RESEARCH BULLETIN 1112 JUNE 1979

# The Economics of Corn Stover as a Coal Supplement in Steam-Electric Power Plants in the North Central United States

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AGDEX 771

6-79-2.5M

# Economics of Corn Stover as a Coal Supplement in Steam-Electric Power Plants in the North Central United States

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## INTRODUCTION

The main purpose of this research is to evaluate the economic feasibility of utilizing corn stover as a coal supplement in existing coal burning steam-electric power plants in the North Central United States. This is consistent with the worldwide search for renewable sources of energy accentuated by the rising price of the traditional energy sources (gas, oil, and coal) and their anticipated declining availability. When burned with high sulfur coal, corn stover is both a renewable energy source and a sulfur emission control material.

## THE ENERGY PROBLEM

Since energy is an intermediate input for most agricultural and industrial outputs, energy costs affect most aspects of human life both quantitatively and qualitatively. The price of energy is increasing because of its declining supply and increasing demand over time coupled with the cartelization of the world product market.

Supply of energy is declining because the main sources of energy (oil, gas, and coal) are exhaustible stock resources. It has been shown by Randall (11) and Solow (13) that the only difference between a reproducible capital asset and a stock resource is that the size of the existing stock of a non-renewable natural resource will never increase over time. Pimentel (10) holds that if petroleum was the only source of energy and if all the petroleum resources were used solely to feed the world population, it would last a mere 13 years. Another important characteristic of stock resources is their increasing extraction costs as the rate of their depletion increases with a constant extraction technology. As the low cost shallow mines run out, the same quantity of ore has to be extracted from deeper or more distant mines. As a result, the per unit cost of extracting a given quantity of ore increases.

Energy demand is increasing because of the increase in both world population and per capita income. Economic development and levels of per capita consumption of energy are closely associated. The drive towards a substantial improvement in living standards will exert added claims and growing burdens on world energy supplies (4).

An important indicator of the energy crisis in the United States is the increasing rate of petroleum imports since 1954. In 1954 petroleum imports in the United States were 8.5% of total consumption. The percent of imports to total consumption jumped to 35.5% in 1973 and to 50% in 1977. During that period of time, petroleum import prices were rising.

The North Central States are relatively more industrialized and colder than most parts of the United States. Consequently, they have a higher energy demand per capita than most states. On the supply side, they depend heavily on petroleum imports from other regions. Five of the 12 states of this region produce no coal at all, and two of them do not produce any kind of fossil fuels (Table 1).

The foregoing discussion suggests that today's world including the North Central States and the United States as a whole is facing a real energy problem. It mainly results from the stock and depletable nature of fossil fuels (*e.g.*, oil, gas, coal) which supply most of our energy needs and a growing demand for energy. The obvious solution for the current energy problem at any level of aggregation is to reduce the demand for energy and/or increase its supply. Suggested areas for reducing the demand include discouraging lavish consumption of energy, building smaller houses and cars, going back to organic farming, and encouraging insulation and mass transit. Removing various energy price controls and increasing taxes on fuel materials are frequently mentioned methods of demand reduction.

On the supply side, new alternative sources of energy should be explored and developed as long as they are currently or potentially cost competitive with fossil fuel sources. The most effective method of increasing energy supplies is to develop new renewable sources of energy to replace or supplement the current stock energy sources. Herfendahl holds that "a growing society cannot rely on or require minerals which will run out. Either they run out or consumption is almost zero" (9, p. 61). Herfendahl

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**TABLE 1.—Production of Coal, Natural Gas, and Petroleum in the North Central United States, 1974.**

| | Coal | | Crude Petroleum | | Natural Gas | |
|---|---|---|---|---|---|---|
| Sub-region and State | 1,000 Tons | Percent of Region | 1,000 Barrels | Percent of Region | Million Cubic Feet | Percent of Region |
| East North Central | 127,350 | 90.48 | 59,391 | 38.71 | 152.20 | 59.90 |
| Illinois | 58,215 | 41.33 | 30,669 | 19.99 | 40.00 | 15.74 |
| Indiana | 23,726 | 16.858 | 5,312 | 3.46 | 14.00 | 5.51 |
| Michigan | 0 | 0 | 14,614 | 9.53 | 50.00 | 19.68 |
| Ohio | 45,409 | 32.27 | 8,796 | 5.73 | 48.20 | 18.96 |
| Wisconsin | 0 | 0 | 0 | 0 | 0 | 0 |
| West North Central | 13,395 | 9.52 | 94,037 | 61.30 | 101.9 | 40.10 |
| Iowa | 590 | 0 420 | 0 | 0 | 0 | 0 |
| Kansas | 718 | 0.51 | 66,227 | 43.16 | 16.6 | 6.53 |
| Minnesota | 0 | 0 | 0 | 0 | 0 | 0 |
| Missouri | 4,624 | 3.291 | 60 | 0.04 | 31.4 | 12.36 |
| Nebraska | 0 | 0 | 7,240 | 4.71 | 34.0 | 13.37 |
| North Dakota | 7,463 | 5.303 | 20,235 | 13.19 | 19.9 | 7.83 |
| South Dakota | 0 | 0 | 275 | 0.18 | 0 | 0 |
| North Central States | 140,745 | 100 | 153,428 | 100 | 254.1 | 100 |

Source: Bureau of Mines (3).

further argues that since low cost minerals will inevitably diminish, a world society must increasingly rely upon flow and renewable resources. One major flow resource is biomass, including corn stover which is the focus of this study.

## THE ROLE OF BIOMASS

Biomass is a broad term which includes organic materials such as crops, crop residues normally left on the field, crop processing wastes (cotton gin and major cane extraction residues or bagasse), animal waste (manure), forest products, aquatic plants, and solid waste. The extraction of energy from biomass can be achieved several ways. Generally, liquid fuels can be generated from biomass sources by fermentation, gas fuels by anaerobic digestion, and solid fuel energy by direct combustion. Research is underway on these processes to improve their efficiency.

Purdue University has developed a process that increases the efficiency of cellulosic fermentation to produce alcohol from crop residues. This process has been proven in the laboratory and plans are underway to field test it in a pilot plant. This technology looks promising as a major breakthrough in the utilization of biomass residues as a source of liquid fuels.

## CORN STOVER COMBUSTION

The energy content of crops and crop residues results from solar energy captured by plants in the photosynthesis process. Part of that energy is digestible and used as food and the other part is indigestible by humans because it is mostly cellulose. The major indigestible part of the plant energy is contained in agricultural crop residues and is a major sub-set of total biomass. Among crop residues, corn stover has the highest BTU value per unit of weight because of its relative efficiency in utilizing atmospheric carbon dioxide ($CO_2$) (12). The estimated BTU value of corn stover dry matter ranges between 6,500 BTU/lb (2) to 8,000 BTU/lb (1, 15). The average heat value for coal is 12,200 BTU/lb. For corn stover to be economically feasible as a coal supplement, it must be cost competitive. The cost of producing a certain amount of energy (1 million BTU is the conventional unit) from corn stover should be less than or equal to the cost of an equivalent amount of energy produced using coal. The major task of this research is the determination of the cost of a unit of heat generated using corn stover for a variety of situations and assumptions.

In addition to its heat value, corn stover is low in sulfur. It can be an emission control material when mixed with high sulfur coal. Corn stover contains 0.017% sulfur (0.053 lb $S_2O$/MBTU), enabling it to function as an emission control material to potentially meet the most restrictive air pollution standards enforced by the Environmental Protection Agency (EPA). The EPA air quality standards differ from one state to another but, generally speaking, coal of more than 1% sulfur (1.639 lb $S_2O$/MBTU) on the average is considered "low quality coal" (5). Further, 62% of the higher sulfur coal reserves in the United States are found east of the Mississippi where 90% of the coal-fired power generation occurs. To meet the EPA sulfur emission standards, it is necessary for coal burning power plants east of the Mississippi to import western coal, or use stack scrubbers, fluidized beds, or some other technology which may be more expensive than corn stover.

