELATIVE WEIGHTS IN FIELD WET LB.	ENERGY AVAILABLE MC ADJUST (BTU/WLB)
GRAIN	46.000	.695	9995.000	9295.350	30.500	1.000	6136.968
COBS	11.333	.171	7961.000	7403.730	61.000	.439	2240.855
STOVER	42.620	.644	7150.000	6649.500	61.000	1.651	1946.705

ITEMS (8-14)	ENERGY AVAILABLE GAS.P.ADJ (BTU/WLB)	NET ENERGY AVAIL. (BTU/WLB)	RELATIVE ADJ.ENER. AVAIL. (TOT.BTU)	QUANTITY FOR DRYING (WET LB)	QUANTITY FOR DRYING (DRY LB)	QUANTITY NITROGEN REMOVED (LB.)	VALUE OF NITROGEN REMOVED (C)
GRAIN	4909.575	1963.830	1963.830	6.524	4.534	.058	1.161
COBS	1792.684	717.074	314.812	17.866	6.966	.025	.502
STOVER	1557.364	622.946	1028.551	20.566	8.021	.074	1.476

ITEMS (15-17)	GATHERING TRANSPORT COST (C/WET.BU)	FIELD MARKET VALUE (C/DR.BU)	PERCENT OF TOTAL AVAIL. (DRY)	PERCENT OF TOTAL AVAIL. (WET)
GRAIN	3.029	19.163	11.650	11.650
COBS	2.233	0.000	72.671	72.671
STOVER	5.142	0.000	22.243	22.243

ECONOMIC SUMMARY *

ITEM	YR	GROSS LP GAS SAVINGS (C/BU)	COLLECTION COST (C/BU)	COST OF NITROGEN REMOVED (C/BU)	MARKET VALUE, BIOMASS (C/BU)	GROSS SAVINGS, BIOMASS (C/BU)	ANNUAL COST OF EQUIPMENT (C/BU)	NET AMT. AVAIL. FOR PURCHASE (C/BU)
GRAIN	1	21.759	3.029	1.161	19.163	-.433	6.343	158.583
COBS		21.759	2.233	.502	0.000	19.024	10.509	262.729
STOVER		21.759	5.142	1.476	0.000	15.141	9.678	241.949
LPGAS,C/G		50.000						
GRAIN	2	25.022	3.029	1.161	19.163	2.830	6.343	158.583
COBS		25.022	2.233	.502	0.000	22.287	10.509	262.729
STOVER		25.022	5.142	1.476	0.000	18.405	9.678	241.949
LPGAS,C/G		57.500						
GRAIN	3	28.776	3.029	1.161	19.163	6.584	6.343	158.583
COBS		28.776	2.233	.502	0.000	26.041	10.509	262.729
STOVER		28.776	5.142	1.476	0.000	22.159	9.678	241.949
LPGAS,C/G		66.125						
GRAIN	4	33.092	3.029	1.161	19.163	10.900	6.343	158.583
COBS		33.092	2.233	.502	0.000	30.357	10.509	262.729
STOVER		33.092	5.142	1.476	0.000	26.475	9.678	241.949
LPGAS,C/G		76.044						
GRAIN	5	38.056	3.029	1.161	19.163	15.864	6.343	158.583
COBS		38.056	2.233	.502	0.000	35.321	10.509	262.729
STOVER		38.056	5.142	1.476	0.000	31.439	9.678	241.949
LPGAS,C/G		87.450						
GRAIN	6	43.764	3.029	1.161	19.163	21.572	6.343	158.583
COBS		43.764	2.233	.502	0.000	41.029	10.509	262.729
STOVER		43.764	5.142	1.476	0.000	37.147	9.678	241.949
LPGAS,C/G		100.568						
GRAIN	7	50.329	3.029	1.161	19.163	26.137	6.343	158.583
COBS		50.329	2.233	.502	0.000	47.594	10.509	262.729
STOVER		50.329	5.142	1.476	0.000	43.712	9.678	241.949
LPGAS,C/G		115.653						
GRAIN	8	57.879	3.029	1.161	19.163	35.687	6.343	158.583
COBS		57.879	2.233	.502	0.000	55.144	10.509	262.729
STOVER		57.879	5.142	1.476	0.000	51.261	9.678	241.949
LPGAS,C/G		133.001						
GRAIN	9	66.560	3.029	1.161	19.163	44.368	6.343	158.583
COBS		66.560	2.233	.502	0.000	63.825	10.509	262.729
STOVER		66.560	5.142	1.476	0.000	59.943	9.678	241.949

LPGAS,C/G	152.951						
GRAIN 10	76.544	3.029	1.161	19.163	54.352	6.343	158.583
COBS	76.544	2.233	.502	0.000	73.809	10.509	262.729
STOVER	76.544	5.142	1.476	0.000	69.927	9.678	241.949
LPGAS,C/G	175.894						
GRAIN 11	88.026	3.029	1.161	19.163	65.834	6.343	158.583
COBS	88.026	2.233	.502	0.000	85.291	10.509	262.729
STOVER	88.026	5.142	1.476	0.000	81.409	9.678	241.949
LPGAS,C/G	202.278						
GRAIN 12	101.230	3.029	1.161	19.163	79.038	6.343	158.583
COBS	101.230	2.233	.502	0.000	98.495	10.509	262.729
STOVER	101.230	5.142	1.476	0.000	94.613	9.678	241.949
LPGAS,C/G	232.623						
GRAIN 13	116.414	3.029	1.161	19.163	94.222	6.343	158.583
COBS	116.414	2.233	.502	0.000	113.679	10.509	262.729
STOVER	116.414	5.142	1.476	0.000	109.797	9.678	241.949
LPGAS,C/G	267.513						
GRAIN 14	133.877	3.029	1.161	19.163	111.685	6.343	158.583
COBS	133.877	2.233	.502	0.000	131.142	10.509	262.729
STOVER	133.877	5.142	1.476	0.000	127.259	9.676	241.949
LPGAS,C/G	307.639						
GRAIN 15	153.958	3.029	1.161	19.163	131.766	6.343	158.583
COBS	153.958	2.233	.502	0.000	151.223	10.509	262.729
STOVER	153.958	5.142	1.476	0.000	147.341	9.678	241.949
LPGAS,C/G	353.785						

* ALL VALUES BASED ON A BU. AT 15.50 PERCENT MOISTURE CONTENT

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RATIOS	RELATIVE DRY WT. IN FIELD	GROSS ENERGY AVAIL.	NET ENERGY AVAIL.	TOTAL GROSS COSTS	AVERAGE GROSS SAVINGS	AVAIL. FOR PURCHASE
GRAIN/COBS	4.059	5.096	6.238	-5.475	.604	.604
GRAIN/STOVER	1.079	1.509	1.909	-2.263	.655	.655
COBS/STOVER	.266	.296	.306	.413	1.066	1.066
COBS/GRAIN	.246	.196	.160	-.183	1.657	1.657
STOVER/GRAIN	.927	.663	.524	-.442	1.526	1.526
STOVER/COBS	3.761	3.376	3.267	2.420	.921	.921

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