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ENVIRONMENTAL ASPECTS OF ALTERNATIVE
WET TECHNOLOGIES FOR PRODUCING ENERGY/
FUEL FROM PEAT

Final Report

By
Randall T. Smith

May 1, 1981

Work Performed Under Contract No. AC18-80FC10169

Energy Resources Co., Inc.
Walnut Creek, California

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

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Alternative Wet Technologies
for Producing Energy/Fuel
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ABSTRACT

Peat in situ contains up to 90 percent moisture, with about 50 percent of this moisture trapped as a colloidal gel. This colloidal moisture cannot be removed by conventional dewatering methods (filter presses, etc.) and must be removed by thermal drying, solvent extraction, or solar drying before the peat can be utilized as a fuel feedstock for direct combustion or gasification. To circumvent the drying problem, alternative technologies such as wet oxidation, wet carbonization, and biogasification are possible for producing energy or enhanced fuel from peat.

This report describes these three alternative technologies, calculates material balances for given raw peat feed rates of 1000 tph, and evaluates the environmental consequences of all process effluent discharges. Wastewater discharges represent the most significant effluent due to the relatively large quantities of water removed during processing. Treated process water returned to the harvested bog may force in situ, acidic bog water into receiving streams, disrupting local aquatic ecosystems.

1. INTRODUCTION AND SUMMARY

This report represents the findings and recommendations concerning environmental aspects of peat utilization using a select group of processing technologies. These processes are capable of converting a peat feedstock into methane, process steam, or an enhanced peat fuel without prior dewatering of the high-moisture feedstock. Three general process categories have been identified in this study: wet carbonization, wet oxidation, and biogasification. Wet oxidation processes have been utilized in industrial applications to reduce organic contaminant loads in aqueous waste streams. No previous peat-related applications using wet oxidation have been found. Biogasification is another waste treatment process, and has also been used in Russia to convert solubilized peat into ethanol. Wet carbonization has been used with peat feedstocks in Europe for many years. Its application to domestic peat resources is presently in the pilot-scale stage of development.

The primary objective of this study is to identify technical constraints relating to the effective control of process effluents from the wet peat conversion technologies. To accomplish this objective, the following four-task approach was used:

1. Literature Review

Inasmuch as this project represents a preliminary, scoping analysis, all available literature to date has been reviewed to locate the most recent experimental results and related ongoing projects. It is anticipated that new analyses and concepts will become available within the next six months to a year as current projects are completed or additional experimental task areas are begun.

The three process categories (five different processes in all) were selected based on their technical and economic feasibility, the likelihood of their development into commercial-scale ventures, and on the availability of data relating to process design and the characterization of effluents. Conceptual flow diagrams have been prepared for each process.

2. Mass Balance Calculations

Mass balances were developed based on the conceptual flow diagrams and experimental information obtained from the available experimental, pilot-scale, and commercial-scale data bases.

3. Environmental Regulation and Effluent Quality

To the extent possible, waste streams identified and quantified in the mass balance calculations were characterized, based on experimental analyses found in the literature. The significance of various waste streams were then determined.

Parallel task efforts summarized environmental regulations that could possibly apply to a peat development project. There are numerous federal and state regulations pertaining to air and water quality, and industrial waste discharges.

4. Review of Environmental Control Technologies

All technically available environmental control technologies were reviewed with respect to their applicability to wet peat conversion processes. Considerable emphasis was given to the area of wastewater treatment.

5. Recommendations

The results of these task areas have identified significant research needs. Areas not specifically addressed by experimental analysis have been detailed.

The basic concept behind wet peat conversion technologies is to produce a fuel product that exhibits better qualities than the raw peat. In the cases of wet carbonization and wet oxidation, heat and pressure are used to physically disrupt the colloidal structure that binds peat solids to molecules of water. Once freed from the peat (at the molecular level), mechanical dewatering techniques can be used more effectively to reduce the peat moisture content from around 90 percent to 50 percent by weight. The difference between wet carbonization and partial wet oxidation is that process heat is supplied externally in the former, while portions of the peat feed are internally combusted (rapidly oxidized) in the latter.

Complete wet oxidation carries internal peat slurry combustion to the fullest extent, leaving an inert ash/water sludge, oxidized peat liquor, and high pressure steam suitable for turbine expansion and electricity generation.

Biogasification also conditions the raw peat with heat and chemicals, but for the purpose of solubilizing the peat organics into the slurry liquor. Peat solids are separated, dewatered, and used as boiler fuel to generate process heat; the peat liquor carries the primary product feedstock into anaerobic digesters, where bacterial cultures acclimated to peat organics break down the molecules into a gas consisting of CO₂ and methane. After separation and purification, pipeline-quality methane is produced, ready for injection into the existing natural gas pipeline network.

It is difficult to accurately compare these processes to each other on a per-ton or per-Btu basis, due to the varied nature of end products and the inexact science of lab-scale data extrapolation. However, gross differences in effluent stream flows, normalized to an equivalent feed rate (1000 tons per hour raw peat containing 10 percent solids by weight), can be compared. Table 1-1 presents summarized mass balance results for each of the five processes discussed in this report. Two of the five processes (Koppelman process and Biogasification) have been designed to discharge much of the incoming peat slurry water before it enters the main conversion process, thus circumventing the need for thorough (and expensive) wastewater treatment. As discussed in later sections, it may be necessary to provide minimal treatment operations to these waters, such as pH neutralization. The important point is that secondary wastewater treatment facilities for the Koppelman and Biogasification processes can be designed for a smaller capacity, handling more concentrated effluents.

Table 1-1

Summary of Net Discharges from Section 3 Mass Balance Calculations
 (Based on 1000 tph raw peat feed, 90 wt % moisture)

Process/Quantity (tph)	Gas	Solid ^a	Raw Peat Water ^b	Process Water ^c	Evaporated Water (vented steam)
Wet Carbonization	24	76.2	0	868.8	31
Koppelman Process	51.4	51.1	600	286.7	10.8
Partial WAO	1.7	120.0	0	878.3	0
Complete WAO	36.7	32.7	0	930.6	0
Biogasification ^d	102.3	79.6	500	363.3	0

NOTES:

^aSolid refers to either sludge (wet) or fuel product (wet).

^bRaw peat water refers to slurry water released prior to the main process conditions, which requires no treatment or only primary treatment prior to discharge.

^cProcess water refers to those liquid streams (containing dissolved solids, if applicable) requiring primary and secondary treatment prior to discharge.

^dTotals add up to 1045.2 instead of 1000 due to the quantified feed rate of 45.2 tph dry alkali during peat solubilization.

From the lab-scale experimental analyses of process effluents, wastewaters, sludges, and gaseous discharges should contain no unique or untreatable components that conventional environmental control technologies can't successfully remove. Of particular interest in the area of waste treatment are those processes that integrate sludge utilization and wastewater treatment directly into the processing plant. The Koppelman process, as described in this report, utilizes wet oxidation to provide wastewater treatment as well as process heat. Wet carbonization (JP Energy OY design) and biogasification processes utilize junk wood from the bog (in the former case) and residual sludge from organics solubilization.

In any successful peat conversion process, maximum energy efficiencies will be obtained wherever waste heat is fully utilized. Considering the sufficiently high organic nature of some of the waste streams, careful process design can make use of the heating value in these streams and return it to the process. Those conversion processes that presently utilize two of the peat conversion technologies show the most promise (from a preliminary technical basis): wet carbonization using wet air oxidation; and biogasification using wet oxidation as a pre-treatment step.

Recommendations for additional research are steered towards exhaustive effluent analyses. Data is needed to characterize each waste stream in terms of constituents that may be detrimental to the environment or process hardware; detailed mass and energy balances are also needed for whatever level of process development is currently operating (e.g., bench-scale, pilot-scale, or commercial). There is currently research underway in all three general areas of peat wet technologies in regards to technical process development. Although some environmental-related data is being analyzed, more emphasis must be placed on the large-scale considerations of treatment requirements, and the incorporation of treatment processes into the overall plant design.

2. STATUS OF WET PEAT TECHNOLOGY DEVELOPMENT

2.1 INTRODUCTION

This section on wet peat technology development is included to introduce the processes chosen for mass balance calculation in section 3. Five processes are discussed in three general categories: wet carbonization, wet oxidation, and biogasification. Research in the area of peat wet carbonization has been performed by three different organizations, one with its origin in Finland (JP Energy OY), one sponsored by DOE and Minnesota Gas Company, and one privately developed in California (the Koppelman Process). The Koppelman process represents such a different approach to wet carbonization that it is discussed separately in this section and throughout the rest of the report.

Wet oxidation processes are divided into partial and complete oxidation techniques, since partial oxidation produces an enhanced peat fuel solid, and complete oxidation is used to produce process steam. At the time of this writing no actual laboratory or pilot-scale experiments with peat wet oxidation have been performed. Information is based on preliminary studies and extrapolation from wet oxidation of other high moisture feedstocks.

Research in the biogasification of peat is being conducted by Dynatech R/D Company and the Institute of Gas Technology (IGT). Their findings and program goals are highlighted in this section, and utilized as the basis for process quantification in section 3.

For each of the three general wet peat technology categories, historical developments are first summarized to identify previous experimental successes and problems. Current project activities are then discussed, and include preliminary process flow diagrams and final product characteristics.

2.2 WET CARBONIZATION

Wet carbonization is a process where elevated temperatures (300-800°F) and pressures (300-2000 psi) are used to physically disrupt the structural characteristics of raw peat. During wet carbonization, the colloidal structure of the peat breaks down, releasing CO₂ and water, and producing lower molecular weight (50-200 M.W.) organic compounds. The resulting solids are more easily dewatered by mechanical filtration, and demonstrate a higher heating value (dry basis) than the original peat material. The displaced liquid contains high concentrations of dissolved organics, which can be utilized to produce methane, alcohols, or process steam, depending on the methods used.

Commercial-scale development of peat by wet carbonization has not occurred in the U.S., although there are several examples of its use across Europe since the beginning of this century. A few examples are described below.

2.2.1 Historical Development

The first commercial wet carbonization plant was operated in Dumfries, Scotland, between 1915 and 1920, following several years of pilot plant operation at that site. The commercial scale plant utilized batch rather than continuous operations and was plagued by corrosion and scaling problems. Acids produced during the wet carbonization process limited the life of heat exchanger tubes to 3 to 6 months; slaked lime was added to the

peat slurry to reduce corrosion, but this in turn increased the ash content of the briquetted fuel product and caused rapid fouling of the heat exchanger tubes.^{1,2} The Dumfries plant was shut down in mid-1921 and dismantled by the end of 1927.³

Another commercial-scale peat wet carbonization plant was built in Boksitogorsk, U.S.S.R. in 1938. This plant was designed to utilize both the enhanced solid product (sold as briquettes) and the residual liquid phase (for chemical production). Milled peat initially containing about 67 weight percent moisture was batch-loaded into autoclaves at maximum process conditions of 374°F and 190 psia for 20 to 30 minutes. The process used was similar to the Fleissner process for beneficiation of lignite, which was tested in North Dakota in the 1950's. The carbonized peat then went through repeated filtration steps using plate-and-frame filter presses and a vacuum-filtered rotary drum. The dewatered solids contained about 37 to 40 weight percent moisture and were produced at a rate of 50,000 tons/year. It is interesting to note, however, that briquetted peat accounted for only one-fourth of the plant's revenue; 75 percent of the plant product value came from chemical production using the highly organic aqueous phase.

The steam distillate from the autoclaves contained dilute concentrations of furfural^a (0.5%), which was continuously distilled to yield a furfural-rich stream suitable

^aFurfural is a colorless, oily liquid (C₅H₄O₂) derived from cellulosic waste materials (usually oat hulls, rice hulls, corn cobs, bagasse, etc.) and used for solvent refining of lubricating oils, butadiene, and other organics. Furan (C₄H₄O) is prepared from furfural and is used as a solvent for resins or as a tanning agent.

for market. Filtrate from the peat dewatering presses was first neutralized with lime water, then fed into fermentation tanks where acclimated yeast culture digested the dissolved organics to produce alcohol. Distillation produced an ethanol stream of 93 to 94 percent quality.⁴

Beginning in 1951, the Swedish Peat Company and the Swedish government funded the development of wet carbonization in that country leading to the construction of a one-tenth commercial scale pilot plant in Sostala, Sweden. The plant commenced operation in 1954 and completed experimental runs totaling approximately 1,000 hours. The plant was shut down in 1964 due to the availability of low-cost petroleum. Problems in the plant involved fouling and scaling of heat exchangers and erosion damage to pumps, pipes, and other equipment due to the abrasive nature of the slurry.⁵

2.2.2 Current Status

Two wet carbonization processes are currently undergoing transition from pilot plant operation to development as a commercial-scale process. Each process is sufficiently unique to discuss them individually here and in later sections of the report. The first operation is being developed in Sweden using the Myreen process; a North American company, Wheelabrator-Frye, Inc., is a licensee of this process and is exploring the feasibility of building the nation's first peat fuel plant. The second wet carbonization approach is known as the Koppelman process, developed by Edward Koppelman and SRI International. This process is also involved in feasibility studies to determine the success of a commercial-scale plant in the state of Maine. Each process is discussed below.

The JP Energy OY Peat Fuel Process (Bertel Myreen)

Renewed work on wet carbonation was resumed in Finland in 1974 with the advent of drastically increased oil prices. This work was privately sponsored by Ra Shipping OY and was aimed at further improving the heat economy of the wet carbonization plant and in overcoming certain equipment difficulties previously experienced. Unit operations were tested on commercially available equipment, and a pilot plant was subsequently constructed and commenced operating in May of 1977.

The pilot plant equipment was sized for approximately 20,000 tons per year of production but was not configured to operate for sustained periods at this rate (due to storage capacity, water capacity, etc.). Ra Shipping formed a joint venture with Jaakko Poyry Engineering, a major international engineering and construction company headquartered in Helsinki. This joint venture is called JP Energy OY. Recently several other Finnish companies including Neste, the state owned oil company, Kemira OY, a major Finnish chemical company, and Imadran Vioma OY, formed a consortium to advance the technology in Scandinavian countries. This consortium holds the Finnish license to the process and is currently sponsoring enlargement of the pilot plant and additional pilot runs, as well as complementary programs, including work aimed at peat wet harvesting techniques and the use of peat derived fuel in oil and gas boilers and furnaces.

Figure 2-1 shows the simplified process flow diagram of the JP Energy Peat Fuel Process (based largely on Bertel Myreen's design, who is now a consultant for JP Energy OY in Finland). In this process, raw peat is first

Figure 2-1

Simplified Process Flow Diagram For Wet Carbonization of Peat
(JP Energy OY Process)

fed to a peat pulper, where it is diluted by hot process water and worked to a pumpable slurry. Impurities are removed by screening the slurry through the perforated sheet casing of the pulper drum. Oversized material (too large to pass through 3/8" holes) generally consists of junk wood from the bog, which is used to generate steam in the process steam boiler. Junk wood can often exceed 10 percent of peat deposits by weight in Scandinavian peat bogs, and therefore represents a valuable and economic process fuel source.

The accepted peat slurry is gravity fed into a large container serving as a buffer tank and storage for nine hours' production.

From the buffer tank the raw peat slurry is pumped to the slurry preheaters. A good energy economy in the preheaters is very important for the energy yield of the whole process. The slurry is heated in four different stages to the carbonizing temperature, in the first stage by secondary heat in hot process water, in the second by back-pressure steam, in the third by hot carbonized peat slurry and in the fourth stage by live high-pressure steam.

Tube heat exchangers designed especially for this purpose are used in the first and second preheating stages. Forced convection between the tubes and the viscous raw peat slurry is achieved by rotating the tube bundle in the vat forming the heat exchanger shell. The peat suspension is prevented from rotating along with the tube bundle by a thick central shaft.

The raw peat slurry temperature is about 104°F at the outlet from the heat exchangers with hot process water in the tubes. In the second heating stage, the temperature is elevated to 149°F. Fouling of the heat transfer surface may occur at higher temperatures, thus the raw peat slurry is not further heated in recuperative heat exchangers.

The third preheating stage is carried out in a preheating tower, specially designed for this purpose. In this tower, heat exchange takes place between the raw peat slurry and the carbonized peat slurry flowing from the carbonizing reactor. Although the preheating tower has no heat transfer surfaces vulnerable to fouling, nevertheless the solids in the two slurries are not mixed with each other in the tower.

The tower is a vertically mounted pressure vessel, internally divided into 10 identical sections (5 are shown in Figure 2-2). Each section has a built-in cyclone and an annular condenser space. The hot carbonized peat slurry flows through a throttling valve to the cyclone in the lowest section of the tower. By pressure reduction expansion steam is released from the slurry. This steam is separated from the slurry in the cyclone and led through the annular gap to the condenser space. Raw peat slurry is pumped to this space through atomizing nozzles as droplets with a temperature below the condensing temperature of the steam. The carbonized peat slurry is thus cooled by giving off expansion steam in the cyclone and the raw peat slurry is heated by condensing this steam on the raw peat spray in the condenser space. The peat slurries are led in counter-current through the sections of the preheating tower.

Figure 2-2

The Working Principle of the Preheating Tower
Used in the JP Energy OY Peat Fuel Process

Source: Reference 6

The raw peat slurry is heated by live steam to the reaction temperature in the carbonizing reactors. These reactors are specially designed to give a favorable residence time distribution for the peat particles. The reactor pressure is 350 psi, partly due to carbon dioxide formation in the reactor.