In the North Central United States, corn has the highest residue production of all crops grown (16). Moreover, this region is a net importer of energy and most of its coal reserve is high-sulfur coal that does not meet EPA emission standards when burned alone or without treatment. For example, more than 50% of the coal in the state of Ohio, which has a considerable share of the coal production in this region (Table 1), has more than 4% sulfur content.

Corn stover is also a soil erosion control material. It provides soil nutrients and it can be used for livestock feed and bedding. In determining the feasibility of corn stover as a coal supplement, the benefit of reducing the sulfur emissions externality resulting from burning high sulfur coal and the external and private costs (soil and nutrient loss) associated with the removal of stover from the soil are considered in this research. Other costs include the opportunity cost of harvest, storage, and transport of the stover. This is in contrast to limited previous research on the feasibility of stover as a fuel. Buchele (2) and Starr (15) analyzed stover as a fuel but did not account for some of the externalities and used engineering type cost estimates for harvest and transport rather than opportunity costs.

Two case studies of power plants chosen from the population of power plants in the North Central States are used for the analysis of this problem. The Ames, Iowa, power plant which was converted in 1975 to use solid waste is chosen to represent the medium size power plants (150 tons/day). The Peru, Indiana, power plant is chosen to represent the small size power plants (50 tons/day). The selection of these two power plants also represents the two most common types of boilers: the pulverized coal boiler and the stoker boiler. The Ames power plant has both types of boilers and the Peru plant has the pulverized coal type of boiler which is the most common in the region.

## OBJECTIVES

The general purpose of this study is to assess the economic feasibility of using corn stover as a fuel supplement for coal in steam-electric power plants in the North Central United States.

The specific objectives are:

- To determine the economic feasibility of harvesting, storing, transporting, and firing corn stover as a fuel supplement in two case steam-electric plants.
- To perform sensitivity analysis on the major variables such as coal prices, costs of collecting and firing stover, stover BTU content, changes in technology, and the level of throughput.
- To generalize the results of the case studies and sensitivity analysis to the North Central States, using a sample of power plants.

## GENERAL METHODOLOGY

Because of the lack of a market price for corn stover, break-even point analysis is found to be the most appropriate methodology to determine the feasibility of corn stover as a fuel supplement for coal. The market for corn stover is conceptualized as having a supply (farm sector), a demand (power plant sector), and a transportation sector to link supply and demand. The quantitative relationships that determine the break-even points of each of the three sectors are formulated. The interaction between the three sectors makes up the complete model that determines the feasibility of stover as a supplemental fuel.

### Farm Sector

The farmer will not supply his stover to the power plant unless he is paid at least his opportunity cost. This is the break-even point of the farm sector. This cost is composed of the harvest cost, the storage cost, and the net value of the stover itself. The net value of stover is the nutrient content of stover, plus the value of stover for erosion control and livestock feed and bedding, less any reduced costs in tillage associated with stover removal.

It is difficult to quantify the value of stover as an erosion control material based upon the available data. Schrader (14) and Gupta (7) argue that there is a safe limit of stover removal that leaves the soil intact depending upon the type of soil, the slope of the land, and the soil conservation practices. Consultation with agronomists and agricultural extension agents in the localities of the case studies (Ames, Iowa, and Peru, Indiana) was used to determine the total amount of stover that could be safely removed for feed, bedding, and fuel. The same consultations were used to determine the proportion of total stover needed for livestock feed and bedding. The maximum amount of stover available for use as a fuel is the difference between the total amount that can be safely removed and the amount needed for livestock feed and bedding adjusted for a machine harvest efficiency of 64%. This procedure implicity assumes zero erosion control costs and with the machine efficiency adjustment provides a conservative estimate of available stover for energy. Assuming that farmers will not remove more than the surplus residue, the opportunity cost of the removed stover is the cost of the fertilizers (N, P, K) it contains.

For the savings in reduced tillage, only chopping costs are considered. Plowing and disking costs may be reduced in some cases by the removal of stover, but these savings are not considered to avoid overestimation of the feasibility of stover as a fuel.

Based on the foregoing considerations, the farm sector relationship is formulated as follows:

$$\text{Min PsF/MBTU} = \text{CH} + \text{CS} + \text{NVS} \qquad [1]$$

where:

Min PsF/MBTU = minimum price the farmer can accept for the amount of stover that generates one MBTU of heat
CH = harvest cost for the amount of stover that generates one MBTU of heat
CS = storage cost for the amount of stover that generates one MBTU of heat
NVS = net value for the amount of stover that generates one MBTU of heat. The savings of foregone chopping costs minus the fertility loss.

The most common types of equipment for harvesting stover in the North Central Region are the stacker, the large round baler, and loose chop. Farm sector costs are estimated for these three systems of stover harvest. Each system of harvest has different associated transportation and firing systems. Farm storage costs also differ with the harvest system. To identify the least cost system, the stacker, the large round baler, and the loose chop costs are estimated and compared.

**Power Plant Sector**

A power plant will not use the corn stover as a fuel unless it costs the same or less than the cost of using coal per unit of heat value. The break-even point of the power plant sector is the maximum price the power plant can pay for stover. This maximum price is the cost of using coal less any costs associated with the use of corn stover in the power plant.

The cost of using coal is composed of the delivery price of coal, the handling and processing costs, and the sulfur emission control costs (if any). The costs associated with the use of corn stover at the power plant are the necessary modifications of the boiler(s), storage, and conveying costs. The maintenance and operating costs of these installations are also part of the costs associated with the use of corn stover as a power plant fuel. Based upon these costs, the relationship of the power plant sector is as follows:

$$\text{MaxPsP/MBTU} = \text{Pc} + \text{PRc} + \text{Ec} - \text{CUS} \qquad [2]$$

where:

MaxPsP/MBTU = maximum price the power plant can pay for the amount of stover generating one MBTU of heat
Pc = price of coal per MBTU
PRc = processing costs of coal per MBTU
Ec = sulfur emission control costs per MBTU
CUS = cost of using stover per MBTU. This is composed of capital costs (amortized using the flow method of capital depreciation), maintenance and operation costs. The per unit capital cost assumes utilization of full modified boiler(s) capacity.

To conform to the EPA sulfur emission standards, the Ames power plant is blending high sulfur Iowa coal with low sulfur Colorado coal. The other case study (Peru power plant) would use the same method if required to conform to the standards set for it. To impute the value of stover as a sulfur emission control material, a linear programming model is used. The model is solved with and without corn stover assuming a zero price for corn stover. The difference between the cost of the coal blend with and without the stover is the shadow price or the value of stover as a sulfur emission control material.

