DOE/CS/50005--T1-App.C-F

DE83 000369

ENERGY INPUTS AND OUTPUTS OF FUEL-ALCOHOL PRODUCTION,

APPENDICES C THROUGH F,

METHANOL FROM CELLULOSE

Prepared for the

Office of Vehicle and Engine Research and Development
U.S. Department of Energy

AC01-80CS 50005

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

April, 1982

Prepared by

JACK FAUCETT ASSOCIATES, INC.
5454 Wisconsin Avenue
Chevy Chase, Maryland 20015

and

BATTELLE-COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

TABLE OF CONTENTS

PAGE

APPENDIX

TABLE OF CONTENTS (Continued)

LIST OF EXHIBITS

LIST OF EXHIBITS (Continued)

ABBREVIATIONS

Btu	British thermal unit
bbl	barrel
bu	bushel
C	degrees centigrate
cu ft	cubic foot
d	distance
DDG	distiller's dark grains
DTE	dry ton equivalent
F	degrees Fahrenheit
gal	gallon
HHV	higher heating value
hp	high pressure
hr	hour
K	Potassium
kw	kilowatt
kwhr	kilowatthour
lb	pound
lp	low pressure
LPG	liquefied petroleum gas
M	thousand
MLRA	major land resource area
MM	million
N	Nitrogen
P	Phosphorus
psia	pounds per square inch absolute
psig	pounds per square inch gauge
ton	2,000 lb
wt	weight
yr	year

BTU CONVERSION FACTORS

Fuel	Units	HHV
Coal	Btu/ton	22,500,000[a]
Distillate	Btu/gal	140,000
Electricity Consumption	Btu/kwhr	3,413
Ethanol	Btu/gal	84,200
LPG	Btu/gal	95,000
Lubricating Oil	Btu/gal	145,000
Methanol	Btu/gal	64,350
Motor Gasoline	Btu/gal	125,000
Natural Gas	Btu/cu ft	1,020
Petrochemicals	Btu/gal	125,000
Residual Fuel Oil	Btu/gal	150,000

ELECTRICITY CONVERSION FACTOR

Fuel	Btu's consumed/Btu electricity produced
Coal	3.05

---

[a] When no specific coal characteristics were known, the energy content of a "standard ton" of coal (22,500,000 Btu) was used. Other values were used when more appropriate and are indicated in footnotes.

SI CONVERSION FACTORS

1 acre = 4046.8564 square meters
1 bbl = 158.98284 liters
1 Btu = 1054.35 joules
1 cu ft = 0.028316847 cubic meters
1 gal = 3.7854118 liters
1 lb = 453.592 grams
1 mile = 1609.344 meters
1 psi = 0.0680460 atmospheres
1 ton = 907184.74 grams
273.15 + 5/9(F-32) = degrees Kelvin
273.15 + C = degrees Kelvin

OTHER CONVERSION FACTORS

1 acre = 0.40468564 ha
1 bbl = 42 gal
1 Btu = 252 calories
1 bu barley = 48 lb
1 bu corn = 56 lb
1 bu grain sorghum = 56 lb
1 bu oats = 32 lb
1 bu wheat = 60 lb
1 psi = 6895 pascals
1 square mile = 640 acres

APPENDIX C

FOREST RESIDUES

The high Btu content and clean-burning properties of wood make it an attractive energy source. Forest residues, because of their inherent unsuitability for other uses, are particularly well-suited to be consumed for their energy content, assuming that the engineering and economic constraints are not prohibitive.

The forest products industry is currently the largest user of forest residues for fuel. Within the industry, the pulp and paper sector utilizes 92 percent of total wood energy consumed and has conducted much of the research on using wood residues for energy (Zerbe, 1978).

But despite the value of wood as a fuel, a large volume of wood fiber (1.6 billion cubic feet in 1970) is left in U.S. forests as residue from harvest operations (U.S. Forest Service, 1974). Pre-commercial cuttings, understory removal, and annual mortality are included in this estimate. These residues could be collected during normal harvesting operations using conventional harvesting equipment. They would be well-suited for conversion to methanol.

In this appendix, estimates are developed of the amount of fuel that would be consumed in the collection of forest residues, by harvest system type and by logging operation. Separate estimates are developed for both the Eastern and Western regions of the United States. The appendix concludes with a discussion of the availability of both forest residues and mill residues.

C.1 Selection of Harvest Systems

There are three types of harvest systems used in U.S. forests: a commercial timber harvest, a commercial thin, and a stand improvement thin. In each of these systems, all or portions of a tree may be available for conversion to alcohol. Any harvested wood could be cut into half-inch diameter chips usable as feedstock for alcohol conversion processes. Definitions of each of the harvest systems are provided below.

Commercial Timber Harvest and Commercial Thin. A commercial harvest or thin is the harvest of timber for sawlogs, pulpwood, and/or veneer logs. In a commercial harvest, an entire area is cleared of trees. In a commercial thin, only selected trees are cut for sale or consumption. Only 2.5 percent of commercial forest land is subject to commercial thins (OTA, 1980).

Most forest products manufacturing operations require just a portion of the tree, specifically the stem, or "merchantable bole," for use as raw material. It is that portion of the stem, four inches or more in diameter, that is of commercial value (Howlett and Gomache, 1977). The tree is initially cut at the base above ground (very little whole-tree pulling of stumps and roots is employed), and then the entire tree is transported (skidded) from the felling site to a landing. There the tops and branches are removed (delimbing) and left behind.

An average of 35 percent of the above-ground tree weight represents residue (15 percent in bark; 20 percent in foliage, tops, and branches) (Howlett and Gomache, 1977). After harvesting, the foliage, tops, and branches could be chipped into smaller pieces either at the landing site or at the plant.

Stand Improvement Thin. Stand improvement thinning (i.e., the selective removal of small or inferior trees) is practiced by foresters seeking to improve conditions for growing commercial stock. Typically, 40 percent of the forest stand will be thinned, creating additional growing space for the higher quality trees (OTA, 1980). The increased availability of sunlight, water, and nutrients allows for more rapid growth of the remaining trees and, thus, leads to increased biomass production. Dead, diseased, and inferior quality trees are cut, skidded to a landing, and then chipped. Currently, only 1.8 percent of commercial forest lands are treated with timber stand improvement practices (OTA, 1980).

C.2 Selection of Sites

After consultation with foresters across the country, two regions were selected for analysis: the West (Arizona, Western Alaska, Western South Dakota, Nevada, New Mexico, Utah, Montana, Idaho, Colorado, Wyoming, Oregon, Washington, Northern California), and the East (forested areas east of the Dakotas). The energy consumed in harvest operations will vary somewhat by terrain, tree species, soil type, slope, stem diameter, other environmental conditions, and equipment operating efficiencies. Unfortunately, detailed energy consumption data are not kept by most forest industry companies. Typically, the only records available are total annual fuel consumed and total annual tons, cords, or cubic feet harvested. The state of the art in forestry record keeping does not provide or permit a detailed breakdown.

Within the two large regions, differences in energy input requirements arise from the utilization of different equipment for different terrains. The major differences occur in the equipment and methods used in the skidding function. In the East, skidders are used to move trees from the felling site to a landing. Cable yarders are used in the West, where slopes exceed 30 percent.

C.3 Energy Consumption Estimates

This section discusses the methods and data used to estimate energy inputs to the collection of forest residues.

C.3.1 Literature Review

Although much information is available on forest residues as an energy source, little hard data exist on the energy consumed in the field. A number of U.S. Forest Service Experiment Stations around the country were contacted for information on forest operation requirements. The Northwest Experiment Station and the Northcentral Experiment Station were the only two Forest Service Stations that have conducted detailed energy analyses on the harvesting of residues. However, the American Pulpwood Association (APA) surveyed member operations in 1975 to determine the fuel consumed in typical harvesting operations. The data developed were average figures for the South, the Northeast and the Lake States. In addition, the Southwide Energy Committee has published information on petroleum product consumption in systems used for energy wood harvesting in the South. To fill in the gaps and improve on these data sources, harvesting managers, equipment manufacturers, private logging contractors, and forest product companies throughout the country were contacted to obtain information on harvesting operations.

C.3.2 Elements of the Net Energy Balance

The three different harvesting systems (commercial harvest, commercial thin, and stand improvement thin) were analyzed in order to determine the energy required to obtain forest residues. Energy inputs were assessed for the specific operations and equipment types within each harvest system. For the commercial harvest and commercial thin systems, only those operations required for obtaining residues were counted in the energy analysis. That part of the forest operation attributable to obtaining sawlogs was not included (i.e., felling, skidding, and delimbing in the East, and felling, cable yarding, and delimbing in the West). For stand improvement thins, the energy used in harvesting the tree was counted in the energy analysis.

The primary energy consuming elements of each of the three harvest systems are:

Harvesting. This includes felling of the tree, transport of the entire tree from the felling site to a landing, delimbing of tops and branches at the landing, and loading onto a truck. In the East, manual systems are used just as extensively as mechanized systems. For felling and delimbing, manual systems use chain saws; mechanized systems use feller-bunchers and mechanical slashers. For the most part, manual systems are also used in the West. In the East, transporting the wood to the landing is done by skidders. In the West, cable yarders are used because the land is generally steeper. A description of the equipment follows (Corcoran, 1976):

•	Chain Saw:	A portable, gasoline powered, manually controlled machine with a toothed chain used to fell trees and remove limbs.
•	Feller-Buncher:	A mobile machine that holds a tree by means of a clamp and cutting head, shears it at the stump, then swings and deposits the tree onto a pile on the ground.
•	Cable Yarder:	A cable hauling system used in transporting trees from the felling site to a landing under steep conditions. The system consists of a hoist with two or more winches

powered by an internal combustion engine. Wire ropes are wound along the winches and spun up a tower. The wire ropes are cabled across the skyline. A carriage equipped with hooks travels along this wire. A log is then hooked and lifted up, enabling it to be cabled back along the wires to a landing.

- Skidder: A tractor unit equipped with a winch or grapple that gathers and skids loads of full trees, tree length boles or logs behind itself from the stump area to a roadside landing.

- Loader: A hydraulically operated boom and grapple used to gather logs or tree lengths for loading onto a truck.

Chipping. Chipping entails feeding the stems and branches resulting from a commercial harvest of thin or whole trees, or from a stand improvement thin operation, into a chipper unit. In Eastern operations, the wood is either chipped and blown into storage piles which are later loaded into vans, or the chips are blown directly into vans. These vans then transport the green wood chips to the plant. In Western operations, chipping usually occurs at the plant because it is more economical to load the large diameter trees onto trucks for transport.

- Chipper: A machine that cuts logs and tree-length wood to small chips of a 1/2 inch diameter by means of a rotating drum or disc, carrying a series of blades. The chips leave the cutting device (in an air-stream induced by the fan effect of the chipping mechanism) and are automatically conveyed into transport vehicles or stockpiles.

Transportation from Harvest Site to Plant. Wood is hauled by truck over an average 100-mile round trip for both Eastern and Western operations with a full load of 19.13 tons.

Miscellaneous Activities. This includes energy consumed in crew transport, maintenance vehicles, repair equipment, and supervision.

C.3.3 Assumptions

Differences in energy consumption were not determined for softwood stands versus hardwood stands. Data found in a study that estimated total energy production and consumption for these types of stands show that the differences are minimal and would not justify a breakdown of this nature (Pimentel, 1980). For this analysis, a mixed hardwood-softwood stand is assumed generating an average of 7.5 dry tons of residues per acre for the East (282 cu ft/acre) and 14.4 dry tons of residues per acre for the West (2,248 cu ft/acre) (Howlett and Gamache, 1977). Thus, to generate the 2,000 dry tons of residues per day required by the conversion facility, 267 acres must be harvested in the East and 139 acres in the West.

The energy expended in the manufacture of the various pieces of equipment is not included in the energy inputs. Only the fuel consumed in operating the equipment while harvesting and transporting wood to the plant is considered.

Manual labor is not taken into consideration nor are any other factors required to produce a ton of dry wood. Chipping and chainsaw requirements are assumed not to differ between regions (Bulkholder, 1981) or harvest methods (Corcoran, 1977). This is also true for the fuel consumed per ton-mile in trucking residues to the plant.

Data provided as units per green ton were assumed at 50 percent moisture content. Data provided as cords presented a problem: a cord of wood is a volume measure of 128 cu ft of piled round wood that can differ in dry weight from about 1,900 lb to 3,500 lb (Smith and Corcoran, 1976). An average 1.5 DTE per cord (Smith and Corcoran, 1976) was used whenever data were provided in units per cord. The actual average ton per cord number may be lower. However, such a difference would not be significant in contrast to the energy consumed in transporting residues from the forest to the plant.

The energy used to fell, delimb, and transport trees to a landing in a commercial harvest or thin is assigned to the commercial wood. The practice of stand improvement thinning, however, presents a more difficult problem in the assignment of energy costs. At present, stand improvement thinning for the purpose of improving the growing conditions for the more merchantable trees is performed on only a limited number of acres of commercial forest land (1.8 percent of the total). Dead trees, or those otherwise unacceptable for use as sawlogs or in the production of paper products, are felled and skidded out of the woods so that they do not impede the harvest of the commercially acceptable trees.

However, when the unacceptable trees are thinned out to allow the commercially usable trees to flourish, the energy consumed in felling and skidding the dead trees must be assigned to harvesting the commercial trees and not to the energy costs of using the thinned out wood for methanol production or some other use. If the dead or commercially poor trees are removed specifically for their use as fuel, for particle board fabrication, or as a forest residue feedstock for methanol production, then it would be valid to assign the energy costs in thinning to that specific end use.

Our analysis of stand improvement thinning as a feedstock source for methanol conversion includes the energy consumed in felling and skidding the unacceptable or dead trees based on the assumption that thinning is not practiced to improve the in-woods growing conditions (though this would be a beneficial side effect). In those cases where the economic value of the thinned out wood and improving the growing conditions for the remaining commercial trees motivates the decision to thin, then the energy costs should properly be shared between inputs to harvesting the commercial trees and using the thinned wood. Where foresters only thin to improve in-woods growing conditions, the energy consumed in thinning should only be assigned to harvesting the commercial trees.

C.3.4 Energy Input Estimates

The energy input estimates calculated for the collection of forest residues by harvest system, by operation, and by region are presented in Exhibit C-1 and Exhibit C-2. Exhibit C-3 provides a summary table of energy consumed in all the systems. Amounts are expressed in Btu's per dry ton equivalent (DTE) and in gallons per DTE. Diesel fuel is the primary fuel for all equipment except chainsaws, which are powered by gasoline.

Since both are widely used, manual systems and mechanized systems are included in data shown for stand improvement thins in the East. Only manual systems are considered for the West due to complications that arise using mechanized systems on steep slopes.

Assumptions and data sources are listed with the tables. Where more than one data source is used for a particular operation, an average number is calculated.

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	1 cord green wood = 1.5 DTE							
	7.5 dry tons forest residues generated per acre (828 cubic feet per acre) (2)							
• COMMERCIAL THIN OR COMMERCIAL HARVEST								
— Chipping	Chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal of diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal of diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
TOTAL	COMMERCIAL THIN OR HARVEST		2.83				396,460	396,460

Sources

(1) APA, 1975.
(2) Howlett and Gomache, 1979.
(3) Burkholder, personal communication, 1981.
(4) Tillman, 1978.
(5) Smith and Corcoran, 1976.
(6) U.S. Forest Service - PNW Experiment Station, 1980.
(7) Knapton, 1981.
(8) U.S. Forest Service — NC Experiment Station, 1978.
(9) Southwide Energy Committee, 1980.

*Includes the following states: ME, NH, VT, MA, CT, RI, DE, MD, NJ, NY, PA, WV, MI, ND, SD (east), WI, IL, IN, IA, KS, KY, MN, MD, NB, OH, NC, SC, VA, FL, GA, AL, MS, TN, AR, LA, OK, TX

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Manual System								
— Felling	Trees felled by chainsaws used at the stump — chainsaw energy requirements: (5),(1),(9)	0.286					35,750	35,750
— Skidding	1,831 feet = skidding distance (1) — skidder energy requirements: (4),(5),(1)		0.622				87,080	87,080
— Delimbing	Trees delimbed at landing with chainsaws — chainsaw energy requirements: (5),(1),(9)	0.281					35,125	35,125
— Chipping	Trees chipped at landing — chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Miscellaneous	Crew transport, supervision, maintenance		0.40				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MANUAL SYSTEM	0.57	3.85				610,415	610,415

Sources

See the first page of this exhibit.

EXHIBIT C-1: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE EASTERN UNITED STATES*

(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Mechanized System								
— Felling	Trees felled by feller-buncher — feller-buncher energy requirements: (1),(5),(8),(9)		0.436				61,040	61,040
— Skidding	1,831 feet = skidding distance (1) — skidder energy requirements: (1),(4),(5),(9)		0.622				87,080	87,080
— Delimbing	Trees delimbed by a mechanized slasher unit — slasher energy requirements: (1)		0.580				81,200	81,200
— Chipping	Trees chipped at landing — chipper energy requirements: (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Transportation by Truck	50 miles full x $\frac{\text{0.2361 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{\text{0.1902 gal diesel}}{\text{mile}}$ x $\frac{1}{\text{19.13 tons}}$ x $\frac{\text{2 tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Miscellaneous	Crew transport, supervision, maintenance		0.40				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MECHANIZED SYSTEM		4.87				681,780	681,780

Sources

See the first page of this exhibit.

EXHIBIT C-2: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE WESTERN UNITED STATES*

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	1 cord green wood = 1.5 tons							
	14.4 dry tons forest residues generated per acre (2,248 cubic feet per acre) (2)							
• COMMERCIAL THIN OR COMMERCIAL HARVEST OPERATION								
— Loading	Knuckleboom loader loads sawlogs onto trucks — energy requirements: (5)		0.342				47,880	47,880
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Unloading	Knuckleboom loader unloads sawlogs from (5) truck		0.342				47,880	47,880
— Chipping	Wood chipped at the plant — chipper energy requirements: (1),(2),(3),(4),(5),(6)		0.609				85,260	85,260
TOTAL	COMMERCIAL THIN OR HARVEST		3.51				492,220	492,220

Sources

(1) APA, 1975.
(2) Howlett and Gomache, 1979.
(3) Burkholder, personal communication, 1978.
(4) Tillman, 1978.
(5) Smith and Corcoran, 1976.
(6) U.S. Forest Service — PNW Experiment Station, 1980.
(7) Knapton, 1981
(8) Southwide Energy Committee, 1980.
(9) U.S. Forest Service — NC Experiment Station, 1978.
(10) Linda Ferguson, John Mandzak, and Max Ekenburg, personal communications, 1981.
(11) Linda Ferguson, personal communication, 1981.

*Includes the following states: AK (coastal), OR, WA, CA, ID, MT, SD (west), WY, AZ, CO, NM, NV, UT

EXHIBIT C-2: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES FOR A COMMERCIAL THIN, COMMERCIAL HARVEST, AND STAND IMPROVEMENT THIN OPERATION IN THE WESTERN UNITED STATES*

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• STAND IMPROVEMENT THIN								
— Manual System								
— Felling	Trees felled by chainsaws at the stump - energy requirements: (1),(5),(8)	0.286					35,750	35,750
— Yarding	Cable-yarders skid trees to landing site — 1831 feet = skidding distance — energy requirements: (11)		0.507				70,980	70,980
— Delimbing	Trees delimbed at landing with chainsaws — energy requirements: (1),(5),(8)	0.281					35,125	35,125
— Loading	Knuckleboom loader loads sawlogs onto trucks — energy requirements: (5)		0.342				47,880	47,880
— Transportation by Truck	50 miles full x $\frac{0.2361 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		1.23				172,200	172,200
	50 miles empty x $\frac{0.1902 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{19.13 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.99				139,000	139,000
— Unloading	Knuckleboom loader unloads sawlogs at plant (5)		0.342				47,880	47,880
— Chipping	Sawlogs chipped at plant (1),(3),(4),(5),(6)		0.609				85,260	85,260
— Miscellaneous	Crew transport, supervision, maintenance		0.400				56,000	56,000
TOTAL	STAND IMPROVEMENT THIN: MANUAL SYSTEM	0.57	4.42				690,075	690,075

Sources

See the first page of this exhibit.

EXHIBIT C-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF FOREST RESIDUES: SUMMARY OF ALL SYSTEMS

Region	Operation	Petroleum Products						
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
• EASTERN UNITED STATES	—Commercial Thin or Commercial Harvest		2.83				396,460	396,460
	—Stand Improvement Thin: Manual System	0.57	3.85				610,415	610,415
	—Stand Improvement Thin: Mechanized System		4.87				681,780	681,780
• WESTERN UNITED STATES	—Commerical Thin or Commercial Harvest		3.51				492,220	492,220
	—Stand Improvement Thin: Manual System	0.57	4.42				690,075	690,075

Specific Inputs. Transportation is by far the largest energy consuming element in the process of collecting residues for alcohol feedstock. The importance of this element can be seen in each harvest system energy analysis, as presented in Exhibits C-1 and C-2.

Chipping is the only other significant energy consuming operation for commercial cuts. Regional differences in energy consumption for chipping result from the way residues are collected. The additional energy required to load and unload stems and trees for Western commercial harvest systems causes the energy differences between East and West. Western forest product companies are currently experimenting with chippers on site. If the use of in-woods chipper units increases in the future, the differences between the two regions could disappear.

The combined operations of transporting wood from the felling site to the landing and chipping the residues account for a significant portion of the energy costs for stand improvement thins. For manual systems in the East, approximately 32 percent of total inputs is consumed by skidders and chippers. In a mechanized system, the equipment consumes 28 percent of the total energy. Cable yarders and chippers account for approximately 25 percent of the total energy consumed for manual thin operations in the West. These figures would only change by 2.5 to 3.0 percentage points if either the lowest energy consumption in chipping figure reported was used (65,500 Btu per DTE reported by Tillman, 1978) or the highest consumption figure was used (104,000 Btu per DTE reported by U.S. Forest Service — PNW, 1980). The change in these percentage figures would be negligible for skidders since data reported were very consistant.

Mechanized harvesting systems require 10 percent more energy than manual systems. This is due to the fuel needed to power mechanized slashers and feller-bunchers.

C.3.5 Possibilities For Reduced Energy Consumption

It is expected that the figures represented in the tables will decrease in the future due to the implementation of energy-conserving techniques. Forest product companies are promoting and implementing fuel-saving activities such as the matching of optimum engine size (horsepower) with level of operation required for a job, increased maintenance of equipment, and reduction of unnecessary engine idling.

C.4 Potential Availability of Residues

Logging Residues

The amount of logging residues available vary greatly by region (Exhibit C-4). The total above-ground forest residue produced in 1970 was estimated at 83 million DTE (Inman, 1977). Large volumes are produced in the West, particularly in the old-growth forests of Oregon, Washington, and northern California. Timber harvesting in those forests generates large amounts of debris. However, use of this excess material by regional pulp and fiberboard industries has progressed slowly because of the availability of lower cost mill residues from lumber and plywood industries (Quinney, 1975).

The largest volumes of logging residues are generated in the South, but these unused materials are not concentrated in accessible areas (i.e., at any given site, only small volumes are generated) (Quinney, 1975). As a result, these residues are not economical to collect. In addition, the Southern pulp and paper industry is increasing its use of the whole tree which will further limit the availability of residues.

The residues left unused from logging operations in the East can amount to substantial quantities, but in general they are widely scattered and probably could not economically support a methanol conversion facility. (Quinney, 1975).

Increased utilization of logging residues depends on two factors. First, the expansion of the pulp and paper industry has increased demand for wood fiber. Therefore, competition may exist in some regions between use of the residues for pulp and use of the residues for energy.

Second, a portion of the logging residues should remain on the forest floor to ensure adequate nutrient replenishment. This amount will differ by tree species, age, and soil. Excessive removal of residues could result in soil-nutrient depletion, thus causing a decline in total biomass production. Nutrients might then be needed in the form of manufactured fertilizers (Hall, 1980).

EXHIBIT C-4: SUMMARY OF LOGGING AND MILLING RESIDUES (BY REGION) IN THE U.S. (10^3 DTE) — 1970[a]

Region[b]	Logging Residues					Mill Residues (Wood and Bark)		Total Unused Residues
	Wood[c]	Bark[d]	Tops and Branches[e]	Stump-Root System[f]	Total	Total	Unused	
Northeast	3,451	608	5,248	9,832	19,139	6,600	2,300	21,439
North Central	2,253	397	5,550	9,554	17,754	6,400	2,100	19,854
Southeast	6,684	1,179	10,152	21,066	39,081	11,400	4,500	43,581
South Central	6,552	1,167	12,560	26,084	46,363	16,700	4,600	50,963
Pacific Northwest	7,249	1,279	9,833	24,467	42,828	27,800	4,200	47,028
Pacific Southwest	1,876	331	2,730	6,729	11,666	8,800	3,300	14,966
Northern Rocky Mountain	1,337	236	2,027	5,125	8,725	6,600	2,100	10,825
Southern Rocky Mountain	351	63	665	1,625	2,704	1,800	1,000	3,704
Total U.S.	29,753	5,260	48,765	104,482	188,260	86,100	24,100	212,360

(a) Source: Hall et al. (1980), data adapted from Inman (1977).

(b) Regions are defined as follows: Northeast - Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania and West Virginia. North Central - Michigan, Minnesota, North Dakota, South Dakota (East), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska and Ohio. Southeast - North Carolina, South Carolina, Virginia, Florida and Georgia. South Central - Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma and Texas. Pacific Northwest - Oregon, Washington and coastal Alaska. Pacific Southwest - California and Hawaii. Northern Rocky Mountain - Idaho, Montana, South Dakota (West) and Wyoming. Southern Rocky Mountain - Arizona, Colorado, Nevada, New Mexico and Utah.

(c) Figures include both growing stock and non-growing stock.

(d) Bark estimated as 15 percent of total weight of wood and bark.

(e) Tops and branches, including foliage, estimated as 15 percent of the sum of: timber harvested (including bark), total residues from growing stock and non-growing stock volume.

(f) Assumes that stump-root systems represent 25 percent of total tree biomass. Includes only stump-root systems of commercial species 5 inches or more in diameter at breast height.

Mill Residues

Total mill residues generated in the U.S. in 1970 were estimated at about 86 million DTE (Exhibit C-4). This figure includes only residues generated in the manufacture of lumber, plywood, and miscellaneous wood products, such as shingles, pilings, and posts. Mill residues can provide a ready source of energy, if available. However, approximately 75 percent of these residues were used for some purpose in 1970. Approximately 56 percent of the residues were used for non-energy products, primarily wood pulp, and the remaining 19 percent were either used as fuel within the forest products industry or sold.

Demands for mill residues are apt to increase rapidly as the forest products industry continues to move towards energy self-sufficiency. In any case, this source is not likely to be available for energy use outside of the forest products industry, except in relatively limited local situations.

APPENDIX D

SILVICULTURAL BIOMASS FARMS

Energy farms and energy farming represent technologies for expanding the biomass resource "pie" to accommodate the production of alternative energy supplies. Energy production is the primary purpose of these farms: biomass is grown and harvested specifically for its energy content. Biomass crops include trees, corn, sugar cane, sorghum, and ocean kelp. These can either be burned directly as fuel or be converted into various synthetic fuels. In many respects, the energy farm concept is similar to the application of intensive agricultural practices to crops grown for food. Under intensive management systems, energy farm sites are extensively prepared and short-rotation[1] energy crops are planted, fertilized, irrigated, and harvested using methods and equipment that have close analogs in conventional agricultural operations.

As yet, silvicultural energy or biomass farms have not been demonstrated in the U.S. However, other countries, particularly Canada and Sweden, have extensively evaluated and are actively pursuing the application of short-rotation forest harvesting to meet national energy needs. In Sweden, where oil imports account for 70 percent of their total energy supply, a large-scale program is under development to practice short-rotation forestry on as much as five percent of Sweden's total land area (Pettersson, 1980). Canada, with its large biomass production capability per capita (i.e., large productive land mass/small population), has a significant potential for energy plantations. The biomass grown on an energy plantation would be used to generate electricity (Middleton et al., 1976).

A silvicultural biomass farm can be characterized as the planting of selected, rapidly growing hardwood or softwood tree species at close spacings (MITRE, 1977a). The tree crop is harvested at intervals, or rotations, ranging from 2 to 10 years (depending on the species growth characteristics) over the expected lifetime of the farm facility. Short-rotation forestry offers the following advantages for energy farming (MITRE, 1977a; Fege, Inman, and Salo, 1979):

---

[1] *Short-rotation refers to the harvesting of crops over short intervals of time, e.g., every 2 to 10 years for trees without replanting. A new rotation refers to a new growth cycle following harvesting, not to a new crop being planted.*

- high yields per unit land area during juvenile growth;
- lower land requirements for a given yield;
- early returns on initial investments;
- labor efficiency through mechanization;
- harvest efficiency, through the application of field crop production practices; and
- the ability to take advantage of cultural and genetic advances quickly.

As conceptualized by MITRE (1977a), intensive crop management practices would be applied on a silvicultural biomass farm. These practices would include fertilization, irrigation, and weed control. A largely mechanized harvest system would be employed to remove the above ground biomass without affecting the sprouting capacity of the stumps and to minimize land damage. Other units would be used to convert, transport, and store a year-round supply of biomass in a form compatible with the selected conversion technology.

Silvicultural biomass farms, because they are managed to maximize energy production, yield substantially more biomass per unit area than conventionally managed forests. Part or all of this difference in production could be devoted to alcohol fuels production without reducing our capacity to meet current and near-term fuel wood and forest products industry needs. The Department of Energy has estimated that 1,480 dry tons of wood per day would be needed to produce 50 million gallons of methanol per year (Segal, 1979). At productivity levels of 5 tons per acre-year, one acre of forest land would produce 460 gallons of methanol. In order to obtain enough methanol for a 10 percent mixture with the 100 billion gallons of gasoline consumed in the United States, some 22 million acres of forest land production would be needed per year. This is 3 percent of the total current forest acreage in the U.S. (740 million acres) (Segal, 1979; OTA, 1980). Approximately 65 percent of all forest land in the U.S. is classified as commercial, i.e., produces at least 20 cubic feet per acre-year (OTA, 1980).

In this appendix, the energy inputs for the growing, harvesting, and processing of wood feedstocks for conversion into alcohol fuels are identified on the basis of a conceptualized operation of a silvicultural biomass farm.

D.1 Selection of Species

The impact silvicultural biomass farms will have as an alternative energy source will depend on two factors. The first is biomass productivity, i.e., the yield per unit time and area (MITRE, 1977a). Productivity varies as a function of the species planted, the cultural practices used, and site conditions (i.e., soil characteristics, climate, etc.). Species selection, site management, and to some extent site conditions can be altered, within certain biological limits, in order to meet biomass quantity and quality objectives.

Correct species selection is particularly important. Selection criteria include rapid early growth, ease of establishment and regeneration, wide geographical distribution, and resistance to major insect and fungal pests. Perennials are preferred since they can be harvested almost continually throughout the year, permitting more efficient use of machinery and manpower (although there is some loss in productivity if the harvest occurs throughout the year rather than at the end of the growth season). Hardwoods are preferred due to their ability to coppice (i.e., sprout from stumps). Regeneration through coppicing precludes the need for replanting a new tree crop after each harvest and also makes possible propagation by cloning (Szego et al., 1978). Many of these same species, however, have limited site adaptability. Species-site compatibility, therefore, must be carefully evaluated. Ultimately, the most critical selection criterion is the ability to produce high yields under the conditions specified by site location. Exhibit D-1 lists those hardwood and softwood species considered to be best candidates for use in silvicultural biomass farms and describes the limits of their geographical ranges.

Actual yields for a given species on a given site would depend on stand density and management intensity, but studies across many species indicate that yields of 2 - 12 dry tons equivalent (DTE) per acre per year may now be possible and future yields of 15 - 20 DTE per acre per year are expected (MITRE, 1977a; Fege, Inman, and Salo, 1979). One candidate species in particular, Populus, has been the subject of several productivity studies and, as a result, has been selected as the candidate species for this analysis. (Populus includes eastern and black cottonwoods and various hybrid poplars). Bowersox and Blankenhorn (1979), in their survey of the literature and from their experience with dense plantation cultures, concluded that annual productivity of 2 dry tons/acre could be expected for a wide range of sites and Populus parentages in the northeastern United

EXHIBIT D-1: RANGES OF CANDIDATE SPECIES FOR SILVICULTURAL BIOMASS FARMS

Species	Range
American sycamore	All states east of the Great Plains except Minnesota.
Eucalyptus spp.[1]	Generally frost-free areas of the Southeast and California.
Loblolly pine	Coastal Plain and Piedmont from Delaware and Central Maryland south to Central Florida and west to eastern Texas.
Populus spp.[1]	
Eastern cottonwood	Southern Quebec and Ontario to southeastern North Dakota, south to western Kansas, western Oklahoma, southern Texas, northwestern Florida, and Georgia.
Black cottonwood	South along the Pacific Coast from Kodiak Island and southeastern Alaska to mountains in southern California. Eastward into southwestern Alberta, south-central Montana, central Idaho, northern Utah and Nevada.
Sweetgum	Connecticut southward throughout the East to central Florida and eastern Texas. It is found as far west as Missouri, Arkansas and Oklahoma, and north to southern Illinois.
Tulip-poplar	Throughout the eastern U.S. from southern New England west to Michigan and south to central Florida and Louisiana.
Red alder	Confined to the Pacific Coast region from southeastern Alaska south through Washington, northern Idaho, and western Oregon to Santa Barbara, California.

Source: MITRE, 1977a.

[1] Spp. = Species

States. Close to 3 dry tons/acre could be achieved, without fertilizer or irrigation, by carefully selecting optimum sites and parentage stocks best suited to those sites (Bowersox and Blankenhorn, 1979).

As mentioned above, silvicultural biomass farming can produce successive crops without replanting (at least for a maximum of 10 years). Yields of successive rotations are difficult to predict, but coppice crop yields can be expected to be as large or larger than first rotation yields. The number of sustained yield rotations and the yields that are possible depend on several factors (Bowersox and Blankenhorn, 1979):

(1) initial tree density at planting,
(2) the number of years per rotation, and
(3) the investment in fertilizer and irrigation.

As a rule of thumb, increasing the planting density necessitates a decrease in the rotation length.[1] For Populus, maximum rotation length is believed to be no more than 3 to 5 years for a maximum of 4 to 5 rotations per planting. A possible harvesting strategy of 3 years, 3 years, then 4 years has been suggested for short rotations of Populus (Bowersox and Blankenhorn, 1979).

As yet there are only data for yields from two rotations of Populus. Blankenhorn and Bowersox (1980) report average annual yields for second rotation crops for dense stands of Populus (in the absence of fertilizer and irrigation) of 4 to 5 dry tons per acre per year, which are double the first rotation yields of 2 dry tons per acre per year. Fertilizing and/or irrigating the stand could further increase yields to 5 dry tons per acre per year in the first rotation and up to a maximum of 8 dry tons per acre per year for 3, 4, or more rotations.

To maintain site productivity for several rotations, fertilization and irrigation is necessary (Bowersox and Blankenhorn, 1979). Whole-tree harvesting every 3 to 5 years can deplete upper and lower soil nutrients. These nutrients must be replaced either by the application of fertilizers and/or by returning parts of the tree that have nutrient value (for example, harvesting after leaf fall). Bowersox and Blankenhorn (1979) estimate that fertilization alone could produce a 20 percent increase per year in productivity, irrigation alone a 5 percent increase per year, and fertilization and

---

[1] *T. Bowersox, personal communication, 1980.*

irrigation together, a 30 percent increase per year. As yet, no side-by-side productivity studies have actually been completed on only fertilized vs. only irrigated vs. fertilized and irrigated dense stands.[1]

D.2 Site Selection

Land availability and suitability operates as the second important controlling factor. Unlike biomass productivity, the availability of land for energy farming can be only partially influenced by changes in technology.[2] Instead, socio-economic factors are far more influential, as they determine the balance between competing land uses (including energy farming) and future trends in the supply and demand for land.

Four criteria have been suggested for designating suitable sites for silvicultural biomass farms (MITRE, 1977c; Szego et al., 1978):

- at least 25 inches of precipitation per year;
- a slope no greater than 30 percent (17 degrees) to allow mechanized crop management;
- arable land, i.e., Soil Conservation Service (SCS) land classes I-IV; and
- areas with a population density less than 300 persons per square mile.