The carbonized peat slurry is cooled to 176°F in the preheating tower. Dewatering of the slurry is then carried out by pressure filters. This operation is semi-continuous and fully automatic. The filter cake discharged from the pressure filters has a moisture content of 50 percent, roughly the same moisture content as in milled peat. A further decrease of the peat fuel moisture content is obtained by thermal drying in a flash dryer with flue gases from the steam boiler. At this stage of operation, the carbonized peat occurs in pulverized form. The dried product can easily be pelletized into weather-proof pellets which are easy to handle. Dusting during transport and at the consumer level is avoided, as are problems with varying moisture content in the fuel.

The use of higher severity carbonizing conditions has recently been suggested by other experimenters in the U.S. JP Energy has found, and other researches have more recently confirmed, that solubilized and gaseous losses (CO_2 and volatile hydrocarbons) increase substantially with increased processing severity (time or temperature).⁷ These more severe processing conditions do not result in a commensurate improvement in dewatering capability which has already been reached at the milder process conditions utilized in the JP Energy process. Devolatilization of the peat does improve the Btu content of the final product somewhat (by increasing carbon content), but this devolatilization substantially deteriorates both combustion properties of the fuel (burning rate) and chemical reactivity.

Mild processing conditions substantially reduce water treatment requirements on the filtrate. Severe processing conditions also substantially increase plant capital costs, lower plant heat economy, and necessitate the use of undeveloped equipment.

Table 2-1 compares peat derived fuel with the raw peat from which it was produced. Note that 72 percent of the dry matter was retained while its Btu content was increased. Nitrogen and oxygen content were reduced, thereby increasing the carbon content slightly. Primary material losses include carbon dioxide, and water soluble and volatile organic matter. Most of the changes in the peat, however, are physical rather than chemical, resulting in coagulation of colloids and the opening of micropores, thus making mechanical dewatering of the dry matter possible.

Table 2-1

Chemical Changes In Raw Peat By Wet Carbonization
Using the JP Energy OY Process

	Raw Peat	Processed Peat Products				
	Dry Matter	Dry Matter	Water Soluble Organic Matter	Water	Carbon Dioxide	Volatile Organic Matter
Mass Balance (%)	100	72	11	8	7	2
Elemental Analysis (wt % dry basis)						
C %	53.1	62.1	45.2	-	27.3	76.6
H %	5.4	5.2	5.5	11.1	-	6.2
S %	0.2	0.3	-	-	-	-
N + O %	36.3	25.5	49.3	88.9	72.7	17.0
Ash %	5.0	6.9	-	-	-	-
Gross Calorific Value (Btu/lb)	9060	10950	7280	-	-	14700

Source: Reference 5

The Koppelman Process

The Koppelman process differs in many aspects from the JP Energy OY process. First, the peat slurry is initially dewatered prior to the reactor vessel, where it is fed by a screw conveyor mechanism. This reduces the load on wastewater treatment systems and improves process heat balances. Secondly, the Koppelman process operates at more severe reactor conditions, producing different by-products and requiring different process design parameters. The following paragraphs describe the Koppelman process in more detail, and discuss current project plans for a commercial-scale unit.

The heart of the Koppelman process is a reactor consisting of an externally heated inclined tube through which the feedstock is conveyed by a screw conveyor. As the peat passes through the reactor it is exposed to temperatures exceeding 750°F and pressures of about 1500 psi. As the temperature of the feedstock is increased, the moisture is displaced as a steam, and then mild carbonization occurs. The steam flows downward through the reactor countercurrent to the feedstock and, under the high pressure maintained in the reactor, condenses to the liquid phase. The latent heat of vaporization is thereby returned to the feedstock. The water is removed through a slotted screen wiped by the screw. Volatile tars and noncondensable gases produced by pyrolysis and carbonization also flow downward through the reactor and transfer heat to the solids. The tars are deposited on the solids and are ultimately partially carbonized. The gases have sufficient fuel value to meet the thermal requirements for the process. K-Fuel product is discharged from the top of the reactor and can be densified before it is cooled and removed from the system.

A schematic flow diagram for the Koppelman process is shown in Figure 2-3.

Figure 2-3

Peat Wet Carbonization (Koppelman Process) Flow Diagram

As shown in Figure 2-3, wastewater from the reactor is treated by wet air oxidation to remove solubilized organics and to generate medium quality process steam for peat pre-heating. Koppelman is also considering other wastewater treatment options, such as anaerobic digestion, for use with the process.

One of the significant design differences with the Koppelman process is that much of the peat slurry water is removed prior to its entrance into the reactor. Experimental results have shown that free water (in a Maine peat sample) can be reduced from 92 percent to 75 percent with only 50 psi pressure at ambient temperature.⁸ The effects of preliminary peat dewatering on the overall process mass balance are discussed in Section 3.

Removing the peat slurry water prior to the reactor represents a significant advantage during wastewater treatment. The released slurry water contains a relatively small organic fraction compared to the reactor wastewater stream, and therefore should require no secondary treatment (wastewater treatment processes are discussed in more detail in Section 4.3). Koppelman⁸ claims that this slurry water stream can probably be returned to the peat bog with little or no treatment, although all aqueous effluent streams shown in Figure 2-3 will most likely require pH adjustment and clarification prior to return to the bog.

The commercial feasibility of the Koppelman Process is being investigated under a grant from the U.S. Department of Energy. Under this grant, Mr. Koppelman and a group of organizations are conducting a study that could lead to the construction of a plant in Maine for producing 50,000 tons/year of K-fuel from peat and/or waste bark.

The peat deposit selected for study is in Washington County, Maine, and is comprised of sphagnum peat in depths over 20 ft. This type of peat, commonly sold for horticultural purposes, is fibrous and has an in situ moisture content of 90 percent to 95 percent. Unlike more decomposed peats, this fibrous peat can be pressed and dewatered to approximately 75 percent moisture. This moisture level is acceptable for introduction into the Koppelman reactor. The design basis for the peat portion of the study is, therefore, based on directly harvesting the wet peat, dewatering the wet peat by mechanical presses, and using the resulting pressed peat at 75 percent moisture as feedstock for the process. This procedure allows 9 to 10 months of harvesting per year rather than the 3 to 4 months experienced by horticultural harvesting operations using the milled technique.

The reactor module being considered in this study consists of four reactors, each 40 ft long with twin 13-1/2-in.-diameter screws to convey the feedstock through the reactor. The reactors are designed for a maximum operating product temperature of 1000°F and a maximum operating pressure of 1500 psig. After preparation, the feed is introduced into the reactor by an extruder. The twin screws convey the material up the reactor through the heating zones. By-products from the reactor include fuel gas, with a lower heating value of 285 Btu/scf, and wastewater. K-Fuel drops to a product extruder, which forms fuel pellets. These pellets are conveyed to a cooler to reduce their temperature to 180°F and then are conveyed to product storage.

Table 2-2 illustrates the effects of the Koppelman process on two types of peat. The fuels products derived from Canadian sphagnum reflect various degrees of treatment. Sample A received the most severe treatment and has the highest heating value. Sample C is the least carbonized.

Table 2-2

Characteristics of Raw Peat and K-Fuel
From the Koppelman Process

		Peat Type					
		Canadian Sphagnum				Finnish	
		As Received	Product A	Product B	Product C	As Received	Product
Ultimate Analysis (Wt %, dry basis)							
	C	51.8	90.7	74.1	71.36	53.09	74.43
	H	3.14	3.35	5.69	5.25	5.88	3.79
	S	0.15	0.14	0.14	0.13	0.21	0.22
	N	0.61	0.83	0.88	0.72	1.68	2.64
	O	43.08	0.61	17.1	20.28	33.16	6.08
	Ash	1.22	4.40	2.13	1.26	5.98	12.84
Higher Heating Value (Btu/lb)							
		8,702	14,454	13,535	12,775	8,274	12,681

Source: Reference 9

It is interesting to note the variation in oxygen content, which decreases with an increase in process severity. Not shown in the table, but equally important, is the reduction in volatile matter that occurs with increasing process severity. For the Canadian peat samples listed, the volatile matter content ranged from 18 percent (sample A) to 48 percent (sample C); treatment parameters can be controlled to yield any level of volatile content, depending on the desired ignition characteristics of the fuel product.

Data on the Finnish peat show that the oxygen content was significantly reduced, and the heating value improved by more than 4000 Btu/lb over the heating value of the dry feedstock.

IGT Experimental Work

The Institute of Gas Technology (IGT) has conducted several bench-scale tests to determine effluent quality characteristics from peat wet carbonization. Analyzed as part of a comprehensive peat fuel process,^a the IGT experiments have produced detailed product analyses that will be used in later sections of this report. A summary of IGT's experimental approach, objectives, and results are presented below.¹⁰

The objective of IGT's wet carbonization study is to evaluate the effectiveness of wet carbonization for reducing the liquid-retention capacity and improving the mechanical dewatering characteristics of peat. A reduction in the liquid-retention capacity of peat is desirable to lower the slurry

^aIGT is experimenting with several peat dewatering processes for use as a pre-treatment step for peat thermal gasification.

liquid concentration required in a pumpable peat slurry. An improvement in the mechanical dewatering characteristics of peat is desirable to maximize water removal by mechanical methods and thus minimize the peat thermal drying requirements.

In all, 21 initial wet-carbonization tests were conducted at various pressures, temperatures, and carbonization times. A summary of the operating conditions and ultimate analyses of the solid residues produced during the wet carbonization tests are presented in Table 2-3. The objective of the first 12 tests (Runs PWC-1 through PWC-12) was to determine the effect of temperature, pressure, and residence time on the toluene-retention capacity (TRC) of wet-carbonized peat.^a Runs PWC-13 through PWC-16 were conducted to produce sufficient quantities of carbonized residue for high-pressure compaction tests. A slight decrease in TRC had been observed with an increase in carbon conversion. Therefore, the objective of Runs PWC-17 through PWC-21, in conjunction with results of all earlier tests, was to further investigate the effects of different operating conditions on peat carbon conversion.

^aToluene-Retention Capacity tests were used by IGT as an indicator to determine the relative quantities of liquids required to make a pumpable peat slurry. TRC tests were conducted in graduated cylinders containing a known amount of peat (or wet carbonized peat). Toluene was added, and the mixture was stirred and allowed to settle until a layer of toluene just appeared above the peat surface. The excess toluene was carefully removed with a syringe. The TRC is calculated as the pounds of toluene per pound of dry peat in the remaining mixture.

The wet-carbonization apparatus consisted of a small high-pressure autoclave (about 200 milliliter capacity) installed in a vertical-tube furnace. The furnace could provide rapid heating up to 1800°F if required. Samples could be withdrawn from a top-mounted line that fed into an ice-water-bath condenser to collect water and other condensable liquids. The noncondensable gases produced during wet-carbonization tests PWC-2, 3, 4, and 21 were collected downstream from the condenser in a large (19-liter capacity) evacuated gas cylinder.

The results in Table 2-3 show a considerable amount of scatter, however, certain trends can be observed. Increasing the wet-carbonization pressure and temperature from 200 psig and about 400°F to 375 psig and about 530°F at a holding time of 2 minutes and a heat-up time of 30 to 60 minutes (compare Runs PWC-5, 8, 14, 15, and 17 with Runs PWC-10 and 11) results in an increase in average carbon conversion from 10 percent to 21 percent of the feed carbon. Increasing the holding time from 2 to 20 minutes and the heating time from about 30 to 60 minutes (compare Runs PWC-5, 8, 14, 15, and 17 with Runs PWC-2, 3, 4, and 19) at the same pressure and temperature (about 200 psig and 400°F) results in an increase in average carbon conversion from 10 percent to 28 percent of the feed carbon. An increase in heat-up time from 32 to 52 minutes at 375 psig, about 530°F, and 2 minutes holding time (compare Runs PWC 10 through 12) increases the carbon conversion from 19 percent to 28 percent of the feed carbon. Increasing the heat-up and holding times appears to significantly increase the carbon conversion during peat wet carbonization. However,

Table 2-3
Operating Conditions and Analysis of Solids
IGT Wet Carbonization Tests

Run No.	Feed	PWC-1	PWC-2	PWC-3	PWC-4	PWC-5	PWC-6	PWC-7	PWC-8	PWC-9	PWC-10
Operating Conditions											
Temperature, °F		450	410	390	390	375	410	390	390	445	525
Pressure, psig		200	200	200	200	200	200	200	200	300	375
Time, min		20	20	20	20	2	2	2	2	2	2
Heat-Up Time, min		60	70	60	53	31	219	107	30	30	32
Ultimate Analysis, wt %											
Carbon	50.5	63.3	60.6	59.5	60.7	57.9	51.8	52.5	55.8	55.6	56.5
Hydrogen	5.1	5.0	4.0	4.1	3.9	5.2	5.0	5.1	4.9	4.7	4.7
Others	32.9	18.6	13.0	14.1	16.2	21.4	27.2	29.1	25.4	23.7	22.9
Ash	11.5	13.1	22.4	22.3	19.2	15.5	16.0	13.3	13.9	16.0	15.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon Conversion, %	0		38.4	39.2	28.0	14.9	26.3	10.1	3.6	20.9	19.1
Run No.	PWC-11	PWC-12	PWC-13	PWC-14	PWC-15	PWC-16	PWC-17	PWC-18	PWC-19	PWC-20	PWC-21
Operating Conditions											
Temperature, °F	535	535	390	390	410	390	400	390	400	410	410
Pressure, psig	375	375	200	200	200	200	200	200	200	200	230 ^c
Time, min	2	2	2	2	2	2	2	10	20	2	60
Heat-Up Time, min	42	52	23	27	27	22	35	51	45	58	60
Ultimate Analysis, wt %											
Carbon	56.7	54.7	48.3	53.0	52.3	53.1	51.9	51.1	52.9	51.1	55.0
Hydrogen	4.7	4.7	4.7	5.2	5.1	5.2	5.0	4.9	4.9	4.9	5.2
Others	21.6	23.3	28.6	29.2	29.8	30.4	29.3	28.2	27.5	29.3	26.1
Ash	16.8	17.3	18.4	12.6	12.8	11.3	13.8	15.8	14.7	14.7	13.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon Conversion, %	22.9	28.0	40.2 ^a	4.2	7.0	— ^b	14.4	26.4	18.1	20.8	8.6

Notes:

^aWhen compared to Run PWC-13, the results from Runs PWC-14 and PWC-15 seem to be erroneous. The error is probably due to the method of sampling the feed material used in this test.

^bPlease ignore the results of this test because the analyses of the carbonized peat seem to be in error when compared with the feed analyses. The error is probably due to the method of sampling the feed material used in the test.

^cMaximum pressure in the autoclave for 20 minutes.

Source: Reference 10

the carbon conversion obtained in Run PWC-21 during which nothing was removed from the autoclave during the 60-minute heat-up or the 60-minute holding time at 410°F and about 230 psig was only 8.6 percent of the feed carbon. The regulation of pressure by venting or bleeding gas from the autoclave results in the evolution of more gases than from completely closed tests.

Gas samples were taken during Runs PWC-2 through PWC-4 in order to determine the typical composition range for open autoclave tests at moderate operating conditions (200 psig, 390°F, 20 minutes). For comparison, a gas sample was taken after Run PWC-21, which was a closed autoclave test. Gas analyses were not performed on any other PWC off-gases because no significant variations in composition were expected. Analyses of the gas samples taken during Runs PWC-2 through PWC-4 and after PWC-21 showed that carbon dioxide was the major constituent of the gases produced in these tests. The gases collected after PWC-21 contained more than 98 mole percent carbon dioxide, indicating that the closed operating procedure for PWC-21 (described above) suppressed the formation of hydrocarbon gases. Most of the carbon dioxide is derived from the decomposition of carboxyl groups in the peat organic material that is more easily evolved than other hydrocarbon gases such as methane or ethane.

All the components detected in the liquids produced from wet carbonization of peat (except for minute quantities of naphthalenes from Run PWC-21) contained nitrogen in aromatic compounds or oxygen in acids, alcohols, or aldehydes and ketones. In addition, the results show that the amounts

of methanol and acetone formed during Run PWC-21 were considerably lower than those formed during Runs PWC-2 through PWC-4. About 330 ppm of ethanol was present in the liquid sample from Run PWC-21, although no ethanol was detectable in the liquid samples from Runs PWC-1 through PWC-4. The concentration of acetic acid was similar in all of the samples.

Additional tests have been run at conditions ranging from 375°F to 610°F, 290 to 2200 psia, and 0 to 80 minute residence times.^a Various tests were performed to determine the effects of residence time on peat conversion. Results show that the effect of residence time is most significant between 0 and 20 minutes, especially at lower temperatures (around 400°F or lower). Results also indicate that residence times of more than 20 minutes do not significantly improve carbon conversion.

Temperature variations produced corresponding variations (at a fixed residence time) in carbon and oxygen conversions. The results show that increasing temperature from 400° to 600°F (at a 20-minute residence time) increased carbon conversion during wet carbonization from about 22 percent to 35 percent of the feed carbon.¹⁰ An increase in wet-carbonization temperature from 400° to 600°F (at a 20 minute residence time) also increased oxygen conversion from about 50 percent to about 78 percent of the oxygen contained in feed peat.

^aThe purpose of tests conducted with a residence time of 0 minutes was to determine conversion levels during the period required to heat the autoclave to a desired temperature.