The general form of the model is as follows:

$$\text{Min C} = \sum_{i=1}^{n} X_i P_i$$

subject to:

$$\sum_{i=1}^{n} S_i X_i \leq S$$

$$\sum_{i=1}^{n} H_i X_i = 1$$

where:

Min C = minimum cost of the blend generating one MBTU of heat
$X_i$ = amount of fuel i in pounds
$P_i$ = price of fuel i per lb, where the price of corn stover = 0
$S_i$ = sulfur dioxide content/lb of fuel i
S = sulfur standard set for the power plant (lb of $S_2O$/MBTU)
$H_i$ = heat content of fuel i (BTUs/lb)
n = number of coal and stover fuels

**Transportation Sector**

Transportation of stover from the farm to the power plant could be handled several ways. The stover could be delivered to the power plant by the farmer or picked up at the farm by the power plant. In either case, a custom hauler could be used. If the stover is delivered to the power plant, the relevant transportation distance is the radius of the circle or "stover shed" from which enough stover can be collected to meet the power plant level of throughput. In this case, the farmers at the margin will determine the price of stover and the farmers located closer to the plant will earn a rent. If the stover is to be picked up at the farm, the appropriate hauling distance is the weighted average distance from the stover shed to the plant. In the main analysis of the two case studies, it will be assumed that the stover will be delivered to the power plant. In the sensitivity analysis, it will be assumed that the stover is picked up at the farm.

The other components of transport cost are the loading and unloading costs and the cost per loaded mile. The total transportation cost function is:

$$\mathrm{TRPC} = \mathrm{LUC} + \mathrm{CLM} \times \mathrm{D} \qquad [3]$$

where:

TRPC = Total transportation cost/MBTU
LUC = the loading and unloading costs of the amount of stover that generates one MBTU
CLM = cost of hauling the amount of stover that generates one MBTU for 1 mile
D = hauling distance required to meet plant capacity

### The Complete Model

The break-even point of the system is realized when the summation of the farm sector cost/MBTU and the transportation cost/MBTU is equal to the maximum price the power plant can pay for stover per MBTU.

$$\mathrm{CH} + \mathrm{CS} + \mathrm{NVS} + \mathrm{LUC} + \mathrm{CLM} \times \mathrm{D} = \mathrm{Pc} + \mathrm{PR_c} + \mathrm{E_c} - \mathrm{CUS}$$

or

$$\mathrm{CH} + \mathrm{CS} + \mathrm{NVS} + \mathrm{LUC} + \mathrm{CLM} \times \mathrm{D} - \mathrm{Pc} - \mathrm{PR_c} - \mathrm{Ec} + \mathrm{CUS} = 0 \qquad [4]$$

If the result of equation [4] is less than or equal to zero, stover is assumed to be feasible as a coal supplement. If it is greater than zero, stover is infeasible at 1977 prices of coal.

## DATA COLLECTION

Data on corn stover are available from the Stanford Research Institute (SRI) in Crop, Forestry, and Manure Inventory for the United States (16). Although this source contains detailed and comprehensive data on crop residues in the United States, it has some limitations, particularly regarding corn residue. The SRI data assumes 55% of the corn stover is fed to livestock. Consultation with agricultural extension agents in Story County, Iowa, and Lancaster County, Nebraska, and animal scientists and agronomists at Ohio State University, Iowa State University, and the University of Nebraska reveals that the amount of stover fed to animals in the Corn Belt probably does not exceed 10% of the stover produced annually. Calculating the maximum amount of stover that could be fed to the livestock in the North Central States also showed that 55% is too high for most of the North Central States. The SRI data have been adjusted based upon the maximum quantity of stover consumable by livestock (Table 2). This revision also overestimates the amount of stover fed to livestock, but it is closer to reality than the SRI base data.

The estimates of the costs for the farm and transport sectors are developed primarily from custom rates. Custom rates are published annually by the Cooperative Extension Services in the North Central States. Table 3 presents the average custom rates for hay harvest, chopping, and transportation for Indiana and Iowa. An effort was made to get the actual custom rates in the localities of the two case studies (Ames, Iowa, and Peru, Indiana) but such data were not available. However, the county extension agents in Story County, Iowa, and Miami County,

**TABLE 2.—Adjusted SRI Data on Corn Stover Production and Utilization in the North Central States.**

| | Maximum Stover Consumable by Livestock* | | Stover Returned to the Soil | | Total† |
|---|---|---|---|---|---|
| Region and State | 1,000 Tons | Percent | 1,000 Tons | Percent | 1,000 Tons |
| East North Central | 4,249.0 | 13 | 28,165.2 | 87 | 32,434.2 |
| Illinois | 1,070.0 | 7 | 14,377.6 | 93 | 15,447.6 |
| Indiana | 419.5 | 5 | 7,630.5 | 95 | 8,100.0 |
| Michigan | 541.5 | 3 | 1,413.4 | 97 | 1,924.9 |
| Ohio | 916.0 | 22 | 3,206.4 | 78 | 4,122.4 |
| Wisconsin | 1,302.0 | 46 | 1,537.3 | 54 | 2,839.3 |
| West North Central | 10,989.8 | 28 | 28,277.5 | 72 | 39,267.2 |
| Iowa | 2,310.5 | 13 | 15,312.8 | 87 | 17,623.3 |
| Kansas | 1,909.5 | 96 | 71.0 | 4 | 1,980.4 |
| Minnesota | 1,123.5 | 16 | 5,959.1 | 84 | 7,082.6 |
| Missouri | 1,387.2 | 48 | 1,510.6 | 52 | 2,897.8 |
| Nebraska | 2,307.0 | 31 | 5,180.1 | 9 | 7,487.1 |
| North Dakota | 150.6 | 100 | 0 | 0 | 150.6 |
| South Dakota | 1,801.5 | 88 | 243.9 | 12 | 2,045.4 |
| North Central States | 15,238.8 | 21 | 56,442.7 | 79 | 71,701.4 |

*Numbers of livestock multiplied by their respective maximum annual stover consumption (beef cow = 1 ton, dairy cow and sheep = 0.5 ton).

†Source: Stanford Research Institute (16).

TABLE 3.—Average Custom Rates in Indiana and Iowa for Three Harvest Systems, 1977.

| | Indiana* | | | Iowa† | | |
|---|---|---|---|---|---|---|
| | 3-Ton Stacks $/Stack | Large Round Bale (1,500 lb) $/Bale | Loose Chop $/Ton | 3-Ton Stacks $/Stack | Large Round Bale (1,500 lb) $/Bale | Loose Chop $/Ton |
| Harvest | 23.00 | 11.90 | 8.84 | 18.10 | 7.70 | 9.48 |
| Chopping | 6.63 | 6.63 | 6.63 | 5.50 | 5.50 | 5.50 |
| Transportation | | | | | | |
| Loading and Unloading | 6.24 | 0.40 | 0.76 | 4.00 | 0.32 | 0.72 |
| Cost per Loaded Mile | 0.60 | 0.09 | 0.32 | 0.50 | 0.07 | 0.26 |

*Source: Indiana Custom Rates for Power Operated Farm Machines. Coop. Ext. Serv., Purdue Univ., W. Lafayette, Indiana, 1977.
†Source: Estimated 1977 Iowa Farm Custom Rates. Coop. Ext. Serv., Iowa State Univ., Ames, 1977.

Indiana, felt that the average custom rates were close to the custom rates in their counties.

The cost estimates for the power plant conversion were provided by Mr. Gordon Smith, a consultant engineer from Akron, Ohio, experienced in conversion of power plants to fire solid waste (Appendix Tables I and II). Cost data on the processing of stover were provided by Farmhand, Inc., Jeffrey Manufacturing Co., and Battelle Memorial Institute (Appendix Tables III, IV, and V).

Price of coal, type of coal, sulfur and BTU content of coal, and the EPA standards set for each case power plant were provided by the management of the two power plants analyzed in this research and are summarized in Table 4.

To generalize the results of the two case studies to the region, 53 power plants were randomly chosen from the power plant population in the North Central States. Data on coal prices, custom rates, power plant stover capacity and availability were collected for each of the 53 power plants (Appendix Table VI). This sample represents approximately 22% of the population of power plants in the region.