In Section D.5, these criteria are applied towards estimating the potential silvicultural biomass farm resources available for the production of methanol fuels. MITRE's (1977a) analysis indicated that 50 percent of the potentially available land for silvicultural biomass farming was located in the Southeast. Our analysis has therefore been performed for a silvicultural biomass farm on an optimum site (i.e., one which meets all suggested criteria) in the southeastern United States. In cases where MITRE's (1977c) energy input data are used, their data for a site in Louisiana are chosen as representative of the Southeast region.

D.3 Selection of a Management System

The operation and design of a silvicultural biomass farm is affected by the feedstock demands of the conversion technology. In this case, the desired feedstock is green wood

---

[1] *Ibid.*

[2] *Investments in fertilizer and irrigation can reduce acreage requirements in some instances up to 50 percent (MITRE, 1977d).*

chips less than one inch in diameter. The quantity required for the methanol conversion facility described in Appendix F is 730,000 dry tons per year or 1.4 million green tons per year (assuming a 50 percent wet weight moisture content). At productivity levels of 4 - 12 dry tons per acre-year, these feedstock demands require planting 20,000 - 60,000 acres each year to be harvested after 3 years.[1]

To produce these yields and annual growth levels envisioned for silvicultural biomass farms, it is most likely that intensive management practices, similar to those applied in field crop production, will have to be used. These would include extensive site preparation, mechanized planting, and fertilizing and irrigating the stand. Other options, such as harvesting naturally growing vegetation at a site for its energy value, do not require cultivating, planting, fertilizing, and irrigating the site. However, yields under the so-called "caretaker" system are much less (2 - 3 dry tons per acre-year maximum for Populus). Intensive management offers the opportunity to select high-yielding tree species that are well adapted to a site. These trees can then be planted at a density that facilitates mechanized harvesting and according to a schedule designed to produce a year-round supply of biomass feedstock (Szego et al., 1978). Tree age, size, form, and structure are kept uniform.

For the present analysis, needed planted acreage is calculated on the basis of an average yield of 21 dry tons per acre under intensive management after 3 years growth. This is based on the selection of 7 dry tons per acre per year as the maximum sustainable yield from data presented by Bowersox and Blankenhorn (1979). A total of 107,000 acres is required for the biomass farm at the selected optimum site. Eventually, 105,000 acres will be planted in three 35,000 acre plots to supply 2,000 dry tons per day (730,000 DTE per year). A total of 2,000 acres is assumed to be needed for roads and irrigation lanes (i.e., 2 percent of planted acreage, MITRE, 1977c).

The first step is to clear and prepare the land for planting. This includes clearing the land of its current plant growth (which might be usable as feedstock), tilling the soil, applying fertilizers and lime to correct soil nutrient deficiencies, applying herbicides to control weeds, and building the needed road and irrigation system networks. The next phase is to plant the prepared acreage with seedlings or cuttings of the selected species. These seedlings are grown in nurseries and are planted either manually or by

---

[1] *Actual total farm acreage would be higher with the addition of needed acreage for irrigation lanes, storage areas, and the needed road network.*

using a mechanized tree planter. Seedlings are planted only in the first year of each 10 year cycle. Successive crops arise by coppicing. How these seedlings are spaced when they are planted, however, is important in determining the growth and productivity of the stand throughout its lifetime. They must be planted close enough to produce a dense canopy of leaves, but not so close that seedlings must compete for light and nutrients. Seedling spacings of 1' x 4', 2' x 4', and 4' x 4' (as measured within and between each row) have been suggested as most productive (U.S. EPA, 1978). This corresponds to 10,900; 5,450; and 2,725 plants per acre, respectively. It is also suggested that plantings be staggered for the initial years of farm operation and over each planting year so that subsequent harvests are also staggered. This is done to provide the desired year-round supply of harvestable biomass feedstock (MITRE, 1977a).

The analysis presumes use of Populus in a 4 foot by 4 foot planting density. Bare root seedlings are planted by mechanized tree planters as the site is prepared. A three-year rotation length is chosen on the basis of Bowersox and Blankenhorn's (1979) data showing a maximum annual growth increment at 3 years for Populus hybrids. A ten year maximum period before replanting each 35,000 acre unit is also established from their data (i.e., 3 crops harvested per planted unit). Herbicides and pesticide applications would also be made, but needed amounts are very much site, species, and situation dependent. Therefore, no amounts have been specified (MITRE, 1977c; Bowersox and Blankenhorn, 1979).

With an intensive system, cultivation after planting includes applying nitrogen, phosphorus, and potassium fertilizers and supplemental irrigation water. How often and how much fertilizer and irrigation water should be applied depends on the site conditions, the species planted, and to some extent, when and how often the trees are harvested.[1]

Since the amount of fertilizer needed depends on the species planted and specific site conditions, it is difficult to generalize to a fertilization scheme (Bowersox and Blankenhorn, 1979). For analysis purposes, it is assumed that each 35,000 acre plot is fertilized:

---

[1] *MITRE (1977a) examined 10 possible silvicultural biomass farm sites in the U.S. With the only exception being agricultural land sites in California, needed irrigation amounts were established at an average of one acre-foot per acre per year irrigating over the first three years of each rotation (equal to 6 years in their analysis).*

(a) annually with 89 lb per acre of nitrogen as liquid urea (46 percent nitrogen);

(b) only for the first year of each rotation with 89 lb per acre of potassium as potassium chloride (but normalized as 60 percent K_2O); and

(c) only for the first year of each rotation with 89 lb per acre of phosphorus as concentrated superphosphate (46 percent P_2O_5).[1]

These amounts represent two-thirds the quantities needed for corn crops.[2]

Enough fertilizer for a three year period (10,133 tons of liquid urea; 2,590 tons of potassium chloride; and 3,378 tons of concentrated superphosphate) is assumed to be transported by truck over a distance of 100 miles from a production facility also located in the Southeast region. All fertilizer applications are made during the growing season. Mechanical sprayers are used to apply all fertilizers needed in the first year of each rotation. Nitrogen fertilizer applications for the second and third years of each rotation are combined with applications of irrigation water.

Irrigation water would be applied following a schedule and in amounts compatible with the site's climate and yearly precipitation. Automatic sprinkler (traveller) systems, fogger nozzle systems, flood irrigation, and drip systems have been suggested as possible irrigation systems for silvicultural biomass farms (MITRE, 1977a; Bowersox and Blankenhorn, 1979). For the southeastern site analyzed here, it is assumed that irrigation will be performed at a level of 326,000 gallons of water per acre per year over the 120 day growing season of each year of each rotation (MITRE, 1977c).[3] Precipitation is assumed to provide sufficient moisture for the rest of the year.

A traveller sprinkling system is selected because each unit needed (MITRE, 1977c):

---

[1] *Values based on Bowersox and Blankenhorn's (1979) analysis assuming a fertilizer requirement of 200 lb of nitrogen, phosphorus, and potassium for a 10,000 acre farm.*

[2] *T. Bowersox, personal communication, 1980.*

[3] *Irrigation needs would actually have to be established for each site. MITRE (1977c) established these numbers as representative for their 10 sites analyzed (except California) and their numbers have been used here.*

- requires only one man to operate;
- is adaptable to a wide range of field sizes and shapes;
- is easy to transport;
- has a wide range of travel speeds and application rates;
- is capable of a uniform application within a 200-foot watering radius; and
- is adaptable to rolling or irregular topography.

Each traveller system consists of a pump, power unit, main supply pipe, flexible irrigation hose, four-wheeled traveller unit, and sprinkler. Drawing water from one or several main supply pipes, each traveller unit is drawn down the 10 - 12 foot wide irrigation lanes by a cable reeled in from a fixed point. Traveller units are moved around the site by tractors.

The final stage is harvesting the tree crop. This is a highly mechanized process involving equipment specially designed to harvest most of the above-ground biomass, leaving an undamaged stump able to coppice. MITRE (1977c) proposed harvesting during the winter months when the trees are dormant in order to take advantage of the last productive year of growth per rotation and to avoid adversely affecting the regeneration of the next crop. Compared to year-round harvesting, however, shortening the harvesting season to the winter months would require:

- more equipment to harvest the same acreage;
- a year without a harvest with every 10 year replanting cycle since replanting cannot start until spring of the following year;
- additional yields, to compensate for losses in storage;
- on-site storage for stockpiling the harvested feedstock supply until used; and
- 25 percent more fuel for the harvesting equipment, due to the effect of winter operations on fuel consumption (Southwide Energy Committee, 1980).

Therefore, a year-round, staggered planting-harvesting schedule has been assumed. Harvesting of each planted unit is assumed to occur at a rate of 96 acres per day which produces the needed daily yield of 2,000 dry tons. Harvesting operations are based on an 8 hour day, 7-day week, and 52-week year. Since the feedstock is produced at the rate it is used, minimal on-site storage is needed. Replanting each 35,000-acre plot is assumed to occur as the third coppice crop is harvested. This schedule is depicted in Exhibit D-2. In actual operation, planting operations would have to be compressed to correspond to the planting season. Therefore, harvesting operations for the third coppice crop must be adjusted to compensate.

For any type of woodland operation, several factors are critical to the selection of a harvesting method (Koch, 1980): (a) terrain feature, (b) soil characteristics, (c) weather, (d) stand density, (e) tree diameter distribution, (f) species mix, (g) the scale of the harvesting operation, (h) tract size, and (i) the purpose for which the trees are harvested, i.e., for fuel, pulpwood, wood products, or chemical products. Considering the large tract sizes envisioned for a single species silvicultural biomass farm where stand density is high and the tree diameter distribution is fairly uniform but small (less than 8 inches after 3 to 4 years growth), a whole-tree harvesting system seems best suited for producing the needed quantity and quality of wood feedstock.

There are two types of whole-tree harvesting systems: chipping at the stump and chipping at the landing. Choosing between these systems depends to a large extent on harvesting costs and efficiency. Production rates and harvesting costs are highly dependent on tree diameter (Plummer, 1977). With three to four year rotations for each crop, tree diameters may reach a maximum of 8 inches depending on the species, but probably will average 4 inches or less. This is in contrast to diameters of 12 to 20+ inches after the rotation lengths of 30 or more years common to commercial forestry operations where the trees are harvested for pulpwood or wood products. For a whole-tree chipping system common to pulpwood operations (utilizing feller-bunchers, grapple skidders, and a whole-tree chipper at a landing), the number of cords processed per hour drops dramatically as the tree diameter declines, while the cost per cord increases (Plummer, 1977). Such a system, clearly, would not prove economical for a silvicultural biomass farm operation of the type we have described. Instead, a whole-tree system utilizing a mobile harvesting unit which fells and chips the smaller trees at the stump would seem to be a more economical and efficient harvesting method. Such a system would be similar to the use of combines in conventional agricultural operations in cutting a swath two planted rows in width through the planted tract.

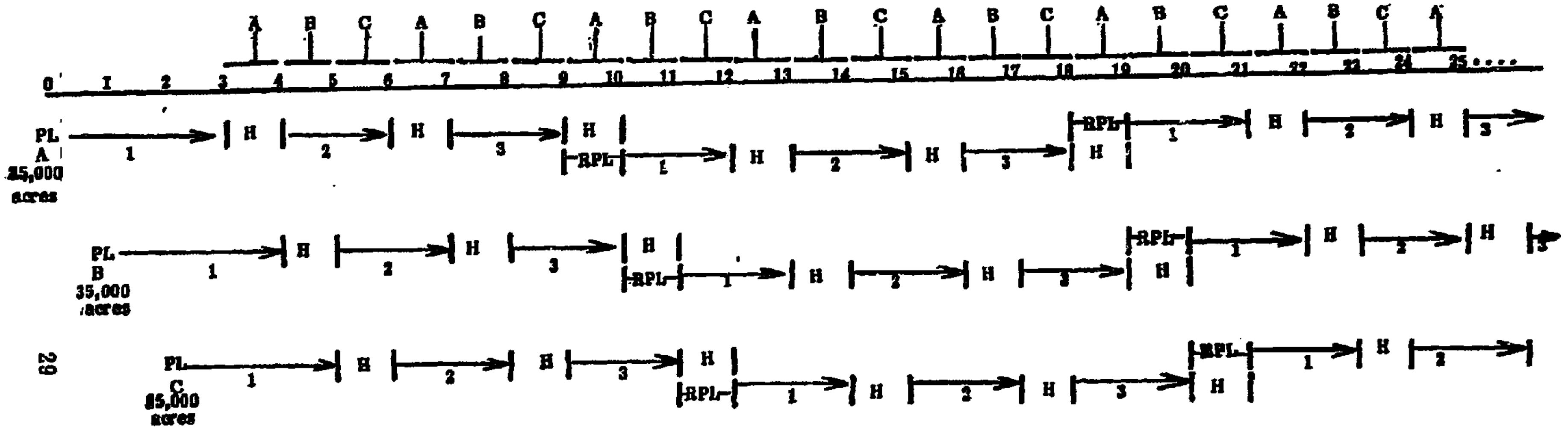
Such a chip-at-stump system has therefore been assumed in the present analysis. Besides being able to produce more tons (or cords) per hour than a chip-at-landing system for trees sized 8 inches or less, a chip-at-stump system also minimizes field traffic and

EXHIBIT D-2: PROPOSED PLANTING HARVESTING REPLANTING SCHEDULE FOR A SILVICULTURAL BIOMASS FARM BASED ON A THREE YEAR ROTATION PERIOD, YEAR ROUND HARVESTING, AND A MAXIMUM OF TEN YEARS BEFORE REPLANTING

Total Farm Acreage: 107,000 acres in three 35,000 acre plots
Total Planted Acreage: 105,000 acres

Production: 470,000 green tons/yr., 735,000 dry tons/yr.
Average Yield/Acre After 3 Yrs. Growth: approx. 21 tons/acre

Harvest of 735,000 dry tons/year at a rate of 2,000 dry tons/day from plots A, B, and C (=96 acres per day)



KEY: PL = site preparation and planting
H = harvesting, year round at rate of 96 acres/day
RPL = replanting
1 = first growth
2 = second coppice crop
3 = third coppice crop

Assumes: harvesting each crop after 3 year intervals at a rate of 96 acres/day, 365 days/yr. — after 10 years, each plot is replanted as the third coppice crop is gradually harvested therefore soil disturbance and can be designed to operate at close spacings. The number of harvester units needed is estimated to be 23 on the basis of the following equation derived by MITRE (1977c):

$$\text{units needed} = C \times \frac{P_a}{MAI \times R \times S \times W \times HPS \times FE \times LE}$$

where:

C = 8.25, the reciprocal of 0.1212, the number of acres in a swath one foot wide and one mile long

P_a = annual production = 730,000 DTE per year

MAI = mean annual growth increment = 7 DTE per acre per year

R = rotation length = 3 years

S = harvester speed = 1 mph (Koch, 1980)

W = swath width = 8 feet (2 rows at 4 ft spacing)

HPS = working hours per harvest season = 2,920 hours

FE = field efficiency = 0.60

LE = labor efficiency = 0.09

(Note: MAI, S, HPS, and FE are all site dependent)

This figure agrees with calculated equipment needs of 20 - 24 mobile harvesters estimated from reported production capacities for first generation harvesters of 12 - 15 dry tons of biomass per hour (96 - 120 tons per 8 hour shift) (Koch, 1980). Unfortunately, only a few mobile harvester/chipper units have been built and tested under field conditions. None of these field conditions have corresponded to dense, short-rotation plantations (Koch, 1980).[1] As a result, data on fuel consumption rates and production rates are limited. This will change with further testing, but, for the time being, this limited data must be supplemented with fuel consumption figures for a chip-at-landing system.

These mobile harvesters cut and chip the whole trees and blow these chips into trailing chip forwarder vehicles. Two, 10-ton capacity, quick-dump chip forwarders are

---

[1] *J. Odair, personal communication, 1980.*

harvester units, 48 forwarders would be needed to transport chips to temporary storage areas at the gasification plant.

The wood gasification plant is assumed to be located at the center of the surrounding 107,000-acre silvicultural biomass farm site. This minimizes feedstock transportation costs. The average, one-way, harvesting-site-to-plant transportation distance is calculated to be 5 miles.[1] Alternative plant site locations would necessitate the use of highway tractor-trailers to transport the wood chips to the gasification plant.

Other process components include feedstock storage and drying. Storage areas can be located at several places on the farm site or on the gasification plant site. In this analysis, storage and feedstock drying take place at the gasification facility.

Finally, labor is used throughout, particularly during the land preparation and planting stages (although the energy used in labor is not considered in this analysis). Overall, less labor is needed for a silvicultural biomass farm than for a conventional forestry operation. Also included in the operation of a biomass farm (but not considered as energy inputs) are such miscellaneous operations as planning, supervision, maintenance, field support/supply, and crew transport. The biomass farm described above forms the basis for evaluating energy inputs in the next subsection.

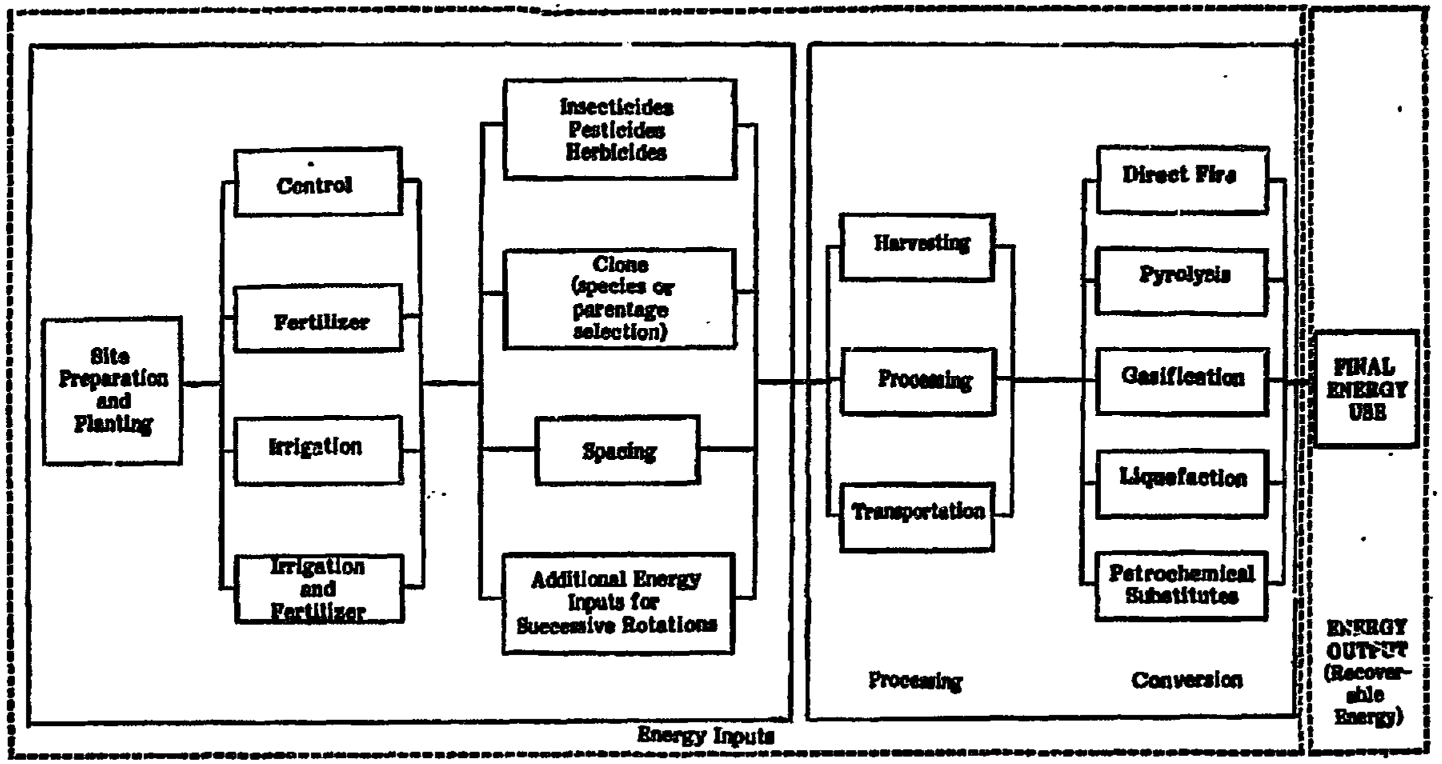
D.4 Energy Consumption Estimates

Exhibit D-3 illustrates the elements of a net energy analysis for a silvicultural biomass farm managed under an intensive system. In estimating the petroleum and nonrenewable fuel inputs to silvicultural biomass farm operations, this analysis has distinguished between "primary" and "secondary" inputs. The tables that follow present consumption estimates for only the primary inputs, that is, the fuels consumed by the equipment used in each operation and fuels consumed in the manufacture of fertilizers. Labor inputs and energy consumed in the manufacture of the equipment used are considered to be secondary inputs.

---

[1] *If the 107,000 acre biomass farm site is seen as a circular area, the average distance from all points within that area is two-thirds of the radius r.*

EXHIBIT D-3: NET ENERGY ANALYSIS OF AND INTENSIVELY MANAGED SILVICULTURAL BIOMASS FARM



NET ENERGY = ENERGY OUT - ENERGY IN

Adapted from: Bowersox and Blankenhorn, 1979.

D.4.1. Literature Review

A search conducted of the current literature for estimates of energy inputs in biomass farm operations revealed two types of data sources. The first type was fuel consumption data for harvesting wood for pulp and paper use, such as the 1975 American Pulpwood Association (APA) fuel use survey and reports from the Southwide Energy Committee (SEC) (1980). The APA reported average fuel consumption figures for typical harvesting operations based on surveys of member operations in the South, Northeast, and Lake States. The Southwide Energy Committee presented similar data for pulpwood harvesting operations in the southeastern United States. Supplemented by data from contacts with forest product companies and equipment manufacturers, APA and SEC data have been used for representative fuel consumption rates for silvicultural biomass farm harvesting operations. It should be recognized, however, that wood harvesting operations for pulp and paper uses are not directly comparable to the operation visualized for a silvicultural biomass farm. Harvesting a uniform and dense stand of trees that grow to a maximum of 4 to 8 inches in diameter requires different equipment needs, design, and operation than harvesting widely spaced, 22-inch diameter trees after at least 30 years of growth. These differences were reflected in the biomass harvesting system selected.

Other sources of energy consumption estimates were analyses of conceptualized silvicultural biomass farm designs. The most important of these were a series of MITRE reports and the more recent analyses of Bowersox and Blankenhorn et al. The design and operation of the silvicultural biomass farm analyzed is based on selected elements taken from those reports. MITRE's reports defined the operational characteristics and parameters of a biomass farm and the potential availability for silvicultural biomass farms in the United States. Bowersox and Blankenhorn provided information on sustainable productivity with and without fertilizers and irrigation, maximum rotation lengths, and estimated energy inputs for several proposed silvicultural biomass farm operations.

D.4.2. Energy Input Estimates

Exhibits D-4 and D-5 show primary nonrenewable energy input estimates for the silvicultural biomass farm operations described above. The table below shows that fertilizing and irrigating the biomass farm site are the two major energy consuming

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION*

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SITE PREPARATION								
— Land Clearing	Clear land of a natural timber stand with brush growth — growth chipped and burned for process fuel — use gallon per ton consumption figure for a chain saw used in the woods at the stump — (1)	0.13					16,250	16,250
— Tilling and Other Soil Preparation	Medium site preparation using a 200 horsepower shear blade tractor and 150 horsepower root rake tractor — (2)							
	Shear Tractor: 2 acres/hour 10 gal diesel fuel/hour 5 gal diesel fuel/acre		0.24				33,600	33,600
	Root Rake Tractor: 1 acre/hour 7 gal diesel fuel/hour 7 gal diesel fuel/acre		0.33				46,200	46,200
TOTAL	SITE PREPARATION	0.13	0.57				96,050	96,050

Sources

(1) Southwide Energy Committee, 1980.
(2) Georgia Forestry Commission, 1980.

* Utilization per ton figures shown were calculated on the basis of a final yield of 21 ovendry tons per acre after 3 years of growth producing a total of 735,000 dry tons per year (at a rate of 2,000 dry tons per day) for each 35,000 acre planted unit.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION
(Continued)

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• PLANTING								
	65 horsepower crawler tractors pulling a medium duty tree planter — (3)							
	1.25 acres/hour 1.75 gal diesel fuel/hour 1.40 gal diesel fuel/acre		0.07				9,800	9,800
TOTAL	PLANTING		0.07				9,800	9,800

Sources

(3) Georgia Forestry Comm'ssion, 1980.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FERTILIZER								
— Manufacture	N applied as liquid urea which is 46 percent nitrogen — apply 89 lb N per acre per year — equals 4673 tons nitrogen over 3 years and 10,133 tons liquid urea — (4)			0.02	381	0.002	2,994	421,314
	K applied as muriate of potassium which is 60 percent K_2O — apply 89 lb K_2O per acre *for only the first year of each* rotation or 148 lb muriate of potassium per acre equals 1,558 tons K_2O and 2,590 tons muriate of potassium over 3 years — (4)			<.0001	4	0.0004	<.0001	14,080
	P applied as concentrated superphosphate (CSP) which is 46 percent P_2O_5 — apply 89 lb P_2O_5 per acre *for only* the first year of each rotation or 193 lb CSP per acre — equals 1,558 tons P_2O_5 or 3,378 tons CSP over 3 years — (4)	0.0001	0.0005	0.02	21	0.002	3,094	74,484
— Application	Mechnical sprayer used to apply fertilizers needed in first year of each rotation only — fertilizers all applied at once — uses 0.25 gal diesel fuel per acre — (5) — due to density of stand in second and third years of the rotation, sprayers cannot be used — applied as mixture with irrigation water		0.01				1,400	1,400

<u>Sources</u>

(4) Bowersox and Blankenhorn, 1979; MITRE, 1977a.
(5) Blankenhorn, Bowersox, and Murphy, 1978.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FERTILIZER								
— Transportation	Every 3 years need to transport to farm site a total of 16,101 tons of fertilizer — over 3 years apply total of 920 lb fertilizer/acre							
	Liquid urea: 10,133 tons							
	Potassium Chloride: 2,590 tons							
	CSP: 3,378 tons							
	Transporting chemical and allied products by truck involves an energy input of 2,930 Btu's diesel fuel per ton-mile with an average load of 18 tons — assume fertilizer transported a distance of 100 miles		0.04				5,660	5,660
TOTAL	FERTILIZER	0.0001	0.051	0.04	388	0.004	13,058	313,770

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
● IRRIGATION								
	Automatic sprinkler (traveller) system to irrigate the stand over a 120 day growing season each year of the rotation							
— Moving the Traveller Unit	0.65×10^9 Btu diesel fuel consumed per year produce 250,000 dry tons per year — (6) — converts to 2,600 Btu's diesel fuel/dry ton		0.02				2,600	2,600
— Traveller Unit Operation	112×10^9 Btu energy consumed per year to produce 250,000 dry tons/year or 448,000 Btu/dry ton — (6) — assume all is diesel fuel		3.2				448,000	448,000
TOTAL	IRRIGATION		3.22				450,600	450,600

Source

(6) MITRE, 1977c.

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• HARVESTING AND CHIPPING								
	Mobile harvester/chipper consumes 15 gal diesel fuel per hour, operates 8 hours per day, 365 days per year to harvest 96 acres/day — equals 1.25 gal diesel fuel/acre		0.06				8,400	8,400
TOTAL	HARVESTING AND CHIPPING		0.06				8,400	8,400

EXHIBIT D-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK PRODUCED FROM A SILVICULTURAL BIOMASS FARM OPERATION

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• FORWARDING OF WOOD CHIPS								
	Chip forwarder trailing harvester/chipper consumes 2.4 gal diesel fuel/hour — (7) — operates 6 hours per day, 365 days per year to harvest 96 acres per day — equals 0.15 gal diesel fuel per acre		0.007				980	980
	chip forwarder transporting chips to plant site (8)							
	5 miles full x $\frac{0.50 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{10 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{DTE}}$		0.50				70,000	70,000
	5 miles empty x $\frac{0.40 \text{ gal diesel}}{\text{mile}}$ x $\frac{1}{10 \text{ tons}}$ x $\frac{2 \text{ tons green wood}}{\text{acre}}$		0.40				56,000	56,000
TOTAL	FORWARDING		0.91				126,980	126,980

<u>Sources</u>

(7) Southwide Energy Committee, 1980.
(8) APA, 1975.

EXHIBIT D-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON WOOD FEEDSTOCK FROM A SILVICULTURAL BIOMASS FARM: SUMMARY OF ALL ENERGY INPUTS

Energy Consuming Element		Petroleum Products						
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SITE PREPARATION		0.13	0.57				96,050	96,050
• PLANTING			0.07				9,800	9,800
• FERTILIZER								
— Manufacture		0.0001	0.0005	0.04	386	0.004	6,058	509,778
— Transport			0.04				5,600	5,600
— Application			0.01				1,400	1,400
• IRRIGATION			3.2				450,600	450,600
• HARVESTING AND CHIPPING			0.06				8,400	8,400
• FORWARDING			0.91				126,980	126,980
TOTAL	ALL ENERGY INPUTS	0.13	4.86	0.04	386	0.004	704,888	1,208,608

components of the operational design analyzed, accounting for 43 percent and 37 percent, respectively, of total energy consumed (in Btu per dry ton). In contrast, the energy consumed in either planting or harvesting the tree crop accounts for only one percent of the total.

Energy Consumed in Each Farm Operation Category

Operation Category	Btu per dry ton of wood	Percent of total
Site Preparation	96,050	7.9
Planting	9,800	0.8
Fertilizer	516,778	42.8
Irrigation	450,600	37.3
Harvesting/Chipping	8,400	0.7
Forwarding	126,980	10.5
TOTAL	1,208,608	100.0

Considering differences in assumptions and design, these results agree well with other analyses of energy inputs to silvicultural biomass farm operations. MITRE (1977c) also considered only primary energy inputs in its analysis, because estimates by Alich and Inman (1974) showed that the energy inputs in equipment manufacture accounted for only a small fraction of total inputs. In MITRE's analysis of a site in Louisiana, total energy expended per dry ton of wood feedstock was calculated to be 1,108,320 Btu (relative to producing 250,000 DTE per year). Of this total, the energy consumed in irrigating the site with a traveller unit accounted for 40 percent. Energy consumed in the manufacture of the fertilizer made up 37 percent of the total energy consumed per dry ton of feedstock. Energy requirements for harvesting were less than 3 percent of the total. The only major difference between our analyses and MITRE's was in the energy consumed in transporting the harvested biomass from field storage to the conversion plant. MITRE (1977c) attributed 6 to 7 percent of the total energy consumed to this operation. The design analyzed in the present study, which assumes that the gasification plant is located at the center of the farm site, minimizes the feedstock transportation distance. Transportation of the feedstock, depending on distance, can represent almost 50 percent of the total energy input (Smith and Corcoran, 1976).

Blankenhorn, Bowersox, and Murphy (1978) also established energy input figures for a conceptualized silvicultural biomass farm operation following a 10-year growth and harvest cycle. Again, the energy consumed in fertilizer manufacture and application accounted for a significant fraction (67 percent) of the total energy consumed by an intensive system. Fuel energy requirements for site preparation, planting, and harvesting represented 32 percent of the total. Only 0.5 percent of the total energy consumed could be attributed to equipment manufacturing inputs. Irrigation of the site was not included in their analysis.

D.4.3 Possibilities For Reduced Energy Consumption

Perhaps the largest energy savings from the analysis above would result from the substitution of animal wastes or treated sewage for manufactured fertilizers. As shown in the preceding tables, 48 percent of the total energy inputs to a silvicultural biomass farm operation is consumed in the manufacture of fertilizers. The use of animal wastes or municipal sewage would significantly reduce this energy input, provided that the fuel energy consumed in transporting these materials to the site did not outweigh the reductions gained. Another possibility would be to grow nitrogen fixing plants among the trees.

D.5 Potential Silvicultural Biomass Farm Resources Available

The location of silvicultural biomass farms operation will be influenced by a variety of factors, including the economics of competing land uses, decisions concerning the use and management of national forest lands, and the costs associated with transporting the feedstock to the gasification plant. The only regions of the country where biomass farms would probably not be located are the Mountain States, the Southwest, and California. Actual site selection would require a site-by-site compatibility analysis such as that performed by MITRE (1977c) in selecting ten representative sites.

Location of the gasification plant at the center of the biomass farm site, as assumed in the above analysis, minimizes feedstock transport costs and fuel consumption.

In evaluating land suitable for silvicultural biomass farms, MITRE (1977c) developed six land availability "scenarios." The most likely sources of land for such farms were found to be included in their Scenarios 2 and 3. Scenario 2 consisted of all permanent pasture, forest and range land in Soil Conservation Service (SCS) capability classes I-IV[1]; Scenario 3 consisted of the same lands plus all rotation hay and pasture land, hayland

and openland formerly cropped in these four classes. Both scenarios exclude present cropland. The two scenarios contain 270 and 320 million acres, respectively, with nearly half the acreage located in the southeastern United States (Production Regions 2, 3, and 6).

MITRE conservatively estimated that only 10 percent of the total could be devoted to silvicultural biomass farms. Exhibit D-6 summarizes the total land areas available and estimated biomass yields which could be obtained if MITRE's scenarios were followed. Exhibits D-7 through D-9 show the distribution of these land areas and yields across nine United States farm production regions.

Szego et al. (1978) estimated available land for energy plantations at 175 million acres using criteria which

(1) excluded prime cropland, commercial forest, pasture, range and recreational land;

(2) lands west of 101st meridian except for the western slopes of the Pacific coastal mountains (areas receiving less than 20 inches of precipitation per year); and

(3) areas where population density exceeded 300 people per square mile.

Szego et al. (1978) did not apply the assumption that only 10 percent of this total possible land area would be available.

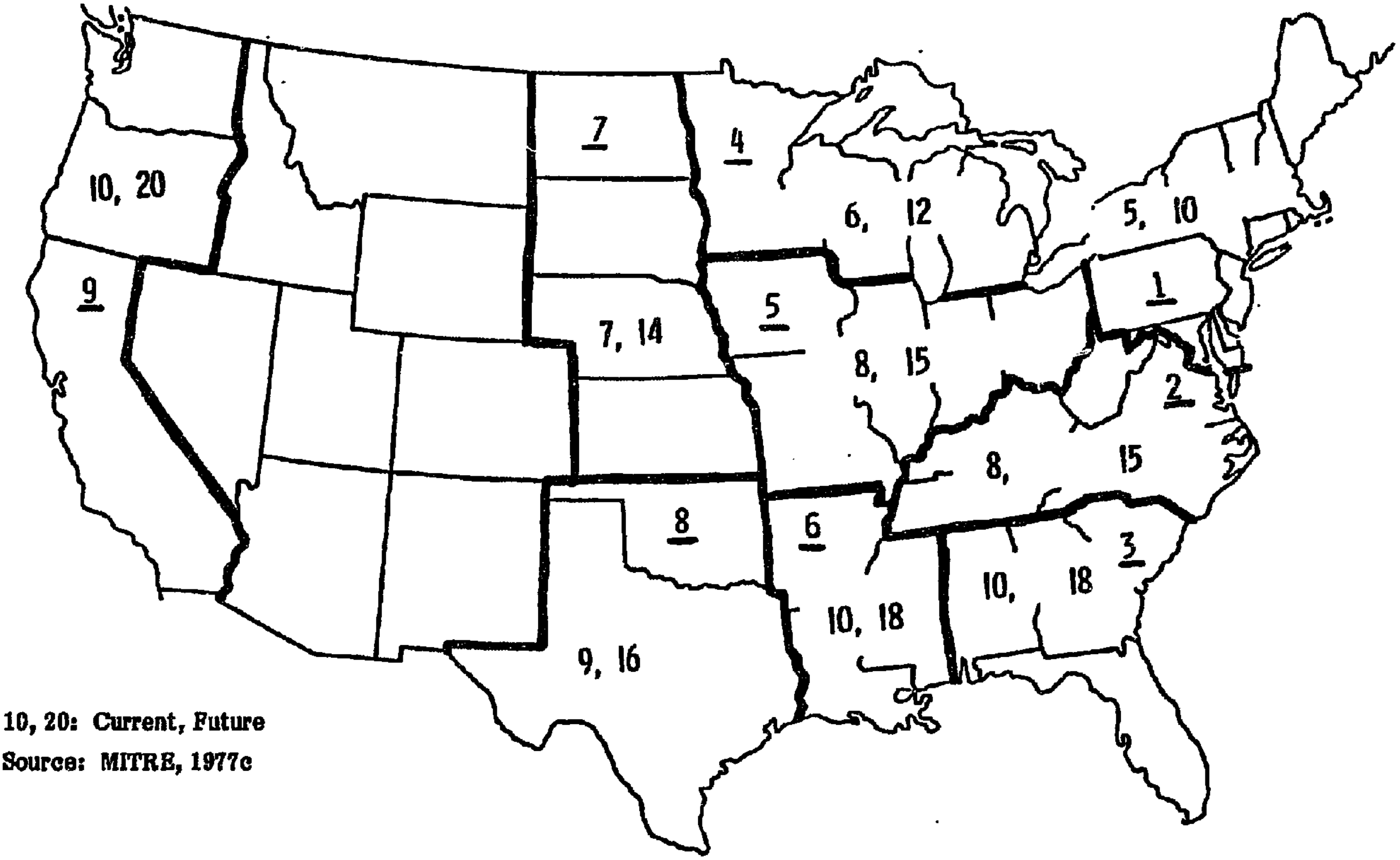
As urban and suburban expansion continues, however, the supply of land available for all other uses including energy farming will decrease. This may be offset somewhat by the increased use of more marginal lands (along with selecting more adaptable, less site demanding species) provided that the investment in more intensive cultivation results in adequate, economical, biomass yields (U.S. EPA, 1978).