Chemical analyses of the filtrate and pressate obtained during mechanical dewatering of the wet-carbonized peat show that about 12 percent of the feed carbon was solublized and that temperature and residence time had no significant effect on the percentage of feed carbon appearing in the filtrate. The percentage of the feed carbon converted to gas - analyzed to be primarily carbon dioxide - is calculated by the difference between total carbon conversion and the total carbon recovered in the wet-carbonized peat and the filtrate. An increase in temperature (at a constant residence time of 20 minutes) increased gas yield from about 12 percent to 23 percent of the feed carbon.

IGT is currently planning additional wet carbonization research. In September of 1980 IGT began the design and construction of a process development unit (PDU) for continuous wet carbonization of peat. The feed rate for the PDU is 800 lb/hr (1.6 gpm) of 95 wt % moisture peat slurry, with reactor temperatures of 350-550°F, residence times of 10 to 40 minutes, and pressures around 290 psia.³

2.3 WET OXIDATION

2.3.1 Historical Development

Wet oxidation is the most widely used non-biologic process to destroy relatively small amounts of organic materials as solids or liquids in aqueous solution or suspension. Chemical changes take place in wet oxidized solids not only for sterilization but to improve filterability characteristics. In some applications complete oxidation of the organics is desired and can be obtained by increased quantities of oxygen.

Hundreds of industrial installations throughout the world utilize wet oxidation for process stream conditioning, such as wastewater and sludge treatment facilities, and munitions plants. The technology, design data, and engineering/operating know-how are well established for wet oxidation applied to almost any organic material. The technology has not been commercially applied to peat; however, bench-scale testing of peat wet oxidation is being performed as a pretreating step in DOE's peat biomethanation project, and in recently initiated project efforts studying various wet peat oxidation process (sponsored through DOE/Grand Forks Energy Technology Center).

2.3.2 Current Status

Partial Oxidation of Peat

The concept of partial wet oxidation of peat is similar to wet carbonization in that elevated pressures and temperatures are used to physically alter the raw peat. These operating conditions disrupt the colloidal bonds in the peat structure, yielding dissolved organics in the aqueous phase, carbon dioxide gas, and a residual solid that is more easily dewatered by mechanical means. The difference between partial wet oxidation and wet carbonizations is that the former generates the reaction conditions directly, from within the reaction vessel, as discussed below.

To raise the large quantities of water in raw peat to the temperature necessary for carbonization requires the supply of considerable heat in addition to the small amount released by the carbonization reaction. Once heated, the heat energy

must be recovered through a series of heat exchangers if the process is to be economical, and this recovery step becomes difficult due to the nature of the material and the eventual fouling of any heat transfer surfaces. Partial wet oxidation reduces these problems by burning in place some of the more combustible constituents of the wet peat feedstock.

When oxygen is supplied to the raw wet peat in the closed vessel being heated to the lower range of temperatures used for wet carbonization, a rapid oxidation is initiated and takes place autogeneously with a large increase in both temperature and pressure. Even surrounded by water, the oxidation is extremely rapid and is a true combustion. The rate of the reaction increases rapidly with temperature and the pressure due to the pressure of water and of the gases formed. Oxygen solubility and rate of diffusion increases greatly because of the pressure effect, which outweighs the temperature increase that normally reduces gas solubilities.

The degree of combustion of the peat is controlled by the supply of oxygen, unlike usual combustion in furnaces which is controlled by the supply of fuel. Therefore, by controlling the amount of oxygen feed for a given rate feed of peat only a portion of the peat feed is combusted; this partial combustion may be stopped at a desired point (by stopping the flow of oxygen) to obtain a high yield of intermediary products. If partial wet oxidation is used to produce an enhanced peat product, the rate of oxygen is controlled so that the reaction temperature rises only to the level needed to break the colloid. The resulting material is a peat slurry that can be more easily dewatered by mechanical presses.

Using pure oxygen in a reactor vessel at 375°F and 300 psi, the combustion gases formed consist of about 85 percent carbon dioxide (after water separation).¹² The wet peat material remaining will contain 70 to 85 percent of the original solids, depending on the peat composition and the degree of oxidation.

Figure 2-4 illustrates a simplified partial wet oxidation peat process flow diagram, using air as the oxygen source. Initial startup of the otherwise continuous process will require an external heat source to establish reactor conditions and begin the oxidation process. Additional energy gains must be utilized in Figure 2-4 if the process is to be energy-efficient, such as using the post reactor stream pressure let-down for incoming air compression, and utilizing as much heat transfer between outgoing and incoming peat slurry streams as technically practical.

The slurry preparation step shows the addition of alkali into the peat/water slurry. Several classes of solids, when deposited on suitable catalytic support material or impregnated into the bulk of the oxidizable material, have been found to accelerate the rate of oxidation of various organic compounds in aqueous waste. However, the limited literature available does not specify an optimum alkali catalyst for peat wet oxidation, although metals, oxides, and carbonates have been found to be effective heterogenous catalysts. Possibly the most frequently mentioned catalysts for wet oxidation are the chromites of copper or manganese and combinations thereof. It is possible that the alkali concentrations of the raw peat may be sufficient to promote high reactivity without the need for additional catalysts.

Figure 2-4

Preliminary Process Flow Diagram for Partial Wet Oxidation of Peat

Complete Oxidation of Peat

Little experimental information is available regarding peat utilization and conversion by wet oxidation. However, Dr. Donald Othmer has developed a process concept for the utilization of peat by complete wet oxidation using air as the oxygen source. Although not verified technically or economically, the process represents one possible approach to peat utilization based on an established industrial technology. The following discussion is based largely on Othmer's work¹² with input from process developments by Zimpro, Inc.¹³

As shown in Figure 2-5, the peat slurry is fed from the storage tank in the correct ratio of water to solid so that the reactor receives between 10 and 30 times as much water as solid. Since wet air oxidation (WAO) must occur in the liquid phase, the water/solids ratio must be sufficiently high so that the reaction heat will not evaporate all the water, and so the peat slurry remains in a pumpable form.

A special pump, which has been developed for feeding other organic slurries into WAO, forces the peat slurry into the reactor at a pressure controlled between 1000 and 3000 psi. The peat is burned at a temperature between 350°F and 650°F to carbon dioxide and water. Approximately 98 percent of the organic matter is oxidized; the remaining 2 percent is carried out of the reactor in the sludge and water slurry, which is separated (releasing steam), filtered (to remove free water and dissolved solids), and either recycled, treated, or removed for disposal.

Figure 2-5
Preliminary Process Flow Diagram for Complete Wet Oxidation of Peat

Steam and non-condensable gas from the WAO reactor are passed through a condenser-reboiler and feedwater heater to generate clean process steam for industrial use or electricity generation. A maximum pressure of the pure steam generated will always be less than the WAO reactor pressure due to heat transfer losses. However, Othmer estimates the generated steam will have a maximum pressure of 800 psig at 520°F with WAO reactor conditions at 650°F and 3500 psig. A realistic initial plant of this type would probably produce steam at about 250 psig and 405°F, with reactor conditions at 500°F and 1000 psig.¹²

Feed water heater blowdown is then separated into an aqueous and gaseous phase. The remaining steam and non-condensable gases are still at elevated pressures, and this pressure is used to assist the air compression step before final separation of the gases and condensed steam. Throughout the process, heat recovery steps are taken to minimize heat losses and maximize energy efficiency.

The pressure of the steam discharging from a WAO boiler may be regulated within narrow limits, as with any conventionally fired boiler, by partially opening or closing a valve on the steam discharge. Balancing of more important changes in steam demand from a WAO unit is accomplished by adjustment of the air supply. This adjustment is more important than in conventional furnaces because of the need for high compression pressures.

The efficiency of a fuel-fired boiler can be expressed as the difference of the heat leaving in the steam from the

heat in the feedwater, divided by the heat of combustion in the supplied peat. With suitable process design and operation of a WAO unit, Othmer has estimated a thermal efficiency of 75 percent. (This value, however, does not reflect peripheral operation power needs, such as air compression, slurry pumping, sludge dewatering, and wastewater treatment.)

Additional Research

The U.S. Department of Energy, through the Grand Forks Energy Technology Center, is sponsoring laboratory and analysis research aimed specifically at developing a technically and economically feasible peat wet oxidation process.

All variations of wet oxidation will be considered: partial and complete oxidation, using oxygen and air. Mass balances, energy balances, effluent characterization, and process design are all subtasks of this effort. The results of this study should be available around mid-1982, and will provide valuable information directly relating to this project summary.

2.4 BIOGASIFICATION

2.4.1 Historical Development

Anaerobic digestion is similar to wet oxidation in that it is a well-known and widely-used technology for treatment of sewage sludge and many other biomass materials. With proper care and nutrition, certain types of bacteria digest these organic materials, breaking them down into a disposable solid phase composed primarily of single-cell proteins, and releasing relatively pure methane gas in the process. This technology is also similar to wet oxidation in that it has not been used on a commercial basis to convert peat to more useful forms, despite its long and widespread use as a waste conversion process.

Anaerobic digestion of peat has been the subject of experimentation since 1926, when the Swedish Royal Institute of Technology conducted tests at mesophilic temperatures (75° to 90°F). Among other findings, it was shown that thermal pretreatment and the addition of alkali materials enhanced the digestion of peat and the production of methane. The Soviets conducted research on anaerobic digestion of peat at thermophilic temperature (133°F) during the 1950's.

Peat hydrolyzate from the Russian semi-industrial pilot plant Boksitogorsk peat dewatering factory has been used for alcohol production.⁴ (This plant also incorporated peat wet carbonization and is discussed in Section 2.2.1.) In this plant, filtrate from wet carbonized peat dewatering was clarified, neutralized, and fed into large fermentation tanks.

The fermentors were inoculated with approximately 1 ounce of acclimatized yeast culture per gallon of process liquor, then fermented for 6 to 8 hours at 86°F. From one ton of peat at 37 percent moisture, the Boksitogorsk plant produced 1.6 to 2.1 gallons of ethyl alcohol. Laboratory tests produced higher yields around 3.2 gal/ton.

In Sweden, interesting pilot scale experiments have been conducted to evaluate in situ production of methane from peat bogs.¹⁴ In this process, methane naturally produced in peat bogs was dissolved in ground water. This methane-rich water was pumped to a degassing station above ground where the methane was separated.^a The water was then recycled underground for reuse. The concentration of methane in water of 20 ppm was reported under a circulation flow rate of 26.4 gal/second. It was estimated that about 35 percent of the methane produced was consumed for maintaining the process operation. This process is very interesting due to its very low operating cost, inexpensive transport and handling of raw materials, and relatively low capital cost. However, fluctuations in bog temperature will undoubtedly occur due to normal climatic variations, which will affect methane production rates. Localized bog temperature control should be considered in conjunction with this process.

2.4.2 Current Status

A two-stage biogasification process is under investigation at Dynatech R/D Company for the production of methane from peat. This project initiated at IGT

^aEnergy Alcohol Corporation of America, Inc., is currently investigating the use of this Swedish technology for methane separation in North Carolina peatlands.³⁷

in 1975¹⁸ with Dynatech becoming involved in 1977. The biogasification program is divided into a four-phase experiment, as described below.

Phases I and II were an 8-month feasibility study that began in November, 1977, sponsored by the Minnesota Gas Company. Phase I was a preliminary experimental investigation which indicated that a substantial percentage of the energy value in solubilized peat was fermented to methane. Experimental work utilized reed-sedge peat exclusively as directly hydro-mined by the U.S. Bureau of Mines from the Red Lake area of Minnesota.¹⁵ Phases III and IV are a continued development program that began in October 1979 sponsored by the Minnesota Gas Company and the U.S. Department of Energy. Phase III was an optimization of a continuous multistage bench-scale biogasification process. Results from Phase III are being used to provide scale-up data necessary for a process development unit (PDU) of approximately 1 dry ton of peat/day (Phase IV).

The program is divided into the following five tasks:

Task 1 Simulate a Multi-staged Pretreatment Reactor - the objective is to evaluate reaction conditions of temperature, pressure, degree of oxidation, degree of solubilization, and alkali concentration using Minnesota reed sedge peat. Batch mode pretreatment (2-liter capacity) information will be obtained prior to multi-stage design and operation.

- Task 2 Anaerobic Fermentation - the objective of this task is to confirm that peat pretreatment products are employed by anaerobic microorganisms for methane production. Yields and gas production rates will be determined using microorganisms acclimated to peat pretreatment products.
- Task 3 Evaluation of Solid and Liquid Process Effluent Streams - the objectives are to evaluate the solid residue streams of the process as a boiler fuel and to assess the environmental aspect of liquid effluent returned from the process to peat extraction areas.
- Task 4 Predictive Process Model and Economic Analysis - the objective of this task is to continue a comprehensive engineering analysis of the entire biogasification process based on additional experimental data obtained and detailed unit operation performance. The process model will enable determination of operating parameters costs of plants ranging in size from 25 to 250 billion Btu/day of SNG.
- Task 5 Planning for Process Development Unit - the objective is to prepare specific design plans and experiments at the PDU scale.

The following paragraphs describe Dynatech's experimental peat biogasification work.

The present work at Dynatech has been oriented towards obtaining a definitive process model on which full-scale plant economics may be based. The process model consists of three system components: 1) peat solubilization; 2) peat oxidation; and 3) peat fermentation. Although both solubilization and oxidation can occur in the same reaction vessel, it has been determined that these are two discrete processing steps.¹⁶

In step 1, peat and alkali (Na_2CO_3) are reacted at elevated temperatures to produce a solubilized peat product. In this step the peat is hydrolyzed, producing many types of substituted phenols such as condensed and uncondensed quaicyl. The substituent groups are carbon side chains containing 3 to 5 carbon atoms.

During the oxidation step, the carbon side chains on the aromatic rings are oxidized into carboxylic and aldehydic functional groups. The side chains are oxidized more easily than the benzene rings due to their lower activation energy. The amount of energy released during oxidation should make the oxidative step self-sustaining.

In the third step the conditioned peat is anaerobically biodegraded to methane and carbon dioxide. Dynatech investigated digestion conditions using both batch and continuous processes at mesophilic (95°F) conditions, using sewage sludge micro-organisms.

Results from laboratory tests indicate that untreated peat (not solubilized and oxidized) was virtually unused by anaerobic organisms to produce methane. However, anaerobic organisms not previously acclimated to the alkaline heat treatment products of peat utilized soluble organic material from various pre-treatment process conditions. Results show that up to 53 percent of the solubilized peat heating value was biologically converted to methane after alkaline heat treatment. Higher yields of methane may be possible with recycling of microorganisms previously acclimated to the peat products. The amount of methane produced from soluble products of treated peat under alkaline conditions (both oxidative and non-oxidative) was generally about twice that of non-alkaline conditions.¹⁵

A preliminary design for a commercial-scale peat biogasification plant has been made by Dynatech which will produce 75 million ft³ of pipeline quality methane per day.¹⁷ A simplified process flow diagram for the plant is illustrated in Figure 2-6 and discussed below.

Peat slurry at 3 percent solids is pumped from the bog to the nearby plant (within a 5 mile radius). At the plant the slurry is dewatered to about 25 percent solids by large rotary vacuum filters and rotary screw presses. The released slurry water is used during product gas purification, and then can be returned directly to the bog for reuse in transport slurry preparation.^a

Excess heat from the pre-treatment reactor is used to pre-heat the dewatered peat slurry. The warmed peat is then mixed with alkali (Na_2CO_3) and process water prior to the oxidation and solubilization reactor to form an 8 percent peat solids slurry.

^aAs with the Koppelman process, this slurry water may require some primary wastewater treatment prior to ultimate return to the bog.

Figure 2-6

Simplified Process Flow Diagram for the Peat Biogasification Process

Dynatech's process design calls for five vertical pre-treatment reactors in series for solubilizing and oxidizing the peat organics. The peat slurry remains in the reactor series for 15 minutes at 320 psig and 300°F, assuming reactor dimensions of 15 ft in diameter by 40 ft high.

Following heat exchange the conditional slurry (now at 140°F) is separated from reaction gases and dewatered in a two-step process. Helical centrifuges first separate peat liquor from the solids, leaving a sludge containing 13 percent solids. Inclined rotary or rotary screw presses are then used to bring the 13 percent sludge up to 35 percent solids. Dynatech claims the sludge can be used as a boiler fuel in a steam boiler for process electricity generation. Additional dewatering, probably by thermal drying, will be required in order to reduce the sludge moisture content to below 50 wt. percent for combustion.

The separated peat liquor is fed to ten anaerobic digestion tanks in parallel, where the liquor remains for 3 days. Gas released during digestion is drawn off the headspace of each tank at atmospheric pressure and 140°F. Raw gas is about 55 percent methane, 45 percent CO₂, and is saturated with water. Gas compressors compress the raw gas to 1000 psig, which is then cleaned to remove moisture, CO₂, and any trace quantities of H₂S.

The digestion or fermentation of peat will produce a considerable amount of heat that must be removed in order to maintain constant conditions within the digestion tanks. Increases in temperature may reduce or even stop microbial activity. Therefore, this heat can be removed by transfer through cooling towers, or used within the process gas for pre-heating purposes or sludge drying.

Digester by-products are withdrawn and separated to yield a stream of digested liquor and biomass. The liquor stream is returned to the process where it is reinforced with additional alkali and mixed with raw peat before entering the pre-treatment reactor. Any excess liquid is treated as necessary and returned to the bog. The biomass stream is the result of bacterial action in the anaerobic digester, and consists of cellular material produced by the culture of anaerobic microorganisms. Portions of this material is returned to the digestion tanks to maintain high levels of acclimated bacteria; the remainder can be utilized as a cattle feed or fertilizer.

3. PROCESS MASS BALANCES

3.1 INTRODUCTION

Section 2 introduced the wet technologies chosen for investigation in this report. In this section, each of the five processes are quantified using a peat feed rate of 1000 tons per hour (tph). The peat is slurried, heated, oxidized, pressed, cooled, and converted into gaseous, liquid, and solid process streams.

Mass balance calculations have been based on the best available information from research activities currently underway in most peat technology areas. It is important to realize, however, that extrapolations of data from laboratory or pilot-scale tests are not necessarily representative of true commercial-scale conditions. Assumptions and calculations used for each process mass balance are explained in understandable terms, and all data sources have been fully referenced.

The approach to calculating mass balances varied for each process in relation to the type and extent of available data. Wet carbonization and complete wet oxidation probably represent the two extremes used: for the wet carbonization mass balance, data from both experimental laboratory work and estimated process end-products were used. Qualitative lab analyses indicated the compositions of gaseous and liquid streams, from which actual tonnage percentages could be calculated.^a For complete wet oxidation, one reference had

^aThis high degree of numerical accuracy is misleading, however. Autoclaved product analyses from 2-liter laboratory tests may in no way represent actual emissions from a continuously fed industrial-scale pressure vessel. Therefore, all mass balance calculations in Section 3 probably have the same range of uncertainty, regardless of the origin of the data.

performed a detailed mass and energy balance for wet air oxidation using coal as the feedstock. In this case, process streams were already quantified, yet had to be modified to fit the process description for peat used in both Section 2 and Section 3. No experimental analyses of stream compositions were available, so it was assumed that coal and peat feedstocks generated roughly the same mass proportions throughout the process.

Each set of mass balance calculations is accompanied by a process flow diagram (similar to those presented in Section 2) and a tabular summary of effluent descriptions and quantities. Section 3.5 then compares all five processes in terms of effluent discharges, highlighting advantages and disadvantages resulting from the various process designs and limitations.

3.2 WET CARBONIZATION

3.2.1 JP Energy OY Process

The flow diagram and process kinetics for the JP Energy OY (Myreen) Peat Fuel Process are combined here with experimental data from the IGT wet carbonization tests. IGT data from laboratory tests at or near similar operating pressures, temperatures, and residence times have been incorporated into the mass balance calculations to provide necessary estimates of stream characteristics not included in the JP Energy OY process literature.

Table 3-1 lists the process conditions used for the wet carbonization mass balance calculations. Figure 3-1 illustrates the process flow diagram, and the following text explains the mass balance calculations and assumptions identified in Table 3-2.

As instructed by DOE during this project, the raw peat feed is assumed to be 90 percent moisture by weight, and is treated by the wet carbonization process at a rate of 1000 tons per hour. Despite the naturally high moisture content the peat appears dry, if not slightly moist. To slurry the peat for hydraulic transport (from the bog and through the carbonization process) the peat is mixed with process water until a pumpable slurry is achieved. IGT experiments used a slurry containing 95 percent water, which, when used with a peat containing only 10 percent solids, yields a weight ratio of raw peat/slurry water of 1:1. This ratio appears realistic when compared to actual ratios used for transporting coal by slurry pipeline. Therefore, the stream exiting from slurry preparation contains 1000 tph raw peat and 1000 tph process water. (More accurately, the stream contains 100 tph peat solids, and 1900 tph water containing approximately 3.4 tph dissolved solids from the process water.)

Figure 3-1

Simplified Process Flow Diagram For Wet Carbonization of Peat
(JP Energy OY Process)

Table 3-1

Process Conditions and Calculations Used In
The Wet Carbonization Mass Balance

Ultimate Analysis of Peat (Minnesota)⁴⁰
 wt %, dry basis

C	49.90
H	5.09
S	0.27
N	2.73
O	30.71
Ash	11.30

Reactor Conditions⁵ 392°F
 365 psia
 30 min. residence time

Experimental Data Used for Calculations^{3,7}

Test Conditions 400°F
 290 psia
 20 min. residence time

Slurry Composition 95% water (by weight)

Process Carbon Balance

	Percentage
Input	100.0
Output	
By-product gas	15.0
Dissolved in filtrate	13.0
Retained in solid	72.0
(by difference)	
	100.0

Oxygen Loss From Feed 50%

Final Moisture Content of
 Mechanically Dewatered,
 Carbonized Peat 36%

Source: References 3, 5, 7, 23

Table 3-2

Peat Wet Carbonization Process Mass Balance
 1000 tph Raw Peat (10% Solids) Feed

Stream No. (Fig. 3-1)	Process Step	Material Description	Quantity (tph)
1	slurry prep	raw peat	900 water 100 solids
2	slurry prep	recycled process water	(1000 process water)
3	steam injection	saturated steam	50
4	product dewatering	process wastewater	1911.4 water 7.4 soluble organics
5	product dewatering	dewatered product	68.6 solids 38.6 water
6	product gas vent		24.0 gas
7	thermal drying	final peat product	68.6 solids 7.6 water
8	wastewater treatment	wastewater	911.4 water 7.4 soluble organics
9	treated wastewater disposal	treated wastewater	861.4 water 7.4 treated solids

As the slurry travels through two (possibly more) heat exchangers on its way to the preheat tower, no mass transfer occurs. Energy (heat) is exchanged, but energy balances are not included as part of this study.

The design of the pre-heating tower was described in Section 2.2.2. Gases produced during wet carbonization (steam, hydrocarbon gases, CO_2 , and other non-condensable gases) are used to provide pressurized transport of the peat material, through the dewatering step, until the gases are released with the boiler flue gas following the peat thermal drying process. Several calculation steps were necessary to quantify and characterize the gas stream, as explained below.

The percent of feed carbon converted to gas is shown in Table 3-1 and is calculated as the difference between total carbon conversion and the total carbon recovered in the wet-carbonized peat and the filtrate.³ For a Minnesota peat carbonized at 400°F for 20 minutes, approximately 15 percent of the feed carbon was converted to gas, primarily carbon dioxide. Product gases from earlier autoclave tests by IGT at similar reactor conditions ¹⁰ (390°F for 20 minutes at 200 psig) were analyzed to determine gas composition; these results, combined with the value for weight percent carbon in the raw peat (Table 3-1), have been used to determine the approximate tonnage of gas produced from a feed of 1000 tph peat. Table 3-3 illustrates the calculation procedure used: First, mole percent composition values (Column A) were converted to a weight percent basis using atomic weights (AMU), summing the values, and normalizing to yield a total of 100 percent (Column B). Due to the number of calculations

Table 3-3

Calculation of Wet Carbonization Gas Composition Weight

Gas Sample Composition	Column A	Column B	Column C	Column D
	Mole % ^a	Weight % ^b	Carbon Weight (tons)	Gas Weight (tons)
CO	2.19	1.80	.19	.44
CO ₂	68.24	88.11	5.82	21.34
H ₂	19.67	1.154	0	0.27
CH ₄	5.91	2.77	0.51	0.68
C ₂ H ₆	1.16	1.02	0.20	0.25
C ₃ H ₈	0.51	0.66	0.13	0.16
n-C ₄ H ₁₀	0.26	0.44	0.09	0.11
i-C ₄ H ₁₀	0.13	0.22	0.045	0.05
H ₂ S	0.00	0	0	0
Furans (C ₄ H ₄ O)	0.51	1.02	0.18	0.26
Pyrroles (C ₄ H ₅ N)	0.13	0.23	0.04	0.05
Acetone (C ₃ H ₆ O)	0.39	0.66	0.10	0.16
Ethylene (C ₂ H ₄)	0.64	0.5	0.11	0.13
Propylene (C ₃ H ₆)	<u>0.26</u>	<u>0.32</u>	<u>0.07</u>	<u>0.08</u>
Total	100.00	98.93	7.485 ^c	23.98

Notes:

- Mole % analyses from Reference 10, run No. PWC-3, at the following test conditions: 390°F, 200 psig, 20 min. residence time, 60 min. heat up time.
- Individual percentages do not sum to 100% due to rounding.
- The total carbon weight (7.485 tons) based on 15% of Feed C in gas (Reference 3) and 49.90 wt% C in an ultimate analysis of Minnesota peat (Reference 23). 100 tons/hour of dry peat are fed through the process.

involved in this step, the resulting total is slightly less than 100 percent. Second, 15 percent of the original peat feed carbon has been converted to a gaseous form, and from the analysis of a Minnesota peat (Table 3-1), 49.90 percent of the dry peat material is carbon. With 100 tons of dry peat processed per hour, this results in approximately 7.5 tph of carbon being converted to gas ($.499 \times 100 \text{ tph} \times .15 = 7.485 \text{ tph carbon in gas}$).

Returning to Table 3-3, the third step involved distributing the 7.5 tons of carbon to each of the quantified constituents in the gas stream (Column C). Finally, actual tonnages of each gas constituent were calculated based on the carbon weights in column C. Assuming the IGT gas composition analysis is representative of yields at those reactor conditions, approximately 24 tph of gas (excluding steam) are produced by wet carbonization of 100 tph of dry peat solids.

After passing through the wet carbonization reactor and pre-heater, the peat slurry is mechanically pressed to separate the free water from the carbonized peat. To estimate the distribution of solids between the filtrate and the filtered product, an iterative approach was used. The iterative constraints were: 1) the filtered peat product contained 36 percent water by weight; and 2) some of the original solids have been solubilized and are carried off in the filtrate. To begin the calculation, it was assumed that no organic solids were solubilized; therefore, all peat solids remaining after gaseous losses were assumed to be in the final peat product. At 36 wt % moisture (with 76 tph solids), an initial water tonnage distribution was established (1857 tph in filtrate, 43 tph in peat product). At this point, wastewater analyses from early IGT experiments were used to estimate quantities of dissolved solids (see Table 3-4).

Table 3-4

Calculation of Wet Carbonization Wastewater Composition

Liquid Sample Composition	Column A	Column B
	mg/l ^a	tons/hour ^b
Methanol (CH ₃ OH)	1610	3.00
Ethanol (CH ₃ CH ₂ OH)	—	—
Acetone (CH ₃ COCH ₃)	720	1.34
2-Butanone (CH ₃ CHCOCH ₃)	160	.30
Acetic Acid (CH ₃ COOH)	800	1.49
Propionic Acid	—	—
Pyridine (C ₅ H ₅ N)	40	.07
2-Methylpyridine (C ₆ H ₇ N)	40	.07
3+4-Methylpyridine (C ₇ H ₉ N)	10	.02
Ethylpyridine (C ₆ H ₆ N)	8	.01
Methylpyrazine (C ₅ H ₆ N ₂)	91	.17
2-Furaldehyde (C ₄ H ₃ OCHO)	8	.01
5-Methylfuraldehyde (CH ₃ C ₄ H ₂ OCHO)	97	.18
<u>o</u> -Hydroxybenzaldehyde (HOC ₆ H ₄ CHO)	—	—
Naphthalene	—	—
Methyl Naphthalene	—	—
Phenol (C ₆ H ₅ OH)	218	.41
<u>o</u> -Cresol (CH ₃ C ₆ H ₄ OH)	51	.09
<u>m</u> + <u>p</u> -Cresol (CH ₃ C ₆ H ₄ OH)	60	.00
<u>o</u> -Methoxyphenol (CH ₃ OC ₆ H ₄ OH)	3	.00
<u>o</u> -Ethoxyphenol (C ₂ H ₅ OC ₆ H ₄ OH)		
<u>m</u> + <u>p</u> -Ethoxyphenol (C ₂ H ₅ OC ₆ H ₄ OH)	63	.12
2, 4-Xylenol [(CH ₃) ₂ C ₆ H ₃ OH]	4	.01
<u>o</u> -Ethylphenol (C ₂ H ₅ C ₆ H ₄ OH)	2	.00
<u>m</u> + <u>p</u> -Ethylphenol (C ₂ H ₅ C ₆ H ₄ OH)	12	.02
C ₃ -Phenol	3	.01
C ₄ -Phenol	<1	.00
		7.42

Notes:

- From Reference 10, test run No. PWC-3.
- Based on 1861.4 tons/hour wastewater from wet carbonization process flow calculations. Iterations between net fuel solids and resulting wastewater tonnages produced these results.

Column A represents quantities (in mg/l) of wastewater components from wet carbonization at 390°F, 200 psig, and 20 minute residence time. Using the initial estimate of 1857 tph of wastewater, column A values were converted to tons of organic component per hour in column B. The sum of column B values produced an initial estimate of the dissolved solid tonnage. This sum was then subtracted from the filtered peat solids tonnage, which forced an adjustment of the water distribution. Now with a modified wastewater estimate a new column B was calculated. The final estimates are 7.4 tph dissolved solids and 1861.4 tph wastewater.

Note that calculations for determining dissolved solids did not incorporate estimates for process steam condensate (these calculations are explained in the next paragraph). The reason for this procedure is that the IGT autoclave tests used an external heat source instead of injected steam; therefore dissolved solids estimates are based on slurry water quantities only.

To estimate the process steam requirements, the conditions inside JP Energy OY's reactor must be known. Estimates for ΔT in the reactor can be obtained from Figure 2-2, which shows the inlet and exit temperatures from the pre-heating tower creating a 21.6°F (12°C) temperature increase. At 392°F the heat of vaporization (h_{fg}) for steam is 836 Btu lb⁻¹, and the specific heat of the 95 percent water slurry is estimated at 0.97 Btu lb⁻¹ °F⁻¹. Based on these values and a slurry feed rate of 2000 tph, 50 tph steam are needed to maintain reactor conditions.^a

^a21.6°F x 0.97 Btu lb⁻¹ °F⁻¹ = 20.95 Btu lb⁻¹ slurry.
2000 tph slurry x (20.95/836) = 50 tph steam.

Additional steam generating capacity is needed to drive an expansion turbine for pump power, but this quantity is recycled in its own closed loop and need not be quantified.

The 50 tph water for steam are added to the slurry quantity in the reactor vessel, and are separated from the peat material along with the 1861 tph of wastewater calculated earlier, creating a total wastewater stream of 1918.8 tph (includes 7.4 tph dissolved solids).

The wastewater is utilized within the process in two ways as shown in Figure 3-1. About 1000 tph of the stream is recycled as peat slurry water. The 1000 tph includes approximately 4 tph of dissolved solids. Figure 3-1 also shows this waste stream utilized as a flue gas scrubbing solution to remove fine particulate. (The flue gas requires no scrubbing for SO₂ due to the inherently low sulfur content of the peat fuel used in the steam boiler.)

The remaining wastewater is used to pre-heat incoming peat slurry, then is directed to the wastewater treatment facility. Following treatment 50 tph is returned to the steam boiler for reuse. The final discharged water stream tonnage is equal to the original peat water minus moisture in the peat product, minus water evaporated in the thermal dryer. To reduce the moisture content in the mechanically dewatered peat product from 36 percent to 10 percent, 31 tph water must be evaporated by dry flue gas from the steam generator. The preliminary mass balance for wet carbonization is now complete.

Net discharges from 1000 tph raw peat fed into the wet carbonization plant are summarized in Table 3-5. Approximately 918 tph of wastewater must be treated for 1000 tph of peat feed.

Table 3-5

Summary of Net Discharges from Wet Carbonization of Peat
(1000 tph feed rate; 90% moisture)

Steam Description	Quantity (tph)
Raw Peat In	1000
Gaseous Effluent	24
Liquid Effluent	868.8
Peat Fuel Product	76.2
Evaporated Water	31

3.2.2 Koppelman Process

Mass balance calculations for the Koppelman process have been based on limited information made available through SRI International. Much of the specific process characteristics are of a proprietary nature and are thus not available.

Information used to prepare the Koppelman process mass balance is listed in Table 3-6. Figure 3-2 illustrates the flow diagram, identifying stream flow numbers presented in Table 3-7.

Figure 3-2

Peat Wet Carbonization (Koppelman Process)
Flow Diagram and Mass Balance

Table 3-6

Process Conditions and Calculations Used In The Koppelman
Process Mass Balance

Reactor Conditions

1st stage: 200° - 400°F
2nd stage: 750° - 850°F
1500 psia

(No other information is available.)

Fuel Product Yield

46% to 55% of dry weight of raw peat

Fuel product is 90% solids by weight

(46% is used for mass balance calculations
to illustrate high range of wastewater
discharge.)

Material Balance

Based largely on preliminary Koppelman process mass
balance using woodwaste feedstock.

Additional calculations provided by personal communication
with R.G. Murray, SRI International, March 24, 1981.

Source: References 8, 9.

Table 3-7

Peat Wet Carbonization (Koppelman Process) Mass Balance
 1000 tph Raw Peat (10% solids) Feed

Stream No. (Fig. 3-2)	Process Step	Material Description	Quantity (tph)
1	peat feed prep	raw peat	900 water 100 solids
2	peat feed prep	discharged water	600 water
3	peat feed prep	dewatered peat feed	300 water 100 solids
4	reactor	product gas	31.4 gas
5	reactor	wastewater	294.9 water 22.6 diss. organics
6	flash separator	condensed water vapor	90 water
7	air compression for WAO	air	235 air
8	turbine/compressor	gas	255 gas
9	water discharge	treated water	207.5 water
10	fuel product	K-fuel	46.0 solids 5.1 water

The first step identified in Figure 3-2 differs from JP Energy OY in that water is removed from the raw peat instead of added to create a pumpable slurry. Mechanical presses remove two-thirds of the peat's moisture with about 50 psi of pressure. The water pressed from the peat is at ambient temperature and contains relatively low levels of organics, so it is assumed that it can be returned directly to the bog with little or no treatment. (Western Peat Company of British Columbia is currently disposing of pressate in this manner.)

The raw peat now contains 75 percent water by weight (stream No. 3). After pre-heating, the peat is fed by twin screws into the Koppelman reactor where carbonization and pyrolysis occurs. Heat for the reaction is supplied externally by superheated steam, generated from the fuel gas produced in the reactor (stream No. 4). Because the superheated steam is a closed-loop external heat source, no mass balance calculations for the steam boiler are necessary.

Based on similar mass balance calculations for the Koppelman process using woodwaste feedstocks,⁸ 31.4 tph of low-Btu fuel, gas are expected to be generated.

Wastewater generated within the reactor is withdrawn from the bottom of the inclined vessel at elevated pressure, and is fed directly into a wet air oxidation (WAO) reactor for conditioning.^a The contents of the wastewater stream (stream No. 5) are estimated at 294.9 tph water with 22.6 tph dissolved organic solids. These values were obtained by difference from material inputs minus final products and vented fuel gas.

^aOther wastewater treatment options have been considered, but WAO can provide process steam for the plant while conditioning the wastes.

Products from the WAO are used in several ways: flash steam (stream No. 6) from the treated water stream is used to pre-heat incoming peat, and cool (by evaporation) the extruded peat fuel product. Approximately 10.8 tph are evaporated in the spray cooler, based on a 51 tph peat product feed rate, a ΔT of 570°F (750° - 180°F), and an assumed $C_p = 0.4 \text{ Btu lb}^{-1} \text{ } ^\circ\text{F}^{-1}$. Of the originally estimated 90 tph flash steam,³⁶ 79.2 tph remain for disposal to the bog or other receiving water.

An additional 207.5 tph of treated wastewater (stream No. 9) are discharged from the separator and from expansion in a turbine to assist air compression requirements for the WAO reactor. It is roughly estimated that 235 tph air are required by the WAO reactor.³⁶ An equivalent amount of gases are expelled from the reactor along with about 20 tph of gases produced during oxidation of dissolved solids (stream No. 8).

Based on a fuel product yield containing 46 percent of the original peat solids and 10 wt % moisture, 51.1 tph of peat fuel (K-fuel) are withdrawn at a temperature around 180°F.

A summary of net discharges from 1000 tph raw peat feed through the Koppelman process is shown in Table 3-8. Although 886 tph of water are discharged from the process, only 317 tph may require secondary treatment prior to disposal or reuse in the plant. The concept of dry peat transport instead of a peat/water slurry can greatly reduce the capacity requirements for extensive wastewater treatment (assuming the raw peat pressate needs only primary treatment).

Table 3-8

Summary of Net Discharges from The Koppelman Process
(1000 tph feed rate; 90% moisture)

Stream Description	Quantity (tph)
Raw Peat In	1000
Gaseous Effluent	51.4
Liquid Effluent	886.7
Peat Fuel Product	51.1
Evaporated Water	10.8

3.3 WET OXIDATION

3.3.1 Partial Wet Oxidation

The process flow diagram for partial wet oxidation of peat is shown in Figure 3-3 and identified stream locations quantified in Table 3-9. For these mass balance calculations, air was chosen as the oxidant supply instead of industrial grade oxygen. Although a significant factor in actual plant design and plant economics, the choice between air and oxygen has little effect on mass balance estimates. Calculations have been based largely on reports by Othmer¹¹ and Zimpro, Inc.¹³

As shown in Figure 3-3, raw peat is slurried with process water in a 1:1 ratio to produce a pumpable slurry containing 95 wt % moisture (1900 tph water, 100 tph peat solids). An unquantified amount of alkali may be added to help solubilize part of the peat organic material, which improves the rate of oxidation within the pressurized reactor vessel. (Much of the alkali would be recycled along with the slurry water, but some would be lost through wastewater treatments.) Oxidation air is compressed at a rate of about 106 tph, based on the proportion of oxidation air/dry feed solids in reference 13. Since this is only partial wet air oxidation (WAO), the referenced proportion must be factored by the estimated amount of peat solids oxidized. Othmer¹¹ cites Cederquist claiming that 10 percent of the peat solids are oxidized in partial WAO. The resulting air requirement is thus 106 tph.

Gases produced during wet oxidation consist primarily of CO₂ and saturated steam, with trace amounts of hydrocarbons. Assuming the 10 tph of peat solids oxidized consists

Figure 3-3

Preliminary Process Flow Diagram for Partial Wet Oxidation of Peat

of carbon and hydrogen (a fair assumption), approximately 18 percent of the feed C and H is converted to CO₂ and water using oxygen from the compressed air.^a From this estimate, 9.1 tph C and .9 tph H react with approximately 31.6 tph to form 33.3 tph CO₂ and 8.3 tph H₂O. The total quantity of gas released is then 107.7 tph, which consists of the 10 tph oxidized peat solids and approximately 74.4 tph of oxygen-depleted air. The raw gas is separated (streams 4 and 5) to recover saturated water vapor for return to the reactor.

Blowdown from the WAO reactor is filtered to separate freed water from the conditioned peat product. Othmer estimates that up to two-thirds of the peat moisture can be removed at this point, leaving a burnable peat fuel containing 33 percent moisture by weight.¹¹ Othmer also states that about 10 percent of the peat solids are solubilized and discharged with the blowdown. Therefore, stream 6 (Figure 3-3) contains the original 1900 tph water plus the 8.3 formed during oxidation, 80 tph solids, and 10 tph dissolved solids. The final peat product then consists of 80 tph solids and 40 tph water (making a 33 wt % moisture peat product), and the remaining tonnages are carried off in the filtrate (stream 7). Part of the filtrate is recycled for slurry preparation (1000 tph); the remaining 878 tph must be treated prior to disposal.

^aThe following peat analysis was used from reference 10:

Ultimate analysis, wt % dry basis	
C	50.5
H	5.1
Others	32.9
Ash	11.5
	<u>100.0</u>

Table 3-9

Partial Wet Air Oxidation Mass Balance
 1000 tph Raw Peat (10% Solids) Feed

Stream No. (Fig. 3-3)	Process Step	Material Description	Quantity (tph)
1	slurry prep	raw peat	900 water 100 solids
2	slurry prep	slurry water	1000 water
3	oxidation reactor	oxidation air	106 air
4	oxidation reactor	reactor gas	107.7 gas
5	oxidation reactor	condensed steam	8.3 water
6	oxidation reactor	liquor and solids	1908.3 water 80 solids 10 dissolved solids
7	product dewatering	pressate	10 dissolved solids 1868.3 water
8	product dewatering	peat product	80 solids 40 water
9	wastewater treatment	treated filtrate	878.3 water

A summary of net discharges from partial WAO of peat is listed in Table 3-10. For 120 tph of enhanced peat fuel, 878 tph wastewater must be treated. Additions of alkali solids would be added with the raw peat as necessary to replenish solubilized alkali discharged with the wastewater.

Table 3-10

Summary of Net Discharges from Partial Wet Air Oxidation of Peat
(1000 tph feed rate; 90% moisture)

<u>Stream Description</u>	<u>Quantity (tph)</u>
Raw Peat in	1000
Gaseous Effluent	1.7
Liquid Effluent	878.3
Peat Fuel Product (33 wt % moisture)	120.0

3.3.2 Complete Wet Oxidation

Zimpro, Inc., a Wisconsin company specializing in the design and construction of wet oxidation boilers, has performed a mass balance for the complete oxidation of a coal-water slurry.¹³ This balance has been used to approximate the mass balance using 1000 tph of raw peat feed. The process flow diagram is shown in Figure 3-4, identifying stream locations quantified in Table 3-11.

To the 1000 tph of raw peat is added 1000 tph process water (streams 1 and 2 in Figure 3-4) to create a pumpable slurry containing 95 percent water. Alkali solids can be added here if desired. The addition of a small amount of alkali will fix the acetic acid formed as an intermediary product of WAO, and will allow its subsequent separation from the reactor blowdown. With younger peats the addition of sulfuric acid yields various organics including sugars which may be fermented after neutralizing the blowdown liquid.¹¹

Compressed air is injected into the reactor vessel at a rate of 1062 tph, and, once at operating temperatures, combustion of the peat organics begins. During oxidation, parts of the original peat solids are converted into gas, water, and dissolved solids. According to proportional calculations based on reference 13, the peat solids are converted into the following material tonnages: 38.0 tph water (steam), 36.7 tph non-condensable gases, and 14.9 tph dissolved solids, leaving 10.4 tph solids in the solid phase.

Figure 3-4

Preliminary Process Flow Diagram for Complete Wet Oxidation of Peat

Table 3-11

Complete Wet Air Oxidation Mass Balance

Stream No.	Process Step	Material Description	Quantity (tph)
1	slurry prep	raw peat	900 water 100 solids
2	slurry prep	process water	1000
3	air compression	air	1061.9
4	separator 1	condensed steam	1501.4
5	separator 2	combustion gases	1098.6
6	separator 2	water	375.4
7	separator 3	steam	18.2
8	sludge dewatering	filtrate	26.4 water 9.2 dissolved solids
9	sludge dewatering	filter cake	16.6 water 5.7 dissolved solids 10.4 solids
10	wastewater treatment		921.4 water 9.2 treated dissolved solids

Steam for electricity generation is produced by a closed loop heat exchange with the actual steam produced in the WAO reactor. Mass balance calculations of the outside steam loop are not necessary here; however, based on reference 13 calculations, approximately 1313 tph steam at 100 psig and 338°F can be produced in the outside loop. The WAO reactor generates approximately 500 tph steam at 450°F.¹³

Water and steam condensate are manifolded to wastewater treatment, except for 1000 tph of process water, which is recycled for slurry preparation. The total water tonnage from streams 4, 6, 7, and 8 equals 1921.4 tph water and 9.2 tph dissolved solids. Subtracting the 1000 tph water for slurry preparation leaves 930.6 tph of process liquid requiring treatment prior to disposal.

A summary of net discharges from complete WAO of peat is listed in Table 3-12. To generate approximately 1.7×10^9 Btu/hr (500 MW) of steam from 1000 tph raw peat, approximately 930 tph of wastewater must be treated prior to disposal.

Table 3-12

Summary of Net Discharges from Complete Wet Air Oxidation of Peat
(1000 tph feed rate; 90% moisture)

Stream Description	Quantity (tph)
Raw Peat in	1000
Gaseous Effluent	36.7
Liquid Effluent	930.6
Residual solids	32.7

3.4 BIOGASIFICATION

Mass balance calculations for the biogasification of peat are based on a preliminary process design developed by Dynatech R/D Company.¹⁷ Dynatech's commercial-scale plant is designed to produce 75×10^6 SCFD of pipeline quality methane from 7740 tons/day of dry peat. This feed rate is equivalent to 322.5 tons/hours dry peat; for the purposes of this study, Dynatech's mass balance was normalized to a 100 tph dry peat feed and used as the basis for the following calculations.

Figure 3-5 illustrates the peat biogasification process flow diagram, identifying key process streams quantified in Table 3-13. It is assumed that, wherever possible, process effluent is recycled for re-use within the plant. The use of recycled effluent will reduce the capacity requirements for wastewater treatment and can reduce the consumption of alkali, but the compounded sodium levels in the peat stream may inhibit digestion activity.

Peat slurry at 3 percent solids is pumped from the bog to plant (stream No. 1). This incoming slurry contains the design tonnage of 1000 tph raw peat, and 2333 tph water (creating the 3 percent solids slurry). Since process water will be recycled for use as slurry water, the original bog water is removed here and returned to the bog after little or no treatment. Portions of this water are used later in the process for scrubbing CO_2 from the product gas. A 25 percent solids slurry results from initial dewatering, releasing 2833 tph water. Alkali (Na_2CO_3) and process water are added to the dewatered peat slurry in a static mixer (streams 3 and 4) to produce an 8 percent peat solids slurry.

Figure 3-5

Simplified Process Flow Diagram for the Peat Biogasification Process

Table 3-13

Biogasification Process Mass Balance
1000 tph raw peat (10% solids) feed

Stream No.	Process Step	Material Description	Quantity (tph)
1	slurry receiving	raw peat slurry	1000 raw peat 2333 water
2	slurry dewatering	slurry water	2833 water
3	alkali mixing	Na ₂ CO ₃	45.2
4	alkali mixing	process water	750.0
5	air compression	air	90.0
6	pre-treatment product separation	gas	120.6
7	primary liquor separator	sludge	18.7 solids 13.7 dissolved solids 111.8 water
8	primary liquor separator	liquor	82.2 dissolved solids 1038.2 water
9	secondary liquor separator	sludge	18.7 solids 3.9 dissolved solids 31.0 water
10	secondary liquor separator	liquor	9.8 dissolved solids 80.8 water
11	anaerobic digestion	raw gas	73.2
12	gas purification	gas by-products	1.5 H ₂ O 50.0 CO ₂ - - H ₂ S
13	gas purification	methane	21.7
14	biomass dewatering	biomass and bacteria culture	26.0
15	biomass dewatering	digested liquor	1111.8
16	wastewater treatment	treated water	361.8

Alkali tonnages are based on a 0.4 molar solution as cited in reference 17. Using Na_2CO_3 addition on a per-dry peat basis, 45.2 tph of alkali are added to the slurry. This value incorporates recycled alkali entering with the recycled process slurry. Na_2CO_3 is but one of several bases used in experimental tests by Dynatech. Other successful alkalis are NaOH and K_2CO_3 . The ultimate selection of alkali will be largely based on availability and cost. About 750 tph recycled process water are needed to create the 8 percent peat solid slurry.

Solubilization and oxidation of the peat slurry occurs in the pre-treatment reactor, which is energy self-sustaining. Air for oxidation is compressed to 320 psig at a rate of 90 tph (stream No. 5). Post-reactor product gases are separated from the conditioned peat stream and either vented or expanded through a turbine/generator to produce electricity for on-site use. Gas discharge from the oxidation pre-treatment contains 13.5 percent of the original peat feed carbon (reference 15), which combines with peat oxygen (17.1 tph) and air oxygen (18.9 tph) to form CO_2 . The remainder of the gas is oxygen depleted air with unquantified amounts of hydrocarbon gases. Of the total gas weight 30.6 tph of original peat dry weight is lost as CO_2 .

The conditioned peat stream is passed through a series of two types of deliquoring steps, a centrifuge separator immediately followed by rotary screw presses. According to normalized mass balance calculations from Dynatech, 90.6 tph of additional peat liquor is released from the screw presses, resulting in an increase in sludge solids content from 13 percent to 35 percent.¹⁷ The masses of streams 7 and 9 are therefore 144.2 and 53.6 tph, respectively. This yields a value for undissolved solids of 18.7 tph, which is removed by stream 9 and used for boiler fuel.

The peat stream entering the centrifuge deliquoring units contains 1150 tph water and 114.6 tph solids in dissolved and undissolved form. By subtracting 18.7 tph of resulting undissolved solids, it can be assumed that 95.9 tph of the original peat and alkali solids have been solubilized. The combined liquor quantities entering anaerobic digestion consist of 1119 tph water and 92 tph of dissolved solids.

Prior to entering the anaerobic digesters, the peat liquor may require additional chemicals to neutralize its pH value. A mass balance for chemical addition is not included here due to insufficient data on which to make a realistic assumption. However, any mass addition at this step would be reflected in streams 14 and 15.

Approximately 73.2 tph raw gas are generated during anaerobic digestion and consist of CO_2 , water, CH_4 , and possibly some H_2S . The raw gas is compressed to pipeline pressures of 1000 psia and then cleaned to remove 1.5 tph water (in ethylene glycol contact towers and by gas compression), 50.0 tph CO_2 (in water scrubbing towers), and unquantified trace amounts of H_2S (in activated carbon contact towers). The resulting gas stream consists of 21.7 tph methane at 1000 psia and 60°-100°F.

About 26 tph of wet excess biomass are generated in the digesters by the microorganisms. This excess is separated from the digested liquor and portions are returned to the anaerobic digesters to recycle acclimated bacteria cultures and nutrients. The remaining biomass can be utilized as cattle feed or fertilizer.

The separated digested liquor-stream (stream No. 15) is divided: 750 tph is recycled as stream 4, and the remaining 361.8 tph are treated as necessary prior to discharge.

A summary of net material flows through a peat biogasification plant is listed in Table 3-14. It is important to note that of the 863 tph of discharged water, only 362 tph should require secondary wastewater treatment prior to disposal. The separated slurry water is similar to the original bog water, except possibly for increased quantities of suspended particulates. Primary treatment methods (pH adjustment and clarification) may be necessary before slurry water can be returned to the bog. The sludge from stream 9, if burned as boiler fuel, will produce an ash material requiring standard ash disposal practices. The 30.6 tph of pre-treatment gases released with oxygen-depleted air (stream 6) may require flaring, depending on the organic content. It is estimated that, much, if not all, of the gas will be CO₂.

Table 3-14

Summary of Net Discharges from Biogasification of Peat
(1000 tph feed rate; 90% moisture)

Stream Description	(Stream Location)	Quantity (tph)
Raw Peat in Alkali Addition		1000 45.2
Liquid Effluent	(2) 500 (12) 1.5 (16) 361.8	863.3
Residual Solids	(9) 53.6 (14) 26	79.6
Gaseous Effluent	(6) 30.6 (12) 50 CO ₂ 21.7 CH ₄	102.3

3.5 DISCUSSION

This section has developed preliminary mass balance calculations for five different alternative wet technologies for peat conversion. When compared as a group, the variations in generated effluent quantities become significant, most noticeably in the area of wastewater generation. To more easily compare the effluent quantities from each process, Table 3-15 summarizes the mass balances developed in this section. Although these values represent rough approximations based on little empirical data, they can be used to identify processes that will require further design developments in order to minimize environmental impacts due to effluent discharges.