## RESULTS OF THE CASE ANALYSES

### Ames, Iowa, Power Plant

The Ames power plant is already converted to burn solid waste. It has two stokers and one pulverized coal boiler. To reduce the sulfur emissions of the high sulfur Iowa coal, this power plant is using low sulfur Colorado coal to conform to the EPA sulfur emission standards.

The stover combustion capacity of one of the stoker boilers is 150 tons/day. To compare the results of the analysis of the stoker boiler with the pulverized coal boiler, a 150 ton/day level of throughput is also used for the pulverized coal boiler.

Four scenarios are analyzed for this power plant: stoker boiler without emission control costs, stoker boiler with emission control costs (Ec), pulverized coal boiler without emission control costs, and pulverized coal boiler with emission control costs (Ec).

The farm, transportation, and power plant sector costs are estimated for each of the four scenarios. The cost of sulfur emission control is imputed using the linear programming model discussed earlier. The

TABLE 4.—Summary Characteristics of the Coal Used in Ames, Iowa, and Peru, Indiana, Power Plants, 1977.

| | BTU Content (BTU/lb) | Sulfur Content (percent) | EPA Sulfur Standard (lb/MBTU) | Prices ($/ton) |
|---|---|---|---|---|
| **Ames, Iowa*** | | | 5 | |
| Iowa Coal | 9,345 | 5.5 | | 17.71 |
| Colorado Coal | 12,200 | 0.5 | | 32.51 |
| **Peru, Indiana†** | | | 6 | |
| Indiana Coal | 11,000 | 4.0 | | 26.50 |
| Colorado Coal‡ | 12,000 | 0.5 | | 36.00 |

*Personal interview with power plant managers, summer 1977.
†Personal interview with power plant managers, winter 1977.
‡The price of Colorado coal for the Peru plant is estimated based on discussion with three coal shipping companies located in Columbus, Ohio.

**TABLE 5.—Economic Feasibility of the Ames, Iowa, Power Plant (150 Tons/Day) Scenarios at 9% Interest and 1977 Prices of Coal.**

**Maximum Power Plant Price—Farm and Transport Costs in $/MBTU**

| | Stoker Boiler | | Pulverized Coal Boiler | |
|---|---|---|---|---|
| | Without Ec* | With Ec | Without Ec | With Ec |
| 3-Ton Stack | —0.249 | 0.164 | —0.292 | 0.101 |
| Large Round Bale | —0.414 | —0.001 | —0.457 | —0.139 |
| Loose Chop | —0.629 | —0.216 | —0.672 | —0.470 |

*Ec refers to sulfur emission control costs.

capital cost of modifying the power plant is amortized using 5, 9, and 13% interest rates as part of the sensitivity analysis. However, the 9% rate is assumed to be the most likely or appropriate rate of interest over the life of the project.

By adding the farm and transportation sector costs and subtracting the maximum price the power plant can pay, the feasibility of stover is determined. Table 5 summarizes the results of the break-even point analysis for the four scenarios considered for the Ames, Iowa, power plant (150 tons/day throughput) at the 9% interest rate on capital and 1977 prices of coal. A positive value reflects an economically feasible or "better than break-even" alternative.

Excluding the sulfur emissions control costs from the cost of using coal at the Ames power plant, corn stover is not feasible even for the least cost harvest system (the stacks) and the stoker boiler, which costs less to modify than the pulverized coal boiler. Including the sulfur emission control costs, the stack harvested stover is feasible for both types of boilers (Table 5).

### Peru, Indiana, Power Plant

This power plant has three pulverized coal boilers and uses Indiana coal which does not meet the EPA sulfur emission standards. The level of stover throughput estimated for the largest boiler is 50 tons/day. As with the Ames power plant, the analysis is conducted for the Peru case for each sector at three interest rates using 1977 prices of coal. Since this power plant has only pulverized coal boilers, only two scenarios are considered: pulverized coal boilers with and without sulfur emission control costs.

Without sulfur emission control costs, stover is not feasible for this power plant at the 9% interest rate (Table 6). The system is also not feasible or does not break even at 5% interest on capital. Including the sulfur emission control costs (assuming this power plant has to fully conform to EPA sulfur emission standards), the stack harvested stover is feasible only if the interest rate on capital is 5%. At 9% interest on capital, it falls short of feasibility by $0.018/MBTU; *i.e.,* if this power plant used corn stover as a supplemental fuel it would incur a loss of $0.234/ton if it internalized the sulfur emission control costs and paid 9% interest rate on capital.

The main factors that contribute to the relatively higher feasibility of stover in Ames than in Peru are the lower custom rates and the lower per unit modification costs at Ames. Modification costs are lower at Ames because of the size economies of boiler conversion. The higher level of throughput at Ames yields a lower per unit modification cost ($0.295/MBTU) compared to Peru ($0.476/MBTU) for the same type of boiler (pulverized coal) and the same rate of interest (9%). The per unit modification costs are more than one and one-half times higher at Peru. The economies of size are further discussed in the sensitivity analysis section which follows.

## SENSITIVITY ANALYSIS

Sensitivity analysis is performed on the major variables that affect the feasibility of stover as a fuel. Specific independent variable or parameter changes required for the system to break even are determined holding all other parameters constant. The major variables are: price of coal, custom rates, BTU content of stover, plant modification costs, level of throughput, changes in harvest technology, and hauling distance.

Independence of the major parameters can be assumed in the sensitivity analysis with the exception of level of throughput which may affect plant modifi-

**TABLE 6.—Economic Feasibility of Peru, Indiana, Pulverized Coal Boiler (50 Tons/Day) Scenarios at 9% Interest and 1977 Prices of Coal.**

**Maximum Power Plant Price—Farm and Transport Costs in $/MBTU**

| | Pulverized Coal Boiler | |
|---|---|---|
| | Without Ec* | With Ec |
| 3-Ton Stack | —0.318 | —0.018 |
| Large Round Bale | —0.751 | —0.456 |
| Loose Chop | —0.786 | —0.591 |

*Ec refers to sulfur emission control costs.

**TABLE 7.—Independent Variable Percent Changes Needed for the Stack System to Break Even at 1977 Coal Prices and 9% Interest on Capital for the Two Case Studies.**

| | Ames, Iowa (150 Tons/Day) | | | | Peru, Indiana (50 Tons/Day) | |
|---|---|---|---|---|---|---|
| | Stoker Boiler | | Pulverized Coal Boiler | | Pulverized Coal Boiler | |
| Parameter | Without Ec (Percent) | With Ec (Percent) | Without Ec (Percent) | With Ec (Percent) | Without Ec (Percent) | With Ec (Percent) |
| **Price of Coal** | + 22 | — 17 | + 36 | — 8 | + 25 | + 1.2 |
| **Modification Costs** | N.A. | — 70 | N.P. | — 34 | — 66 | — 4 |
| **Stover BTU Content** | + 26 | — 12 | + 36 | — 7 | + 25 | + 1.2 |
| **Hauling Distance** | N.A. | + 107 | N.A. | + 66 | N A. | — 17 |
| **Harvest Cost** | — 54 | + 35 | — 68 | + 22 | — 53 | — 3 |

(+) refers to percent increase in a parameter needed for the break-even point.
(—) refers to percent decrease in a parameter needed for the break-even point.
N.P. The break-even point could not be obtained even if the parameter is equal to zero.
0 No change is needed for the break-even point. The case is at least break even at the specified level.
N.A. Not applicable.

cation cost, hauling distance, and/or transport costs. Plant modification costs might also increase as the result of such things as rapid escalation of wages and older plant and equipment. Hauling distance may increase or decrease at a constant level of throughput due to variation in stover density. The price of coal, BTU content of stover, and harvest cost decreases from new technology can all be assumed independent. A separate sensitivity analysis is done on the interrelated variables or parameters.

