PEATLAND ENERGY OPTIONS SYSTEMS ANALYSIS

PEATLAND ENERGY OPTIONS: SYSTEMS ANALYSIS

Technical Supplement to Energy from Peatlands: Options and Impacts

by

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INTRODUCTION

Minnesota's peatlands offer a large and untapped energy resource. With the state's dependence on imported energy, examining the possibilities for developing these peatlands has become increasingly important. Recent efforts by the Minnesota Department of Natural Resources (MDNR) have included an inventory of the state's total peat resource while other research efforts have examined the technical and environmental barriers to using peatlands as a source of energy. Unexamined until now, however, has been the amount of energy that would be required to develop the peatlands in various ways. Estimates of such requirements should prove useful in assessing the net amounts of energy that would be available from each of the various development methods now being considered by the state. The Center for Urban and Regional Affairs, as part of its Peat Policy Project, has completed a study centering on the energy requirements of various alternatives for developing the state's peatlands for energy. The results of this work are summarized on the following pages.

The analysis presented here is based on assumptions the authors and other University researchers felt characterized the development opportunities of the peatlands. Different results may be possible given a different set of assumptions. The detailed assumptions and all the mathematical calculations which made up the bulk of the analysis may be found in the full research report (Aiken 1981) which is on file at the University of Minnesota office of the Center for Urban and Regional Affairs.* Only a few of the important assumptions, basic to the descriptions of the various processes, are included here along with the results. The authors and reviewers feel that this analysis does present reasonable estimates of the net energy that would be available from the various different development alternatives.

Net energy represents the total energy content of the peat or peat crop actually extracted or harvested from the peatland, minus the energy needed to produce a usable form of fuel, and minus the peat or

*An edited version of this full research report is expected to be published later this year as a research report of the University of Minnesota's Agricultural Experiment Station.

peat crop that is lost during transportation and processing. While the net energy available is an important factor in determining the optimal approach to developing the peatlands, it is by no means the only factor. Environmental consequences, economic development opportunities, market forces, and life of the peatlands are only a few of the other important factors to consider before making a decision as to how Minnesota's peatlands might best be developed.

DEVELOPMENT ALTERNATIVES

The peatlands can be used in two general ways: through a renewable approach, which offers a continuous stream of energy crops, and through a non-renewable approach, where peat is extracted and used up over a limited period of time. While the fuels produced may be similar with either approach, the materials used as feedstock differ. For the nonrenewable approach, peat can be mined in three different ways: it can be milled, sodded, or hydrated. In contrast, the renewable approach uses the peatland as a growing medium which in turn produced energy crops that are then harvested.

The feedstock, peat or energy crop, then is converted into fuels that the residential, commercial, industrial, or transportation sectors of society can use as a source of energy. Fuels produced can include synthetic natural gas (SNG), through gasification; electricity, with or without district heating, through direct combustion; briquettes, through compression; and alcohol, through fermentation and distillation. Since alcohol production from peat and wetland energy crops is still in the preliminary research stages in this country, it is left out of this analysis. Production of electricity and briquettes have proven technologies and the impetus to develop technologies for gasification to produce SNG have been significant in Minnesota.

THE ENERGY POTENTIAL

It is estimated that Minnesota's peatlands amount to a total of 5.9 million acres, but not all of the lands are available for development. The Minnesota Energy Agency has assumed approximately 2.5 million acres of peatlands will be available for energy development after various physical, economic, social, and environmental factors are taken into account (MEA 1980). If one assumes the peatlands to have a usable depth of 5 feet, a higher heating value* (HHV) of 6,000 BTU/lb. and a specific weight of 15 lb./cu.ft. (35 percent moisture content), the after ditching available peat resource per acre is equal to 1.92×10^{10} BTU per acre for a total 4.80×10^{16} BTUs of available energy potential.

Calculations of the total energy potential under the renewable approach cannot readily be compared with calculations for the non-renewable approach. By growing biomass on the peatlands, they can be expected to last far into the future under a proper land management program. Using the 2.5 million acre figure, a mean annual supply of biomass feedstock can be determined. The cattail, an aquatic plant that has been shown to be productive on wetlands, has been chosen as the biomass reference energy source for this study. Studies done by a University of Minnesota research team under the direction of Professor Douglas Pratt have shown that cattails can yield up to 15 dry matter tons/acre a year of which 40 percent (leaves and shoots) is above ground and 60 percent (rhizomes and roots) is below ground (Pratt et al. 1980). Assuming that 10 percent of the plant weight is left behind to ensure regeneration of the next year's crop and assuming a dry weight HHV of 7,500 BTU per pound, the annual yield for biomass is 2.10×10^{8} BTU/acre. While this total resource per acre estimate is much less than that of the peat extraction approach, it must be recognized that this is an annual yield.

These estimates of the total energy potential in Minnesota's peatlands represent the amount of energy available prior to extraction or harvesting. The energy potential in terms of a final fuel product depends on the combination of extraction/harvesting method selected, the transportation distance, and the conversion processes used. Since the production, transportation, and conversion processes consume energy, and some of the insitu resource is lost, the amount of energy available to the consumer (net energy potential) is less than the total energy potential estimates just presented. The analyses used by the CURA Peat Policy Project to determine the net energy potential of Minnesota's peatlands are presented here in summary form. The first section compares the three extraction methods associated with the nonrenewable approach. The second section examines production of biomass on the peatlands. The

*Higher heating value (HHV), as distinct from lower heating value (LHV), includes the latent heat of condensation of water vapor given off with the products of combustion of a fuel.

third section, looks at the conversion processes in light of their energy efficiencies. The feedstock production methods and conversion processes are combined to evaluate which combination will prove to be most energy efficient under the assumptions set forth in this paper. Finally, the key findings of the analysis are summarized in the fourth section.

I. PEAT EXTRACTION: THE NONRENEWABLE APPROACH

Peat can be extracted either by milling, sodding or hydrating. Each process results in a different form of peat feedstock. The milling method produces a powder-like product that is readily adapted to a variety of conversion alternatives. Sodding compacts the peat into an eight to twelve inch sod. Hydrating combines peat with water to produce a slurry. The slurry must be pumped to a dewatering facility and dewatered before it is useful as a feedstock.

Natural peat, as it is found in the peatlands, is 80 to 95 percent water. All current methods of converting peat to a usable fuel require that it be dewatered. The milling and sodding processes allow the extracted peat to remain on the field surface for air drying. The hydraulic extraction process, however, requires a substantial amount of dewatering through both mechanical and heating procedures.

When comparing these three extraction processes, six operational categories are used to calculate the net energy: 1) peatland preparation, 2) extraction and collection, 3) processing, 4) transportation, 5) dewatering, and 6) losses. We will consider each extraction process separately. Since each method is different, the categories are not necessarily ordered in the same way. The energy requirements will be shown by detailing the amount of energy called for in each of the above categories. Tables summarizing the energy requirements, the energy losses, and the energy efficiencies of each extraction process are presented at the end of this section.