From Table 3-15, gas production is highest for biogasification, reflecting the desired conversion of peat solids into methane and other non-condensable gases. Solids production is highest for those processes producing an enhanced peat fuel. It is difficult to compare values in this column, however, due to the various moisture contents in the respective solids.

Untreated water discharges represent a significant difference between process designs. By removing slurry transport water, and as much peat water as possible prior to conditioning processes, the water load on secondary wastewater treatment facilities is greatly reduced. This concept is not suited to WAO; however, the wet carbonization process could readily utilize this approach (as utilized in the Koppelman Process) and reduce the water tonnages requiring extensive treatment.

Table 3-15

Summary of Net Discharges from Section 3 Mass Balance Calculations
(Based on 1000 tph raw peat feed, 90 wt % moisture)

Process/Quantity (tph)	Gas	Solid ^a	Raw Peat Water ^b	Process Water ^c	Evaporated Water (vented steam)
Wet Carbonization	24	76.2	0	868.8	31
Koppelman Process	51.4	51.1	600	286.7	10.8
Partial WAO	1.7	120.0	0	878.3	0
Complete WAO	36.7	32.7	0	930.6	0
Biogasification ^d	102.3	79.6	500	363.3	0

NOTES:

^aSolid refers to either sludge (wet) or fuel product (wet).

^bRaw peat water refers to slurry water released prior to the main process conditions, which requires no treatment or only primary treatment prior to discharge.

^cProcess water refers to those liquid streams (containing dissolved solids, if applicable) requiring primary and secondary treatment prior to discharge.

^dTotals add up to 1045.2 instead of 1000 due to the quantified feed rate of 45.2 tph dry alkali during peat solubilization.

4. ENVIRONMENTAL ASPECTS

4.1 INTRODUCTION

This section is divided into three areas. Section 4.2 summarizes the available information from experimental analyses that deals with waste stream characterization. For each process (where information is available), wastewater, gaseous effluents, and solids characteristics are described. Data varies from one process to another, and the format for effluent characterization ranges from a single BOD₅ value for wastewater up to a compound-specific mole fraction analysis. ERCO has made no attempt to characterize effluents without actual empirical data, therefore the material in this first section is presented in as much detail as provided by the original references.

Section 4.2 also discusses the federal and state regulations that would apply to a peat development project and its discharges. State environmental standards have been included for Minnesota and Maine, two of the states that have high potential for hydraulic peat harvesting and/or wet peat technology utilization.

Section 4.3 highlights many environmental control technologies that could be used for treatment of wet peat process effluents. The topic of wastewater treatment is the most significant concern, and is discussed in the greatest detail.

The final section presents a preliminary environmental impact analysis based on the results from previous sections in this report.

4.2 ENVIRONMENTAL CONDITIONS AND REGULATIONS

4.2.1 Effluent Quality

4.2.1.1 Wastewater Quality

There is little information currently available that provides wastewater analysis data in terms of BOD, COD, TDS, and other standard wastewater quality indicators. Information provided in the wet peat process literature is summarized below.

Wet Carbonization

In the JP Energy OY wet carbonization process, almost 870 tons per hour of wastewater require treatment. Myreen states that the water is highly contaminated by dissolved organic matter and may have a Biological Oxygen Demand (BOD) as high as 4000 ppm.⁶ IGT laboratory tests determined that nearly three-fourths of the organic wastewater loading results from methanol, acetone, and acetic acid.¹⁰ (See Table 3-4 for the listing of wastewater composition.)

Recent estimates from the Koppelman process (using waste bark instead of peat) wastewater effluents are listed in Table 4-1. Analysis results shown in the table indicate the wastewater contains a high organic content; specific constituents other than phenol, ammonia, and cyanide are not known. It should be noted that the Koppelman process design, as discussed in earlier section, integrated wet oxidation wastewater treatment into the overall plant process. The wastewater characteristics in Table 4-1 represent the waste stream entering the wet

oxidation reactor, not the reactor discharge. The post-oxidation wastewater characteristics are not known, although the wet oxidation process should effectively condition the stream so that quality criteria can be met (more is said on this subject in later sections).

Table 4-1

Characteristics of Wastewater from the
Koppelman Reactor
(waste bark feedstock)

Temperature (°F)	150
Soluble COD (ppm)	46,000
Soluble BOD (ppm)	24,800
Soluble TOC (ppm)	32,400
Phenols (ppm)	1,200
Ammonia-N (ppm)	30
Cyanide (ppm)	<0.7
pH	3.0

Source: Reference 8

Wet Oxidation

Partial WAO "conditions" the peat slurry without oxidizing all of the organic matter; some of the raw peat organics are solubilized and retained in the process wastewater. However, WAO breaks the long-chain organic molecules into readily degradable materials suitable for separation, fermentation, chemical feedstocks, or biological water treatment.

In complete WAO, all but approximately 2 percent of the peat organics are oxidized. The wastewater stream carries dissolved and suspended inorganics in oxidized form as soluble salts, oxides, and silicates. Remaining organics are removed with the sludge and/or wastewater, and may require additional treatment if concentrations exceed effluent standards. The wastewater stream is usually acidic and may include sulfuric acid and its salts in an amount roughly equivalent to the sulfur in the peat. It may be neutralized with lime or other alkali, depending on the necessary processing for in-plant water recycle.

Biogasification

Sources of liquid effluent from biogasification include the following:¹⁷

- the liquid effluent from the pretreatment process which is highly alkaline and high in sodium or potassium,

- the liquid effluent from the digestion process which may contain slightly higher concentrations of sodium or potassium than those in the original bog peat, and
- the liquid effluent from the gas purification process which contains carbonic acid.

4.2.1.2 Gaseous Effluent Quality

Wet Carbonization

Table 3-3 lists approximate tonnages of wet carbonization gas effluent constituents. About 68 mole % of the gaseous discharge is CO_2 , with small amounts of CO , CH_4 , C_2H_6 , H_2 , $\text{C}_4\text{H}_4\text{O}$ (furans), and other light hydrocarbons. This analysis represents the most comprehensive effluent analysis of all the processes considered in this report.

Reactor gas characteristics from the Koppelman process are listed in Table 4-2, based on waste bark feedstock. The analysis indicates similar proportions of CO_2 , lower H_2 , and higher percentages of CO and methane.

Table 4-2
Reactor Gas Characteristics from the
Koppelman Reactor
(waste bark feedstock)

<u>Component</u>	<u>Mole Percent</u>
H ₂	4.64
CO	7.74
CO ₂	69.10
CH ₄	11.21
C ₂	3.84
C ₃	1.73
C ₄	0.69
C ₄₊	0.95
H ₂ S	0.10
	<u>100.00</u>
Lower heating value (Btu/scf)	285
Molecular weight	37.46

Source: Reference 8

Wet Oxidation

Atmospheric discharges from partial WAO will be similar to those from wet carbonization, with the possible addition of higher levels of water vapor. (No wet oxidation gaseous discharges have been analyzed in the literature for any feedstock similar to peat.)

In complete WAO, all sulfur in the feed peat is oxidized to the sulfate form, and organic nitrogen converts to ammonia and its salts. Therefore, there is neither SO_x or NO_x in the gases ultimately discharged.

Biogasification

Since gaseous methane is the desired end product, specific atmospheric discharges result from gas scrubbing processes. Gas scrubbing is designed to remove water, CO_2 , and H_2 from the gas stream. No other gaseous constituents have been identified in the literature.¹⁷ The removed water is discharged in the liquid phase, and the CO_2 is scrubbed by process water which is then returned to the bog, where the CO_2 effervescs into the atmosphere within two to three days. Hydrogen sulfide may be generated in quantities exceeding allowable levels in pipeline gas, and must be removed. The proposed removal technique involves activated carbon columns.

4.2.1.3 Solid Effluent Quality

Wet Carbonization

In both the JP Energy OY and Koppelman processes, the produced solids represent the desired peat fuel product. The

only other solid waste stream comes from the steam generating boilers fed by waste wood from bog harvesting operations and by peat fuel solids. The wood and/or peat ash produced will resemble dry ash from conventional coal or wood-fired boilers.

Wet Oxidation

Partial WAO produces an enhanced peat fuel solid similar to that produced by wet carbonization. No other solids streams are identified.

Complete WAO produces a sludge consisting of peat inorganic material, dissolved solids, and water. The characteristics of the sludge are not evaluated in the literature;¹³ however, little treatment, if any, should be required prior to disposal because most of the raw peat organic matter has been oxidized. Additives may be required to neutralize the pH.

Biogasification

Solid wastes from the biogasification process are suggested for use as a boiler fuel. Complete combustion of the sludge will produce a dry, oxidized inorganic ash and a gaseous phase consisting of water vapor, CO₂, particulates, hydrocarbons, SO_x, and NO_x. Peat, with its generally low sulfur and mineral content, would have comparably low emissions of SO_x and particulate air pollutants. Conversely, the relatively high nitrogen content inherent in peat could result in increased NO_x formation during combustion. This potential impact is somewhat offset by the low peat combustion temperatures.

4.2.2 Applicable Regulations

The extraction and utilization of U.S. peat resources will encounter a multitude of regulatory constraints. Peat development for energy, unlike domestic coal development, is accelerating after establishment of the regulatory milieu. For this reason peat development, with its inherent requirements for energy facility siting, surface harvesting, wetlands disruption, air and water discharges, and reclamation, should expect to receive vigorous regulatory scrutiny.

As in most projects, the magnitude of the development will determine the degree of complexity in obtaining the necessary regulatory approvals. The primary regulatory hurdles for any scale of peatland development will be the state and Federal regulations for wetlands protection, surface water pollution discharges, and air quality maintenance standards. The secondary regulatory issues will focus on hazardous waste disposal, health and safety, Coastal Zone Management, and broad NEPA regulations.

Existing and developing Federal, state, and local environmental regulations are expected to require few modifications to meet the new challenges of peat energy development. Certain unique aspects of peat utilization can be expected to necessitate some modifications to regulations once the significant environmental issues and processes are well characterized.

The regulatory issues must be addressed on a site-specific basis as the need arises, not only because of local variances, but also due to the fluctuating status of certain

regulatory requirements. Many of the laws and regulations which may apply to peat developments are presented in Table 4-3. These laws and regulations are grouped according to the environmental categories which they most closely represent.

Air Quality Issues

The list of air quality concerns from peat resembles a similar list associated with coal mining and utilization activities. Significant emissions will include: fugitive dust, CO, CO₂, NO_x, SO_x, particulates, hydrocarbons, and metals. State Implementation Plans (SIP) will provide the basis for specific control programs.

Most areas in the U.S. have reported local or area-wide violations of National Ambient Air Quality Standards (NAAQS) for total suspended particulates (TSP), including most peat-rich areas.

Ambient levels of nitrogen dioxide generally meet NAAQS in peat-rich areas. In the future, NO₂ may be included in emission controls designed to control ambient oxidant levels. Oxidants (as well as TSP) are on the EPA's control priority list and PSD review is required for NO₂ emissions exceeding 10 tons per year. This is of particular concern for peat combustion since NO_x levels may be higher for peat than for coal combustion, due to the relatively higher nitrogen concentrations in peat.

NAAQS for SO₂ is met in almost all peat-rich areas. The proximity of Class I areas to peat-rich areas may cause difficulties in obtaining air quality related permits. Peat

Partial Listing of Environmental Laws and Regulations
Potentially Applicable to Commercial Scale Peat Development

Air Quality

Clean Air Act

New Source Performance Standards

National Ambient Air Quality Standards

Prevention of Significant Air Quality Deterioration

Water Quality

Clean Water Act

National Pollutant Discharge Elimination System

Water Resources Development Act

Protection of Navigable Waters Act

Safety of Public Water Systems Act

Soil and Water Resources Conservation Act

Solid Waste and Hazardous Waste

Resource Conservation and Recovery Act.

Toxic Substances Control Act

Hazardous Waste Management System

Ecology

Wilderness Act

Protection of Wetlands

National Environmental Policy Act

Endangered Species Act

Fishery Conservation and Management Act

Other

Federal Energy Regulatory Commission Certificates

Energy Supply and Environmental Coordination Act

National Energy Conservation Act

Powerplant and Industrial Fuel Use Act

Occupational Safety and Health Act

Hazardous Materials Transportation Act

Surface Mining Control and Reclamation Act

Noise Control Act

combustion facilities should not be located in areas experiencing ambient SO₂ problems or in areas with known adverse meteorological conditions that would result in ambient SO₂ problems if new emission sources were introduced. Peat, with its generally low sulfur content, would have comparably low emissions of SO_x. However, current regulations on coal combustion now require flue gas desulfurization regardless of coal sulfur content, and similar regulations may apply to a peat burning facility.

NAAQS for non-methane hydrocarbons (NMHC) are exceeded in many urban areas and are grossly exceeded by existing coal conversion facilities. Hydrocarbons by themselves do not produce a direct health hazard, but they do contribute to the formation of oxidants that can damage vegetation and cause irritation to the eyes and throats of humans. They are one of the reactants in the formation of photochemical smog. Peat conversion facilities will probably not emit enough NMHC to create a significant problem. Emissions of NMHC from storage vessels at peat synfuels plants should comply with environmental requirements. Polycyclic aromatic hydrocarbons (PAH) emissions from peat combustion and from peat synfuel plants should be in compliance with health related requirements.

The most significant air quality regulation potentially applicable to peat development is the Prevention of Significant Air Quality Deterioration (PSD) regulation requiring construction permits for new or modified sources. Peatlands may be near PSD Class I areas due to their remote wilderness locations, wildlife values, and proximity to Indian reservations. (Class I areas represent clean air areas and allow the least amount of atmospheric degradation.) These PSD regulations were the subject of a significant court case which resulted in a ruling mandating that certain revisions be made to the 1978 regulations (Alabama Power Company v. Costle, 13 ERC 1225). To satisfy the court's ruling, EPA promulgated the revised version of the PSD regulation.

The revised or amended regulations have a significant impact on the peat industry. Under 1978 and present PSD regulations, a major stationary source^a must obtain a permit prior to on-site construction. To secure a construction permit, a major source may be required to conduct ambient air quality and meteorological monitoring and air pollutant dispersion modeling, and to apply the best available control technology to limit air pollutant emission. EPA may require up to a year of pre-construction monitoring and take up to a year to review each application prior to permit approval.

The most significant revision to the PSD regulation that affects peat development is the treatment of fugitive dusts in determining whether or not a source is a major source. Under the 1978 regulations, a source was considered to be major if, prior to the use of emission controls, the source was determined to have the potential to emit greater than 250 tons per year of any criteria pollutant, including fugitive dusts. Criteria pollutants are those pollutants for which EPA has established ambient air quality standards. As a result of the Alabama decision, EPA revised the 1978 regulations to consider potential emissions as those pollutants discharged to the atmosphere after the application of pollution controls and without including fugitive emissions.

^aA source included in the 28 "major emitting facility" source categories listed in the regulation having potential emissions of greater than 100 tons/year for one or more pollutants (250 tons/year for those sources outside the 28 source categories) is considered to be a major source.

By ignoring fugitive dusts and applying controls prior to predicting potential emissions, EPA has now made it possible for peat industries to progress with pilot studies and even commercial facilities, if well controlled, without being exposed to the potential delays and capital costs associated with full PSD permit reviews. However, it must be stressed that EPA has not exempted peat industries from permit requirements but merely adjusted the regulations to focus on those pollutant emissions and facility sizes considered to have a greater impact on existing air quality. State and local regulations may not have been amended to reflect EPA's revised PSD regulations. Thus, careful consideration should be given to the impacts of state and local regulations in addition to EPA's regulations while assessing project feasibility.

Ambient Air Quality Standards are set at the Federal level. Individual states can adopt their own PSD program (subject to federal EPA approval) as long as the state standards are equivalent to or more strict than the national standards. The national ambient air quality standards (NAAQS) are listed in Table 4-4. Of the three states most active in peat development (Minnesota, Maine, and North Carolina), only Minnesota has adopted stricter air quality standards (for SO₂ levels only).

Currently, there are no federal new source performance standards (NSPS) for peat gasification and combustion, or fuel conversion processes used to produce briquetted peat. However, the use of peat for power generation is subject to NSPS for fossil fuel fired steam generators (subpart D) and electric utility steam generators (subpart Da) of Title 40, part 60 of the Code of Federal Regulations.

Table 4-4

National Ambient Air Quality Standards

Pollutant	Averaging Time	Primary Standard Levels	Secondary Standard Levels
SO ₂	Annual (arithmetic mean)	80mg/m ³ (0.03 ppm)	---
	24 hour*	365mg/m ³ (0.14 ppm)	---
	3 hour*	---	1300mg/m ³ (0.5 ppm)
Particulate Matter	Annual (geometric mean)	75mg/m ³	60mg/m ³
	24 hour*	260mg/m ³	150mg/m ³
NO _x	Annual (arithmetic mean)	100mg/m ³ (0.05 ppm)	100mg/m ³ (0.05 ppm)

*Not to be exceeded more than once per year

Water Quality Issues

Waters from drainage, dewatering facilities, and process discharges must meet state effluent discharge standards for pH and BOD/COD levels, chemical and metal compounds, and settleable solids.

Due to the relatively low pH of peat bog waters, all discharges from peat development will have to be controlled to meet existing state and federal discharge standards and not alter pH values of the receiving stream from established criteria.

Both the Federal government and states have effluent standards governing BOD and COD discharges. Presently, no applicable federal effluent standards under the National Pollution Discharge Elimination System (NPDES) for release of process water from peat harvesting and processing have been established. With the development of large-scale operations water pollution standards governing BOD and COD discharges would be expected in order to maintain designated stream water quality classifications. Through state and federal permit procedures, public interest in the project impacts on water quality would be reviewed through local public hearings.

At present, there are no effluent or water quality standards for organic acids. Organic compounds can cause taste and odor problems for humans and have been shown toxic towards aquatic plants and animals.²⁹ Standards for organic acid concentrations, however, are more qualitative than quantitative.

Heavy metals discharge from industrial processes is governed under the state and federal effluent standards. These standards are designed to reduce net effluent discharges and comply with state water quality classifications. However, no effluent standards currently exist for peat processing facility discharges.

Research conducted in Minnesota has shown that mercury, arsenic compounds, and other elements are present in peatlands. These products could be released by harvesting and processing into the aquatic environment. With the Toxic Substance Control Act (TSCA), Resource Conservation and Recovery Act (RCRA), and the amendments to the Water Pollution Control Act, there is a growing awareness of potential toxic and carcinogenic properties of liquid waste streams. These acts require a thorough study of direct wastewater streams to isolate and identify toxic products and necessitate development control strategies to prevent their release.

State and federal water effluent standards govern the discharge of total dissolved solids and settleable solids from various industrial processes. The discharge standards are established on an industry by industry basis and are formulated on the amount of process material. There is a lack of effluent standards for peat harvesting and energy production. Until such standards are developed, effluent standards for mining and forest products industrial sectors would probably be used.

At the state level, industrial discharges into receiving waters must be approved and licensed in accordance with the appropriate state regulatory agency. Although not specifically designed for peat developments, Minnesota requires secondary

wastewater treatment for all municipal sewage and biodegradable industrial wastes. Minnesota defines secondary treatment facilities as works that provide effective sedimentation, biochemical oxidation, and disinfection of effluents in order to meet the standards listed in Table 4-5.

In comparison to Minnesota, the State of Maine approves industrial water discharge licenses on a case-by-case basis, depending on the type of effluent and the receiving water.²⁰

Solid Waste Issues

Recent regulatory activity concerning solid wastes has focused on the issue of hazardous wastes and their management. The list of hazardous wastes include several compounds that are by-products of some of the peat conversion facilities discussed in this report. These compounds include phenols, benzene, and certain trace elements. No current regulations specifically apply to peat process effluents; however, solid wastes generated from the combustion or wet combustion of peat may be subject to applicable regulations on coal combustion facilities. Effluents from combustion processes such as fly ash, bottom ash and slag, and flue gas emission control wastes are not listed as hazardous wastes and are therefore exempt from the otherwise required monitoring and permitting activities. Though not considered hazardous, generators of such combustion by-products must still follow proper disposal practices for landfilling and ponding of solid wastes as described in Section 1008 of the Resource Conservation and Recovery Act (RCRA).

Table 4-5

Industrial Water Discharge Standards,
State of Minnesota

<u>Substance or Characteristic</u>	<u>Limiting Concentration or Range*</u>
5-Day Biochemical Oxygen Demand*	25 milligrams per liter
Total suspended solids*	30 milligrams per liter
Oil	Essentially free of visible oil
Phosphorus**	1 milligram per liter
Turbidity	25
pH range	6.5-8.5
Unspecified toxic or corrosive substance	None at levels acutely toxic to humans or other animals or plants life, or directly damaging to real property.

*The arithmetic mean for concentrations of 5-day biochemical oxygen demand and total suspended solids shall not exceed the states values in a period of 30 consecutive days and 45 milligrams per liter in a period of 7 consecutive days.

**Where the discharge of effluent is directly to or affects a lake or reservoir. Removal of nutrients from all wastes shall be provided to the fullest practicable extent wherever sources of nutrients are considered to be actually or potentially detrimental to preservation of enhancement of the designated water uses.

Source: Reference 19

4.3 ENVIRONMENTAL CONTROL TECHNOLOGIES

4.3.1 Wastewater Treatment

The well-established procedures for municipal and industrial wastewater treatment are categorized as primary, secondary, and tertiary treatments. Because of their proven acceptance and somewhat conventional nature, they are mentioned here in summarized descriptions only. Other treatment options include wet oxidation and biogasification - the same technical procedures used as the peat conversion processes. Their uses as ultimate wastewater treatment systems are also discussed in this section.

The entire treatment process involves many operations; those mentioned in this section account for the significant operations. Figure 4-1 illustrates the complete wastewater treatment process flow diagram, identifying the relationship primary, secondary, and tertiary treatment have with other treatment steps. This figure should be used as an outline for the following discussions about wastewater treatment.

4.3.1.1 Primary Treatment

Primary treatment consists of three principal processing steps: Equalization, neutralization, and clarification.

Equalization techniques are desirable both to lessen facility costs by allowing design based on conditions nearer to the average, and to improve operation by decreasing the variability of the feed. Of particular importance are:

Figure 4-1
Conventional Wastewater Treatment Flow Diagram

Source: Reference 21.

- Leveling of contaminant concentration
- Self-neutralization
- Flow equalization
- Spill containment
- Holding for steady feed to a biological systems during the manufacturing unit downtime
- Concurrent treatments, e.g., settling and oxidation

Neutralization of excessively acidic or basic peat process wastewaters is required prior to further treatment and/or discharge. Bacteria and aquatic life are sensitive both to rapid pH variation and to pH levels outside the range of about 6 to 9. Consequently, surface waters and biological treatment units must be protected against unneutralized wastewater. A pH adjustment also is dictated in several other situations, including protection of construction materials, breaking of emulsions, insolubilization of certain organic materials, and control of chemical reaction rates (e.g., chlorination).

Many reagents can be used in neutralization reactions. The reaction systems themselves range from simple limestone pits to complex in-line mixing units.

Clarification, along with neutralization, represent the usual minimum requirement of pollution control regulations. Insoluble materials not only constitute a visible indication of pollution but also can have significant harmful effects in the receiving streams. The range of available separation equipment is sufficiently broad to allow tailoring of each facet of the separation process to the unique character of the suspension problem.

As mentioned in Section 3, several of the wet peat processes utilize peat slurry water separation techniques prior to the reactor. The respective authors indicate that these streams

can be returned directly to the bog with little or no treatment. It is expected that, at a minimum, these streams will require treatment to reduce suspended solids and to buffer the pH. While it may be true that these streams are similar in character to in situ peat bog water, the displaced and returned water will upset the saturated (or near-saturated) conditions in the bog, resulting in an increased rate of bog drainage into nearby receiving waters. Primary treatment methods should satisfactorily condition these water streams prior to bog discharge.^a

4.3.1.2 Secondary Treatment

Biological methods of wastewater treatment are considered the second, and most significant process in terms of actual destruction of harmful aqueous organics. The function of biological treatment processes is to remove organic matter and at times ammonia from wastewater through the metabolic means of oxidation and cell synthesis. Although several physical and chemical approaches have been proposed as substitutes, biological treatment remains the only proven means of economically abating the oxygen depletion caused by the discharge of wastewater contaminated with low concentrations of a mixture of biodegradable organic compounds. If this organic matter were to reach the receiving body of water, bacteria would oxidize it and thereby reduce the oxygen resources upon which aquatic life is dependent. Biological treatment processes are basically an accelerated form of these natural water purification mechanisms. Organics causing problems in addition to oxygen depletion also are economically removed, e.g., materials toxic to fish and odorous in water supplies.

Biological treatment processes are categorized according to the growth-phase of the bacteria, the method of contacting the organic food with the bacteria, and the presence or absence of molecular oxygen. The common types of systems are:²²

^aThe concept of slurry water separation remains a significant process advantage, since the need for additional secondary treatment capacity has been (potentially) eliminated.

Activated Sludge
Aerated Stabilization
Facultative Ponds
Anaerobic Lagoons
Trickling Filters

Activated Sludge

The activated sludge process is widely used in municipal waste processing plants and can be readily applied to peat process wastewater streams. The activated sludge process can stabilize soluble organic material to a low level in a short period because a high concentration of flocculant biological solids is maintained in the aerated or oxygenated tank in which the waste and bacteria are contacted. This concentration is maintained by routing the mixed liquor flowing from the aeration tank through a secondary clarifier, and recycling most of the settled solids back to the aeration tank.

Aerated Stabilization

Aerated stabilization is accomplished using a dispersed-growth system without biological-solids recycle. This process sometimes is termed "aerated lagooning" since the simplest prototype consists of one or more aerators installed in a large pond with the accomplishment of only partial mixing. However, full advantage of this approach can be realized by installing sufficient aeration capacity to keep the system completely mixed, and to satisfy the oxygen requirements of the system. Due to the already dispersed nature of the culture, the aerated-stabilization approach does not require as close control over variations in temperature, pH, and organic loading as does the activated sludge process. A disadvantage of the aerated-stabilization process is a practical limitation in maximum BOD removal of about 75 percent, primarily due to the dispersed bacteria in the effluent and inhibition of the biological reactions at cold temperatures.²²

Facultative Ponds

These are the most common lagoons employed for stabilizing municipal waste water. The bacterial reactions include both aerobic and anaerobic decomposition, and hence, the term facultative pond. Waste organics in suspension are broken down by bacteria releasing nitrogen and phosphorus nutrients, and carbon dioxide. Algae use these inorganic compounds for growth, along with energy from sunlight, releasing oxygen to solution. Dissolved oxygen is in turn taken up by the bacteria, thus closing the symbiotic cycle. Oxygen is also introduced by reaeration through wind action. Settleable solids decomposed under anaerobic conditions on the bottom yield inorganic nutrients and odorous compounds; for instance, hydrogen sulfide and organic acids. The latter are generally oxidized in the aerobic surface water thus preventing their emission to the atmosphere.²⁴

Bacterial decomposition and algal growth are both severely retarded by cold temperature. During winter when pond water is only a few degrees above freezing, the entering waste organics accumulate in the frigid water. Microbial activity is further reduced by ice and snow cover that prevents sunlight penetration and wind reaeration. Under this environment, the water can become anaerobic causing odorous conditions during the spring thaw, until algae become reestablished. This may take several weeks depending on climatic conditions and the amount of waste organics accumulated during the cold weather. For this reason facultative ponds may not be a satisfactory treatment option for peat processing plants located in northern climates (e.g., Maine or Minnesota).

Anaerobic Lagoons

Bacteria anaerobically decompose organic matter to gaseous end products of carbon dioxide and methane. In addition, intermediate odorous compounds, such as organic acids and hydrogen sulfide, are formed. The two primary advantages of anaerobic treatment compared with an aerobic process are the low production of waste biological sludge and no need for aeration equipment. The disadvantages are that incomplete stabilization requires a second-stage aerobic process and the relatively high temperature required for anaerobic decomposition. The important characteristics for a waste water to be amenable to anaerobic treatment are: high organic strength particularly in proteins and fats, relatively high temperature, freedom from toxic materials, and sufficient biological nutrients.

The use of anaerobic lagoons for peat wastewater treatment may not be a successful option due to the cold northern winters. Odor problems, even in relatively unpopulated peatland regions are a potential nuisance.

Trickling Filters

The trickling filtration process utilizes biological growth on a contact medium over which the wastewater flows. Sufficient void space in the "filter" is provided. The microorganisms are cultivated usually either in a packed bed of crushed stone or on a system of vertical plastic sheeting.

Waste water sprinkled over fixed media produces biological slimes that coat the surface. The films consist primarily of bacteria, protozoa, and fungi that feed on waste

organics. As the waste water flows over the slime layer, organic matter and dissolved oxygen are extracted, and metabolic end products such as carbon dioxide are released. Dissolved oxygen in the liquid is replenished by absorption from the air in the voids surrounding the filter media. Although very thin, the biological layer is anaerobic at the bottom. Therefore, although biological filtration is commonly referred to as aerobic treatment, it is in fact a facultative system incorporating both aerobic and anaerobic activity.

Trickle filters will generally not give as clean an effluent stream as will an activated sludge process. In wastewaters with high organic loadings, the fraction of the BOD converted may be as low as 40 percent. Use of trickle filter treatment together with an activated sludge process is an established practice, and in the case of peat processing, a trickle bed treatment system would most likely be placed in front of the activated sludge process to act as a roughing filter.

4.3.1.3 Tertiary Treatment

Tertiary treatment methods are used in an overall wastewater treatment process to remove specific contaminants which are resistant to biodegradation, are toxic, or are otherwise entrained in the aqueous discharge from secondary treatment facilities. Several methods can be used individually, or in series as needed, to remove particular contaminants. The list of tertiary treatment methods includes the following:

- Precipitation/Coagulation
- Filtration
- Activated Carbon Adsorption
- Ion Exchange

Removal of metals as their hydroxides is the most common precipitation application in wastewater treatment operations. The amount of lime or other alkali added is dependent upon the required effluent concentration; removal of metals to 1.5 times their solubility in water is the level of effectiveness to be expected.²²

Coagulation by added chemicals serves to chemically destabilize the particles so that agglomeration may occur. Mechanisms include charge neutralization, compaction of the double-ionic layer, polymer bridging, and enmeshment in hydroxide floc. Flocculation is the process of bringing the particles into contact to allow agglomeration. Metal hydroxides of iron or aluminum serve both to reduce the particle charge and to adsorb the colloids. Organic polymers serve to bond the particles together.

Filtration techniques are used to remove suspended solids from treated wastewater streams prior to discharge. Clarifiers are often used for this purpose, and are also used prior to secondary treatment operations.

Both activated carbon and ion exchange techniques are used to remove such materials as phenols, color bodies, and certain organic acids from wastewater streams. Although quite effective, the use of these methods represents a significant increase in wastewater treatment costs, especially if large capacity units are required. The need for carbon adsorption or ion exchange as a tertiary or primary treatment for peat process effluents can only be determined from a comprehensive peat wastewater quality analysis.

4.3.1.4 Combined Peat Processes

It has been shown in Sections 2 and 3 how combinations of the three wet peat processes can be used not only to produce an enhanced peat fuel (solid or methane), but to provide wastewater treatment or process water conditioning. Three examples of combined process designs have been discussed, and are highlighted here from the perspective of wastewater treatment.

The Koppelman process design utilized wet air oxidation to treat the peat water stream leaving the Koppelman reactor. The WAO reactor has been fully integrated into the overall process design so that heat from the WAO reactor is recovered by slurry preheating.

Partial WAO and biogasification of peat share parallel concepts where oxidation is used to "condition" the raw peat. In the case of partial WAO, conditioning produces a filterable peat solid suitable for boiler fuel or briquetting; the liquid waste stream contains dissolved organics that will require some form of secondary treatment discussed earlier. In the case of biogasification, conditioning produces a liquor containing soluble peat organics suitable for conversion by anaerobic digestion into methane; the waste stream in this case is a solid by-product suitable for boiler fuel (following thermal drying).

It is not clear from the literature what degree of wastewater treatment is necessary for the liquid effluent from peat biogasification. Assuming a relatively low organic content, further biological treatment (trickle filter,

perhaps) may suffice. The incorporation of another WAO unit for the purpose of wastewater control would most likely not prove cost-effective, and the heat produced does not appear needed within the biogasification process. (In fact, the digester tanks require cooling to maintain steady operating temperatures.)

4.3.2 Gaseous Effluents Control

As discussed in section 4.2, no New Source Performance Standards (NSPS) exist for peat conversion plants. In the event that NSPS for some other process (say pulp and paper industry, or coal combustion) are deemed applicable to peat conversion plants, the primary concerns regarding atmospheric discharge will be with SO₂, NO_x, and particulates. SO₂ levels in peat gas discharges will be within NSPS due to the inherently low sulfur levels in peat. Particulates, NO_x, hydrocarbons, H₂S, CO₂, and other gases will potentially be emitted, in quantities that may exceed 100 tons/year. PSD requirements will then apply to atmospheric discharges and could be especially strict due to the possible location of peatlands in Class 1 (pristine) areas.

Various gas effluent streams are produced from the wet peat technologies discussed in sections 2 and 3. In processes that burn peat bog woodwaste or peat fuel to generate steam (wet carbonization and biogasification), particulate loading and concentrations of NO_x and CO₂ are the significant parameters. Wet oxidation gas effluents should contain no particulate, but consist primarily of CO₂, water vapor, N₂, and hydrocarbon gases.

Various environmental control technologies are discussed here in highly summarized form. The control technologies represent conventional, industrially-proven processes, however, site-specific incorporation of these processes will depend not only on the quantities of gases produced but on the corrosive nature of the waste stream.

4.3.2.1 Particulate Control

Development of a particulate control strategy is dependent on several factors: total particulate loading, size distribution of particles, and degree of removal required. Because of the differences in feed size requirements, stoker furnaces produce larger fly ash particle than furnaces burning pulverized peat. In small boilers where stoker furnaces are used (the likely choice for a process peat-fired furnace) the choice of control device may be made from a number of candidates due to the large particle size. Final selection will be based on a number of additional characteristics such as pressure drop, flue gas velocity, and cost.

Wet particulate scrubbers may prove to be an attractive option due to the abundance of process water available for use. Depending on the particulate loading and the compositional nature of the particles, treated process wastewater could be used for once-through water circulation in a wet scrubber, then either discharged to the bog or returned to wastewater treatment for settling.

Baghouses or cyclones can also be used successfully due to the modular nature of their design. These dry methods can be economically sized to provide efficient particulate removal for small stoker-type furnaces.

4.3.2.2. Flue Gas Desulfurization

As discussed in section 4.2.2, SO₂ emissions from peat-fired boilers should be low due to the inherently low sulfur content in peat. However, future regulations may require some degree of SO₂ control for peat combustion regardless of the discharged quantity. Therefore, flue gas desulfurization (FGD) techniques are briefly mentioned here.

Two general types of control have been used over the past 30 years: wet and dry processes. The dry processes consist of a gas/solid contacting system where the SO₂ is absorbed by the solid matter. Dry lime/limestone injection, and adsorption on activated carbon, finely ground charcoal, coke and silica gel have all been tested and applied to boilers to varying degrees. The wet FGD processes have had by far the greatest use to date in utility and industrial boiler applications. Eight processes have been used on a commercial scale in the United States. In all of these processes, SO₂ is absorbed in a water slurry or solution and reacts to form sulfurous acid (H₂SO₃). This acid in turn is neutralized by an alkali contained in the system. All processes are classified into one of two categories, nonregenerable or regenerable. Nonregenerable processes generate a sulfite/sulfate waste product which requires disposal. The regenerable processes regenerate the alkali and produce one of several by-product sulfur compounds which can be marketed.

4.3.2.3 Nitrogen Oxide Control

Combustion modification and flue gas treatment are two approaches applicable to peat combustion processes for control

of nitrogen oxides (NO_x) emissions. The former suppresses the formation of the NO_x in the furnace through the alteration of combustion conditions, and the latter destroys the NO_x after they have been formed. Major emphasis in the United States has been on combustion modification, since it is the less costly way of complying with current federal emission regulations.

NO_x formed in combustion processes originates from two sources: (1) oxidation of molecular nitrogen in the combustion air via a thermal process to form "thermal NO_x ;" and (2) conversion of nitrogen chemically bound in the fuel to "fuel NO_x ." The relative contributions of these two sources have a very important bearing on the effectiveness of different combustion-modification techniques. Although peat has relatively high fuel nitrogen concentrations that could result in increased NO_x formation during combustion, this affect would be offset by the low peat combustion temperatures.

Removal of nitrogen oxides from boiler flue gas is considerably more difficult than preventing their formation by combustion modifications. The problems inherent in this type of system are that large amounts of gas must be handled, and the NO_x is present in dilute concentrations.

4.3.2.4 Gaseous Hydrocarbon Control

Significant quantities of methane and non-methane hydrocarbons may be released from wet peat processes, primarily partial wet oxidation and wet carbonization. In these cases, incineration by flaring may represent the most cost-effective control strategy. Activated carbon filters could also be utilized, though the comparative costs would have to be thoroughly evaluated.

4.3.3 Solid Waste Control

Solid peat process by-products range from fly ash to wet biomass, and environmental control techniques will vary for each particular stream. No unique or unproven control technologies are necessary, however; in most process discussions (section 2), treatment and disposal options were suggested in the literature.

For example, the peat biogasification process produces two distinct solid waste streams, a boiler ash (from combustion of residual peat solids) and a biomass (produced during anaerobic digestion). Dynatech¹⁷ claims that the mineral-rich ash from the burned peat sludge can either be returned to the mined bog or combined with the excess biomass to form a fertilizer composite. The biomass alone can be utilized as a cattle feed or fertilizer.

In the likely event that these and other process solid waste streams find no market in the unpopulated peatland areas, various treatment and disposal options need to be considered.

Lagoon disposal of digested sludge is often economical where inexpensive land is available at or close to the treatment plant site. The advantages are simplicity of operation, flexibility, and suitability for plants of any size. Lagoon drying can be a regular operational procedure, or can be used temporarily during peak load periods. Disadvantages are the possibility of groundwater pollution and odor nuisance if the sludge is not completely digested.

Liquid disposal of digested sludge on agricultural land is popular where acceptable sites are located within convenient hauling distance. This process is often used in rural areas by plants equipped with anaerobic digestors that condition the sludge before spreading. The use of this disposal method must consider surface water runoff characteristics and the percolation effects of the topsoils. It may be possible to return liquid sludge to the bog surface in this manner.

Landfills are commonly used as final disposal sites for incinerator ash, dried digested sludge, and dewatered raw sludge cake. The latter poses both nuisance and health problems unless the fill sites are designed to prevent ground and surface water pollution, and are covered daily with earth. Many cities bury waste sludge in their sanitary landfill along with municipal refuse. The basic operations include spreading, compacting, and covering the solid wastes with excavated soil daily.

Since any solid waste disposal site for a peat processing plant would most likely be located very near the plant (large, open areas; low transportation costs), water infiltration and leaching will be significant concerns. The high levels of water retention in peatland soils may create an unsuitable environment for disposal, unless clay-lined or plastic-lined fill areas are used. Thorough analyses of all solid waste streams are necessary to determine whether special treatment and disposal processes are even needed.

4.4 PRELIMINARY IMPACT ANALYSIS

In estimating the impacts from wet peat processing on air, water, and land resources, it is assumed that appropriate environmental control techniques, as discussed in section 4.3, are integrated into the respective process. Therefore all atmospheric discharges, treated process wastewaters, and residual solids meet state and federal standards prior to discharge. This does not necessarily imply that no environmental impacts will occur. The primary ecological disruptions are related to water handling, followed by solid wastes. Atmospheric impacts will be relatively minor due to the smaller magnitude of the quantities, and the availability of effective environmental control technologies.

4.4.1 Water-Related Impacts

There are two wastewater streams of concern. As discussed in section 2, some wet peat processes initially dewater the raw peat slurry so that more recycled process liquor can be utilized. The raw peat filtrate can supposedly be returned to the bog with only primary treatment since it was never subjected to any process conditioning. The second wastewater stream is the discharge from wastewater treatment processes; this stream should be relatively clean and should pose no environmental concern except disruption caused by the sheer volume of discharge. Each of these two streams is discussed below.

Bog Water Return

Unless man-made dikes or levees are constructed around peat bog areas undergoing hydraulic mining, the return of neutralized and clarified peat water and slurry water will dilute the remaining in situ solids beyond their water saturation level. The excess water will be forced out of the bog and into nearby lakes or streams. Even though this water represents naturally-formed water characteristic to peatlands, bog water may significantly alter other receiving water characteristics.

To better understand the possible impacts from the release of peat waters to other receiving waters, it is important to understand the nature of peat water quality and characteristics. The following paragraphs summarize peat water characteristics and the potential impacts caused by its release.

The chemical composition of waters from ombotrophic bogs and minerotrophic fens are quite different. Bog waters exhibit low conductivity, low pH, and high color values as compared to fens. Low conductivity indicates low concentrations of dissolved mineral ions, primarily because the ions in bog waters are obtained almost exclusively from atmospheric precipitation. The low pH and high color values, however, result from contact with the humic soil. The relatively high acidity (pH 3 to 4) of the bog waters affects the solubility and hence the concentration of many minerals, which in turn affects the ion concentrations. Acidity may also be influenced by anaerobically produced hydrogen sulfide which diffuses to bog pools where it is oxidized to sulfuric acid.²⁵ High color values of bog waters appear to be caused by humate or iron-humate compounds derived from decomposing organic material.²⁶

While perched bogs exhibit higher concentrations of organically derived ions (organic N, ammonia N, nitrate N, P, Cl, Fe, K, Na, and Al), studies indicate that fen waters have higher concentrations of mineral ions such as Ca, Na, Mg, Mn, Cu, Zn, Si, and sulfate due to groundwater flow.²⁷ The inflow of calcium bicarbonate accounts for the near neutral pH of fen water. Since the solubility and concentration of Fe and Al are inversely influenced by pH, the higher pH of fens results in their reduced concentrations.²⁸

There is a substantial volume of literature attesting to the toxicity of aqueous humic substances towards plants and animals. This could become a significant concern if large-scale bog drainage is considered for peat harvesting. Below are highlights of several of these reports.

Polyphenolic humic acids are known to be strong chelating agents for inorganic ions, and may prevent their uptake by aquatic plants.

Two University of Florida researchers³⁰ found that water forced out of peat swamps is highly toxic and repellent to fish that inhabit receiving lake water. In related studies a Soviet researcher³¹ reported that water staters (*Ascellus aquaticus*) died within 24 hours when placed in peat bog water, probably due to low pH. Studies in Wisconsin blackwater lakes fed by peat bogs show that fish are "slow growing and stunted."³²

The Freshwater Biological Institute at the University of Minnesota conducted a series of tests to determine the degree of bog water toxicity towards prey fish (e.g. fathead minnows).³³ They concluded that considerable volumes of bog water must enter watersheds before toxicity to prey fish is observed. Toxicity

effects probably follow pH effects, although the effects from dissolved compounds may also be significant. Lake water acts as a buffer on the acidic bog waters; additional tests at the Institute conclude that lake water can receive at least an equal amount of bog water before lowering of the lakewater pH is observed.

The apparent overall conclusion from these various studies indicate that bog waters may be highly toxic to plants and animals not accustomed to bog environments. Adverse effects would result during bog drainage, as released waters enter streams, watersheds, and nearby lakes. However, once mixed with these other aquatic systems, the diluted bog waters have a greatly reduced toxic impact. In fact, tests at the Freshwater Biological Institute imply that diluted bog waters may actually stimulate the production of phytoplankton in receiving lakes.²⁹ This would create an environmentally advantageous impact, especially in the nutrient-starved lakes of northern Minnesota.

Fully Treated Process Wastewater Return

The following discussion relates to the volumes of water returned to the bog, not its quality. It is assumed that treated wastewater will actually be of higher quality than the in situ bog water described earlier. Problems will arise as the net solids removal from a bog increases the water/solids ratio, thus altering the balanced bog water drainage patterns. Although the discussion is under the heading of fully treated water return, it also applies to the unprocessed peat bog water return, since both water streams will disrupt the water/solids ratio of the receiving peatland.

Hydraulic peat extraction results in reduced interception losses and increased available storage within the basin created by extraction. As subsurface flow from the surrounding peat fills the basin, the available moisture storage in the peat surrounding the pond may increase. Evaporation from the pond may exceed evapotranspiration losses from the previously undisturbed peatland.

These impacts become particularly important if an outlet, either natural or artificial, drains the harvesting pond. If an outlet exists, maximum discharge from the harvest site may increase due to the quicker outflow response of a free water surface as compared to the original peatland. This may be particularly true when extraction is halted or completed with no further increase in storage. A decrease in minimum discharge from the harvest site may also be attributed to the quicker runoff response. Minimum flow and total water yield may be decreased if evaporation rates increase.

If no outlet exists, the impacts of undrained peat harvesting may be diminished as discharge will probably occur through the surrounding peat, similar to the undisturbed peatland. Maximum discharge from the harvest site may not be significantly changed. However, minimum flow and total water yield from the harvest site would be reduced if evaporation losses increased.

The impacts of undrained peat harvesting (with outlets) on watershed discharge characteristics, like drained harvesting methods, may also depend upon location of the harvest site. If located near the headwaters of the watershed, the harvest site may increase maximum discharges from the watershed. If the harvest site is not extensive and if located near the bottom of the basin, a decrease in maximum flow from the watershed may occur.

For watersheds which contain harvest ponds (without outlets), the impacts on watershed discharge may be minimal. Maximum discharge is not expected to change significantly due to pond outflow, which must flow through peat material. Minimum discharge and total water yield, however, are expected to decrease if evaporation increases; the magnitude of decrease depends on the size of the harvest area.²⁸

The impacts of water return associated with peat extraction are currently being investigated by the Minnesota Department of Natural Resources.²⁸ More must be known of the hydrologic consequences of peat utilization before the "easy" solution of bog water return can be accepted. If water quantities are found to be the problem, the treated process wastewaters will be of suitable quality so that they could be discharged directly to a nearby river or stream. Careful pre-harvesting planning may be able to design the hydraulic extraction schedule so that in situ techniques can be used to minimize water-related impacts. Three such techniques are: buffer zones, pH control, and permeability control.³⁴

Buffer Zones

Buffer zones are used to control and/or limit subsurface and surface interchange of waters within the harvest areas and between the harvest area and surrounding environs. Buffer zones also provide areas of undisturbed natural habitat for the protection and perpetuation of biotic components of the system.

These buffer zones will be left around the periphery of harvest areas; between the limits of areas of peat removal and surface drainages such as rivers and creeks; and within harvested areas.

The location, size, and extent of buffer zones will be governed by local conditions and land forms and will be specifically delineated during the planning phase of peat removal.

pH Control

Both natural and artificial methods are available for control of pH of ponded waters within the peat recovery site and of any surface or subsurface waters leaving the area. In all cases where natural means of control of pH are available, they will be preferred over chemical treatment.

Several natural methods for control of pH are available. Some that may be used in the peat harvest process are discussed below.

- pH in surface ponds may be controlled by upwelling of water from near-surface aquifers.
- Where suitable, water may be passed through calcareous, in situ soils.

Artificial means of pH control as described below may also be used.

- Water may be chemically neutralized at the processing plant before being returned to the harvest area.
- Pond waters may be mechanical aerated.
- Biological aeration may possibly be induced into some aquatic systems where natural techniques are not feasible.

Permeability Control

Control of vertical and horizontal movement of surface and subsurface waters within the harvest area and between the harvest area and surrounding environs may be achieved by use of permeability characteristics.

Use of the permeability characteristics of natural materials will be the preferred method of control, where indicated. Some of these techniques include:

- The use of layers of humic and sapric peat, a relatively impermeable material (10^{-6} - 10^{-8} cm/sec). Leaving a foot of in situ humic and sapric peat at the bottom of a ponded area would effectively control permeability.
- The use of relatively impermeable in situ clays. Some of the artificial methods using permeability control are:
 1. Construction of cut-off walls, using both sheet piling and/or recompacted clays.
 2. Construction of berms and dikes where indicated.
 3. The routing of certain surface waters to areas less susceptible to seepage.

4.4.2 Air-Related Impacts

No significant air-related impacts are expected from a peat processing plant utilizing appropriate air pollution control equipment. Collected flyash has been demonstrated to be a safe soil conditioner and could be used for soil reclamation.³⁵ Levels of SO_2 will be low prior to scrubbing, and will be well within standards following flue gas desulfurization. NO_x emissions may be a problem, and could produce the characteristic brownish haze from nitrogen dioxide formation. Actual production rates of NO_x from peat combustion have not been clearly established.

One potentially significant problem is the release of trace elements from peat into the atmosphere. Studies on Minnesota peats found that mercury concentrations were as great or greater than the average concentration for coal (about 1 ppm).²⁹ Since burning of coal is now a major source of atmospheric Hg, burning of peat may also be expected to be a significant source of Hg pollution. An unanticipated finding was that peat samples lost their mercury on simple air drying, implying that the mercury in peat may be in its elemental or some other very volatile form. Thus, the mere drying of peat will ultimately release the peat-bound Hg to the atmosphere.

4.4.3 Solid Waste Impacts

Landfilling of treated (or suitably inert) sludges and ash may pose leaching problems unless mitigated by the permeability control techniques mentioned earlier. Incineration of solid wastes has either been incorporated into some process designs (section 2) for generation of process heat, or else incineration could be used solely for the purpose of waste solids reduction. If the solids exhibit stable mechanical characteristics (i.e., no re-liquefaction from rainfall, etc.) and minimal leaching, these waste products could be utilized during peatland reclamation activities. Disposal acreage will not be a constraint, since peatlands are undeveloped expansive areas. It is important, however, to be fully aware of all applicable disposal regulations and standards so that a minimum degree of environmental degradation will occur.

5. RECOMMENDATIONS

Research and development work is currently underway in all wet peat technology areas discussed in this report. The most recent project area is wet oxidation, sponsored by DOE's Grand Forks (N.D.) Technology Center. This initial program effort will commence by mid-1981 and will develop more detailed process designs and characterize process waste streams. Although environmental control technology design is not necessarily a major component of this effort, thorough characterization of waste streams will provide valuable information that can be used to design and size treatment/control processes.

In all areas of wet peat technology research (wet carbonization, Koppelman process, biogasification, and wet oxidation) more emphasis is needed on product/by-product characterization. Other research areas involved with technical feasibility, regulatory implications, ecological disturbances, and market analysis have been conducted, but cannot be integrated adequately without thorough laboratory and pilot-scale effluent analyses. Initial conclusions based on previous literature and the results from this study indicate that wastewater characterization is the highest priority research area.

From a technical process perspective, two of the five processes examined (the Koppelman process and Biogasification) show considerable reductions in wastewater treatment requirements due to peat slurry dewatering prior to processing. If the released bog and peat slurry water requires little or no treatment prior to its return (to the bog), this dewatering procedure represents a significant design improvement over other peat slurry processes. Slurry dewatering should be carefully considered for JP Energy OY wet carbonization and for wet oxidation processes.

Because of the inherent design requirements for a high water content slurry in wet oxidation, slurry dewatering may not be a feasible possibility. For this reason, wet oxidation may be best utilized as a support process for combusting aqueous waste streams, as in the Koppelman process. On the other hand, complete wet air oxidation may produce a wastewater stream requiring little or no treatment, and therefore could be discharged directly to a receiving stream.

Another recommended research area is really an update of existing regulatory analyses for peat development operations. Since the publication of such studies,^{34,35} environmental regulations and standards are up for review in Congress. The Clean Air Act, among others, may be significantly altered, and new implications regarding peat and peatland developments may arise. Work on this regulatory analysis, however, should be performed after the effluents from peat processes have been characterized.

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