Table 7 shows the independent variable or parametric changes for the break-even point to be realized at 9% interest on capital for the stack system of harvest at the Ames and Peru plants. The system is generally most sensitive to the independent variables of coal price, stover BTU content, and harvest cost.

For the Ames case to break even without emission control costs (Ec), the price of coal has to increase by 22%. If Ec is included, the price of coal can drop by 17% and the system would still break even (Table 7). Without emission control costs, the BTU content has to increase by 26% before the Ames case can break even and by 25% for the Peru case to break even. If the higher estimate of the stover BTU content of 8,000 BTU/lb (used by Starr (14) and Benson (1)) is used instead of 6,500 BTU/lb, both cases would be feasible even without including sulfur emission control costs at 1978 prices of coal.

If the harvest cost dropped by 54% (change in technology), both the Ames and Peru cases would break even without including Ec (Table 7). Such a drop in harvest cost is not impossible. Stover might be combine harvested with the corn grains in the same operation. This could also reduce the impact of the timeliness problem of stover harvest and fall plowing.

The system is least sensitive to variations in the hauling distance variable. The Peru case is not feasible regardless of whether the stover is delivered at the power plant or picked up at the farm. The hauling distance can increase by 107% and the Ames stoker boiler including the emission control costs would still break even. Without including the emission control costs, all the cases considered would not be feasible even if the hauling distance is zero.

Sensitivity analysis to test the impact of the size of boiler converted or level of throughput on the per

**TABLE 8.—Stoker Boiler Capital, Maintenance, and Operating Costs and Stover Transportation Cost/MBTU for Five Boiler Sizes (Stack System)—Ames, Iowa.**

| Power Plant Capacity | Required Distance | TPC* | KC + MOP* $/MBTU | | | TPC + KC + MOP* $/MBTU | | |
|---|---|---|---|---|---|---|---|---|
| Tons/Day | (Miles) | $/MBTU | 5% | 9% | 13% | 5% | 9% | 13% |
| 50† | 7.62 | 0.199 | 0.269 | 0.352 | 0.444 | 0.468 | 0.551 | 0.643 |
| 75† | 9.04 | 0.217 | 0.244 | 0.310 | 0.334 | 0.461 | 0.527 | 0.551 |
| 100† | 10.10 | 0.231 | 0.224 | 0.282 | 0.319 | 0.455 | 0.513 | 0.550 |
| 125† | 10.92 | 0.242 | 0.206 | 0.251 | 0.306 | 0.448 | 0.493 | 0.548 |
| 150† | 11.71 | 0.252 | 0.187 | 0.232 | 0.283 | 0.439 | 0.484 | 0.535 |
| 175‡ | 13.85 | 0.280 | 0.151 | 0.210 | 0.310 | 0.431 | 0.480 | 0.521 |
| 200‡ | 16.54 | 0.315 | 0.145 | 0.180 | 0.230 | 0.460 | 0.495 | 0.585 |

*TPC = Transportation costs, KC = plant capital costs, MOP = plant maintenance and operating costs.
†Estimates are based upon the data collected for the Ames, Iowa, case study.
‡The extrapolated estimates shown by the dotted lines of Figure 1.

unit cost of firing and transporting the stover (the scale effect) is reported in Table 8. Five boiler sizes or full capacity levels of throughput at 50, 75, 100, 125, and 150 tons/day of stover are employed to show the scale effect for the Ames stoker boiler. It is found that as the boiler size increases, the per unit modification cost decreases. However, as boiler size increases, the per unit transportation costs also increase (Table 8). This relationship between the boiler size or power plant capacity and the per unit modification and transportation costs is also depicted in Figure 1. The optimum level of throughput increases with the rate of interest. It is found to be 100, 137, and 168 tons/day respectively at the 5, 9, and 13% interest rates on capital (Figure 1).

## GENERALIZATION OF RESULTS TO NORTH CENTRAL REGION

It is difficult to generalize the results of two case studies to the diversified North Central Region. However, some indication of the general feasibility of stover as a fuel can be given based upon the results of the sensitivity analysis and a sample of power plants. A sample (n = 53) was randomly chosen from the population of power plants in the North Central States. Data on coal prices, quantity and density of stover, custom rates of harvest, and the level of throughput of each sample power plant were collected and are summarized in Appendix Table VI.

Power plants that have higher coal prices and lower custom rates than those of Ames and a level of

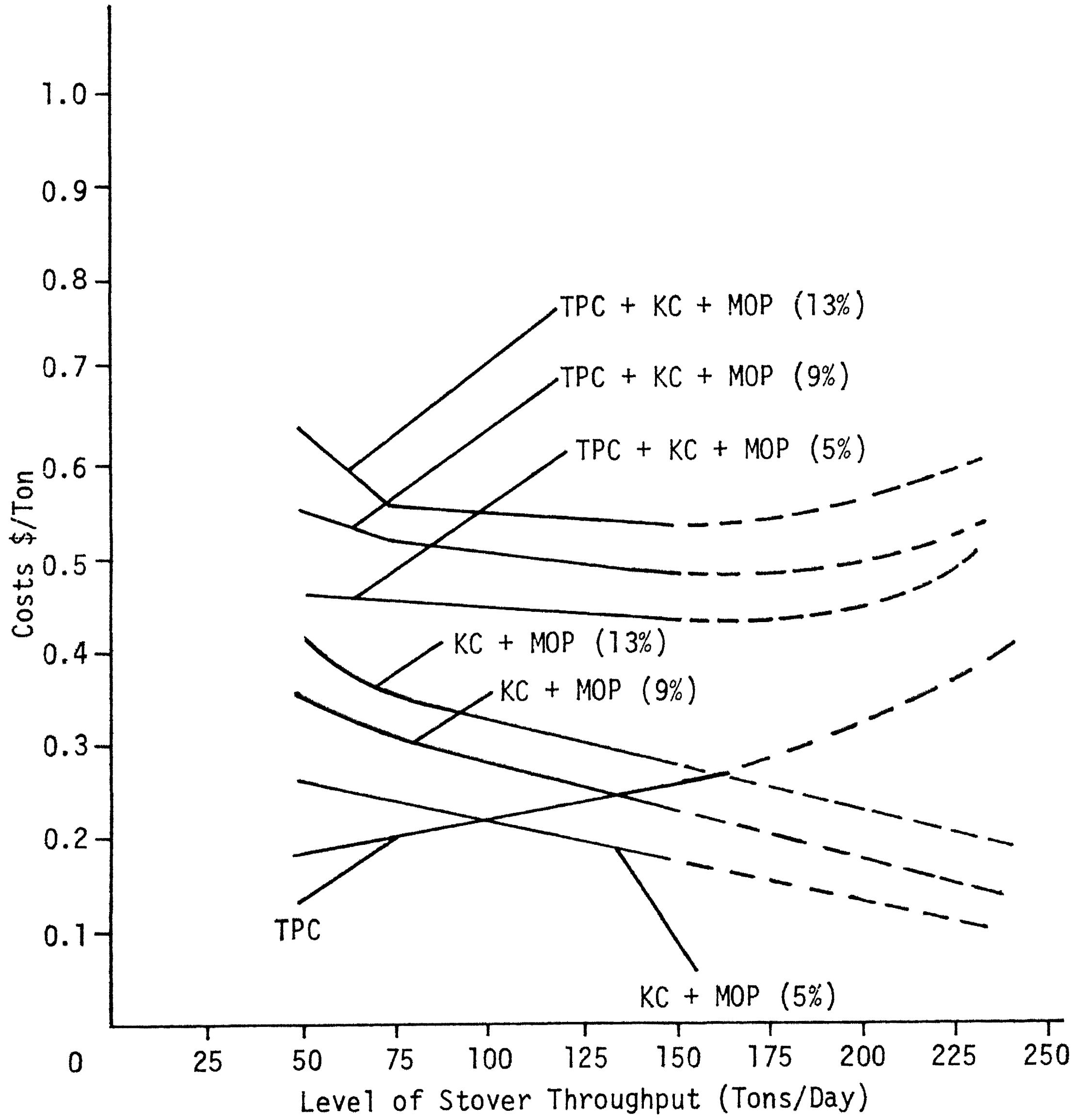

**FIG. 1.—The relationship between the power plant modification and stover transportation costs and the level of stover throughput.**