EXHIBIT D-6: LAND AREA AND PROJECTED FEEDSTOCK YIELD (IN DRY TONS PER YEAR) FROM 10 PERCENT OF THE AREA IN THE TWO MOST LIKELY LAND AVAILABILITY SCENARIOS FOR SILVICULTURAL BIOMASS FARMS

	Total Land Area Available (millions acres)	Wood Feedstock Yield From 10% of This Total Land Area (millions of dry tons/year)	
		Current	Future
SCENARIO #2 SCS Classes I-IV: Forest, Pasture, Range	268.3		
Production Region			
1	29.0	14.5	29.0
2	36.5	29.2	54.8
3	51.1	51.1	92.0
4	33.5	20.1	40.2
5	28.5	22.8	42.8
6	35.2	35.2	63.4
7	6.5	4.6	9.1
8	42.3	38.1	67.7
9	5.6	5.6	11.2
SCENARIO #3 SCS Classes I-IV: Forest, Pasture, Range Rotation Hay/Pasture Hayland, Open Land Formerly Cropped	324.5		
Production Region			
1	38.0	19.0	38.0
2	43.8	35.0	65.7
3	53.0	53.0	95.4
4	44.9	26.9	53.9
5	44.1	35.3	66.2
6	38.0	38.0	68.4
7	9.1	6.4	12.7
8	46.4	41.8	74.2
9	7.2	7.2	14.4

Source: MITRE, 1977c.

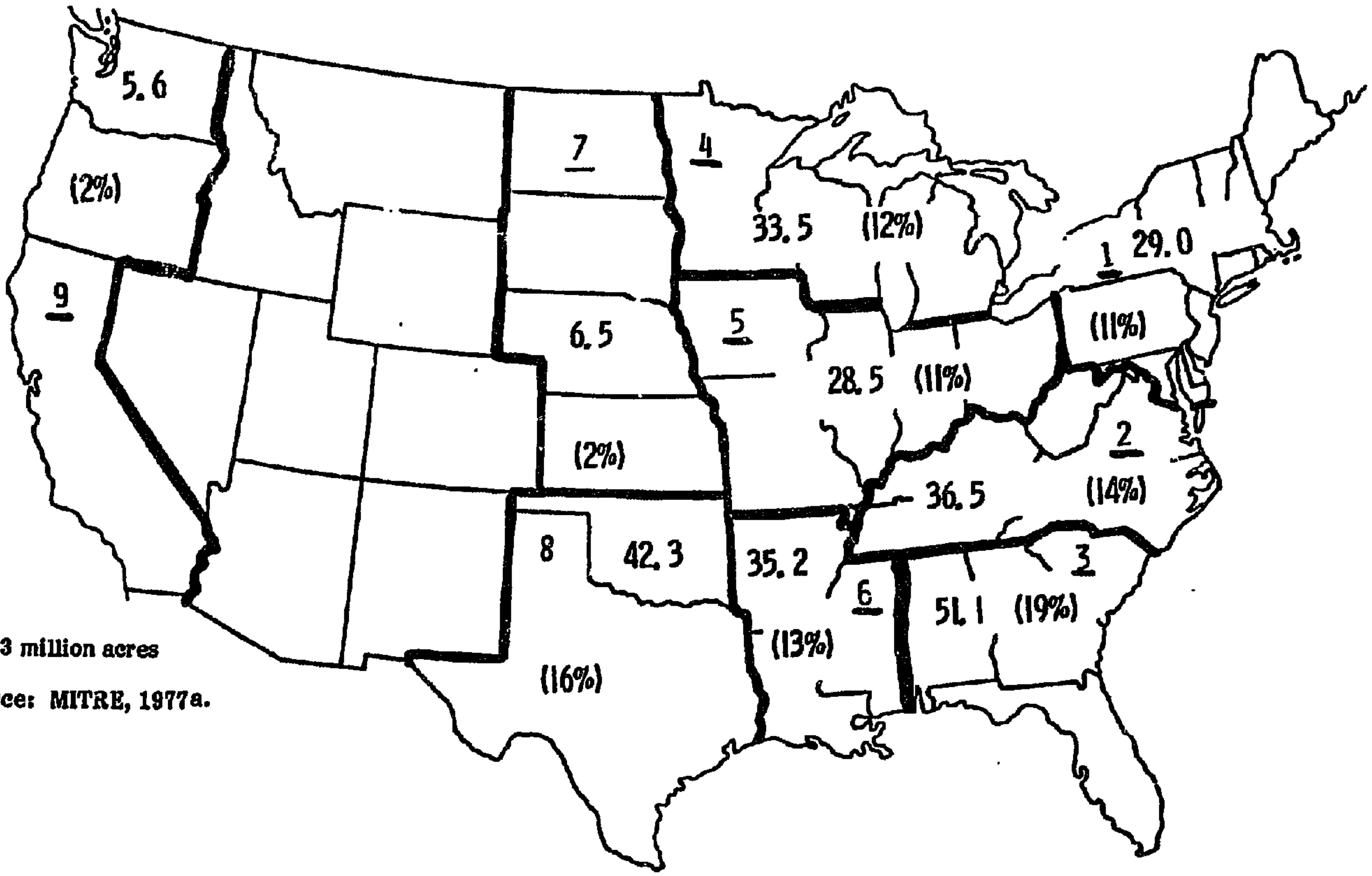
EXHIBIT D-7: ESTIMATED CURRENT AND FUTURE BIOMASS YIELDS ON SILVICULTURAL BIOMASS FARMS IN FARM PRODUCTION REGIONS 1-9.
(Dry tons per acre per year)



10, 20: Current, Future

Source: MITRE, 1977c

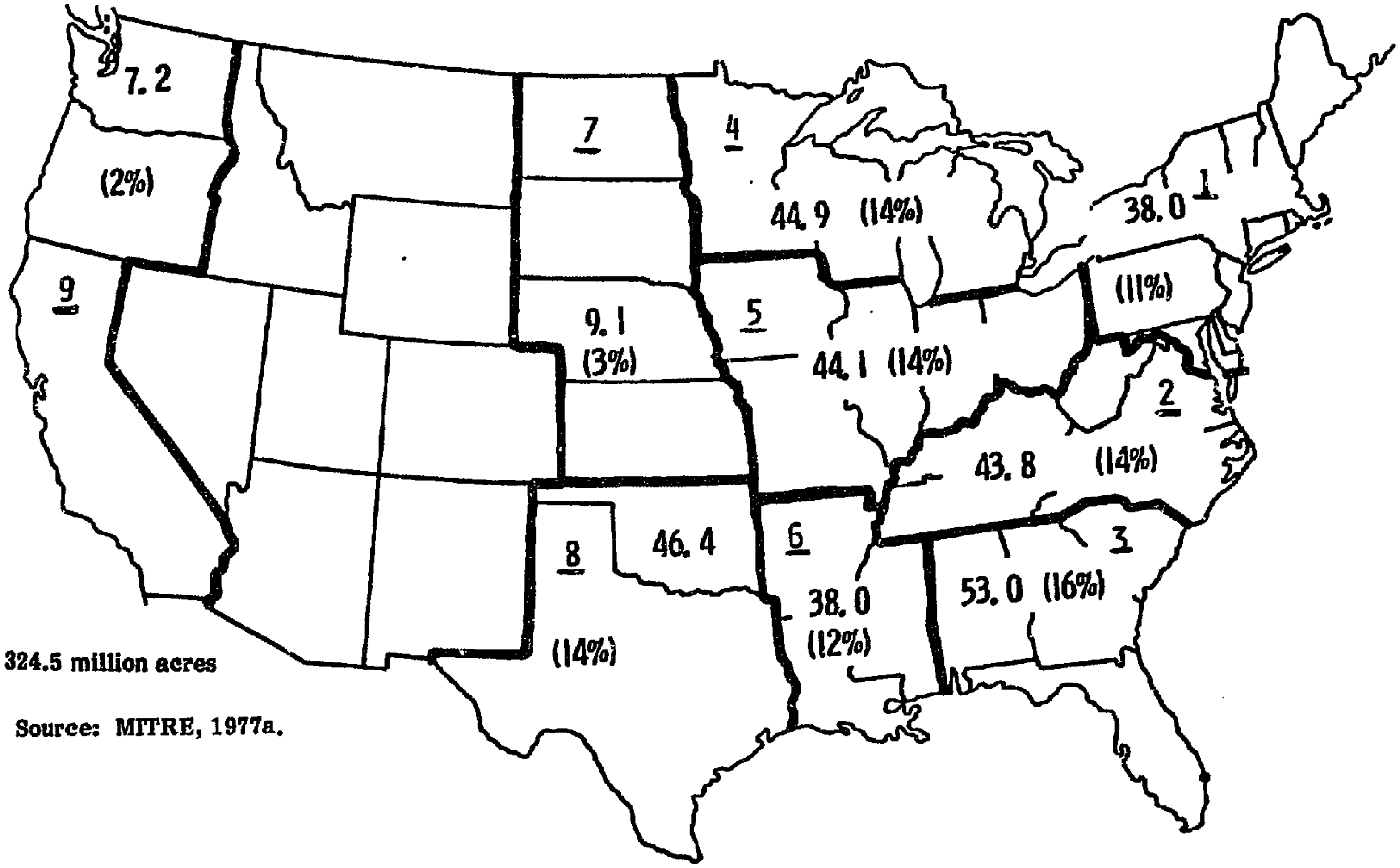
EXHIBIT D-8: DISTRIBUTION OF AVAILABLE LAND IN SCENARIO 2: CLASSES I-IV; FOREST, PASTURE, RANGE Million Acres (% of Total)



268.3 million acres

Source: MITRE, 1977a.

EXHIBIT D-9: DISTRIBUTION OF AVAILABLE LAND IN SCENARIO 3: SCS CLASSES I-IV; FOREST, PASTURE, PASTURE, ROTATION HAY AND PASTURE, HAYLAND, OPEN LAND FORMERLY CROPPED
Million acres (% of Total)



324.5 million acres

Source: MITRE, 1977a.

APPENDIX E

AGRICULTURAL RESIDUES

Agricultural residues are an interesting potential source of cellulose for methanol conversion. They are a by-product of agricultural production; by definition residues are the parts of the plant other than the grain, seed or fiber for which the plant is grown (Larson, 1979).

Among agricultural residues, the present analysis is limited to field residues; these constitute 94 percent of the organic solids produced annually as crop residues. The other 6 percent are from centralized locations such as cotton mills and sugar refineries (U.S. EPA, 1978). There are no harvesting or transportation energy costs associated with the collection of such non-field residues.

Although crop residues are often perceived as a waste, they may perform many functions. Crop residues are sometimes used as animal feed and bedding (Larson, 1979); corn cobs may be used in the manufacture of chemicals (U.S. EPA, 1978).

But even when the residues decay in the field, they have a value. Crop residues contain nitrogen, phosphorous, and potassium, as well as other less energy-intensive nutrients. When crop residues are left on the field, most of these nutrients eventually return to the soil. When crop residues are removed, additional fertilizer (which has a significant energy value) must be applied to the soil to maintain the soil nutrients at the level that would otherwise exist in the presence of decaying residues.

Crop residues also provide soil with organic matter, which increases soil fertility and reduces soil density (Robertson and Mokma, 1978). In energy terms, an increase in soil density increases the power required to plow the soil. Organic matter also maintains soil porosity, which permits high rates of water and oxygen infiltration and reduces the quantity of water that must be added to the soil for adequate plant growth. In dry, but as yet nonirrigated areas, this can significantly affect grain production. Even in irrigated areas, the ability of high-porosity soil to hold water may affect energy consumption due to the energy-intensive nature of irrigation.

But more important than the loss of fertilizer nutrients (which can be replaced with manufactured fertilizer) and organic content (which can be replaced with manure) is the increased loss of topsoil (due to wind and water erosion) that results from residue removal. The Soil Conservation Service develops estimates of soil loss tolerance for particular soil types and field depths (U.S. Soil Conservation Service, 1973). At present, average soil loss per acre on cultivated land in the United States is well above the maximum soil loss level per acre at which current productivity can be maintained (Lockeretz, 1980). These conditions exist at a time when residue removal (which can increase soil loss by a factor of two) is only rarely practiced. In much of the United States, the removal of residues would increase already intolerable levels of erosion and reduce long-term soil productivity. This would be an unacceptable result of residue collection. This analysis is therefore limited to the collection of those residues that can be removed without causing soil loss to exceed tolerance levels.

While the removal of residues causes the direct loss to the soil of the residues' nutrient and organic content, residue removal also causes an indirect loss. An increase in residue removal, even within the soil loss tolerance level, increases erosion. This eroded soil comes from the top, fertile, soil layer, which is higher in organic matter and nutrients than the soil underneath. The resulting indirect losses of nutrients and organic matter due to the erosion caused by residue removal may be 50 to 100 percent of direct losses from residue removal (Lockeretz, 1980).

In addition to the costs of erosion that accrue to a farmer, society incurs additional costs in the form of increased sedimentation in rivers and reservoirs, as well as increased water pollution from soil-associated pesticides, fertilizers, and organic matter.

To a certain extent, the problems of erosion caused by residue removal can be solved through the application of alternative conservation methods. These include: rotating crops; planting inter-row crops such as clover, alfalfa and winter vetch and then plowing these under as green manure; contour plowing; double cropping; strip cropping; terracing; and conservative tillage methods, such as chisel-plowing and no-till.

If the removal of all or some crop residues will not cause intolerable soil loss, or if that soil loss can be alleviated through conservation practices, then residues will be available as an energy source.

There is considerable attention aimed at the use of grain residue as a boiler fuel to heat the distillation of ethanol from grain. Although crop residues have the advantage of being low in sulfur compared with coal, coal is currently cheaper (OTA, 1980) as a boiler fuel than residues. This may seem counter-intuitive when one considers that these residues would otherwise decay in the fields, but the costs of utilizing them include the costs of purchasing harvesting equipment, harvesting and transporting residues, replacing lost fertilizer, and storing the residues for an average of six months between annual harvests.

As a feedstock, residues can be fermented to ethanol via enzymatic or acid hydrolysis, or converted to methanol. Although the use of agricultural residues as an alcohol feedstock is technologically feasible, current economics preclude the building of facilities for such production. Nevertheless, there is much current research in the field (Tyner, 1980).

In this appendix, estimates are developed of energy consumption resulting from the collection and of the overall availability of such residues.

E.1 Selection of Species

As stated above, this analysis is limited to developing energy estimates for the collection of residues from field crops, as opposed to the collection of residues available at a central facility.

Among those crop residues conventionally left in the field, corn and wheat residues are available in the greatest quantity. Soybeans, grain sorghum, rice, barley and oats also produce significant amounts of residues. Hay, all of which is harvested for feed, is not considered residue (Skidmore, 1979).

In assessing the types of residues suitable for methanol conversion, the ability of residues to be collected in the fall and stored until their use must be taken into account. Tyner (1980) notes that soybean residues decompose rapidly and therefore cannot be stored up to a year before they are used. Soybean residues are also difficult to collect. Therefore, soybean residues have been excluded from consideration in this analysis.

E.2 Selection of Sites

Those regions of the country that produce the greatest quantity of crops also produce the greatest quantity of crop residues: the Corn Belt and the Great Plains. Moreover, these regions produce crop residues beyond what is needed to control erosion, i.e., they produce residues available to support a methanol production facility. Within the Great Plains and Corn Belt regions, the only crops that produce available residues are corn and small grains.

Within each of these two regions, three Major Land Resource Areas (MLRA's) were selected for analysis. MLRA's are geographically-associated land resource units. States may contain 6 to 12 MLRA's (Gupta, 1979), although MLRA's cross state borders. In the Corn Belt region, the areas selected were: MLRA 102 located in southwestern Minnesota and eastern South Dakota; MLRA 115, located in southern Illinois and eastern Missouri; and MLRA 107, located mostly in western Iowa. In the Great Plains region, the areas selected were: MLRA 80, located in central Texas, central Oklahoma and southern Kansas; MLRA 73 located in north central Kansas and southern Nebraska; and MLRA 63, located in central South Dakota.

In selecting MLRA's for analysis, only those areas where residues can be collected without increasing soil erosion beyond tolerable levels have been considered. The three MLRA's analyzed in each region represent a range of the energy consumption per dry ton residue collected and delivered to a centrally-located conversion facility. In selecting these sites, no attempt was made to determine whether or not the collection of agricultural residues at these sites would be economic.

E.3 Energy Consumption Estimates

This section describes the methods used to derive energy consumption data per dry ton equivalent (DTE) of residues delivered to a centrally-located cellulose conversion facility in six MLRA's.

E.3.1 Literature Review

Numerous studies on the use of crop residues as an energy source were reviewed in a search for information relating to energy consumption in residue collection. Because of the effect of residue availability on the energy used in transporting the residues, information was required on residue availability as well as on the energy requirements for residue collection activities.

A common, but incomplete, method of assessing total residue availability is to obtain published data on crop yields and to multiply those yields by the appropriate crop residue factor from the table below. The product is the total tonnage of residues by crop (Gupta, 1979).

Crop	Ratio of Straw Residue to Grain (by weight)
Corn	1:1
Sorghum	1:1
Spring wheat	1.3:1
Winter wheat	1.7:1
Durum wheat	1:1
Oats	2:1
Barley	1.5:1

This residue tonnage, summed across all crops, is the total residue produced. Much of this residue, however, cannot physically be collected, or would contribute to a significant erosion hazard if collected. Hence, total residue available for collection is significantly lower.

Tyner (1980) estimates that one ton of corn or sorghum residues per acre is uncollectable for residue yields of less than 5,300 lbs per acre. For yields higher than 5,300 lbs per acre, 37.5 percent of residues are uncollectable. For small grains, Tyner assumes that 500 lb of residues per acre cannot be collected.

In addition to this physical constraint, much of the collectible residue should be left on the soil to curtail water and/or wind erosion, reducing total residue availability further.

Only in the past few years have energy analysts considered the effect of residue removal on erosion, an effect long recognized by soil scientists. One reason for this delay may have been the difficulty in quantifying the impact of residues on erosion control. This impact will vary dramatically by site, thus calling into question nationally-applied estimates such as those of Alich et al (1976) on typical residue availability.

The level of soil erosion is influenced by many factors. Water erosion depends on the level of rainfall, the soil type, the slope length, the slope gradient, the crop management technique, and an erosion control factor. These factors can be multiplied together using the universal soil loss equation (see Gupta, 1979) to produce estimates of soil loss due to water erosion. Wind erosion also depends on a variety of factors (soil erodibility, ridge roughness, climate, field length, and vegetative cover), but the relationship of these factors is sufficiently complex to require a computer program to calculate soil loss in each area (Posselius and Stout, 1980).

Thus, the determination of the amount of residues that can be removed for energy or other uses requires substantial site-specific data. For the present analysis, use has been made of data developed in a series of papers by Science and Education Administration (SEA) scientists (Larson, 1979; Gupta et al., 1979; Lindstrom et al., 1979; and Skidmore, et al., 1979). These papers provide estimates of the amount of residues that can be safely removed. The estimates were developed on the MLRA level; estimates of energy consumption per ton of residues developed in the present analysis have therefore been performed at the MLRA level.

The estimates of energy consumed in collection and transport of crop residues are based on equations developed by Clarence Richey for a Purdue University study for the OTA (Tyner, 1980). While other data sources provide estimates of energy consumption per acre of cropland, the Purdue estimates take into account the effect of variations in residue availability on diesel fuel consumption. Therefore, this method of estimating energy was deemed preferable for this analysis. The Purdue equations calculate energy consumed in the collection of a specific type of residues using only two variables: the harvestable residue in tons per acre and the average distance to the conversion facility in miles.

E.3.2 Assumptions

In utilizing the data discussed above on residue availability, several assumptions have been made.

First, all residues available for harvest are assumed collected. However, because of the various hazards to the soil and other costs associated with residue collection, many farmers may fail to have crop residues collected on their lands. In some other areas, the tons per acre that can be removed safely is relatively low. As a result, the removal of such residues will be significantly less economic (in terms of energy as well as labor) than the removal of residues in areas where erosion is less of a problem. The assumption, then, that all residues available will be collected, is an optimistic one.

Second, all residues collected are assumed transported to a centrally-located methanol-producing facility. In reality, some of the residues would probably be kept on the farm for use as animal bedding or feed, but this is difficult to quantify.

Third, cropland is assumed to be uniformly distributed within an MLRA. This permits estimation of an average transport distance to a conversion facility for crop residues produced in the MLRA.

Fourth, a certain amount of solar drying of residues on the field is assumed. Such drying reduces bacterial losses as well as the weight of residues that must be transported to the conversion facility. Estimates of the moisture content of residues transported were obtained from Tyner (1979). These are: 12 percent moisture for small grains, and 15.5 percent moisture for corn residues after solar drying. At these moisture levels, the quantity of cellulose required for the conversion process is somewhat lower than if cellulose with 50 percent moisture is used. Accordingly, a 300,000 gallon/day methanol plant is estimated to require only about 1750 DTE of agricultural residues per day (as opposed to 2000 DTE per day when wood, with 50 percent moisture, is used).

E.3.3 Energy Input Estimates

There are several steps involved in the collection of agricultural residues. The residues are first cut close to the ground (a step which may occur routinely during harvest) and raked into windrows. The windrows are then gathered and packed into bales which are then moved to a roadside storage area. Finally, the bales are transported by truck to the processing facility.

Equations for energy consumption in each of these operations, in terms of diesel fuel consumed per acre, are presented in the previously mentioned Purdue study (Tyner, 1980). Converting the Purdue equations for corn and small grains to produce estimates of diesel fuel consumed per dry ton of residues yields:

Diesel Fuel Consumption in Gallons/Ton

Operations	Corn residues (750 lb dry wt bale)	Small grain residues (665 lb dry wt bale)
Cut and windrow	1.18/R	0.61/R
Bale	0.262 + 1.11/R	0.295 + 0.77/R
Move to Roadside	0.51	0.574
Transport to Plant	0.067 + 0.059d	0.075 + 0.067d

where R is collectible residues, in dry tons per acre, and d is the average distance to the plant, in miles.

For the Great Plains MLRA's, collectible residues per acre, by crop, were obtained from estimates developed by Skidmore, Kumal and Larson (1979). These estimates were based on 1973-1975 data and reflect the maximum amount which can be collected without increasing soil loss due to wind erosion beyond tolerable levels.

For the Corn Belt MLRA's, collectible residues were estimated in a two-step process. First total residues produced per acre in the Corn Belt were derived from 1977-1979 estimates[1] of total residues produced by region and crop developed by Lockeretz (1980) and shown in Exhibit E-1. Then estimates of residues required to keep soil erosion below tolerance levels were subtracted.

The latter estimates were obtained from those developed by Lindstrom et al (1979) using 1972-1976 data. In the Corn Belt, water erosion is a more serious problem than wind erosion and residue requirements depend upon tillage practices. Lindstrom develop estimates for five different tillage practices. The estimates used in the present analysis assume the use of tillage methods (e.g., no-till) which permit the

---

[1] *Estimates of residue production are less sensitive to the years for which data is used than are estimates of crop yields, since adverse weather and pestilence generally reduce crop yields to a much greater extent than residue yields.*

EXHIBIT E-1: PRODUCTION OF MAJOR CROP RESIDUES[1], BY CROP AND REGION
(Million dry metric tons per year)[1]

	Corn	Wheat	Soybeans	Sorghum	Oats	Barley	Total	
Corn Belt	98.5	9.9	43.5	1.8	3.8	0.1	157.5	(40%)
Northern Plains	27.4	31.0	4.1	10.0	5.8	4.1	82.4	(21%)
Lake States	28.4	5.3	7.4	—	5.8	1.7	48.6	(12%)
Southern Plains	3.9	13.1	1.2	6.4	0.8	0.2	25.6	(6%)
Mountain States	2.6	12.2	—	0.7	0.2	4.4	20.1	(5%)
Appalachia	8.6	1.7	6.3	0.1	0.2	0.3	17.2	(4%)
Pacific	1.8	9.8	—	0.3	0.4	2.6	14.9	(4%)
Delta	0.4	1.0	11.7	0.3	0.2	—	13.6	(3%)
Northeast	6.0	0.7	1.2	—	1.2	0.3	9.4	(2%)
Southeast	3.5	0.5	5.1	—	0.2	—	9.3	(2%)
U.S. (48 states)	181.1	85.2	80.5	19.6	18.6	13.6	398.6	(100%)
% of U.S.	(45%)	(22%)	(20%)	(5%)	(5%)	(3%)	(100%)	

77-79 average, computed from state crop production data in Crop Production, 1979 Annual Summary. sidues computed from crop production using the following values for ratio of dry residue weight to vested crop: corn, 1.0; spring wheat, 1.3; winter wheat, 1.7; durum wheat, 1.0; soybeans, 1.5; ghum, 1.1; oats, 2.0; barley, 1.5 (Lindstrom et al., 1979). Data are for gross production only, with no owances for losses in harvesting, competing uses, or soil conservation constraints on residue removal. gions are those used by USDA for many statistical series (see Agricultural Statistics, 1978, p. 477 for st of states in each).

urce: Lockeretz, 1980.

maximum removal of residues. Such methods are not always used and, because of potential problems with weeds, insects or drainage, they may not always be feasible (Lockeretz, 1980). Hence, the estimates used for available residues in Corn belt MLRA's may be overly optimistic and may result in underestimating energy requirements for residue collection in these areas.

For each of the six MLRA's, the total residue available was determined by multiplying the harvested crop acreage by the residue available per acre. This total was summed across all crops and divided by the land area of the MLRA[1] to obtain dry tons of available residues produced per square mile.

In the Corn Belt and Great Plains regions, crop residues can be harvested only once a year. Therefore, residues must be harvested from an area large enough to supply a conversion facility for an entire year.

As previously observed, a 300,000 gallon/day methanol plant requires about 1750 dry tons per day of agricultural residues. Allowing for bacterial, transport and storage losses of 15 percent (Tyner, 1980), yields an annual requirement of about 750,000 dry tons per year. This figure was then divided by available residue production per square mile to obtain the (minimum) area necessary to provide residues for one 300,000 gallon/day methanol plant. Assuming a circular area and a centrally located plant yields an average transport distance of two-thirds the radius of the area.

As the equations presented above show, energy consumption per ton of residues increases with decreased residue availability per acre and with increased average transport distance.

In addition to the direct use of energy in the harvesting of crop residues, significant indirect energy consuming elements must be considered as well. As stated in the introduction, the removal of residues will increase pollutants (difficult to quantify in energy terms) and reduce soil tilth (making the soil harder to plow).

---

[1] *W. Larson and E. Skidmore, personal communications.*

One significant and possibly quantifiable indirect energy cost is lost grain production caused by a new harvest schedule. If winter rain or snow comes early, while a farmer is still harvesting crop residues, there may not be enough time for the farmer to prepare the ground for spring planting. This preparation must then take place in the spring, delaying planting and reducing yields (e.g., if plowing and fertilizing must be done in the spring instead of the fall, corn yields, especially susceptible to a shorter growing season, will suffer). According to a Purdue crop production model, using actual weather and field conditions data for 600 acres in Indiana for 1968-1974, the harvesting of residues would have resulted in an average reduction in corn production of 1.6 bu/acre. This would have been between one and two percent of total crop production.

For the Indiana study area, the Purdue study shows an average residue yield of 1.1 tons per acre. At an average loss of 1.6 bushels of corn per acre, each ton of residue harvested would have reduced corn production by approximately 1.5 bushels. The energy consumed in the production of this corn must be added to the energy cost of residue collection.

A much more significant indirect energy input to the collection of residues is the loss of the nutrient value of the residues. The organic content of the residues would be lost to the soil but would probably not be replaced. However, the common fertilizer elements (nitrogen, potassium and phosphorus) contained in the removed residues would have to be replaced with additional fertilizer, which has a very significant energy cost. Exhibit E-2 shows the nutrient content of the small grains and corn residues, as well as the total energy consumption of the manufacture of an equivalent amount of fertilizer.

In the first year following their return to the soil, perhaps only 2 to 3 percent of residue nutrients would be available. Over time, however, much of the nutrients would be available as a natural fertilizer. However, erosion and/or minerals in the soil would reduce the value of residues as fertilizer. The phosphorus in residues, in particular, may form compounds with other elements in the soil and, therefore, has little value as fertilizer.

The estimates of energy consumption for collecting residues in each of the six selected MLRA's are presented in Exhibits E-3 through E-8. For each MLRA, the estimates for

EXHIBIT E-2: IMBEDDED FERTILIZER IN CORN AND WHEAT RESIDUES PER DRY TON OF RESIDUES

		Petroleum Products						
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Liquid Fuels	Btu's Total Energy
	Energy in Fertilizer, (1); Nutrient content of residues, (2)							
• FERTILIZER IN CORN RESIDUES	1.1% N			0.012	574.7	0.0009		
	.1% P	0.00015	0.00066	0.020	27.0	0.00017		
	1.6% K			0.0002	37.1	0.0012		
	Total	0.00015	0.00066	0.0322	638.8	0.00227	4,900	707,600
• FERTILIZER IN WHEAT STRAW (similar for barley, oats) (2)	.5% N			0.0055	261.2	0.00042		
	.1% P	0.00015	0.00066	0.020	27.0	0.00017		
	.6% K			0.00008	13.9	0.00046		
	Total	0.00015	0.00066	0.02558	302.1	0.00105	4,000	335,700

Sources
(1) Derived from: Tyson, Belzer and Associates, 1980.
(2) S. Kresovich, Personal Communication.

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 1.08 tons/acre (1) Average transport distance (d): 20.8 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		1.09					153,080	153,000
	—Bale		1.29					180,600	180,600
	—Move to Roadside		0.51					71,400	71,400
	—Transport to Plant		1.29					181,200	181,200
— Fertilizer (4)		0.00015	0.00066	0.032		638.8	0.00227	4,900	707,600
— Reduced Corn Production (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	280,000
SUBTOTAL		0.19	4.35	0.034	0.080	811.0	0.00359	845,700	1,553,800
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.65	0.006	0.014	143.2	0.00064	113,900	274,200
TOTAL	CORN RESIDUES — MLRA 102	0.23	5.00	0.040	0.094	954.2	0.00423	759,600	1,828,000

Sources

(1) Derived from: Lindstrom et al. 1979

(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.

(3) Tyner, 1980.

(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.

(5) Corn production reduced on average by about 1.5 bushels per ton of residues collected (see text); energy consumption shown is estimated energy required to produce a compensating increase in corn production as shown in Exhibit A-24.

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.39 tons/acre (1) Average transport distance (d): 20.8 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		0.44					61,600	61,600
	— Bale		0.85					118,900	118,900
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		1.47					205,600	205,600
— Fertilizer (4)		0.00015	0.00066	0.026		302.1	.00105	3,900	335,700
— Reduced Production of Small Grains (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	3.49	0.028	0.080	474.3	0.00237	525,000	1,062,200
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.52	0.004	0.014	71.1	0.00036	78,800	159,300
TOTAL	SMALL GRAINS RESIDUES — MLRA 102	0.23	4.01	0.032	0.094	545.4	0.00273	603,800	1,221,500

Sources:

(1) - (4) See first page of this exhibit.

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-3: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 102

(Continued)

Energy Consuming Element	Assumptions	Petroleum Products							
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.57 tons corn and 0.43 tons small grains:								
	Corn residues	0.13	2.85	0.023	0.054	543.9	0.00241	433,000	1,042,000
	Small grain residues	0.10	1.73	0.014	0.040	234.5	0.00117	260,000	525,000
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 102	0.23	4.58	0.037	0.094	778.4	0.00358	693,000	1,567,000

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Petroleum Products LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 0.95 tons/acre (1) Average transport distance (d): 32.2 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		1.24					173,900	173,900
	—Bale		1.43					200,400	200,400
	—Move to Roadside		0.51					71,400	71,400
	—Transport to Plant		1.97					275,400	275,400
— Fertilizer (4)		0.00015	0.00066	0.032		638.8	0.00227	4,900	707,600
— Reduced Corn Production (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	5.31	0.034	0.080	811.0	0.00359	780,600	1,688,700
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.80	0.006	0.014	143.2	0.00064	137,700	298,000
TOTAL	CORN RESIDUES — MLRA 115	0.23	6.11	0.040	0.094	954.2	0.00423	918,300	1,986,700

Sources

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn.

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.24 tons/acre (1) Average transport distance (d): 32.2 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		0.49					68,900	68,900
	—Bale		0.92					128,200	128,200
	—Move to Roadside		0.57					80,400	80,400
	—Transport to Plant		2.23					312,500	312,500
— Fertilizer (4)		0.00015	0.00066	0.026		302.1	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	4.37	0.028	0.080	474.3	0.00237	648,500	1,185,700
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.66	0.004	0.014	71.1	0.00036	97,300	117,900
TOTAL	SMALL GRAIN RESIDUES — MLRA 115	0.23	5.03	0.032	0.094	545.4	0.00273	745,800	1,303,600

Sources

(1) - (4) See first page of this exhibit

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-4: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 115
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products				Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)				
• AVERAGE CROP RESIDUES	One ton crop residues is 0.69 tons corn and 0.31 tons small grains:								
	Corn residues	0.16	4.21	0.027	0.065	658.4	0.00292	634,000	1,371,000
	Small grain residues	0.07	1.56	0.010	0.029	169.1	0.00085	231,000	423,000
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 115	0.23	5.77	0.037	0.094	827.5	0.00377	865,000	1,794,000

EXHIBIT B-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN RESIDUES	Collectible residues (R): 1.02 tons/acre (1) Average transport distance (d): 31.5 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		1.16					162,000	162,000
	—Bale		1.38					193,200	193,200
	—Move to Roadside		0.51					71,400	71,400
	—Transport to Plant		1.93					269,600	269,600
— Fertilizer (4)		0.00015	0.00066	0.032		638.8	0.00227	4,900	707,600
— Reduced Corn Production (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	5.14	0.034	0.080	811.0	0.00359	757,700	1,663,600
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.77	0.006	0.014	143.2	0.00064	113,700	249,600
TOTAL	CORN RESIDUES — MLRA 107	0.23	5.91	0.040	0.094	954.2	0.00423	871,400	1,913,400

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn.

EXHIBIT 8-5: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Petroleum Products LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAIN RESIDUES	Collectible residues (R): 1.02 tons/acre (1) Average transport distance (d): 31.5 mi (2)								
— Harvest and Transport (3)	— Cut and windrow		0.46					64,700	64,700
	— Bale		1.06					148,400	148,400
	— Move to Roadside		0.57					80,400	80,400
	— Transport to Plant		2.19					306,000	306,000
— Fertilizer (4)		0.00015	0.00066	0.026		302.1	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	4.44	0.028	0.080	474.3	0.00237	658,000	1,195,200
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.67	0.004	0.014	71.1	0.00036	98,700	179,300
TOTAL	SMALL GRAIN RESIDUES — MLRA 107	0.23	5.11	0.032	0.094	545.4	0.00273	756,700	1,374,500

Sources

(1) - (4) See first page of this exhibit

(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT 2-[illegible] ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 107
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
AVERAGE CROP RESIDUES	One ton crop residues is 0.84 tons corn and 0.16 tons small grains:								
	Corn residues	0.19	4.97	0.034	0.079	601.5	0.00355	732,000	1,607,000
	Small grain residues	0.04	0.82	0.005	0.015	87.3	0.00043	121,000	220,000
OTAL	AVERAGE TON CROP RESIDUES — MLRA 107	0.23	5.79	0.039	0.094	688.8	0.00398	853,000	1,827,000

EXHIBIT E-6: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 80

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Petroleum Products LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
SMALL GRAIN RESIDUES	Collectible residues (R): 0.66 tons/acre (1) Average transport distance (d): 36.1 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		0.92					129,400	129,400
	—Bale		1.46					204,600	204,600
	—Move to Roadside		0.57					80,400	80,400
	—Transport to Plant		2.49					349,100	349,100
— Fertilizer (4)		0.00015	0.00066	0.026		302.1	0.00105	3,900	335,700
— Reduced Production of Small Grains (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
UBTOTAL		0.19	5.60	0.028	0.080	474.3	0.00237	822,000	1,359,200
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.84	0.004	0.014	71.1	0.00036	123,300	203,900
TOTAL	SMALL GRAIN RESIDUES — MLRA 80	0.23	6.44	0.032	0.094	545.4	0.00273	945,300	1,563,100

ources

1) Derived from: Lindstrom et al. 1979
2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
3) Tyner, 1980.
4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of preceding exhibit).

EXHIBIT E-6: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 80
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
AVERAGE CROP RESIDUES	*One ton crop residues is 1.00 tons small grains*	0.23	6.44	0.032	0.094	545.4	0.00273	945,000	1,563,000
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 80	0.23	6.44	0.032	0.094	545.4	0.00273	945,000	1,563,000

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Petroleum Products LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
CORN RESIDUES	Collectible residues (R): 0.89 tons/acre (1) Average transport distance (d): 41.8 mi (2)								
— *Harvest and Transport* (3)	— *Cut and windrow*		1.33					185,600	185,600
	— Bale		1.51					211,300	211,300
	— Move to Roadside		0.51					71,400	71,400
	— Transport to Plant		2.53					354,600	354,600
— Fertilizer (4)		0.00015	0.00066	0.032		638.8	0.00227	4,900	707,600
— Reduced Corn Production (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	6.04	0.034	0.080	811.0	0.00359	882,400	1,790,500
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	0.91	0.006	0.014	143.2	0.00084	132,400	268,500
TOTAL	CORN RESIDUES — MLRA 73	0.23	6.95	0.040	0.094	954.2	0.00423	1,014,800	2,059,000

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn.

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Petroleum Products: LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
SMALL GRAIN RESIDUES	Collectible residues (R): 0.35 tons/acre (1) Average transport distance (d): 41.8 mi (2)								
– Harvest and Transport (3)	—Cut and windrow		1.74					244,000	244,000
	—Bale		2.50					349,300	349,300
	—Move to Roadside		0.57					80,400	80,400
	—Transport to Plant		2.88					402,600	402,600
– Fertilizer (4)		0.00015	0.00066	0.026		302.1	0.00105	3,900	335,700
– Reduced Production of Small Grains (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
UBTOTAL		0.19	7.85	0.028	0.080	474.3	0.00237	1,134,800	1,672,000
– Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	1.39	0.004	0.014	71.1	0.00036	200,300	295,100
TOTAL	SMALL GRAIN RESIDUES — MLRA 73	0.23	9.24	0.032	0.094	545.4	0.00273	1,335,100	1,967,100

urces

) - (4) See first page of this exhibit

) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of this exhibit).

EXHIBIT E-7: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 73
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products							
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• AVERAGE CROP RESIDUES	One ton crop residues is 0.295 tons corn and 0.705 tons small grains:								
	Corn residues	0.07	2.05	0.012	0.028	281.5	0.00125	299,000	607,090
	Small grain residues	0.16	6.51	0.023	0.066	384.5	0.00192	941,000	1,387,080
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 73	0.23	8.56	0.035	0.094	666.0	0.00317	1,240,000	1,994,000

EXHIBIT E-8: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 63

		Petroleum Products							
Energy Consuming Element	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
• SMALL GRAINS RESIDUES	Collectible residues (R): 0.15 tons/acre (1) Average transport distance (d): 144.9 mi (2)								
— Harvest and Transport (3)	—Cut and windrow		3.39					474,400	474,400
	—Bale		4.57					640,200	640,200
	—Move to Roadside		0.57					80,400	80,400
	—Transport to Plant		9.78					1,369,700	1,369,700
— Fertilizer (4)		0.00015	0.00066	0.026		302.1	0.00105	3,900	335,700
— Reduced Corn Production (5)		0.19	0.16	0.002	0.080	172.2	0.00132	54,600	260,000
SUBTOTAL		0.19	18.47	0.028	0.080	474.3	0.00237	2,677,600	3,160,400
— Bacterial and Transport Losses	Represents embedded energy in additional residue collected to allow for a 15 percent loss of total residue collected and stored (3)	0.04	3.26	0.004	0.014	71.1	0.00036	472,500	557,700
TOTAL	CORN RESIDUES — MLRA 63	0.23	21.73	0.032	0.094	545.4	0.00273	3,150,100	3,718,100

Sources:

(1) Derived from: Lindstrom et al. 1979
(2) Derived from: Lindstrom et al. 1979 and W. Larson, personal communication.
(3) Tyner, 1980.
(4) Derived from: Tyson, Belzer and Associates, 1980, and S. Kresovich, personal communication.
(5) Energy required to increase production of small grains to compensate for reduced production resulting from residue collection assumed to be same as for corn (see first page of preceding exhibit).

EXHIBIT B-8: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES IN MLRA 63
(Continued)

Energy Consuming Element	Assumptions	Petroleum Products				Natural Gas (cu ft)	Coal (tons)	Btu's Petroleum Products	Btu's Total Energy
		Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)				
● AVERAGE CROP RESIDUES	One ton crop residues is 1.00 tons small grains	0.23	21.73	0.032	0.094	545.4	0.00273	3,150,000	3,718,000
TOTAL	AVERAGE TON CROP RESIDUES — MLRA 63	0.23	21.73	0.032	0.094	545.4	0.00273	3,150,000	3,718,000

corn and for small grains are developed separately and then combined on the basis of the relative production of the two categories of residue. The estimates for the six MLRA's are summarized in Exhibit E-9.

The largest input in almost all of the MLRA's is the fertilizer value of the residues, an indirect energy input. The second largest input is the energy cost of transporting the residues, reflecting the extreme sensitivity that residue collection costs have with respect to transportation distances. Notably, the total energy consumption estimates in five of the six MLRA's are quite similar (about 1.6 MM Btu/ton), while they are about double this value in MLRA 63, where expected residue yields per acre are low and estimated transport distances high. This emphasizes the relative sensitivity of these results to transport distances and expected residue yields.

E.3.4 Possibilities for Reduced Energy Consumption

Probably the most significant reduction in energy consumption could be achieved by reducing the capacity of the methanol production facility. The smaller the facility, the smaller the average distance that residues must be transported. In view of the size of the transportation energy input, this could produce a significant energy saving.

Another interesting possibility would be the use of combines that harvest and bale residues at the same time as grain. Such combines would: eliminate the need to travel over each acre twice to collect residues (a considerable savings in labor as well as energy); and increase the amount of residues that can be physically collected (due to improved harvesting equipment). On the other hand, the use of such combines would tend to: increase the length of the grain harvest, which may endanger crop collection; require the baling of wet residues, which are more susceptible to bacterial degradation than dry residues; and require considerable investment in the form of new equipment.

E.4 Potential Availability of Residues

The SEA study from which the data on harvestable residues were obtained examined residue availability in six southern states and in eastern Oregon, in addition to the Corn Belt and the Great Plains. Tyner (1980) expanded on this work, developing estimates of

EXHIBIT E-9: ENERGY CONSUMPTION ESTIMATES PER DELIVERED DRY TON OF CROP RESIDUES: SUMMARY OF ALL MLRA'S ANALYZED

	Petroleum Products							
	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	LPG (gal)	Natural Gas (cu ft)	Coal(1) (tons)	Btu's Petroleum Products	Btu's Total Energy
• CORN BELT								
Major Land Resource Area 102	0.23	4.58	0.037	0.094	778.4	0.00358	693,000	1,567,000
Major Land Resource Area 115	0.23	5.77	0.037	0.094	827.5	0.00377	865,000	1,794,000
Major Land Resource Area 107	0.23	5.79	0.039	0.094	888.8	0.00398	853,000	1,827,000
• GREAT PLAINS								
Major Land Resource Area 80	0.23	6.44	0.032	0.094	545.4	0.00273	945,000	1,563,000
Major Land Resource Area 73	0.23	8.56	0.035	0.094	666.0	0.00317	1,240,000	1,984,000
Major Land Resource Area 63	0.23	21.73	0.032	0.094	545.4	0.00273	3,150,000	3,718,000

residue availability for the rest of the country. That report's final estimate of total residues available for collection in the United States is shown in Exhibit E-10. Note that usable residues represent only one-fifth of total residues produced (previously shown in Exhibit E-2).

The amount of harvestable residue that would actually be collected would be smaller than the available residues estimated in Exhibit E-10. Farmers may be reluctant to invest the time and money necessary to collect the residues if only a small portion of the residues may be safely removed, or they may not wish to remove the residues at all, in view of the nutrients the residues provide to the soil and their erosion-reducing properties. Also, as stated earlier, not all residues collected are available for conversion to cellulose. Some are used on the farm or sold to livestock producers for animal feed or bedding. Collected residues may also be used as a heat source through direct combustion.

Significant quantities of collectible residues are available primarily from prime farm land: very flat land (less than two percent slope) with rich, deep soil. Most such land is already being farmed. Hence, potential additions to cropland are likely to come primarily from more marginal farm land and are not likely to be capable of supplying significant quantities of residues.

In areas of low usable residue density, transport costs will be high, and the building of a capital-intensive conversion facility would be unlikely. Soil, climate and productivity conditions combine to make five states the producers of 48 percent of the usable crop residues in the United States. Eleven other states produce 35 percent, and the remaining 32 states in the lower 48 combined produce only 17 percent of the usable residues. Given this distribution of residue availability, residues for alcohol production are likely to come primarily from the top twelve states[1] (which produce 73 percent of the total available residues).

---

[1] *In order of usable residue production, these states are: Minnesota, Illinois, Iowa, Indiana, Ohio, Wisconsin, California, Washington, Kansas, Nebraska, Texas and Arkansas.*

EXHIBIT E-10: TOTAL USABLE CROP RESIDUE IN THE UNITED STATES BY CROP

Crop	Amount (M tons)	Harvestable Acres (M acres)	Average Yield (tons/acre)
Corn	37,098	39,122	.95
Small grains	33,623	36,324	.93
Sorghum	1,452	4,100	.35
Rice	5,457	2,516	2.17
Sugar	590	331	1.78
Total	78,220	82,393	.95

Source: Tyner, 1980.

APPENDIX F

METHANOL FROM CELLULOSIC FEEDSTOCKS

In this appendix, estimates are developed of the energy inputs and outputs for the production of methanol from cellulosic materials. Production of methanol from cellulose involves drying the cellulosic feedstock to ten percent moisture and decomposing it at a high temperature to produce synthesis gas. This gas is primarily carbon monoxide (CO) and hydrogen (H_2). Steam is added to the gas; impurities are removed; and the gas is condensed under high pressure to form methanol. Distillation then removes any other impurities. The production process is described in somewhat more detail below.

F.1 Selection of Technology

At the present time, none of the technologies for conversion of wood or other cellulosic materials to methanol are considered commercially proven. Nevertheless, the equipment used in much of the process described below is proven in other, similar, commercial applications. Of the various process steps, only the gasification of wood has not been demonstrated on a commercial scale.

The technology selected for this energy analysis comes from a recent study (Mudge et al, 1981) that combines the Battelle Pacific Northwest Laboratories catalytic wood gasification technology, the Benfield acid gas removal technology, and the ICI methanol synthesis technology. The overall process flow is presented in Exhibit F-1.

F.2 Process Description

The raw material for the plant is green wood chips or agricultural residues. These are received by truck and placed into storage via a chain feeder and tripper/stacker belt conveyor. Quantities that must be kept in storage vary by feedstock — no significant storage is needed for wood harvested daily from a silvicultural farm, but a facility using agricultural residues would have to store up to a year's supply. Bulldozers in the storage area spread the piles and aid in reclaiming. Chips are reclaimed from storage using chain reclaimers and sent to the process on a belt. There is a screening station to remove rocks and tramp iron from the chips and to separate oversize chips for further chipping.

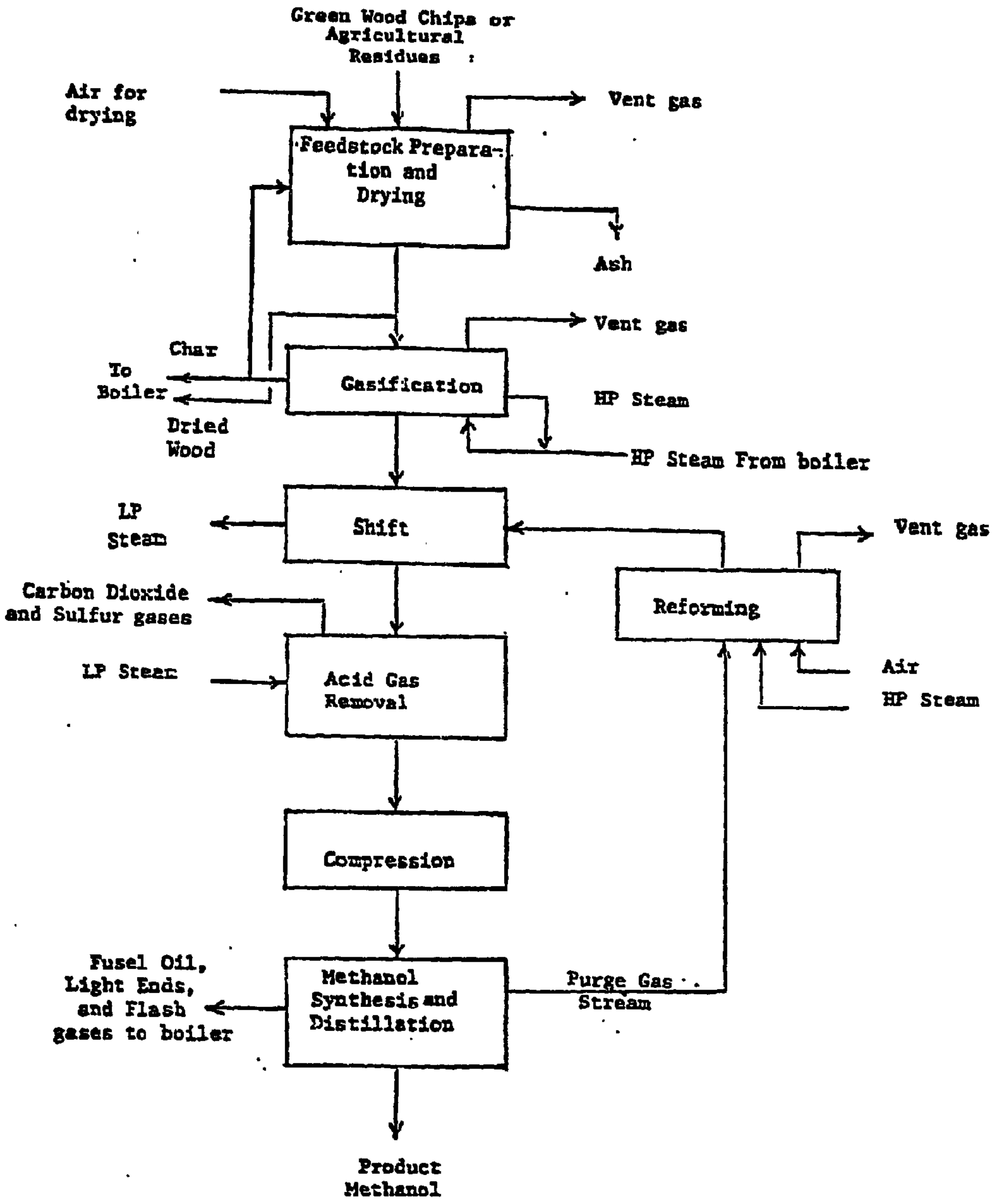


EXHIBIT F-1: SIMPLIFIED OVERALL PROCESS FLOW DIAGRAM FOR MANUFACTURING FUEL GRADE METHANOL FROM CELLULOSIC FEEDSTOCKS

Source: ICI/PNL Process

The feedstock is then dried to 10 percent moisture in single pass, annular cross section, rotary dryers. The dryers are equipped with their own burners, which are fueled by char from the gasifier.

The dried chips are conveyed to the gasifier feed bin. About 14 percent of the dry wood entering the gasifier area must be burned to heat the gasifier. The remaining chips are continuously fed to the gasifier through a lock hopper system.

The gasifier is a fluidized bed containing catalyst balls, wood chips, and char. The gasifier operates at 150 psia and 1,380 F. High pressure steam is introduced into the gasifier both for the gasification reactions and to fluidize the solids. In the gasifier, the wood chips break down to synthesis gas and char. Char and catalyst are continuously removed from the gasifier through a lock hopper system. The catalyst is recycled to the gasifier, while the char is used for fuel in other process units.

The hot synthesis gas (primarily hydrogen and carbon oxides, with very little methane) is then cooled to about 350 F in a waste heat boiler. Superheated steam at 600 psig is generated in this gasifier waste heat boiler. Entrained solids are removed from the cooled gas in cyclones and bag filters.

The synthesis gas is then sent to the shift section. Only part of the synthesis gas must be reacted with steam to achieve the desired ratio of carbon monoxide to hydrogen. The rest of the gas bypasses the shift reactor, is combined with reformer effluent, and then sent to a waste heat boiler that generates 150 psig saturated steam. Both streams are then combined and further cooled to 200 F. The heat removed from the gas is used to heat boiler feedwater to 200 F.

Gas from the shift reactor is sent to the acid gas removal section, where carbon dioxide and any traces of sulfur containing gases are removed. The gas is then compressed to 1,000 psig with a multistage centrifugal compressor.

The gas enters the methanol synthesis loop and is circulated by a centrifugal compressor. Methanol and some water are formed in the methanol reactor. Heat exchangers are used to recover heat from the gas mixture exiting the reactor. Part of this heat is used for distillation to purify the methanol, part to heat incoming gas. The methanol is condensed from the gases and purified by distillation. Light ends containing dimethyl ether and sidestream containing higher alcohols are sent to the boiler for use as fuel.

The purge stream is removed from the synthesis loop and sent to the reformer. A portion of the gas is burned to provide heat for reforming, the rest is sent to the reactor. The purge gas contains hydrocarbons (mostly methane) that build up in the system. These are converted to hydrogen and carbon oxides in the reformer. The hot reformed gas (1,600 F) is used to preheat the feed gas, and then it is sent to the shift section for further heat recovery.

Steam for the process is generated in the gasifier, the shift waste heat boilers, and the main boiler. The main boiler is fired mainly by gasifier char, but it also uses a small amount of wood, the light ends, and fusel oil from the methanol distillation.

F.3 Process Chemistry

The chemistry of gasifying wood and other cellulosic materials is complex. The overall reactions have been simplified for the purpose of illustration.

In the gasifier, cellulose, hemicellulose and lignin in the wood are reacted with steam to form synthesis gas. The major reactions are

$$(CH_2O) + H_2O = nCO + nH_2 + H_2O$$

$$(CH_2O)_x + H_2O = CO_2 + 2H_2$$

$$(CH_2O)_x = C + H_2O$$

$$C + H_2O = CO + H_2$$

$$(CH_2O)_x = CO_2 + CH_4$$

The water shift reaction is used to adjust the ratio of carbon monoxide to hydrogen for methanol synthesis.

$$CO + H_2O = CO_2 + H_2$$

Acid gas removal with a Benfield system involves absorbtion in hot potassium carbonate to form bicarbonate (or bisulfide).

$$K_2CO_3 + CO_2 + H_2O = 2KHCO_3$$

The absorbent is regenerated by the reverse reaction.

The methanol synthesis is accomplished by the catalytic reaction of carbon monoxide with hydrogen.

$$CO + 2H_2 = CH_3OH$$

Purge gas from the methanol synthesis loop containing methane is reformed with steam to produce hydrogen which is then recycled to the shift reactor.

$$CH_4 + H_2O = CO + 3H_2$$

$$CH_4 + 2H_2O = CO_2 + 4H_2$$

F.4 Energy Consumption Estimates

The inputs to the methanol process are given below. The data are presented per unit of methanol:

Dry Wood	6.63 ton/1,000 gal or
Dry Agricultural Residues	5.8 ton/1,000 gal
Electricity	1,767 kwhr/1,000 gal
Diesel Fuel	1.09 gal/1,000 gal

The diesel fuel is consumed by bulldozers in the wood storage area; the electricity and wood are consumed in the process.

The consumption of energy by type within the process is shown in Exhibit F-2. The reader is cautioned that the energy consumed by each process section may vary considerably from one design to another due to the placement of heat exchangers and other energy conserving equipment.

Exhibit F-3 summarizes energy inputs to methanol from cellulose. Exhibit F-4 presents the energy output. Cellulose and energy requirements for producing a given amount of methanol varies a function of the moisture content of the feedstock.

F.5 Sensitivity Analyses

Plant Size. The process plant energy requirements per ton of raw material are not a function of plant scale. The energy needed to transport raw material to the plant, however, does depend on plant size. An economic plant would process about 2,000 dry tons of wood per day to make about 1,000 tons of methanol (300,000 gal) per day. A plant processing about 1,000 dry tons would be close to the lower limit of economic size. The upper limit is dependent on transportation costs; the maximum plant size is probably about 5,000 DTE of wood per day. Between those two bounds the process energy balance is independent of plant size.

Feedstock. Virtually any cellulosic feedstock can be gasified and the resulting synthesis gas converted to methanol. The energy balance will be sensitive to the moisture in the feed. Variations in ash content will have a negligible impact on the energy balance. The raw wood composition assumed was 49.5 percent moisture. This is typical of forest residues and wood from a silvicultural farm. Agricultural residues may have a lower moisture content, depending on the amount of solar drying in the field. For this analysis, corn residues were assumed to be 15.5 percent moisture; small grains residues were assumed to be 12 percent moisture (Tyner, 1980). These lower levels of moisture resulted in estimated energy savings of .23 and .24 Btu of wood per Btu of methanol, respectively. The sensitivity to moisture content is nonlinear.

The moisture content of wood is more or less independent of weather, although it could increase somewhat during storage in a rainy season or decrease during a dry season. The moisture content of agricultural residues will be more variable and particularly more sensitive to weather conditions immediately prior to collection.

EXHIBIT F-2: METHANOL FROM WOOD ENERGY BALANCE
PNL/ICI PROCESS

Process Section	Dry Wood tons per 10^6 Btu Methanol	Electricity[2]	Char (Dry) Btu per Btu Methanol	By-Product Fuel Btu per Btu Methanol	hp Steam[1] Consumed Btu per Btu Methanol	hp Steam[1] Produced Btu per Btu Methanol	lp Steam[1] Consumed Btu per Btu Methanol	lp Steam[1] Produced Btu per Btu Methanol
Feed Preparation & Drying		-	-0.251					
Gasification	-1.019	-	+0.346		0.145	0.095		0.029
Shift		-						0.062
Acid Gas Removal		-					0.092	
Compression		--						
Methanol Synthesis		-		+0.134				
Reforming		-		-0.082	0.097			
Steam Generation	-0.011	-	-0.095	-0.052		0.147		
Miscellaneous		-						
TOTAL	-1.03	-0.286	0	0	0		0	

---

[1] hp steam is 600 psig, 750 F; lp steam is 150 psig saturated. Energy of steam taken as enthalpy above water at 0 C (32 F).

[2] Electricity consumption by process section not available. Some electricity consumed in each section, greatest amount consumed in compression.

N.B. Process requirements shown on this table apply only to wood. Energy inputs are somewhat lower for the process fed by agricultural residues.

EXHIBIT F-3: ENERGY INPUT ESTIMATES FOR THE METHANOL CONVERSION FACILITY PER 1000 GALLONS METHANOL PRODUCED

Energy Consuming Element	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Distillate (gal)	Petroleum Products Residual Fuel (gal)	Natural Gas (cu ft)	Coal[1] (tons)	Btu's Petroleum Products	Btu's Total Energy
	Feedstock Requirements							
	6.63 DTE Wood 5.8 DTE Agricultural Residues							
• STORAGE	- Bulldozers move and reclaim feedstock		1.09				152,600	152,600
• PROCESS	- Most energy from feedstock							
	- Electricity, 1,767 kwhr[2]					0.82		18,393,960
	TOTAL PROCESS ENERGY INPUTS		1.09			0.82	152,600	18,546,560

[1] Based on use of 11,250 Btu/lb bituminous coal.
[2] Electricity requirement is for wood feedstock (see Exhibit F-2). Requirement is somewhat lower when agricultural residues are used.

EXHIBIT F-4: ENERGY OUTPUT ESTIMATES FOR THE METHANOL CONVERSION FACILITY PER 1000 GALLONS OF METHANOL PRODUCED

	Energy Output Estimate	Methanol (gal)	Petroleum Products			Natural Gas (cu ft)	Coal (tons)	Btu's Liquid Fuels	Btu's Total Energy
			Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)				
●	METHANOL	1,000						64,350,000	64,350,000
TOTAL	METHANOL	1,000						64,350,000	64,350,000

BIBLIOGRAPHY FOR APPENDICES C THROUGH F

The following partially annotated bibliography contains listings for the sources used in Appendices C-F.

Alich, J.A., Jr. and Inman, R.E., Effective Utilization of Solar Energy to Produce Clean Fuel, Stanford Research Institute, Menlo Park, CA (1974).

Presents initial work on energy inputs and outputs for a proposed silvicultural biomass farm design.

Alich, J.A., Jr.; Inman, R.E.; Ernest, K.; et al., Evaluation of the Use of Agricultural Residues as Energy Feedstock, Vol. I, Stanford Research Institute. Springfield, VA: NTIS, #PB-260763 (July 1976).

Since agricultural residues (crop and forest wastes and animal manures) constitute a potential supplemental source of energy, the authors examine the availability of such residues and evaluate their potential use as an energy feedstock. The research objectives are to: (1) develop a nationwide county-by-county inventory of residues generated, their quantity and condition, their current uses or disposal practices, their net availability, location, distribution and seasonality, and a computer file as an aid in summarization and analysis; and (2) assess the practicality and costs of collecting and using residues on the basis of geographic concentration patterns and the economics of collection, transportation, and usage. The report is presented in two volumes: the method of approach used in inventory development, the collection, harvesting, and conversion economics, and the overall concept assessment are presented in Volume I. (Author's abstract).

The data used are averaged over 1971-73. They present residue factors and percent dry weight for many crops.

Allmaras, R.R.; Gupta, S.C.; Pikul, J.F., Jr.; and Johnson, C.E., "Tillage and Plant Residue Management for Water Erosion Control on Agricultural Land in Eastern Oregon," Journal of Soil and Water Conservation 34:2 (1979).

We estimated soil erosion by water in the major land resource areas (B7, B8, B9) of eastern Oregon. Combinations of tillage and crop residue handling, terracing, and contouring were evaluated as control alternatives. Wheat-fallow, especially, and wheat-pea sequences predominated. Soil erosion exceeded tolerance limits in the wheat-fallow sequence on slopes over 20 percent even with all three management inputs. All three management inputs were needed on slopes between 12 and 20 percent. Tillage and residue management, along with contouring, sufficed on slopes less than 12 percent. The three major land resource areas in eastern Oregon (1.94 million hectares) produce 1.3 million metric tons of small grain residues annually, 60 percent of which can be harvested from 88 percent of the 344,200 hectares harvested. (Author's abstract).

American Pulpwood Association, "Fuel Survey." Washington, D.C.: American Pulpwood Association (1975).

This source reports average fuel consumption rates for various equipment used in 11 basic pulpwood logging systems — averaged over pulpwood operations in the South, Northeast, and Lake States.

types and amounts of energy utilized, their sources, points of consumption and patterns of flow, State energy consumption and production, and geographic extent and nature upon which energy resources are drawn. (Data base abstract).

Cullen, D.E. and Barr, W.J., *Harvesting of Close-Spaced Short-Rotation Woody Biomass.* Princeton, NJ: Mathtech, Inc. (1980).

Davis, C.H., and Blouin, G.M., *Energy Consumption in the U.S. Chemical Fertilizer System from the Ground to the Ground.* Muscle Shoals, AL: Tennessee Valley Authority Division of Chemical Development (1976).

This paper presents data on all energy used in fertilizer production from the mining of fertilizer feedstocks to the application of the final product.

The paper includes maps that locate plants producing the various fertilizers.

Davis, C.H. and Blouin, G.M., *Fertilizers, Energy, and Opportunities for Conservation.* Muscle Shoals, AL: Tennessee Valley Authority Division of Chemical Development (1980).

This paper looks at the high cost of natural gas and recent industry conservation developments.

The authors believe that ammonia can be made more cheaply from coal than from natural gas at its free market price.

Davis, C.H., and Blouin, G.M., "How Much Energy Does Fertilizer Consume?," *Farm Chemicals* 140:6, pp. 18-20, 22 (1977).

This article describes the synthetic procedures and energy used to produce the most common forms of fertilizer.

Davy McKee Corporation, *Report and Analysis of Plant Conversion Potential to Fuel Alcohol Production.* Washington D.C.: National Alcohol Fuels Commission (1980).

This report presents data and other information on excess and idle alcohol production capacity. The report lists those factories available for alcohol production, for the following types:

- Distilleries
- Breweries
- Wet Corn Milling
- Sugar Factories
- Cheese Whey
- Potato Byproducts
- Citrus Waste

For each of these factory types, the report describes the process used and the energy type and input necessary to make alcohol.

Fege, A., "Energy From Biomass," *Solar Energy Handbook.* Edited by J.F. Kreider and F. Kreith, Chapter 25. New York, NY: McGraw-Hill Publishing Co. (1981).

This chapter discusses basis for converting solar energy into the classical energy content of plants — the biomass resource base; the processes for converting biomass to useful fuels, and the concept of silvicultural energy farming as a promising future system for increasing the amount of energy supplied by biomass. (Author's summary).

Fege, A.S.; Inman, R.E.; and Salo, D.J., "Energy Farms for the Future," Journal of Forestry. Washington, D.C.: Society of American Foresters, pp. 358-361 (1979).

Silviculture energy farms may provide wood for energy at competitive prices in the future. In a study undertaken for the Department of Energy, costs were projected at $20 to $34 per dry ton for hardwoods grown under 2 to 10 year rotations. The major costs were estimated to be harvest and transportation to conversion facility, and such intensive cultural practices such as fertilization and irrigation. Up to 4.5 quads (10^{15} Btu per quad) of energy feedstocks could be produced in the United States annually, at an average annual yield of 8 dry tons per acre. The authors assume 30 million acres of land would be available for energy farm use out of the 300 million acres possible. (Author's abstract).

Flaim, S.J., Neenan, B., Dauve, J., and Map, H.P., Jr., Costs for Alternative Grain Residue Collection Systems. Golden, CO: Solar Energy Research Institute (June 1981).

Gasohol Study Group, Report of the Energy Research Advisory Board on Gasohol. Washington, D.C.: DOE (1980).

This study examines the net energy and economic benefits of gasohol production.

Gasslander, J.E.; Mattsson, J.E.; and Sundberg, U., A Pilot Study on the Energy Requirements in Forest Logging. Garpenberg, Sweden: Swedish University of Agricultural Sciences (1979).

Georgia Forestry Commission, Forest Management Department, Fuel Consumption -- Whole Tree Chipping Operation. Macon, Georgia: Georgia Forestry Commission (1980).

This source presents fuel consumption rates for a whole tree chipping operation, for light, medium, and heavy site preparation, and for tree planting.

Gupta, S.C.; Onstad, C.A.; and Larson, W.E., "Predicting the Effects of Tillage and Crop Residue Management on Soil Erosion," Journal of Soil and Water Conservation, 34:2 (1979).

Using the universal soil loss equation, we delineated those areas from which crop residues could be removed from the soil surface for other uses without erosion exceeding the soil loss tolerance limit. We also calculated the amount of crop residues produced, and determined the amounts available for removal. Here we present the sources of data and computation procedures used in this study and illustrate the kind of information available from the computer analysis. (Author's abstract).

Hall, E.H.; Allen, C.M.; Ball, D.A.; Burch, J.E.; Conkle, H.N.; Lawhon, W.T.; Thomas, T.J.; and Smithson, G.R., Comparison of Fossil and Wood Fuels. Prepared for the U.S. EPA. Columbus, Ohio: Battelle-Columbus Laboratories (1975).

Hall, E.H.; Burch, J.E.; Eischen, M.E.; and Hale, R.W., Environmental and Technological Analysis of the Use of Surplus Wood as an Industrial Fuel. Prepared for the U.S. EPA. Columbus, Ohio: Battelle-Columbus Laboratories (1980).

Hannon, B. and Perez Blanco, H., Ethanol and Methanol as Industrial Feedstocks, University of Illinois at Urbana-Champaign (1979).

This paper contains data on energy consumption on two methods each of manufacturing ethanol and methanol. The paper also lists many valuable references.

Hansson, L.R., "Bio-Energy in Sweden: Energy Plantation Overview," Bio-Energy Conference Proceedings. Washington, D.C.: Bio-Energy Council (1980).

Description of Sweden's plans for short-rotation energy plantations.

Haynes, V.O., Energy Use in Petroleum Refineries. Springfield, VA: NTIS, #ORNL/TM-5433 (1976).

This volume presents detailed information on petroleum refining processes and energy consumption required by fuel type.

Hittman Associates, Inc., Fuel Energy Consumption in the Coal Industries. Springfield, VA: NTIS, #PB-237 151/GSL (1974).

Information on the basic structure and characteristics of the coal mining industry is presented. Particular emphasis is placed on fuel use by major type and production process and exploring possibilities for fuel substitutability and conservation alternatives. (Data base abstract).

This report analyzes Census of Mineral Industries data from 1967.

Hoeft, R.G. and J.C. Siemens, Energy Consumption and Return from Adding Nitrogen to Corn, Illinois Agricultural Experiment Station (1975).

Holt, R.F., "Crop Residue, Soil Erosion, and Plant Nutrient Relationships," Journal of Soil and Water Conservation 34:2 (1979).

Crop residues contain plant nutrients that must be replaced if the residues are removed from the field. Removal of crop residues will increase wind and water erosion, and the eroded sediment will carry plant nutrients with it. The combined nutrient removal in residues and erosion under existing cropping practices would be greater in the Corn Belt than in the Southeast, central Oregon, or the Great Plains. (Author's abstract).

Howlett, K. and Gamache, A., Silvicultural Biomass Farms -- Forest and Mill Residues as Potential Sources of Biomass. Prepared for U.S. Department of Energy. Springfield, VA: NTIS (1977).

Hypes, T.L. and Stuart, W.B., "Preliminary Analysis of Harvesting Costs by Diameter Class," Industrial Forestry Operations Program, School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA (1981).

This source analyzes harvesting costs relative to tree diameter, lists labor costs and fixed and variable costs for equipment, and cites time per tree and time per cord figures for several harvesting operations.

Jawetz, P., "The Economic Realities of Alcohol Fuels," The Sugar Journal (January, 1980). (Found in HR Hearings 2/22/80, Oversight/Alcohol Fuels).

This article argues that the octane-improving quality of ethanol must be considered when evaluating the economics of gasohol. In the making of premium unleaded, one gallon of ethanol replaces 1.6 gallons of regular unleaded.

JBF Scientific Corporation, "Evaluation of Processes for Producing Gasoline From Wood." Washington, D.C.: DOE, Advanced Energy Systems Division, Office of Policy and Evaluation, #DOE/PE/70048-72 (1980).

If the United States is to diminish or eliminate petroleum imports, it must pursue: (1) conservation, (2) production of conventional fuels from unconventional feedstock sources, and (3) development of unconventional energy production systems. This report describes several production processes for producing conventional fuels (gasoline and alcohol) from wood. This assessment considers: (1) the extent to which these processes can contribute to fuel supply, (2) the energy and economic costs involved with these processes, and (3) strategies available to accelerate commercialization if one or more of the processes is judged to be worthy of implementation. Technical and economic comparisons among several biomass gasification processes are made. Methanol production from wood appears the most promising. (Author's abstract).

Johnston, B.D., Fuel and Energy Use in a Coastal Logging Operation. Vancouver, British Columbia: Forest Engineering Research Institute of Canada (1979).

Keays, J.L., "Biomass of Forest Residuals," Forest Product Residuals, AICHE Symposium Series 71 (146). New York, New York: American Institute of Chemical Engineers (1975).

Knapton, D.A., An Investigation of Truck Size and Weight Limits, Technical Supplement, Vol. 3: Truck and Rail Fuel Effects of Truck Size and Weight Limits. Cambridge, MA: U.S. DOT, Transportation Systems Center (July 1981).

Koch, P. "Harvesting Energy Chips from Forest Residues — Some Concepts for the Southern Pine Region," U.S.D.A., U.S. Forest Service, Southern Forest Experiment Station, General Technical Report SO-33 (1980).

Residues from southern forests include tops, branches, central root systems, brush, cull trees, trees of unmerchantable species, and trees too small for economic harvest by conventional methods. Before such residues can be used by industry to produce energy, they must be reduced to chip form and delivered to mill stockpiles at a cost that will permit proposed wood-energy processes to operate competitively. Processes, for which wood chips are the feedstock, include combustion, gasification, pyrolysis, liquefaction, and hydrolysis and fermentation.

This paper describes and illustrates about a dozen harvesting methods which can be classified according to procedure as follows:

- Chip whole trees at the stump.
- Extract sawlogs at the stump; bunch and forward branches.
- Chip whole trees at the landing.
- Extract sawlogs at the landing; then chip, chunk, or bale branches.
- Chip residues at the mill.
- Transport complete trees to the mill (stem, crown, roots, and foliage); at mill, divert tree portions to use of highest value.

The cost of energy chips delivered into mill stockpiles, including 30-percent pretax profit on harvesting investment, will likely range from $18 to $33 per ton (green-weight, 1980 basis). (Author's summary).

Lanouette, W. J., "Gasohol No Longer a Laughing Matter as Carter Presses for More Production," National Journal (February 9, 1980).

This article contains a boxed story on the net energy balance. The article cites studies by DOE, NAFC, Katzen Associates and Battelle/API without coming to a conclusion on the energy balance.

Larson, W.E., "Crop Residues: Energy Production or Erosion Control?" Journal of Soil and Water Conservation 34:2 (1979).

How much potential energy is contained in crop residues? How best can crop residues be used? A team of U.S. Department of Agriculture scientists computed where crop residues are produced in abundant quantities, what plant nutrients the residues contain, and the effects of tillage and residue management on wind and water erosion as well as water runoff. The team also estimated how much residue could be removed from the land without exceeding soil erosion tolerance limits. This article and the seven articles that follow it present the details of these studies. (Author's abstract).

Lindstrom, M.J.; Gupta, S.C.; Onstad, C.A.; Larson, W.E.; and Hoft, R.F., "Tillage and Crop Residue Effects on Soil Erosion in the Corn Belt," Journal of Soil and Water Conservation 34:2 (1979).

We calculated potential soil erosion by water for major land resource areas (MLRAs) in the Corn Belt using the universal soil loss equation and current cropping practices. Annual erosion rates ranged from 44.7 metric tons per hectare (19.9 t/a) in MLRA 107 to 9.7 metric tons per hectare (4.3 t/a) in MLRA 103 for a conventional fall-plow, spring-disk tillage system with all residues removed. With no conservation practices applied, only 36 percent of the cultivated area in the Corn Belt would have a soil erosion rate less than or equal to the allowable limits established by the Soil Conservation Service. Use of tillage and residue management systems increases this area to 78 percent. When soil erosion is the only restraint, the maximum amount of residues that can be removed from cropland in the Corn Belt is 58 percent of the total produced. Most of this is located in 4 of the 14 MLRAs. However, variations in residue production and the erosion index within MLRAs pose serious limitations to removal of large amounts of residues for other uses. (Author's abstract).

Little, Arthur D., Inc., Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume XV. Fertilizer Industry Report. Springfield, VA: NTIS, #PB-264 281/7ST (1976).

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes. Volume 15 deals with the fertilizer industry and examines two areas in which energy conservation and pollution control are in conflict: the reduction of nitrogen oxide emissions from nitric acid plants and switching from natural gas to fuel oil for firing fertilizer dryers where emissions are presently controlled by bag filters. (Data base abstract).

Lockeretz, William, Using Crop Residues to Provide Alcohol (May 1980). (To be published by NTIS.)

Martin, W., "Residues-Erosion vs. Energy," Agricultural Research (April 1980).

This article describes the research of Edward Skidmore, who has developed estimates of average annual residue production in 29 MLRAs in the great plains.

Skidmore estimated available residues from wheat, barley, oats, corn and sorghum from 1973-75 average yields of those crops. He then subtracted the estimated amount of applied residue that would be lost from tillage and weathering. He compared that result with the amount needed to control wind erosion in each MLRA as determined by computer solution of a USDA wind-erosion equation.

The author quotes Skidmore as saying that oats, barley and sorghum do not produce large quantities of residue in excess of what is needed to control wind erosion. The author softens that statement by noting that such a generalization does not take into account localized or field-by-field differences. However, it would be accurate for large areas (such as the area needed to supply a methanol conversion facility).

Meekhof, R.; Gill, M.; and Tyner, W., Gasohol: Prospects and Implications. Washington, D.C.: USDA AER #458 (June 1980).

This study emphasizes the economics of alcohol and gasohol production. The study makes projection of the effects of increased production of alcohol on crop volumes and prices.

Middleton, P.; Argue, R.; Burrell, T.; and Hathaway, G., "Canada's Renewable Energy Resources: An Assessment of Potential." Toronto, Canada: Middleton Association (1976).

Rising costs of conventional, frontier, and nuclear energy production and the prospect of future shortages have prompted a resurgence of interest in alternative, renewable energy technologies. This study constitutes a preliminary step in determining which sources, technologies, and applications may be appropriate in Canada and when and under what conditions they might be technically and economically viable. Principal sources of renewable energy (solar radiation, wind, and biomass), as well as waves, thermal gradients and, sensible heat sources are reviewed to establish, in general terms, their significance in the Canadian context. Next, the technical characteristics, efficiency, costs, impacts, and state of the art of sixteen harnessing or conversion technologies are presented as an information base upon which to build an assessment of potential. A method of comparing the life cost of a renewable energy system to that of the likely conventional alternative is proposed and applied in cases where adequate technical and economic data are available. A variety of different economic assumptions are also outlined under which the renewable systems would be cost competitive. This costing methodology is applied in detail to four Case Studies: solar space and water heating — residential; photovoltaics — residential; wind generator — 200 kW; and anaerobic digestion of livestock wastes. Finally, the potential for renewable energy approaches in Canada is explored and evaluated from three perspectives: technical viability, economic viability, and implementation. (Author's abstract).

MITRE Corporation, Silvicultural Biomass Farms Volume I: Summary Technical Report #7347. Washington, D.C.: U.S. Energy Research and Development Administration, Division of Solar Energy (1977a).

This volume summarizes a six-volume report on the silviculture energy farm concept as a potential source of wood/bark biomass for conversion to useful energy products. The report discusses energy farm design, site selection, species selection and needed productivity, biomass farming costs, and energy budget analyses. It also identifies needed research areas for the development of silvicultural biomass farms to commercial status within a reasonable time frame.

MITRE Corporation, Silvicultural Biomass Farms Volume III: Land Suitability and Availability Technical Report #7347. Washington, D.C.: Energy Research and Development Administration, Division of Solar Energy (1977b).

Land suitability criteria were developed and used to identify potentially available land for silvicultural biomass farms. Six land availability scenarios were chosen for analysis. The annual potential production of biomass energy was estimated on a regional basis assuming the use of 10 percent of the potentially available land in each of the six scenarios and estimated biomass yields. Ten hypothetical biomass farm sites were selected and described.

MITRE Corporation, Silvicultural Biomass Farms Volume IV: Site-Specific Production Studies and Cost Analyses Technical Report #7347. Washington, D.C.: U.S. Energy Research and Development Administration, Division of Solar Energy (1977c).

This report evaluates the concept of silviculture energy farms for the production of wood/bark feedstocks for conversion into useful energy products by selecting 10 sites representing a variety of climatic, topographic and land use situations. Six of the ten sites were representative of "preferred" site conditions or of locations where plantings might reasonably be placed in the future. The authors developed estimates of yield, farming costs, energy inputs, and energy outputs for these ten sites.

Monteith, D.B., "Energy Production and Consumption in Wood Harvest," CRC Handbook of Energy Utilization in Agriculture, pp. 449-464. Boca Raton, FL: CRC Press, Inc. (1980).

This chapter provides a variety of energy balance tables for a wide range of forest conditions, management practices and type of harvest.

Mudge, L.K. et al, Investigation of Catalyzed Steam Gasification of Biomass, Battelle Pacific Northwest Laboratory, Report PNL 3695. Washington, D.C.: U.S. Department of Energy (January 1981).

Mueller Associates, Inc., Price/Cost Parity Between Ethanol and Petroleum, Baltimore, MD (July 1979).

This analysis reviews data on the relationship between the price of petroleum and the price of corn, using data from the Energy and U.S. Agriculture, 1974 Data Base and a 1974 Bonner and Moore Associates' Study. Cost data for ethanol production came from Midwest Solvents' Kansas plant.

The results employ assumptions that favor the economics of ethanol production, and therefore the authors warn that the parity price of gasohol is probably higher than the value found — approximately $47/bbl. of crude petroleum, if the ethanol is produced in a coal-fueled plant.

Valuable data sets in this report include:

- A chart of energy consumed in MBtu/acre and Btu/gallon ethanol vs. fuel type.
- A chart of costs per gallon of ethanol and gasohol distilled by steam from oil and coal vs. the price of crude petroleum.

Municipal Environmental Research Lab, "Fuel and Energy Production By Bioconversion of Waste Materials: State-of-The Art," by Ware, S.A. Silver Spring, MD: Ebon Research Systems (August 1976).

This report is a state-of-the-art summary of biological processes for converting waste cellulose materials (agricultural, municipal and lumbering wastes) to fuels. It indicates the locations and quantities of suitable wastes and discusses the status of the current processing schemes. The processes discussed are: Acid hydrolysis followed by fermentation; enzyme hydrolysis followed by fermentation; anaerobic digestion of manure and municipal solid waste; and, biophotolysis. (Data base abstract).

Onstad, C.A., and Otterby, C.A., "Crop Residue Effects on Runoff," Journal of Soil and Water Conservation 34:2 (1979).

Crop residues on the soil surface decrease runoff from all storm sizes and eliminate runoff from most small storms. Runoff reductions and consequent increases in soil water storage are greatest on less permeable soils. The increase in soil water storage is greatest in the southeastern U.S. (Author's abstract).

Office of Technical Assessment, "Land Availability," Energy from Biological Processes, Vol. II — Technical and Environmental Analyses. Washington, D.C.: Office of Technology Assessment (1980).

This chapter discusses marginal lands available for biomass. Cropland is defined as "land used for the production of adapted crops for harvest, alone, or in a rotation with grasses and legumes."

The authors use Soil Conservation Service 1977 data.

Pettersson, E., "Bio-Energy in Sweden," Bio-Energy Conference Proceedings. Washington, D.C.: Bio-Energy Council (1980).

This article provides a description of Sweden's planned use of biomass resource for energy.

Pimentel, D., Handbook of Energy Utilization in Agriculture. Boca Raton, FL: CRC Press (1980).

Pimentel, D., et al, "Biomass Energy from Crop and Forest Residues," Science 212, pp. 1110-1115 (June 5, 1981).

Plummer, G.M., "Harvesting Cost Analysis," Logging Cost and Production Analysis Timber Harvesting Report #4. Long Beach, MS.: Forestry and Harvesting Training Center, USM Gulf Park Campus (1977).

This source presents various methods of analyzing factors of costs and production in logging for use in logging production analyses, and reports data collected over several years of field analysis from several forest product companies and universities.

Posselius, J. and Stout, B.A., "Crop Residue Availability for Fuel," East Lansing, MI: Michigan State University Agricultural Engineering Department (August 1980).

This paper presents a computer program that takes into account all relevant factors and calculates the amount of crop residue available from each individual field. The most apparent limitations of the computer program are how well the data input reflects the actual system and the users knowledge of the area being analyzed. A brief look at crop residues role in soil maintenance and the methodology used in this program will help resolve the limitations. (abbreviated author abstract).

Quinney, D.N., "Economics of Utilizing Residues From Logging—Problems and Opportunities," Forest Product Residues. AICHE Symposium Series 71 (146). New York, New York: American Institute of Chemical Engineers (1975).

Ranney, J.W. and Cushman, J.H., "Silvicultural Options and Constraints in the Production of Wood Energy Feedstocks," Bio-Energy Conference. Washington, D.C.: Bio-Energy Council (1980).

Producing wood for use as energy feedstock is neither simple nor clearly economically competitive with alternative fuels or other users of wood at this time although its local availability can dictate its use for energy. Preliminary evaluations of existing wood vegetation, climatic and soil limitations, land availability, existing wood use, and silvicultural (forestry) management alternatives indicate that the United States could annually produce the equivalent of about 10 exajoules of wood for energy almost immediately and perhaps 13-15 exajoules by the year 2000 — a significant energy source. Schemes for production to reach these figures range widely in energy investment, energy return, compatibility with local site conditions, and regional productive capability. Major barriers to the production of wood for energy include collection/procurement methods, environmental impacts, and viability of using wood feedstocks of fuel versus other uses. (Author's abstract).

Robertson, L.S., and Mokma, D.L., "Crop Residue and Tillage Considerations in Energy Conservation" (East Lansing, MI: Michigan State University Extension Bulletin E-1123, February 1978).

Robinson, J.S., ed., Fuels From Biomass-Technology and Feasibility. Park Ridge, NJ: Noyes Data Corporation (1980).

This book contains excerpts on magnitude and location of biomass sources and specifics on the quantities of forestry residues, including amounts, composition, etc. The book also: (1) includes logging and mill residues; (2) presents some cost data on forestry residues; (3) discusses the energy farm concept in general and silvicultural biomass farms in particular: (a) the design concept; (b) tree species considered; (c) distributions, yields; (d) characteristics; (e) process elements; (f) constraints, (g) energy consumption; (h) projections of current trends.

Rocks, L., Fuels for Tomorrow. Tulsa, OK: Pennwell Books (1980).

This book assesses synfuels and other potential fuel sources. In the chapters on alcohol fuels, the author presents a brief discussion of the various alcohol synthesis methods.

Rose, A.B., Energy Intensity and Related Parameters of Selected Transportation Modes: Freight Movements. Springfield, VA: NTIS, # ORNL-5554 (June 1979).

A study was undertaken to determine the causes of the divergences among published energy intensity values and to prepare a set of consistent values. This volume presents the findings in relation to the freight transportation modes. After a brief overview of the important factors to be considered and the potential pitfalls facing users and analysts of energy intensity values, each of the major means of freight transportation — air, marine, pipelines, rail, and truck — is discussed. In each of the chapters, after a critique of the available data sources, a consistent time series of operational data and energy intensity values is presented for the major sectors of each mode. In addition, the energy-use effects of the major operational and hardware parameters are quantified so that the given energy intensity values may be modified to reflect a variety of possible changes in the transportation systems. Finally, matrices giving the great-circle distances and modal circuity ratios among the 50 largest standard metropolitan statistical areas are included to facilitate intermodal comparisons. (Author's abstract).

Ruthenburg, K., and Dunwoody, J.E., Agricultural Energy Requirements and Land Use Patterns in Illinois. Springfield, IL: Illinois Dept. of Business and Economic Development, Springfield Division of Energy (1976).

This report was undertaken by the Illinois Division of Energy to evaluate the energy impact of remaining agricultural production caused by withdrawing land from agricultural production. An assessment was made on the energy impact in terms of the additional energy needed to produce more corn and soybeans on less area of land. Both direct and indirect energy impacts have been assessed. (Data base abstract).

Schnittker Associates, Ethanol: Farm & Fuel Issues. Washington, D.C.: National Alcohol Fuels Commission (1980).

The current U.S. and world grain situations are described as well as adjustments which would be likely for fuel production of 1, 2 and 4 billion gallons of ethanol annually in the 1985-86 period. Predicted acreage shifts in corn, soybeans, wheat, and the total of seven major crops are shown. The most likely effects on the feed grains markets both here and abroad are discussed. The value of corn for fuel both with and without the gasoline tax exemption is compared to the actual farm price expected if in the base case (1 billion gallons) real corn prices do not rise. In the higher 2 and 4 billion gallon cases, increases in the real cost of corn and its impact on food prices and the CPI are estimated. A theoretical maximum level of ethanol production recognizing market factors is discussed in terms of acreage, yield, corn production and the fuel ethanol available. Agricultural and other policy frameworks are discussed. (Author's abstract).

Segal, M.R., Alcohol Fuels: Methanol, Ethanol, Gasohol, Issue Brief #1874087. Washington, D.C.: Congressional Research Service (1979).

Skidmore, E.L.; Kumal, M.; and Larson, W.E., "Crop Residue Management for Wind Erosion Control in the Great Plains," Journal of Soil and Water Conservation 34:2 (1979).

We delineated those croplands in the Great Plains where crop residues might be removed without exposing the soil to wind erosion. On the basis of grain yield data, we estimated the residues produced per unit of land by crops. We determined mean soil erodibility and climatic factors for each of 29 major land resource areas and used these factors in the wind erosion equation to estimate the residues needed to control wind erosion. The residues produced in excess of those needed for soil conservation depend on the kind and amount of residues, soil erodibility, climate, tillage management, and judgment of erosion and degradation hazard. (Author's abstract).

Smith, D.M. and Johnson, E.W., "Silviculture: Highly Energy Efficient," *Journal of Forestry* 75:4, p. 208 (1977).

This article presents techniques of intensive silviculture that require increased amounts of oil. More wit, imagination, and intelligence may be forms of administrative attention that can reduce energy consumption. No foundation exists in the implication that intensive silviculture is in the same trap as modern agriculture. Savings possible in nitrogen fertilization and mechanical site preparation of regeneration are discussed. (Data base abstract).

Smith, N. and Corcoran, T.J., "The Energy Analysis of Wood Production for Fuel Applications," *Symposium of Net Energetics of Integrated Synfuel Systems.* Orono, Maine: *University of Maine* (1976).

This paper discusses types of wood harvesting equipment; typical production rates and fuel consumption figures for this equipment; energy use in tree length wood production system and a whole tree chip system; and probable energy requirements for a short-rotation wood fuel crop.

Southwide Energy Committee, "Petroleum Product Consumption and Efficiency in Systems for Energy Wood Harvesting," Jackson, MS (1980).

Reports petroleum product consumption for 6 harvesting systems practiced in the southeastern United States. Includes mechanized whole tree harvesting.

Szego, G.C.; Fraser, M.D.; and Henry, J.F., *Design, Operation, and Economics of the Energy Plantation as an Alternate Source of Fuels.* Warrenton, VA: *Intertechnology/Solar Corporation* (1978).

This paper discusses the use of an energy plantation to grow plants to be converted to methanol, with this methanol used as a fuel source. The authors estimate the amount and location of land that could be used in such an energy plantation effort. An analysis of the economics of energy plantations includes a breakdown of fuel costs.

Tillman, D.A., *Wood as an Energy Resource III Wood Fuel Farms or Plantations.* New York, New York: *Academic Press* (1978).

This source evaluates wood fuel farm or plantation concept, discussing:

- minimum operating conditions
- detailed energy trajectory (energy inputs vs. energy outputs)
- energy efficiencies
- limitations of concept.

The author concludes that a measurable energy contribution from wood energy farming will not occur until the twenty-first century.

TRW, *Energy Balances in the Production and End-Use of Alcohols Derived from Biomass.* Washington, D.C.: *National Alcohol Fuels Commission* (1980).

This volume is the most extensive study on the net energy of ethanol. However, the study is limited to the production of inputs from Illinois and a processing plant in Illinois.

Within those limitations, the study considers corn, corn/sweet sorghum, and cellulose; and several fermentation processes fueled by residual oil, natural gas, coal and bagasse. The study finds a positive net energy for all of these cases.

The report also contains data on energy investments in refined petroleum products, natural gas production, coal production and electric power generation.

Tyner, Wallace E., ed., "The Potential of Producing Energy from Agriculture," Energy From Biological Processes Vol. III - Appendixes. Washington, D.C.: Office of Technology Assessment (September 1980).

Tyson, Belzer and Associates, 1979 Energy Use Survey. Washington, D.C.: The Fertilizer Institute (1980).

This source provides tables of energy consumption by type of fertilizer and type of fuel.

U.S. Department of Agriculture, Economic Research Service, Structure of Six Farm Input Industries. Washington, D.C.: USDA, ERA-357 (1968).

This pamphlet presents ten pages of information on each of the following six industries:

- Petroleum
- Farm Machinery and Equipment
- Fertilizers
- Chemical Pesticides
- Livestock Feeds
- Farm Credit

For each industry, the pamphlet describes the relationship between that industry and the farm industry. This includes the dollar input into farming from each industry, as well as the unit input.

For this study, the pamphlet lists the plant locations of major fertilizer mixing plants.

U.S. Department of Agriculture, Agricultural Statistics, 1978. Washington, D.C.: GPO (1978).

U.S. Department of Agriculture, Forest Service, The Outlook for Timber in the United States, (1974) FRR No. 20.

This report contains 1970 data on commercial timberland, other forest lands, wood types, plant residues, etc, as well as projected trends to 2020.

U.S. Department of Agriculture, Forest Service -- North Central Experiment Station. Final Report: Forest Residues Energy Program. St. Paul, MN: U.S. Forest Service (1978).

U.S. Department of Agriculture, Forest Service — Draft Cost and Feasibility of Harvesting Beetle — Killed Lodgepole Pine in Eastern Oregon. Portland, Oregon: Pacific Northwest Forest and Range Experiment Station (1980).

U.S. Department of Energy, Energy Information Administration, Annual Report to Congress, Vol. 2. Washington, D.C.: DOE (1979).

This source contains data on the thermal content of fuels, by type and ton or barrel equivalent, as appropriate.

U.S. Department of Transportation and U.S. Department of Energy, National Energy Transportation Study. Washington, D.C.: DOT (July 1980).

This study provides data on the movements of fuel by type and mode. It is an update to Congressional Research Service, National Energy Transportation, Vol. I: Current Systems and Movements.

U.S. Environmental Protection Agency, Preliminary Environmental Assessment of Biomass Conversion to Synthetics Fuels. Washington, D.C.: Industrial Environmental Research Laboratory, EPA-600/ 7-78-204 (1978).

This document discusses the concept of silvicultural biomass farming including process components for intensive management, and contains information on candidate species, cultivation practices, harvesting schedules and practices, storage needs and constraints, and projections of current trends and recommendations.

U.S. House of Representatives, Committee on Science & Technology, Subcommittee on Energy Development and Applications, Oversight/Alcohol Fuels. Washington, D.C.: GPO (February 22, 1980).

These hearings concern the economics of the production of alcohol fuels, and the size and type of government assistance programs.

U.S. House of Representatives, Committee on Science & Technology, Subcommittee on Advanced Energy Technology & Energy Conservation Research Development and Demonstration, Opportunities for Energy Savings in Crop Production. Washington, D.C.: GPO (January 1978).

This report notes that the largest opportunities for energy savings in crop production are in irrigation, crop drying and nitrogen fertilizer alternatives. The report recommends cloud seeding instead of irrigation; solar crop drying; and alternative feedstocks for nitrogen production.

U.S. Senate, Energy Security Act, Report #96-824 (1980).

This report contains legislation on the mandate to DOE and USDA to develop programs, research, and incentives toward increasing production of alcohol fuels. This legislation included the development of the OAF at DOE.

U.S. Senate, Committee on Agriculture, Nutrition, and Forestry; Subcommittee on Agricultural Production, Marketing and Stabilization of Prices, The Effect of Alcohol Fuels Development on Agricultural Production, Price Support Programs and Commodity Reserves. Washington, D.C.: GPO (March 14, 1980).

These hearings present views favoring additional production of alcohol fuels.

Van Arsdale, R.T., and Rall, E., Energy and U.S. Agriculture: 1974 Data Base, Volume I, Part A. U.S. Series of Energy Tables and Part B. State Series of Energy Tables. Washington, D.C.: Federal Energy Administration (September 1976)..

This report presents the results of a comprehensive investigation of energy use in U.S. agricultural production for the year 1974. Energy consumption estimates are presented for both national and state levels by fuel type, fertilizer and pesticides, by commodity, by month, and by categories of functional use, including irrigation and crop drying. (Data base abstract).

Weisz, Paul B. and John F. Marshall, "High Grade Fuels from Biomass Farming: Potentials and Constraints," Science 206:4414, pp. 24-29 (October 5, 1979).

This highly mathematical article assesses current technology used to produce fuel grade alcohol. The authors find that every gallon of grain alcohol generated will consume between two and three gallons of high grade fuel.

The analysis looks at corn, wheat and sorghum, among other possible feedstocks.

White, W.C., Energy and Fertilizer Supplies. Washington, D.C.: The Fertilizer Institute (1977).

This paper examines the cost of fertilizer in terms of dollars and energy.

White, W.C., Energy Problems and Challenges in Fertilizer Production. Washington, D.C.: The Fertilizer Institute (1974).

This paper discusses the problems of natural gas curtailment and the high energy consumption of the fertilizer industry.

White, W.C. and Johnson, K.T., Energy Requirements for the Production of Phosphate Fertilizers. Washington, D.C.: The Fertilizer Institute (undated).

Energy use per unit of phosphate product is presented for individual processes and products. Data for the former are exclusive of energy content of any raw material input to the respective product, whereas the latter include energy used in both the process and in material inputs. This separation of energy requirements facilitates energy accounting for downstream conversion products. (Author's abstract).

Zavitkovski, J., "Energy Production in Irrigated Intensively Cultured Plantations of Populus 'Tristis #1' and Jack Pine," Forest Science 25:3, pp. 383-392 (1979).

Energy budgets were prepared for irrigated intensively cultured plantations of Populus 'Tristis #1' and jack pine in northern Wisconsin. Energy inputs into biomass production (site preparation, fertilization, weed control, irrigation, and harvesting) and into material processing (chipping and drying) amounted to about 20 percent of the total energy at age 10. The available energy (after deducting energy inputs) in 10-year old plantations of Populus 'Tristis #1' and jack pine was 2,353 and 1,863 MBtu/ha, respectively, which is equivalent to the energy in 430 and 340 barrels of oil. This was 43 and 13 percent more energy than that reported for highly productive, nonirrigated, intensively cultured stands in eastern United States. Net energy returns were linearly and positively correlated with energy invested in both irrigated and nonirrigated intensively cultured plantations and a naturally regenerated forest. This indicates that energy invested in irrigation brings commensurate energy returns. The available energy from forest biomass, which is negligible when compared with the total energy consumption in the United States, could be increased by a widespread application of existing agronomic technology. (Author's abstract).

Zerbe, J.I., "Impacts of Energy Developments on Utilization of Timber in the Northwest," Proceedings of Northwest Private Forestry Forum. Portland, Oregon (1978).

DOE|CS|50005--T1-App.G-H

DOE/CS/50005--T1-App.G-H

DE83 000370

ENERGY INPUTS AND OUTPUTS OF FUEL-ALCOHOL PRODUCTION.

APPENDICES G AND H.

METHANOL FROM COAL

Prepared for the

Office of Vehicle and Engine Research and Development
U.S. Department of Energy

AC01-80CS50005

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

April, 1982

Prepared by

JACK FAUCETT ASSOCIATES, INC.
5454 Wisconsin Avenue
Chevy Chase, Maryland 20015

and

BATTELLE-COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

LIST OF EXHIBITS

LIST OF EXHIBITS (Continued)

ABBREVIATIONS

B	billion
Btu	British thermal unit
C	degrees Centigrade
cu ft	cubic foot
F	degrees Fahrenheit
gal	gallon
HHV	higher heating value
hp	high pressure
hr	hour
kw	kilowatt
kwhr	kilowatthour
lb	pound
lp	low pressure
M	thousand
MM	million
psia	pounds per square inch absolute
psig	pounds per square inch gauge
T	trillion
ton	2,000 lb
wt	weight
yr	year

BTU CONVERSION FACTORS

Fuel	Units	HHV
Coal	Btu/ton	22,500,000[a]
Distillate	Btu/gal	140,000
Electricity Consumption	Btu/kwhr	3,413
Ethanol	Btu/gal	84,200
LPG	Btu/gal	95,000
Lubricating Oil	Btu/gal	145,000
Methanol	Btu/gal	64,350
Motor Gasoline	Btu/gal	125,000
Natural Gas	Btu/cu ft	1,020
Petrochemicals	Btu/gal	125,000
Residual Fuel Oil	Btu/gal	150,000

ELECTRICITY CONVERSION FACTOR

Fuel	Btu's consumed/Btu electricity produced
Coal	3.05

---

[a] *When no specific coal characteristics were known, the energy content of a "standard ton" of coal (22,500,000 Btu) was used. Other values were used when more appropriate and are indicated in footnotes.*

SI CONVERSION FACTORS

1 acre = 4046.8564 square meters
1 bbl = 158.98284 liters
1 Btu = 1054.35 joules
1 cu ft = 0.028316847 cubic meters
1 gal = 3.7854118 liters
1 lb = 453.592 grams
1 mile = 1609.344 meters
1 psi = 0.0680460 atmospheres
1 ton = 907184.74 grams
273.15 + 5/9(F-32) = degrees Kelvin
273.15 + C = degrees Kelvin

OTHER CONVERSION FACTORS

1 acre = 0.40468564 ha
1 bbl = 42 gal
1 Btu = 252 calories
1 bu barley = 48 lb
1 bu corn = 56 lb
1 bu grain sorghum = 56 lb
1 bu oats = 32 lb
1 bu wheat = 60 lb
1 psi = 6895 pascals
1 square mile = 640 acres

APPENDIX G

COAL

Since the turn of the century, coal has been losing its energy market share to oil and natural gas. By 1949, coal was still the primary energy resource in the U.S. supplying nearly 41 percent of the nation's energy needs, but this was down from 90 percent in 1900. Coal's steady decline in energy market share continued until the last decade.

The decline in domestic production of oil and gas and the increasing cost of these premium fuels, dramatized by the two oil embargoes, ended and then reversed this decline in coal's market share. In each of the years 1973-1978, coal accounted for about 18 percent of U.S. energy consumption, with this share rising to 19.1 percent in 1979 and 20.6 percent in 1980 (U.S. Department of Energy (DOE), 1981c). A comparison of coal's share of the energy market with those of the other energy sources is provided in the following table.

U.S. CONSUMPTION OF ENERGY BY SOURCE – 1980

Source	10^{15} Btus	Percent of Total
Coal	15.674	20.6
Natural Gas	20.437	26.8
Petroleum	34.249	44.9
Hydroelectric	3.126	4.1
Nuclear	2.704	3.5
Other	0.114	0.1
Total	76.267	100.0

Source: U.S. Department of Energy, 1981c.

The increase in coal's market share is likely to continue as the rising price of oil makes substitution of coal more attractive.

The primary coal user will continue to be the electric utility industry. In 1980, electric utilities consumed 569.2 million tons of coal or 81 percent of the total coal consumed (DOE, 1981c). The conversion of on-line, oil-fired electric generating capacity to coal and Congressional legislation[1] forbidding the building of oil-fired electrical generating capacity will further increase the use of coal by electric utilities.

The following table shows that, after utilities, the industrial sector is the second largest consumer of coal, followed by the residential/commercial Sector. The transportation sector presently consumes only negligible amounts of coal. However, as stated in Section 1, there is a potential for the indirect use of coal as a transportation fuel by converting the coal to a liquid fuel suitable for use in the existing market.

U.S. ENERGY USE BY SOURCE

(in percent)

Source	Electric Utilities	Industry	Residential Commercial	Transportation
Coal	77.4	21.4	1.2	—
Natural Gas	18.5	41.1	37.4	3.0
Petroleum	8.8	25.9	12.8	52.5

Source: U.S. Department of Energy, 1981c.

In this section, the energy consumed in mining coal for eventual conversion to methanol is analyzed. Energy consumption estimates are developed for both underground and surface mining methods.

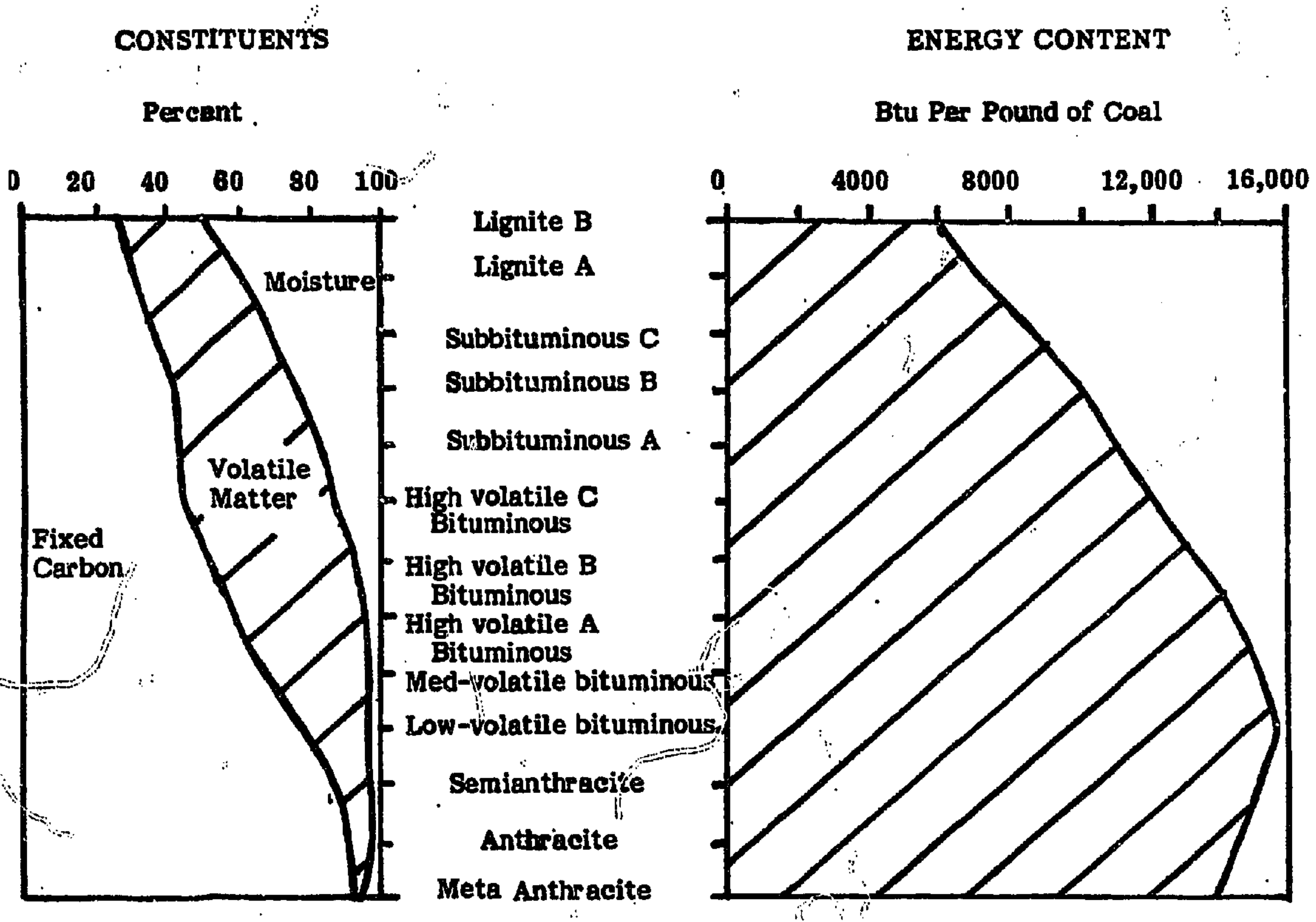
G.1 Mine Location

Coal deposits are generally distinguished by their carbon content as well as moisture content and heating value. The different coal types or ranks, by increasing carbon content, are: lignite, subbituminous, bituminous, and anthracite coals. Heating value or the Btu content per pound peaks at 14,000 Btu with the low volatility bituminous coals (see Exhibit G-1).

---

[1] *The Powerplant and Industrial Fuel Use Act of 1978 (P.L. 95-620).*

EXHIBIT G-1: CHARACTERISTICS AND ENERGY CONTENTS OF DIFFERENT COAL RANKS



SOURCE: Cuff and Young, 1980.

The distribution of coal reserves in this country is shown, in tabular form, in Exhibit G-2 and in the U.S. Geological Survey (USGS) map reproduced as Exhibit G-3. The first of these exhibits gives the demonstrated reserve base[1] by coal rank, State, and whether the coal is appropriate for mining by surface or underground methods. About 90 percent of these reserves are bituminous or subbituminous coal. Most of the subbituminous coal is located in Montana and Wyoming, identified as the Northern Great Plains Province on the USGS map. Much of the bituminous coal is located in the Eastern Province (i.e., the Appalachian Region) and the eastern part of the Interior Province (i.e., Illinois, Indiana and Western Kentucky).

All types of coal are suitable for gasification (the first step in the production of methanol); however, not all sources of coal are equally likely to be used for producing methanol (or other coal-derived synthetic fuels). In particular, coal used for such purposes is most likely to come from areas containing large volumes of coal which can be mined economically and, preferably, where adequate water supplies can be obtained.

A methanol production facility must be sited in coal resource areas where sufficient quantities of coal for methanol conversion are available over and above near-term coal demands. Any one methanol plant must be large enough to achieve appropriate economies of scale. Current projections place economic plant capacity in the range of 6,000 to 25,000 tons of coal per day. This places a constraint on coal resource size. Assuming a plant life of 20 years and a 300-day per year operating schedule, between 36 million and 150 million tons of coal would be needed to supply the methanol production facility. Exhibit G-4 shows the coal regions which have the greatest potential for supplying the large volumes of coal required for this purpose.

The most economic means of transporting large volumes of methanol is by pipeline. Since pipeline transport of methanol is both less costly and more energy efficient than transport of the coal (by rail or slurry pipeline) required to produce the methanol, location of the methanol plant in the vicinity of the coal source is generally preferred.

Gasification processes, however, require substantial amounts of water for cooling and as a source of hydrogen. The particular gasification process assumed in the present analysis requires 5.3 gallons of water for each gallon of methanol produced, or 82

---

[1] *The demonstated reserve base consists essentially of those coal resources which are deemed economically and legally available for mining.*

ON JANUARY 1, 1976, ACCORDING TO RANK AND POTENTIALLY MINEABLE BY UNDERGROUND AND SURFACE METHODS
(in millions of tons)

STATE	ANTHRACITE		BITUMINOUS		SUBBITUMINOUS		LIGNITE		TOTAL[a]	
	UND.	SURF.	UND.	SURF.	UND.	SURF.	UND.	SURF.	UND.	SURF.
Alabama	—	—	1,724.2	284.4	—	—	—	1,083.0	1,724.2	1,367.4
Alaska	—	—	617.0	80.5	4,805.9	640.7	—	14.0	5,473.0	735.2
Arizona	88.6	—	—	325.5	—	—	—	—	—	325.5
Arkansas	25.5	7.8	163.1	107.0	—	—	—	25.7	251.7	140.5
Colorado	—	—	8,467.9	676.2	3,972.1	149.2	—	2,965.7	12,465.4	3,791.0
Georgia	—	—	0.5	0.4	—	—	—	—	0.5	0.4
Idaho	—	—	4.4	—	—	—	—	—	4.4	—
Illinois	—	—	53,128.1	14,841.2	—	—	—	—	53,128.1	14,841.2
Indiana	—	—	8,939.8	1,774.5	—	—	—	—	8,939.8	1,774.5
Iowa	—	—	1,736.8	465.4	—	—	—	—	1,736.8	465.4
Kansas	—	—	—	998.2	—	—	—	—	—	998.2
Kentucky	—	—	17,582.9	8,418	—	—	—	—	17,582.9	8,418
Louisiana	—	—	—	—	—	—	—	b	—	b
Maryland	—	—	913.8	134.5	—	—	—	—	913.8	134.5
Michigan	—	—	125.2	1.6	—	—	—	—	125.2	1.6
Missouri	—	—	1,418.0	3,596.0	—	—	—	—	1,418.0	3,596.0
Montana	—	—	1,385.4	—	69,573.5	33,843.2	—	15,766.8	70,958.9	44,610.1
New Mexico	2.3	—	1,258.8	601.1	889.0	1,846.8	—	—	2,150.1	2,447.9
North Carolina	—	—	31.3	0.4	—	—	—	—	31.3	0.4
North Dakota	—	—	—	—	—	—	—	10,145.3	—	10,145.3
Ohio	—	—	13,090.5	6,139.8	—	—	—	—	13,090.5	6,139.8
Oklahoma	—	—	1,192.9	425.2	—	—	—	—	1,192.9	425.2
Oregon	—	—	b	—	14.5	2.9	—	—	14.5	2.9
Pennsylvania	6,966.8	142.7	22,335.9	1,391.8	—	—	—	—	29,302.7	1,534.4
South Dakota	—	—	—	—	—	—	—	426.1	—	526.1
Tennessee	—	—	627.2	337.9	—	—	—	—	627.2	337.9
Texas	—	—	—	—	—	—	—	3,181.9	—	3,181.9
Utah	—	—	6,283.8	267.9	1.1	—	—	—	6,284.9	267.9
Virginia	137.5	—	3,277.0	888.5	—	—	—	—	3,414.5	888.5
Washington	—	—	255.3	—	835.3	481.5	—	8.1	1,090.6	489.5
West Virginia	—	—	33,457.4	5,149.1	—	—	—	—	33,457.4	5,149.1
Wyoming	—	—	4,002.5	—	27,644.8	23,724.7	—	—	31,647.2	23,724.7
Total east	7,104.3	142.7	155,233.7	39,362	—	—	—	1,083.0	162,337.9	40,587.7
Total west	116.4	7.8	26,785.9	7,543	107,736.2	60,689.0	—	32,533.6	134,638.4	100,773.3
U.S. TOTAL[a]	7,220.7	150.5	182,019.6	46,905.0	107,736.2	60,689.0	—	33,616.6	296,976.3	141,361.0

[1] Includes measured and indicated resource categories as defined by the U.S. Bureau of Mines and U.S. Geological Survey and represents 100% of the coal in place.

a. Data may not add to totals shown due to rounding.

b. Quantity undetermined.

Source: U.S. Department of Energy, 1980.

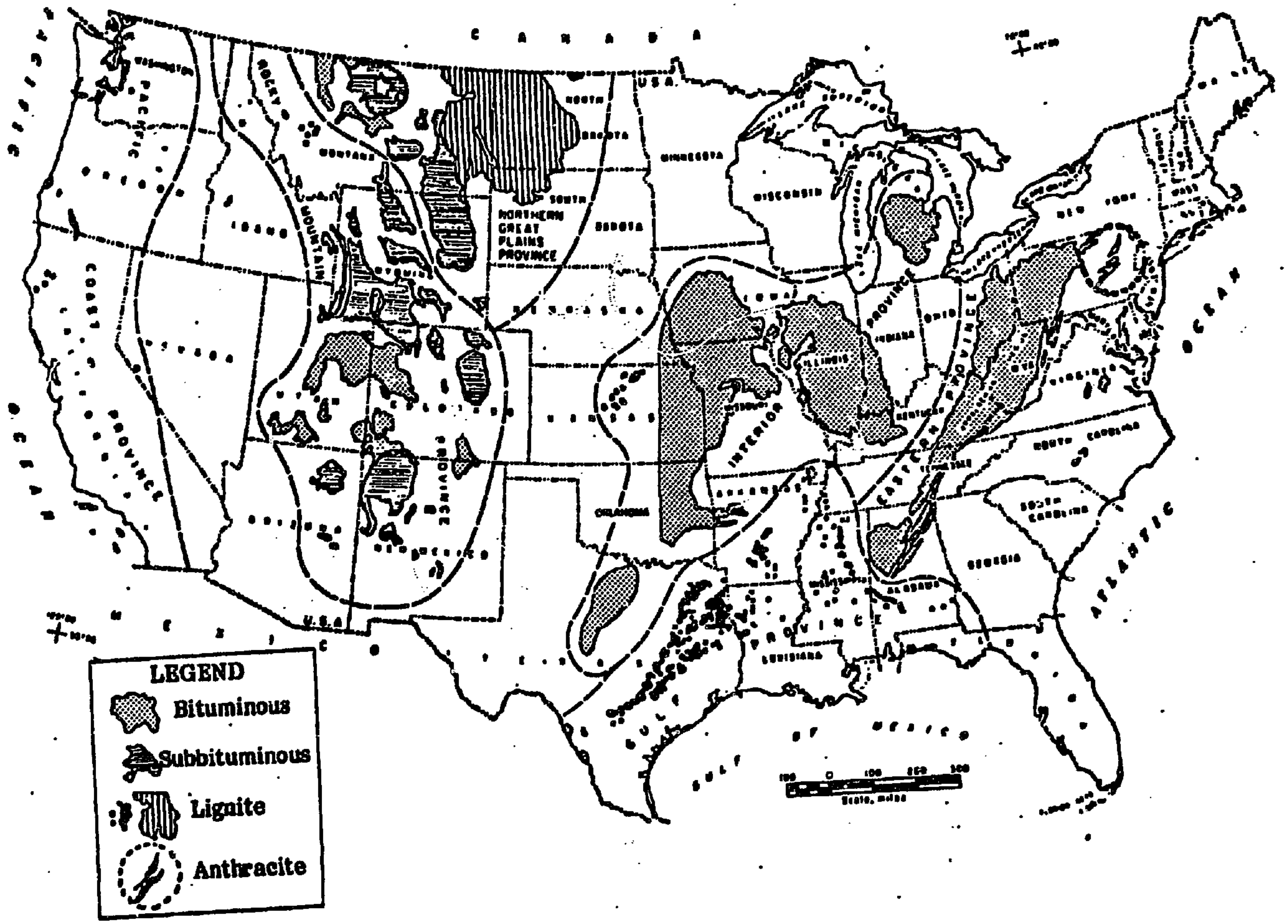


EXHIBIT G-3: COAL FIELDS OF THE CONTIGUOUS UNITED STATES

Source: U.S. Department of Energy, 1980. Adapted from U.S.G.S. Coal Map of the United States, 1960.

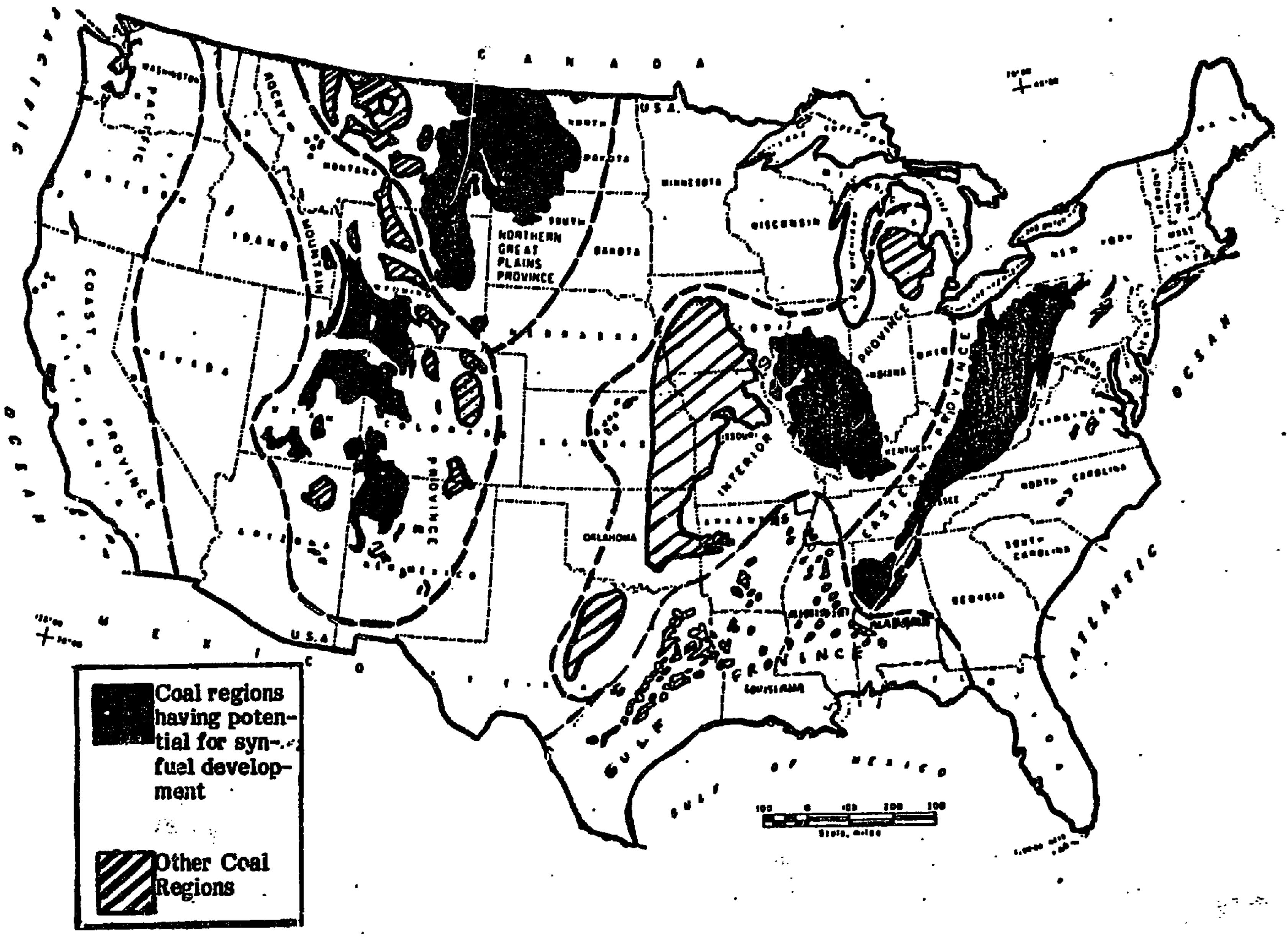


EXHIBIT G-4: COAL RESOURCES MOST LIKELY TO BE USED FOR SYNFUELS PRODUCTION

Source: U.S. Department of Energy, 1980. Adapted from U.S.G.S. Coal Map of the United States, 1960. U.S. Department of Interior, Geological Survey, 1979.

gallons of water per million Btu of methanol (McGeorge, 1976). (Coal mining, by comparison, typically requires between 0.5 and 2.5 gallons per million Btu.) Other synfuel processes may require less water. In particular, direct liquefaction processes do not require the large amounts of process water required for medium and high-Btu gasification, and water consumption of all processes can be reduced (at substantial cost) by recycling of cooling water. Nonetheless, all synfuel processes are considered to be major consumers of water.

As a result, many of the Western regions identified in Exhibit G-4 as having potential for providing coal for synfuel facilities may not contain appropriate sites for the location of these facilities, either because local water is insufficient to supply such facilities or because the water is already fully appropriated to other uses. These areas, as well as those having both sufficient coal resources and sufficient unappropriated water supplies, are depicted in Exhibit G-5.

The analysis presented in this report presumes a minemouth location for the methanol plant. However, it is likely that synfuel plants will be constructed at non-minemouth locations as well as minemouth locations. In addition to lack of water, reasons for selecting non-minemouth locations may include labor costs and availability and related socio-economic factors. The lack of water in a specific area thus does not mean that coal in that area may not be appropriate for supplying synfuel plants located in areas where sufficient water is more readily available.

G.2 Mining Technology

The two most significant methods of underground mining methods are room-and-pillar and longwall mining. Commonly used with either method are continuous miners and loaders which convey the coal away from the cutting face and automatically load the coal onto shuttle cars or conveyors. In the United States, most of the coal mined underground is removed by the room-and-pillar method. Longwall mining involves taking successive slices over the length of a long working face. It is used extensively in Europe but has only recently been introduced in this country. Longwall methods can remove more coal than room-and-pillar methods, though at some increased risk of mine subsidence. For coal seams whose location makes it possible to tolerate some subsidence, and particularly for seams located at relatively greater depths, the use of longwall methods should increase. For coal beds up to 10-feet thick, longwall methods can recover up to 85 percent of the coal, while room-and-pillar methods can recover

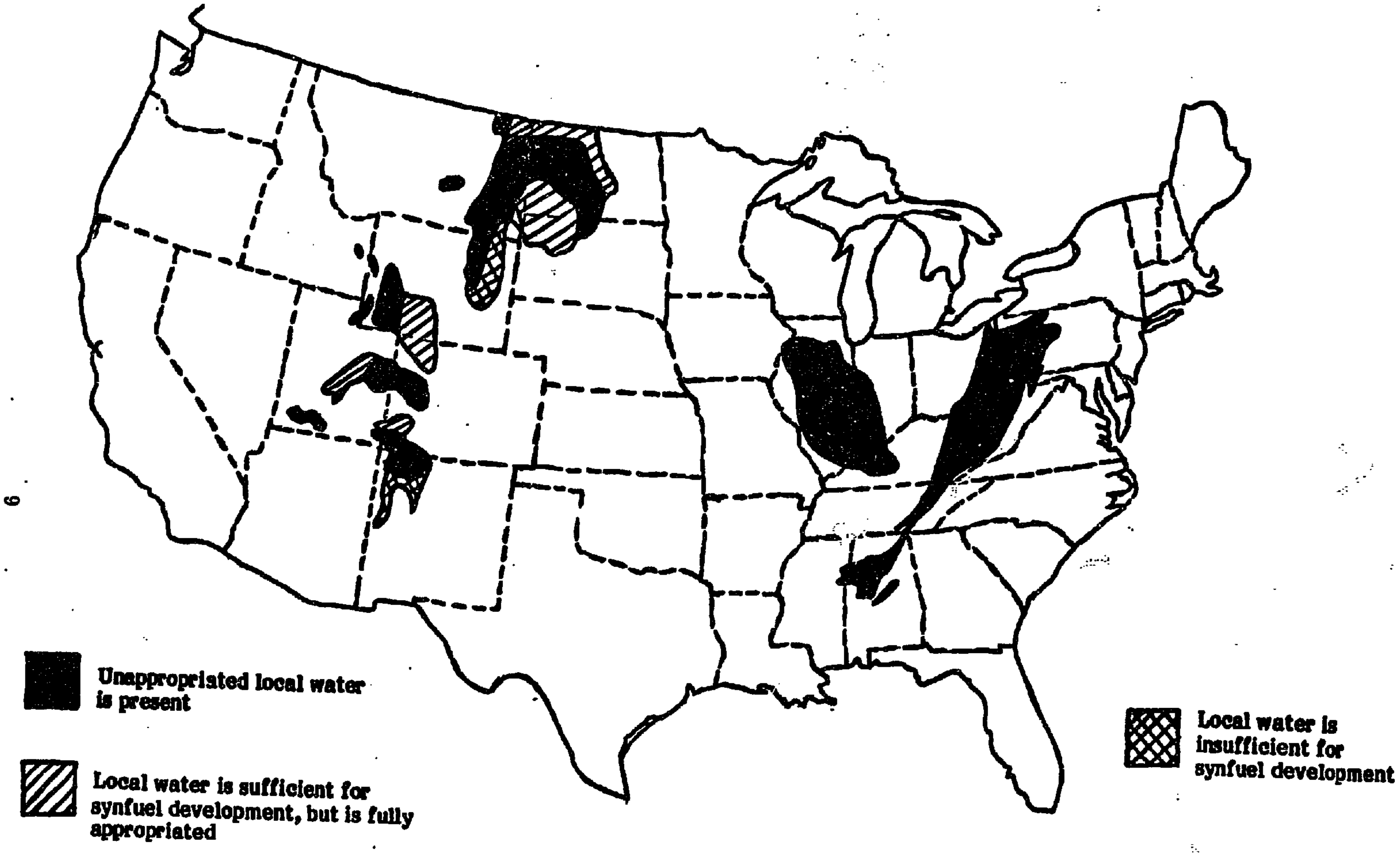


EXHIBIT G-5: WATER RESOURCES AVAILABLE FOR ADDITIONAL USE IN AREAS OF POTENTIAL SYNFUELS DEVELOPMENT

SOURCE: U.S. Department of Interior, 1979.

only 57 percent (Cuff and Young, 1980). The recovery rates for both types of mining drop sharply for thicker seams, but, for any seam thickness, they are always greater for longwall mining.

Most of the equipment used in underground mining is powered by electricity, thus avoiding the problem of venting exhaust gases from diesel-driven equipment. Continuous underground mining machines also use a large amount of lubricating oil, both on moving parts and at the working face. Energy requirements increase with increasing seam depth (because of the deeper shafts which are required) and with decreasing seam thickness (because of the greater area over which a given amount of coal is spread).

Surface mining methods include strip mining and auger mining. Strip mining is further subdivided into area mining, contour mining, and mountaintop removal. Of these methods, area mining is the most common and the only method analyzed in the present study. Coal recovery for strip mining methods averages around 80 to 90 percent.

For surface mines requiring the removal of large amounts of overburden, electricity is the most common form of energy used. Usually, such mines utilize electricity supplied by coal-burning power plants located nearby. Petroleum products are used as fuel for diesel-powered equipment, mixed with ammonium nitrate for use as an explosive, and used for lubrication. Petroleum usage is most significant when coal seams are located near the surface and which thus can be mined by diesel-powered equipment (Berkshire, 1981). As is the case for underground mines, energy requirements increase with increasing seam depth (because of the greater amount of overburden which must be removed) and with decreasing seam thickness (because of the greater area over which a given amount of coal is spread).

G.3 Energy Consumed in Mining

For reasons discussed in Section 4.1 of the Summary Volume, energy consumed in coal mining does not enter into the estimates of overall energy consumption of methanol production. Nonetheless, since coal mining is a significant step in the production of methanol from coal, the energy requirements of this step are of interest. Estimates of average energy consumed per ton for all coal mined are developed in this section as well as estimates for several specific underground and surface mines.

G.3.1 National Average Energy Consumption

Estimates of national average energy consumed in coal mining are presented in Exhibit G-6. These estimates were derived from 1977 Census data on electricity, fuels and explosives consumed by the bituminous coal and lignite mining industry (U.S. Department of Commerce (DOC), 1980b and 1981) and from 1977 DOE data on bituminous coal and lignite mined (DOE, 1979d). Estimates of the energy required to produce explosives are based on data for prilled (i.e., pelletized) ammonium nitrate presented in Exhibit G-7. (Estimates of energy required to produce other explosives could not be obtained because the processes are considered proprietary. These explosives, all of which use ammonium nitrate as a base, may be somewhat more energy intensive than ammonium nitrate; however, they represent less than fifteen percent of all explosives used in coal mining.)

Total energy consumption is about 326,000 Btu per ton of coal mined. If, as assumed, all electricity used is generated from coal, more than half the energy consumed (168,000 Btu) is from coal. Petroleum products (predominantly lubricating oil and diesel fuel) account for about thirty percent of energy consumption. The manufacture of explosives accounts for nearly ten percent of energy consumption and most of the natural gas consumption.

G.3.2 Energy Consumed by Specific Mines

The national data presented in Exhibit G-6 fail to distinguish between underground and surface mines or between large mines and small mines. Accordingly, additional analysis was performed to obtain estimates of energy consumption by moderately large underground and surface mines.

The primary source of data used for these analyses was a series of reports on the capital investment and operating costs of underground and surface coal mines produced by the U.S. Bureau of Mines (BOM) of the U.S. Department of the Interior (1975d; 1976a; 1976c) and DOE (1977; 1978c; 1979a). These reports present estimates of capital and operating costs of typical mines producing various amounts of coal from seams of selected depths and thicknesses in several parts of the country. These included estimates of electric power requirements and direct fuel costs.

EXHIBIT G-6: ENERGY CONSUMPTION PER TON OF MINED COAL

		Petroleum Products						
	Assumptions	Motor Gasoline (gal)	Lubricating Oil and Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Bituminous coal and lignite mining industry (SIC 121)	Total production in 1977: 601.3 MM tons (1)							
	Total energy consumption in 1977:							
	— Electricity (2): 10,145 MM kwhr					0.006730*		151,400
	— Direct Fuels (2 and 3): Gasoline: 61.5 MM gal Distillate: 368.7 MM gal Residual: 52.3 MM gal Natural Gas: 1697 MM cu ft Coal: 474,400 tons	0.089	0.533	0.0757	2.5	0.000686	97,100	146,200 (4)
	— Explosives (3): Ammonium nitrate: 1601 MM lbs Other explosives: 222 MM lbs 1823 MM lbs			0.0005	26.5	0.000070	100	28,750
TOTAL BITUMINOUS COAL AND LIGNITE INDUSTRY		0.089	0.533	0.0762	29.0	0.007486	97,200	326,300

*Based on use of 22,500,000 Btu per ton coal.

Sources:
(1) DOE, 1979d.
(2) DOC, 1981.
(3) DOC, 1980b.
(4) Estimated directly from source data. Includes other purchased fuels and undistributed fuels.

EXHIBIT G-7: ENERGY CONSUMED IN PRODUCING PRILLED AMMONIUM NITRATE

	Energy Consumption per Pound of Ammonium Nitrate		
	Physical Units		Btu
Residual Fuel	0.0002	gal	29
Natural Gas	10.19	cu ft	10,393
Coal	0.000027	tons	685*
			11,107

*Based on use of 22,500,000 Btu per ton coal.

Sources: Tyson, Belzer and Associates, 1980.
Davis and Blouin, 1976.

Note: Energy requirements for all explosives were assumed to be equal to those for ammonium nitrate (see text).

These reports contain data for sixteen mines, twelve of which are designed to produce a minimum of two million tons annually. Each of these mines could thus produce enough coal to supply the 1.8 million tons of coal required annually by the smallest methanol plant considered to be economic. The largest of the mines is designed to produce five million tons annually. Two to four of these twelve mines would be required to supply the 7.5 million tons required annually by the largest plant currently contemplated.

The twelve mines consist of seven underground mines and five surface mines. The major characteristics of each of these mines, including their size, seam depth and seam thickness, are presented in Exhibit G-8. The mining plans assumed by BOM and DOE are summarized in Exhibit G-9, and the power-driven equipment requirements are shown in Exhibit G-10.

The BOM and DOE reports provide estimates of electricity consumption by underground mines and of the daily cost of electricity for surface mines, as well as the daily cost of fuel for all mines. The cost figures were converted into estimates of energy consumption by dividing by appropriate estimates of unit cost. For surface mines, the cost of electricity was based on the cost used by DOE (1978c) for underground mines in 1978 (3 cents/kwhr) and indexed on the basis of data on the average annual cost of electricity to industrial users from DOE's Monthly Energy Review (1981c). For all mines, the cost of distillate and residual fuel were based on the average cost of these fuels to bituminous and lignite coal mines in 1977 (DOC, 1981) (43.45 and 41.8 cents per gallon, respectively) and indexed on the basis of average annual price data from the Monthly Energy Review.

The energy consumption estimates reflect the use of fuels and electrical energy in the following operations:

- Strip mining
  - removal of overburden
  - removal of coal
  - restoration of sites
  - transfer of coal out of the pit
- Underground mining
  - opening of shafts

EXHIBIT G-8: CHARACTERISTICS OF SELECTED COAL MINES

Mining Operation	Mine Number	Mining System	Average Coal Seam Depth (ft)	Average Coal Seam Thickness (inches)	Acres Per Year of Coal Resource Mined	Mine Output (MM tons per year)	Index Year For Cost	Source
• Underground —Bituminous	(1)	Continuous Room and Pillar	800	72	7,600[a]	2.38	1978	1
	(2)	Continuous Room and Pillar	800	48	10,035[b]	2.06	1975	2
	(3)	Continuous Room and Pillar	800	72	6,639[b]	2.04	1975	3
	(4)	Continuous Room and Pillar	800	48	15,053[b]	3.09	1975	2
	(5)	Continuous Room and Pillar	800	72	10,326[b]	3.10	1975	3
	(6)	Continuous Room and Pillar	800	72	16,228[b]	4.99	1975	3
	(7)	Continuous-Longwall	800	48	10,305[c]	2.60	1976	4
• Surface —Bituminous Interior Province	(8)	Area	70	60	415[d]	3.36	1977	5
—Subbituminous Northern Great Plains Province	(9)	Area	65	684	55[d]	5.0	1977	5
	(10)	Area	120	360	84[d]	4.0	1979	6
—Lignite Northern Great Plains Province	(11)	Area	60	240	98[d]	3.0	1979	6
	(12)	Area	50	120	327[d]	5.0	1979	6

(a) Assumes 57 percent recovery; 1,830 tons of coal per acre-foot with a 20 year life.
(b) Assumes 57 percent recovery; 1,800 tons of coal per acre-foot with a 20 year life.
(c) Assumes 70 percent recovery; 1,830 tons of coal per acre-foot with a 20 year life.
(d) Assumes 90 percent recovery.

Sources:
(1) DOE, 1978
(2) BOM, 1975d.
(3) BOM. 1976c.
(4) BOM, 1976b.
(5) DOE, 1977.
(6) DOE, 1979a.

EXHIBIT G-9: MINING PLANS FOR SELECTED COAL MINES

Mining Plan Descriptions

(1) 12 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 300 tons of coal per shift.

(2) 10 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 312 tons of coal per shift.

(3) 9 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 344 tons of coal per shift.

(4) 15 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 312 tons of coal per shift.

(5) 14 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 344 tons of coal per shift.

(6) 22 continuous miner units operating 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 344 tons of coal per shift.

(7) 4 continuous miner units develop panels for the 4 longwall units; both units operate 3 shifts per day, 5 days per week, 220 days per year, for 20 years assuming each unit averages 300 and 700 tons of coal per shift, respectively.

(8) overburden blasted and removed by electric dragline; electric shovel and diesel front-end loader load coal into trucks; diesel bulldozer and scraper remove and replace topsoil; overburden is removed 3 shifts per day, 345 days per year, for 20 years; coal loading operates 2 shifts per day, 220 days per year, for 20 years.

(9) diesel tractor scraper removes topsoil; coal loaded with electric dragline and shovels into trucks; overburden is removed 3 shifts per day, 345 days per year, for 20 years; coal loading operates 2 shifts per day, 220 days per year, for 20 years.

(10, 11, 12) diesel tractor scraper removes topsoil; overburden drills, stripping equipment, loading shovels, pumps, and lighting equipment operated by electric power; overburden removed by electric dragline and diesel bulldozer; coal loaded by electric shovel and diesel front-end loader into trucks; overburden removed 3 shifts per day, 345 days per year, for 20 years; coal load operates 2 shifts per day, 220 days per year, for 20 years.

EXHIBIT G-10: EQUIPMENT USED IN SELECTED COAL MINES

EXHIBIT G-10: EQUIPMENT USED IN SELECTED COAL MINES

	Continuous Miner	Longwall Miner	Loading Machine	Shuttle Car	Roof Bolter	Ratio Feeder	Aux. Fan	Mentrip Jeep	Mechanic Jeep	Personnel Jeep
● Underground										
(1)										
quantity	12		12	24	12	12	12	12	10	6
horsepower	600		160	135	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	4	10	10
kw used at full load	5,371		1,432	2,417	448	1,119	269	134	34	34
(2)										
quantity	10		10	20	10	10	10	10	5	6
horsepower	220		160	100	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	6	15	15
kw used at full load	1,641		1,194	1,492	373	933	224	112	56	34
(3)										
quantity	9		9	18	9	9	9	9	4	6
horsepower	600		160	135	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	6	15	15
kw used at full load	4,028		1,074	1,813	336	839	201	101	45	34
(4)										
quantity	15		15	30	15	15	15	15	6	10
horsepower	220		160	100	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	6	15	15
kw used at full load	2,462		1,790	2,238	560	1,399	336	168	67	56
(5)										
quantity	14		14	28	14	14	14	14	6	8
horsepower	600		160	135	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	6	15	15
kw used at full load	6,266		1,671	2,820	522	1,305	313	156	67	45
(6)										
quantity	22		22	44	22	22	22	22	10	10
horsepower	600		160	135	50	125	30	15	15	7.5
hrs. at full load	15		15	15	18	15	18	6	15	15
kw used at full load	9,847		2,626	4,431	821	2,052	492	246	112	56
(7)										
quantity	4	4	4	8	4	4	4	8	6	6
horsepower	550	625	160	135	50	125	15	15	15	7.5
hrs. at full load	10	16	10	10	12	10	18	4	15	15
kw used at full load	1,641	1,865	477	806	149	373	45	90	67	45

EXHIBIT G-10: EQUIPMENT USED IN SELECTED COAL MINES
(Continued)

Rock	Supply	42-Inch	Ventilation	Outside Elec.	Extra for Pumps,	Shops, Lighting,

EXHIBIT G-10: EQUIPMENT USED IN SELECTED COAL MINES
(Continued)

	Rock Duster	Supply Motor	42-Inch Conveyor	36-Inch Conveyors		Ventilation Fans	Outside Elec. Equip.	Hoists	Extra for Pumps, etc.	Shops, Lighting, etc.
• Underground										
(1)										
quantity	12	5	4	4	4					
horsepower	30	80	125	100	50					
hrs. at full load	12	12	15	15	15	24	14	15	10	24
kw used at full load	269	298	373	298	149	746	895	1,343	448	463
(2)										
quantity	10	4	3	2	10	1				
horsepower	30	80	125	100	50	500				
hrs. at full load	12	12	15	15	15	24			10	
kw used at full load	224	239	280	149	373	373			373	
(3)										
quantity	9	5	3	2	7	1				
horsepower	30	80	125	100	50					
hrs. at full load	12	12	15	15	15	24			10	
kw used at full load	201	298	280	149	261	373			373	
(4)										
quantity	30	7	3	3	12	1				
horsepower	30	80	200	100	50	500				
hrs. at full load	12	12	15	15	15	24			10	
kw used at full load	671	418		224	448	373			373	
(5)										
quantity	14	6	3	12		1				
horsepower	30	80	200	150		500				
hrs. at full load	12	12	15	15		24			10	
kw used at full load	313	358	448	560		373			373	
(6)										
quantity	22	8	3	20						
horsepower	30	80	300	150						
hrs. at full load	12	12	15	15		24				10
kw used at full load	492	477	671	895		373				522
(7)										
quantity	5	3		12		1				
horsepower	30	80		100		500			400	
hrs. at full load	12	12		16		24			10	24
kw used at full load	112	179		395		373			298	482

• Surface	Bull-dozer (diesel)	Tractor Scraper (diesel)	Front-end Loader (diesel)	Crawler Drill (diesel)	Crawler Drill (electric)	Crawler Shovel (electric)	Walking Dragline (electric)	Haul Trucks (diesel)
(8) quantity	2	1	1	—	1	1	1	7
(9) quantity	2	1	1	—	1	2	1	9
(10) quantity	1	—	1	—	1	1	1	7
(11) quantity	1	—	1	—	1	1	1	5
(12) quantity	1	—	1	—	1	1	1	7

- removal of coal
- transfer of coal out of the mine
- handling of slag, spoil and refuse

The estimates presented for underground mines are based on surveys of Eastern underground mines, particularly in northern West Virginia, but they can be assumed to be reasonably representative of all underground mines of the indicated size (two to five million tons per year) operating on seams of the indicated depth (800 feet) and thickness (48 or 72 inches). An 800-foot seam depth and 48 to 72-inch seam thickness is fairly typical of mines in the Appalachian and eastern Interior coal resource areas; however, coal seam thickness and depth in the Western states is far more variable. Exhibit G-11 summarizes data on seam thickness and depth of major new underground and surface mines which have been planned or proposed. It can be seen that in the West, where only the most economically attractive resources are presently of commercial interest, planned mines are limited to seams which lie at relatively shallow depths and/or are relatively thick.

The BOM and DOE reports do not contain information on explosives required for individual mines. Accordingly, estimates of explosives required were derived from national data on explosives used in coal mining and total coal produced. These are shown in Exhibit G-12. The data in this exhibit divide explosives used in 1977 between underground and surface mines. This division was inferred from the division existing in 1972 (DOC, 1975) and the assumption that the rate of growth of explosives used per ton of coal mined would be the same for both types of mines.

Since a minemouth location has been assumed for the methanol plant, the energy consumed in transporting the coal from the mine entrance to the plant will be minimal and has not been included in the analysis. (However, the energy required to transport the coal within the mine from the seam face to the loading station is included as part of the estimate of mining energy requirements.) Secondary energy inputs, such as energy consumed in the production of the equipment used, have also been excluded from the analysis.

The resulting estimates of energy consumption per ton are presented in Exhibit G-13 for the seven underground mines and in Exhibit G-14 for the five surface mines. A summary of estimated energy consumption for the twelve mines is presented in Exhibit

EXHIBIT G-11: FUTURE COAL MINES PROJECTED TO EXPAND FUEL
SOURCES IN EASTERN AND WESTERN STATES

EXHIBIT G-11: FUTURE COAL MINES PROJECTED TO EXPAND FUEL SOURCES IN EASTERN AND WESTERN STATES

		No. of New Mines		Coal Seam Thickness (inches)		Overburden Depth (feet)	
Region	State	Underground	Surface	Underground	Surface	Underground	Surface
East	Alabama	13	6	34 - 78	20 - 40	500 - 2500	NR
	Georgia	—	5	—	10 - 22	—	50 - 75
	Illinois	9	6	60 - 100	48	200 - 950	65 - 100
	Indiana	1	4	72	48 - 65	450*	30 - 100
	Kentucky	19	8	50 - 72	60 - 72	300 - 1000	50 - 125
	Maryland	1	—	56 - 100	—	NR	—
	Ohio	10	2	48 - 66	48	70 - 530	60*
	Pennsylvania	28	2	40 - 85	NR	160 - 540	NR
	Tennessee	2	1	36 - 40	36	NR	150*
	Virginia	10	—	NR	NR	60 - 84	NR
	West Virginia	47	15	40 - 101	30 - 50	735*	NR
West	Alaska	—	1	—	240 - 600	—	shallow
	Arkansas	1	—	47 - 72	—	500 - 1000	—
	Colorado	46	31	48 - 324	36 - 480	250 - 2200	2 - 260
	Montana	—	12	—	144 - 720	—	4 - 200
	New Mexico	1	15	NR	48 - 128	NR	150 - 200
	North Dakota	—	10	—	24 - 300	—	0 - 150
	Oklahoma	7	12	36 - 72	16*	600 - 1400	NR
	Texas	—	5	—	24 - 180	—	47 - 70*
	Utah	28	3	60 - 168	132*	1200*	90*
	Wyoming	5	22	48 - 192	36 - 1440	300 - 1800	0 - 710

NR: Not reported *only one figure reported (-): zero

Source: BOM, 1978.

EXHIBIT G-12: EXPLOSIVES USED IN BITUMINOUS COAL AND LIGNITE MINING

	Explosives Used (MM lbs)			Coal Produced (MM tons)	Explosives Used (lbs) per Ton of Coal
	Ammonium Nitrate	Other	Total		
1972					
Total Industry (1)	899.6	92.0	991.6	595.4	1.67
1977					
Total Industry (2)	1,601.0	221.5	1,822.5	691.3	2.63
Underground Mines (3)	9.4	75.5	84.9	265.9	0.32
Surface Mines (3)	1,591.6	146.0	1,737.6	425.4	4.1

Sources:

(1) DOC, 1975 and DOI, 1973.
(2) DOC, 1981 and DOE, 1979d.
(3) Coal production from DOE 1979d; explosives used estimated from data in above sources.

EXHIBIT G-13: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC UNDERGROUND MINING OPERATIONS

EXHIBIT G-13: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC UNDERGROUND MINING OPERATIONS

		Petroleum Products						
Coal Type and Mining Method	Assumptions	Motor Gasoline (gal)	Lubricating Oil and Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	Mine parameter data presented in order of seam depth in feet (D), seam thickness in inches (T), acres of resource mined per year (A/yr), and mine output in millions of tons per year (MMt/yr) Source is cited in parentheses.							
Mine #1	800' D; 72" T; 7,600 A/yr; 2.38 MMt/yr (1)							
Bituminous Coal	— Electricity, 255,500 kwhr/day (1), 220 days/yr					0.01092*		245,800
Continuous Room and Pillar Mining System	— Direct Fuels $350,000/yr (1978) for lubricating and hydraulic oil (1) at 40.3¢/gal (2)		0.365				52,900	52,900
	— Explosives 0.32 pounds per ton of coal (see Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #1 (Underground, Bituminous, 2.38 MMt/yr)		0.365	0.00007	3.26	0.01093	52,900	302,300

*Based on use of 22,500,000 Btu per ton coal.

**Less than 50 Btu.

Sources:				
	(1)	DOE, 1978c.	(4)	DOE, 1978a.
	(2)	DOC, 1980c; DOE, 1981c.	(5)	BOM, 1976c.
	(3)	BOM, 1975d.	(6)	BOM, 1976b.

EXHIBIT G-13: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC UNDERGROUND MINING OPERATIONS
(Continued)

Coal Type and Mining Method	Assumptions	Petroleum Products		Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
		Motor Gasoline (gal)	Lubricating Oil and Distillate (gal)					
Mine #2	800' D; 48" T; 10,035 A/yr; 2.06 MMt/yr; (3)							
Bituminous Coal	— Electricity, 121,941 kwhr/day (3)					0.00602*		135,500
Continuous Room and Pillar Mining System	— Direct Fuels 514,800/yr (1975) for lubricating and hydraulic oil (3) at 36.8¢/gal (2)		0.679				98,500	98,500
	— Explosives Equivalent to 0.10 pounds of ammonium nitrate per ton of coal (Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #2 (Underground, Bituminous, 2.06 MMt/yr)		0.679	0.00007	3.26	0.00603	98,500	237,600
Mine #3	800' D; 72" T; 8,639 A/yr; 2.04 MMt/yr; (5)							
Bituminous Coal	— Electricity, 156,787 kwhr/day (5)					0.00782*		176,000
Continuous Room and Pillar Mining System	— Direct Fuels $510,800/yr (1975) for lubricating and hydraulic oil (5) at 36.8¢/gal (2)		0.68				98,600	98,600
	— Explosives Equivalent to 0.10 pounds of ammonium nitrate per ton of coal (Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #3 (Underground, Bituminous, 2.04 MMt/yr)		0.68	0.00007	3.26	0.00783	98,600	278,200

*Based on use of 22,500,000 Btu per ton coal.

**Less than 50 Btu.

Sources:
(1) DOE, 1978c.
(2) DOC, 1980c; DOE, 1981c.
(3) BOM, 1975d.
(4) DOE, 1978a.
(5) BOM, 1976c.
(6) BOM, 1976b.

EXHIBIT G-13: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC UNDERGROUND MINING OPERATIONS
(Continued)

		Petroleum Products						
Coal Type and Mining Method	Assumptions	Motor Gasoline (gal)	Lubricating Oil and Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Mine #4	800' D; 48" T; 15,053 A/yr; 3.09 MMt/yr; (3)							
Bituminous Coal	— Electricity, 179,866 kwhr/day (3)					0.00592*		133,300
Continuous Room and Pillar Mining System	— Direct Fuels 772,200/yr (1975) for lubricating and hydraulic oil (3) at 36.8¢/gal (2)		0.679				98,500	98,500
	— Explosives 0.32 pounds per ton of coal (see Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #4 (Underground, Bituminous, 3.09 MMt/yr)		0.679	0.00007	3.26	0.000593	98,500	235,400
Mine #5	800' D; 72" T' 10,326 A/yr; 3.18 MMt/yr; (5)							
Bituminous Coal	— Electricity, 234,415 kwhr/day (5)					0.00750*		168,800
Continuous Room and Pillar Mining System	— Direct Fuels $794,700/yr (1975) for lubricating and hydraulic oil (5) at 36.8¢/gal (2)		0.678				98,300	98,300
	— Explosives 0.32 pounds per ton of coal (see Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #5 (Underground, Bituminous, 3.18 MMt/yr)		0.678	0.00007	3.26	0.00751	98,300	270,700

*Based on use of 22,500,000 Btu per ton coal.

**Less than 50 Btu.

Sources:
(1) DOE, 1978c.
(2) DOC, 1980c; DOE, 1981c.
(3) BOM, 1975d.
(4) DOE, 1978a.
(5) BOM, 1976c.
(6) BOM, 1976b.

EXHIBIT G-13: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC UNDERGROUND MINING OPERATIONS
(Continued)

		Petroleum Products						
Coal Type and Mining Method	Assumptions	Motor Gasoline (gal)	Lubricating Oil and Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Mine #6	800' D; 72" T; 16,228 A/yr; 4.99 MMt/yr; (5)							
Bituminous Coal	— Electricity, 361,260 kwhr/day (5)					0.00736*		165,700
Continuous Room and Pillar Mining System	— Direct Fuels $1,250,000/yr (1975) for lubricating and hydraulic oil (5) at 36.8¢/gal (2)		0.681				98,700	98,700
	— Explosives 0.32 pounds per ton of coal (see Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #6 (Underground, Bituminous, 4.99 MMt/yr)		0.681	0.00007	3.26	0.00737	98,700	268,000
Mine #7	800' D; 48" T; 10,305 A/yr; 2.6 MMt/yr; (6)							
Bituminous Coal	— Electricity, 108,760 kwhr/day (6)					0.00426*		95,800
Continuous-Longwall Mining System	— Direct Fuels $407,700/yr (1976) for lubricating and hydraulic oil (6) at 36.3¢/gal (2)		0.432				62,600	62,600
	— Explosives 0.32 pounds per ton of coal (see Exhibit G-7)			0.00007	3.26	0.00001	**	3,600
TOTAL	MINE #7 (Underground, Bituminous, 2.6 MMt/yr)		0.432	0.00007	3.26	0.00427	62,600	162,000

*Based on use of 22,500,000 Btu per ton coal.

**Less than 50 Btu.

Sources:
(1) DOE, 1978c.
(2) DOC, 1980c; DOE, 1981c.
(3) BOM, 1975d.
(4) DOE, 1978a.
(5) BOM, 1976c.
(6) BOM, 1976b.

EXHIBIT G-14: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC SURFACE MINING OPERATIONS

EXHIBIT G-14: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC SURFACE MINING OPERATIONS

Coal Type and Mining Method	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Lubricating Oil and Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
	Mine parameter data presented in order of seam depth in feet (D), seam thickness in inches (T), acres of resource mined per year (A/yr), and mine output in millions of tons per year (MMt/yr) Source is cited in parentheses.							
Mine #8	70' D; 60" T; 415 A/yr; 3.36 MMt/yr; (1)							
Bituminous Coal Interior Province Area Mine	— Electricity $985,600/yr (1977) (1) at 2.69¢/kwhr (2)					0.00501*		113,500
	— Direct Fuels $435,100/yr. (1977) for diesel fuel and lubricating and hydraulic oil (1) at 43.45¢/gal (2)		0.298				41,700	41,700
	— Explosives 4.1 pounds per ton of coal (see Exhibit G-7)			0.0008	26.8	0.00007	100	29,200
TOTAL MINE #8 (Surface, Bituminous, 3.36 MMt/yr)			0.298	0.0008	26.8	0.00508	41,800	184,400

*Based on use of 22,500,000 Btu per ton coal.

Sources:
(1) DOE, 1977.
(2) DOC, 1980c; DOE, 1981c.
(3) DOE, 1979a.

EXHIBIT G-14: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC SURFACE MINING OPERATIONS
(Continued)

Coal Type and Mining Method	Assumptions	Petroleum Products: Motor Gasoline (gal)	Petroleum Products: Lubricating Oil and Distillate (gal)	Petroleum Products: Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Mine #9	65' D; 684" T; 55 A/yr; 5.0 MMt/yr; (1)							
Subbituminous Coal Northern Great Plains	— Electricity $302,200/yr (1977) (1) at 2.69¢/kwhr (2)					0.00117*		23,400
Area Mine	— Direct Fuels $435,100/yr. (1977) for diesel fuel and lubricating and hydraulic oil (1) at 43.45¢/gal (2)		0.20				28,000	28,000
	— Explosives 4.1 pounds per ton of coal (see Exhibit G-7)			0.0008	26.8	0.00007	100	29,200
TOTAL MINE #9 (Surface, Subbituminous, 5.0 MMt/yr)			0.20	0.0008	26.8	0.00124	28,100	80,600
Mine #10	120' D; 360" T; 84 A/yr; 4.0 MMt/yr; (3)							
Subbituminous Coal Northern Great Plains	— Electricity $990,000/yr (1979) (3) at 3.32¢/kwhr (2)					0.00388*		77,600
Area Mine	— Direct Fuels $387,000/yr. (1979) for diesel fuel and lubricating and hydraulic oil (3) at 69¢/gal (2)		0.14				19,600	19,600
	— Explosives 4.1 pounds per ton of coal (see Exhibit G-7)			0.0008	26.8	0.00007	100	29,200
TOTAL MINE #10 (Surface, Subbituminous, 4.0 MMt/yr)			0.14	0.0008	26.8	0.00395	19,700	126,400

*Based on use of 20,000,000 Btu per ton coal.

Sources:
(1) DOE, 1977.
(2) DOC, 1980c; DOE, 1981c.
(3) DOE, 1979a.

EXHIBIT G-14: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL
FOR SPECIFIC SURFACE MINING OPERATIONS
(Continued)

EXHIBIT G-14: ENERGY CONSUMPTION ESTIMATES PER TON OF MINED COAL FOR SPECIFIC SURFACE MINING OPERATIONS
(Continued)

Coal Type and Mining Method	Assumptions	Petroleum Products Motor Gasoline (gal)	Petroleum Products Lubricating Oil and Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Mine #11	60' D; 240" T; 98 A/yr; 3.0 MMt/yr; (3)							
Lignite Northern Great Plains	— Electricity $486,000/yr (1979) (3) at 3.32¢/kwhr (2)					0.00363*		50,800
Area Mine	— Direct Fuels $297,000/yr. (1979) for diesel fuel and lubricating and hydraulic oil (3) at 69¢/gal (2)		0.143				20,100	20,100
	— Explosives 4.1 pounds per ton of coal (see Exhibit G-7)			0.0008	26.8	0.00007	100	29,200
TOTAL MINE #11 (Surface, Lignite, 3.0 MMt/yr)			0.143	0.0008	26.8	0.0037	20,200	100,100
Mine #12	50' D; 120" T; 327 A/yr; 5.0 MMt/yr; (3)							
Lignite Northern Great Plains	— Electricity $1,603,000/yr (1979) (3) at 3.32¢/kwhr (2)					0.00740		103,600
Area Mine	— Direct Fuels $699,000/yr. (1979) for diesel fuel and lubricating and hydraulic oil (3) at 69¢/gal (2)		0.203				28,400	28,400
	— Explosives 4.1 pounds per ton of coal (see Exhibit G-7)			0.0008	26.8	0.00007	100	29,200
TOTAL MINE #12 (Surface, Lignite, 5.0 MMt/yr)			0.203	0.0008	26.8	0.00747	28,500	161,200

*Based on use of 14,000,000 Btu per ton coal.

Sources: (1) DOE, 1977.
(2) DOC, 1980c; DOE, 1981c.
(3) DOE, 1979a.

G-15. Total energy consumption is between 235,000 and 303,000 Btu per ton for the room-and-pillar mines, 162,000 Btu per ton for the longwall mine, and between 80,000 and 185,000 Btu per ton for the surface mines.

Energy consumption for the room-and-pillar mines is somewhat below the 326,000 Btu per ton figure previously obtained for all coal mines, and energy consumption for the other mines is even lower. The results, however, are not completely comparable. The estimate for all coal mines includes all energy consumed by establishments engaged in mining and preparing coal. This estimate thus includes a small amount of energy consumed in cleaning coal as well as energy (and, in particular, gasoline and residual fuel) consumed in various activities conducted by such establishments but not included in the analysis of the individual mines.

Among the individual mines, Mines 1-8 produce bituminous coals. Since such coals normally contain between twenty and thirty million Btu per ton, for the room-and-pillar mines (Mines 1-6) energy consumed in mining generally represents about one percent of the energy content of the coal, while for Mines 7 and 8 this energy consumption represents less than one percent of the energy content of the coal. Mining the last four surface mines (Mines 9-12) also generally requires somewhat less than one percent of the energy content of the lower-Btu subbituminous and lignite coals being mined.

It can be seen from Exhibit G-13 that almost all primary energy consumed by underground mines is in the form of electricity and lubricating and hydraulic oil. The energy embodied in explosives represents less than two percent of total energy consumption. All electricity is presumed to be coal derived. Allowing for electric-generating losses, the energy content of the coal consumed represents between 55 and 85 percent of total energy consumption of the underground mines studied.

In the case of surface mines (see Exhibit G-14) explosives account for a more significant share of energy consumption, between 15 and 40 percent of the total. Energy embodied in explosives is primarily natural gas, though some coal and a very small amount of residual fuel are also consumed. Also required are petroleum products for operating diesel-powered equipment and for mixing with explosives. The energy content of the coal consumed (primarily for electricity generation) represents between 25 and 65 percent of the energy consumed by the surface mines studied, and that of petroleum products between 15 and 35 percent. The differences in the relative

EXHIBIT G-15: COMPARISON OF ENERGY CONSUMPTION ESTIMATES FOR VARIOUS MINES

Mine Number	Mining System	Source	Seam Depth (ft)	Seam Thickness (in)	Output (MMt/yr)	Btu/ton
Underground						
1.	Room and Pillar	DOE, 1978	800	72	2.38	302,300
2.	Room and Pillar	BOM, 1975d	800	48	2.06	237,600
3.	Room and Pillar	BOM, 1976c	800	72	2.04	278,200
4.	Room and Pillar	BOM, 1975d	800	48	3.09	235,400
5.	Room and Pillar	BOM, 1976c	800	72	3.18	270,700
6.	Room and Pillar	BOM, 1976c	800	72	4.99	268,000
7.	Longwall	BOM, 1976b	800	48	2.60	162,000
Surface						
8.	Area	DOE, 1977	70	60	3.36	184,400
9.	Area	DOE, 1977	65	684	5.0	80,400
10.	Area	DOE, 1979a	120	360	4.0	126,400
11.	Area	DOE, 1979a	60	240	2.0	100,100
12.	Area	DOE, 1979a	50	120	4.0	161,200

importance of electricity and petroleum products are primarily due to differences in the equipment used in these mines.

Energy requirements for coal mining are sensitive to seam depth and thickness and to mining technology and equipment used. Halving the thickness of a coal seam results in doubling the area which must be mined and (depending, in part, on equipment characteristics) increases energy requirements by fifty to eighty percent (Berkshire, 1981). Increasing seam depth similarly results in a somewhat less than proportional increase in energy requirements.

Because of different equipment characteristics and different engineering assumptions, the energy-consumption estimates of the various mines are not directly comparable. The estimates for room-and-pillar mining of a 72-inch seam developed in BOM, 1976c, for example, indicate that more electricity and total energy will be required than those developed in BOM, 1975d, for a 48-inch seam, though one would normally expect the reverse would be the case. The results for the various surface mines, however, are in conformity with the general rule that energy requirements increase with increasing depth and decreasing seam thickness. It is also interesting to note that the results for the three mines for which a consistent set of estimates was developed in BOM, 1976c, (Mines 3, 5 and 6) indicate a small decrease in energy consumption with increasing mine size, and that the same observation holds for the two mines for which a consistent set of estimates was developed in BOM, 1975d, (Mines 2 and 4).

G.4 Coal Transport

The energy consumption estimates presented in the preceding section represent all energy consumed in mining. As such, they include energy consumed in the removal of coal from the mine, a form of local transport which is intrinsic to the mining process. Since a minemouth location has been assumed for the methanol plant, no additional coal transport is required. If, however, the methanol plant were to be located at a greater distance from the mine, additional energy would be consumed in transport.

For several route-specific coal movements, it has been estimated (Rogozen, et.al., 1978) that transport by unit train requires between 350 and 540 Btu of diesel fuel per ton-mile and that (allowing for conversion losses) transport by slurry pipeline requires, per ton-mile, between 410 and 1300 Btu of fuel to generate electricity. Thus, for a

1000-mile unit-train haul of subbituminous coal from a Western mine to a Midwestern methanol plant, between 350,000 and 540,000 Btu of diesel fuel would be required, representing two to three percent of the energy content of the coal being transported. For corresponding transport by slurry pipeline, between 410,000 and 1,300,000 Btu of coal would be needed to generate electricity for slurrying, pumping and dewatering.

G.5 Potential Availability of Coal

DOE projections of total domestic coal production and use of coal for synthetic fuels through the year 2020 are shown in Exhibit G-16. The projections indicate that, in the next forty years, total coal production will more than quadruple. Of the 3.5 billion tons of coal to be produced in 2020, more than one-third will be used to produce synthetic fuels, and over ninety percent of that will be used to produce coal-derived liquids (DOE, 1981b). A total of 25.8 quads (quadrillion Btus) of coal is projected to be used for this purpose.

The methanol process analyzed in this study (see Appendix H) has an overall energy efficiency of 53 percent, but technologies now being developed have indicated overall energy efficiencies of up to 58 percent. Such technologies may be capable of producing about 0.57 Btu of methanol per Btu of coal.[1] If all coal which is projected to be used for production of liquids is converted to methanol at a coal-to-methanol energy efficiency of 57 percent, about 14.7 quads of methanol (230 billion gallons) will be produced.

This volume of methanol represents about 72 percent of the 20.3 quads of liquid transportation fuels consumed annually; about 84 percent of the 17.4 quads of these fuels projected to be consumed in 2020 under the scenario presented in Exhibit G-16; and about 58 percent of the 25.4 quads of liquid fuels projected to be used for all purposes in 2020 under this scenario (DOE, 1981b, Table 4.13). Thus the DOE projections indicate that, within forty years, we will be obtaining a major portion of our liquid fuels from coal-based synthetics. (The actual quantity of such fuels which would be obtained from the projected 25.8 quads of coal to be used for this purpose will, of course, depend on the efficiency of the conversion process. If processes with energy

---

[1] *The ratio of methanol energy content to coal energy content is slightly lower than the overall energy efficiency of the process because the latter value includes an energy credit for byproduct sulfur produced. (See Section H.4 for further discussion.)*

EXHIBIT G-16: PROJECTIONS OF COAL PRODUCTION AND USAGE OF COAL FOR SYNTHETIC FUELS

	1980	1985	1990	1995	2000	2010	2020
Total Production (millions of tons)	835	1,000	1,400	n.a.	1,900	n.a.	3,500
Used for Synthetic Fuels (millions of std. tons)[a,b]	0	17	111	169	182	609	1,227[b]
Coal-Oil Mixture	0	8	18	3	—	—	—
Coal Gases	0	5	55	68[c]	18[c]	49	80
Coal Liquids	0	4	38	98	164	560	1,147

n.a. — Projections of total coal production in 1995 and 2010 not available from consistent source.

[a] A standard ton contains 22.5 million Btu.

[b] Because of projected decline in average Btu content of mined coal, projections imply that actual tons devoted to synthetic fuels will be higher than indicated in table. Projections indicate coal mined in 2020 will average 21.1 million Btu. On this basis, 1308 million tons of coal will be required to supply the 27.6 quadrillion Btu of coal projected to be used by synfuels in 2020.

[c] Projections of coal used by synfuels in midterm (1985-1995) and longterm (2000-2020) developed separately, thus producing apparent discontinuity in projected production of coal gases between 1995 and 2000.

Sources: DOE, 1981b, Tables S.2, 3.29 and 4.19. Projections are for the middle oil-price scenario.
DOE, 1981c.

efficiencies exceeding 57 percent are developed, the quantity of liquid fuels to be produced will be higher; if processes are used which produce other fuels, such as gasoline or synthetic oils, but at a lower energy efficiency, the energy content of the liquid fuels will be lower.)

In evaluating this information, it is important to consider the ability of our coal resources to sustain the 3.5 billion tons-per-year production rate projected for 2020. Total identified coal resources are 1.9 trillion tons and there are an additional 2.0 trillion tons of hypothetical resources.[1] The portion of these resources which are economically and legally available for mining, however, is only 438 billion tons (DOE, 1980a). This last category of coal is known as the demostrated coal reserve base (DCRB) and its size and distribution by State was previously presented in Exhibit G-1.

It is not possible to recover all coal in the DCRB. BOM estimates of recoverable reserves are usually based on a 50 percent recovery factor for underground mining and an 80 percent recovery factor for surface mining, though some observers use higher rates (Cuff and Young, 1980). Applying the more conservative 50 percent and 80 percent factors to the DCRB data in Exhibit G-1 yields an estimate for recoverable reserves of 262 billion tons. Of these reserves, 43 percent would be mineable by surface methods with the remainder requiring underground methods.

Defining recoverable coal reserves in this way clearly requires some interpretation. Much of the coal in these reserves is less attractive to mine from both economic and net-energy standpoints than coal which has been mined in the past. Much of the most economically mined Eastern coal has already been mined; mining in the East, in the future, will turn increasingly to seams which are thinner, lie at greater depths, or have higher sulfur content than seams mined in the past. As the economically attractive coal seams currently being mined in the West are played out, mining of less attractive seams will be necessary in the West as well. Thus, as our recoverable reserves are depleted, some increase in the energy required for mining (currently about 1.5 percent of coal energy content) and transporting coal will result.

---

[1] *"Hypothetical coal resources" consist of estimated resources in unexplored parts of known coal basins and are limited to a depth of less than 6000 feet.*

On the other hand, recoverable reserves are, to some extent, expandable. Improved coal-recovery techniques (such as longwall mining) will increase the recoverability factors. New coal reserves may be discovered. And the increasing value of coal will eventually make mining of thinner seams or at deeper depths economic (though the increasing energy requirements of such mining will place a limit on the extent to which mining of deep coal and coal in thin seams will ever become economic).

With the foregoing discussion in mind, it may be observed that, at an annual 3.5 billion-ton rate of production, this country's 262 billion tons of recoverable reserves will last about 75 years. Allowing for coal to be consumed between now and 2020, a 3.5 billion-ton annual rate of production achieved in 2020 and maintained in subsequent years would result in exhausting the 262 billion tons of recoverable reserves in about 2070. Our recoverable coal reserves thus appear to be sufficient to support the rate of coal production being projected for 2020 for a reasonably long time, but certainly not forever. DOE's projected rates of coal production for 2020 (3.5 billion tons for all purposes, 1.3 billion tons for synthetic fuels) thus appear to be reasonable, but it would not appear to be prudent to set a target much above this level.

On the basis of this discussion, it may be concluded that it is reasonable to expect to obtain as much as 15 quads of liquid fuels annually from coal. This volume represents nearly 75 percent of present annual consumption of liquid transportation fuels, and about 70 percent of projected annual consumption of liquid fuels for all purposes in the year 2020. Whether or not methanol will be one of these synthetic fuels will depend upon both the relative economics of methanol-fueled and conventionally fueled engines and the relative economics of the competing coal-conversion processes, as well as on energy-efficiency, environmental, safety and health factors and on governmental policy.

APPENDIX H

METHANOL FROM COAL

This appendix describes the estimated energy requirements to convert mined coal to fuel grade methanol. Investigation of the further conversion of methanol to gasoline (using the Mobil M or similar technology) is beyond the scope of this study. Neither does this study attempt to evaluate all the individual steps within a process required for methanol production in terms of their being altered in order to lower the overall energy balance.

H.1 Selection of Technology

The Texaco-gasification/ICI methanol-synthesis process was selected for evaluation in this study. This process was chosen because it is near commercial readiness and appears economically competitive. As can be seen from Exhibit H-1, the Texaco and Koppers KBW gasifiers[1] are the most popular technologies for the methanol production projects that have applied to the Synthetic Fuels Corporation for subsidies. ICI is one of the most frequently used methanol-synthesis technologies.

While coal properties may dictate the selection of the gasification process, published studies indicate that methanol processes using the Texaco gasifier are superior to those using the Koppers-Totzek (K-T), Lurgi, Winkler, and British Gas Council (BGC)-Lurgi Slagger processes in terms of overall energy requirements and applicability to different coals (McGeorge, 1976; Chow et al., 1977). The Texaco gasifier has been considered for many of the coal gasification feasibility studies for plants to be built in the immediate future. In addition, the Texaco system has the ability to gasify both eastern and western U.S. coals.

For the liquefaction step, the ICI low-pressure synthesis was selected because it is an established process, and, as shown in Exhibit H-1, it is widely used for commercial methanol synthesis. It is a good example of typical technology. Lurgi, Mitsubishi Gas Chemicals (MGC), Haldor-Topsoe and Wentworth also offer commercial methanol

---

[1] *The KBW gasifier is also a near-commercial gasifier. It is a newer design than the Koppers-Totzek (K-T) system. KBW has a different heat transfer system and increased capacity compared to K-T, but the gas composition and energy efficiency are similar.*

EXHIBIT H-1: PROPOSED METHANOL PROJECTS

Name	Location	Gasifier	Methanol Synthesis	Further Conversion
Beluga Methanol Project	Granite Point, AK	Winkler	ICI	
Chokecherry (Energy Transition Corp)	Moffat County, CO	Koppers KBW	n.a.	
Mapco Synfuels Inc.	White County, IL	Texaco	Lurgi	
Clark Oil & Refining	St. Clair County, IL	n.a.	n.a.	
W.R. Grace	Edmonson County, KY	Texaco	n.a.	
Convent Methanol Project (Texaco)	Convent, LA	Texaco	n.a.	
Whitehorn Gasification Project (Hercules, Norfolk & Western)	Montgomery County, MD	n.a.	n.a.	Mobil
EG&G	Fall River, MA	Texaco	n.a.	
Grants Project (Energy Transition Corp)	Grants, NM	n.a.	n.a.	
Peat-to-Methanol Project (Energy Transition Corp)	Croswell, NC	Koppers KBW	n.a.	
A-C Valley Corp.	Venango County, PA	Koppers	ICI	Mobil
Keystone Project (Westinghouse)	Cambria & Somerset Counties, PA	Westinghouse	n.a.	
Tennessee Synfuels Associates (Koppers + Citgo)	Oak Ridge, TN	Koppers (KBW)	ICI	Mobil/MTG
Energy Synfuels Associates	Emery County, VT	Lurgi dry bottom	n.a.	
Hampshire Energy (Kaneb Service, Koppers Northwestern Mutual Life)	Gillette, WY	Lurgi and Koppers KBW	n.a.	Mobil/MTG

n.a. = not available

SOURCE: Alcohol Week, 2, 3 (April 6, 1981).

technology. Chem Systems is developing a methanol technology, but as it is not commercially proven it has not been considered in this analysis. However, the Chem Systems process is more energy efficient than the ICI process. The Chem Systems process has higher heat recovery from the methanol reactor and lower compression energy, because of lower operating pressure requirements for the gasifier (Chia, et al., 1979).

The ICI methanol synthesis is used in many commercial installations throughout the world. In late 1979, there were 24 commercial methanol plants in operation and five in design or construction using the ICI technology. This compares to seven operating Lurgi methanol plants (plus four under construction) and eight MGC (plus three in design or construction).

Other process steps, such as the air separation and oxygen compression, shift, acid-gas removal, Claus sulfur plant, tail-gas treatment, and coal preparation, are all standard established processes and may be considered to have comparable energy requirements for the same input/output stream characteristics. Their selection depends more on the coal properties and operating pressure levels in the system as a whole.

Coal gasification technologies may be generally classified into three groups: fixed-bed technology, fluidized-bed technology, and entrained-bed technology. Some of the established processes are: Lurgi (fixed bed), Winkler (fluidized bed), Texaco (entrained-bed), and K-T (entrained bed). Although these processes had a significant number of applications in the past, it appears from recent preliminary screenings that, for methanol synthesis, the Texaco process is superior to the other processes in terms of overall thermal efficiency, coal use, oxygen requirements and capital investment (McGeorge, 1976; Chow et al., 1977). The higher operating pressure of the Texaco gasifier compared to the others contributes to the higher overall thermal efficiency in methanol synthesis. Other pressurized gasifiers (for example pressurized Winkler) would be expected to give similar overall process efficiencies. Full-scale Texaco coal-gasification units are now being built in the U.S. for demonstration purposes.

The Texaco process may be applied to a wide variety of caking and non-caking bituminous and subbituminous coals. However, the conventional Lurgi and Winkler gasifiers are limited to non-caking coals. In the United States these coals are found primarily in the West.

Oxygen-blown coal gasification systems (where gasification takes place in the presence of pure oxygen, rather than air) have higher overall thermal efficiencies, lower unit product capital requirements, and increased product yields than the air-blown systems. All the above mentioned processes can be operated as oxygen-blown processes. For methanol synthesis from coal, oxygen-blown gasification would be preferred. An oxygen-blown system would produce medium-Btu gas while an air-blown system would produce low-Btu gas.

H.2 Process Description

Exhibit H-2 presents a simplified flow diagram of the overall process.

Coal of size 8" x 0 is conveyed from the mine to a 15-day storage pile.[1] Coal from this pile is then reduced to 3/4" x 0 size in Ring Mill crushers. A portion of the 3/4" x 0 coal is combined with wet char in a double-shaft paddle mixer. This mix then serves as the boiler fuel.

By means of regulating feeders, 3/4" x 0 coal from a surge bin is discharged into rod mills for wet grinding to 14 mesh x 0. The amount of water added to the mill is controlled by a density controller located at the discharge of each mill. A slurry is formed of 50-54 percent solids by weight. The slurry is next pumped to ball mills where the solids are reduced so that 80 percent are sized less than 200 mesh. The slurry is stored in a day-tank to serve the gasification section.

The oxygen plant section consists of an air separation plant and a compressor. An air-separation plant, operating at 92 psig, produces oxygen for the gasifier. The oxygen is then compressed to 935 psig in steam-driven centrifugal compressors. Air cooling is used in the intercoolers; water cooling is used in the turbine exhaust steam-condensers.

The preheated coal slurry and oxygen are introduced through a special burner into the Texaco gasifiers. At about 800 psig and 2000-3000 F, the coal is partially oxidized to carbon monoxide, hydrogen, and carbon dioxide. Because of the high temperature, no

---

[1] *8" x 0 refers to the upper and lower size of coal pieces. All the coal will pass through a screen with 8-inch openings. The zero indicates that there is no minimum size and that the coal contains very small particles (fines). 14 mesh x 0 means all coal passes through a screen with 14 holes per inch.*

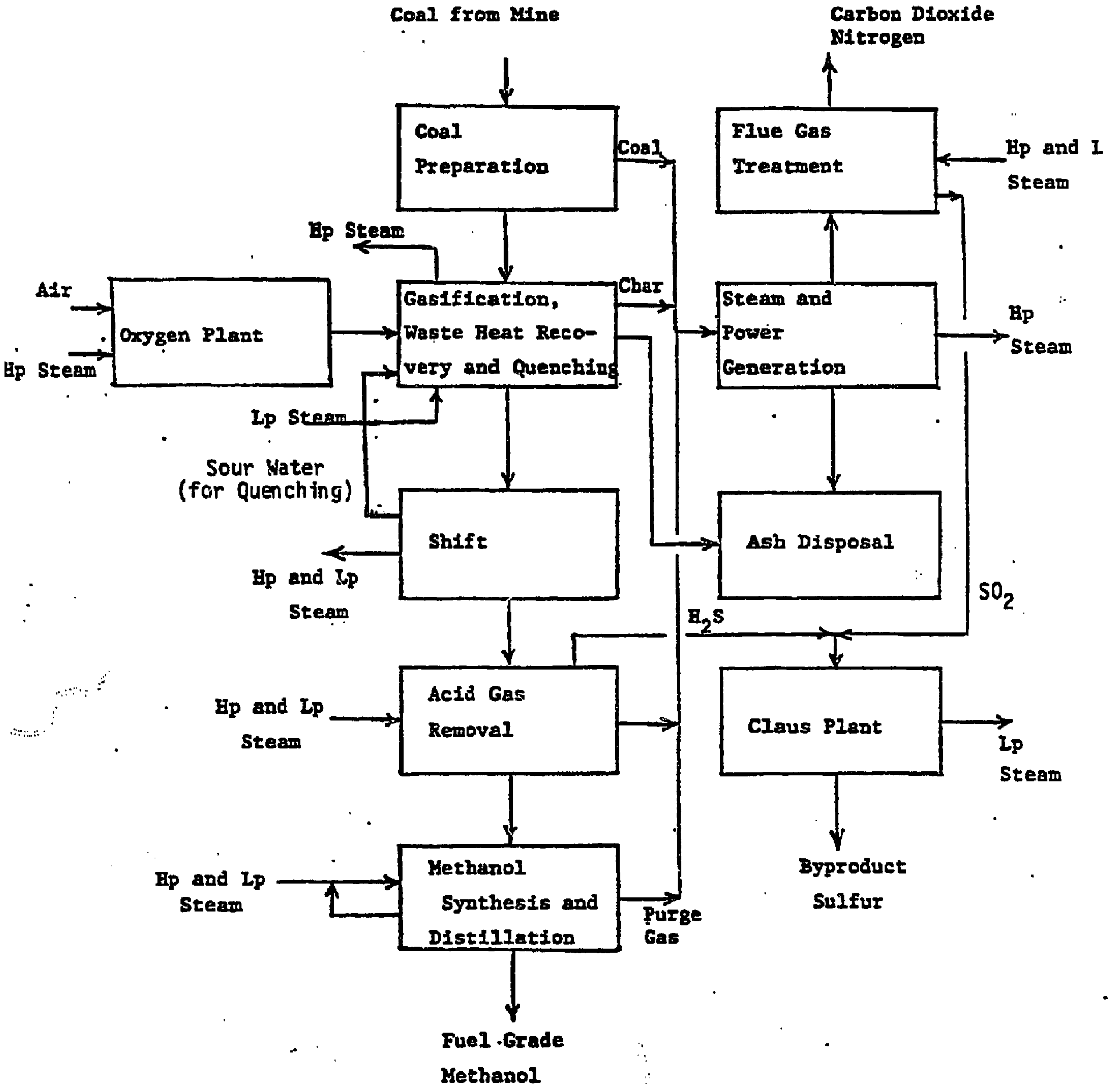


EXHIBIT H-2: SIMPLIFIED PROCESS FLOW DIAGRAM FOR MANUFACTURING FUEL GRADE METHANOL FROM COAL tars, oils, phenols and other by-products are formed in the gasifier. Most of the sulfur present in the coal is converted to hydrogen sulfide (H_2S) and small amounts of carbonyl sulfide (COS), while the organic nitrogen is reduced to free nitrogen with some traces of ammonia (NH_3) and hydrogen cyanide (HCN). Temperature in the gasifier is maintained above the melting point of the ash in order to yield a free-flowing molten slag through the lockhopper system. About 95 percent of the carbon in the feed is converted to the synthesis gas in the slagging entrained downflow Texaco gasifier; the remaining carbon is recovered as char from the quench scrubber. Sour water from the shift is used for quenching the synthesis gas, thus eliminating the requirement of additional steam for the shift reactor.

Slag is removed from gasifier via lockhoppers. The slag, which contains about 0.5 percent carbon, is separated into fine and coarse fractions. The fines, containing substantially more carbon, may be either recycled to the gasifier or discarded with the coarse slag.

The quenched gas from the slag separator is next cooled to about 600 F in a waste heat boiler generating 1270 psig, 576 F steam.

The synthesis gas is then sent to the shift section where the hydrogen/carbon-monoxide ratio is adjusted to the stoichiometry required for methanol synthesis. A sulfur tolerant catalyst for the shift reactor was assumed, because this approach would eliminate the requirement of an additional acid-gas removal step ahead of the shift reactor. A waste-heat boiler operating on the reactor effluent gases would generate high and low pressure steam. The shifted gas is sent to the acid-gas removal section for the removal of sulfur compounds and carbon dioxide.

The synthesis gas from the treating unit next feeds into the makeup compressor of the methanol synthesis section. The makeup compressor compresses the gas to about 1550 psig. The compressed gas is first combined with synthesis recycle gas before it is sent to the methanol synthesis loop. This loop consists of a synthesis converter, heat-exchange train, and a recycle compressor. Methanol and some water are formed in the synthesis converter. After condensation, the mixture is distilled to remove the water. Part of the heat recovered in the heat-exchange train is used to preheat the feed and to supply heat for the distillation unit. The remaining heat is used in the acid-gas removal section. The makeup and recycle compressors are driven by condensing steam turbines.

Light ends containing dimethyl ether are used as the fuel for the boiler. A purge gas stream is removed from the synthesis loop. The purge gas contains methane and is used as boiler fuel.

In the particular design selected for analysis, the Selexol unit (a part of the acid-gas removal section), would selectively remove hydrogen sulfide and provide it as a feed gas at about 23 mole percent hydrogen sulfide to the Claus sulfur plant. Steam is generated in the sulfur plant and used in the acid-gas removal unit. Molten sulfur is recovered for sale.

Part of the high-pressure steam required for the process is produced in the gasification, shift, Claus sulfur plant, and methanol synthesis sections in heat recovery boilers. The remaining high pressure steam is generated in the steam plant operating on char from the gasifiers, purge gas from the synthesis section, and coal. Also, saturated steam from the process waste-heat-boilers is superheated to 950 F. Electric power is generated from the high pressure steam. Air for the boiler is preheated to 220 F by low-pressure steam. Tail gases from the sulfur plant and a large amount of CO_2-rich gas from the Selexol unit are also fed into the boiler.

The remaining sulfide in the tail gas is incinerated in the boiler. The incinerated tail gas and the boiler flue gas are treated in a Wellman-Lord desulfurization unit. The Wellman-Lord unit concentrates the sulfur dioxide in the gas. The sulfur dioxide is then sent to the sulfur plant for conversion to elemental sulfur.

H.3 Process Chemistry

The gasification step combines partial oxidation and steam reforming of the carbon contained in the coal. The oxidation step provides the heat needed for the steam-carbon and pyrolysis reactions. The major reactions in the gasifier are:

$$C + O_2 = CO_2$$

$$C + \frac{1}{2} O_2 = CO$$

$$C + CO_2 = 2CO$$

$$C + H_2O = CO + H_2$$

$$CH_x = C + \frac{x}{2} H_2$$

There are additional reactions which form the synthesis gas hydrocarbons as follows:

$$4CH_x = xCH_4 + (4-x)C$$

$$C + 2H_2 = CH_4$$

Sulfur contained in the coal forms acidic gases, mainly hydrogen sulfide (H_2S):

$$S + H_2 = H_2S$$

In the shift process step, the carbon monoxide (CO) to hydrogen (H_2) ratio is adjusted in the shift reaction:

$$CO + H_2O = CO_2 + H_2$$

The acidic gases, mostly carbon dioxide (CO_2) and hydrogen sulfide, are removed, and the carbon monoxide and hydrogen synthesis gas is sent to the methanol synthesis loop. There, they combine to form methanol (CH_3OH):

$$CO + 2H_2 = CH_3OH$$

There are also side reactions which lead to the formation of water:

$$CO_2 + 3H_2 = CH_3OH + H_2O$$

$$CO + H_2 = C + H_2O$$

$$2CH_3OH = CH_3OCH_3 + H_2O$$

In the sulfur plant, part of the hydrogen sulfide, recovered in the acid-gas removal process step is oxidized to sulfur dioxide (SO_2):

$$H_2S + \frac{3}{2}O_2 = H_2O + SO_2$$

This sulfur dioxide is mixed with the rest of the hydrogen sulfide and with the sulfur dioxide recovered from the flue gas desulfurization system. The gases are then converted to elemental sulfur and water in the Claus sulfur plant according to the reaction:

$$2H_2S + SO_2 = 3S + 2H_2O$$

H.4 Energy and Materials Consumption

The primary energy balance is based on the conversion of eastern bituminous coal to fuel grade methanol. The coal composition used in the following analysis had a higher heating value (as received) of 11,340 Btu per pound, 6.4 percent free moisture, and the following analysis (McGeorge, 1976):

Carbon	66.9%
Hydrogen	4.5
Oxygen	8.4
Nitrogen	1.3
Sulfur	4.5
Ash	14.4
	100.0%

The fuel grade methanol produced contains 99.8 percent methanol, 0.1 percent higher alcohols and less than 0.1 percent water.

The only significant energy input to the process is coal. The electricity used in the process is generated in the plant. The coal is used primarily in the gasifier but some is also used to fuel the boiler. Char from the gasifier and fuel gas generated in the process are also burned in the boiler. Waste heat is recovered wherever feasible. The fuel and energy balance within the plant is given in Exhibit H-3.

There is also a small amount of diesel fuel consumed by bulldozers in the coal storage area. For a plant consuming 10,000 tons of coal per day, four bulldozers operating eight hours each would consume about 280 gallons per day, or about 0.15 gallons of diesel fuel for every 1,000 gallons of methanol produced (Hoffman, 1981).

EXHIBIT H-3: METHANOL FROM COAL ENERGY BALANCE TEXACO/ICI PROCESS[1]

Process Section	Coal tons per 10^6 Btu Methanol	Electricity[4] Btu per Btu Methanol	Char (Dry) Btu per Btu Methanol	By-Product Fuel Btu per Btu Methanol	hp Steam[2]		lp Steam[2]	
					Consumed Btu per Btu Methanol	Produced Btu per Btu Methanol	Consumed Btu per Btu Methanol	Produced Btus per Btus Methanol
Coal Preparation		-0.027						
Gasification	-0.078	-0.007	+0.029			0.283	0.013	0.007
Oxygen Plant					0.330			
Shift		-0.001				0.035		0.124
Acid-Gas Removal		-0.005			0.068		0.034	
Methanol Synthesis		-0.004		+0.113	0.177	0.071	0.103	0.030
Claus Sulfur Plant		-0.001						0.011
Tail-Gas Boiler and Flue-Gas Cleaning		-0.005			0.014		0.036	
Steam Generation	-0.007	-0.002	-0.029	-0.113	0.334	0.645	0.015	
Power Generation		+0.079			0.111			0.029
Miscellaneous[3]		-0.027						
TOTAL	-0.085	0.000	0.000	0.000	0.000		0.00	

(1) balance shown is for the base case described in the text.
(2) hp steam is three levels: 1,175 psig, 925 F; 1,275 psig, saturated; and 550 psig, 750 F.
lp steam is at two levels: 100 psig, saturated; and 20 psig saturated. Steam enthalpy above water at 32 F.
(3) Includes cooling tower, sour water stripper, and others.
(4) Electricity calculated on the basis of 10,400 Btu of coal consumed per kwhr of electricity produced.

EXHIBIT H-3: METHANOL FROM COAL ENERGY BALANCE TEXACO/ICI PROCESS[1]

EXHIBIT H-3: METHANOL FROM COAL ENERGY BALANCE TEXACO/ICI PROCESS[1]

					hp Steam[2]		lp Steam[2]	
Process Section	Coal tons per 10^6 Btu Methanol	Electricity[4] Btu per Btu Methanol	Char (Dry) Btu per Btu Methanol	By-Product Fuel Btu per Btu Methanol	Consumed Btu per Btu Methanol	Produced Btu per Btu Methanol	Consumed Btu per Btu Methanol	Produced Btus per Btus Methanol
Coal Preparation		-0.027						
Gasification	-0.078	-0.007	+0.029			0.283	0.013	0.007
Oxygen Plant					0.330			
Shift		-0.001				0.035		0.124
Acid-Gas Removal		-0.005			0.068		0.034	
Methanol Synthesis		-0.004		+0.113	0.177	0.071	0.103	0.030
Claus Sulfur Plant		-0.001						0.011
Tail-Gas Boiler and Flue-Gas Cleaning		-0.005			0.014		0.036	
Steam Generation	-0.007	-0.002	-0.029	-0.113	0.334	0.645	0.015	
Power Generation		+0.079			0.111			0.029
Miscellaneous[3]		-0.027						
TOTAL	-0.085	0.000	0.000	0.00	0.000		0.00	

(1) balance shown is for the base case described in the text.
(2) hp steam is three levels: 1,175 psig, 925 F; 1,275 psig, saturated; and 550 psig, 750 F.
lp steam is at two levels: 100 psig, saturated; and 20 psig saturated. Steam enthalpy above water at 32 F.
(3) Includes cooling tower, sour water stripper, and others.
(4) Electricity calculated on the basis of 10,400 Btu of coal consumed per kwhr of electricity produced.

A sulfur byproduct is obtained in the process. The energy credit, which is based upon fuel consumption data for sulfur mining in the 1977 Census of Mineral Industries, is 3444 Btu per pound sulfur. The components of this energy credit are shown in Exhibit H-4.[1]

Based on the above assumptions, feedstock characteristics, and the energy balance shown in Exhibit H-3, the energy input to the methanol manufacturing process is calculated to be 5.5 tons of 11,340 Btu/lb bituminous coal per thousand gallons of methanol produced, or 1.94 Btu of total energy input per Btu of methanol produced. The sulfur byproduct energy credit, predominantly natural gas, is determined to be 440 pounds of sulfur per thousand gallons of methanol, or 0.024 Btu of total energy per Btu of methanol. These results are summarized in Exhibit H-5.

Overall, the net energy consumed by the methanol production process is 1.92 Btu per Btu of liquid fuel produced. None of the consumed energy is petroleum. Overall energy efficiency, expressed as the higher heating value (HHV) of the products (methanol and sulfur) divided by the energy content of the process inputs (coal), is calculated to be 53 percent.

H.5 Sensitivity Analysis

The energy requirements depend somewhat on the amount of residual water in the methanol. The base case described above produces fuel grade methanol with no more than 0.1 weight percent water. This grade would be suitable for blending with gasoline. If the methanol is to be used neat in an internal combustion engine or as a feed for the Mobil methanol to gasoline process, the methanol can contain as much as 5 percent water. With the higher water content in the product, less energy is used in distillation.

---

[1] *The inclusion of this energy credit presumes that all of the by-product sulfur is used industrially and replaces sulfur which would otherwise be mined. This may not be true for plants in some Western locations due to the availability of by-product sulfur from Alberta and the high transportation costs to Eastern markets. Energy credits would be inappropriate for any sulfur production which does not result in a corresponding reduction in sulfur mining.*

Although most analyses take an energy credit at the heating value of sulfur (3,990 Btu/lb), this analysis uses the fuel required for a typical Frasch sulfur mine as the credit. This is fuel not consumed in sulfur mining and thus available to the rest of the economy because of the methanol manufacture. The energy consumption in mining is close to the heating value of sulfur, and the total sulfur energy credit is small compared to the energy consumed in the process. Therefore, the method of treating the sulfur energy credit has little impact on the overall energy balance.

EXHIBIT H-4: ENERGY CONSUMPTION PER POUND OF MINED SULFUR

EXHIBIT H-4: ENERGY CONSUMPTION PER POUND OF MINED SULFUR

		Petroleum Products						
	Assumptions	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	Btu Petroleum Products	Btu Total Energy
Sulfur mining industry (SIC 1477)	Total production in 1977: 5,822 M long tons (1)							
	Total energy consumption in 1977 (2):							
	—Electricity: Purchased: 45.0 MM kwhr Generated: na (2)					0.0000005*		12
	—Direct Fuels: Gasoline: 0.4 MM gal Distillate: 1.15 MM gal Residual Fuel: na (3) Natural Gas: 43.2 B cu ft Coal: none	0.00003	0.000088	(3)	3.31		16	3,432 (4)
TOTAL SULFUR MINING		0.00003	0.000088	(3)	3.31	0.0000005	16	3,444 (4)

*Based on use of 22,500,000 Btu per ton coal.

Sources:
(1) BOM, 1980.
(2) DOC, 1981.
(3) Data withheld by Census to avoid disclosing operations of individual companies.
(4) Estimated directly from source data. Includes generated electricity, residual fuel, other purchased fuels and undistributed fuels.

EXHIBIT H-5: NET LIQUID FUELS AND TOTAL ENERGY CHANGE ACHIEVED IN THE PRODUCTION OF 1000 GALLONS OF METHANOL FROM COAL

		Petroleum Products						
	Methanol (gal)	Motor Gasoline (gal)	Distillate (gal)	Residual Fuel (gal)	Natural Gas (cu ft)	Coal (tons)	MBtu Liquid Fuels	MBtu Total Energy
INPUTS								
• **FEEDSTOCK:** 5.5 tons of bituminous coal						-5.5 (1)		-124,740
• **STORAGE:** Bulldozers move coal			-0.15				-20	-20
• **PROCESS:** All energy from feedstock								
OUTPUTS								
• **SULFUR:** 440 lbs		+0.013	+0.04		+1,460	+0.0002	+10	+1,510
• **METHANOL:** 1,000 gallons	+1,000						+64,350	+64,350
NET ENERGY PRODUCTION/CONSUMPTION	+1,000	+0.013	-0.11		+1,460	-5.5	+64,340	-58,900

(1) Based on use of 11,340 Btu/lb bituminous coal.

The direct reduction in the energy used in the distillation by increasing the water content from 0.1 to 5 weight percent would be about 0.03 Btu fuel/Btu methanol if the steam for distillation were raised directly in a boiler. This represents the upper limit of potential savings from the purity reduction. In the design used for the base case, part of the steam used in distillation is extracted from the power generation turbine. Reducing the methanol purity to 95 percent would result in elimination of this steam extraction and would only reduce the fuel consumption by 0.012 Btu/Btu. The exact amount of energy to be saved by changes in purity would vary with the specific design, but would remain a small fraction of the total energy.

The overall energy efficiency of the methanol synthesis is sensitive to the pressure in the gasifier. Because the volume of synthesis gas produced in the gasifier is greater than the volume of oxygen input to the gasifier, increasing the gasifier pressure decreases the energy needed for compression prior to methanol synthesis. There is some flexibility in methanol synthesis pressure, and it can be adjusted to optimize the total system. For commercial processes, methanol synthesis occurs at 1000-2000 psig. The Chem Systems methanol process, which is under development, is expected to operate as low as 500 psig (Chow, 1977). The gasifier and methanol synthesis pressures for the base case were 800 and 1540 psig.

The energy analysis has been conducted on the basis of a high sulfur eastern bituminous coal. Studies indicate that the Texaco gasifier system is slightly more energy efficient with a typical western bituminous coal than with eastern bituminous (Schlinger, undated; Child, 1979). However, variations from seam to seam in both the eastern and western coal fields make this generalization suspect. As long as the coals are of comparable quality, the energy consumed in the methanol process should be similar.

Methanol from lower-Btu coals would require the input of more energy because more coal slurry must be pumped into the reactor to produce a ton of methanol. This, in turn, means a higher percentage of the coal must be burned to provide heat, more material must be heated to reaction temperature, and more oxygen is consumed and more carbon-dioxide produced per unit of methanol produced. The characteristics of each coal must be investigated on a case-by-case basis, but as a crude approximation, the energy consumed in coal preparation, gasification, and oxygen plant varies inversely with the Btu content of the coal. The energy for acid-gas (carbon-dioxide) removal also increases with decreasing Btu content. The energy used by other downstream operations is relatively insensitive to coal Btu content.

Lower rank coals like lignite and some subbituminous coals are not suitable for the conversion to methanol using the Texaco gasification system described (Chia, 1979). In addition to the low Btu content of these coals, whose impact is discussed above, it is inappropriate to count the tightly bound moisture as slurry water. Moisture content may typically be 30 to 35 percent in lignite and some subbituminous coals (e.g., Wyodak coal). Thus, even more water must be evaporated in the gasifier with these coal types than would be expected on the basis of Btu content alone.

Dry-fed gasifier systems (such as Lurgi) may be suitable for conversion of lower rank coals to methanol. The energy consumed in these systems is not significantly affected by free (unbound) moisture in the range typically found in coal. The evaluation of such systems is beyond the scope of this study.

The sulfur content of the coal has a very small impact on the energy balance. Because steam is generated in the Claus sulfur plant and because an energy credit is obtained for byproduct sulfur, the energy balance improves slightly with increasing sulfur content. These energy credits are directly proportional to the sulfur content. The total steam generated in the sulfur plant with a 4.5% sulfur coal is about 1.5 percent of the total steam used in the plant. Therefore, the impact of sulfur content is very small.

Variations in the ash content of coal should not influence the energy balance significantly, although the grinding of coal, operating conditions of the gasifier, and the slag removal section are more sensitive to ash content than the other sections of the process.

The caking and non-caking coal characteristics would not have any influence on the Texaco process, nor on the overall energy balance of the coal-to-methanol process (Schlinger, 1978).

The coal-to-methanol process plant energy requirements are not sensitive to plant scale.

The overall energy balance is sensitive to the details of process design. Maximum heat recovery is designed into the process analyzed in this study. In an actual commercial installation, the economics of the situation may dictate against maximum heat recovery. Normally, such optimization would not change the overall energy efficiency by more than a few percent.

H.6 Potential for Reduced Energy Consumption

The choice of the technologies for the process will also impact overall energy use. The system analyzed in this study is believed to be most representative of technologies likely to be built in the immediate future. The Chem Systems methanol process appears to be more energy efficient but it is still at the pilot stage of development.

The overall energy efficiency of several methanol processes reported in the literature have been calculated for this report on the basis described above. These efficiencies are compared in the table below. In the cases where electricity was purchased rather than generated within the plant, the energy input was taken at 10,400 Btu per kilowatt hour.

Process	Gasifier Pressure Psig	Coal Heating Value Btu/lb	Alcohol Purity Percent	Overall Energy Efficiency Percent
A. Texaco/ICI	800	11,340	99.9	53
B. Texaco/Chem Systems	1,200	12,150	97.0	57
C. Koppers-Totzek/Chem Systems	6	12,235	97.5	53
D. BGC Lurgi/Chem Systems	350	12,235	97.5	58
E. Badger/Lurgi	500	12,840	99.5	56

Process A is the Texaco gasifier/ICI methanol system used in this analysis. Process B is based on a conceptual design of the Texaco gasifier/Chem Systems methanol system (Chia, 1979). It also involved a higher gasifier pressure than Process A. Both processes A and B use Selexol gas purification technology.

Process C is based on the Koppers-Totzek gasifier with Chem Systems methanol synthesis (Chow, 1977). Process D uses the British Gas Council Lurgi slagging gasifier with Chem Systems methanol (Chow, 1977). The Koppers-Totzek gasifier is considered commercially proven; the British Gas Council Lurgi is in the near-commercial category. Both use the commercially available Benfield system for gas purification.

Process E is based on a Badger conceptual design that uses Rectisol gas purification and Lurgi methanol synthesis (Badger Plants, Inc., 1978). The gasifier design is an oxygen-blown, slagging wet-bottom, pressurized entrained-bed design which has never been demonstrated.

The conclusion drawn from the above table is that developing technologies have the potential to improve the energy efficiency of methanol manufacture somewhat. It may be several years, however before these efficiencies are realized.

BIBLIOGRAPHY FOR APPENDICES G AND H

The following partially annotated bibliography contains listings for the sources used in Appendices G and H as well as other sources located in the course of this research.

Argonne National Laboratory, National Coal Utilization Assessment - An Integrated Assessment of Increased Coal Use in the Midwest: Impacts and Constraints, Vol. II. Argonne, IL: Argonne National Laboratory (1977a).

This study was performed as a part of the Argonne National Laboratory Regional Studies Program. The purpose of the Regional Studies Program is to assess the impacts and consequences associated with alternative energy options on a regional basis, and to identify and analyze alternative mitigation and solution strategies for increasing the acceptability of these options.

The National Coal Utilization Assessment (NCUA) is being conducted as a part of the Regional Studies Program. This particular study is focusing on impacts and constraints on increased coal utilization. In addition, a major focal point for the study is the identification and analysis of alternative solution strategies applicable to these constraints and problems. The study results are presented in two volumes. Volume I contains the Executive Summary and Major Findings. Volume II contains detailed information on Energy Supply and Demand, Siting, and Impacts.

Argonne National Laboratory, U.S. Energy Research and Development Administration Survey of Electric Utility Demand for Western Coal. Argonne, IL: Argonne National Laboratory (1977b).

This report presents the results of a survey of electric utility demand for western coal. The sources of survey information are: (1) Federal Power Commission Form 423 data on utility coal purchases covering the period July 1972 through June 1976 and (2) direct survey data on utility coal-purchase intentions for power plants to be constructed by 1985. Price and quantity assembled and presented to illustrate price and market-share trends in individual consuming regions over recent years. Coal source, quality, and quantity data are presented for existing and planned generating plants.

Averitt, P., Coal Resources of the United States, January 1, 1974, U.S. Geological Survey Bulletin 1412. Washington D.C.: GPO (1975).

Badger Plants, Inc., "Conceptual Design of a Coal to Methanol Commercial Plant," Report to the U.S. Department of Energy, FE-2416-24 (1978).

Berkshire, L., U.S. Department of Energy, Process Evaluation Office, Morgantown, West Virginia, Personal Communication, (1981).

Buras, N., "Water Constraints on Energy Related Activities," presented at the American Society of Civil Engineering Specialty Conference Proceedings, Conservation and Utilization of Water and Energy Resources, (August 1979).

Chia, W.S., et al., "Coal-to-Methanol Via New Processes Under Development: An Engineering and Economic Evaluation," C.F. Braun and Co., Report to the Electric Power Research Institute, EPRI AF-1227 (1979).

Child, E.T., "Current Status of the Texaco Coal Gasification Process," presented at the Ammonia from Coal Symposium, Tennessee Valley Authority, Muscle Shoals, AL (May 1979).

Chow, T.K., et al., "Screening Evaluation: Synthetic Liquid Fuels Manufacture," Ralph M. Parsons Company, Report to the Electric Power Research Institute, EPRI AF-523 (1977).

Colorado Energy Research Institute, Net Energy Analysis: An Energy Balance Study of Fossil Fuel Resources. Golden, CO: Colorado Energy Research Institute (April 1976).

This study examines industrial energy production in fossil fuels, emphasizing those of the Western United States. It accounts for the complete direct and indirect energies which must be utilized to produce energy from fossil fuels. These include the direct and indirect energies which "drive" or sub-sidize" the production. It includes those energies sequestered in materials needed to build and operate the industrial production and transportation facilities which either directly or indirectly are necessary for energy production. The study includes all steps in bringing fossil fuels from reserves in the ground to the point of end use (exploration, extraction, conversion, transportation, etc.).

Cuff, D.J., and Young, W.J., The United States Energy Atlas. New York: The Free Press, A Division of Macmillan Publishing Co., Inc. (1980).

Locates and describes the amount and distribution of all energy sources, from nonrenewable resources such as coal, oil, natural gas, and nuclear fuels, to renewable resources, including solar power, windpower, and biomass. Provides information on all energy resources now in use and those proposed for the future, including the relative amounts of each resource by state and region; consumption and transportation patterns by region; the United States' energy needs—past, present, and future; and the position of the United States in world energy supplies.

Hoffman, R., Plant Manager, Potomac Electric Power Company, Morgantown, WV, Personal Communication (1981).

Hydrocarbon Processing, 59, pp. 191-193 (November 1979).

Jenkins, D.M., McClure, T.A., and Reddy, T.S., "Net Energy Analysis of Alcohol Fuels." Washington, D.C.: American Petroleum Institute (November 1979).

Library of Congress, Congressional Research Service, National Energy Transportation, Current Systems and Movements, Vol I, Washington, D.C.: Library of Congress (1977).

Library of Congress, Congressional Research Service, Synfuels from Coal and the National Synfuels Production Program: Technical, Environmental, and Economic Aspects, prepared for the U.S. Senate Committee on Energy and Natural Resources, publication number 97-3, Washington, D.C.: GPO (1981).

McGeorge, A., "Economic Feasibility Study, Fuel Grade Methanol From Coal," Dupont Company, Report to the Energy Research and Development Administration (1976).

Mujadin, M.J., American Natural Service Co., (Grain Plains Gasification Associaties), personal communication (November 18, 1980).

Peele, R. and Church, J.A., eds., Mining Engineers' Handbook, Third Edition, New York: John Wiley and Sons, Section 4: Explosives (1966).

Rogozen, M.B., et. al, "Environmental Impacts of Coal Slurry Pipelines and Unit Trains", in Office of Technology Assessment, Task Reports: Slurry Coal Pipelines, Volume II, Part 2. Springfield, VA: NTIS, #PB-278 677 (1978).

Schlinger, W.G., "Coal Gasification Development and Commercialization of Texaco Coal Gasification Process," unpublished paper, Texaco, Inc., Montebello, CA.

Schlinger, W.G., "The Texaco Coal Gasification Process for Manufacture of Median Btu Gas," presented at the Department of Energy Conference on Coal Use for California, Pasadena, CA (May 1978).

Schlinger, W.G., Falbe, J. and Specks, R., "Coal Gasification for Manufacture of Hydrogen," presented at the joint meeting of the American Chemical Society and the Chemical Society of Japan, Honolulu, Hawaii (April 1979).

Shelton, J.E., "Sulfur," Mineral Commodity Profiles, U.S. Department of Interior, Bureau of Mines Washington, D.C.: Bureau of Mines (July 1979).

TRW, Energy Balances in the Production and End-Use of Alcohols Derived From Biomass. Washington, D.C.: U.S. National Alcohol Fuels Commission (1980).

U.S. Department of Commerce, Bureau of the Census, 1972 Census of Mineral Industries. Washington, D.C.: GPO (1975).

U.S. Department of Commerce, Bureau of the Census, 1977 Census of Manufactures, "Miscellaneous Chemical Products," Industry Series, MIC77-1-28H. Washington, D.C.: GPO (1980a).

U.S. Department of Commerce, Bureau of the Census, 1977 Census of Mineral Industries, "Bituminous Coal and Lignite Mining," Industry Series, MIC77--1-12A, Washington, D.C.: GPO (1980b).

U.S. Department of Commerce, Bureau of the Census, 1977 Census of Mineral Industries, "Chemical and Fertilizer Mineral Mining," Industry Series MIC77-1-14D, Washington, D.C.: GPO (1980c).

U.S. Department of Commerce, Bureau of the Census, 1977 Census of Mineral Industries, "Fuels and Electric Energy Consumed", Industry Series MIC77-SR-5, Washington, D.C.: GPO (1981).

U.S. Department of Energy, Basic Estimated Capital Investment and Operating Costs For Three Coal Mines, Springfield, Virginia: NTIS, FE/EES-781 (1977).

U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, DOE/EIA-003513, Washington, D.C.: GPO (March 1978a).

U.S. Department of Energy, Economic Analysis of Coal Mining Costs for Underground and Strip Mining Operation. Washington, D.C.: GPO (1978b).

U.S. Department of Energy, Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Utilizing a Continuous Mining System. Washington, D.C.: GPO (1978c).

U.S. Department of Energy, Basic Estimated Capital Investment and Operating Costs for Subbituminous and Lignite Coal Strip Mines, Springfield, VA: NTIS, FE/EES-79/6 (1979a).

U.S. Department of Energy, The Report of the Alcohol Fuels Policy Review, Springfield, VA: NTIS, #DOE-PE-0012 (1979b).

U.S. Department of Energy, Energy Data Reports, Production of Coal, Bituminous, and Lignite. Washington, D.C. (March 30, 1979c).

U.S. Department of Energy, Energy Information Administration, Bituminous Coal and Lignite Production and Mine Operations — 1977. Washington, D.C.: GPO (1979d).

U.S. Department of Energy, Energy Information Administration, Bituminous Coal and Lignite Production and Mine Operations - 1978. Washington, D.C.: GPO (1980 a).

This is the third annual report on bituminous coal and lignite production and mine operations published by the Energy Information Administration (EIA). It is a continuation of the series previously included as a chapter in the Minerals Yearbooks published by the Bureau of Mines, U.S. Department of the Interior.

This report is primarily a compilation of tables and illustrations that detail various aspects of bituminous coal and lignite production and mine operations in the United States in 1978. It covers such basic sectors as production tonnages, mining methods, employment, productivity, coal preparation, values, shipments, and coalbeds mined during the year. The data are from mines that produced 1,000 tons or more. All production tonnages represent marketable coal and as such exlcude refuse.

The data are generally listed according to coal-producing States. Some data are also listed by coal-producing county and coal-producing district. To highlight the regional differences of coal production, certain data have been aggregated according to the three major coal-producing regions: Appalachian, Interior, and Western.

U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, DOE/EIA-0035(80/12). Washington, D.C.: GPO (December 1980b).

Presents energy consumption and production statistics by source and sector.

U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Vol. III: Forecasts, Washington, D.C.: GPO (1981a).

U.S. Department of Energy, Energy Information Administration, Short Term Energy Outlook, Washington, D.C.: GPO (1981b).

U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, DOE/EIA-0035 (81/03). Washington, D.C.: GPO (March 1981c).

U.S. Department of Interior, Bureau of Mines, Coal — Bituminous and Lignite in 1972, Mineral Industry Surveys. Washington, D.C. (1973).

U.S. Department of Interior, Bureau of Mines, The Reserve Base of Bituminous Coal and Anthracite for Underground Mining in the Eastern United States, Information Circular 8655. Washington, D.C.: GPO (1974a).

U.S. Department of Interior, Bureau of Mines, Fuel and Energy Consumption in the Coal Industries. Springfield, VA: NTIS, #PB-237151 (1974b).

This report presents results for the coal industries: 1) bituminous coal, 2) lignite, 3) bituminous and lignite mining services, 4) anthracite and 5) anthracite mining services. Fuel and electricity consumption is presented in a series of tables for the year 1967, defined as the base year, and for 1971, 1973, and 1974. The major processes represented in these tables are: 1) Mining and 2) Preparation. Fuel and electricity usage are also tabulated by state, Census Bureau Division and Census Bureau Region in the years 1971 and 1973.

U.S. Department of Interior, Bureau of Mines, The Reserve Base of U.S. Coals by Sulfur Content, Part 1, The Eastern States, Information Circular 8680. Springfield, VA: NTIS, #PB-243031 (1975a).

The Bureau of Mines has compiled coal reserve data for the United States as of January 1, 1974, for bituminous and anthracite coalbeds 28 inches or more in thickness to a maximum depth of 1,000 feet and for lignite beds 60 inches thick or greater. These data were organized by State, country, coalbed, and rank. To evaluate the reserve by sulfur content, the reserve and analytical data from the Bureau of Mines energy data bank were synthesized using computer techniques.

U.S. Department of Interior, Bureau of Mines, The Reserve Base of U.S. Coals by Sulfur Content, Part 2, The Western States, Information Circular 8693. Springfield, VA: NTIS, #PB-249702 (1975b).

This Bureau of Mines report delineates the coal reserve base of anthracite, bituminous and subbituminous coals, and lignite, by mining method and sulfur content, for coal-bearing States west of the Mississippi River. The parameters used to establish the reserve base definition are the result of a joint agreement by the Federal Bureau of Mines and the U.S. Geological Survey.

U.S. Department of Interior, Bureau of Mines, The Reserve Base of Coal for Underground Mining in the Western United States, Information Circular 8678. Washington, D.C.: GPO (1975c).

U.S. Department of Interior, Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines, Information Circular 8689. Washington, D.C.: GPO (1975d).

U.S. Department of Interior, Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines, Information Circular 8703. Springfield, VA: NTIS, #PB-252495 (1976a).

U.S. Department of Interior, Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwall Mining, Information Circular 8720. Washington, D.C.: GPO (1976b).

U.S. Department of Interior Bureau of Mines, Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines, Information Circular 8682A. Springfield, VA: NTIS, #PB-252-567 (1976c).

U.S. Department of Interior, Bureau of Mines, Coal Recovery from Bituminous Coal Surface Mines in the Eastern United States: A Survey, Information Circular 8738. Washington, D.C.: GPO (1977).

U.S. Department of Interior, Bureau of Mines, Projects to Expand Fuel Sources in Eastern States - An Update of Information Circular 8725 - Survey of Planned or Proposed Coal Mines, Coal and Noncoal Conversion Plants, Electric Generating Plants, Oil Refineries, Uranium Enrichment Facilities, and Related Infrastructure in States East of the Mississippi River (as of July 1977), Information Circular 8765. Washington, D.C.: GPO (1978a).

U.S. Department of Interior, Bureau of Mines, Projects to Expand Energy Sources in the Western States - An Update of Information Circular 8719 - Survey of Planned or Proposed Coal Mines; Electric Generating, Coal Conversion, and Waste-to-Fuel Plants; Oil Shale and Tar Sands Projects; Geothermal Facilities; Uranium Mines, Mills, and Enrichment Facilities, Natural Gas Processing and Storage Facilities; Oil Refineries and Terminal Facilities; Railroads; and Coal Slurry, Petroleum, and Natural Gas Pipelines, in States West of the Mississippi River (as of August 1977), Information Circular 8772. Washington, D.C.: GPO (1978b).

U.S. Department of Interior, Bureau of Mines, Minerals Yearbook: 1977, Volume I, Metals and Minerals, Washington, D.C.: GPO (1980).

U.S. Department of Interior, Geological Survey, Synthetic Fuel Development: Earth Science Considerations, Washington, D.C.: GPO (1979).

U.S. Department of Interior, Mining Enforcement and Safety Administration, Active List of Permissible Explosives and Blasting Devices Approved Before December 31, 1975, Informational Report 1046. Washington, D.C. (1976).

U.S. National Alcohol Fuels Commission, Fuel Alcohol: An Energy Alternative for the 1980's. Washington, D.C.: GPO (1981).

U.S. Water Resources Council, Water Requirements, Availabilities, Constraints, and Recommended Federal Actions, Project Independence Blueprint, Final Task Report, Washington, D.C.: GPO (1974).

U.S. Water Resources Council, The Nation's Water Resources, 1975-2000, Vol. I: Summary, Washington, D.C.: GPO (1978).

Waitzman, Don, Tennessee Valley Authority, personal communication (1981).

Weismantel, G.E., "Coal Stars as 1980's Methanol Feed," Chemical Engineering, 47 (Jan. 12, 1981).