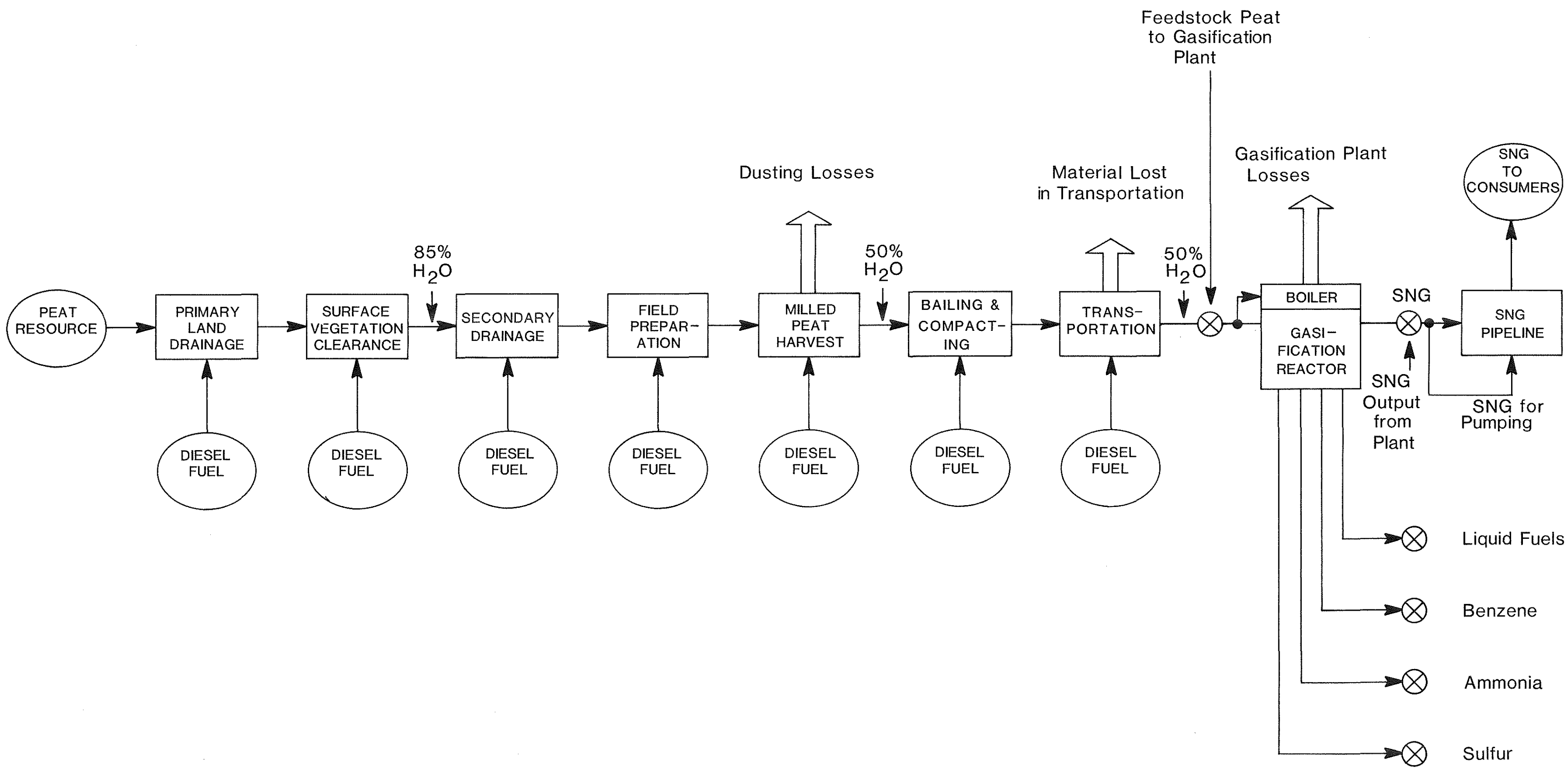
MILLED PEAT EXTRACTION

Figure 1 presents a flow diagram of the milled peat extraction process when milled peat is converted into synthetic natural gas.

Peatland Preparation

Prior to the actual extraction of the peat, the peatland surface must be cleared of vegetation and a drainage system must be established so a substantial amount of water can be drained off the peatland. Surface vegetation is cleared by a machine similar to a bulldozer. Primary ditches are dug prior to vegetation clearance using large ditchdigging equipment. After this, secondary ditches are dug in a similar

FIG ① MILLED PEAT EXTRACTION



fashion in-between the primary ditches. The drainage system is completed by cambering the peatland so that the surface level allows water to drain into the ditches.

Peatland Preparation Step	Energy Required
Surface vegetation clearance	1.17×10^6 BTU/acre
Construction of drainage ditches	1.08×10^5
Surface cambering	3.51×10^5
Total Land Preparation	1.63×10^6 BTU/acre

Extraction and Collection

The actual removal of the peat from the prepared surface involves two steps. First the top centimeter of peat is scarified or cut away from the surface and then remains on the peatland for air drying. It is often turned over to facilitate more efficient drying. After sufficient drying, to approximately 50 percent moisture content, it is collected by a large machine similar to a vacuum cleaner. Since it is assumed that a five foot depth is available for extraction of peat and only one centimeter is extracted at a time, 152 passes are necessary to extract the five feet of peat.

Extraction and Collection Step	Energy Required
Separation of peat from surface	1.17×10^5 BTU/acre
Vacuuming of extracted peat	1.76×10^5
Total extraction and collection for each pass	2.93×10^5 BTU/acre
for 152 passes	4.46×10^7 BTU/acre

Processing

When the milled peat is collected, its consistency is similar to that of powder. Because of this, it must be compacted into bales so that it can economically be transported over longer distances. After baling, the volume of the milled peat has been reduced to one-third of its original volume.

Processing Step	Energy Required
Baling of milled peat	4.77×10^7 BTU/acre

Transportation

After the milled peat has been compacted into bales, it is transferred to a conversion or processing facility. For this analysis, the plant is assumed to be 30 miles from the peatland, and a large vehicle with a capacity of 46,000 lbs. is used for transporting the peat.

Transportation Step	Energy Required
Transportation of baled peat	1.51×10^8 BTU/acre

Dewatering

For the milled peat process, dewatering is achieved by air drying on the peatland surface. No additional energy is required.

Losses

Since milled peat has a powderlike consistency, it can easily be lost. It is assumed in this analysis that 2 percent is lost in the wind prior to and during the actual vacuum extraction, and a further 2 percent is lost during loading and transportation operations. While this does not consume any energy, it represents a significant loss of potential energy.

Transportation & harvesting losses - 4 percent

SOD PEAT EXTRACTION

Figure 2 shows the sod peat extraction process when the peat is converted into synthetic natural gas.

Peatland Preparation

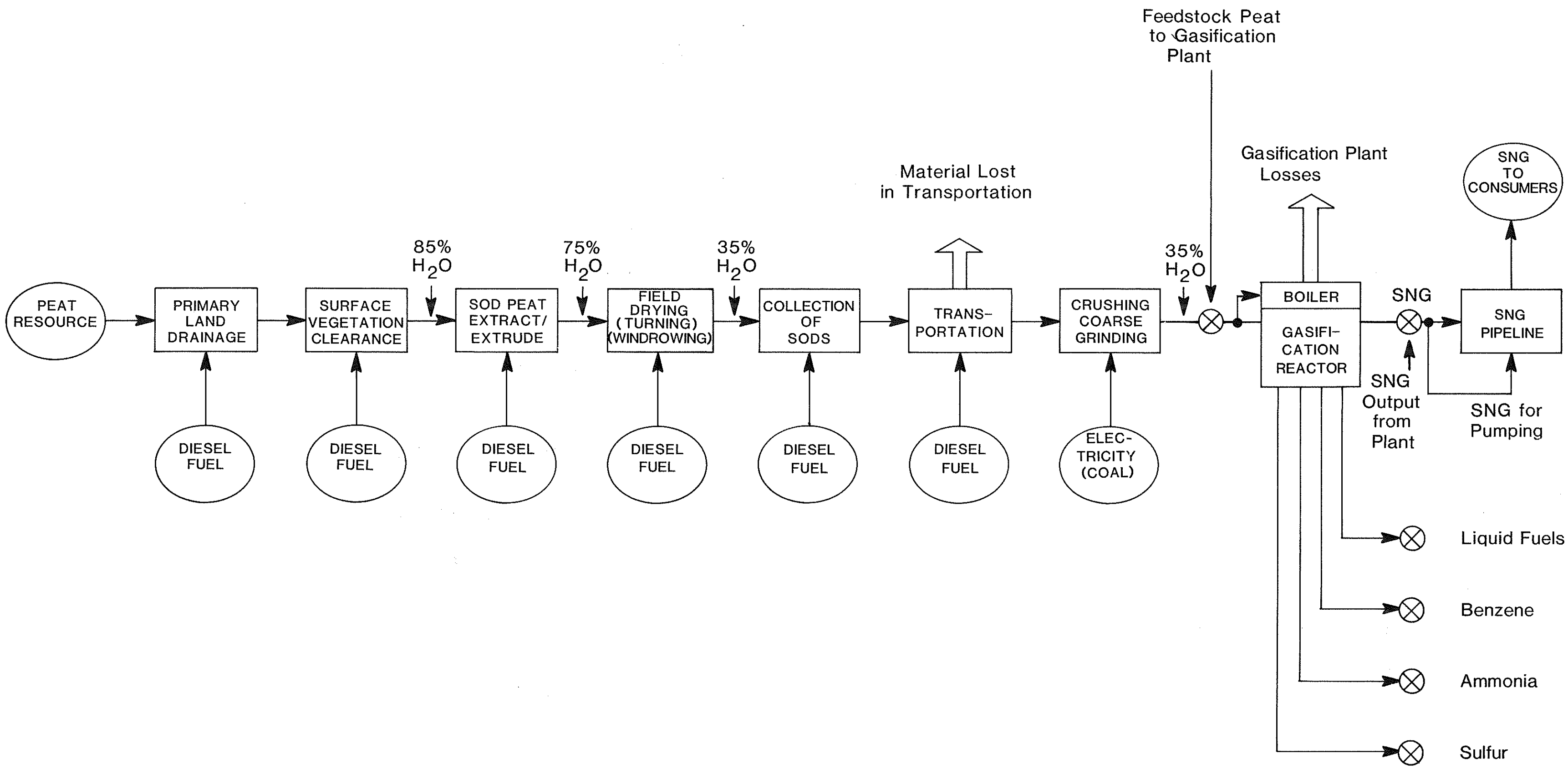
The preparation of the peatland surface and drainage system is the same as for milled peat extraction except that sodding peat requires only a one step drainage process.

Peatland Preparation Step	Energy Required
Surface vegetation clearance	1.17×10^6 BTU/acre
Construction of drainage ditches	5.40×10^4
Total land preparation	1.22×10^6 BTU/acre

Extraction and Collection

To remove the peat a machine slices and extracts the peat from the land surface or a ditch, macerates it thoroughly so that peat from different depths and therefore at different stages of decomposition is blended together, and then extrudes the peat back onto the land as sods. These sods are left on the peatland surface to dry. To aid in drying, the sods are turned and then collected into windrows. Once the peat reaches the desired moisture content, the sods are collected and loaded into trucks.

FIG ② SOD PEAT EXTRACTION



Extraction and Collection Step	Energy Required
Extraction and extrusion	1.70×10^8 BTU/acre
Turning and windrowing	4.24×10^6
Collection and loading	5.68×10^6
Total extraction and collection	1.79×10^8 BTU/acre

Transportation

The same assumptions that held for the transportation of milled peat can be used for sod peat. Since the sods and the bales of milled peat are of different weights, the fuel requirements for each method differ depending on the number of trips required.

Transportation Step	Energy Required
Transportation of sod peat	1.19×10^8 BTU/acre

Dewatering

As with milled peat, sodded peat is dewatered by allowing the sods to remain on the peatland surface. No energy is required except for turning and windrowing (already included in the extraction and collection steps).

Processing

It is assumed that before sodded peat can be efficiently converted to a usable fuel it must be ground to a consistency similar to that of milled peat. This is done by an electrically driven grinder which first crushes the sods and then grinds them to a coarse consistency.

Processing Step	Energy Required
Crushing/coarse grinding	9.49×10^7 BTU/acre

Losses

During transportation and handling of the sods it is assumed that a loss of 1 percent of the peat would occur.

Transportation and harvesting losses - 1 percent

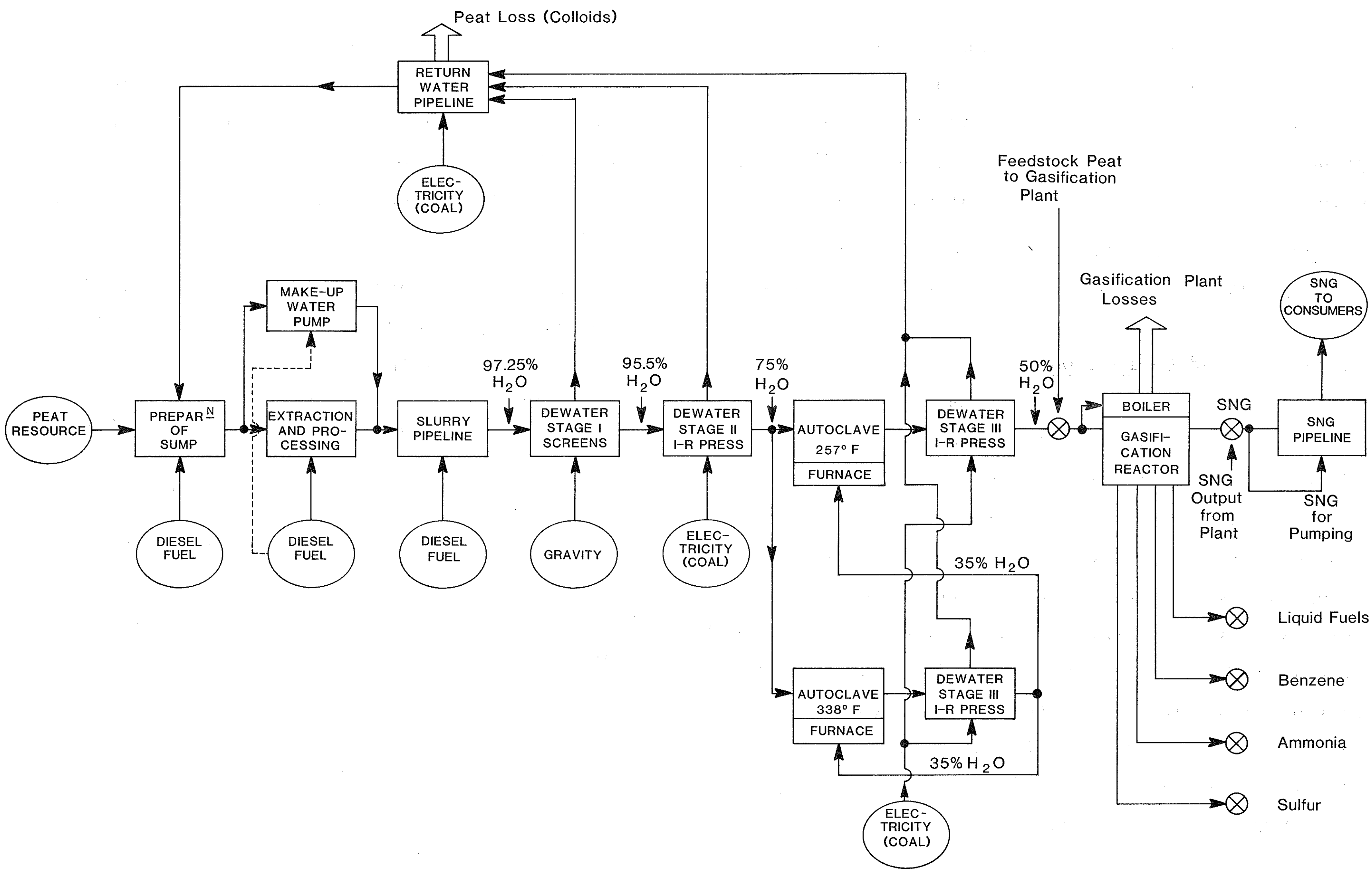
HYDRAULIC PEAT EXTRACTION

This extraction process is shown in Figure 3 for peat when it is transformed into synthetic natural gas.

Peatland Preparation

Unlike sod or milled peat extraction, clearing vegetation and establishing a drainage system are not necessary. Instead a sump is required, where a hover-

FIG ③ HYDRAULIC PEAT EXTRACTION



craft or floating raft can be placed to hold the equipment that will extract the peat. It is assumed in this analysis that only a one acre initial sump is required for each 1,000 acres of peatland that will be mined. The amount of energy consumed in preparing this sump is negligible, especially when compared to the other operational categories.

Peatland Preparation Step	Energy Required
Preparation of sump	1.60×10^3 BTU/acre

Extraction and Collection

The extraction process is carried out from a hovercraft or floating raft placed in the sump. (Western Peat Moss Company, Vancouver, and British Columbia use this method.) Either a clam shell device on the end of a dragline or a cutter head operating at the end of a suction pipe is used to extract the peat. Large debris is removed as the peat is filtered through screens and mixed with water to increase the moisture content of the peat to at least 97 percent (3 percent solids concentration by weight). The result is a slurry, ready for pipeline pumping to a central point.

Extraction and Collection Step	Energy Required
Hydraulic extraction	2.92×10^7 BTU/acre

Transportation

After the peat is extracted, it is transported by pipeline to a dewatering facility, assumed here to be three miles from the extraction location. Pumping is required to move the peat slurry through the pipeline. When the peat has been dewatered, the effluent water is returned to the peatland through a separate pipeline.

Transportation Step	Energy Required
Slurry pipeline pumping	5.36×10^8 BTU/acre
Return water pumping	1.31×10^7
Total transportation	5.49×10^8 BTU/acre

Processing

Hydraulic extraction requires no processing similar to that involved in milled or sod peat extraction. The dewatering changes the structure of the peat as described next.

Dewatering

The peat slurry received at the dewatering facility is greater than 97 percent water and less than 3 percent peat solids by weight. To be suitable for a feedstock, the moisture content must be reduced to 50 percent before the gasification process or to 35 percent for other conversion processes. Dewatering is done in several stages. First, the slurry is passed through a primary filter or screen. A negligible amount of energy is used here. Then the slurry is mechanically pressed in an Ingersoll-Rand "Twin Roll Vari-Nip" press which reduces the moisture content to approximately 75 percent.

The next stage changes the physical structure of the peat so that more moisture can be released. This is done in an autoclave unit, which heats the peat under pressure. Depending on the final moisture content that is needed, the temperature is increased to either approximately 257°F for gasification (50 percent moisture content) or approximately 338°F for other conversion processes (35 percent moisture content). After the desired temperature is reached, the peat is passed through the Vari Nip press again producing a peat feedstock ready for conversion to usable fuel.

Dewatering Step	Energy Required
Mechanical dewatering Stage I	1.90×10^{7} BTU/acre
Autoclaving to 338°F (35% moisture)	2.27×10^{9}
Autoclaving to 257°F (50% moisture)	1.69×10^{9}
Mechanical dewatering Stage II	3.81×10^{6}
Total dewatering to:	
35% moisture content	2.29×10^{9} BTU/acre
50% moisture content	1.71×10^{9} BTU/acre

Losses

Losses are substantial in the first stage of dewatering. Peat is lost in the form of colloidal particles when the slurry is passed through the primary screens. The lost peat is returned to the peatland along with the effluent water. Over a longer period of time, some of the loss may be recovered as the water is recycled through the extraction process. Unrecycled colloids presumably will settle out at the bottom of the excavated area as a very fine slime. The losses associated with hydraulic extraction are estimated here to be 20 percent, based on consultations with those familiar with this extraction procedure.

Extraction and transportation losses - 20 percent

In addition to the material losses described above, some of the peat feedstock is combusted to provide heat for the autoclaving process. The percentage of the initial resource used in this way depends on the final moisture content required. For dewatering to 50 percent moisture content this amounts to 8.79 percent and for dewatering to 35 percent moisture content, 11.8 percent.

SUMMARY

Table 1 summarizes the energy required to extract the peat for each of the three extraction methods. Hydraulic extraction is by far the least energy efficient of the three choices, requiring almost ten times more energy than milled peat to produce the same 50 percent moisture content needed for gasification. Milled peat extraction is the most energy efficient of the three, but this is partially misleading as is shown in Table 2, where peat losses are compared for each of the three methods of extraction. If the peat losses during the extraction, transportation, and conversion processes plus the peat consumed as fuel for dewatering are subtracted from the total energy available in the peatland, the actual energy content of the peat feedstock will result (Table 3).

Table 1. Peat Extraction Energy Requirements

Steps in the Process	Milled		Sod		Hydraulic	
	BTU/acre	Fuel Type	BTU/acre	Fuel Type	BTU/acre	Fuel Type
Peatland preparation	1.63×10^{6}	Diesel	1.22×10^{6}	Diesel	1.60×10^{3}	Diesel
Extraction and collection	4.46×10^{7}	Diesel	1.79×10^{8}	Diesel	2.92×10^{7}	Diesel
Processing	4.77×10^{7}	Diesel	9.49×10^{7}	Elec./Coal	0	
Transportation	1.51×10^{8}	Diesel	1.19×10^{8}	Diesel	5.49×10^{8}	Diesel & Coal
Dewatering						
to 35% moisture content			0		2.29×10^{9}	Coal & Peat
to 50% moisture content	0				1.71×10^{9}	Coal & Peat
Total to produce feedstock with:						
35% moisture content			3.94×10^{8}		2.87×10^{9}	
50% moisture content	2.45×10^{8}				2.29×10^{9}	

Table 2. Peat Losses During Conversion to Feedstock

Steps in the Process	Milled		Sod		Hydraulic	
	BTU/acre*	Percent	BTU/acre*	Percent	BTU/acre*	Percent
Peatland preparation	0		0		0	
Extraction and collection	$3.84x10^8$	2.0	0		0	
Processing	0		0		0	
Transportation	$3.84x10^8$	2.0	$1.92x10^8$	1.0		
Dewatering					$3.84x10^9$	20.0
Total Loss	$7.68x10^8$	4.0	$1.92x10^8$	1.0	$3.84x10^9$	20.0

*Losses in terms of equivalent energy lost.

Table 3. Energy Content of Peat Feedstocks

	Energy Content	Percent of Extracted Peat
Milled peat	$1.84x10^{10}$ BTU/acre	96.0
Sod peat	$1.90x10^{10}$	99.0
Hydraulic		
(50% H_2O)	$1.37x10^{10}$	71.2
(35% H_2O)	$1.31x10^{10}$	68.2

To measure the net energy efficiency of each production process one must add the additional non-peat energy used in processing to the total resource and divide that into the feedstock energy content. This is represented by the equation:

$$\text{Net Energy Efficiency} = \frac{\text{Energy content of feedstock}}{\text{Total energy available + additional external energy inputs}}$$

For the milled peat extraction process, the net energy efficiency is computed as:

$$\frac{1.84\text{x}10^{10}\ \text{BTU/acre}}{1.92\text{x}10^{10}\ \text{BTU/acre} + 2.45\text{x}10^{8}\ \text{BTU/acre}} = 94.8$$

Table 4 compares the net energy efficiencies of each production process.

Table 4. Net Energy Efficiency of Peat Extraction Processes

Milled (50% moisture content)	94.8%
Sod (35% moisture content)	97.0%
Hydraulic	
(to 35% moisture content)	66.1%
(to 50% moisture content)	69.1%

II. PRODUCING BIOMASS: THE RENEWABLE APPROACH

Growing some form of biomass on the peatlands offers another alternative for producing energy from this resource. An advantage to this approach is that it potentially supplies an energy source indefinitely given the proper management program. A disadvantage is the need for a greater amount of land in order to produce the same amount of energy per year relative to, for example, sod peat extraction.

In addition, the heating or energy content of biomass is slightly less than that of the peat it is grown on. At 35 percent moisture content, biomass is typically measured at 4875 BTU/lb (HHV) while peat offers a heating content of 6000 BTU/lb (HHV).

The cattail was selected to be the reference biomass energy crop in this study. Other energy crops that could have been chosen include phragmites (grasses), sedges, and woody plants such as willow, poplar, and alder. The selection of the cattail was based not only on the readily available information due to current research efforts in Minnesota but also on the fact that this wetland energy crop may reduce the need for extensive drainage, thereby minimizing the possible adverse environmental effects.

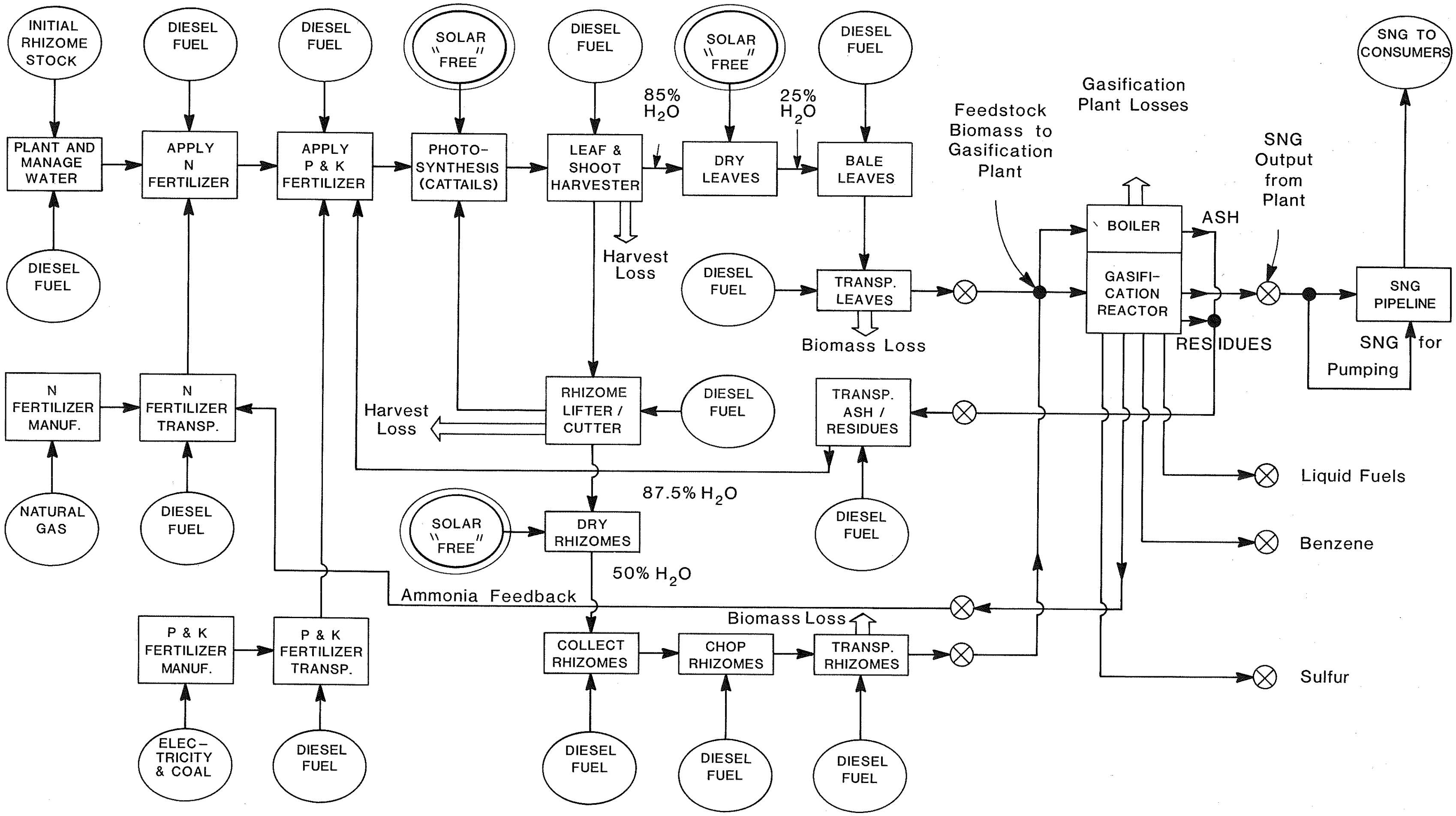
Five stages can be identified in the production and processing of cattails for use as an energy feedstock. These include planting and crop management, manufacturing and applying fertilizer, harvesting, processing and drying, and transportation to the conversion facility. Prior to this, the peatland must be prepared for production. Unlike the milled or sod peat extraction alternatives, drainage is unnecessary before cattail production begins. Land preparation, instead, involves clearing the peatland and leveling the surface if necessary. The energy used for clearing and leveling is negligible if averaged over many years of continuous biomass production.

The stages in the cattail biomass production process are shown in Figure 4, where the biomass feedstock is then converted into synthetic natural gas.

Planting and Crop Management

Two methods of cattail planting are possible: seeding or planting rhizomes (the below ground por-

FIG ④ CATTAIL BIOMASS PRODUCTION – HARVEST



tion of the plant). If seeding is chosen, approximately three years will be needed for the cattail stand to reach maturity, whereas rhizome planting allows full regeneration in one season. For this reason plant seeding is not discussed here. Furthermore, by deliberately leaving 10 percent of the rhizomes undisturbed during harvesting, no further replanting of rhizomes may be needed in future years. Since only one planting is necessary initially, the energy used in planting is spread over a number of years and thus again is counted as negligible for any given year.

Proper management is required to insure the growth of the plant. This includes the assurance of proper water levels during the various stages of growth. To do this water is pumped either into or out of the peatland to maintain these levels after evaporation, transpiration, and normal precipitation have been accounted for.

Planting and Crop Management Step	Energy Required
Pumping for water management	4.27×10^5 BTU/acre/year

Fertilizing

As in agricultural production energy crops will need fertilizer to yield substantial amounts of biomass. Generally three types of fertilizers are applied: nitrogen (N), phosphorus (P), and potassium (K). The actual amounts of fertilizer required to maintain productivity at a specific level will depend on the natural nutrients available in the soil and water; the rate of the nutrient loss; and, in the case of nitrogen, the symbiotic nitrogen fixation potential of the peatland ecosystem.

We have assumed that nitrogen will be applied in the form of anhydrous ammonia (NH_3). Because of the uncertainty as to the required amounts of nitrogen, two cases are presented here. The upper limit requires 900 lbs. of nitrogen per acre to be applied to the peatland each year. The lower limit is 230 lbs. per acre per year. The manufacturing of the anhydrous ammonia is an energy intensive process that uses natural gas as the key component.

The annual requirements of phosphorus and potassium are assumed to be 120 lbs. per acre and 250 lbs. per acre respectively. These two nutrients are applied in the forms of P_2O_5 for phosphorus and K_2O for potassium. By recycling the sludge and/or ash produced during the conversion process, 90 percent of the requirements for these two nutrients can be satisfied. This byproduct is supplemented with super phosphate and muriate of potash to make up the remaining 10 percent.

The transportation of the fertilizer is assumed to be done by truck for a distance of 500 miles. Very little is known about the actual requirements since the site of fertilizer production facilities was not determined. Fertilizer is applied annually in a two step process. First the nitrogen is injected into the soil as liquid anhydrous NH_3. The best time for this is in the fall immediately after harvesting. Second, the phosphorus and potassium supplements are mixed with the sludge-ash byproduct and the resulting mixture is applied to the field surface.

Fertilizer Step	Energy Required
Nitrogen	
Lower Limit	
Production	4.84×10^{6} BTU/acre/year
Transportation	1.73×10^{5}
Application	1.29×10^{5}
Upper Limit	
Production	1.90×10^{7}
Transportation	6.76×10^{5}
Application	1.29×10^{5}
Phosphorus and Potassium	
Production	8.93×10^{4}
Transportation	1.16×10^{5}
Application	2.05×10^{4}
Total Fertilizer	
for lower limit	5.37×10^{6} BTU/acre/year
for upper limit	2.00×10^{7} BTU/acre/year

Harvesting

Harvesting the cattails is also a two step process. The above ground portion of the plants (leaf and shoots) is collected with a machine that cuts near ground level and then collects them. The rhizomes are harvested by lifting them to the surface and cutting and collecting them. It is assumed that 10 percent of the rhizomes remain for regeneration the next season.

Harvesting Step	Energy Required
Leaf and shoot harvesting	$3.74/10^4$ BTU/acre/year
Rhizome harvesting	7.36×10^4
Total Harvesting	1.11×10^5 BTU/acre/year

Processing and Drying

This stage involves the drying, which is totally dependent on the weather. No energy other than the free energy from the sun is assumed to be used for drying. The leaves and shoots are dried prior to harvesting while the plant is still standing. The rhizomes must be spread out for solar drying after harvesting. The processing step involves baling the leaves and shoots and chopping the rhizomes so they conform more to the requirements of the feedstock for conversion.

Processing and Drying Step	Energy Required
Leaf and shoot drying	0
Leaf and shoot baling	1.59×10^5 BTU/acre/year
Rhizome drying	0
Collection of dried rhizomes	5.33×10^4
Rhizome chopping	4.91×10^5
Total Processing and Drying	7.03×10^5 BTU/acre/year

Transportation

As was assumed in previous sections, the conversion facility is 30 miles from the peatland site. Both the leaf and shoot bales and the chopped rhizomes are trucked to the conversion facility. In addition, the sludge/ash by-products are returned to the peatland site. This is done as a return load for some of the empty trucks that have transported the processed cattails, so that additional energy consumed is only that necessary to run a full truck as compared to an empty truck.

Transportation Step	Energy Required
Leaf and shoot transportation	4.94×10^5 BTU/acre/year
Rhizome transportation	8.89×10^5
Sludge/ash transportation	5.08×10^3
Total Transportation	1.39×10^6 BTU/acre/year

Losses

A significant amount of the cattail is lost during the harvesting step. A further 1.6 percent of the harvested crop is assumed to be lost during transportation.

Losses	Percent
Leaf and shoot harvesting loss	7.1
Root and rhizome harvesting loss	14.3
Transportation loss	1.6
Total Losses	23.0

SUMMARY

Table 5 summarizes the total energy requirements in the production and preparation of biomass (cattails) for conversion to some usable form of energy for the consumer. Both high and low nitrogen cases are presented. They vary depending on the fertilizer needs of the organic soil. Since the production of nitrogen fertilizer is energy intensive, a substantially larger amount of energy is required in the high nitrogen case as compared with the low nitrogen case.

Table 6 presents the losses during harvesting and transportation of the biomass. The losses are the same for both the high and low nitrogen cases, and represent 23 percent of the potential biomass (cattail) resource before harvesting. Therefore, at the time of conversion, a total of 77 percent of the initial potential resource energy is available for the production of SNG, electricity, or another fuel.

Energy Content of Biomass Feedstock	1.62×10^8 BTU/acre/year	77% of potential biomass energy

Table 5. Energy Requirements for Production and Harvesting of Biomass (Cattails)

Steps in the Process	Lower Nitrogen Limit (BTU/acre/year)	Upper Nitrogen Limit (BTU/acre/year)	Fuel Type
Planting	4.27×10^5	4.27×10^5	Diesel
Fertilizer	5.37×10^6	2.00×10^7	Natural Gas and Coal
Harvesting	1.11×10^5	1.11×10^5	Diesel
Processing and drying	7.03×10^5	7.03×10^5	Diesel
Transportation	1.39×10^6	1.39×10^6	Diesel
Total to Produce Feedstock	8.00×10^6	2.26×10^7	

Table 6. Biomass Losses During Conversion to Feedstock

Steps in the Process	Equivalent Energy Loss (BTU/acre/year)	Percent of Available Resource
Planting and crop management	0	0
Fertilizer	0	0
Harvesting	4.50×10^7	21.4
Processing and drying	0	0
Transportation	3.30×10^6	1.6
Total	4.83×10^7	23.0

The measurement of net energy efficiency for the biomass process is calculated by using the efficiency equation used earlier (page 19).

Energy Efficiency for Biomass Process	
for low nitrogen case	74.2%
for high nitrogen case	.69.5%

III. COMPARING THE CONVERSION PROCESSES

Three general types of conversion processes are discussed here for transforming the peat or biomass feedstock into useful forms of fuel. These are gasification to produce a synthetic natural gas, direct combustion to produce electricity and/or district heating, and the production of briquettes for use in heating and cooking. Each process is discussed briefly, with a description of only the major characteristics and steps in creating a usable fuel for the consumer. Several literature sources were consulted in determining the amount of energy that would be used and the efficiency associated with each process. Summary tables 7 and 8, found after the descriptions, present the net-energy values of each feedstock-conversion combination.

It is also important to note that this analsis does not consider the efficiency of use of the final fuel form. While the manufacture of briquettes may appear relatively more efficient than the production of electricity, there is a difference in their direct usability. The homeowner can use electricity directly (to run motors or produce artificial light, for example), whereas briquettes must be burned again before they are useful, thus going through another conversion process.

GASIFICATION

The gasification of peat or biomass yields synthetic natural gas (SNG). Peat can be converted to SNG in the form of methane through either biogasification or hydrogasification. The hydrogasification process can be controlled more easily in large scale plants and for this reason is used in this analysis.

During hydrogasification SNG is produced when feedstock reacts with steam and oxygen at high pressures and temperatures. The feedstock should ideally have a moisture content of not more than 50 percent. After the initial reaction, the liquids (gasoline blending feedstocks, oil, ammonia, and water) are removed. The resulting gas is then purified by removing carbon dioxide (CO_2) and hydrogen sulfide (H_2S). A medium level BTU gas is formed and is upgraded to pipeline quality SNG (what the homeowner uses) by catalytic methanation.

The complete process not only produces SNG (52.4 percent of the energy content of the feedstock) but also a number of by-products, including liquid fuels (8.4 percent), benzene (3.8 percent), ammonia (2.3 percent), and sulfur (.1 percent).

After production, SNG is transported by pipeline from the conversion facility to the consumer. Since the SNG must be pumped through the pipeline system, more energy is needed for this final transportation step. It is estimated that pipeline pumping of SNG needs about one-third the energy equivalent lost in the transmission of electricity over the same distance. Since electrical transmission losses are typically 10 percent of the energy generated we assume here an SNG pumping requirement of 3.33 percent of the SNG energy content.

DIRECT COMBUSTION

Direct combustion of peat or biomass can produce either electricity or steam or hot water for district heating systems. Europe has shown that this is a viable alternative. After the feedstock has arrived at the conversion facility it is further dried to a moisture content of 35 percent. It is then ground to a fine consistency - fine enough to be blown directly into the combustion chanber by a fan. The conversion of the chemical energy in the feedstock to thermal energy takes place in the combustion chamber. The thermal energy contained in the hot flue gases is then transferred to steam or hot water through the heat exchange systems of boilers, steam tubes, water heaters, and economizers.

At this point, the difference between cogeneration (district heating and electricity) and the supplying of either district heating or electricity, but not both, becomes evident. When the option of producing just electricity is taken, the steam is passed through a turbine which transforms the thermal energy into mechanical energy and then into electricity via a generator. Degraded heat is collected in a condensing system and then released into the atmosphere via cooling towers, or dumped into a lake or river as warm cooling water. For this analysis a plant that produces 50 MW of electricity was used with a first law efficiency* of 32 percent.

When choosing the cogeneration alternative, exhaust steam heat from a back pressure (rather than a condensing) turbine is transferred to steam or hot water and then used directly for home and commercial

*The traditional device efficiency (energy out divided by energy in) is based on the first law of thermodynamics. Second law efficiencies (sometimes known as task efficiencies) take into account energy quality as well as quantity.

heating. Thermal energy, contained in the steam or hot water (in newer systems) is transferred under pressure to the surrounding area through a distribution system. For this alternative, the conversion plant is assumed to have an electrical generation capacity of 35 MW with a 27 percent first law efficiency. In addition, the district heating component contributes another 64.8 MW of thermal equivalent output. The production of steam or hot water for district heating only is also possible, with a first law efficiency of 80 percent.

Again, it is important to consider the energy lost or used to transmit either the electricity over transmission lines or the hot water or steam through pipes. Electrical transmission losses are typically 10 percent of the net electrical output from the generation plant. The pumping energy required and the heat losses are major factors to consider for the district heating system. In such a system, steam or hot water must be pumped to the home or business and then returned to the conversion facility. The larger the system, the greater the heat losses will be. This analysis assumes that 10 percent of the resulting steam or hot water is lost during distribution.

BRIQUETTING

This process produces briquettes which are used for home heating or cooking. The feedstock arrives at the conversion facility with varying moisture contents (35 percent for sod, hydraulic peat, and biomass but 50 percent for milled peat). A significant amount of energy is required to further dry the feedstock to the required moisture level of 10 percent. Both heat and pressure are used in the drying. The feedstock is formed into briquettes in a pressing machine. They are then transported to the consumer via truck. During transportation it is assumed that one percent of the resource is lost.

SUMMARY

Table 7 presents in summary form the energy content of the fuel which results after peat or energy crops have been harvested and converted to a usable fuel product. Energy values are given as percentages of the total initial potential energy in the resource. In other words, the table shows what percentage of the original resource energy before extraction or harvesting is available for consumption by the consumer in the form of SNG, electricity, or briquettes after all the processing, transportation, and conversion is complete. For example, when the option of district heating and electricity is chosen after sod peat extraction, 59.5 percent of the total resource is available to the consumer after the losses from the mining, and conversion processes are accounted for.

The overall efficiency of each option is detailed in Table 8. These figures represent the overall net energy value of each combination. The amount of additional external energy required in harvesting, transportation, and processing (such as diesel fuel for extraction or electricity for crushing and grinding) has been included along with the initial resource energy content figure in Table 7. In summary then, the net energy efficiency ranges from 85.4 percent for briquetting after sod peat extraction to 16.5 percent when one produces electricity only, after using either hydraulic peat or biomass feedstock grown with the high nitrogen option. The difference in net energy efficiencies between the various options will prove useful in choosing what approach Minnesota should take if it is decided to harvest some of the peatlands.

Table 7. Energy Content in Fuel Product (as Percentages of the Initial Potential Energy in the Resource)

Fuel Product	Fuel Resource with Extraction or Harvesting Process				
	Sod Peat	Milled Peat	Hydraulic Peat	Energy Crop (Biomass) High N	Energy Crop (Biomass) Low N
Feedstock delivered to conversion plant site	99.0%	96.0%	71.2%	77.0%	77.0%
Gasification (SNG + by-products)	66.3	64.3	47.7	49.8	49.8
Gasification (SNG only) as delivered to consumers	50.1	48.6	36.1	39.0	39.0
Electricity only - as delivered to consumers	24.7	22.1	17.0	18.3	18.3
Cogeneration (district heating and electricity) - as delivered to consumers	59.5	53.4	41.0	44.2	44.2
District heating only (thermal energy) - as delivered to consumers	62.8	56.5	43.2	46.8	46.8
Briquettes as delivered to consumers	91.3	82.7	62.9	69.9	69.9

Table 8. Net Energy Efficiency (Energy Content in Fuel Product as Percentages of the Energy in the Initial Resource + All Additional Energy Requirements)

Fuel Product	Fuel Resource with Extraction or Harvesting Process				
	Sod Peat	Milled Peat	Hydraulic Peat	Energy Crop High N	Energy Crop Low N
Feedstock delivered to conversion plant site	97.0%	94.8%	69.1%	69.5%	74.2%
Gasification (SNG + by-products)	65.0	63.5	46.3	45.7	48.9
Gasification (SNG only) as delivered to consumers	49.1	48.0	35.0	35.8	38.2
Electricity only - as delivered to consumers	24.2	21.8	16.5	16.5	17.6
Cogeneration (district heating and electricity) - as delivered to consumers	58.3	52.7	39.7	39.9	42.6
District heating only (thermal energy) - as delivered to consumers	58.9	53.4	40.7	40.9	43.6
Briquettes as delivered to consumers	85.4	78.1	59.1	60.6	64.5

IV. KEY FINDINGS

This analysis has attempted to take into account all relevant points of energy consumption. A few important key findings should be remembered.

Hydraulic mining is by far the least efficient of the three extraction alternatives. This is for three reasons. First, the material losses associated with this extraction method are high, representing 20 percent of the total available resource. The peat is lost to a great extent in the form of colloids which escape through the Stage I dewatering filters and are returned to the sump. Second, the pumping of the peat slurry consumes a significant amount of energy. There has been some doubt expressed about the availability of water to produce this slurry, particularly in dry seasons. Finally, unlike the "free" dewatering that characterizes both sod peat and milled peat mining, the dewatering of hydraulically extracted peat consumes an even greater amount of energy than that needed for pumping. In fact, dewatering accounts for between 75 and 80 percent of the energy consumed during the extraction and processing procedure.

Transportation is an energy intensive step in the extraction procedure for all three mining methods. For this reason, it is important to examine the possibilities of locating peat conversion facilities as close to the mining operations as possible.

Energy crops require fertilizer and this requirement has a large impact on the net energy remaining after processing. Since nitrogen production is very energy intensive, lower nitrogen requirements would greatly reduce the amount of energy required for production. For sustained high yields, however, the nitrogen replaced must balance that extracted on an annual basis.

The renewability of energy crops offers the advantage of extending the peatlands life for many years. Recognizing the larger amount of land needed for growing energy crops and, therefore, the larger amount of land disturbed partially offsets this advantage. This tradeoff along with the generally lower net energy values for energy crops make further study necessary. However there appears to be no reason why an acceptable compromise between energy cropping and hydrology and wildlife conservation could not be worked out. Efficient equipment for energy crop harvesting is required so that harvesting losses can be minimized.

Solar energy can be used very effectively to reduce energy requirements in processing. This is most evident in comparing the drying processes used for peat extraction. This "free" energy is used for the sod peat and milled peat methods but is not compatible with the hydraulic extraction process where the energy requirements are consequently much higher.

When energy efficiencies are compared, it must be recognized that this analysis has only considered the net first law efficiencies of the final end use fuel forms without comparing the differences in the usability of that final fuel by the consumer. While the manufacture of briquettes may appear relatively more efficient than the production of electricity, electricity can be used immediately to run motors or light lights whereas briquettes must be burned in order to become useful, thus going through yet another energy consuming conversion process. Thus the high net energy efficiency gained in producing briquettes may be more than lost in this additional energy conversion process.

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