throughput higher than 50 tons/day (based on both available stover and plant capacity) are considered "most likely" to be feasible. Those power plants that have lower coal prices and higher custom rates, or higher coal prices and lower custom rates than those of Ames, are considered "likely" to be feasible if they have a level of throughput higher than 50 tons/day. Those power plants that have lower coal prices and higher custom rates than those of Ames, or have a level of throughput lower than 50 tons/day, are considered "unlikely" to be feasible.

The sample of 53 power plants is divided into these three categories based upon coal prices, custom rates, and level of throughput. Table 9 shows that 32% are most likely to be feasible, 21% are likely to be feasible, and 47% are unlikely to be feasible based upon 1977 prices of coal and the foregoing criteria. Appendix Table VI summarizes this information for the entire sample of 53 power plants.

## SUMMARY AND CONCLUSIONS

The current energy crisis is basically caused by the stock nature of the dominant energy sources (oil, gas, and coal). Because of the growing rate of energy consumption, the depletion of fossil fuels is inevitable. Flow resources such as biomass are assumed to be more appropriate sources of energy if they are currently or potentially cost competitive. In this research, the economics of using corn stover as a power plant fuel to supplement coal is investigated in two steam-electric power plants: Ames, Iowa, and Peru, Indiana.

Based on the assumption that the price of coal increases at a faster rate than the relevant costs of converting and using corn stover, the feasibility of corn stover as a fuel at small power plants similar to the Peru, Indiana, plant is foreseeable in the near future.

The sulfur emission control costs proved to be very important for the economic feasibility of stover. If the sulfur standards become more stringent and are more rigorously enforced, stover feasibility would improve. If the proposed requirement of installing stack scrubbers in all the coal-using power plants is imposed, the value of corn stover as a sulfur emission reducing material would decline, depending upon the additional amount of low sulfur coal needed for blending with higher sulfur coal. This is the case where the stack scrubber is not sufficient to reduce the sulfur emissions to the required level.

The results of the sensitivity analysis reveal that among the independent variables or parameters, the price of coal (including the sulfur emission control costs or higher priced low sulfur coal), the BTU content of stover, and the harvest cost are important determinants of feasibility of stover as a power plant fuel. The optimization of stoker boiler size or level of throughput and the associated transport costs for the Ames case occur somewhere between 100 and 168 tons of stover per day depending on the rate of interest assumed.

The stack system of harvest proved to be the least cost system of harvesting and firing the corn stover. The large round bale system involves lower transport cost than the stack system but the stack system is much less costly to harvest and fire at the power plant.

The results of the sensitivity analysis and a sample of power plants (n = 53) are used to generalize the results of the two case studies to the North Cen-

**TABLE 9.—Likelihood of Stover Feasibility in a Sample (n = 53) of Power Plants Drawn from the North Central States.**

| | Most Likely | | Likely | | Unlikely | |
|---|---|---|---|---|---|---|
| Sub-region and State | No. | Percent | No. | Percent | No. | Percent |
| East North Central | 8 | 27.6 | 6 | 20.7 | 15 | 51.7 |
| Illinois | 6 | 75.0 | 0 | 0.0 | 2 | 25.0 |
| Indiana | 0 | 0.0 | 1 | 67.0 | 3 | 33.0 |
| Michigan | 0 | 0.0 | 3 | 50.0 | 3 | 50.0 |
| Ohio | 2 | 25.0 | 1 | 12.5 | 5 | 52.5 |
| Wisconsin | 0 | 0.0 | 1 | 33.0 | 2 | 67.0 |
| West North Central | 9 | 37.5 | 5 | 20.8 | 10 | 41.7 |
| Iowa | 3 | 37.5 | 3 | 37.5 | 2 | 25.0 |
| Kansas | 0 | 0.0 | 0 | 0.0 | 1 | 100.0 |
| Minnesota | 5 | 83.3 | 0 | 0.0 | 1 | 16.7 |
| Missouri | 0 | 0.0 | 1 | 33.0 | 2 | 67.0 |
| Nebraska | 0 | 0.0 | 1 | 33.0 | 2 | 67.0 |
| North Dakota | 0 | 0.0 | 0 | 0.0 | 2 | 100.0 |
| South Dakota | 1 | 100.0 | 0 | 0.0 | 0 | 0 0 |
| Total | 17 | 32.1 | 11 | 20.7 | 25 | 47.2 |

tral States. Some 32% of the power plants in the North Central States have more favorable conditions for feasibility of stover as a fuel than those of Ames, Iowa. Those power plants that have comparable conditions to those of Ames are 21% and those that have less favorable conditions are 47% of the power plants in the region.

Based on the sample power plants having more favorable or comparable conditions to Ames, the priportion of corn stover that could be economically utilized in steam-electric power plants in the North Central Region is estimated as 12% of the annually produced stover in the region. This represents a saving of approximately 20 million tons of coal or 488 trillion BTUs per year. Although coal and oil are not perfect substitutes, this coal saving is equivalent to approximately 87 million barrels of crude oil per year. This is a large number but it represents less than 10 days of crude oil imports at current levels.

In the 12-state North Central Region, Ohio ranks seventh in corn stover production, second in coal production, second in the delivered price of coal to power plants, eighth in conformation to EPA sulfur standards, and first in the number of coal burning steam-electric plants. However, a majority of the coal burning power plants are located outside of the northwest quadrant of the state where most of the corn is produced. Preliminary evidence suggests that 8 of the 39 coal burning steam-electric plants in Ohio may have the necessary capacity and corn production in proximity for stover combustion to be economically feasible.

More research is needed on the potential for corn stover as well as solid waste and forest biomass combustion, particularly in coal burning industrial boilers which in Ohio are 10 times more numerous than steam-electric plants. Further research is also needed on the economic feasibility as well as the energy balance of alternative uses of corn stover and other crop and forest biomass for methane, ethanol, and other thermochemical and biological conversion products. The recent discovery at Purdue University of a more efficient solvent process for the conversion of cellulosic material to ethanol looks particularly promising in this regard.

The potential combustion of corn stover in steam-electric power plants is by no means a panacea for the energy problem. However, it would move in the direction of less dependence on nonrenewable fossil fuels, and that appears to be a good move.

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## APPENDIX

**APPENDIX TABLE I.—Stoker Boiler Modifications and Capital Cost Estimates for Five Levels of Stover Throughput (Tons/Day).**

| | Level of Throughput | | | | |
|---|---|---|---|---|---|
| | 50 tons/day ($1,000) | 75 tons/day ($1,000) | 100 tons/day ($1,000) | 125 tons/day ($1,000) | 150 tons/day ($1,000) |
| Storage Bin | 124 | 185 | 223 | 267 | 316 |
| Storage Bin Foundation and Structure | 50 | 70 | 90 | 110 | 130 |
| Storage Bin Installation | 25 | 37 | 45 | 55 | 63 |
| Stoker Grate Addition | 0 | 0 | 0 | 0 | 0 |
| Controls and Instruments | 20 | 20 | 20 | 20 | 20 |
| Boiler Modifications | 150 | 150 | 150 | 150 | 150 |
| Pneumatic Conveying | 120 | 125 | 130 | 135 | 140 |
| Electrical | 22 | 23 | 24 | 25 | 26 |
| Engineering and Contingency | 51 | 61 | 68 | 77 | 84 |
| Total | 561 | 671 | 750 | 839 | 929 |

Source: Cost estimates provided by Mr. Gordon Smith, consultant engineer, Akron, Ohio.

**APPENDIX TABLE II.—Pulverized Coal Boiler Modifications and Capital Cost Estimates for Five Levels of Stover Throughput (Tons/Day).**

| | Level of Throughput | | | | |
|---|---|---|---|---|---|
| | 50 tons/day ($1,000) | 75 tons/day ($1,000) | 100 tons/day ($1,000) | 125 tons/day ($1,000) | 150 tons/day ($1,000) |
| Storage Bin | 124 | 184 | 223 | 267 | 316 |
| Storage Bin Foundation and Structure | 50 | 70 | 90 | 110 | 130 |
| Storage Bin Installation | 25 | 37 | 45 | 55 | 63 |
| Stoker Grate Addition | 234 | 245 | 292 | 321 | 350 |
| Controls and Instruments | 20 | 20 | 20 | 20 | 20 |
| Boiler Modifications | 150 | 150 | 150 | 150 | 150 |
| Pneumatic Conveying | 120 | 125 | 130 | 135 | 140 |
| Electrical | 22 | 23 | 24 | 25 | 26 |
| Engineering and Contingency | 74 | 86 | 97 | 108 | 119 |
| Total | 819 | 914 | 1,071 | 1,191 | 1,314 |

Source: Cost estimates provided by Mr. Gordon Smith, consultant engineer, Akron, Ohio.

### APPENDIX TABLE III.—Stack Stover Processing (Shredder) Capital Costs for Five Levels of Stover Throughput (Tons/Day).

| | Throughput | | | | |
|---|---|---|---|---|---|
| | 50 tons/day | 75 tons/day | 100 tons/day | 125 tons/day | 150 tons/day |
| | Dollars | | | | |
| Shredder | 12,500 | 17,380 | 17,380 | 25,150 | 25,150 |
| Motor | 3,500 | 5,000 | 5,000 | 5,000 | 5,000 |
| Building for Shredder | 8,000 | 10,000 | 10,000 | 12,000 | 13,000 |
| Receiving Floor | 4,000 | 5,000 | 6,000 | 7,000 | 7,000 |
| Conveying System to Storage Bin | 11,875 | 11,875 | 15,500 | 16,500 | 18,625 |
| Tractor | 12,000 | 12,000 | 12,000 | 12,000 | 12,000 |
| Front End Loader | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Total | 53,875 | 63,255 | 67,880 | 79,650 | 82,775 |

Sources: Estimates for the tractor and the front end loader provided by the John Deere Co., Grove City, Ohio. Other estimates provided by Mr. Richard Freddly, Jeffrey Dresser Manufacturing Division, Columbus, Ohio.

### APPENDIX TABLE IV.—Large Round Bale Stover Processing (Tub Grinder) Capital Costs for 50 Tons/Day Stover Level of Throughput.

| | |
|---|---|
| Tub Grinder | $18,000* |
| 150 H.P. Motor | 6,000† |
| Building for Tub Grinder | 8,000† |
| Receiving Floor | 4,000† |
| Conveying System | 11,875† |
| Tractor (80 H.P.) | 12,000* |
| Front End Loader | 2,000* |
| Total | $61,875 |

*Estimates provided by Mr. Don Hoagland of Farmhand Company.

†Estimates provided by Mr. Richard Freddly, Jeffrey Dresser Manufacturing Division, Columbus, Ohio.

### APPENDIX TABLE V.—Loose Chop Stover Processing, Storage, Conveying, and Firing Costs for 50 Tons/Day Stover Throughput.

| | |
|---|---|
| **Silo Filler** | |
| Gehl Forage Box | $ 2,970 |
| Blower | 2,040 |
| Radiator | 129 |
| Belt | 80 |
| McCurdy Elevator (32 ft) | 650 |
| Mulkey Elevator (44 ft) | 900 |
| Scaffolding | 169 |
| Electrical Equipment | 441 |
| Building | 10,000 |
| Receiving Floor | 6,000 |
| Sub-total | $ 23,379 |
| **Storage, Conveying, and Boiler Modifications** | |
| Design | 15,000 |
| Fabrication and Erection | 143,000 |
| Miscellaneous Hookups | 1,000 |
| Boiler Feeding | 109,000 |
| Sub-total | $268,000 |
| Total | $291,379 |

Source: Estimates provided by Mr. P. W. Cover of the Battelle Memorial Institute, Columbus, Ohio.

**APPENDIX TABLE VI.—Summary of Key Variables Affecting Feasibility of Corn Stover as a Power Plant Fuel for Sample of Plants in North Central States (n = 53).**

| Sub-region and State | Sample Power Plant | County | Quantity of Stover (Tons/Day)* | Density of Stover (Tons/sq mi)* | Stover Capacity (Tons/Day† | Type of Boiler† | Custom Rates ($/Ton)‡ |  | Coal Prices** ($/Ton) |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  | Stacks | Round Bale |  |
| East North Central |  |  |  |  |  |  |  |  |  |
| Illinois |  |  |  |  |  |  | 4.93 | 7.80 |  |
|  | Bartonville | Tazwell | 404 | 204 | 1556.9 | Pulv. |  |  | 18.13 |
|  | Joliet | Will | 737 | 292 | 2259 | 76% pulv. |  |  | 19.23 |
|  | Joppa | Massoc | 11.18 | 26 | 3077 | Pulv. |  |  | 22.13 |
|  | Oakwood | Vermillion | 448 | 163 | 419 | Pulv. |  |  | 19.94 |
|  | Rochelle | Ogle | 338 | 178 | 97 | Stoker |  |  |  |
|  | Springfield | Sangamon | 266.4 | 172 | 47 | Pulv. |  |  | 20.05 |
|  | Rockford | Winnebago | 183 | 113 | 178 | 36.7% pulv.<br>63.3% stoker |  |  | 19.03 |
|  | Winnetka | Cook | 36 | 13 | 10.5 | Stoker |  |  | 22.55 |
| Indiana |  |  |  |  |  |  | 7.67 | 15.80 |  |
|  | Centerton | Morgan | 81 | 72 | 598 | Pulv. |  |  | 13.96 |
|  | Lawrenceburg | Dearborn | 9 | 17 | 2030 | 45.4% pulv. |  |  | 14.98 |
|  | Madison | Madison | 178 | 133 | 2831 | Pulv. |  |  | 13.39 |
|  | Peru | Miami | 90 | 136 | 52.3 | Pulv. |  |  | 26.72 |
|  | Terre Haute | Vigo | 170 | 89 | 446.0 | Pulv. |  |  | 27.20 |
| Michigan |  |  |  |  |  |  | 8.32 | 13.00 |  |
|  | Coldwater | Branch | 102 | 73 | 98 | Stoker |  |  |  |
|  | Detroit | Macomb | 212 | 19 | 132 | Pulv. |  |  | 28.00 |
|  | Escanaba | Delta | 0 | 0 | 242 | Stoker |  |  | 30.08 |
|  | Lansing | Ingham | 74 | 52 | 52 | Pulv. |  |  | 27.12 |
|  | Marysville | St. Clair | 23 | 17 | 542 | 41% pulv. |  |  | 25.79 |
|  | Wyandotte | Wayne | 5 | 4.5 | 138 | 41% pulv. |  |  | 16.65 |
| Ohio |  |  |  |  |  |  | 6.63 | 10.60 |  |
|  | Beverly | Washington | 11 | 9.5 | 436 | Pulv. |  |  | 18.35 |
|  | Brilliant | Jefferson | 2.4 | 3.4 | 551 | Pulv. |  |  | 16.36 |
|  | E. Palestine | Columbiana | 17 | 18 | 86 | Stoker |  |  |  |
|  | N. Bend | Hamilton | 7 | 6.4 | 780 | Pulv. |  |  | 18.92 |
|  | Shelby | Richland | 47 | 36 | 45 | Pulv. |  |  |  |
|  | S. Dayton | Montgomery | 60 | 49 | 755 | Pulv. |  |  | 26.11 |
|  | Springfield | Clark | 106 | 37 | 211 | 66.67% pulv.<br>33.33% stoker |  |  | 25.13 |
|  | St. Mary's | Auglaize | 98 | 88 | 71 |  |  |  |  |
| Wisconsin |  |  |  |  |  |  | 11.62 | 15.60 |  |
|  | Green Bay | Brown | 13 | neg. | 975 | Pulv. |  |  | 30.87 |
|  | Lacrosse | Lacrosse | 26 | 33 | 22 | Stoker |  |  | 20.39 |
|  | Madison | Dane | 197 | 271 | 93 | 32% pulv. |  |  | 24.44 |

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*Computed from the Stanford Research Institute data (16) after adjusting it for quantity of stover fed to livestock.

†Computed from: Steam Electric Plant Factors, National Coal Association, Washington, D. C., April 1975.

‡Custom rates from Annual Reports, Cooperative Extension Services, Land Grant Universities, 1977.

**Annual Summary of Cost and Quality of Electric Utility Plant Fuels, Bureau of Federal Power Commission, May 1977, and Steam Electric Plant Factors, National Coal Association, Washington, D. C., 1976.

**APPENDIX TABLE VI (Continued).—Summary of Key Variables Affecting Feasibility of Corn Stover as a Power Plant Fuel for Sample of Plants in North Central States (n = 53).**

| Sub-region and State | Sample Power Plant | County | Quantity of Stover (Tons/Day)* | Density of Stover (Tons/sq mi)* | Stover Capacity (Tons/Day)† | Type of Boiler† | Custom Rates ($/Ton)‡ | | Coal Prices** ($/Ton) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Stacks | Round Bale | |
| West North Central | | | | | | | | | |
| Iowa | | | | | | | 6.03 | 10.27 | |
| | Ames | Stony | 308 | 184 | 159 | 65 % pulv.<br>35 % stoker | | | 20.68 |
| | Bettendorf | Muscatine | 159 | 132 | 381 | 91 % pulv. | | | 19.06 |
| | Carroll | Carroll | 275 | 168 | 123 | Stoker | | | 18.27 |
| | Cedar Rapids | Linn | 227 | 140 | 89 | Pulv. | | | 23.43 |
| | Eagle Grove | Wright | 336 | 193 | 7 | Pulv. | | | 14.27 |
| | Pella | Marrion | 157 | 113 | 153 | Stoker | | | 13.87 |
| | | | | | | | | | 22.56 |
| | Waterloo | Black Hawk | 330 | 196 | 89 | 66.1 % pulv.<br>33.9 % stoker | | | 26.15 |
| Kansas | | | | | | | 6.20 | 11.69 | |
| | Parson | Labette | 12 | 8 | 6 | 35 % pulv. | | | |
| Minnesota | | | | | | | 5.20 | 9.75 | |
| | Austin | Mower | 227 | 295 | 20 | Pulv. | | | 31.51 |
| | Cohasset | Itasca | neg. | neg. | 1242 | Pulv. | | | 18.45 |
| | Fairmont | Martin | 350 | 688 | 51 | 32 % stoker | | | 21.72 |
| | Ortonville | Big Stone | 88 | 364 | 168 | Stoker | | | 19.27 |
| | Rochester | Olmsted | 128 | 100 | 72 | Pulv. | | | 30.93 |
| | Worthington | Nobles | 280 | 641 | 23 | Pulv. | | | 21.72 |
| Missouri | | | | | | | 6.73 | 10.34 | |
| | Henry County | Henry | 26 | 20 | 1287 | Pulv. | | | 9.09 |
| | Kansas City | Clay | 16 | 22 | 1091 | Pulv. | | | 19.03 |
| | Marshall | Saline | 83 | 62 | 107 | 62.3 % pulv.<br>37.7 % stoker | | | 23.73 |
| Nebraska | | | | | | | 6.44 | 10.30 | |
| | Alliance | Bux Butte | 7 | 6 | 63 | Stoker | | | 20.68 |
| | Fremont | Dodge | 138 | 148 | 233 | Pulv. | | | 23.54 |
| | Lincoln | Lancaster | 19 | 8 | 22 | Pulv. | | | 0 |
| North Dakota | | | | | | | 5.20 | 7.28 | |
| | Stanton | Mercer | neg. | 0.2 | 746 | Pulv. | | | 4.54 |
| | Wahpeton | Richland | 75 | 29 | 95 | Stoker | | | 9.27 |
| South Dakota | | | | | | | 5.20 | 8.58 | |
| | Sioux Falls | Minnehaha | 139 | 13 | 82 | 47.9 % pulv.<br>52.1 % stoker | | | 24.90 |

*Computed from the Stanford Research Institute data (16) after adjusting it for quantity of stover fed to livestock.

†Computed from: Steam Electric Plant Factors, National Coal Association, Washington, D. C., April 1975.

‡Custom rates from Annual Reports, Cooperative Extension Services, Land Grant Universities, 1977.

**Annual Summary of Cost and Quality of Electric Utility Plant Fuels, Bureau of Federal Power Commission, May 1977, and Steam Electric Plant Factors, National Coal Association, Washington, D. C., 1976.

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Ohio's farm families benefit from the results of agricultural research translated into increased earnings and improved living conditions. So do the families of the thousands of workers employed in the firms making up the state's agribusiness complex.

But the greatest benefits of agricultural research flow to the millions of Ohio consumers. They enjoy the end products of agricultural science—the world's most wholesome and nutritious food, attractive lawns, beautiful ornamental plants, and hundreds of consumer products containing ingredients originating on the farm, in the greenhouse and nursery, or in the forest.

The Ohio Agricultural Experiment Station, as the Center was called for 83 years, was established at The Ohio State University, Columbus, in 1882. Ten years later, the Station was moved to its present location in Wayne County. In 1965, the Ohio General Assembly passed legislation changing the name to Ohio Agricultural Research and Development Center—a name which more accurately reflects the nature and scope of the Center's research program today.

Research at OARDC deals with the improvement of all agricultural production and marketing practices. It is concerned with the development of an agricultural product from germination of a seed or development of an embryo through to the consumer's dinner table. It is directed at improved human nutrition, family and child development, home management, and all other aspects of family life. It is geared to enhancing and preserving the quality of our environment.

Individuals and groups are welcome to visit the OARDC, to enjoy the attractive buildings, grounds, and arboretum, and to observe first hand research aimed at the goal of Better Living for All Ohioans!

# The State Is the Campus for Agricultural Research and Development

Ohio's major soil types and climatic conditions are represented at the Research Center's 12 locations.

Research is conducted by 15 departments on more than 7000 acres at Center headquarters in Wooster, eight branches, Pomerene Forest Laboratory, North Appalachian Experimental Watershed, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres