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This technical report is being transmitted in advance of DOE patent clearance and no further dissemination or publication shall be made of the report without prior approval of the DOE Patent Counsel.

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This technical report is being transmitted in advance of DOE review and no further dissemination or publication shall be made of the report without prior approval of the DOE Project/Program Manager.
PROCEEDINGS OF THE U.S. DEPARTMENT OF ENERGY

THIRD TECHNICAL CONTRACTORS' CONFERENCE ON PEAT

PREPARED FOR

UNDER CONTRACT NO.
DE-AC01-78ET10159

APRIL 29 & 30, 1981
BETHESDA, MARYLAND

A JOINT VENTURE OF
UOP INC. AND
SYSTEM DEVELOPMENT CORPORATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
FOREWORD

The official proceedings of the April 29 and 30, 1981 Third Technical Contractors' Conference on Peat, sponsored by the U.S. Department of Energy and held in Bethesda, Maryland, are presented in this document. The conference brought together state and industrial peat researchers who are currently receiving DOE support.

The two day conference, hosted by UOP Inc./System Development Corporation, covered ongoing state peat resource estimation programs for eleven states; peat gasification research by the Institute of Gas Technology, Gas Research Institute, Minnegasco, Rockwell International, Northern Natural Gas Company, and Dynatech R/D Company; peat dewatering research by the Institute of Gas Technology, First Colony Farms and the University of Pennsylvania; and conceptual design of peat production from the Carbondale Mining Technology Center.

In addition to these proceedings, there are a number of other peat publications available from states, industry, and DOE. If you require further information concerning this and subsequent conferences or peat publications, please contact me.

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## OPEN FORUM

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CONFEREECE SCHEDULE
Wednesday, April 29, 1981

Welcome
Melvyn J. Kopstein
Manager, DOE Peat Development Program

Moderator-
Arden Walters
Environmental Advisor
UOP/SDC

Morning Session - State Resource Estimation Program Update

Overview of State Peat Resource Programs
Franklin I. Honea
DOE, Grand Forks Energy Technology Center

Morning Session - Peat Gasification

GRI Joint Program Involvement
John Hoppe
Gas Research Institute

Alternative Fuels Feasibility Study
Al Rader and Joe Sorge
Consultants to Minnesota Gas Company

Single-Stage Fluidized-Bed Gasification
Dharam Punwani
Institute of Gas Technology

Afternoon Session - Peat Gasification

Rockwell International
Joseph Friedman, Program Manager
Peat Hydrogasification Programs
Rockwell International

Peat Pilot Plant Studies
Richard Biljetina
Institute of Gas Technology

Northern Natural Gas Company Update
Russell Pargett, Project Manager
Northern Natural Gas Company
Dean Lampe and Internorth, Inc.
Afternoon Session - Peat Gasification

Peat Biogasification
Donald Wise
Dynatech R/D Company
CONFERENCE SCHEDULE
Thursday, April 30, 1981

Morning Session - Peat Dewatering

High-Pressure Wet Carbonization
Joseph E. Paganessi
Institute of Gas Technology

Peat Water Retention Properties
David J. Graves
University of Pennsylvania

Solvent Extraction Dewatering
Mike Mensinger
Institute of Gas Technology

Peat Dewatering
Andrew Allen
First Colony Farms

Afternoon Session

Conceptual Design of Peat Production
Ronald Mathis
Carbondale Mining Technology Center
and
Peter De Bakker
Foster Miller Associates

Environmental and Socioeconomic Impact Assessment
Melvin J. Kopstein
Manager, DOE Peat Development Program

Open Forum
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Dr. Melvyn J. Kopstein, Manager, DOE Peat Development Program:

Good morning. Welcome to the Third Department of Energy Technical Contractors' Conference on Peat. These conferences have been successful in promoting the exchange of technical information and in providing an appropriate forum for each contractor to demonstrate meaningful progress in his project area.

The next conference is being planned for October or November of this year.

The agenda reflects a number of elements which are different from the format in the first two conferences.

First, Frank Honea, who is a member of the technical staff at the Grand Forks Energy Technology Center, will be discussing all of the state peat resources estimates. Grand Forks has been designated as the lead technology center for peat and low rank coals. I will gradually transfer a large peat of the peat project management responsibility to GFETC. In so doing, I will concentrate my efforts on overall program management which will include an active role in each of your projects.

Second, a status review of the DOE-supported peat gasification feasibility study will be presented. George Sall of the DOE Office of Fossil Energy will discuss the subject together with his contractor.

Third, a presentation will be made by Ron Mathis, who is a member of the technical staff of the Carbondale Energy Technology Center, about the subject of peat harvesting. The project that he will be discussing is being supported by the DOE Office of Mining.

Fourth, John Hoppe will address this group concerning the interest in and the role of the Gas Research Institute in peat gasification.
Finally, I will initiate discussion in the areas of environmental and socio-economic impact assessment. Currently, there are no contractors performing work for DOE in these important areas.

As many of you are aware, significant changes are taking place in the Department of Energy. These changes affect personnel, budget and program direction and scope. Changes in the format of the peat program are likely. The new administration has recommended to Congress that $5 million of the previously approved 1981 peat budget be rescinded. Another recommendation was to delete peat from the 1982 peat budget. This is in contrast to the Carter Administration request of $5.7 million.

DOE management has taken the position that the gasification development element of the program has already been successful in demonstrating that peat is an excellent feedstock for conversion to pipeline quality gas.

Aside from the obvious fiscal considerations, the changes in the near-term requests for peat funding are based upon the premise that work must be concentrated on addressing the environmental and remaining technical issues associated with peat gasification to bring the available technology to the same advanced level as gasification.

Funding for these important activities would carry over from 1981 and be available from a cross-cut program in 1982. While the level of support for this program has not been determined, it will be sufficient to fund efforts that are germane to the redirected goals, as well as sufficient to expand the program scope to include small-scale developmental work in liquids production, beneficiation, direct combustion and harvesting.

In spite of the proposed reductions in the level of funding for peat, I am confident that DOE will continue to support an aggressive and broad-based peat program.
I want to take this opportunity to express my gratitude and appreciation to the UOP/SDC group for their excellent work in arranging for this conference and publishing the proceedings.

Thank you and welcome to the conference.
OVERVIEW OF STATE PEAT RESOURCE PROGRAMS

Franklin I. Honea, Project Manager, Peat
Gale G. Mayer, Research Chemist

U.S. Department of Energy
Grand Forks Energy Technology Center
Grand Forks, N.D. 58202
INTRODUCTION

The United States has large deposits of peat with recoverable fuel value roughly estimated at about 1443 quads (10^{15} \text{Btu}), which is equivalent to 240 billion barrels of oil. Currently, the potential importance of peat as a feedstock for gasification and as a fuel source is being evaluated by the U.S. Department of Energy (DOE). As part of this evaluation, a better estimate of available U.S. peat reserves is needed. To obtain this information, grants are issued to states to participate in surveys of their state peat reserves. Presently, eleven states have received grants, and a grant to a twelfth state is in process. This presentation includes an overview of the peat resources in the United States and the status of the peat surveys for each state participating in the grant program.

DOE PEAT SURVEY PROGRAM

The objective of the DOE peat survey program is to determine the amount and location of fuel-grade peat in the U.S. that may be harvested in an environmentally acceptable manner. The United States has large areas of organic soils including peat deposits in Alaska, in the northern states including Minnesota, Wisconsin and Michigan, on the east coast from Maine to Florida, and on the Gulf coast. The approximate locations of most major U.S. peat reserves are indicated on the map in Figure 1 (1). The 12 states which are currently participating in the DOE peat program are outlined on the map. These states include Alaska, Maine, Michigan, Minnesota, North Carolina, and South Carolina with survey grants initiated in 1979, and Georgia, Florida, Louisiana, Massachusetts, New York, and Rhode Island with grants initiated in 1980 and 1981.

In 1911, Davis estimated the peat reserves in the contiguous states at 12.9 billion tons on an air dried basis (2). In 1922, Soper and Osburn estimated 13.8 billion tons (air dried) (4). This latest estimate, as presented in Table 1, included the non-permafrost areas of Alaska for a total of 120.3 billion tons of U.S. peat reserves.
Figure 1 U.S. Regions Containing Significant Amounts of Peat Resources
The preliminary U.S. peat reserves from 1976 as presented in Table 1 include 52.6 million acres. The six states which started peat surveys in 1979 under the DOE grant program (as indicated by dark dots on Table 1) comprise about 77 pct of the total estimated reserves. The six states added in 1980 and 1981, which would increase the coverage to include over 95 pct of the estimated reserves, are shown by open dots.

To meet the objective of the DOE peat survey program to determine the amount and location of fuel grade peat, the grants to each state included four tasks, as follows:

Task 1. - Assess existing data and establish priorities for peat areas to be surveyed.

Task 2. - Identify sampling procedures and strategy.

Task 3. - Procure equipment and supplies; and

Task 4. - Make preliminary estimate of peat reserves.

Each state is required to make periodic and annual reports to DOE with copies to other states and is required to attend the semi-annual DOE contractors meetings to compare survey techniques and results. For purposes of the peat survey, fuel-grade peat is generally defined as peat with minimum heat value of 8000 Btu/lb (dry basis) and a maximum ash level of 25 pct (dry basis). Minimum depth for commercial grade peat is defined as 5 feet with a minimum area of 80 acres per square mile.

More information on the status of the peat surveys in each state is presented in the next section.
### Table 1

**Preliminary Estimated United States Peat Resources**

<table>
<thead>
<tr>
<th>State</th>
<th>Acres (Millions)</th>
<th>Quantity&lt;sup&gt;a&lt;/sup&gt; (Billions Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>27.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>61.7</td>
</tr>
<tr>
<td>Minnesota</td>
<td>7.2</td>
<td>16.5</td>
</tr>
<tr>
<td>Michigan</td>
<td>4.5</td>
<td>10.3</td>
</tr>
<tr>
<td>Florida</td>
<td>3.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>2.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1.8</td>
<td>4.1</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Maine</td>
<td>0.78</td>
<td>1.8</td>
</tr>
<tr>
<td>New York</td>
<td>0.65</td>
<td>1.5</td>
</tr>
<tr>
<td>Hawaii</td>
<td>0.48</td>
<td>1.1</td>
</tr>
<tr>
<td>Georgia</td>
<td>0.43</td>
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<td>Indiana</td>
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<td>.9</td>
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<tr>
<td>Massachusetts</td>
<td>.35</td>
<td>.8</td>
</tr>
<tr>
<td>Virginia</td>
<td>.31</td>
<td>.7</td>
</tr>
<tr>
<td>Washington</td>
<td>.20</td>
<td>.5</td>
</tr>
<tr>
<td>All Other States</td>
<td>1.50</td>
<td>3.4</td>
</tr>
<tr>
<td>South Carolina</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhode Island</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52.6</strong></td>
<td><strong>120.3</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup> Assumes peat dried to 35 weight percent moisture, deposits are 7 feet thick, and have a bulk density of 15 lbs per cubic foot.

<sup>b</sup> Excludes peat in permafrost areas.

* Surveys began in 1979.
* Surveys initiated in 1980 and 1981.

Source: Reference 3
SUMMARY OF STATE SURVEYS

The summary of the peat surveys include two groups of states. The first group of six states, which initiated surveys in 1979, include Alaska, Maine, Michigan, Minnesota, North Carolina, and South Carolina. These six states have completed one annual report and Tasks 1 through 3 for the first year. The second group comprises six states in which surveys were started in 1980 and 1981: Georgia, Florida, Louisiana, Massachusetts, New York, and Rhode Island.

STATES WITH SURVEYS INITIATED IN 1979

Alaska - Don Markle, Alaska Division of Energy and Power Development, and Stuart E. Rawlinson, Geologist, Division of Geological and Geophysical Surveys, Alaska Department of Natural Resources. Initial grant was awarded on September 9, 1979.

The Phase I, first year study was conducted jointly by Northern Technical Services and Ekono, Inc. The purpose of Phase I was to determine the location, area, quantity, and fuel characteristics of the Alaskan peat resource. A map of Alaska indicating the fuel peat probability provinces and ratings of the peat was completed in 1980. Detailed surveys were completed for several areas adjacent to communities that could use additional fuel for energy. These areas are indicated on the map in Figure 2. The results for the peat sites surveyed in 1980 are summarized in Table 2. Areas surveyed (1.858 million acres) included the Anchorage area, Susitana Valley, Matanuska Valley, and Kenai Peninsula.

A Final Report, Volume I, on Peat Resource Estimation in Alaska was published in August 1980. Two maps on fuel peat probability provinces were included.

For Phase II, Alaska Division of Energy and Power Development has awarded a contract to the Alaska DNR, Division of Geological and Geophysical Surveys. The purpose of Phase II is to determine the energy potential of the peat resource of Alaska available for local utilization. The Dillingham area is being studied this year and the Matanuska-Susitana area north of Anchorage will be studied.
Figure 2  Potential Alaskan Fuel Peat Areas
## Table 2
Distribution of Peat Series in Mantanuska-Susitna Valleys and Kenai Peninsula

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Resource Areas</th>
<th>Salamatof</th>
<th>Clunie</th>
<th>Doroshin</th>
<th>Starichkof</th>
<th>Total Acres Surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acres</td>
<td>% Cover</td>
<td>Acres</td>
<td>% Cover</td>
<td>Acres</td>
<td>% Cover</td>
</tr>
<tr>
<td>Anchorage Area</td>
<td>4184</td>
<td>3.53</td>
<td>-</td>
<td>-</td>
<td>4489</td>
<td>3.79</td>
</tr>
<tr>
<td>Susitna Valley</td>
<td>224,090</td>
<td>33.4</td>
<td>0,280</td>
<td>1.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Matanuska Valley</td>
<td>62,590</td>
<td>13.9</td>
<td>0,040</td>
<td>2.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total Mat-Su/</td>
<td>310,864</td>
<td>23.0</td>
<td>20,320</td>
<td>1.5</td>
<td>4489</td>
<td>0.33</td>
</tr>
<tr>
<td>Anchorage Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homer-Ninilchik</td>
<td>39,081</td>
<td>14.4</td>
<td>-</td>
<td>-</td>
<td>11,660</td>
<td>4.3</td>
</tr>
<tr>
<td>Kenai-Kasilof</td>
<td>46,294</td>
<td>19.4</td>
<td>3371</td>
<td>1.4</td>
<td>4108</td>
<td>1.7</td>
</tr>
<tr>
<td>Kenai Peninsula</td>
<td>85,375</td>
<td>16.7</td>
<td>3371</td>
<td>0.7</td>
<td>15,768</td>
<td>3.1</td>
</tr>
<tr>
<td>Total Area (Mat-Su + Kenai)</td>
<td>396,239</td>
<td>21.3</td>
<td>23,691</td>
<td>1.3</td>
<td>20,257</td>
<td>1.1</td>
</tr>
</tbody>
</table>
studied in 1982. The energy consumption of candidate communities in the Dillingham area include:

<table>
<thead>
<tr>
<th>Community</th>
<th>Space Heat (Billion Btu)</th>
<th>Power (GWh)</th>
<th>Diesel Fuel (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dillingham</td>
<td>100</td>
<td>2.5</td>
<td>500,000</td>
</tr>
<tr>
<td>Naknek</td>
<td>20</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>King Salmon</td>
<td>20</td>
<td>--</td>
<td>50,000</td>
</tr>
<tr>
<td>New Stuyahok</td>
<td>20</td>
<td>0.3</td>
<td>62,000</td>
</tr>
</tbody>
</table>

The annual peat bog area required to meet the total energy requirement in the Dillingham area would be about 0.6 square miles.

Selection criteria for candidate bogs include the following:

1. Distance to utilization site not to exceed 30 miles by road, 50 miles by rail;
2. Distance to major road less than 5 miles;
3. Bog area to exceed 80 acres, preferably 320 acres per square mile;
4. Consideration of drainage and other physical constraints, and
5. Areal continuity.

During Phase I, 5 sites near Dillingham were surveyed. The approach to be used in Phase II near Dillingham includes: remote sensing of area (A2 on Phase I peat map), reconnaissance sampling of prime bogs, air photo mapping, and detailed sampling of prime bogs that meet selection criteria.
The Maine survey is being conducted in three phases, essentially as indicated on the map in Figure 3. Tasks 1, 2, and 3 were completed in Phase I.

The Phase I (FY79) survey covered the following county areas: eastern Aroostook, northern Penobscot, eastern Piscataquis, Washington, and part of Hancock. A total of 57 peat deposits was surveyed. Analytical results for 81 samples from the Great Heath (2645 acres) in Washington County are of special interest since trace element analysis was included along with peat type, thickness, proximate and ultimate analysis, and heating value.

The Phase II (FY80) survey covered the following county areas: northern Aroostock, western Piscataquis, Somerset, and Franklin. Fifty-one peat deposits were surveyed.

Estimates to date of fuel-grade peat resources are 70 million tons of air-dried peat, with 45 million tons from Area I and 25 million tons from Area II. These peat resources are predominantly high-quality sphagnum moss peat underlain with reed-sedge peat. The peat properties include heating values between 8600 to 10,500 Btu/lb and ash contents below 8 pct on a moisture free basis. Ranges of values for other properties on a moisture free basis include: volatile matter, 60 to 75 pct; fixed carbon, 20 to 30 pct; sulfur, 0.1 to 0.6 pct (0.2 pct average); nitrogen, 0.6 to 2.0 pct; hydrogen, 4.8 to 5.9 pct; and oxygen, 28.9 to 40.9 pct.

A final report on Phase I was published in July 1980. This report includes peat distribution and thickness maps, analytical results, and fuel-grade peat resource estimates for the 57 peat deposits surveyed in Phase I. A large-scale quality map for the Great Heath is also included.

Cartographic work on the distribution and thickness maps for the 51 deposits surveyed in FY80 is in progress and will be included in the final report for Phase II. Phase III survey work will proceed this summer in the following...
Figure 3 Maine Peat Resource Evaluation Mapping Areas

-11-
county areas: northern and western Kennebec, northern Androscoggin, northern Cumberland, northern Knox, York, Sagadahoc, Lincoln, and southwestern Waldo. Areas in Franklin and northern Oxford counties were determined to be less promising for further exploration.

**Michigan** - Dr. John E. Mogk, Principal Investigator, Michigan Energy and Resource Research Association. Initial DOE grant was awarded in July 1979.

To provide the framework for a comprehensive peat survey in Michigan, the state is divided into 16 soil-geomorphic provinces, as shown on Figure 4. Individual peat types, defined by the U.S.D.A. Soil Conservation Service as organic soil series, are methodically investigated within each province. Field and laboratory investigations have been undertaken to evaluate the energy potentials and classifications of each organic soil series found within a province. During the first phase of the project, Province III was selected for pilot testing as a Michigan area with substantial peat deposits offering high potential as an energy resource.

During 1979, field sampling began at peat bogs in Province III. Project participants cooperated to design an effective field sampling procedure for this work that would supply the data required.

Preliminary data has indicated significant differences in energy potentials among soil series. The Greenwood Series and the Rifle Series meet criteria for fuel-grade peat. On a moisture-free basis, the Greenwood Series averages 9382 Btu/lb heating value, 3.9 pct ash, 0.8 pct nitrogen, 0.2 pct sulfur, 72.7 pct volatile matter and has a bulk density of 0.12 g/cc. The Rifle Series has 8367 Btu/lb heating value, 12.5 pct ash, 2.0 pct nitrogen, 0.53 pct sulfur, 57.6 pct volatile, and 0.15 g/cc bulk density. Current and subsequent data will be summarized for soil series within each soil-geomorphic province to quantify the peat energy potential of the province. Work accomplished in field year 1979 demonstrated a flexible Michigan program for carrying out future work effectively. Ultimately, province data will be combined to produce a statewide estimate of the energy potential in Michigan's extensive peat resources.
Figure 4  State of Michigan Soil-Geomorphic Provinces

Compiled by: Michigan Tech. Univ. 1980

scale statute miles
0 25 50 75 100
Province III is estimated to contain approximately 301,000 acres of fuel grade peat. The breakdown by soil series is as follows:

<table>
<thead>
<tr>
<th>Organic Soils</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lupton</td>
<td>269,740</td>
</tr>
<tr>
<td>Greenwood</td>
<td>15,480</td>
</tr>
<tr>
<td>Carbondale</td>
<td>13,045</td>
</tr>
<tr>
<td>Houghton</td>
<td>435</td>
</tr>
<tr>
<td>Spaulding</td>
<td>2,328</td>
</tr>
</tbody>
</table>

Initial field investigation has shown the deposits for Lupton and Greenwood series to be uniform and accurate with respect to the taxonomic unit. Accordingly, the plots sampled for detailed analysis should be representative of the average condition of the sampled bogs and of the taxonomic unit. Average deposit thickness, for these two series, is well within the 122 cm minimum limit. The average depth was 290 cm for the Lupton deposits and 264 for the Greenwood series.

The 1980 field work also concentrated on Onaway-Emmet Drumlins, Province III. Some field studies were conducted in neighboring Provinces IV - Kalkaska-Rubicon-peat Plains, and II - Iron River-Michigamme Hills. During the 1980 field season, eight bogs were surveyed in Menominee County (Province III). Three of these bogs were mapped as Greenwood and five were mapped as Rifle in the original soil survey of Menominee County. Thirty soil samples were collected from 14 pedons that were studied in detail in the areas mapped as Rifle peat. Sixty-three Rifle peat samples were collected for laboratory analysis. A total of 300 depth observations were made in 30 transects of eight separate bogs.

An annual progress report on the peat resource estimation in Michigan was published on March 3, 1980. Work has been completed for Province III, and the preliminary base map with the peat deposit locations has been prepared. Final analysis of the energy related data is pending receipt of the Btu data from the Department of Energy, Coal Analysis Laboratory. To date, sample turn-around...
time from the Department of Energy laboratory has been very slow (over three months).

Priority areas for the 1981 field season have been selected. Most of the effort will be expended in Province IV, but preliminary work in Provinces II and V will also begin. Using published Soil Conservation Service soil surveys, Michigan Agricultural Experiment Station land type inventories, special studies reported by the Michigan Agricultural Experiment Station and Department of Natural Resources and after consulting with political and scientific leaders, Province IV was identified as having energy peat deposits as promising for development as those in Province III. Province IV - Kalkaska, Rubicon Peat Plains - encompasses the flat to pitted outwash plains of the eastern portion of the Upper Peninsula. Large broad acres of organic soils totaling approximately 457,160 acres have been delineated.

Minnesota - Dr. Dennis Asmussen, Department of Natural Resources. The Minnesota peat program started in 1976 and a DOE grant was awarded in September 1979.

Counties with large peat deposits that have been or are planned to be surveyed are indicated in Figure 5. In 1979 and 1980, detailed surveys were conducted in Koochining, Aitkin, and southwestern St. Louis counties. The survey estimates for Koochining County are 1.5 million acres of peat with 0.40 million acres of fuel-grade peat (greater than 5 feet thick). Aitkin County had 0.42 million acres of peat with 0.12 million acres greater than 5 feet thick.

Most of the peat surveyed is hemic, reed-sedge peat. The average peat properties on a moisture-free basis for Koochining and Aitkin counties are as follows: heating value, 8933 Btu/lb; ash, 8.2 pct; volatile matter, 64.3 pct, fixed carbon, 27.2 pct; nitrogen, 2.2 pct, and sulfur, 0.4 pct.

A progress report on "Inventory of Peat Resources in Minnesota" was issued in January 1977. Many reports and maps have been published since then, including an "Inventory of Peat Resources" report for southwestern St. Louis county in May 1979. Based on the more recent, detailed surveys, a report on Koochining County is in print, and a report on Aitkin County is scheduled for May 15, 1981.
Beltrami and Lake of the Woods counties
725,000 acres (estimated)

Koochiching County
1,147,360 acres (surveyed)

SW St. Louis County
278,660 acres (surveyed)

Carlton County
137,000 acres (estimated)

Aitkin County
419,680 acres (surveyed)

Figure 5 Peat Resources Map of Minnesota
The Minnesota Land Management System is being utilized to evaluate and map the availability of peat land. The mapping uses 40 acre grids and four categories (Category 1, excluded; Category 2, private and Federal; Category 3, wildlife management prohibiting leasing; and Category 4, administratively available for leasing). Initial mappings indicate that 1.168 million acres of the 1.57 million acres of peat identified in Koochining and Aitkins Counties are "administratively available." About 0.311 million acres of this available peat are greater than 5 feet thick.

For FY81, surveys are planned for Beltrami, Lake of the Woods, and Carleton counties. Preliminary field work was initiated in November and December of 1980. Survey work in Carleton County is scheduled to start in May and be completed by July. An attempt will be made to derive the heating value statistically based on such peat properties as moisture, pH, degree of decomposition, bulk density, and ash level.

North Carolina - Dr. Roy L. Ingram, Department of Geology, University of North Carolina. The initial DOE grant was awarded in May 1979.

Major peat deposits in North Carolina are indicated on Figure 6. The peat occurs in pocosins, river flood plains, and Carolina bogs. Most of the survey work to date has concentrated on the pocosin deposits. A summary of work completed and estimates of peat resources for North Carolina is presented in Table 3. The estimated area of peat deposits is about 0.7 million acres or 620 million tons on a moisture-free basis (1.08 million tons air-dried at 35 pct moisture).

Most North Carolina peat is a black, fine-grained highly decomposed hemic to sapric peat. For most pocosin deposits, the thickness of the peat is 7 to 8 feet in the center, with a median thickness of about 4-1/2 feet. The median properties for moisture-free peat (based on 200 samples with less than 10 pct ash) are as follows: heating value, 10,200 Btu/lb; ash, 4 pct; volatiles, 61 pct; fixed carbon, 35 pct; carbon, 60 pct; hydrogen, 5.2 pct; oxygen, 29 pct; nitrogen, 1.4 pct; and sulfur, 0.2 pct.
Figure 6 Location of North Carolina Peat Deposits
Table 3
Summary of Work Completed
On North Carolina Peat Deposits

<table>
<thead>
<tr>
<th>DEPOSIT</th>
<th>AREA Mi²</th>
<th>WEIGHT MF-PEAT 10⁶ tons</th>
<th>SITES SAMPLED</th>
<th>SAMPLES COLLECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. POCOSIN DEPOSITS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Dismal Swamp</td>
<td>100</td>
<td>60-g*</td>
<td>333</td>
<td>1737</td>
</tr>
<tr>
<td>B. Pamlimarle</td>
<td>360</td>
<td>210-g</td>
<td>582</td>
<td>3231</td>
</tr>
<tr>
<td>C. Gull Rock</td>
<td>6</td>
<td>4-f</td>
<td>16</td>
<td>79</td>
</tr>
<tr>
<td>D. Gum Swamp-Bay City</td>
<td>11</td>
<td>5-p</td>
<td>21</td>
<td>110</td>
</tr>
<tr>
<td>E. Light Grounds</td>
<td>9</td>
<td>5-e</td>
<td>97</td>
<td>504</td>
</tr>
<tr>
<td>F. Open Grounds</td>
<td>15</td>
<td>9-f</td>
<td>29</td>
<td>68</td>
</tr>
<tr>
<td>G. Croatan</td>
<td>40</td>
<td>23-f</td>
<td>243</td>
<td>1175</td>
</tr>
<tr>
<td>H. Hofmann Forest</td>
<td>10</td>
<td>6-f</td>
<td>27</td>
<td>134</td>
</tr>
<tr>
<td>I. Holly Shelter</td>
<td>6</td>
<td>4-f</td>
<td>9</td>
<td>58</td>
</tr>
<tr>
<td>J. Angota</td>
<td>20?</td>
<td>12?-f</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>K. Green Swamp</td>
<td>10</td>
<td>6-f</td>
<td>33</td>
<td>182</td>
</tr>
<tr>
<td>II. RIVER FLOODPLAINS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Chowan</td>
<td>40?</td>
<td>25?-p</td>
<td>5</td>
<td>54</td>
</tr>
<tr>
<td>B. Roanoke</td>
<td>50?</td>
<td>29?-p</td>
<td>25</td>
<td>204</td>
</tr>
<tr>
<td>C. Tar</td>
<td>10?</td>
<td>6?-p</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>D. Neuse</td>
<td>10?</td>
<td>6?-p</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>E. Cape Fear</td>
<td>20?</td>
<td>11?-p</td>
<td>59</td>
<td>831</td>
</tr>
<tr>
<td>III. CAROLINA BAYS</td>
<td>350?</td>
<td>200?-p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Baldean County</td>
<td></td>
<td></td>
<td>51</td>
<td>294</td>
</tr>
<tr>
<td>B. Crowen County</td>
<td></td>
<td></td>
<td>8</td>
<td>31</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1063</td>
<td>620</td>
<td>1538</td>
<td>8692</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.7x10⁶ acres</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Quality of estimate: e - excellent, g - good, f - fair, p - poor
An annual report on peat resources in North Carolina was published in November 1980. Based on survey work completed to date, considerable interest has been generated, including a proposal by the N.C. Electrical Membership Corporation to use peat as a boiler fuel, an application to mine a 3600-acre tract in the Light Ground Pocosin, and a pilot project to extract methane gas from water in swampy peat bogs. Also, the First Colony Farm has been actively developing peat deposits since about 1975 on the Pamlimarle Peninsula.

A final estimate of the peat reserves in the Light Ground Pocosin has been determined. Volumes of peat were determined from an isopach map showing the varying thickness of the deposit, and the volumes were then multiplied by measured bulk densities to determine the total reserve of this deposit. Additional survey work and analytical calculations are required to complete estimates for the other pocosins, river floodplain, and Carolina bog deposits. Refinements are also required to estimate the energy potential of these reserves. The amount of fuel-grade peat in North Carolina may be significantly lower than the estimated peat reserves, since the average thickness of the pocosins is about 4-1/2 feet.

South Carolina - Dr. Torgny J. Vigerstad, Project Manager, South Carolina Energy Research Institute. The initial DOE grant was awarded in August 1979.

The map in Figure 7 indicates the large peat deposits in South Carolina. The status of the peat surveying is also indicated on the map for each deposit. Detailed surveys have been conducted for the Snuggedy Swamp in Colleton County and for the Savannah River region in Jasper County. Preliminary samples have also been taken from other peat deposits in the state. A summary of the preliminary peat resource estimates based on limited surveying and sampling is presented in Table 4. The estimated total resource is about 74,218 acres or 0.142 billion tons (air-dried at 35 pct moisture).

Based on the Snuggedy Swamp samples, South Carolina peat is woody and grass-sedge peat that is high decomposed hemic with some sapric. On a dry basis, the mean peat properties are as follows: heating value, 9853 Btu/lb; ash, 4.5
Figure 7  Approximate Locations of Major Peat Deposits in Coastal Plain Counties of South Carolina
Table 4
Preliminary Estimated Peat Resources in South Carolina

<table>
<thead>
<tr>
<th>County</th>
<th>Acres</th>
<th>Dry Weight (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colleton</td>
<td>17,026</td>
<td>26.0</td>
</tr>
<tr>
<td>Jasper</td>
<td>13,000</td>
<td>21.0</td>
</tr>
<tr>
<td>Charleston</td>
<td>5,102</td>
<td>5.3</td>
</tr>
<tr>
<td>Berkeley</td>
<td>4,590</td>
<td>4.7</td>
</tr>
<tr>
<td>Horry</td>
<td>19,500</td>
<td>20.0</td>
</tr>
<tr>
<td>Georgetown</td>
<td>15,000</td>
<td>15.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>74,218</td>
<td>92.5</td>
</tr>
</tbody>
</table>

Note: 92.5 million tons (dry) = 0.142 billion tons air-dried at 35 pct moisture.

pct; volatile matter, 58.5 pct; fixed carbon, 36.9 pct; hydrogen, 4.2 pct; carbon, 59.4 pct; oxygen, 27.9 pct; nitrogen, 1.1 pct; and sulfur, 0.7 pct.

A final report for the first year of the peat resource estimation in South Carolina was published on August 31, 1980. This report includes maps, tables of analytical results, and preliminary estimates of peat resources for the six counties with major peat deposits -- Colleton, Jasper, Charleston, Berkeley, Georgetown, and Horry counties.

In the last quarter, activities include isopach mapping of peat thickness in the Snuggedy Swamp, development of cross sections for ash, moisture, and water holding capacity for transects from deposits in Jasper County, and identification of several new potential peat deposits in Berkeley County. Since Snuggedy Swamp in eastern Colleton County has been surveyed more extensively than other deposits in South Carolina, this deposit was chosen for initial computer mapping. All depth data from the surveys plus all depth data that could be accurately mapped from published reports or from files of the Organic Sediments Research...
Center (University of South Carolina) were digitized and plotted using the "surface II" computer mapping program. Point thickness and isopach maps are presented in the quarterly report dated January 1, 1981.

A new soil conservation service report on Berkeley County has indicated the existence of some relatively sizeable deposits of organic soil. One of these deposits is about 5 square miles in area and two are about 2 square miles. In the second quarter of 1981, preliminary sampling in all of the organic soil regions was begun. Samples were taken from Hell Hole Bay, Ocean Bay, Middle Bay, and Pigeon Bay. The ash levels for the samples generally are above the 25 ppt criterion for fuel grade peat.

In the coming quarter, field reconnaissance of the Combahee deposit in Colleton County and the Savannah River deposit in Jasper County will commence. Probing will continue along the Black River in Georgetown County and Waccumi River in Horry County. Laboratory analysis of peat samples will also continue.

By the end of this second year, evaluations are expected to be completed on the major deposits in Colleton, Jasper, Berkeley, Marion, and Georgetown Counties, and some resource data will have been obtained on all of the major peat deposits in South Carolina. The study is on schedule for completion of the survey of peat resources for the entire state in one additional year (August 1982).

STATES WITH SURVEYS INITIATED IN 1980 AND 1981

Georgia - Bob Didocha, Technology Applications Laboratory, Georgia Institute of Technology. DOE grant is scheduled for award in FY81.

The coastal plains area of Georgia is similar to those of North and South Carolina, but the surveys that have been done in the Georgia plains are very spotty. Figure 8 (from the South Carolina Survey Annual report) indicates the plains area from Virginia through North Carolina, South Carolina, and Georgia into Florida. Ponds and bays exist all along the coastal plains and in the uplands part of Georgia. The southern part of the state, which borders on
Figure 8 Distribution of Carolina Bays in Coastal Plain of N.C., S.C. and Georgia
Florida, is an area that is underlain by limestone. There are two active peat mines presently in the state, with reserves that have been estimated anywhere from 0.1 to 1 billion tons. The types of peat that exist in Georgia are reed-sedge, sedimentary, and woody peat - all good fuel grade peat.

Florida - Doug Roberts, Governors Energy Officer. DOE grant awarded in March 1981.

Florida includes potential peat deposits along the Atlantic Coast, inland over the Everglades and near the Gulf Coast as indicated on the U.S. map, Figure 1. Florida has about 5.7 pct of the U.S. peat resources. Preliminary estimates show about 3.0 million acres or 6.9 billion tons of air-dried peat for Florida.

Louisiana - Dr. Charles Groat, Louisiana Geological Survey. DOE grant awarded in March 1981.

The Louisiana Geological Survey has begun an investigation of peat distribution in coastal Louisiana. This program is directed towards mapping of peat deposits in Louisiana, description of peat characteristics, and evaluation of their potential for commercial production as an energy resource. Louisiana's reserves were estimated in 1979 at 4.1 billion tons by the U.S. Department of Energy. To this date, the Louisiana Geological Survey has reviewed relevant literature and examined logs of existing boreholes that have encountered peat. This information was used to produce a preliminary evaluation of the geologic significance of identified peat deposits and define peat prospect areas for additional mapping and sampling investigations.

In coastal areas, significant peat deposits can reasonably be expected to occur as surficial or buried organic matter accumulations in marsh and swamp environments (See Figure 9). In south Louisiana, these environments occur mainly gulfward of the youngest coastwise Pleistocene terrace, the Prairie, and correspond closely to the extent of the Mississippi River Deltaic Plain. The selected prospect areas are located within the Pontchartrain Basin, the Barataria Basin, and the Atchafalaya Basin. These basins are interdistributary lowlands formed
Figure 9 Louisiana Peat Resource Areas
by cycles of deltaic sedimentation that contributed to a low rate of inorganic sediment input relative to the rate of organic matter accumulation.

The next phase of the program will be detailed mapping and sampling within the identified prospect areas. Initial activities will include field sampling and description of peat sequences and sample analysis. Interpretations of aerial photography, topographic maps, cross sections, and other available map data will be used to extrapolate general peat characteristics throughout and beyond the prospect areas. Maps depicting peat types, peat thicknesses, energy characteristics, and environmental setting of peat deposition will be used to estimate peat reserves within the selected prospect areas. New prospect areas will be identified for detailed study at a later time. Peat resource evaluation will be paralleled by environmental assessment of principal peat occurrence areas. It is the ultimate goal of this program to map the location and quantity of fuel grade peat that can be commercially produced in an environmentally acceptable manner.

Massachusetts - Dr. Lillian Morgenstern, Massachusetts Office of Energy Resources. The DOE grant was awarded on March 1, 1981.

The Massachusetts Executive Office of Energy Resources and the Massachusetts State Geologist have jointly identified three primary areas for initial peat sampling in the eastern portion of the state. These areas are indicated on the map in Figure 10. Parties are scheduled to be in each of the three areas in late April to gather data for site descriptions, and hand coring parties are scheduled to be in the field by mid-May. The quadrangles selected for sampling are identified below by zones, and the approximate areal extent of each zone is provided.

**Area I** includes the quadrangles of: Mansfield, Norton, Brockton, Taunton, Whitman, Bridgewater

**Quadrangle (s):** Taunton - Brockton
- Zone 1 - Hockomock Swamp (4 x 6 miles)
- Zone 2 - Little Hockomock (1 x 2 miles)
Figure 10 Massachusetts Peat Resource Survey Areas
Quadrangle: Norton
Zone 3 - Hemlock Swamp (2 x 2 miles)

Quadrangle: Whitman
Zone 4 - Beach Hill Swamp (1-1/2 x 2 miles)

Quadrangle: Bridgewater
Zone 5 - Great Cedar Swamp (3 x 1 miles)
Zone 6 - Meetinghouse/Beaverdam (2 x 2-1/2 miles)
Zone 7 - Purchade Brook Area (1 x 2 miles)

Area II includes the quadrangles of: Worcester South, Grafton, Blackstone

Quadrangle: Worcester South
Zone 1 - Bugs Swamp (2 x 1/2 mile)
Zone 2 - Cedar Swamp (1 x 1/2 mile)

Quadrangle: Grafton
Zone 3 - Miscoe (1-1/2 x 1/2 mile)
Zone 4 - West River Area (1/2 x 1/2 mile)

Quadrangle: Blackstone
Zone 5 - Long Meadow (1/2 x 1/2 mile)
Zone 6 - Corner Brook (2 x 1/2 mile)

Area III includes the quadrangles of: Lowell, Lawrence, Billerica Wilmington, Reading, Salem

Quadrangle: Lowell
Zone 1 - Beaver Brook Area (1 x 1 mile)
Zone 2 - Spruce Swamp (1/2 x 1/2 mile)
Quadrangle: Lawrence
Zone 3 - Great Swamp (1-1/2 x 2 miles)
Zone 4 - Peat Meadow (1 x 1 mile)
Zone 5 - Fish Swamp (1 x 1/2 mile)

Quadrangle: Billerica
Zone 6 - Toplet Swamp (1 x 1 mile)
Zone 7 - Great Swamp (2 x 3 mile)

Quadrangle: Wilmington
Zone 8 - Wilmington Junction (2 x 3 miles)
Zone 9 - Wilmington Junction (composite) (10 x 5 miles)

Quadrangle: Reading
Zone 10 - Cedar Swamp (3 x 3 miles)
Zone 11 - Wills Brook Area (1 x 2 miles)

Quadrangle: Salem
Zone 12 - Wenham Swamp (3 x 2 miles)
Zone 13 - Orne Swamp (2 x 1-1/2 miles)
Zone 14 - "Airport" Swamp (1 x 1/2 mile)

New York - Jeffrey M. Peterson, Project Associate, New York State Energy Research and Development Authority. DOE grant awarded with starting date of April 1, 1981.

Based on the preliminary U.S. estimated peat resources, New York has about 0.65 million acres of peatland containing 1.5 billion tons of air-dried peat. Carlson & Sweatt-Monenco, Inc., a consulting engineering firm with peat experience, has been proposed to conduct the peat resources survey for the New York State ERDA. The field sampling program for the 1981 season is scheduled to start in April or May and to be completed by the end of September.
The principal objective for year 1 is to determine the energy potential and distribution of peat resources in New York State. This goal will be achieved in the following manner:

(a) Peat deposits will be inventoried for the entire State of New York. This inventory will include the location (UTM coordinates), surface area, and the type of deposit. However, protected land areas, such as parks, wildlife reserves, and the like, will have low priority and may be included in the study only if there are sufficient time and budget remaining at the end of the study.

(b) The quality and quantity of peat within the deposits will be inferred from aerial photographs supported with ground checks at representative locations.

(c) Laboratory analyses will be carried out on a limited number of peat samples to obtain preliminary basic information on the fuel characteristics of New York peat.

(d) Criteria will be developed for the evaluation of regional peat potential, and counties will be prioritized, with the most promising areas in selected counties to be surveyed in detail.

(e) The detailed survey will be carried out on a limited number of bogs (approximately 5,000 - 10,000 acres) within the top priority county(ies).

(f) The detailed field work will include the establishment of grid determination of peat profiles at 300 - 500 foot centers from surface to bottom, using the Hiller auger and von Post classification for recording peat characteristics. From selected locations, peat samples will be taken by piston sampler for laboratory analyses.

(g) Laboratory analyses of the selected samples from the detailed survey will define the fuel characteristics (proximate analyses, calorific values) of the selected bogs in detail.
A final report will be prepared on the results of the peat inventory for the entire State. Included in the final report will be the results of the detailed survey on the selected bogs, which will include such information as:

- field survey procedures,
- peat distribution and isopach maps,
- quantities of fuel grade peat,
- humification and peat profiles,
- surface elevation maps,
- drainability and access information,
- recommendations on the potential use of surveyed deposits and direction of future investigation for the State,
- results of laboratory analyses on fuel quality, and
- other significant features such as surface vegetation, fire activity, and the impact by man.

Rhode Island - Mr. Richard Goldfine, State of Rhode Island, Energy Administration. Initial DOE grant awarded on March 9, 1981.

Prior to this DOE grant, Rhode Island performed a detailed survey of peat resources on Block Island. The location of Block Island relative to the rest of Rhode Island and Massachusetts is indicated in Figure 11. The survey of Block Island indicated 63,564 tons of potential peat resources in seven peat bogs. The best quality peat (10-20 pct ash and greater than 5500 Btu/lb air-dried) was located in the Ambrose Swamp and New Meadow Hill Swamp, with a total estimated peat resource for the two swamps of 26,670 tons, air-dried. Additional information on the Block Island survey was reported previously at the last Peat Contractors' Meeting.

CONCLUSIONS AND RECOMMENDATIONS

Eleven states are currently conducting peat surveys under DOE grants, and a 12th state is scheduled to be included in 1981. Six of these states (Alaska, Maine, Michigan, Minnesota, North Carolina, and South Carolina) began surveys
Figure 11 Location of Block Island, Rhode Island

Figure 11 Location of Block Island, Rhode Island
in 1979, and five more were added in 1980 (with grants funded in the Spring 1981). Georgia is scheduled for funding in 1981; and Wisconsin, Alabama, and Ohio have expressed some interest in joining the program. The status of the 12 states has been presented in the preceding section. To make a complete survey and evaluation of fuel-grade peat resources, most states will require 3 to 4 years of effort.

Minnesota survey results serve as a good example of how much fuel-grade peat may actually be available from the total peat resource. Results for several counties included 1,567,000 acres of total peat reserve with 532,000 acres (34 pct) greater than 5 feet thick. Out of these total acres, 1,168,000 acres (75 pct) were administratively available for leasing and 311,000 acres of this (or 20 pct of the original) were greater than 5 feet thick. Of course, the thicker peat will yield more tons per acre and more quads, so the total potential quads available as fuel grade peat will be higher than the 20 pct area indicated.

Based on these considerations, the following recommendations are made:

1) State surveys should be concerned with determining overall peat resources for accurate determination of the total U.S. resources rather than concentrating on low quantities of peat for local consumption; and

2) These state surveys should identify the location and amount of fuel grade peat resources.

Another consideration of future peat sample analyses would be the addition of ash elemental analysis. This analysis is very useful for predicting reactivity for gasification and liquefaction and for predicting ash fouling and slagging potential for direct combustion. Trace element analysis, as was performed in the Great Heath in Maine, is also important in the evaluation of potential pollutants from peat processes.
REFERENCES


4. Data from U.S. Dept. of Agriculture, Soil Conservation Service, Conservation Needs Inventory, 1967, Dr. R.S. Farnham, Professor of Soils Science, Univ. of Minn.
QUESTIONs AND ANSWERS

Q: How would you define "administratively available"?

Of the four land categories we defined, those areas actually available for the state or Federal government to lease were those we called "administratively available." However, that doesn't mean that that's the only peat available, since, for example, some in the first category could be contracted for from private parties.

Peat in all categories is being included as fuel-grade peat. It's just that there is a proviso that some of it may not be available for energy applications. Even the peat that is administratively available might not be environmentally acceptable, for that matter.

Q: Are you suggesting that you'd like to have similar information from other states?

A: Yes.
Q: If you'd like information on administratively available areas, then I think we need a definition, so we'll be able to give you that information.

A: It's not what was requested in advance but it certainly would be useful information. Of course, that could come out of the environmental studies and the other studies, too, but it's strictly a state matter. The Department of Energy is only interested in the total amount of fuel-grade peat in the United States. The administrative part is not really of interest in these studies, although I think it would be in the final analysis. However, the first thing is to find out how much we have so we can find the value of the resource. For example, when the coal was reported as a resource, it's not broken down as administratively available. We want a parallel resource estimate available for peat. We don't want all these different breakdowns.

Q: We've seen that Florida is listed as having large reserves of peat. I wonder what the basis for that is, from a fuel-grade peat point of view?

A: Of course, we haven't actually done any work in connection with this survey because the funds have not been available until right now. I think the original estimates were probably based on a combination of a Florida Geological Survey bulletin in the 1940s by Davis plus more recent estimates. Also, all the peat in that estimate existed to depths of at least 5 feet, with an average depth of 7 feet assumed. So that would at least fall within the framework of fuel-grade peat but, if we knew that it was all fuel-grade peat, then we wouldn't have to do the survey. That's one of the things we want to find out.
Q: I'd like someone to discuss just very briefly the quality variations in a peat bog. When we get down into the commercialization and the practical application of that stuff, I'm wondering whether we're going to have blending problems, if we have a system that doesn't respond rapidly?

A: I think, from what I've seen so far, they didn't have as much variability as we had in lignite. It was more predictable on sulfur levels and things, although, you know, in lignite you can go along and you can find, say, 8-tenths of a percent sulfur in a lot of seams and then all of a sudden you may have 2.1% sulfur. So they could have that kind of problem, too. So if they sampled, say, 10 samples in a bog, it's quite possible that they may not have gotten a variation.

I think I can give you some insight with regard to the Michigan bogs. The quality variation is largely dependent on the amount of so-called ash, which really isn't ash for the most part at all but silt and sand and the like. If you've got a bog that's in the potholes in an outwash plain, at least at the period when the sand was blowing, at some lower level in the bog there's going to be just too much sand for it to qualify. In other words, it will be over 25%.

Similarly, if you have bogs in areas that are periodically flooded, for example, our Houghton muck, which is along streams that periodically flood, again you're going to have too much sand. Once you check and you find you're over the 25%, you might as well forget it.

On the other hand, if you have the bogs that grew in lakes where the system was pretty well stabilized, you'll rarely have more than 10%. Sometimes, I suppose dust farms in the past brought sand in, but you rarely have more than 10% ash and in some bogs you're considerably below that.
Q: How about resource estimation for peat bogs?

A: It depends on where it is. If you talk about the bogs that are up in the Laurentian Highlands where they extend into Michigan, where the bottom of the bog is very irregular, the best you can do is take an average estimate. On the other hand, Mr. Honea spoke about the bogs on the drumlins. Those have relatively round bottoms so you don't have much difficulty in making an estimate.

Then, we're fortunate, as you mentioned, if we find a deposit that is mapped as Rifle peat and having checked to make sure that it is, we know all Rifle peat is energy grades. More than that, in Michigan we've got soil maps for the whole state. So, therefore, if they draw Rifle peat or Lupton Peat or Greenwood peat, we know they're all energy grade. We only have to determine what the depth of the peat is to come up with an average and thus a resource estimation.

COMMENT: We were quite interested in this very question and the way I thought of it was in terms of how we'd devise a mining plan and we spent a couple of days looking at the variability in ash contents over an area.

In one swamp in South Carolina, the Snuggedy Swamp, the variability from point to point is highly significant. If you do an analysis of variance between samples and within samples, which would be your depth, actually, compared to point, you find that the variability is greater among points than among depths.

In Minnesota in Koochiching County, we found the opposite, that the variability is much greater on depth than it is between points. So it does vary from bog to bog. The Minnesota peats had less variability over all than the ones that we have in South Carolina.
The other point we found was that the ash content varies and the sulfur content varies the most of all the analyses that we're making, if you look at all the proximate ultimate analyses.

Q: Primarily vertically?

A: That depends on the bog. For instance, the coefficient of variation of ash can be upwards of 80% while the coefficient of variation for Btu is around 4 to 5, which led us to do some regression analysis on ash and Btu. It's our opinion that there is really no reason to do many Btu analyses because you can predict within plus or minus 5% the average Btu content of a bog just by knowing the ash. We haven't done that kind of analysis on sulfur, but we'd like to recommend it highly.

You've got a great data base here on peats in the United States. Some routine statistical analyses could probably show you how to go about other surveys in other states, where to spend your money and what kind of mining problems you might have.
GRI JOINT PROGRAM INVOLVEMENT

by

John Hoppe

Gas Research Institute
When I was first asked to make a presentation, I was given a format and I looked at the format and it said how I should present the various projects that I've been working on and I kind of scratched my head and I said, Gee, this doesn't really apply since we're co-funding most of the projects and I really can't give a status of the projects that we're co-funding. It's more your turn to give the status of those projects. So what I felt I would do was talk a little bit about the joint program between GRI and DOE and also talk a little bit about GRI and where we came from and how we developed. I think this would be supportive of some of the people here who don't have a full understanding of what our involvement is.

In 1971, the American Gas Association went into an agreement with ERDA and the Office of Coal Research for a program of about $80 million that they would be funding to support various research and development programs in the coal gasification area. Some of the programs that were being looked at, at that time, were Hygas, BI-GAS, Adgas, CO2-Acceptor, synthane, steam iron and so on. These were the basis of the AGA program at that point, and for a period of about 7 years research went into these various processes.

In 1978 GRI was formed as an offshoot of AGA and was made a nonprofit, separate corporation founded to separately fund the coal gasification area and the fossil fuels area. The AGA maintained pipeline research and development and anything that had to do with intrastate pipelines and so on.

The program at that time for GRI was about an $80 million program, and approximately $10 million of that program was put into the fossil fuel area or the area of supply, as we call it. There are four different areas in GRI, supply being one, basic research being another, efficient utilization, which I think many people are hearing a lot more about, which deals directly with industry in trying to more efficiently use gas is another area, and environmental and safety is another area.

My area is in the supply area and it's called Fossil Fuels Development Programs.
We also have unconventional gas programs. We also have biomass programs in the supply area.

Under the Fossil Fuels Program we presently have peat gas, as well as several coal gasification processes, including Exxon and Westinghouse, that we're funding.

GRI's program selection is made by various means. We go out and we look for processes and programs which we would like to fund independently. We put out RFPs looking for particular areas that we would like to fund. We accept unsolicited proposals for funding in any of the areas that we are interested in. We also co-fund programs with industry in trying to develop certain items towards commercialization and we have this joint program with DOE in which we co-fund both coal gasification and peat gasification.

The joint program agreement allows us to fund on a one-third/two-thirds level, one-third GRI and two-thirds DOE, and this is an agreement which has been in standing since 1979 and will be renewed for 3 years coming September of this year.

The program management is basically a straightline management. We have a steering committee which consists of representatives of industry, the National Science Foundation, GRI, and DOE. This steering committee is the top level of the management team.

Underneath the steering committee we have an operating committee -- No, we have the program directors of which one is DOE and one is GRI, being Lowell Miller at this time from DOE and Ab Flowers from GRI.

Then below that on a line management basis, we have the operating committee, which has representatives of both DOE and GRI on its committee. This operating committee is where the programs are directed from and where the actual program management sits.

Under the operating committee, of course, we have project management in the various areas and various programs that we work with in both DOE and GRI.
Some of the peat funding programs that we have been involved in since 1979:

We have been involved in the 6-state resource assessments with Alaska, North Carolina, Minnesota, South Carolina, Maine, and Michigan. These states began the resource assessments in '79 and this became the basis for that part of the program.

We also became involved with IGT in the PDU testing in the development of the peat gas process and at that time there was a decision to proceed with modifying the hygas gasifier to become a peat gas gasifier and we started working -- we started funding the efforts in the design phase of those modifications.

Also, in '79 we had some harvesting and dewatering studies involvement as well as some environmental work that we were doing both with GRI independently and with DOE.

In 1980, we proceeded to go ahead and fund additionally to the 6 states: New York, Massachusetts, Louisiana, Rhode Island, and Florida, which then made it an 11-state resource assessment program. This program is continuing and will be expanded further and further as time allows.

Also, in 1980 we funded the development of an RFP for environmental and socio-economic assessments to understand what the effects of mining and gasification of peat would be on a broad basis. This RFP has been let, I believe, at this point in time and studies will continue on in 1981.

Also, there was a number of other studies that we became involved with: feedstock classification, dewatering studies, solvent extraction, single stage fluidization studies, and also studies in kinetics. Wet carbonization is another and then, of course, the peat gas PDU testing was completed in 1980 under the joint funding of DOE and GRI and the hygas modifications moved into the construction phase and most of that was completed also in 1980 in preparation for the pilot plant test program.
In addition, GRI's economics group singley funded several programs, mainly being subcontracted through IGT and those were resource, harvesting, dewatering, beneficiation, economics and studies in that area of economics to be parallel with the DOE/GRI programs.

In 1981, the same program that I just described for 1980 has been proposed on an overall basis. The resource assessment, states and resource assessment program, as I mentioned, will be expanded to include Rhode Island and a number of the other states, I don't have them all listed.

There are also wet carbonization studies that are in the program, aqueous phase dewatering, long range studies by the University of Pennsylvania, hydrogasification by Rockwell, which is part of the program, and then pilot plant work with IGT which is continuing now into the operational testing stages.

Of all of these programs, DOE is now in the process of massaging with the administration the overall programs to try to find out what will be happening in the 1981 year. We have at GRI dedicated a certain amount of funds to the pilot plant testing at this point and we now await the administration's decision as to where the funding will be for the DOE program and at that point in time we will dedicate that additional funds that are necessary to cover our one-third share.

That's about all I have with the exception that the program that has been going on in IGT I think we have been following very closely and they have made some very good efforts in the peat gasification. I think they have made a breakthrough and I believe that their tenacity and their continuing efforts in trying to keep this program going have allowed them to reach the point that they are at right now and I'm sure you'll be hearing about that a little bit later on.

We feel that a breakthrough has been made in the gasification of peat and we look forward to future involvement with these programs.
MR. GEORGE SALL

DOE RESOURCE MANAGER FOR PEAT.
It's a pleasure to be here this morning and I feel that, at the risk of boring some of you who have heard this story before, I must tell you why I'm here. It is a confusing story and I have to repeat it periodically so I can keep it straight myself.

About two years ago, three years ago, Congress got very frustrated with the efforts of the federal government in getting a synthetic fuels industry off the ground. They felt enough lip service had been paid to the need for synthetic fuels; now it was time to get something done. So their first effort in this direction was to pass an appropriation of about $300 million in so-called Public Law 96-126. That amount of money was given to the Secretary of Energy and they directed the Secretary of Energy to go out and solicit ideas and thoughts for commercialization of synthetic fuel processes. We called it at that time the Alternate Fuels Program.

Peat itself was defined as a candidate for an alternate fuel. However, peat, to qualify for one of the grants or any grant for Public Law 96-126, had to be altered physically or chemically; direct burning was not allowed.

Out of that effort about 100 grants were made, and they were grants across a wide scale of technologies to conduct feasibility studies of these commercialization processes.

Now a feasibility study in our context at that time, and it still is, of course, is the one step that translates the kind of activities you researchers have been doing such a grand job with into the harsh, cruel world of commercial application. The thought was, Okay, we've heard a lot about this good idea but will it sell on Wall Street? And that basically is the kind of effort that we were contemplating.

I mentioned 100 awards were made, approximately 100. There were 33 in the fossil fuels area, the area in which I am directly involved. The administration of those 33 feasibility studies was given to the Assistant Secretary of Resource Applications to administer. I worked for the Assistant Secretary of Fossil Energy. That is why or how I got into peat.
One of those 33 feasibility studies was for the gasification of peat. As you all know, it was given to the Minnesota Gas Company and you're going to hear a little bit more about that in the next couple of minutes. Things have been happening though. At the present time there is an effort to streamline -- the work they're using in the department. The streamlining effort has been initiated, it hasn't been completed and no one knows what DOE is going to look like when it is completed but the job of Assistant Secretary for Resource Applications was eliminated and the responsibilities that had headed up to that office in DOE were parcelled around into various other assistant secretaries. The group with which I work, and I hesitate to use a name because it changes so often but basically it's the Office of Coal Research Management, was assigned to fossil energy.

We were merged with fossil energy but by no means have we been integrated with fossil energy. So essentially we are doing exactly the same thing we were doing six months ago except that our reporting structure is different. When we want to make a trip we have to get permission from Germantown rather than someone in our own building down at Federal Energy or the Federal Building downtown.

As I mentioned, there was one feasibility study granted under the Alternate Fuels Program, that was to Minnesota Gas Company, the program was initiated last fall, they are 6 months into a 19-month study and with that I plan to call on Mr. Rader who will go into a little bit more detail about the progress they're making.

I must say this group at Minnesota Gas Company and the team that they have put together, from our standpoint, and our standpoint being are they doing what they said they're going to do on time, are they making the reports on time, are they spending the money they said they were going to spend in the way that they said, they have been excellent. They have been one of the great contractors, if you will, with which I have had the pleasure of working.

While Al is coming up here, you know him as the authority on peat but I have found out since knowing him he really broke into this business as a synthetic fuels man because he was responsible for running plants that made town gas back before we found so much natural gas.
ALTERNATE FUELS FEASIBILITY STUDY

Peat to SNG in Minnesota

by

Arnold M. Rader, Consultant

and

John D. Somrock, Director of Supplemental Energy Supply

Minnesota Gas Company
Minneapolis, Minnesota
BACKGROUND

Minnesota Gas Company became interested in peat as a source of supplemental natural gas (SNG) in 1974 and started preliminary studies at the Institute of Gas Technology (IGT) to investigate the feasibility of gasifying peat.

In 1975, Minnegasco made a public announcement of its interest in peat gasification and, at the same time, applied for a base on state-owned land that would support a 250 million cubic-foot-per-day SNG plant for 20 years.

Minnegasco was awarded an ERDA contract in 1976 for a 2 year, $1.25 million dollar Peat Gasification Study. IGT is the subcontractor to Minnegasco for the work on this program. This contract has been extended until December 31, 1981 by the U.S. Department of Energy (DOE). This peat gasification development program is now also supported by the Gas Research Institute (GRI) and the Northern Natural Gas Company.

In addition, Minnegasco has funded studies by the Midwest Research Institute on socioeconomic effects and by Dynatech R/D Company on biological conversion and cooperated with various other efforts. In all, Minnegasco has spent over 1.5 million dollars on peat research.

On April 25, 1980, a proposal was submitted to DOE for a 4 million dollar feasibility study grant for a facility to produce 80 million cubic feet per day of SNG from Minnesota peat. The proposal was accepted and an award for the 3.66 million dollar grant was signed September 30, 1980 by DOE.

The study was begun on October 1, 1980 and is scheduled to be completed on April 31, 1982.

FEASIBILITY STUDY OBJECTIVES

The study is a work of effort to prove the feasibility--technical, economic, environmental, financial, and regulatory--of the design and construction of a facility to produce 80 million cubic feet per day of high Btu SNG from peat.
The basic output from the program desired by Minnegasco is proof of commercial viability—proof that is also satisfactory to the regulatory commission, the financial community, and potential consortium members. Minnegasco requires that the work be directed toward the identification of any uncertainties, risks, and constraints and toward the specification of alternative or backup approaches to overcome such possible adverse findings.

PROJECT TEAM

Management of the Feasibility Study for Minnegasco is by C. D. Applequist, Vice President of Technical Services Division and John D. Somrock, Director of Supplemental Energy Supply. Minnegasco is working with a "State of Minnesota Advisory Council" and the DOE in directing this Feasibility Study.

Work on the various tasks is being performed as follows:

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PROJECT PROGRAM
TECHNICAL TASKS

Tasks 1 & 2 - Peat Harvesting and Dewatering

Preliminary work has focused on identifying and evaluating systems and equipment available. In addition to defining these systems, this task includes developing harvesting and reclamation plans.

Task 3 - Gasification

Preliminary engineering is being defined by Dravo with continuous technical support by IGT.

Task 4 - Long-Lead Items

Identification of equipment with long delivery periods is a portion of the overall project. This will maintain a minimum time schedule.

SOCIO-TECHNICAL TASKS

Most of the effort of the study to date has been on socio-technical tasks.

Task 5 - Site Evaluation

A large area in northern Minnesota has been evaluated to identify suitable sites. This task has been completed. This work will be described in greater detail shortly by Joe Sorge of Ertec.

Task 6 - Environmental, Health, Safety and Socioeconomic Evaluation

A regulatory review was completed in March. Field monitoring of background weather and pollution was begun this month. Other subtasks are on schedule.
Task 7 - Resource Assessment

Data has largely been collected by the Minnesota Department of Natural Resources. Some additional boring and sampling has been performed to further define the peat characteristics and gather additional information on the hydrology and geology.

Task 8 - Market Analysis

This task will primarily evaluate and define markets for by-products from the proposed facility.

Task 9 - Economic and Financial Risk Assessment

This task will develop the cost of producing SNG from peat with associated sensitivity analyses, financial risk analyses, and commercial viability.

MANAGERIAL TASKS
Task 13 - Project Management

Minnegasco, as a cost-sharing contribution to the project, is supplying senior management personnel to coordinate and manage the overall effort.

Task 12 - Management Structural Support

The systems for controlling the project have been defined to ensure a level of management necessary for proper, cost-effective functioning of the project. This task also includes continuous monitoring of the project.

Task 11 - Technical Support

This task provides the program with a review of all technical efforts.
Task 10 - Management Plants for Project Continuation

This task will define the work necessary to continue the overall project after this feasibility study phase.

CONCLUSIONS

The results of this feasibility study, when completed, should provide all the data necessary for decisions by Minnegasco, the State of Minnesota, and the Federal government relative to continuing commercialization of peat gasification. Although it is still early in the effort, the preliminary results have so far been encouraging.
QUESTIONS AND ANSWERS

Q: How large a site did you select for the plant, where did you select it, and why?

A: We selected an area of 400,000 acres in west central Koochiching, and not all of that is peatland. We're only looking for 50 to 65,000 acres to operate that plant. The main purpose in zeroing down that site to about that size is we were looking at blocks of 200,000 acres and we wanted to try and limit our detail studies to a minimum site, a minimum area consisting of two sites. That's where we came up with a roughly 400,000 acre figure.

Q: Why has Minnegasco changed from a 250 million cubic feet per day plant to an 80?

A: This isn't a change. This is only the first stage and 80 million is the first stage of an ultimate 250 million plant. This was our plan back in 1975 when we first made our analysis.

Q: Wouldn't you need resources for the entire plant? They're going to be proximate, I assume.

A: For this portion our task is specifically to look at an 80 million plant. Eventually a wider area would have to be looked at.

Q: Could you tell me if you lined or cased your water wells down to the depth that you sampled from and what were the specific parameters you looked for in this hydrological impact?

A: The wells were sealed to sample water at various levels, some below the peat, some in the peat, at various depths.
As far as what specific parameters we're looking for to determine the hydrology of the area, basically we're starting out with a very limited program to look at the water quality that exists and to determine the way the drilling program was established. The idea was to determine if we can track ground water flow through water chemistry but I can't really give you the specifics of that.

Q: Were you using dye tests for horizontal movement?

A: No. We haven't used any dye tests so far. That may be part of the later studies but that hasn't been determined. We're waiting for the initial feedback from the field program before we define what the ultimate study looks like. There are very little data available up there in that area on hydrolysis, so we're really starting that one at a very preliminary stage.

Q: Assuming there is no pipeline near Koochiching County, are you including a pipeline for the product from the plant to the nearest station? How do you get the product out?

A: At this point we're not including a pipeline. The pipeline was not included in the feasibility study. That would require a separate environmental study and so forth for the pipeline. Tentatively we would need approximately a 150 mile pipeline to connect in with our other natural system that would be big enough to handle the gas from the plant. So it isn't a very large one.
Q: I understand that you have made a preliminary analysis of various Federal regulations, and I was wondering if you can say whether peat harvesting and land reclamation would fall under the surface mining act on reclamation?

A: That can't be determined from a regulatory review at this point. At the present time Minnesota has not defined their legislative peat program, which will certainly go a long way to defining that question. What we've done in defining what our regulatory requirements are is to take a look at things like surface mining requirements and several others and come up with what we consider a reasonably pessimistic regulatory framework.

The feeling is if we can meet that framework then we can meet whatever turns out to be the actual regulatory requirements.

Q: I have 2 questions on the harvesting and dewatering study by Dravo.

1. Where does this stand as far as closing in on completion?
2. Is the study looking at 80 million standard cubic feet per day or 250 million standard cubic feet per day?

A: The feasibility study is for an 80-million cubic foot per day plant. It had to be specific to the guidelines of the proposal on it. On the plans and the scope of the site evaluation, we are looking for blocks of 200,000 acres of peat 7 foot deep which would support a 250 million plant for 20 years.

The reason we use 20 years now is that that is the maximum usable life that you would have on a lease under present Minnesota law. The maximum is 25 years and by the time you got a lease and started using it, you'd only have 20 years left.
The other question on the mining and dewatering, Dravo is doing that work. They are investigating all phases of harvesting peat, mining peat, whichever term you prefer to use. They are investigating all methods, evaluating all methods of dewatering. They are basically looking at one-pass mining or harvesting rather than taking off a half-inch layer at a time as you would with milled peat by the European technology.

We consider that that would be necessary to get by with the environmental permitting required by the State of Minnesota. In other words, we don't think that we would be able to use the mill peat mining technique, say, on 50,000 acres and, by the way, you couldn't mill that much peat on 50,000 acres in Minnesota weather. It would take a larger area to be able to mill that much, even for an 80-million cubic foot per day plant.

So we're looking at a one-pass system. It could be hydraulic or it could be, as is mining, the whole depth that you're planning to take off the bog.

Q: When you were speaking about the extent of the deposits, you said you'd reduced it from 7 million originally to 6 million and then spoke about complying with the 5-foot depth requirement. I didn't get the amount that that reduced it to.

A: We didn't reduce it from 7 to 6, that's the latest. As I mentioned, the DNR is really conducting the drilling survey and they've downgraded the numbers from the original 7.2 to 5.96 million. In dropping down, we were designated to remain within essentially a 5-county area. The available peat in that area is about 1.8 million acres. Then in dropping down to peat with depth greater than 5 feet that drops down further to about 3-quarters of a million, within that 5-county study area. It's not for the entire state.
Q: In Minnesota, is peat included in the normal definition under mineral leases, in leases from the state?

A: We consider it a surface interest in the state but the leasing process is identical with that of mineral resources.

Q: Under existing leases, is peat considered to be included in the normal minerals lease, those that already, let's say, predate the present? Does the legal definition of "minerals" include peat?

A: No, not in our state.
ENVIRONMENTAL SITING CRITERION FOR ALTERNATE FUELS FEASIBILITY STUDY

by

Joseph M. Sorge, Ertec Atlantic, Inc.

Presentation Department of Energy
April 29, 1981
INTRODUCTION

In 1980, the Minnesota Gas Company (Minnegasco) submitted a proposal to the U.S. Department of Energy (DOE) entitled "A Feasibility Study - High Btu Gas from Peat." The proposal covered a feasibility study to assess the overall viability of designing, constructing, and operating a commercial facility for the production of high-Btu substitute natural gas (SNG) from Minnesota peat. On September 30, 1989, Minnegasco was awarded a grant by the Department of Energy to perform the proposed study. To complete the study, Minnegasco assembled a project team having a wide range of expertise. In addition, the State of Minnesota will participate in some parts of the study in an advisory capacity. The items to be investigated by the project team during the feasibility study include peat harvesting, dewatering, gasification process design, economic and risk assessment, site evaluation, environmental and socioeconomic matters.

Prior to undertaking a commitment for the construction and operation of a commercial facility for the production of SNG from peat, Minnegasco must have proof of commercial viability. The goal of the feasibility study is to provide sufficient proof of commercial viability to satisfy, (a) State and possibly Federal regulatory commissions, (b) potential consortium partners, and (c) the financial community. It is anticipated that the results of the feasibility study will identify any uncertainties, risks, or constraints that may evolve during the overall project work and that the approaches necessary to overcome any possible adverse findings will be developed during the investigation.

SITE EVALUATION

Simply stated, site evaluation refers to the process of identification of one or more sites within a broad study region that exhibit most favorable characteristics for development. The methodology selected to accomplish this objective must incorporate the evaluation of hard criteria such as engineering and regulatory requirements as well as more objective concerns such as the perceptions of environmental groups and concerned members of the public. Ertec's
approach to this effort for the Minnegasco project utilized a binary mapping procedure to incorporate hard criteria followed by the use of a modified version of the Rand Corporation's Delphi technique to incorporate more objective concerns. The procedure was successfully used to screen the State designated five county study area to facilitate selection of several potential site areas. These selected areas will be examined in further detail in subsequent phases of the feasibility project.

The development of engineering siting criteria was accomplished through querying of the project team. Each team member was requested to review the minimum plant and harvesting requirements within their particular areas of expertise. Ertec consolidated these responses into a primary set of minimum engineering requirements for the gasification facility. The principal criteria identified were as follows:

1) Availability of peat
2) Availability of water
3) Availability of air quality increment

Additional hard criteria were developed based on a review of the present regulatory framework within which facility licensing would be accomplished. This task was complicated by the lack of a consistent regulatory framework governing the mining and processing of peat within either the State or Federal environmental legislative programs. Regulatory vagaries were overcome through the adoption of a conservative selection of regulatory requirements based on a comparison of peat utilization to the more clearly defined regulatory requirements imposed on coal utilization projects.

Using the hard criteria defined, Ertec utilized several sequential methodologies to identify and evaluate eligible regions and sites for a peat gasification facility in northern Minnesota. Generically, these methodologies included the application of exclusionary or binary criteria to identify eligible regions and the use of a modified Delphi procedure to determine the relative suitability of
the sites identified. By incorporating this approach, three sites were identified, based on their engineering and environmental merits. Two of these sites will be investigated further during the on-going 15-month feasibility study.

SITE EVALUATION PROCEDURE

Prior to the commencement of this program, the State of Minnesota stipulated that Minnegasco's site evaluation study was to be restricted to a five county (Lake of the Woods, Beltrami, Itasca, St. Louis, and Koochiching) study area in northern Minnesota as shown in Figure 2.1-1. Exclusionary screening or binary criteria were employed by Ertec to eliminate from further consideration land areas exhibiting readily identifiable characteristics or "fatal flaws". The criteria selected reflected major Federal and State regulations regarding the development of industrial facilities, issues of public concern, and availability of natural resources. Major categorical criteria incorporated in this screening process included elimination of:

- Developed Areas
- Cultural Activities Areas
- National Forests
- Parks
- Indian Reservations and Ceded Lands
- Areas Without Peat Resources
- Non-Attainment Areas
- Mandatory Class I Areas

Base maps showing all areas excluded from further study on the basis of each identified category were plotted and are shown in Figures 2.1-2 through 2.1-9. By overlaying these maps, as shown on Figure 2.1-10, a composite of the restrictive areas within the study region was developed. The remaining areas having no or few restrictive land uses and consisting of a minimum of 200,000 acres were considered eligible regions. A single eligible region consisting of approximately 400,000 acres, as shown in Figure 2.1-11, was identified in central Koochiching County. This region illustrated, based on the criteria employed, the most favorable characteristics for further investigation. Having identified the eligible region, two or more potential areas or sites were defined within the eligible region boundary. The identification of these sites was based on a judgmental set of criteria that exhibit favorable engineering and environmental
SITE SUITABILITY AND EVALUATION STUDY
MINNESOTA GAS COMPANY

INDIAN RESERVATIONS

LEGEND
- Indian Reservations
- Ledged Lands
- Buffer Zone
- Cities, Towns

SCALE IN MILES
0 20 40
FIG. 2.1-10

DEVELOPED AREAS

CULTURAL ACTIVITIES AREAS

NATIONAL FORESTS

PARKS

INDIAN RESERVATIONS

PEAT RESOURCES

NON-ATTAINMENT AREAS

MANDATORY CLASS I REGIONS

RESULTANT ELIGIBLE REGIONS
characteristics. The criteria used were that: the sites should be adjacent to primary roads and rail transportation but be transected by as few as possible; preferential sites should have major surface water supplies available; and each site must consist of approximately 200,000 acres to fulfill basic project requirements. Three potential areas or sites were identified using these criteria.

The three identified sites were compared in terms of environmental and social constraints or amenities using a modified Delphi technique. This procedure incorporated both the Delphi technique (issue and subissue mailings to the participants) and the nominal group technique (group participation in subissue ratings). The primary objectives of this phase of the study were to obtain a reasoned consensus among the participants on the relative importance of the issues and subissues and to use the numerical ratings to select at least two sites suitable for further investigation during the 15-month feasibility study.

The issues and subissues illustrated in Table 1 were developed through joint participation of Minnegasco, Ertec's principal investigators, the State of Minnesota, and engineering companies participating in the program. These issues and subissues were mailed to a group of individuals who had been selected and invited by Minnegasco to participate in the Delphi program. Through these mailings, participant response to them, and a meeting of many of the participants in Minneapolis on December 6, 1980, a reasoned consensus among the participants was obtained on the issue and subissue ratings.

**TECHNICAL EVALUATION**

Following identification of the various potential study area, Ertec conducted preliminary literature and site reconnaissance surveys to facilitate final site evaluation. Principal investigators were assigned to establish preliminary regional and site specific data for the areas in question. The final step of the site evaluation procedure consisted of the incorporation of the technical site information with the weighted issues of concern defined in the Delphi session. As a result, two sites were selected for potential development of the Minnegasco facility.
Table 1. Issues and Subissues

<table>
<thead>
<tr>
<th>ISSUE/SUBISSUE</th>
<th>COMMUNITY IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Levels</td>
<td>• Aesthetic Impacts</td>
</tr>
<tr>
<td>• Social Impacts</td>
<td></td>
</tr>
<tr>
<td>LAND USE</td>
<td>• Existing Land Use</td>
</tr>
<tr>
<td>• Future Land Use</td>
<td></td>
</tr>
<tr>
<td>SURFACE WATER HYDROLOGY</td>
<td>• Topography</td>
</tr>
<tr>
<td>• Waterbody Location</td>
<td>• Streamflow</td>
</tr>
<tr>
<td>• Water Quality</td>
<td>• Number of Waterbodies</td>
</tr>
<tr>
<td>• Location with Respect to</td>
<td></td>
</tr>
<tr>
<td>Drainage Basins</td>
<td></td>
</tr>
<tr>
<td>GROUND-WATER HYDROLOGY</td>
<td>• Potential for Groundwater</td>
</tr>
<tr>
<td>• Potential for Contamination</td>
<td>• Potential for Contamination</td>
</tr>
<tr>
<td>of Private or Public</td>
<td>• Availability of Groundwater</td>
</tr>
<tr>
<td>Groundwater Supplies</td>
<td></td>
</tr>
<tr>
<td>TERRESTRIAL ECOLOGY</td>
<td>• Unique Species</td>
</tr>
<tr>
<td>• Valuable Species</td>
<td>• Unique Habitats</td>
</tr>
<tr>
<td>• Valuable Habitats</td>
<td></td>
</tr>
<tr>
<td>AQUATIC ECOLOGY</td>
<td>• Unique Species</td>
</tr>
<tr>
<td>• Valuable Species</td>
<td>• Unique Habitats</td>
</tr>
<tr>
<td>• Valuable Habitats</td>
<td></td>
</tr>
</tbody>
</table>
REGIONAL CHARACTERISTICS

The potential area selected for further study lies in the central portion of Koochiching County in northern Minnesota. The area may be characterized as extremely rural, with development restricted primarily to the Route 71 corridor between Bemidji and International Falls. The local economy remains primarily dependent on forestry and the paper industry. The surficial geologic character of the area is dominated by its glacial history. Glacial lakes remaining after final glacial retreat some 12,000 years ago are primarily responsible for the subsequent accumulation of peat in the study area. Sufficient surface water resources exist within the study area to meet anticipated plant requirements. Streamflow generally peaks during spring snowmelt, which usually occurs during April, decreasing to a minimum during August. Groundwater information within the study is severely limited because of limited population and hence water yield information. Available data indicate rather poor well yields in the range of 5-10 gpm from wells drilled into the relatively imprevious sedimentary zone. From an air quality standpoint, the rural character of the study area offers sufficient PSD increment to support the proposed facility. Air quality impact analysis will be complicated by the presence of several Class I areas in the vicinity; however, the buffer zones established during the binary mapping effort are sufficient to insure protection of these areas. The results of Ertec's technical review of the potential sites were consolidated into a site technical rating for incorporation into final site ranking.

ISSUE IMPORTANCE

The results group issue ratings are shown in Table 2. As indicated, surface and groundwater were considered to be the most important issues. Community impact and land use were considered least important, and aquatic and terrestrial ecology were given intermediate ratings. The final rating is considered to be the reasoned consensus of the participants. General agreement with regard to relative importance is indicated by a marked decrease in the standard deviation noted when comparing the final ratings of those of preceding voting rounds.
### Table 2. Results of First and Second Issue Rating

<table>
<thead>
<tr>
<th>Issue</th>
<th>Mean Value of First Rating</th>
<th>Mean Value of Second Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Impact</td>
<td>5.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Land Use</td>
<td>5.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Surface Water Hydrology</td>
<td>8.1</td>
<td>8.0</td>
</tr>
<tr>
<td>Ground-Water Hydrology</td>
<td>7.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Terrestrial Ecology</td>
<td>6.1</td>
<td>4.7</td>
</tr>
<tr>
<td>Aquatic Ecology</td>
<td>6.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>
Site ratings for the subissues were developed by Ertec's principal investigators before and during the Delphi session. These ratings were based on regional and site specific data described earlier in this report. The ratings were made in terms of relative values using a 0 to 3 scale in which 0 indicates that, for the given subissue, the site is unsuitable for development, 1 indicates that it is suitable but has no exceptional amenity with respect to the subissue, 2 indicates greater suitability than 1, and 3 indicates exceptionally high suitability in terms of the particular subissue. The results of the site ratings are shown in Table 3. In summary, sites suitable for further feasibility study were selected based on a binary or exclusionary screening and a detailed consideration of various issues that might affect or be affected by the proposed development of a peat gasification facility in northern Minnesota. These areas are shown in Figures 2.1-12 through 2.1-14. Because there are few really significant differences between the three sites and because data with regard to available peat resources are continuously developing as a consequence of ongoing work by the Minnesota Department of Natural Resources, the region shown in Figure 5.1-1 is being studied in its entirety during the ongoing 15-month feasibility studies.
### Table 3. Site Ratings

<table>
<thead>
<tr>
<th>ISSUE/SUBISSUE</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Community Impact</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Social Impacts</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Land Use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Land Use</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Future Land Use</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Surface Water Hydrology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Water Body Location</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Streamflow</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Water Quality</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of Waterbodies</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Location with Respect to Drainage Basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ground-Water Hydrology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential for Ground-Water</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Contamination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contamination of Public or Domestic Waters</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Available Ground-Water</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Terrestrial Ecology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valuable Habitats</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unique Habitats</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Valuable Species</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unique Species</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Aquatic Ecology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valuable Habitats</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unique Habitats</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Valuable Species</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unique Species</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
SINGLE—STAGE FLUIDIZED—BED GASIFICATION

Eugene J. Pyrcioch
Engineering Supervisor

Francis Lau
Assistant Director
Peat Research

Dharam V. Punwani
Associate Director
Chemical Processing Research
Institute of Gas Technology
Chicago, Illinois
BACKGROUND

IGT's PEATGAS™ process and Rockwell International's SRT process both produce hydrocarbon gases and liquids when operating at moderate temperatures and pressures. The hydrocarbon liquids produced are primarily aromatic. Both processes are directed toward synthetic natural gases (SNG) and require two reaction stages: one for hydropyrolysis and one for production of either hydrogen-rich gas (for the PEATGAS™ process) or hydrogen (for the SRT process). The bioconversion work being conducted by Dynatech R/D is also directed toward production of SNG. No work has yet been done on developing a process for the production of only medium-Btu gas from peat. The medium-Btu gas can be used directly as an industrial fuel gas, or it can be converted to SNG by catalytic methanation. It can also be converted to methanol, gasoline, or diesel fuel by commercially available technology.

OBJECTIVE

The objective of this gasification project is to conduct experiments to obtain data for the design of a single-stage fluidized-bed gasifier using steam and oxygen. The economics of converting peat to synthesis gas and to SNG by the single-stage fluidized-bed gasifier will also be evaluated.

TECHNICAL PROGRESS

The equipment used in this project is the same as that used previously, with some modifications, to investigate the gasification characteristics of chars from Minnesota, North Carolina, and Maine peats. In these tests, the solids were screw-fed to the top of the reactor for free-fall into the fluidized bed.

The equipment was modified (Figure 1) so that peat can be fed directly to the fluidized bed. Peat flows by gravity from the feed hopper through the 6-inch line to the screw conveyor housing. From there it is screw-fed to the tee-section, where it is fluidized with nitrogen in the annulus between the tee-section walls and the standpipe (1.5 inches OD and 1.4 inches ID) for discharging
Figure 1 Schematic Diagram of Single-Stage Fluidized-Bed Peat Gasifier
solids to the residue receiver. Internal modifications to the reactor include a lower gas distributing ring for feeding nitrogen to fluidize and lift the peat into the reactor annulus and an upper feed gas distributing ring for feeding steam and oxygen. The peat is fed into the standpipe by overflowing from the bed around the standpipe. Therefore, in addition to discharging residue from the bed, this standpipe controls the bed height automatically. Gasification of the peat takes place in the annulus formed by the standpipe and the inside wall of the reactor (6.4 inches ID).

A total of 15 tests have been made in the high pressure PDU. A summary of the test results is tabulated in Table 1. More detailed results are presented in the Monthly Status Reports titled "Experimental Program for the Development of Peat Gasification." Thirteen tests have been conducted with Minnesota peat and two tests have been conducted with Maine peat. Table 2 summarizes the operating ranges that were covered during these tests. During the course of the initial tests, it was found that a negligible amount of steam was converted during gasification. Therefore, starting with Run BF-10, no steam was added to the reactor for the remaining tests with Minnesota peat. Complete results through Run BF-10 have been published.

Some preliminary observations can be made concerning the results obtained to date. Increasing the oxygen-to-carbon feed rate increases the carbon gasified. For feed peat containing a relatively high moisture content (greater than about 20 weight percent), increasing the gasification temperature from about 1620° to 1725°F does not significantly increase the carbon gasified (Figure 2). However, the peat containing low moisture content (less than about 10 weight percent) increasing the gasification temperature does increase the amount of carbon gasified.
Table 1. Operating Results of Single-Stage Fluidized-Bed Gasification Tests

<table>
<thead>
<tr>
<th></th>
<th>TOTAL CARBON CONVERSION, %</th>
<th>70 - 94</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS YIELDS, % OF FEED CARBON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1 and C2</td>
<td>3 - 11.8</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>7.5 - 35.8</td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>26.5 - 76.6</td>
<td></td>
</tr>
<tr>
<td>(CO + H2)/4</td>
<td>1.2 - 13.0</td>
<td></td>
</tr>
<tr>
<td>C6H6</td>
<td>0.2 - 2.0</td>
<td></td>
</tr>
<tr>
<td>OIL</td>
<td>0.4 - 3.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Operating Ranges for Single-Stage Fluidized-Bed Gasification Tests

<table>
<thead>
<tr>
<th></th>
<th>Temperature °F</th>
<th>Pressure Psig</th>
<th>Steam/Carbon Mole Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1570 - 1765</td>
<td>250 - 530</td>
<td>0 - 3.6</td>
</tr>
</tbody>
</table>
Figure 2 Effect of Temperature on Carbon Gasified in Single-Stage Fluidized-Bed Gasifier
FUTURE WORK

All remaining tests will be conducted with no steam addition to the reactor. The reactor will be operated at pressures ranging from 125 to 500 psig, temperatures from 1600 to 1800°F, and peat feed moisture of about 20%. Data generated with the three peat feedstocks (Minnesota, Maine, and North Carolina) from the PDU will be analyzed and a kinetic correlation will be developed. Process concepts and economic evaluations will be conducted on the conversion of peat to SNG and synthesis gas by the single-stage fluidized-bed gasifier.
QUESTIONS AND ANSWERS

Q: What is the approximate residence time in your fluidized-bed experiments?

A: About 25 minutes.

Q: We just had a couple of senior student groups from the University of Pennsylvania doing their senior plant design project and, of course, they relied heavily on the data that you had gotten before in your previously proposed designs. Their design was based on the two-stage process because they felt that the benzene was a very valuable product. In fact, I think they found that more than half of the profits came from the benzene rather than from the natural gas.

Do you think this has any chance of being a more economically viable process?

A: I should have spent a little more time when I was comparing two-stage with the single-stage in comparing the product differences. Although the byproducts produced in a two-stage gasification system are valuable, there is a segment of the market that might need methanol. In order to make methanol from a two-stage system you have to handle a lot of byproduct aromatics, and some companies might not like to get into that kind of business. This is not to say that the single-stage process has more potential compared to a two-stage, but it does serve a different segment of the market that is interested in making a single product and not in getting into the business of marketing many types of byproducts. I know there are companies who would not like to get into marketing all kinds of byproducts even though they are valuable.

COMMENT: I might say that this is a very perceptive comment. We have done a lot of economic analysis of processes and we find that the major factor in reducing the cost of gas is the amount of benzene you make for a very simple reason: the Btu value of benzene is more than double the Btu value of any other product that you make in the conversion process.
Benzene now is selling for $1.97 a gallon, which translates into $15 per million Btu, whereas, all the other products, the light oils, the heavy oils, the gas, sell for around $5, $6 per million Btu.

You don't have to be a mathematical genius to realize that if you have a process that makes 15 or 16% of your Btu as benzene, you'll wind up reducing the cost of gas by more than a dollar per million Btu.

There is an almost insatiable market for benzene. We use about 2 billion gallons a year in this country. It's the sixth largest used chemical and the second largest organic chemical. The only one that sells in greater volume is ethylene. It's used both in the manufacture of synthetic fibers and plastics. We have contacted companies like Dow Chemical who are desperate for a long-range, dedicated source of benzene and found that they will buy the output of any plant, if they could get a long-term contract, 20 to 30 years, for supply.
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PEAT GASIFICATION

Joeeph Friedman
Program Manager, Peat Hydrogasification Program
Rockwell International
The abundance of peat in the United States as a large potential fuel resource is a challenge to the technical community engaged in the research and development of fossil energy conversion processes. As peat can be considered to be a very young coal, it is natural that we look to the large body of existing coal conversion technology as a starting point for developing peat conversion processes. It is generally accepted that the direct hydrogenation of solid carbonaceous feed stocks is an efficient route for SNG production. This is illustrated in Figure 1, which is taken from the work by H. R. Linden and shows the two major routes to convert coal to SNG. The first is the classical syngas route where all the carbon in the coal is converted into a mixture of carbon monoxide and hydrogen and subsequently methanated. In the second route, about half of the carbon in the coal is directly reacted with hydrogen to form SNG, and the other half is reacted with steam and oxygen to provide the hydrogen for the direct hydrogasification step.

The ideal process thermal efficiencies are listed in the figure for no heat recovery and for complete heat recovery. For either assumption, the figures show that direct hydrogasification would require 20% less coal (or peat) throughput to make SNG. This is one of the prime motivations for a strong continuing interest in hydrogasification: the capability of saving up to 20% of the process feed stock.

Rockwell became involved in peat hydrogasification process development as a result of its existing program in coal hydrogasification. Perhaps a brief review of the Rockwell Coal Hydrogasification Reactor would be in order. Figure 2 is a schematic presentation of the reactor, which is derived from aerospace rocket reactor technology. A rocket-type injector sprays impinging jets of pulverized coal and hot hydrogen, at about 2000°F, into the reactor. Rapid mixing followed by rapid reaction occurs, and within a few seconds, SNG and other products are formed. It is desirable to inject the pulverized coal or
FIGURE 1

IDEAL GASIFICATION PROCESS THERMAL EFFICIENCIES*

<table>
<thead>
<tr>
<th></th>
<th>WITHOUT HEAT RECOVERY</th>
<th>WITH HEAT RECOVERY</th>
</tr>
</thead>
<tbody>
<tr>
<td>COAL + O₂ + H₂O</td>
<td>55.9%</td>
<td>75.4%</td>
</tr>
<tr>
<td>SYNGAS → METHANE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COAL + H₂</td>
<td>67.5%</td>
<td>90.5%</td>
</tr>
<tr>
<td>METHANE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHAR + O₂ + H₂O</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*LINDEN, H.R. CHEM ENG PROG SYMPOSIUM NO. 54, VOL 61 (1965)
ROCKWELL FLASH HYDROPYROLYSIS REACTOR

REACTOR CONCEPT
SHORT RESIDENCE TIME SYSTEM WITH RAPID MIXING AND REACTION FOLLOWED BY RAPID QUENCH

FEATURES
- RELIABLE — NO MECHANICAL INTERNALS
- MAINTAINABLE — VERY COMPACT, ACCESSIBLE
- OPERABLE — STABLE, QUICK STARTUP
- VERSATILE — ALL FOSSIL FUELS
- FLEXIBLE — LIQUEFACTION OR HIGH-Btu GASIFICATION
- EFFICIENT — HIGH PROCESS THERMAL EFFICIENCY
- ECONOMICAL — NO CATALYST
peat with a minimum of carrier gas in order to minimize the amount of heat the hot hydrogen has to carry into the reactor. This is accomplished by dense-phase feeding, a technique developed at Rockwell that allows the transport of pulverized coal or peat with just enough carrier gas to fill the interstices between the coal particles.

The short reactor residence time is extremely important. Figure 3 indicates the dramatic effect of residence time on reactor size. Thus the development of the short-residence-time (SRT) Rockwell hydrogasification process promises both high thermal efficiency and compact, low-cost reactor hardware.

The major objectives of the DOE-sponsored peat hydrogasification program are shown in Figure 4. Figure 5 shows the envelope of reactor temperatures and pressures encompassed in Rockwell testing and compares it with previous testing at IGT. It is also noteworthy that the Rockwell reactor throughputs were 100 to 1000 times higher.

Figures 6 and 7 show the experimental system used for performing the peat dense-phase feeding studies. Peat is first loaded into the loading feeder and then transported into the feeder tank. Once the feeder tank has been filled with a sufficient charge of peat, the feeder tank is pressurized and its ball valve is opened. The peat then flows through a 2-in. line reducer, the test line itself, and then into a receiver tank. This system is rated for solid feed rates up to 1 T/hr at pressures to 150 psi. The peat flow rates are determined from the load cell and pressure measurements taken on the receiver tank, while carrier gas flow rates are found from the feeder tank pressure and nitrogen pressurant flow measurements.

Typical dense-phase flow engineering data are shown in Figures 8 through 11. It is noted that the data exhibit the classical exponential relationship between mass flux and pressure drop, i.e., a straight-line relationship when plotted on log-log paper. The data are for two line sizes, two moisture contents, and two reducer fittings.
FIGURE 3

200 TPH (1000 psi)

REACTOR SIZE vs

RESIDENCE TIME

Rockwell International
Energy Systems Group
FIGURE 4

ROCKWELL PEAT HYDROGASIFICATION PROGRAM

- EXTEND PEAT HYDROGASIFICATION DATA BASE
- DEVELOP DENSE PHASE FEEDING ENGINEERING DATA
- ANALYTICALLY MODEL REACTOR PERFORMANCE
- PRELIMINARY EVALUATION OF PEAT PROCESS ECONOMICS
FIGURE 5
PEAT HYDROGASIFICATION DATA ENVELOPES

![Graph showing peat hydrogasification data envelopes]
FIGURE 6
DENSE PHASE FLOW FACILITY

FEEDER TANK
LOAD CELL
RECEIVER TANK
LOADING FEEDER
LINE REDUCER
FIGURE 7
SIMPLIFIED FLOW DIAGRAM OF 1 TPH LOW PRESSURE FEED SYSTEM FOR DENSE-PHASE FLOW STUDIES

NITROGEN

LOADING FEEDER

PEAT

FEEDER TANK ~150 psi

GN2 METERING ORIFICE

TEST LINE

LINE REDUCER

LOAD CELL

NITROGEN PRESSURANT

REGULATOR

BACK-PRESSURE REGULATOR

VENT

RECEIVER TANK

DUMP

Rockwell International
Energy Systems Group

80-M4-26-1A
FIGURE 8
TEST LINE PRESSURE GRADIENT AS A FUNCTION OF PEAT SOLIDS MASS FLUX IN A 3/8-in. OD TUBE

BASIS:
TEST LINE 0.305 in. ID
DATA POINTS
○ PEAT 9.6 wt % MOISTURE
FIGURE 9
TEST LINE PRESSURE GRADIENT AS A FUNCTION OF SOLIDS MASS FLUX IN A 1/2-in. OD TUBE

BASIS:
TEST LINE 0.402 in. ID
DATA POINTS
△ PEAT 9.6 wt % MOISTURE
□ PEAT 15.5 wt % MOISTURE
FIGURE 10
LINE REDUCER DROP AS A FUNCTION OF SOLIDS MASS FLUX FOR A 305-in. ID TUBE

BASIS:
DIAMETER REDUCTION
1.780-0.305 in. ID
DATA POINTS
○ PEAT 9.6 wt % MOISTURE
△ PEAT 15.5 wt % MOISTURE
FIGURE 11
LINE REDUCER PRESSURE DROP AS A FUNCTION OF SOLIDS MASS FLUX FOR 0.402-in. ID TUBE

BASIS:
DIAMETER REDUCTION
1.780-0.402 in. ID
DATA POINTS
△ PEAT 9.6 wt % MOISTURE
□ PEAT 15.5 wt % MOISTURE

Rockwell International
Energy Systems Group
A flow diagram of the Rockwell engineering-scale hydrogasification test facility is shown in Figure 12. The reactor is a thin-walled metal cylinder housed within a pressure shell. The space between the reactor wall and pressure shell is insulated to minimize reactor heat loss. This design results in near-adiabatic operation of the reactor with balanced pressures across the reactor wall. Figure 13 shows the insulated reactor being lowered into the pressure shell in preparation for a test. Figure 14 shows an injector used in the testing. Four streams of heated hydrogen impinge on a central stream of dense-phase-fed pulverized peat with the option of injecting additional oxygen through four orifices.

An average proximate and ultimate analysis of the peat feedstock used for this reactor testing effort on a dry basis is shown in Table 1. The actual peat used had moisture contents between 9.21 and 17.60 wt%.

In correlating the experimental results from the hydrogasification test program, a simple peat hydrogasification reactor kinetic model was developed based on earlier analytical efforts of other researchers. A schematic representation of this kinetic model is shown in Figure 15. This analysis uses the devolatilization concept developed by Anthony et al. (Reference 1), which states that pyrolysis proceeds through a large number of multiple parallel reactions that, produce volatiles and rapid-rate carbon. The rapid-rate carbon in turn follows the analysis of Zahradnik and Glenn (Reference 2), which allows the rapid-rate carbon to either react with hydrogen, producing hydrocarbon gases plus char, or to simply cross-link and form char. The result of this derivation shows that carbon or moisture ash-free (MAF) conversion, $\eta$, is given by the equation shown in Figure 16,

where

$\eta$ = carbon or MAF peat conversion

$T$ = peat particle temperature, (K)

$t$ = time, (S)

$R$ = universal gas constant, (J/mol-K)
FIGURE 12
FLOW DIAGRAM OF THE 3/4-TPH ENGINEERING SCALE TEST FACILITY

COAL LOADLING FEEDER

HIGH PRESSURE COAL FEEDER (180 gal.)

N2

COAL

HIGH PRESSURE WATER TANK 600 gal.

O2

H2 HEATER (ELECTRICAL)

TO ON-LINE GAS CHROMATOGRAPH

12-in. DIAMETER REACTOR SHELL 500-1500 psi 1400-2000°F

12-in. DIAMETER CYCLONE REACTOR SHELL 500-1500 psi 1400-2000°F

QUENCH

CONDENSATE RECEIVER

CONDENSATE SEPARATOR (10 gal.)

GAS SAMPLES

FLARE

OFIFICE

BACK PRESSURE REGULATOR

CONDENSATE RECEIVER

V-305

V-265

V-976

150 gal.

360 gal.

12 gal.

600 gal.

V-305

~600°F

H2

ROCKWELL INTERNATIONAL

Energy Systems Group

79-N20-36-10A
FIGURE 13
PHOTOGRAPH OF 3/4-TPH HYDROGASIFICATION REACTOR – INJECTOR ASSEMBLY BEING LOWERED INTO REACTOR PRESSURE SHELL
FACE VIEW OF THE FIRST 3/4-TPH HYDROGASIFIER INJECTOR TESTED
# TABLE 1
PROXIMATE AND ULTIMATE ANALYSIS OF THE MINNESOTA PEAT TESTED

<table>
<thead>
<tr>
<th>ANALYSIS</th>
<th>DRY BASIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROXIMATE ANALYSIS</td>
<td></td>
</tr>
<tr>
<td>wt % ASH</td>
<td>14.84</td>
</tr>
<tr>
<td>wt % VOLATILE</td>
<td>58.16</td>
</tr>
<tr>
<td>wt % FIXED CARBON</td>
<td>27.00</td>
</tr>
<tr>
<td>ULTIMATE ANALYSIS</td>
<td></td>
</tr>
<tr>
<td>wt % CARBON</td>
<td>50.15</td>
</tr>
<tr>
<td>wt % HYDROGEN</td>
<td>5.14</td>
</tr>
<tr>
<td>wt % NITROGEN</td>
<td>2.29</td>
</tr>
<tr>
<td>wt % CHLORINE</td>
<td>0.06</td>
</tr>
<tr>
<td>wt % SULFUR</td>
<td>0.17</td>
</tr>
<tr>
<td>wt % ASH</td>
<td>14.84</td>
</tr>
<tr>
<td>wt % OXYGEN</td>
<td>27.35</td>
</tr>
<tr>
<td>HIGHER HEATING VALUE (Btu/lbm)</td>
<td>8,469</td>
</tr>
</tbody>
</table>
FIGURE 15

KINETIC MODEL FOR PEAT HYDROGASIFICATION

- PEAT → VOLATILES + CHAR + RAPID RATE CARBON

- MULTIPLE PARALLEL DEVOLATILIZATION REACTIONS

- HYDROCARBON GASES + CHAR

- k_2 \cdot P \cdot H_2

- k_3

Rockwell International
Energy Systems Group
DATA POINTS
○ ROCKWELL 1/4 AND 3/4 TPH REACTORS
□ IGT COIL TUBE REACTOR
△ CITIES SERVICE COIL TUBE REACTOR

\[ \eta = \left[ V^* + \frac{C^*}{\left(1 + \frac{1}{bP_{H_2}}\right)} \right] \int_0^\infty \left[ 1 - \exp \left( - \int_0^t k_o \exp \left( \frac{-E}{RT} \right) \, dt \right) \right] \exp \left( \frac{-(E-E_0)^2}{2\sigma^2} \right) \, dE \]
In this equation, conversion, \( \eta \), is determined from the particle temperature-time history and hydrogen partial pressure. There are six model parameters whose values are calculated from actual experimental data; these parameters are defined in Table 2.

The integral carbon conversion data from four separate hydrogasification test reactors were used in determining the model parameters of the equation. These four test reactors and facilities were the Rockwell International 0.25-T/hr entrained-flow reactor, the Institute of Gas Technology (IGT) coiled tube reactor, the Cities Service coal tube reactor, and the Rockwell International 0.75-T/hr entrained-flow reactor of this current study. A total of 48 reactor data points were fitted to the equation using a least-squares, nonlinear, computer curve-fitting routine. The results of this operation can be seen with the values reported for the model parameters shown in Table 2 on both a carbon and MAF peat conversion basis. It should be noted that \( K_0 \) was held constant at \( 1.67 \times 10^{13} \text{ s}^{-1} \), due to the earlier work of Pitt\(^3\), and that \( C^* = (100-V^*) \) was assumed during the computer correlation. The value of \( K_0 \) from Pitt was assigned since this value is consistent with transition state theory.\(^4\)

Letting \( (C^* + V^*) = 100\% \) was added mainly as a convenient simplification because, when this constant was not imposed, the computer solution found \( C^* \) plus \( V^* \) to equal approximately 100\% for the two cases.

A comparison between the model predictions of overall carbon conversion for the experimental conditions of each test point and the experimental results is shown in Figure 16 for carbon conversion. As seen from this figure and Table 2, the model predictions are in excellent agreement with the experimental data: the standard deviations between predicted and experimental values are only 4.3 and 3.7 wt\% for the carbon and MAF peat conversions, respectively. Rockwell's, IGT's, and Cities Service's data mesh very nicely over conversions ranging from 40\% to 85\% for carbon and 45\% to 90\% for MAF peat with about the same degree of scatter. This modeling equation provides a consistent correlation for the experimental data within ranges of operating conditions as follows: reaction temperatures from 850 to 1850°F, hydrogen partial pressure from 0 to 1500 psig, and reaction residence times from 0.50 to 7.7 sec.
### TABLE 2

**MODEL PARAMETERS FOR PEAT HYDROGASIFICATION**

<table>
<thead>
<tr>
<th>MODEL PARAMETERS</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) $k_0$, FREQUENCY FACTOR OF ALL PYROLYSIS REACTION ($s^{-1}$)</td>
<td>$1.67 \times 10^{13}$</td>
<td>$1.67 \times 10^{13}$</td>
</tr>
<tr>
<td>2) $E_0$, MEAN ACTIVATION ENERGY OF ALL PYROLYSIS REACTIONS ($J/mol$)</td>
<td>$2.10 \times 10^5$</td>
<td>$1.88 \times 10^5$</td>
</tr>
<tr>
<td>3) $\sigma$, STANDARD DEVIATION OF ACTIVATION ENERGY DISTRIBUTION ($J/mol$)</td>
<td>$8.43 \times 10^5$</td>
<td>$7.08 \times 10^4$</td>
</tr>
<tr>
<td>4) $V^*$, ULTIMATE PYROLYSIS VOLATILE YIELD (wt %)</td>
<td>68.9</td>
<td>75.8</td>
</tr>
<tr>
<td>5) $C^*$, ULTIMATE RAPID RATE CARBON YIELD (wt %)</td>
<td>31.1</td>
<td>24.2</td>
</tr>
<tr>
<td>6) $b$, RATIO OF HYDROGENATION AND DEPOSITION RATE CONTANTS ($Pa^{-1}$)</td>
<td>$2.39 \times 10^{-7}$</td>
<td>$1.71 \times 10^{-7}$</td>
</tr>
<tr>
<td>7) STANDARD DEVIATION OF MODEL CORRELATION (wt %)</td>
<td>4.3</td>
<td>3.7</td>
</tr>
</tbody>
</table>
In Figure 17, a plot of total carbon conversion vs reactor temperature is shown for a number of hydrogen partial pressures used in Rockwell and IGT experiments. The curves drawn through the data points are given by the equation, with the modeling parameters used shown in Column A of Table 2. As seen in Figure 17, the analysis does adequately predict total carbon conversion and shows the dependence of conversion on temperature and hydrogen pressure in the moderate residence time range of 1-8 sec.

Process design studies and cost estimates were made for three different flash hydropyrolysis (FHP) plants producing approximately 250 billion Btu's of SNG per day from a Minnesota peat by the Cities Service/Rockwell (CS/R) hydrogasification process. The plants are self-sufficient, generating all steam and power from the peat. The peat is supplied to the site with a 50% moisture content. It was seen in this study that benzene coproduction significantly reduces gas cost. A summary of these results is shown in Figure 18.

DESIGN CONFIGURATIONS AND PROCESS DESCRIPTION

All plant configurations are based upon hydrogasifier performance obtained in two test runs conducted at the Rockwell 0.25-T/hr and 0.75-T/hr facilities. The first hydrogasifier test used in this study was Run 300-047 from the 0.25-T/hr test facility, while the second test used was Run 318-049 from this current study. Reactor operating conditions and performance for these two runs are shown in Table 3. The first two plant configurations studied were based upon Run 300-047, which was operated at a hydrogasifier pressure of approximately 500 psig, a reaction temperature of 1692°F, and a relatively high weight ratio (0.529) of hydrogen gas to peat. This test used the preburner method of injection in which hydrogen and oxygen are reacted in a separate upstream chamber to obtain a gas temperature of approximately 2000°F prior to mixing with peat in the reactor. The hydrogen supply to the hydrogasifier is primarily obtained by cryogenically separating hydrogen from the main process stream and recycling it. However, a small portion (approximately 5.1%) of the hydrogen gas feed must be generated in a separate process.
FIGURE 17
TOTAL PEAT CARBON CONVERSION AS A FUNCTION OF REACTOR TEMPERATURE AND HYDROGEN PARTIAL PRESSURE

HYDROGEN PARTIAL PRESSURE
- 90 atm
- 60 atm
- 40 atm
- 0 atm

TODAY TOTAL CARBON CONVERSION (%)

AVERAGE REACTOR TEMPERATURE (°F)
800 1000 1200 1400 1600 1800 2000

HYDROGEN PARTIAL PRESSURE
- 90 atm
- 60 atm
- 40 atm
- 0 atm

TODAY TOTAL CARBON CONVERSION (%)
100 80 60 40 20 0

AVERAGE REACTOR TEMPERATURE (°F)
800 1000 1200 1400 1600 1800 2000

(RESIDENCE TIMES 1-8 seconds; CURVES SHOWN FROM EQUATION 10 WITH THE PARAMETERS OF COLUMN A IN TABLE 2)
FIGURE 18

KEY RESULTS

• THREE CS/R PROCESSES VARIANTS STUDIED
  ▪ PREBURNER/OXYGASIFIER
  ▪ PREBURNER/METHANE REFORMING
  ▪ O₂ FACE INJECTION/OXYGASIFIER
• BENZENE COPRODUCTION REDUCES GAS COST
## Table 3

### Reactor Test Conditions for Economic Study

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Preburner</th>
<th>O₂ Face Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>1692</td>
<td>1812</td>
</tr>
<tr>
<td>Pressure (psig)</td>
<td>497</td>
<td>736</td>
</tr>
<tr>
<td>H₂/Peat (lbf/lbf)</td>
<td>0.529</td>
<td>0.171</td>
</tr>
<tr>
<td>Residence time (s)</td>
<td>1.32</td>
<td>3.31</td>
</tr>
<tr>
<td>Peat moisture (wt %)</td>
<td>9.40</td>
<td>9.21</td>
</tr>
<tr>
<td>Carbon Conversions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wt % to C₆H₆</td>
<td>10.2</td>
<td>6.5</td>
</tr>
<tr>
<td>wt % to C₇H₈</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>wt % to CH₄</td>
<td>38.7</td>
<td>34.8</td>
</tr>
<tr>
<td>wt % to CO</td>
<td>24.1</td>
<td>28.2</td>
</tr>
<tr>
<td>wt % to CO₂</td>
<td>1.5</td>
<td>3.7</td>
</tr>
<tr>
<td>wt % to C₂H₄</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>wt % to C₂H₆</td>
<td>1.9</td>
<td>0.9</td>
</tr>
<tr>
<td>wt % total</td>
<td>76.6</td>
<td>74.3</td>
</tr>
</tbody>
</table>
The first plant design shown in Figure 19 and based on Run 300-047 uses a partial oxidation gasifier to generate the makeup process hydrogen. Here, char and peat are reacted with 1000°F steam and 309°F oxygen (Figure 19, Section 1400) to generate a synthesis gas. This synthesis gas is further processed in a Co-shift reactor (Section 1500) which reacts 97% of the available CO with steam to hydrogen. The acid gases (CO₂ and H₂S) are subsequently removed from this makeup hydrogen stream through the use of water and MEA scrubbers (Section 1600). The makeup gas containing 96.4% hydrogen is then combined with the cryogenically separated recycle hydrogen stream (containing 99.6% hydrogen), compressed from 435 psig to 530 psig and preheated to 1500°F prior to injection into the hydrogasifier.

The second plant design, also based on Run 300-047, uses a steam-methane reforming process for generating the makeup hydrogen in which a portion of the plant product, SNG (pipeline gas), is reacted with steam at 1500°F to produce a hydrogen-rich gas as shown in Figure 20. This gas is further enriched in hydrogen by reacting 91.5% of the CO present in a shift reactor. The carbon dioxide is removed from the gas in an MEA scrubbing system (Section 1600, Figure 20) and compressed from 302 psig to 438 psig. The makeup hydrogen stream (containing 96.3% H₂) is combined with the recycle hydrogen stream (containing 99.7% H₂), compressed from 435 psig to 530 psig, and preheated to 1500°F prior to injection into the hydrogasifier.

The third plant configuration was based upon Run 318-049, which was performed with an injector that feeds oxygen directly to the hydrogasification reaction chamber through its face. This plant design, shown in Figure 21, uses a partial oxidation unit very similar to the one used in the first plant configuration of Figure 19 to produce its required makeup process hydrogen. However, in this third case, fresh peat was not required to be sent to the partial oxidation unit since more than enough char was produced in the hydrogasifier.
FIGURE 19

CASE 1
PEEBURNER/OXYGASIFIER

Rockwell International
Energy Systems Group

80-S8-91-3B
FIGURE 20

CASE 2

PREBURNER/METHANE REFORMING
FIGURE 21
CASE 3
O₂ FACE INJECTION/OXYGASIFIER
PLANT ECONOMICS

Capital Costs - All costs are stated in terms of first quarter 1980 dollars. Scaled costs were escalated in the ratio of the chemical engineering plant cost index for the first quarter 1980 to the index at the date of the study from which the costs were derived. Table 4 presents the total capital requirements for the three plant designs. The capital requirement was lowest for the face injection design (Case 3) and highest for the plant design using the CH₄ reforming process (Case 2).

Annual Plant Operating Costs - Table 5 shows the total gross and net annual operating costs for three plant designs. Peat has been valued at $0.75/MMBtu and is the major component of the gross plant operating cost. Catalyst and chemical costs were factored from other studies. All byproduct values represent market prices on July 25, 1980. Calculations are based on an annual on-stream time of 90% (7.884 operating hours). Note that the byproduct benzene credit for the methane reforming case (Case 2) exceeds the gross operating costs and results in an effective negative net operating cost.

Average Gas Cost - A comparison of average gas costs for the three plant designs is shown in Table 6. The values shown are the average gas costs over a 20-year project life based on the utility financing method with a debt-equity ratio of 75/25 and a return on equity of 15%. Other financing parameters are shown in Table 6.

SUMMARY OF TECHNICAL PROGRESS

Figure 22 shows a summary of the technical progress made to date. Reactor performance has been extended to the high carbon conversion region with a 1000-to-1 scaleup from bench-scale testing. An analytical reactor kinetic model was developed and shown to accurately predict reactor carbon conversion data: this analysis shows the consistency in the data among four separate gasification reactors.
<table>
<thead>
<tr>
<th>PLANT COSTS</th>
</tr>
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<tbody>
<tr>
<td>($MM)</td>
</tr>
<tr>
<td>CASE 1</td>
</tr>
<tr>
<td>CASE 2</td>
</tr>
<tr>
<td>CASE 3</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>OXYGEN PLANT</td>
</tr>
<tr>
<td>151.9</td>
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<tr>
<td>104.3</td>
</tr>
<tr>
<td>150.2</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>PEAT STORAGE AND RECLAIMING</td>
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<td>21.9</td>
</tr>
<tr>
<td>22.9</td>
</tr>
<tr>
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<td>CONTRACTOR CHARGE (11%)</td>
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<td>STARTUP COSTS (5% TPI)</td>
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<td>92.8</td>
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<td>73.8</td>
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<td>WORKING CAPITAL (4.56% TPI)</td>
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<td>84.7</td>
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<td>67.3</td>
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<td>2346.7</td>
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<td>1865.7</td>
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### TABLE 5
**ANNUAL OPERATING COST BREAKDOWN**

<table>
<thead>
<tr>
<th>OPERATING COSTS</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MM Dollars)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEAT ($0.75/ MM Btu)</td>
<td>152.95</td>
<td>161.18</td>
<td>150.85</td>
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<tr>
<td>CATALYSTS AND CHEMICALS</td>
<td>4.55</td>
<td>4.80</td>
<td>4.37</td>
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<td>PURCHASED WATER ($0.50/1000 gal)</td>
<td>3.04</td>
<td>2.63</td>
<td>2.57</td>
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<tr>
<td>OPERATING LABOR (75 MEN/SHIFT AT $10.00/hr)</td>
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<td>6.57</td>
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<tr>
<td>SUPERVISION (20% OF OPERATING LABOR)</td>
<td>1.31</td>
<td>1.31</td>
<td>1.31</td>
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<tr>
<td>ADMINISTRATION AND GENERAL OVERHEAD (60% OF TOTAL LABOR)</td>
<td>4.73</td>
<td>4.73</td>
<td>4.73</td>
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<tr>
<td>OPERATING SUPPLIES (30% OF OPERATING LABOR)</td>
<td>1.97</td>
<td>1.97</td>
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<tr>
<td>MAINTENANCE (3% OF TPI)</td>
<td>49.15</td>
<td>55.68</td>
<td>44.27</td>
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<td>LOCAL TAX AND INSURANCE (1.5% OF TPI)</td>
<td>24.58</td>
<td>27.84</td>
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<tr>
<td>ASH DISPOSAL ($100/Ton)</td>
<td>2.33</td>
<td>2.45</td>
<td>1.64</td>
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<td><strong>GROSS OPERATING COST</strong></td>
<td>251.18</td>
<td>269.16</td>
<td>240.41</td>
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<tr>
<td>BENZENE CREDIT ($1.55/gal)</td>
<td>147.12</td>
<td>243.12</td>
<td>111.99</td>
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<tr>
<td>SULFUR CREDIT ($53/LT)</td>
<td>0.63</td>
<td>0.65</td>
<td>0.51</td>
</tr>
<tr>
<td>AMMONIA CREDIT ($155/Ton)&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>18.03</td>
<td>26.81</td>
<td>26.98</td>
</tr>
<tr>
<td><strong>TOTAL BYPRODUCT CREDITS</strong></td>
<td>165.78</td>
<td>270.58</td>
<td>141.48</td>
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<tr>
<td><strong>NET OPERATING COST</strong></td>
<td>85.40</td>
<td>-1.42</td>
<td>98.93</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> DIFFERENT PEAT COMPOSITION USED FOR THIS CASE

<sup>(2)</sup> ALL NITROGEN IN PEAT NOT FOUND IN CHAR ASSUMED TO FORM AMMONIA
### TABLE 6

**AVERAGE GAS COST COMPARISON**

<table>
<thead>
<tr>
<th>COST BREAKDOWN(1)</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CAPITAL REQUIREMENT ($ MM)</td>
<td>2072</td>
<td>2347</td>
<td>1866</td>
</tr>
<tr>
<td>ANNUAL NET OPERATING COST ($ MM)</td>
<td>85.40</td>
<td>-1.42</td>
<td>98.93</td>
</tr>
<tr>
<td>CAPITAL CONTRIBUTION TO COG ($/MM Btu)</td>
<td>3.03</td>
<td>3.45</td>
<td>2.63</td>
</tr>
<tr>
<td>OPERATING COST CONTRIBUTION TO COG ($/MM Btu)</td>
<td>1.03</td>
<td>-0.02</td>
<td>1.16</td>
</tr>
<tr>
<td>COG ($/MM Btu)</td>
<td>4.06</td>
<td>3.43</td>
<td>3.79</td>
</tr>
</tbody>
</table>

(1) BASED ON
(a) 20-year PROJECT LIFE
(b) 20-year STRAIGHT LINE DEPRECIATION
(c) DEBT – EQUITY RATIO OF 75/25
(d) 9% INTEREST ON DEBT
(e) 15% RETURN ON EQUITY
(f) 48% FEDERAL INCOME TAX
FIGURE 22

IN SUMMARY

- REACTOR PERFORMANCE EXTENDED TO HIGH CARBON CONVERSION REGION
- 1000 TO 1 SCALE UP FROM BENCH SCALE TESTING
- ANALYTICAL MODEL ACCURATELY PREDICTS CARBON CONVERSION
- DATA CONSISTENT WITH BENCH SCALE RESULTS
- HIGH VALUE BENZENE BYPRODUCT PRODUCED
- DENSE PHASE FLOW EQUATIONS DEVELOPED
- PRELIMINARY PROCESS ECONOMICS STUDIED
The general equations describing dense-phase solids transport have been developed and now need to be correlated to experimental data. Finally, preliminary process economics have been studied showing the significant reduction in the cost of high-Btu gas when benzene is coproduced.

FUTURE WORK

A three-part program, as shown in Figure 23, is planned to continue Rockwell's work in peat hydrogasification. First, there will be a more detailed process study, which would develop a preliminary optimized conceptual process design and an economic evaluation of an optimized commercial-scale SNG-from-peat plant using the CS/R hydropyrolysis process.

Second, commercially available drying and grinding peat processes would be evaluated as candidate suppliers of peat feedstock to the Rockwell flash hydropyrolysis (FHP) reactor. Commercially prepared peat from each supplier would be tested in a high-pressure dense-phase feed system to enable selection of suitably processed feedstocks for the CS/R process.

Third, additional 3/4-TPH reactor testing will be performed at reactor parameters that will optimize the overall hydrogasification process. Replicate testing will be conducted with special attention to obtaining good material balances and identifying any and all minor constituents in the product state.

REFERENCES


FIGURE 23

PLANNED FUTURE WORK

- COMMERCIAL PLANT PROCESS STUDY
  - OPTIMIZE PROCESS AROUND PEAT'S SPECIAL PROPERTIES
    - HIGH REACTIVITY
    - HIGH OXYGEN CONTENT
    - LOWER SEVERITY REACTOR PARAMETERS
- PEAT PREPARATION AND FEEDING
- 3/4 TPH REACTOR TESTING
  - REPLICATE TESTING AT OPTIMUM REACTOR PARAMETERS
  - MATERIAL BALANCES
  - MINOR PRODUCT CONSTITUENTS
QUESTIONS AND ANSWERS

Q: What was the cost of peat that you used against those preliminary cost estimates?

A: 75¢ per million Btu was the cost of peat that we assumed.

Q: Why is 75¢ per million Btu the figure usually used?

A: The reason we used it was that other people have used the number and we wanted to have an apples-to-apples comparison with economics of other processes. For instance, when you calculate the cost of gas, you use what you call C. F. Braun methodology, which may have no relationship to reality. It's based on mid-'79 dollars, dollars per million Btu of coal. It's a common basis to compare processes. I'm assuming that the 75¢ per million Btu for peat is also that type of a number, which may not have much relationship to reality but at least gives us a constant basis for comparison.

Q: Your numbers then are just to be taken in that context?

A: Yes. Just to give a direct comparison to other process economics. We used the C. F. Braun guideline, mid-'79 dollars, utility financing to come up with an apples-to-apples comparison with other economic studies.

Q: Is it safe that the sensitivity of peat cost is the same in this process as it is in IGT's process?

A: I'm sure within data scatter it is. If you look at it, the operating costs must be similar. No matter what process you use, when you design a plant, it's going to cost around a couple of billion dollars for this throughput. The operating expenses are directly proportional to the capital require-
ments—which are much larger; they dwarf the operating costs. So there would only be a slight sensitivity to 10¢ or a quarter difference in the price of peat feedstock.

Q: But that depends on the thermal efficiency of your process. If you have a 50% thermal efficiency overall and the price of the peat goes up 25¢ per million, you're going to have to put twice as much peat in. It's going to cost you 50¢ more to make the same amount of gas.

A: Yes.

Q: So it's a pretty strong sensitivity to peat cost.

A: That's if the thermal efficiency changes. Lummus figured out the thermal efficiency on the hydrogasification process as 64%. It will be sensitive to the cost of peat but it will probably be more sensitive to the fact that your plant has to handle a larger throughput of peat if it's a lower thermal efficiency for the same product make and that would even give you a larger increment in the cost of gas than just the thermal efficiency effect.

Q: When you're doing your overall economics and looking at the plant costs, are you taking into consideration storage facilities and transport facilities, et cetera, for the benzene or just the assumption that benzene will be sold?

A: We have about $15 million in the process that's earmarked for handling the benzene after it is made, to upgrade it and get it ready for transportation.
PEATGAS PILOT PLANT STATUS

Richard Biljetina
Associate Director
Pilot Plant Engineering

Dharam V. Punwani
Associate Director
Chemical Processing Research

Institute of Gas Technology
Chicago, Illinois
BACKGROUND

The Institute of Gas Technology (IGT), under the joint sponsorship of the U.S. Department of Energy, the Gas Research Institute (GRI), the Minnesota Gas Company (Minnegasco), and the Northern Natural Gas Company, conducted over 200 peat gasification tests in laboratory-and-POU-scale equipment since 1976. Prior to that, peat gasification work was also conducted for Minnegasco during 1974 and 1975. The results of these tests are very encouraging and show that, on the basis of chemistry and kinetics, peat is an excellent raw material for the production of synthetic natural gas (SNG).

A kinetic model for peat gasification was developed from the laboratory and PDU data. Cost estimates for commercial operation based on this model show that the conversion of peat to SNG by the IGT PEATGAS process is competitive with other alternative sources of SNG. A summary of IGT's work on peat gasification since 1976 was presented at the DOE Peat Contractors' meeting in March 1980.

To further advance peat gasification technology, DOE and GRI have decided to initiate a pilot-plant-scale program using an existing coal gasification pilot plant facility. This facility, which has been operating on coal since 1971 (HYGAS program), was shut down in August 1980 to allow conversion to peat processing. A report covering the initial phases of the pilot plant modifications was given at the Second Technical Contractors' Conference in October 1980.

OBJECTIVES

The overall objectives of the program are to modify the HYGAS pilot plant and conduct peat gasification tests. Four specific tasks meet these objectives:

- Task 1 - Design, procure and install equipment for grinding, drying and screening peat at the HYGAS pilot plant facility.
• Task 2 - Design, procure, and install a lockhopper feed system capable of feeding a nominal 2 tons of peat per hour into the gasifier at pressures up to 500 psig.

• Task 3 - Equipment required for operation with peat was cleaned and repaired during the pilot plant transition period. Arrangements were made to procure and store air-dried peat.

• Task 4 - Gasification tests will be conducted in the modified pilot plant.

TECHNICAL PROGRESS

Only three major pieces of equipment, a peat dryer, a grinder, and a screener, were required to prepare the existing HYGAS coal gasification pilot plant (Figure 1) for peat processing. The modified facility will be able to convert 50 tons of peat to about 0.5 million standard cubic feet of synthetic natural gas (SNG) daily. This phase of the modification program has been completed.

The addition of a lockhopper system for feeding dry peat to the gasifier is also planned. The present pilot plant scheme uses a slurrying technique to inject feed material into the gasifier; however, certain economic advantages can be realized if dry peat is fed to the gasifier, thereby eliminating the additional heat duty of vaporizing the slurrying agent. Work on the lockhopper system is now in progress.

All transition activities associated with converting the pilot plant from coal to peat processing have been completed. Peat has been successfully dried, crushed, and screened in the new equipment, and gasifier peat flow tests using slurry feed injection have begun. A detailed discussion of each of these tasks follows.
Figure 1  IGT Fossil Fuel Gasification Pilot Plant Facility
Task 1 - Design, Procurement, and Installation of Peat Preparation Equipment

Engineering and design work for the acquisition of new drying, grinding and screening equipment was begun in April 1980. Initially this new equipment was located within the available areas of the pilot plant, emphasizing the use of existing equipment and facilities and minimizing any effect on plant operation. The latter constraint was imposed because pilot plant operations continued for the coal program during the initial construction phase. A sufficiently remote area in the coal storage yard was chosen because it allowed uninterrupted plant operation and provided an unobstructed path for peat transport to the gasifier. Figure 2 shows the location of major equipment in the feed preparation area.

Process flow sheets were prepared for the peat preparation system and specifications were issued for the following major equipment items:

a. **Drying System** - Four types of drying systems were investigated: flash, roto-louvered, single-pass rotary drum, and triple-pass rotary drum dryers. A commercial-size triple-pass rotary drum dryer, fabricated by M-E-C Company, was selected and purchased. The unit can dry 16 tons of wet peat per hour from 75% to 10% moisture. It can be turned down to intermediate moisture levels and can be converted to a single-pass dryer in one 8-hour shift. The dryer is fired with a natural gas burner (50 million Btu/hr) and is furnished complete with a raw material self-feeder, inlet and discharge screw conveyors, a cyclone collector, and a flue gas scrubber.

b. **Peat Mill** - Three types of mills (hammer, knife and cage-paktor) were tested before making a final selection. Results indicate that a hammer mill yields the best product (efficiency per pass and fines minimization). The unit, purchased from Prater Industries, is capable of accepting the screener oversize product at a maximum rate of 5 tons/hr.
Figure 2 Plot Plan of Pilot Plant Modifications
c. Screeners - The screeners were specified to provide a -10+80 mesh product feed to the gasifier. Separation of fines and oversize materials was specified at feed rates up to 15 tons/hr. Two screeners were selected from Rotex Inc.

In addition to these major items, specifications for a number of solids transport devices, as well as instrumentation, process piping, structural, foundation, and electrical requirements were prepared. Piping and instrument drawings (P&ID's) and many construction detail drawings were completed.

Construction activities began in June. A temporary feed system was designed and tested to avoid interfering with plant operations during the coal program. The existing feed ramp was removed from the proposed screener and crusher site. All site preparations were completed by mid-August.

Excavation was begun in August after the coal tests were terminated. Foundations for the equipment was erected in December followed by the installation of process, utility, and electrical services.

In January, all equipment was placed in the feed preparation structure, and fabrication of interconnecting ductwork was begun. All mechanical equipment in the drying system was checked, lubricated, and rotated and then turned over to the operating crew in February for drying tests with Minnesota peat. Final ties of the crushing and screening equipment were also completed. Figures 4 and 5 show construction activities in the feed preparation area.

Task 2 - Design, Procurement, and Installation of a Lockhopper Feed System

Engineering and design work for the acquisition of a lockhopper feed system was also begun in April 1980. Since delivery of this type of equipment was projected to be about 1 year, early efforts concentrated on system specifications and the selection of a supplier. A purchase order was placed in May 1980 with Petrocarb, Inc. to supply a lockhopper feed system capable of providing a continuous and measured flow of dry peat to the gasifier at pressures up to 500 psig.
Figure 3  VIEW SHOWING ASSEMBLED DRYER PACKAGE
Figure 4  ERECTION OF STRUCTUAL STEEL FOR THE CRUSHING AND SCREENING CIRCUIT
Figure 5  VIEW SHOWING ENCLOSED FEED PREPARATION STRUCTURE
The lockhopper system, shown in Figure 6, is comprised of two main pressure vessels, called injectors, and includes associated controls, instrumentation, and weight measurement devices. The injectors are configured to handle moist, fibrous material such as peat without feed disruptions from bridging or plugging. The storage injector is located immediately above the primary injector, and the batch transfer of feed between them occurs substantially by gravity. Transfer is automatic and does not interrupt the continuous feeding from the primary injector. Load cell systems are used in both vessels to measure the material flow rate. The load cells in the primary injector continuously monitor weight loss and accurately control the feed rate from 1 to 4 tons/hr. The system is designed so that only about 15% to 20% of the cycle time is required for peat transfer to the primary injector, thereby minimizing the time when a weight rate control system for the primary injector is not functioning. Even during this period, the feed rate is controlled by differential pressure instrumentation, which ensures the continuity of a given feed rate. A totalized weight measurement is also obtained in the feed-injector. A balanced pressure expansion joint was specified between the two injectors to maintain independent measuring capabilities between the feed-injector and primary-injector load cell systems.

In addition to the lockhopper system, IGT's staff is also designing the structural steel for the system as well as a 15-ton peat storage system upstream of the lockhoppers. The design for the lockhopper support structure foundation was completed during the summer, and the foundation for the erection of the structural steel was poured in December. Bid packages for the fabrication and erection of the support structure were completed and sent out for quotations. Three vendors were selected for a final shop evaluation, and after inspecting the fabrication shops to determine their capabilities in meeting delivery schedules and fabrication specifications, Parnell Internal Inc. was selected to fabricate and erect the support structure. The purchase requisition was forwarded for procurement approval in February 1981. Procurement action is required for the support structure and the 15-ton peat storage bin to complete this task. All other items are presently meeting schedule requirements.
16-Ton Storage Hopper

Expansion Joint

Load Cells

Storage Injector

Expansion Joint

Primary Feed Injector

Load Cells

Peat Feed

Peat to Gasifier

Nitrogen

Figure 6 Lockhopper Feed System

(Design Pressure Rating: 500 psig; Design Feed Rate: 2 tons/hr)
Engineering work continues in preparing bid packages for electrical, process and utility services. Preparation of all necessary construction drawings is also continuing.

Task 3 - Pilot Plant Transition Activities

After completion of the coal program, all coal vessels and equipment in the pilot plant were cleaned. The remaining coal in storage was transferred to a remote storage area, and a total of 2200 tons of reed sedge peat was ordered and received from the Northern Peat Company, Grand Rapids, Minnesota. This task was completed in December after storing the peat for operation during the winter months.

Task 4 - Pilot Plant Operation

After completing the mechanical shakedown of the drying system in January, drying tests with Minnesota peat (Figure 7) were started. Seven tests were completed during which peat was dried from about 70 weight percent moisture to levels as low as 5 weight percent moisture. Operating ranges during the drying tests are summarized in Table 1; data from these tests are summarized in Table 2. An initial operating curve comparing dryer flue gas temperature to product moisture content (Figure 8) was developed from these tests for the operators. This curve was used as a guide during the first reactor flow test operation. Chemical decomposition was also tested for during the drying operation; however, no significant difference between the feed and product ash content was evident. Table 3 compares ash concentrations determined by quick ash analysis in the EDC laboratory.

After completing the drying test, the screening and crushing system was commissioned in March. A typical product size distribution from the screeners is given in Table 4. Minor modifications necessary to convert the gasifier to the PEATGAS configuration (Figure 9) were also completed during this time. The refractory grid separating the steam/oxygen gasification zone from the hydrogasification zone in the HYGAS configuration was removed, forming one zone, the char
Figure 7  VIEW OF DRYER OPERATING ON MINNESOTA PEAT
Table 1. Operating Ranges for Peat Drying Tests

<table>
<thead>
<tr>
<th>Number of Tests</th>
<th>7</th>
</tr>
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<tbody>
<tr>
<td>Feed Moisture Content, wt%</td>
<td>65-70</td>
</tr>
<tr>
<td>Product Moisture Content, wt%</td>
<td>5-21</td>
</tr>
<tr>
<td>Product Rate, tons/hr</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>Dryer Exhaust Gas Temp, °F</td>
<td>195-260</td>
</tr>
</tbody>
</table>
Table 2. PEAT DRYER TEST RESULTS FOR MINNESOTA PEAT

<table>
<thead>
<tr>
<th>Description of Stream</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
<th>Peat Feed</th>
<th>Dried Peat</th>
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<td>220 -225</td>
<td>230 -250</td>
<td>260 -</td>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>3/4 3/4</td>
<td>3/3 3/5</td>
<td>3/2 3/2</td>
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<td>1130 1130</td>
<td>1300 1300</td>
<td>1630 1630</td>
<td>1430 1430</td>
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<td>1415 1415</td>
<td>1645 1700</td>
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<td>1445 1445</td>
<td>1915 1915</td>
<td>1500 1500</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Screen Analysis,* wt % on</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>+10</td>
<td>42.3 8.8</td>
<td>45.1 11.5</td>
<td>48.6 14.3</td>
<td>44.1 16.7</td>
<td>43.4 10.4</td>
<td>37.7 10.2</td>
<td>35.0 10.7</td>
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<td></td>
<td></td>
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<td>24.8 27.8</td>
<td>30.3 30.4</td>
<td>24.8 39.6</td>
<td>25.3 30.3</td>
<td>23.9 26.8</td>
<td>25.3 32.9</td>
<td>24.7 32.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>+30</td>
<td>10.2 17.0</td>
<td>7.3 17.5</td>
<td>8.5 16.9</td>
<td>8.9 11.9</td>
<td>9.2 13.6</td>
<td>10.4 18.0</td>
<td>10.1 19.2</td>
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<td>7.6 26.8</td>
<td>8.6 20.4</td>
<td>11.5 19.2</td>
<td>15.1 25.0</td>
<td>17.4 23.0</td>
<td>16.9 25.7</td>
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<td>3.6 4.6</td>
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<tr>
<td>+100</td>
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<td>1.4 3.7</td>
<td>1.2 2.5</td>
<td>2.9 3.9</td>
<td>2.1 6.2</td>
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<tr>
<td>+200</td>
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<td>0.7 1.6</td>
<td>0.8 0.9</td>
<td>1.9 0.9</td>
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<td>1.2 2.7</td>
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<td>2.5 2.6</td>
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<td>2.6 1.6</td>
<td>1.5 5.8</td>
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<td>0.3 2.3</td>
<td>0.9 1.9</td>
<td>1.1 1.1</td>
<td>2.1 3.6</td>
<td>0.5 2.7</td>
<td>0.6 3.2</td>
<td>1.0 1.4</td>
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<td></td>
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<td>100.0 100.3</td>
<td>100.0 100.0</td>
<td>100.0 100.0</td>
<td>100.0 100.0</td>
<td>100.0 100.0</td>
<td>100.0 100.0</td>
<td>100.0 100.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Material Fraction

| +10 | 42.3 8.8 | 45.2 11.5 | 48.6 13.7 | 44.1 16.7 | 43.4 10.4 | 37.7 10.2 | 35.0 10.7 |
| 10/100 | 53.9 34.7 | 51.0 82.8 | 46.9 82.7 | 50.2 73.0 | 53.6 78.9 | 59.0 81.0 | 60.0 83.2 |
| -100 | 3.8 6.5 | 3.8 5.8 | 4.5 3.6 | 5.5 10.3 | 3.0 10.7 | 3.3 8.8 | 5.0 6.1 |
| Total | 100.0 100.3 | 100.0 100.1 | 100.0 100.0 | 99.8 100.0 | 100.0 100.0 | 100.0 100.0 | 100.0 100.0 |

Moisture, wt %

| Moisture, wt % | 67.2 19.2 | 69.9 16.7 | 69.5 16.2 | 69.6 9.78 | 68.2 8.80 | 69.3 5.65 | 68.3 5.07 |

Ash, wt %

| Ash, wt % | 18.5 17.3 | 16.5 16.5 | 19.6 18.7 | 17.8 17.8 | 18.3 16.5 | 15.8 20.6 | 14.2 16.4 |

Bulk Density, lb/ft³

| Bulk Density, lb/ft³ | 28.5 29.6 | 31.2 31.9 | 28.5 28.5 | 35.6 24.4 |

* Average.
Figure 8 Dried Peat Moisture Content vs. Dryer Exit Gas Temperature
Table 3. Peat Dryer Test Results
(Summary of Average Ash* Analysis)

<table>
<thead>
<tr>
<th>Dryer Exit Temperature, °F</th>
<th>Peat Feed, wt% ash</th>
<th>Dried Peat, wt% ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>260</td>
<td>14.2</td>
<td>16.4</td>
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<tr>
<td>250</td>
<td>15.8</td>
<td>20.6</td>
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<tr>
<td>230</td>
<td>18.3</td>
<td>16.5</td>
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<tr>
<td>225</td>
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<td>18.7</td>
</tr>
<tr>
<td>210</td>
<td>16.5</td>
<td>16.5</td>
</tr>
<tr>
<td>195</td>
<td>18.5</td>
<td>17.3</td>
</tr>
<tr>
<td>Avg</td>
<td>17.2</td>
<td>17.7</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.85</td>
<td>1.54</td>
</tr>
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</table>

* Quick ash reported by EDC lab.
Table 4. Typical Peat Product From Screener

Screen Analysis, wt% on

<table>
<thead>
<tr>
<th>Screen Size</th>
<th>Weight %</th>
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</thead>
<tbody>
<tr>
<td>+10</td>
<td>0.1</td>
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<tr>
<td>+20</td>
<td>18.4</td>
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<tr>
<td>+30</td>
<td>15.5</td>
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<tr>
<td>+40</td>
<td>17.9</td>
</tr>
<tr>
<td>+60</td>
<td>33.9</td>
</tr>
<tr>
<td>+80</td>
<td>8.9</td>
</tr>
<tr>
<td>+100</td>
<td>4.6</td>
</tr>
<tr>
<td>+200</td>
<td>0.4</td>
</tr>
<tr>
<td>+230</td>
<td>0.2</td>
</tr>
<tr>
<td>Pan</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Moisture, wt% 5.03
Figure 9 Peatgas Reactor
gasification zone, in the PEATGAS configuration. In addition, the solids transfer line from the first-stage, short-residence-time reaction zone was extended into the char gasification bed. This modification and some minor instrument and data acquisition changes were completed in March, and preparations for the first-reactor flow test were begun. The objective of the first test is to obtain operating experience with the new PEATGAS reactor configuration using Minnesota peat feedstock. Special attention will be given to solids flow throughout the unit and the performance of all instruments and data-acquisition equipment. Slurry feeding will be used to inject the peat into the gasifier during this test, and supplementary heat will be supplied at all times by the start-up burner. Table 5 gives the operating conditions for this test.

The start-up burner was ignited on April 16 after initial start-up preparations were completed. Slurry feeding began early April 19. As of this writing, Test RF-1 is still in progress. Solids flow has been established throughout the reactor. Operation is very good. The drying system is providing a consistent peat product with a moisture content between 5 and 10 weight percent. Peat slurry concentrations exceeding 25 weight percent solids are pumped to the gasifier, which is operating at 500-psig pressure. Feed rates are controlled between 1000 and 2000 lb/hr while the solids flow characteristics and fluidized bed operating variables of Minnesota peat are being studied. Good bed densities (15 to 20 lb/ft³) are being observed in the char gasifier, which is operating at 1100°F. Hydrogen and steam from the start-up burner are providing the reactants to gasify from 50 to 75 weight percent of the peat fed.

FUTURE WORK

Future work will include completing the lockhopper feed system and continuing pilot plant operations to collect a gasifier data base for the production of synthetic natural gas from Minnesota peat.
Table 5. Reactor Flow Test Using Minnesota Peat

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, psig</td>
<td>500</td>
</tr>
<tr>
<td>Peat Feed Rate, lb/hr</td>
<td>1000 - 2000</td>
</tr>
<tr>
<td>Peat Moisture Content, wt%</td>
<td>10</td>
</tr>
<tr>
<td>Peat Slurry Conc., wt% solids</td>
<td>20</td>
</tr>
<tr>
<td>Dryer Temperature, °F</td>
<td>450</td>
</tr>
<tr>
<td>SOG Temperature, °F</td>
<td>1200 - 1400</td>
</tr>
<tr>
<td>SOG Superficial Velocity, ft/s</td>
<td>1.0</td>
</tr>
<tr>
<td>Start-up Burner</td>
<td>on</td>
</tr>
</tbody>
</table>
PEAT CONVERSION: A PARTIAL OVERVIEW

W. Dean Lampe

Corporate Research Division

InterNorth, Inc.

Omaha, Nebraska
INTRODUCTION

Northern Natural Gas Co., a division of InterNorth, Inc., has been monitoring developments in peat conversion research for the past several years. The interest Northern Natural Gas Co. has in peat conversion is derived largely from the fact that major peat deposits lie in close proximity to the northern part of the NNG transmission system.

At the present time, Northern is co-sponsoring some of the research on peat conversion that is being conducted under the Department of Energy Peat Program. Northern has also provided funding for an independent study on peat dewatering, which was carried out at the University of Minnesota. For approximately the past two years, a separate study of peat dewatering has been in progress at the Corporate Research Division of InterNorth.

At this time, the active research being undertaken at InterNorth is not a part of the overall DOE peat program. However, it is intended to be complementary to this program.

STATEMENT OF PURPOSE

Based upon a review of the work completed to date on peat conversion, it is evident that water removal and subsequent disposal, either prior to gasification or following bioconversion, will have a major impact on the overall economics of any peat conversion process. The purpose of the work presently being undertaken at InterNorth is to evaluate alternative methods for peat dewatering, attempt to develop an optimum process for dewatering, to characterize waste water generated in the dewatering step, and to develop a suitable process for its ultimate disposal. In addition, it is planned that an in-depth study of the economics of these aspects of peat conversion will be undertaken.

DEWATERING STUDIES

Initial efforts in the InterNorth peat research program have been largely devoted to dewatering. Several peat dewatering processes have been evaluated
on a desk-top basis. These include mechanical pressing, thermal drying, microwave heating, and liquid extraction.

Mechanical dewatering can be achieved by means of several types of commercially available equipment, including belt presses and centrifuges. However, it is unlikely that a reduction in moisture content below approximately 70% can be achieved mechanically. A mechanical dewatering system would be highly capital intensive. Consequently, this method is judged to be relatively unattractive.

Thermal drying is effective in removing the moisture content of peat to essentially any level desired. However, this process is energy intensive, which is a major shortcoming.

In a cursory laboratory experiment, it was determined that microwave heating was quite effective for dewatering peat. However, because of the relatively low efficiency of electrical power generation and conversion, this method is extremely energy intensive and is, therefore, not a practicable means for peat dewatering.

At the present time, solvent extraction is being investigated as a means for reducing peat moisture content to an acceptable level. Preliminary laboratory requirements indicate that this method may well have merit. There are several aspects of the solvent extraction process that require additional development work. This work is currently under way.

FUTURE ACTIVITIES

Future activities with regard to peat conversion will likely continue to be primarily concerned with solvent extraction. Considerable additional experimentation with extraction will be undertaken in order to fully evaluate the potential of this method of dewatering. This work will continue on a bench-scale basis until sufficient data have been collected to permit either the design of a pilot-scale dewatering unit or to firmly establish the infeasibility of the solvent extraction process for peat dewatering.
Another area of peat conversion in which it is judged that research activity is warranted is waste water characterization and disposal. Liquid wastes will be generated by almost every conceivable method of peat conversion. The quantity of wastewater generated daily will be substantial. Its disposal could well have a major impact on the overall viability of peat utilization as an energy source.
CONTINUED TECHNICAL DEVELOPMENT OF A PEAT BIOGASIFICATION PROCESS

C.F. Ruoff
E. Ashare
D.L. Wise

Dynatech R/D Company
Cambridge Massachusetts 02139
ABSTRACT

A bench-scale experimental development program and the development of an economic process model, were conducted for the conversion of peat to substitute natural gas (SNG). This work is a continuation of an earlier feasibility study (1). The process consists of three steps: a) hot (150°C) aqueous alkali [soda ash (NaCO₃)] solubilization of peat. Solubilization results in the complex ligneous structure of peat being broken down into single ring aromatics with one or more 3 to 5 carbon side chains, b) oxidation of the solubilized peat - resulting in oxidation of the side chains on the peat derived aromatics, the exothermic reaction also providing the process heat, and c) anaerobic fermentation of the solubilized/oxidized peat liquor to fuel gas. While both solubilization and oxidation steps may be carried out in the same peat pretreatment reaction vessel, it was determined that these are two discrete processing steps. It was found that peat solubilization follows first order reaction kinetics with respect to peat and hydroxyl ion concentrations with a rate constant, kₛ, equal to 2.30 x 10⁶ exp (-3300/T[K]) [l/gmole-hr]. The oxidation of solubilized peat was found to follow first order reaction kinetics with respect to solubilized peat and oxygen with a rate constant, kₒ, equal to 7.5 x 10¹⁴ exp (-14650/T[K]) [l/gmole-hr]. It was further experimentally determined that methane fermentation of the pre-treated peat followed first order kinetics, the rate constant was 0.015 days⁻¹ under mesophilic (37°C) and continuous fermentation conditions. This constant is believed to be low primarily due to sodium inhibition caused by the presence of the soda ash. Methane fermentation of pure model compounds, assayed in the peat liquor, was much higher: for example, 0.13 day⁻¹ for benzoic acid and 0.18 day⁻¹ for syringaldehyde. The fuel gas processing cost was calculated using the utility financing method approved by the American Gas Association and the kinetics and yields determined experimentally. A very conservative "base cost" average cost for pipeline quality methane was determined to be $5.93/million Btu for a 70 billion Btu/day plant processing over 8000 tons/day (dry) of peat. A sensitivity analysis revealed that the alkali requirements and digester volume were most critical to the methane cost and that by further process development the average gas cost may be expected to be reduced to 3 to 4 $/million Btu.
INTRODUCTION

The stoichiometry of the several classifications (2) of peat may be described as (3):

\[ C_{12}H_{120}O_{60} \rightarrow C_{62}H_{72}O_{24} + 8CO_2 + 2CH_4 + 20H_2O \]

Although the majority of the world's peat reserves are located in Russia, sufficient quantities exist in the United States to contribute significantly to domestic energy needs in the coming decades. The states with major peat resources, ranked as to energy potential, are Alaska (only peat outside the permafrost regions is considered), Michigan, Minnesota, Florida, Wisconsin, Louisiana, North Carolina, Maine, and New York. Using three criteria that were employed by R. S. Farnhan (4), one can estimate the U.S. energy potential from these resources. The criteria are: 1) an average peat deposit depth of 7 feet, 2) an average bulk density of 15 lb/ft\(^3\) (for 35 percent moisture content), and 3) an average heating value of 6000 Btu/lb (for 35 percent moisture content). On this basis, the total potential energy available from domestic supplies of peat is 1443 quadrillion Btu's (corresponding to 240 billion barrels of oil), thus ranking peat second in recoverable energy to our nation's coal reserve.

Numerous technical problems are associated with the large-scale production of energy from peat. The main obstacle in producing either SNG or electricity is the high moisture content of peat - it is almost 90 percent water. Dewatering is a difficult and costly process that consumes large amounts of energy. The process described herein, peat biogasification, bypasses this problem. In this process (1) the peat is assumed to be wet harvested and then pretreated under alkaline-oxygen conditions and is then anaerobically fermented - all processing being carried out without water removal.

PROCESS DESCRIPTION AND METHODS FOR EVALUATION

The peat biogasification process may be expressed in terms of a three-phase engineering model, as shown in Figure 1.
Phase 1
Peat Solubilization

Phase 2
Peat Oxidation

Phase 3
Anaerobic Fermentation

Raw Peat → Alkali → Air/Oxygen → Methane

Figure 1 Three Phases of Peat Biogasification
In Phase I, peat and alkali ($\text{Na}_2\text{CO}_3$) are reacted at elevated temperatures to produce a solubilized peat product. The peat is hydrolyzed, producing many types of substituted phenols, e.g., condensed and uncondensed guaiacyl. The substituent groups are carbon side chains containing 3 to 5 carbon atoms. Some of the products identified are given in Figure 2.

Phase II is oxidation of the solubilized peat. The carbon side chains on the aromatic rings are oxidized into carboxylic and aldehydic functional groups. The side chains are oxidized more readily than the benzene rings because of the lower activation energy of these side chains. The amount of energy given off in the oxidation of carbon chain side groups provides for energy self-sufficiency of the pretreatment.

Phase III of the biogasification is anaerobic fermentation of the pretreated peat to methane and carbon dioxide. Anaerobic fermentation of aromatic carboxylic acids and aldehydes has been carried out experimentally and reports can be found in the literature (5 - 12). Complete bioconversion to methane and carbon dioxide has been reported for the following aromatic substrates: benzoic acid, phenyl acetic acid, hydrocinnamic acid, and cinnamic acid. The inocula used for these trials was anaerobic sewage sludge. Radioactive tracer experiments have shown that benzoic acid is converted to methane and carbon dioxide with a conversion efficiency of greater than 95 percent. (8)

PROCESS MODELING

The present work was devoted to conducting experiments to develop a process model that described the complex reactions occurring in peat biogasification. This model was then used to determine process economics. This process model divides the peat biogasification into three phases: solubilization of the peat, oxidation of the solubized peat, and anaerobic fermentation of pretreated peat product.

Rate data obtained from the three phases of the biogasification model can be analyzed in two ways. One approach is to assume a mechanistic model and determine whether the model fits the experimental data. If it does not, a different
A. SOLUBILIZED PRODUCTS

Uncondensed Guaiacyl
R = H  R' = OH
or R = H  R' = CH₂OH

Condensed Guaiacyl
R = (CH₃)₃C  R' = H
or R = (CH₃)₃C  R = CH₂OH

B. OXIDIZED PRODUCTS

Where
R' = H or CH₂OH
R = H or (CH₃)₃C or OCH₃

Figure 2 Comparison of the Structure of Products from Peat Solubilization and Peat Oxidation
mechanistic model must be assumed, and the model fitting step is repeated. This approach depends upon finding a mechanistic model that describes the reactions that occur. A second approach to kinetic data analysis is to use an empirical model that incorporates all the processing variables and model parameters. Since the pretreatment process was known to be complex, resulting in many different products from a complex reactant (peat), the mechanistic approach for data analysis was used.

For the solubilization model, it was assumed that the peat was solubilized by the following reaction:

$$C_p + C_B \rightarrow C_s$$

where: $C_p$ - concentration of insoluble peat  
$C_B$ - concentration of hydroxyl ion  
$C_s$ - concentration of soluble peat

Assuming this mechanism, the following rate equation applies:

$$\frac{dC_s}{dt} = kC_pC_B$$

where $k$ is the absolute reaction rate constant. Upon integration this equation yields $C_s = k \int C_p C_B dt$. Analysis of data obtained followed this procedure:

I. Plot $C_p C_B$ vs. $t$,  
II. Measure area vs. $t$, i.e. $\int C_p C_B dt$,  
III. Plot $C_s$ vs. area ($\int C_p C_B dt$) for each $t$,  
IV. Least squares fit gives slope that equals $k$.

This procedure was also followed for the oxidation phase and fermentation phase of the process model. For the numerous oxidation reactions, the following mechanism was assumed:

$$C_s + C_O \rightarrow C_F + C_R$$
where: $C_S =$ concentration of solubilized peat
$C_O =$ concentration of oxygen
$C_F =$ concentration of fermentable products
$C_R =$ concentration of refractory products

The analysis procedure was the same as described above, but there were four rate equations to be developed, i.e., $dC_S/dt$, $dC_O/dt$, $dC_F/dt$, and $dC_R/dt$. The development of the equations and the oxidation model was dependent upon measuring the concentration of fermentable and refractory materials and their change with time.

The third model was used to describe the anaerobic fermentation phase. The following reaction was also assumed to follow first order chemical reaction kinetics:

$$C_F \rightarrow CH_4 + CO_2$$

where: $C_F =$ concentration of fermentable materials
$CH_4 =$ concentration of methane
$CO_2 =$ concentration of carbon dioxide

Batch digesters were set up to yield data for total biodegradability, and from this $C_F$ was calculated. Continuous digesters were set up to give conversion rates.

METHODS AND MATERIALS

The data for the oxidation and solubilization phases of the process model were obtained using a two-liter Parr® reactor. The apparatus for the solubilization phase is shown in Figure 3. Reed-sedge peat, obtained from the Red Lake area of Northern Minnesota (courtesy of the Minnesota Gas Company), was used in all cases. Peat slurry (3 percent total solids) was mixed in a blender and added to the reactor. The reactor was heated to temperature, and a known amount of alkali was injected into the reactor with nitrogen gas. Liquid samples were
Figure 3 Schematic of Parr Reactor Setup
Used in Batch Solubilization and Oxidation Experiments
withdrawn at regular intervals, and the following measurements were taken: total solids, volatile solids, dissolved solids, dissolved volatile solids, and pH. Samples were saved for high pressure liquid chromatograph (HPLC) analysis.

Initially, the oxidation studies were carried out in a manner similar to the solubilization studies. Solubilized peat was added to the Parr® reactor, and it was heated to the desired temperature. Oxygen (200 psig) was injected into the reactor, and its concentration was measured as a function of time. Liquid samples were measured for total solids, volatile solids, dissolved solids, dissolved volatile solids, and pH before and after the test.

Later, another set of oxidation experiments was run, as shown in Figure 4. Here the solubilized peat was added to the reactor, and the reactor was heated to temperature. Air was bled into the reactor at a constant flow rate. The wet test meter recorded the flow rate output, and gas compositions were measured periodically through the sampling septum. The amount of oxygen consumed was computed from the nitrogen/oxygen composition of the off gas. Liquid samples were withdrawn periodically, and total solids, volatile solids, dissolved solid, and volatile dissolved solids were measured. The samples were analyzed by the HPLC. The concentrations of refractory and fermentable products were monitored as a function of time.

In the third phase of the process, anaerobic digestion, two types of systems must be used to obtain the necessary data for the process model: batch digesters and continuous digesters. Batch digesters (Figure 5) were used to determine the ultimate biodegradability of the material, while continuous digesters (Figure 6) were used to determine the rate of fermentation at different retention times.

In the batch digesters, sewage sludge was mixed with the substrate. Nutrients were added, and the pH was controlled by buffer addition. A control batch digester was charged with sewage sludge to determine gas production. Batch digesters were established by continuous culture transfers with the following
Figure 4 Schematic of Parr Reactor Setup Used in Continuous Oxidation Experiments
Figure 6 Schematic Diagram of Apparatus for Batch Digestion of Peat Liquor

Figure 6 Schematic Diagram of Apparatus for Continuous Digestion of Peat Liquor
aromatic compounds as substrates: benzoic acid, cinnamic acid, syringic acid, and syringaldehyde.

Batch digesters were established for peat at different pretreatment conditions. Sewage sludge and cultures acclimated to the aforementioned aromatic compounds were used as the inocula for digestion of the pretreated peat liquor. Nutrients were added in some cases, and the pH was controlled by buffer addition. Continuous digesters (Figure 6) were operated to determine a rate constant for the anaerobic digestion of pretreated peat. These digesters were started by adding 100 ml of cultures acclimated to benzoic acid, syringic acid, cinnamic acid, and syringaldehyde, 100 ml of sewage sludge, and 200 ml of pretreated peat. After significant gas production had begun, the digesters were drained and fed every day with the pretreated peat. Two digesters were set up, one on a 20-day retention time, the other on a 30-day retention time; that is, the total volume of the digester (400 ml) was replaced in 20-days in one case and 30-days in the other case.

EXPERIMENTAL RESULTS

SOLUBILIZATION

The kinetic analysis was carried out by fitting the solubilization data to the proposed model as described earlier. It was assumed that the rate constants of solubilization at several temperatures could be described by an Arrhenius relation, that is, \( k_s = A \exp(E_{\text{act}}/RT) \) where \( A \) is a constant, \( E_{\text{act}} \) is the activation energy, \( R \) is the universal gas constant, and \( T \) is the absolute temperature. A plot of the results from the peat solubilization is given in Figure 7. The slope of the line, obtained from least squares regression analysis, yielded an activation energy of 6.5 kcal/g mole, as shown in Figure 7. The rate equation for peat solubilization was

\[
k_s = 2.30 \times 10^6 \exp \left( -\frac{3300}{T} \right) \text{ [l/hr g-mole]}
\]

This rate expression was used in the process model, described later.
$E_{\text{act}} = 6.5 \text{ kcal/mole}$

**Figure 7 Activation Energy for Solubilization of Peat with Alkali**
The reaction is assumed to occur according to the proposed mechanism: under this hypothesis, as the reaction proceeds, the concentration of oxygen remains proportional to the concentration of unoxidized peat. Thus a correlation may be developed solely in terms of oxygen concentration in which the reaction of solubilized peat (\( C_s \)) to products is 

\[
C_s + \text{O}_2 \rightarrow \text{products}
\]

The kinetic relationship, assuming oxygen (\( C_0 \)) and solubilized peat (\( C_s \)) are present in stoichiometric amounts is,

\[
\frac{d(C_0)}{dt} = -k \cdot C_0^2
\]

This results were analyzed, and Figure 8 shows the rate constants calculated for each temperature. As in the solubilization model, an Arrhenius relationship was assumed between rate constant and temperature. Figure 9 shows a plot of \( \ln k_0 \) versus \( 1/T[K] \). The rate constant for oxidation was determined to be 

\[
k_0 = A \exp(-22,600/RgT)
\]

The important item in the rate constant obtained by this analysis is the activation energy, which agrees well with the continuous oxidation tests discussed below.
Figure 8  Correlation of Rate of Oxidation of Solubilized Peat According to Second Order Reaction Kinetics (Based on Stoichiometric Ratio of Reactants)
Figure 9 Activation Energy for Oxidation of Solubilized Peat

$E_{act} = 22.6$ KCAL/GM MOLE
The second type of oxidation experiment was conducted to monitor product formation with time, using the HPLC. The HPLC analyses were conducted by calculating the total area under the HPLC curve and calculating the percentage due to each group of peaks, i.e., hydrolyzed and oxidized fraction. The oxidized products were then measured as a function of time.

Because of differences in the gradient elution solvents used in the HPLC analysis, it was assumed that in the solubilized peat, 40% of the material was measured in the oxidized peak. As the oxidation proceeded, the oxidized peak became progressively larger, and the percentage of oxidized product could be determined as a function of time. Implicit in this analysis is the assumption that both the solubilized and the oxidized product had similar extinction coefficients (at 254nm). On this basis, a semilogarithmic plot of 100 minus percent conversion versus time was made for each oxidation run (Figure 10) following the rate expression for the mechanistic model of \( \frac{dC_F}{dt} = k_0 C_s C_0 \). Here \( C_F \) refers to the oxidized portion of the HPLC chromatographs and \( C_S \) refers to the hydrolyzed portion. Therefore, the material in the pretreated peat liquor is the \( C_F + C_S \); thus, by basing the analysis on percentages of the pretreatment mix, \( C_F + C_S = 100\% \). Since \( C_0 \) is constant throughout each continuous oxidation run, the integral of the rate expression become \( \ln(100-C_F) = -k_0 C_0 t + \text{constant} \). By plotting \( \ln(100-C_F) \) versus \( t \) for each temperature (Figure 10) a slope of \( k_0 C_0 \) was obtained; by dividing out the partial pressure of oxygen in the reactor for each test, a rate constant for oxidation was obtained for each temperature. Again, an Arrhenius relation was assumed between the rate constant and the temperature. The log of the rate constant was plotted versus inverse temperature in Figure 11. A straight line was obtained giving an activation energy of 29.0 kcal/g mole. This compares reasonably well with the initial set of oxidation trials discussed earlier, in which an activation energy of 22.6 kcal/g mole was obtained. The rate constant expression for oxidation was \( k = 7.5 \times 10^{14} \exp(-14650/T) \). The results of these two sets of rate experiments show that the mechanistic model appears to describe the complex set of oxidation reactions occurring in the pretreatment.
Figure 10 Calculation of Apparent Rate Constant for Oxidation of Solubilized Peat.
Figure 11 Calculation of Oxidation Activation Energy.

\[ E_{\text{act}} = 29.0 \text{ kcal/gmole} \]
FERMENTATION

Results from the acclimated batch digester using benzoic acid and syringic acid are shown in Figures 12 and 13. First order kinetic constants were determined to be 0.13 and 0.18 day⁻¹, for benzoic and syringic acids respectively. Further, essentially complete conversion of the substrates was achieved. These values for the kinetics are higher than the values of 0.1 day⁻¹ determined by Ashare and coworkers (13) for an array of cellulosic substrates such as straw, etc. On the other hand, a kinetic constant for the anaerobic digestion of whey was determined by Wise and coworkers (14) to be 0.2 day⁻¹. It may be noted that acclimated cultures fermenting water soluble organic substrates may be expected to act more rapidly than those fermenting non-soluble cellulosic substrates.

Batch digestion of pretreated peat resulted in conversions of 60% of the total volatile solids in the feed. A first order kinetic constant for the continuous pretreated peat digester may be obtained by plotting 1/(1-fractional conversion) vs. SRT (solids retention time) as shown in Figure 14, in which a value of 0.015 days⁻¹ was determined.

This rate constant for fermentation of the pretreated peat or cooked peat liquor is extremely low; as mentioned before, it is probably due to a high sodium loading (∼3000 mg/l). According to Kugleman and coworkers (15, 16), sodium toxicity in wastewater sludge digestion occurs in the 5000 to 8000 mg/l range. However, the concentration at which toxicity occurs is modified by antagonism, synergism, and acclimation. It is thus probable that this high concentration of sodium (3000 mg/l) is inhibiting the digestion of the pretreated peat. Another possibility is the lack of nitrates or electron acceptors (17). It appears that some sort of electron acceptor is essential for the anaerobic degradation of benzoic acid. In the batch fermentations, the addition of KNO₃ to the digesters increased gas production by a substantial amount (∼5 to 10%). This is another possible inhibition factor that needs to be studied more thoroughly. Without this inhibition, it is anticipated that the rate constant can be increased.
Figure 12 Determination of Benzoic Acid Rate Constant

\[ k = 0.13 \text{ days}^{-1} \]
Figure 13 Determination of Syringic Acid Rate Constant

\( k = 0.184 \text{ days}^{-1} \)
Figure 14 Determination of Fermentation Rate Constant

K = 0.015 days$^{-1}$
ECONOMIC ANALYSIS

An economic analysis was carried out. Some of the key considerations for each processing step are discussed as follows.

SLURRY CONCENTRATION

In the slurry concentration step, the peat slurry - assumed to be obtained by wet harvesting - is dewatered from 3 to 8% solids. The material balance indicates that the amount of water removed is 174,000 tpd (or 28,900 gpm). A fast rate filtration system is capable of removing 20 gpm/ft² (18), thus a 1450 ft² filtration unit would be needed. The efficiency of this process step has been assumed to be 100% (i.e., no peat solids pass through the filter). This efficiency must be determined, but it is expected to be about 98%.

PRETREATMENT REACTOR

The pretreatment step consists of two stages, solubilization followed by oxidation. A two-step plug flow reactor concept is assumed.

Reaction for a typical model compound is seen as follows:

Here the higher heating values of peat and vanillin are approximately 10,250 and 10,830 Btu/lb respectively. The heat of reaction for this reaction is
therefore about -1850 Btu/lb solubilized peat reacted. The amount of heat produced daily is about 2.7 x 10¹⁰ Btu/day. This is more than twice the heat required for the sensible heat difference between the influent and effluent streams and is therefore sufficient to provide the heat for the process.

Another energy requirement in the pretreatment step is the energy necessary to compress the oxygen to the desired pressure. For the 8350 tpd peat solids, the required alkali is 2400 tpd Na₂CO₃ and the required oxygen is 2500 tpd. If oxygen were supplied by compressed air, then 8750 tpd N₂ would be supplied to the oxidation reactor and this N₂ would have to be removed, preferably after the fermentable product stream has been cooled to eliminate significant water and energy loss. For the base line design, it is assumed that 90% of the peat volatile solids is solubilized and that 90% of the solubilized product is oxidized to fermentable products. The assumptions are based on the results presented earlier.

Design of the "base case" preliminary process design followed by an economic process model evaluation and sensitivity analysis. A complete process flowsheet for the base case design is shown in Figure 15 and assumptions in Table 1. A summary of this cost analysis follows.

For a pretreatment temperature of 150°C (the rate constant is 944 l/gmole-hr), a conversion of 90%, and an initial peat concentration of 8% solids (≈ 0.4 gmoles/l), the retention time for solubilization is 0.024 hours. Solubilization reactor volume is approximately 3200 ft³. The size of the solubilization pretreatment reactor is strongly dependent on slurry concentration, temperature (which affects the rate of reaction), and desired conversion. The volume of the pretreatment oxidation reactor is then found to be about 67,000 ft³ based on 90% conversion, k₀' = 4.4 hours⁻¹, and a calculated retention time of 0.5 hours. For a 15 psi oxygen partial pressure and oxygen supplied as compressed air, the pretreatment reactor must be designed for 150 psi operating pressure. This reactor size is strongly dependent on solids concentration, reaction temperature, and conversion.
Figure 15 Overall Flowsheet for Base Case Design
Table 1. Base Case Design Process Assumptions

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry Preparation</td>
<td>3% Solids Feed</td>
</tr>
<tr>
<td></td>
<td>8% Solids Output</td>
</tr>
<tr>
<td>Pretreatment-Solubilization</td>
<td>Plug Flow Reactor</td>
</tr>
<tr>
<td></td>
<td>90% conversion</td>
</tr>
<tr>
<td></td>
<td>0.3 lb Na$_2$CO$_3$/lb peat</td>
</tr>
<tr>
<td></td>
<td>150°C</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Plug Flow Reactor</td>
</tr>
<tr>
<td></td>
<td>90% conversion</td>
</tr>
<tr>
<td></td>
<td>0.4 lb O$_2$/lb solubilized product converted</td>
</tr>
<tr>
<td></td>
<td>150°C</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>10°C Inlet Slurry Temperature</td>
</tr>
<tr>
<td></td>
<td>37°C Exit Temperature for Feed to Digester</td>
</tr>
<tr>
<td>Liquid/Solids Separation</td>
<td>Undissolved Solids Separated to 25% Solids</td>
</tr>
<tr>
<td>Digestion</td>
<td>CSTR</td>
</tr>
<tr>
<td></td>
<td>37°C</td>
</tr>
<tr>
<td></td>
<td>20 day retention time</td>
</tr>
<tr>
<td></td>
<td>67% conversion of fermentable products</td>
</tr>
<tr>
<td></td>
<td>Gas Composition, 60% CH$_4$/40% CO$_2$</td>
</tr>
<tr>
<td>Gas Purification</td>
<td>3% CO$_2$ Concentration in Purified Gas</td>
</tr>
<tr>
<td></td>
<td>1000 psi Output Pressure</td>
</tr>
<tr>
<td></td>
<td>Power Requirement of 300 hp/MMscfd</td>
</tr>
</tbody>
</table>
Another important aspect of the pretreatment step is the energy balance. The major contributions to the energy balance are the sensible heats of the inlet and exit streams and heat of reaction for the oxidation reactor. This heat must be provided by the heat of reaction. The heat of reaction for oxidation can be estimated from the differences in higher heating values of solubilized peat and fermentable products. In one such base case design, it is assumed that the oxygen partial pressure is 15 psi. The total system pressure is dependent on reactor temperature and oxygen partial pressure. For a reactor temperature of 150°C, the steam pressure will be about 70 psi, so if pure oxygen were supplied, the total system pressure would be about 85 psi. If air were used to provide oxygen, the total system pressure would be about 145 psi. The energy required to compress air from 15 to 145 psi to provide 2500 tpd of oxygen can be estimated (assuming isothermal compression) by: horsepower = 0.00436 P_1 Q ln (P_2/P_1). Here Q is the inlet gas flow (2500 tpd of oxygen is equivalent to 195,000 ft³/min of air). The required power for this compression is 28,600 hp, which is approximately 5.4 x 10⁹ Btu/day (assuming 7800 Btu/hp-hr, i.e., 32.5% conversion efficiency). If pure oxygen were used, the energy requirement would be greater. The energy necessary to separate oxygen from air is approximately 3 x 10⁶ Btu/ton (19). Therefore, the energy requirement for supplied pure oxygen is about 7.5 x 10⁹ Btu/day.

**DIGESTER**

Digestion system design is a function of yield, kinetics, temperature, fermentable solids content, and product gas composition. For an assumed rate constant of 0.1 days⁻¹ and twenty-day retention time, the fractional conversion of fermentable solids is \( \frac{K_T}{1+K_T} = 0.67 \). The size of the digester is dependent on assumed values for slurry concentration (8%), retention time (20 days), and throughput (93,000 tpd of water). For these assumptions, the total digester volume is about 60 x 10⁶ ft³. The major capital cost component of the base case design is the digestion step. Other more efficient digestions concepts are necessary to reduce this capital cost. These concepts include anaerobic contact process (which uses cell recycle), an example of which is the anaerobic packed bed filter. The anaerobic contact process is applicable to soluble, fermentable...
substrates with retention times of less than one day. This would reduce the digester volume to about $\frac{1}{50}$ of the CSTR volume.

GAS PURIFICATION

A gas purification step is necessary to provide pipeline quality gas. The digester gas must be treated to remove CO$_2$, H$_2$O, and other impurities. The digester gas will consist of approximately 60% CH$_4$ and 40% CO$_2$ (on a dry basis) and the gas flow to the purification system will be about 111 MMscfd. The power needed in this step, including power to compress the gas to 1000 psi, will be 33,000 hp (20) or an energy equivalent of $6 \times 10^9$ Btu/day.

The energy requirements for the process are for electric power for dewatering, mixing, and gas purification and compression. This power requirement, assuming 32.5% conversion efficiency, is about 24% of the gross energy output. The net energy output is 33% of the energy content of the peat fed.

COST INFORMATION

The "base case" capital costs are presented in Table 2. The costs were estimated from literature values and were updated to December 1980 costs. The costs presented in Table 2 indicate a total plant investment of $266 \times 10^6$. The total equipment costs are $192 \times 10^6$, of which 50% can be attributed to the digester costs and 35% to gas purification. Any major change in process design should be directed at the digestion step, since this is where the greatest reduction in capital costs can be achieved. The gas purification capital costs were developed for an existing process, and it is not expected that any major reduction in this component cost can be achieved. In the sensitivity analysis, the effect of reducing digester retention time, and hence digester volume and costs, will be examined.

The operating costs for the base case design are presented in Table 3. For this analysis, it is assumed that the peat cost is $3$/dry ton, electric power is 5¢/Kwh, and the operating labor requirement is 250 people (at $6$/hr).
<table>
<thead>
<tr>
<th>Equipment Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry Preparation</td>
<td>$100,000</td>
</tr>
<tr>
<td>Pretreatment - Solubilization</td>
<td>100,000</td>
</tr>
<tr>
<td>- Oxidation</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>2,300,000</td>
</tr>
<tr>
<td>Liquid/Solids Separation</td>
<td>8,100,000</td>
</tr>
<tr>
<td>Digesters</td>
<td>97,000,000</td>
</tr>
<tr>
<td>Gas Purification</td>
<td>6,800,000</td>
</tr>
<tr>
<td>Pumps, piping, electrical, instrumentation</td>
<td>15,800,000</td>
</tr>
<tr>
<td><strong>Total Equipment Costs</strong></td>
<td>131,500,000</td>
</tr>
<tr>
<td><strong>Supporting Facilities</strong></td>
<td>6,600,000</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td>138,100,000</td>
</tr>
<tr>
<td>Contractor's Overhead &amp; Profit</td>
<td>13,800,000</td>
</tr>
<tr>
<td>Engineering &amp; Design</td>
<td>6,900,000</td>
</tr>
<tr>
<td><strong>Subtotal Plant Investment</strong></td>
<td>158,800,000</td>
</tr>
<tr>
<td>Contingency</td>
<td>23,800,000</td>
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<tr>
<td><strong>Total Plant Investment</strong></td>
<td>182,600,000</td>
</tr>
<tr>
<td>Interest During Construction</td>
<td>32,900,000</td>
</tr>
<tr>
<td>Start-up</td>
<td>23,000,000</td>
</tr>
<tr>
<td>Working Capital</td>
<td>3,600,000</td>
</tr>
<tr>
<td><strong>Total Capital Requirements</strong></td>
<td>$242,100,000</td>
</tr>
</tbody>
</table>
### Table 3. Base Case Annual Operating Costs

<table>
<thead>
<tr>
<th>Category</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Materials</strong></td>
<td></td>
</tr>
<tr>
<td>Peat ($3/ton)</td>
<td>$ 9,100,000</td>
</tr>
<tr>
<td>Na$_2$CO$_3$ ($60/ton)</td>
<td></td>
</tr>
<tr>
<td><strong>Utilities</strong></td>
<td></td>
</tr>
<tr>
<td>Electric (5¢ KWH)</td>
<td>$28,100,000</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td></td>
</tr>
<tr>
<td>Operating</td>
<td>$3,100,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>Supervision</td>
<td>$1,100,000</td>
</tr>
<tr>
<td><strong>Administration and Overhead</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$4,900,000</td>
</tr>
<tr>
<td><strong>Supplies</strong></td>
<td></td>
</tr>
<tr>
<td>Operating</td>
<td>$900,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$4,000,000</td>
</tr>
<tr>
<td><strong>Local Taxes and Insurance</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$7,200,000</td>
</tr>
<tr>
<td><strong>Gross Operating Cost</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$115,000,000</td>
</tr>
</tbody>
</table>
The annual operating cost is estimated to be $115 MM. The major contributions to the annual operating costs are the cost of alkali and electricity (46 and 25% respectively). (It is assumed that the oxygen is supplied by compressing air; this cost is included in the electric cost and amounts to $10 \times 10^6$, or five times greater.) This suggests that the potential areas for process improvement that could significantly decrease the unit gas cost are alkali requirements and power requirements. The effects of changing these variables on the unit gas cost are discussed in the sensitivity analysis.

The unit gas for the base case design was calculated to be $5.93/\text{MMBtu}$. About 79% of this cost is operating costs, so the alkali costs contribute over 36% to the unit gas cost.

**SENSITIVITY ANALYSIS**

A sensitivity analysis was carried out to show the effects of changing process and economic variables on the unit gas cost. The effects of some of the key variables are shown in Figure 16. A discussion of the effects of these process variables on cost of pipeline quality methane appears below.

**SLURRY COMPOSITION AND PEAT COST**

In the slurry preparation step, it was assumed that the slurry would be dewatered to 8% solids before it was fed to pretreatment reactor. A change in the slurry concentration will affect the required equipment size and cost. The energy balance in the pretreatment step will also be affected since the volume of water flow would change, and therefore the sensible heat in the streams would change. The results of changing slurry composition on unit gas cost are shown in Figure 16 for a concentration range of 4 to 12% (base case = 8%). Over this range, the unit gas cost decreases by 35% when the concentration increases from 4 to 12%. The sensitivity at lower concentrations is greater since there is a greater percent change in liquid volume, i.e., reducing the concentration from 8 to 4% results in doubling the liquid volume, whereas increasing the concentrations from 8 to 12% decreases the liquid volume by one-third. In the base case economic
analysis, the cost of peat was assumed to be $3/ton. This contributed about $0.35/MM Btu to the unit gas cost. The sensitivity of unit gas cost to peat cost is about $0.12/MM Btu per $1/ton peat cost.

PRETREATMENT REACTION

The pretreatment reactor conditions including a plug flow reactor at 150°C with 90% conversion for solubilization and 90% conversion for oxidation. This resulted in retention times of 0.024 hours and 0.5 hours for solubilization and oxidation, respectively, when the kinetic relationships developed from the experimental data were used.

Changes in pretreatment conditions, such as temperature, amount and type of alkali, or oxygen partial pressure, will change the pretreatment retention times. The effect on unit gas cost of varying retention time is shown in Figure 16. (The conditions producing the change in retention time are not specified; the results are presented to determined whether a change in retention time significantly affects unit gas cost.) The results indicate that there is little sensitivity of unit gas cost to changes in this retention time. An increase in retention of an order of magnitude (e.g., from 0.5 to 5.0 hours) results in only a three percent increase in unit gas cost.

Another significant factor related to pretreatment that could significantly affect unit gas cost is the cost of pretreatment chemical. For the base case design, it is assumed that 0.3 lb Na₂CO₃ per lb peat is required with no recycle of Na₂CO₃. If cycle were utilized, the amount of Na₂CO₃ addition would be reduced. Figure 16 shows the effect on unit gas cost of changing the amount of Na₂CO₃/lb peat is added. For the base case 0.3 lb Na₂CO₃/lb peat is added, whereas with 50% recycle, only 0.15 lb Na₂CO₃/lb peat will be added. The sensitivity of this change is significant, with 50% recycle resulting in a 20% decrease in unit gas cost.

Since the pretreatment chemical requirement is a highly sensitive variable, it is one area that should be considered for potential process change. In particular, pretreatment should be investigated to determine conditions that would give
the same yield of solubilized product but require significantly less chemical addition. This would probably result in an increased pretreatment retention time, but since the sensitivity to retention time is insignificant, the net result would be a decreased unit gas cost.

For the base case design, the oxygen partial pressure was assumed to be 15 psi and the oxygen was supplied by compressing air. If the oxygen partial pressure were changed, there would be a change in compression requirement and hence electricity cost. The effect of varying oxygen partial pressure on unit gas cost assumes the only effect is on electricity cost. There is very little sensitivity of unit gas cost to oxygen partial pressure, and if a change in oxygen partial pressure were to result in a significant change in pretreatment retention time (which is also a low sensitivity variable), unit gas cost would not change significantly.

**DIGESTION**

Digester cost contributes about 70% to the capital costs of the system when a 20-day retention time is used. It is apparent that reducing digestion retention time would significantly reduce cost. It has been shown (21, 22) that an anaerobic contact system, such as an anaerobic packed bed filter, is capable of converting a soluble substrate to methane with a retention time on the order of 4-10 hours and giving a conversion efficiency of over 75%. This type of system has not been used with solubilized, oxidized peat product, so the applicability can only be hypothesized. The effect on unit gas cost of using a high rate system is shown in Figure 16. The analysis uses the assumption that the conversion efficiency is the same as for a CSTR, but retention time is reduced. Costs include cost for reactor plus packing (at 50% packing) of $12/ft³, compared to about $1.50/ft³ for a CSTR. The results indicated that unit gas yield is strongly dependent on digester retention time. High rate systems could potentially give higher yields, which would result in even lower unit gas costs. Since a high rate system has the potential to reduce the unit gas cost significantly, and since application of such a system to soluble peat fermentables has not been experimentally verified, it is recommended that such a process be investigated.
Other techniques can also be used to reduce digestion retention time, such as operating at thermophilic conditions or using a contact process (cell recycle). These techniques would also result in lower unit gas costs; this effect can be estimated from Figure 16.

It is apparent from this sensitivity analysis that the variables that have the greatest influence on unit gas cost are the digester retention time and alkali pretreatment chemical cost.

CONCLUSIONS AND RECOMMENDATIONS

During this project, it was found that engineering models based on bench-scale experiments described the complex reactions that occur when peat is reacted under aqueous alkaline/oxidation conditions and then the "cooked" product is anaerobically fermented to fuel gas. Three phases of peat biogasification were successfully expressed as first order kinetic models, namely, alkaline solubilization of peat, oxidation of the solubilized peat, and anaerobic fermentation of the alkali-oxygen treated peat. Using this information, a model was used to project the economics of a full-scale peat biogasification plant.

A sensitivity analysis was performed to determine the sensitivity of unit gas cost to changes in process variables and economic variables. Results show that the variables with the highest sensitivity were the digester retention time and the alkali chemical costs. For example, if 90% of the alkali were recycled, the unit gas cost would be reduced to about $3.70/MMBtu. A reduction in digester retention time from 20 days to 1 day (i.e., by using a version of the anaerobic contact process) would lower the unit gas cost to about $5.00/MMBtu. If both of these very practical process alternatives were incorporated, the unit gas cost would be $2.90/MMBtu. It is clear that these variables must be studied in any further work as they have significant effects on the unit gas cost.

The results of this present program continue to indicate that biogasification of peat to pipeline quality methane is technically feasible, but further research and development is required. The major findings of this study point to the need
for additional work. Specifically, three major areas of continued experimental work are recommended: A) Carry out the continuous solubilization/oxidation of peat to fermentable products - batch cooking is necessary to develop an understanding of the practical processing characteristics; B) Conduct experiments on alternative alkali oxidation systems including alkali recycle as well as use of other alkalis; the use of ammonia, for example, will also eliminate the suspected problem of sodium ion toxicity in the subsequent fermentation step; and C) Development of a high rate digestion process, using a packed bed or anaerobic filter system, for fermentation of the cooked peat liquor to fuel gas. It is to be noted that high rate anaerobic systems are being operated at full scale (21, 22) with hydraulic retention times being reduced from upwards of 20 days down to a period of as low as four hours. Coupled with these necessary experimental tasks, which may be carried out in parallel, will be a strong supportive process engineering phase and economic analysis. In every respect, continued development of the peat biogasification process is merited.

ACKNOWLEDGEMENT

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REFERENCES


Q: You showed the sensitivity of the gas cost to the cost of electricity. Is this a grass roots facility where you generate all the electricity you'd need within the plant, similar to the guidelines C. F. Braun is using for estimating the gas cost with other gas processes?

A: You're right. This is something that probably would be incorporated into the plan, namely integrating the peat feedstock in some way into a self-contained electrical power generation.

Again, in order to be as pragmatic and conservative as we could, we used 5¢ a kilowatt hour for our electrical generation station using peat as the feedstock. In lieu of going into the details or pricing an electrical power generation unit on peat for this size plant, we elected to use 5¢ a kilowatt hour and it was on that basis that the numbers were prepared. The 5¢ per kilowatt hour is an accepted price.

Q: On your heat exchanger, what type do you propose or what kind are you considering?

A: To do the analysis we simply selected an overall heat transfer coefficient in order to get the area. We used either 100 or 150 Btu per hour per square foot degree Fahrenheit, which we thought was a conservative overall heat transfer coefficient, and then costed the system based on information from the text on Chemical Engineering Economics by Peters and Timmerhaus to get a cost for the heat exchangers.
Q: What kind of heat exchanger would it be? My question relates back to how will you transport an 8% solvent system through the heat exchanger? That's not a pumpable slurry. That's not much more dilute than the peat is in the virgin bog. That's between 90 and 92% moisture in the bog and you certainly are not able to pump that material.

A: We have made the assumption that it's 15% solids in the bog and that when it is reconstituted we could pump an 8% slurry.

Q: You may want to check into that.

My next question is on your partial oxidation reactor. In the solubilization reactor you showed the overall stoichiometry of peat plus oxygen or solubilized peat plus oxygen going to the product. And then you formulate your kinetic model based on this system. I have a little bit of difficulty understanding exactly how that was arrived at. It seemed as though you're taking a mass balance and then formulating the kinetic model based on your overall mass balance.

I guess my understanding is that there are probably a lot of reactions taking place in parallel in that system and what you really have to do to do the job properly is formulate a matrix of differential equations assuming that each of the reactions is second order in terms of the solubilized reactant and the oxygen, and then solve the system of simultaneous differential equations.

You did that only with the partial oxidation and the solubilization reaction. I have a little bit of difficulty accepting that.

A: We took the samples from the peat cook with alkali and filtered it through a membrane filter and evaporated it to get the organic material that was solubilized.
When we plotted basically one minus the fraction solubilized versus time on a log one minus concentration versus time plot, we were able to get a straight line, in other words the data fits a first order model.

Q: I'm not debating that when you reduced the data you found that. My question really, once again, is: How do you reduce a system which probably has more than one reaction? I wouldn't say that it has hundreds of reactions but certainly it has more than one reaction and how do you reduce that to just one reaction and come up with a kinetic rate constant?

A: Let's just consider the example. What we should be doing is picking, let's say, a half a dozen compounds and doing the oxidation of each one of those particular solubilized components. We lumped them together as just solubilized peat in order to generate the data for the oxidation step.

Q: You had your high pressure liquid chromatograph. Surely you must have observed a lot of different products. And each of those products was formed by a separate reaction, so to clearly define the system you have to have a kinetic equation for each reaction and then solve the simultaneous system.

A: You're right. It did indeed result in a peak of solubilized material and that kind of gmishe of things was reduced as the oxidized peat increased and it was the area under the curve of what was solubilized and the increase of the curve that was oxidized that we used to get the information on which we based the kinetics for the solubilization to oxidation step.

Now, you're absolutely correct. With the HPLC we should be able to distinguish between some of the individual components. In fact, we narrowed it down to a classification or a category in which at this point we didn't make any distinctions. Let's put benzoic acid and cinnamic and syringaldehyde and these half a dozen or so that would elutriate at that same point that we saw the peat cook liquor elutriate. It wasn't distinguishable as to how much of each one of those we had. It was really a lumped term.
So I cannot tell you what fraction of, let's say, benzoic acid to syringaldehyde we had other than that they both seemed to be there.

Q: Maybe my concern is unfounded. I'm just a little bit concerned that maybe the system was overly simplified, but maybe it wasn't. I just wanted to raise the issue.

Q: A couple of your rate constants were shown on graphs and you drew a straight line through three data points. And I wonder whether you believe that?

Q: I believe we used the oxidation data where we used 130°, 150°, and 170° for the long-term peat cooks to get 3 rate constants. Those 3 were in fact used to get the activation energy. It is indeed as weak as those 3 oxidation data points. We took quite a number of runs and when we felt we had a real good handle on oxidation, as far as all the wrinkles on heating the reactor up to temperature, putting in the oxygen and so forth, when we had some refinements, we were getting at that point what we thought would be our best data. Then we ran 170, 150, 130. We even ran some down to 100 and 75° but the first 3 were used to plot.

So in the sense of the model, that activation energy for the solubilization was from those 3 points.

Q: Did you have more data points? Or could you have fashioned more in order to make the result a little bit more certain than it is right now?

A: I guess there was some decision making on that as to what would be most appropriate. It's the experimental factors involved in the development that led us to select that last set of very carefully defined or very carefully conducted experiments that we were most confident in.
Q: On the part of your presentation which dealt with the digester coming up with your straight line. Is that as a result of a regression analysis?

A: The cumulative data from the continuous digesters were straight lines drawn through the data. The regression analysis was done to get the kinetic constants through the several points on the one over the hydraulic retention time curve. So in that one case we drew a straight line through the data. All other cases were in fact regression analyses.

Q: But if you just follow the points, it really doesn't look like a straight line. I was just wondering on those two whether you had done a regression analysis.

A: That's a good point. It gets into a little bit of where we allow a judgment factor. In fact, these should go through zero. The intercept here in fact would mean that you were getting gas productions at zero time, but obviously this doesn't exist as a data point. What we were finding, and I would offer this comment, particularly in the 20-day retention time, if we acclimated the system and we got it going with the peat liquor, we would tend to obviate the earlier data in favor of something after, in this case, about two weeks operation.

So I'm eyeballing it by biasing it to a plus two week retention time. I just would add though that when we did this curve in which there is no judgment factor permissible, then we did do a regression analysis.

Q: On the 3 points?

A: In this case, just the 3 points, yes. This was for the continuous operation and, by the way, we did not use this in the model. It was really to get us into the ballpark of seeing where our kinetics constant was. We had moved from an order of magnitude below this to approximately this value. We would like to move an order of magnitude above this.
Our batch data show that with model compounds we are an order of magnitude above it.

Q: Can you do a regression analysis with only 3 data points?

A: Yes, you can. Least squares fit could be done with 3 points. It was done with this but my point is we did not use a judgment factor in that. On the data that I just showed you we did.
HIGH-PRESSURE WET CARBONIZATION

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BACKGROUND

Peat has an excellent potential to become a viable fuel source because of its low sulfur content and high reactivity. However, when harvested from the bog it can have moisture content in the range of 50% to 98%, depending upon the method of harvesting. The method used to remove this water will determine whether or not peat is to become an economically viable chemical feedstock or fuel. The mechanical dewatering of raw peat can only reduce the moisture content of the peat to approximately 70%.

Wet carbonization is a thermochemical process wherein the physical and chemical nature of a carbonaceous material is altered by heating the material in water under pressure. The general objectives of this process are to improve the mechanical dewaterability, increase the heating value of the feedstock, and produce a usable chemical feedstock. The process of wet carbonization consists of heating peat-water slurry at elevated pressures in order to disrupt the colloidal nature of the feed material by breaking carboxyl and hydroxyl groups from the molecular structure of the feed material. Disrupting the colloidal nature improves the feed material's mechanical dewaterability. Breaking of carboxyl and hydroxyl groups, which results in removal of oxygen from the carbonaceous material as carbon oxides and water, also increases the heating value of the final product. Increasing the severity of wet carbonization should make it possible to produce potentially useful chemical feedstocks, such as ethyl alcohol, acetic acid, furfural, and other oxygenated organics.

Wet carbonization of peat began in the early 1900's with Ekenberg's work in Europe. Various laboratory- and pilot-plant-scale studies have been conducted by European and North American investigators since then, and summaries of their studies have been presented at previous DOE Contractors' meetings. Under the sponsorship of DOE, GRI, Minnegasco, and Northern Natural Gas, laboratory-scale wet carbonization tests have been conducted with samples of Minnesota, North Carolina, and Maine peats in a batch autoclave. The results of these tests were very encouraging. The data show that wet carbonized peat can be mechanically dewatered (in a laboratory press) to moisture contents as low as 27%.
(Figure 1) and that it could have a heating value as high as 13,000 Btu/lb on a dry basis (Figure 2).

OBJECTIVES

The objectives of this program are to design and construct a continuous wet carbonization process development unit (POU), and to operate the POU to determine the effects of temperature and residence time on the dewaterability and heating value enhancement of Minnesota, North Carolina, and Maine peats. Additional information will be generated on the effect that the wet carbonization process has on the hydrogasification characteristics of these peats. Further information on the heat transfer and slurry transport characteristics will also be obtained.

TECHNICAL PROGRESS

A continuous wet carbonization PDU has been designed to study the effects of temperature and residence time on the dewaterability and wet-carbonization characteristics of peat. A peat-water slurry of approximately 5% dry solid by weight will be fed at a rate of 820 lb/hr. Table 1 lists the proposed operating conditions. A schematic flow diagram of the wet carbonization PDU is presented in Figure 3.

Feed peat (sized -500 microns) will be prepared for the PDU tests and will be placed in one of two 340-gallon slurry preparation tanks. Water will be added to these tanks to adjust the solids concentration to the desired level. Each tank is designed to hold enough slurry for approximately 4 hours of PDU operation. From the slurry feed tank, the slurry will be pumped through the shell and tube heat exchanger (on the tube side) to the first stage of the flash heat exchange system.

The flash heat exchange system consists of three stages of flash heating and three stages of flash cooling. In this system, the pressure of the hot, wet carbonized peat slurry will be reduced in three stages, flashing off steam in
Figure 1: The Effect of Wet-Carbonization on the Final Moisture Content of Dewatered Peats From Minnesota, North Carolina, and Maine
Figure 2 The Effect of Temperature and Residence Time on the Heating Value Enhancement of Wet-Carbonized Minnesota, Maine, and North Carolina Peats
Table 1. Range of Tentative Operating Conditions For Peat Wet Carbonization PDU

<table>
<thead>
<tr>
<th>Type of Peat</th>
<th>Temperature, °F</th>
<th>Operating Pressure, psia</th>
<th>Residence Time, min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota</td>
<td>350 - 550</td>
<td>190 - 1100</td>
<td>10 - 40</td>
</tr>
<tr>
<td>North Carolina</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maine</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The flow rate of the Peat-Water Slurry (5% wt Dry Peat) to First CSTR is 820 lb/hr.
each stage. The saturated steam will then be condensed in the appropriate stage of the flash heater section, thus heating the feed peat slurry. Each stage of the flash heater is approximately 12 inches in diameter by 3 feet long. A 65 gpm recirculation pump will provide an adequate flow of slurry to generate a curtain of liquid to prevent vapor blow-by. Each stage of the flash cooler consists of a 6-inch diameter pipe approximately 3.5 feet long. Figure 4 is a process flow diagram of the flash heat exchange system. From the third stage of the flash heater, the heated peat slurry will be pumped by a reciprocating metering pump to the first continuously-stirred tank reactor (CSTR). Just before the first CSTR, the peat-water slurry will be sparged with superheated steam to adjust the temperature of the slurry to the desired level. The CSTR system consists of CSTR's that can be operated in any combination of series and/or parallel flows. Each CSTR is constructed of 3-1/2 feet of 16-inch, Schedule 100, 316 stainless-steel pipe. The slurry is continuously stirred by an Autoclave Magnedrive II agitator. Three 16-inch-diameter, 8-inch-long heating bands, each having an output of approximately 4000 watts, will be used to maintain the desired CSTR temperature. Four inches of fiberglass insulation will surround the CSTR to minimize heat loss. A proposed CSTR process control and instrumentation diagram is shown in Figure 5. Following the last CSTR, the processed slurry will be transferred to the flash cooler section, where it will undergo three pressure letdown stages to atmospheric pressure.

From the last stage of the flash cooler section, the processed slurry will flow into a 340 gallon combination surge and holding tank before being pumped through a filter press. Upon removal of the wet carbonized solids, the filtrate will then be passed through the shell and tube heat exchanger on the shell side. Both the shell side and tube side flows will utilize a 120 gpm recirculation pump to maintain the desired slurry velocity in this heat exchanger. The cooled, spent liquor can either be recycled to a slurry feed tank or directed to liquor storage for eventual disposal.

Following the completion of the process and equipment designs, construction of the wet carbonization PDU was begun. The general floor layout for the wet carbonization PDU is shown in Figure 6. All long-lead-time items have been requisitioned and purchase orders issued on the majority of the short-term delivery
Figure 4 Schematic Diagram of Flash Heater/Cooler for PDU-Scale Wet-Carbonization Tests
Figure 5 CSTR Process Control and Instrumentation.
items have been completed. The construction of the support structure for the CSTR's and flash heat exchange systems has been completed. The only remaining structural support to be fabricated is for the shell and tube heat exchangers. Installation of the gas sampling and infrared solenoid valve systems has also been completed. Work has begun on the CSTR purge and level control systems. Fabrication of the CSTR's and slurry sampling systems has been initiated. Completion of the PDU is expected to be accomplished in August of this year.

FUTURE WORK

An overview of the wet carbonization program shows that this project consists of the following four tasks:

1. Equipment Design and Construction
2. Continuous Wet-Carbonization Tests
3. Hydrogasification Characterization of Selected Wet Carbonized Peats
4. Process Design and Economics

Hydrogasification characterization tests will be made after the initiation of the wet carbonization tests. Proposed ranges of operating conditions are shown in Table 2.

A comparison of the results obtained in the bench-scale wet carbonization autoclave and those obtained from the wet carbonization PDU will be carried out, primarily to determine scale-up effects. A process design and economic study will be conducted using the PDU-scale data as a basis.
Table 2. Range of Operating Conditions For Wet Carbonized Peat Hydrogasification Tests At 5 Seconds Residence Time

<table>
<thead>
<tr>
<th>Type of Wet Carbonized Peat</th>
<th>Reactor Temperature, °F</th>
<th>Hydrogen Partial Pressure, psia</th>
<th>Reactor Pressure, psia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota, North Carolina, Maine</td>
<td>1000-1500</td>
<td>0-250</td>
<td>250</td>
</tr>
</tbody>
</table>
QUESTIONS AND ANSWERS

Q: Can you tell the group a little about what, in your view, some of the key technical aspects of the project are and the areas that you are going to focus on in your study?

A: Basically some of the key aspects of the heat transfer are what are the characteristics of this material. We are going to try to determine what these characteristics are.

We are going to see if there are any problems in the flash heat exchange system with foaming and tube fouling. I think these are very critical areas in the heat transfer aspect of the system.

Q: Why do you have four CSTRs rather than just the one?

A: We went to the four CSTRs because it offers us quite a bit of flexibility. By taking slurry samples in between each CSTR we can essentially have four different tests. We can get residence times of 10, 20, 30, and 40 minutes.

The cost differential between one large CSTR and four smaller CSTRs was very minimal, and we decided that the additional information gained from each operation was worth the expense.

Q: How does your work differ from, for instance, work that has gone on in Sweden in this kind of technology?

A: The work is similar to what has been done in Sweden and Finland. The main difference is that all of the peats have to be characterized individually, since the variety of European peats may not act the same as the American varieties. For example, we see large differences among the gasification characteristics of Minnesota, Maine, and North Carolina peats. They tend to be site-specific or area-specific.
Q: Does that imply that your technology needs to be site-specific?

A: There would have to be some adjustment in the operational parameters, depending on what site you intend to locate your plant at.

COMMENT: I think I can help out on that question.

The technology in Sweden and Finland comes down to a technology that is intended to produce a beneficiated peat product, a solid product. In this program we are developing a technology more as a dewatering method and are trying to find the least severe conditions of wet carbonization that would be acceptable for the application of conventional solid/liquid separation methods such as pressure filtration.

Additional information will come out of this program and that is why we are going up to as high as 550 degrees F, since the equipment is there. We will also be obtaining some further information on the effects of operating parameters on the properties of the product so that the data will be useful later on when our program is expanded to include beneficiation, liquids production, and combustion with power generation. The more severe the conditions, the more the peat is beneficiated and, thus, has a higher energy content on a unit weight basis and is less expensive to transport.

Further, the technology in Europe has pretty much reduced the operating temperature to a range of about 400 to 450 degrees F. What we want to do is try and study the effect of temperature on the performance. It may be that for one purpose, gasification for example, we will operate at the point of incipient wet carbonization, which is about 375 degrees. If we want to make a solid fuel, we may want to go to more severe conditions.

That is the kind of information we will try and get out of this program.
Q: Have we got any kind of an idea what this will add to the cost of the product?

COMMENT: I think that those who are evaluating wet carbonization in various types of processes -- you can't look at the wet carbonization without looking at the harvesting system that will be utilized for wet peat in conjunction with it. There are basically two approaches. One is for harvesting air-dried peat, which is a very seasonal and labor-intensive sort of approach. Also, if you wanted to make a transportable solid fuel, a less capital-intensive densification step and final thermal dewatering step would be required. The second approach is to use a cheap feedstock, wet extracted or wet harvested peat, and use a more process-intensive and capital-intensive approach.

I think that the jury is probably still out as to which is going to end up with the lowest net cost. In larger scale applications, there is reason to believe that the wet carbonized approach might be lower in overall cost.
HYDROGASIFICATION PDU STUDIES

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BACKGROUND

Two-stage gasification systems for the conversion of peat to substitute natural gas (SNG) generally incorporate a first stage of hydrogasification followed by a second stage of char gasification. Laboratory and PDU-scale tests conducted with peats from Minnesota, Maine, and North Carolina show that the gasification characteristics of peats from different regions could be significantly different. Therefore, it is desirable to determine the gasification characteristics of peat from the major peat deposits of the United States.

For all thermal processes for converting peat to synthetic fuels, the feed moisture content should be about 50 weight percent or less. Dry harvesting methods use solar energy to produce peat containing about 50 percent moisture. Wet harvesting methods produce peat containing 90 to 95 percent moisture, which must be dewatered to 50 weight percent before being used. Several peat mechanical and thermal dewatering methods are commercially available and some improved methods are being developed. The particular method of peat harvesting and dewatering could affect the gasification characteristics of peat.

OBJECTIVE

In the current program, hydrogasification tests are being conducted in two separate tasks. The objective of the first task is to study the gasification characteristics of Florida and Alaska peats. The objective of the second task is to determine the effects of dewatering methodologies on the gasification characteristics of peat. Four different dewatering methods have been selected for testing in this task. These are:

- North Carolina sod peat
- Minnesota peat dewatered in a Sulzer belt press and thermally dried at 300°F in a Sulzer fluidized bed dryer
- Minnesota peat dewatered in a Sulzer belt press and thermally dried in a tray dryer at 250°F
Minnesota peat dewatered by IGT's solvent extraction dewatering process with the preferred solvents.

The effects of temperature, pressure, feed peat moisture content, and feed gas partial pressures on the gasification yields of peat are the primary operating variables being investigated.

**WORK PLAN**

*Equipment Description*

The hydrogasification tests for this project are being conducted in an existing entrained-flow reactor. A schematic flow diagram of the high-pressure, high-temperature, continuous-flow process development unit (PDU) is given as Figure 1. Peat is fed at a rate of about 10 lb/hr into the reactor by the reactor feed gas, which consists of mixtures of steam-hydrogen, hydrogen-nitrogen, or synthesis gas. The mixture enters the coil at the top and attains the desired operating temperature almost instantaneously. Solids residence times in this unit range from 1 to 10 seconds. The product stream exits the reactor bottom and passes through a cyclone. Appropriate flow measurements are made and chemical analyses are performed for data analysis. The product gas stream continues on through an absolute solids filter followed by a condenser. The condensate is collected, measured, and analyzed. Recovery of light and heavy hydrocarbons remaining in the gas stream is accomplished in a high-pressure cold trap followed by mist filters and, if needed, a low-pressure cold trap. The cooled product gas is analyzed by an infrared hydrocarbon analyzer. Additional gas samples are taken for mass spectroscopic analysis. The entire gas flow is finally measured.

*Status Report*

Samples of peat from Florida (Seffner, Florida, near Tampa) and Alaska (Anchorage) have been obtained and analyzed for selection of a representative peat. The Florida peat sample is a reed-sedge peat and meets the DOE criteria for a fuel-grade resource. About 2.5 tons of this peat have been ordered and delivery is
Figure 1 Schematic Diagram of the Peat Hydrogasification Process Development Unit
expected at the end of April. The complete analysis of the Florida peat and analyses typical of Minnesota, Maine, and North Carolina peats are presented in Table 1.

Peat samples obtained from Alaska did not meet the DOE criteria for a fuel-grade resource. Efforts to procure fuel-grade peat from Alaska will continue. When the ground thaws in June, other potential fuel-peat samples will be selected for analysis.

The operating conditions for the hydrogasification tests are temperatures, pressures, and residence times in the range of 1000° to 1500°F, 100 to 500 psig, and 1 to 10 seconds, respectively. The feed gas composition will include hydrogen, steam-hydrogen, and synthesis gas mixtures. A total of 19 tests are planned. In conjunction with these tests, char gasification tests in a thermo-balance unit will be conducted to determine the reactivity of the peat. These tests will be conducted at temperatures of 1500° to 1700° and pressures of 100 to 500 psig. Kinetic models for these two peats will be developed.

Tests to determine the effects of dewatering methodology on the gasification characteristics of peat have begun. Four peat dewatering methods are being investigated:

- Sod harvested, air-dried North Carolina peat from First Colony Farms.
- Wet Minnesota peat mechanically dewatered in a Sulzer belt press and then thermally dried at 300°F in Sulzer's fluidized bed dryer.
- Wet Minnesota peat mechanically dewatered in a Sulzer press and then thermally dried at 250°F in a tray dryer.
- Minnesota peat dewatered by the solvent extraction method.
Table 1. Typical Chemical Analyses of Florida, Minnesota, Maine and North Carolina Peats

<table>
<thead>
<tr>
<th>Peat Sample</th>
<th>Florida</th>
<th>Minnesota</th>
<th>Maine</th>
<th>North Carolina</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate Analysis, dry basis, wt %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>56.3</td>
<td>65.0</td>
<td>60.0</td>
<td>59.9</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>24.0</td>
<td>23.7</td>
<td>36.4</td>
<td>34.9</td>
</tr>
<tr>
<td>Ash</td>
<td>19.7</td>
<td>11.3</td>
<td>3.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Ultimate Analysis, dry basis, wt %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>49.60</td>
<td>49.90</td>
<td>57.10</td>
<td>57.80</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.29</td>
<td>5.09</td>
<td>4.77</td>
<td>4.99</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.62</td>
<td>0.27</td>
<td>0.53</td>
<td>0.22</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.74</td>
<td>2.73</td>
<td>1.17</td>
<td>1.36</td>
</tr>
<tr>
<td>Oxygen (by difference)</td>
<td>22.09</td>
<td>30.71</td>
<td>32.82</td>
<td>30.45</td>
</tr>
<tr>
<td>Ash</td>
<td>19.66</td>
<td>11.30</td>
<td>3.61</td>
<td>5.18</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td><strong>Gross Calorific Value, Btu/lb</strong></td>
<td>9736</td>
<td>8506</td>
<td>9322</td>
<td>9485</td>
</tr>
</tbody>
</table>
Arrangements are presently being made to ship wet peat from Minnesota to Switzerland to be dewatered in a Sulzer belt press. A portion of that peat will be further dried in their fluidized-bed dryer and returned; the remainder will be shipped back to IGT to be dried in a tray dryer at 250°F. Two tests with North Carolina sod peat from the First Colony Farms have been conducted. Table 2 summarizes the operating results from the tests. Chemical analyses are not completed at this time and results will be presented when they become available. Three hydrogasification tests are contemplated for each dewatering method. They will be conducted at 250 psia reactor pressure, solids residence time of 5 seconds, and temperatures of 1200°, 1300°, and 1400°F. Laboratory-scale char gasification tests are also being conducted with these dewatered peats in the thermobalance to determine gasification kinetics. The operating conditions for these tests are 1500°, 500 psig, and steam-hydrogen mixture (50 mol percent hydrogen).

FUTURE WORK

Efforts to procure Alaskan peat will continue. Hydrogasification tests will begin as soon as peat from Florida is received; the project will conclude with tests with Alaskan peat. Tests with the North Carolina sod peat will continue, and as the other dewatered peats are obtained, they will be tested for their hydrogasification characteristics. Efforts are continuing to locate a system large enough to produce sufficient quantities of solvent-dewatered peat. In addition, thermobalance tests will also be conducted with all of these materials.
Table 2. Summary Test Results for the North Carolina Sod Peat

<table>
<thead>
<tr>
<th>Test No.</th>
<th>PDM-1</th>
<th>PDM-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Peat Moisture, %</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Peat Feed Rate, lb/hr</td>
<td>8.9</td>
<td>8.8</td>
</tr>
<tr>
<td>Average Reactor Temp, °F</td>
<td>1420</td>
<td>1200</td>
</tr>
<tr>
<td>Reactor Pressure, psia</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Gas Velocity, ft/sec</td>
<td>17.9</td>
<td>17.3</td>
</tr>
<tr>
<td>Solids Residence Time, sec</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Carbon Conversion, % of feed</td>
<td>59</td>
<td>48</td>
</tr>
</tbody>
</table>
QUESTIONS AND ANSWERS

Q: I am curious about what you consider to be the important differences among peats from Florida, Minnesota, Maine, and North Carolina.

A: The important differences we have found in our previous programs were that North Carolina peat has a significantly lower reactivity, about 30% less, than that of the Minnesota and the Maine peats. We have published this information in our interim reports.

Q: The chart you put up before listed certain characteristics of peat. Are you implying that these are the major reasons for the differences in reactivity?

A: No. The slide that shows the four different peats basically is to indicate their chemical composition, not so much their reactivities.

What the slide shows is the analysis of the Florida peat that we are going to purchase. We are developing a model to relate chemical composition versus reactivity in the hydrogasification products.

Q: What are the characteristics of those peats that you have catalogued? In other words, do you know what kind of original plant materials they were formed from? Do you know where they were found? It seems to me that you are conducting an experiment comparing different kinds of peat and their hydrogasification characteristics. And it would also seem to me that you would want to know as much about those peats as you could before you did your experiments so that you could have some sense of looking for what you would call driving variables. In other words, maybe it is that a reed sedge peat has different qualities from a woody peat.
A: I think we are all addressing the same point, but I think the thing that needs to be understood is that precisely the reason for doing these tests is to come up with a reactivity measurement. And it is much more difficult to isolate just what it is in any particular component or chemical composition. David Graves will address some of these things also, as he tries to determine why peat dewater the way it does. The same question may be asked of coal. Why is a lignite so much more reactive than a subbituminous coal, et cetera? A lot of coal work has been done, but I don't think I have seen anything that exactly says why reactivity is so much higher in one coal versus another, or why specific reactivity tests are conducted on a particular coal incoming from a particular seam.

Q: Well, yes, I would agree. I was just curious, for instance, why you didn't take samples from four localities of Minnesota peats or four Maine peats. Why go to Florida and all over the country at this point if you are trying to find a reactivity measure?

A: Well, the assumption is that the peat sample from one particular peat bog would have very similar characteristics, just like coal samples from a coal seam tend to have very similar characteristics. If you go to a different location where you have a somewhat different coal due to the geological formation of that coal, you might find a different reactivity.

COMMENT: If I may add to that, we are also trying to bracket a range of peats in the United States and we feel that from Florida to Alaska are the two extremes. We already have three states in between. So by looking at Florida and Alaska and coupling that information together with the hydrogasification data that we have for the states of Minnesota, Maine, and North Carolina, we have a very good cross-section. With these results, we will have bracketed all the peats in the United States and can get an idea of just how the reactivity and the gasification properties differ in peat from varying parts of the country.
But you are quite right. Peat is a very diverse material and you only have a certain amount of time and a certain budget, a fixed budget, to analyze it. So this way we feel as though we are getting as much information as we possibly can for the amount of money and the amount of time available.

Q: What kind of information were you gathering about these peats?

A: Well, I think it is really quite a bit more than chemical composition. We are looking at the chemical properties.

A gasification model has been developed with a number of key parameters, and the numerical value of these parameters will vary with peats from different regions. The idea of looking at Alaska and Florida peats is to see, first of all, whether the gasification properties will fit this model and whether the model is successful in predicting the gasification properties, in other words, the reactivity and selectivity, what kind of products are made during hydrogasification; and, second of all, to quantify values for these parameters. And also to look at things like fluid mechanics, things which would be very important if these peats were ever tested on a larger scale in an integrated continuous PDU or pilot plant. These are all critical data that are needed in order to plan prudently experiments at a continuous level.

So really it is not to obtain chemical properties, although that is necessary in order to do the material balances. We want to get the chemical properties and the fluid mechanics for these.
Q: In Florida, there is a type of peat generally known as the Everglades peat, which is different from the type of peat which is largely used for agricultural purposes and is obtained from the central backbone of Florida.

Find out where the Tampa operation obtain its peat, then you would know what kind of Florida peat you have. You see, within the states there are vast differences in geological and ecological settings.

A: We have not surveyed all the peats in Florida. We have procured this particular peat from Delta Soils, a company located in Hillsborough County that gets its peat in a bog close to Tampa. I don't know the exact name of the place.

Q: Is it the coastal type peat?

A: No. It is classified as an inland-type peat.

Q: And you have the inland-type peat. Do you expect to find as much distinction as between the Minnesota and the Maine peat reactions?

A: It's very possible. We are only going to select one peat from each state for this program. We have a program of ten tests per material, and hopefully maybe in the future we can bracket a whole state. I don't know at this time.

Q: I would like to raise the question of whether the difference in the ash level was more critical than the types of peat you chose, since they are quite different.

A: I can't answer the question at this time. I hope to address that question by the time we complete the program.
PRELIMINARY WORK ON WATER RETENTION OF PEAT

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BACKGROUND

At the Second Technical Contractors' Conference on Peat held in October 1980, we presented the rationale for our proposed studies on water retention in peat and some of the techniques that would be used to distinguish among the various types of water. The relevant background material can be found in that report and will not be repeated except to state that water removal is one of the key problems involved in economic utilization of peat. Our goals are to contribute to basic knowledge about mechanisms of water retention so that effective drying techniques can be developed.

WORK ACCOMPLISHED TO DATE

A. Experiments Conducted at Constant Humidity

As described in our previous report, one important fraction of water in peat was expected to be that bound either weakly or strongly to chemical groups. By measuring equilibrium water contents at various humidities, temperatures, etc., we felt that we could characterize this fraction effectively. A thermostatted chamber was set up with a small fan to circulate the air in it. Constant humidity air was continuously recirculated through the chamber at about 450 ml/minute with an FMI pump.

This recirculated air was maintained at constant humidity by bubbling it through a saturated salt solution maintained at constant temperature in a separately thermostatted bath. Table 1 lists some standard salt solutions that can be used to achieve a wide range of constant humidity values. In some cases (primarily high humidity salts such as K₂SO₄), salt crystals formed in the bubbler tube, plugging it up and disturbing operation. This was prevented by using a preceding bubbler containing distilled water so that the incoming air was always at a higher humidity than the salt solution in the thermostatted salt solution bubbler.
Table 1. Relative Humidity of Several Saturated Salt Solutions at 25°C

<table>
<thead>
<tr>
<th>Salt</th>
<th>Relative Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Chloride</td>
<td>12.0%</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>31-32%</td>
</tr>
<tr>
<td>Sodium Nitrate</td>
<td>66%</td>
</tr>
<tr>
<td>Ammonium Chloride</td>
<td>79%</td>
</tr>
<tr>
<td>Potassium Bisulfate</td>
<td>86%</td>
</tr>
<tr>
<td>Potassium Sulfate</td>
<td>97%</td>
</tr>
</tbody>
</table>
A wire stirrup and sample pan in the chamber were suspended from an electronic balance. Two ranges (300 grams with 0.01g precision and 3000 grams with 0.1g precision) could be chosen. An internal microprocessor permitted sample taring and automatically eliminated most of the fluctuation caused by vibration, etc. by averaging readings. A special electronics interface was added to give an analog output for recording at a precision of 0.1%, and a future improvement will provide automatic data logging for computer data reduction. A diagram of this system is shown in Figure 1.

Two varieties of peat were available for initial studies: a relatively fibrous peat from Minnesota and a relatively decomposed peat from First Colony Farms in North Carolina. With each of these samples, the final dry weight was independent of the humidity over a range from 15% to greater than 97%. The moisture content was within 5% of that obtained under severe drying conditions (a vacuum oven at 200°C). Only the rate of drying was affected by chamber humidity.

The small amount of residual water was somewhat surprising, and suggests that (1) very little chemically-bound water was present in the peat, and (2) what water there is is bound very tightly. In agreement with other work, we found that water loss was partially irreversible. As Table 2 shows, dried peat was not able to reabsorb as much moisture as the fresh peat. These experiments will be expanded and continued to learn more about the rates of drying and the factors responsible for irreversible water loss. At present, pore closing owing to capillary forces appears to be a likely explanation.

B. Experiments to Determine Free Water

A high molecular weight dyed polymer (2 million Dalton Blue Dextran 2000) was tried as a probe for free water. A known weight of peat was equilibrated with an aqueous solution of the polymer. If the dyed polymer freely permeated a certain fraction of the peat water, the final dye concentration in the external solution could be used to estimate the free water fraction. Unfortunately, our first results showed that the polymer was adsorbed by the peat sample. Dye concentrations at equilibrium (measured by spectrophotometer) were impossibly
Figure 1 Constant Humidity Peat Dryer
<table>
<thead>
<tr>
<th>Initial Water Content (%)</th>
<th>Water Content After Soaking (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.7</td>
<td>77.6</td>
</tr>
<tr>
<td>4.5</td>
<td>53.8</td>
</tr>
</tbody>
</table>
low. This series of tests will be repeated when a new tracer with non-adsorptive properties can be found.

C. Water Removal by Centrifugal Force

A further set of experiments was designed to estimate pore diameters. As outlined in our previous report, the water retained in an ideal cylindrical pore is directly related to the pore diameter and the centrifugal force applied. A set of special centrifugal filter assemblies (Bio-Analytical Systems) was used to estimate the pore size distribution. The experiments have progressed smoothly so far and indicate a population of pores in the 200-250μ range (Figure 2). Smaller pores could not be measured with the 3000 g maximum centrifugal force applied so far.

These filters are not designed for forces higher than this, but the results to date have been so encouraging that they demand additional work. Two possibilities are obvious: (1) special filters appropriate for high g forces can be constructed, (2) a low surface tension fluid such as methanol can be substituted for the water. Either tactic will permit smaller pores to be measured, and a combination of the two will extend the range of data considerably.

SUMMARY

Preliminary studies in three different areas have been undertaken to date on peat samples from Minnesota and North Carolina. Future studies will expand work in other areas and will continue with the tests already described, both singly and in combination. The two types of samples studied so far are unfortunately not virgin peat. The Minnesota peat contained only about 53% moisture and the North Carolina peat 80% moisture. Peat as obtained from a bog is expected to contain 90 to 95% moisture. Because of the irreversible nature of peat drying, the results quoted should not be interpreted as anything but preliminary approximate findings. Individuals who wish to have peat samples from a specific region evaluated may send them to our laboratory.
Figure 2 Centrifugal Peat Water Removal
QUESTIONS AND ANSWERS

Q: A question related to the cold fluidized-bed dryer. Did you mean to imply that the drying rate was not affected by relative humidity or just that the final equilibrium moisture content did not appear to be affected?

A: The rate is, of course, very strongly dependent on the humidity. At 97% humidity, it might take five or ten days to dry a sample, under our conditions, and at 12% humidity, only a matter of hours.

The rate is also affected by the fan speed. We haven't yet been able to measure the air velocity over the peat. But this would also be an important variable.

However, the ultimate level that you could dry the peat down to doesn't seem to be a function of humidity within that range. The rate, of course, is very strongly influenced.

Q: It wasn't clear on your slide on centrifugal dewatering. Was that vertical axis water remaining or water removed?

A: That was water remaining.

Q: I was going to ask about the dewatering with centrifugal versus pressing it. Would that make a significant difference?

A: What we are interested in is basic information. We think we can make a model that will give a relationship between centrifugal force and the pore radius. I don't think we could do that with pressing.
Q: When the Bureau of Mines tested in Minnesota, with pressing at much higher pressures than 90 psi, they came up with an equilibrium of about 67% total moisture compared to 90% in the original peat. And we repeated this test at the University of North Dakota and they came to the same limit value, and that was with virgin peat. And that seems to be different from what you got with the 53%.

A: When I showed this graph (Figure 2) with the two results and I said this was the Minnesota peat, I didn't mean to imply that our initial sample was pressed to 53%. I should have explained what we did.

We took these peat samples as received from IGT (53% moisture) and we soaked them in water until they had picked up as much moisture as they could, so that the initial Minnesota peat sample "100%", as you saw on another graph, was able to be rehydrated up to about 77%. So that the graph represents going down from a rehydration limit of 77% down to 50% or something in that region.

Q: But if you looked at it from pressing of the original peat, like the virgin peat in Minnesota, it comes out that the limit value would be almost what you show for North Carolina peat. So I'm wondering if there is that much difference.

A: I don't know. It could be.

Q: You mentioned that some of the samples that you have taken were ones in which the peat had been drained for many years previous to the collection of the sample. And I am just wondering if having a peat exposed to the air in which there could be some possible oxidation could be an influence on some of your results. For example, we know that when they take lignite samples they are very careful to keep them under water so there is no oxidation and crumbling.
And, secondly, this idea of raw peat versus reconstituted peat. I don't know the answers there, but it does seem that if you take raw or wet peat, dry it or drain it and then reconstitute it, somehow it just doesn't snap back the same way.

A: These are very preliminary results. We don't consider either of these to be the final word. And that is why I am making this plea for people to send me some virgin peat, so we can repeat these tests on proper samples. This is really what we have to do in order to have meaningful results. These are all very preliminary things here.

Q: How much peat do you need and how do you want it shipped?

A: Even a couple of pounds would be fine. The sort of drying tests I have done so far, I used samples of ten grams. My balance can measure it to 1/100th of a gram. So that is pretty good accuracy.

Now, what we may eventually want to do in the future is the following: We might want to do some rate studies where we take a good sized chunk of peat, maybe four inches square or something like this, and expose one of those surfaces to the controlled-humidity air, at a known air velocity and see what is happening; in other words, is it diffusion through some good sized chunk of peat that is controlling the drying process or some other process? If we did such tests, then we would need, who knows? 20 pounds or 50 pounds or something like that. Also, I would prefer to have something that has been collected below the permanent watertable, and shipped in water.

Q: In listening to your studies here, it strikes me that there is a great deal of similarity between this and dehydration of clays and clay minerals, about which a great deal has been learned.
Among the other things, some years ago, when I was at the Shell Labs studying dehydration of clays, we used mixtures of sulfuric acid and water to get continuous variations in relative humidity and bubble it through the apparatus. And we coupled that with an X-ray diffractometer. In particular, we had the dry air go through the sample chamber of the X-ray diffractometer, so we could observe directly additions of water in layers in the clay structures.

A: I wish we had an X-ray diffractometer. In your case I guess you are really looking at crystal structure changes. And I don't know what sort of thing like that we might have in peat. It is interesting, the comment about clay. I wasn't aware of that. I have recently discovered, though, that people working with sewage sludge have been interested in the same sort of thing and that there is some literature on sewage sludge which is applicable to this, or I think is going to be applicable to peat, as well. So I will certainly look up some of the clay literature. And I would be interested in the references, if you could give them to me.

Q: In the water that is being drained out, what percentage of peat, say in the colloidal stage, would be removed? And what would be the efficiency of the peat that is left as peat and how much peat is removed in a smaller colloidal state? How many extremely small particles of peat are lost then in the centrifuge?

A: None of the particulate matter. The water that comes through is clear. We have filters that have 2/10ths-of-a-micron pore size, and we could easily use those, as well as one micron.

We haven't seen any significant amount of colloidal material coming through, either. In fact, we have used similar pore-size membranes in the dye studies that I mentioned, because, of course, when you soak the peat in the dye solution, some of the colloidal material comes out and you have to remove that before you can put it in the spectrophotometer. The colloids scatter too much light.
So, as far as we can tell, one or two-micron filters seem to be adequate to get rid of essentially all of the colloidal material, or at least a good fraction of it. You can never tell. There can always be colloids down below the wavelength of light that are not visible to the naked eye. But it removes all the visible colloids.

Q: You are trying to isolate the three different means of water retention. I am wondering with your centrifuge, where you are assuming that it is pore retention, if there is a possibility that you are actually rupturing cell walls at that G level.

And do you have any way of, maybe after you do your cell-rupturing experiments, going back and repeating this centrifuge test to corroborate that or see if you really have isolated mechanisms?

A: I would say that based on what I know and what is in the literature, it is very unlikely that we are rupturing cell walls. Cell walls, particularly plant cell walls, are very difficult to break. In fact, for the enzymologist who is trying to extract enzymes from cells, this is always a problem and they resort to all kinds of very complicated things like this freeze-extrusion press that I mentioned, devices where they will shake the sample in a high-speed shaker with glass balls to smash the cells, ultrasonic high-pressure probes that blast a lot of sonic energy in and create cavitation. And even these devices are in some cases not very effective at breaking plant cell walls.

So I would say that it is very unlikely that under only 3,000 Gs we would be rupturing any cell walls at all. I don't have any way of measuring that right now, but I suspect that it is going to be a very minute effect.
Q: I don't understand the micron size. Are you sure you are not plugging up your filter at some point with all these small colloids?

A: I don't believe so. Now, your suggestion is not a bad one. We could take the sample out of there after it had gone through for a certain period of time, put in a fresh filter, and see if more comes out.

It seems to be a fairly good end point, though. You can operate the centrifuge at various speeds and you can also operate it for various periods of time. And it seems to me that what we have seen could not be explained by simple plugging of the filter, although it is certainly something that I am going to have to look into.

These are all very preliminary sorts of results so far.
PEAT DEWATERING: SOLVENT EXTRACTION

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BACKGROUND

IGT's solvent extraction dewatering process is based on the principle that the solubility of water changes significantly with temperature in certain organic solvents, increasing at high temperatures and decreasing at low temperatures. At cool temperatures the solvent and water separate, and the water and solvent can be decanted.

A block flow diagram of IGT's solvent extraction process is shown in Figure 1. The process consists of mixing the wet feed solids with an organic solvent to make a pumpable slurry and then heating the mixture. The temperature and pressure in the reactor will depend on the particular solvent used. The pressure in the reactor will be high enough to prevent water from vaporizing, as this would require extra heat duty.

Because of the increased solubility of water in the solvent at elevated temperatures, most of the water in the solids dissolves in the solvent. Solvent containing the removed water is taken from the high-temperature vessel and cooled to 100°F, causing it to separate into water-rich and solvent-rich layers. The sensible heat contained in this solvent stream is recovered in heat exchangers for heating the incoming raw peat slurry. The solvent-rich layer is recirculated to the front end of the process, and the water-rich layer is sent to wastewater treatment.

A process advantage is that water vaporization is avoided, saving much heat energy.

OBJECTIVE

The objective of this program is to determine the preliminary technical and economical feasibility of using IGT's solvent extraction process for the dewatering of peat. Parallel objectives of the program are to:

- Identify organic solvents that can be readily used to dewater raw peat by IGT's solvent extraction process.
Figure 1 IGT's Solvent Extraction Peat Dewatering Process
• Design, construct, and operate bench-scale equipment for testing the most promising solvents.

• Estimate the preliminary economics of the process for a commercial-scale peat dewatering plant using a selective solvent.

TECHNICAL PROGRESS

PREVIOUS WORK

On the basis of the solubility data in the literature, 10 potential solvents were identified: n-butyl alcohol, isobutyl alcohol, amyl alcohol, methyl ethyl ketone (MEK), furfural, aniline, diethyl ketone (DEK), phenol, o-toluidine, and benzene. The primary criterion used to select the solvents was a high change in solubility for water between 100° and 400°F. The 400°F upper limit was selected because carbonization reactions start at this temperature. A summary of the physical property data for these solvents is presented in Table 1.

If a solvent is mixed with peat, it should separate quickly. Therefore, laboratory-scale tests were conducted to determine how the solvent soaked the peat. The results of the phase-separation and soaking tests are shown in Table 2.

The results of these tests eliminated furfural, aniline, phenol, and o-toluidine from the list of potential solvents, because the settling time and/or the soaking characteristics for these solvents were unfavorable. Because n-butanol and isobutanol have similar properties, isobutanol was eliminated as well.

A bench-scale unit was designed and constructed to conduct dewatering tests with the selected solvents. A schematic diagram of the equipment is shown in Figure 2.

The solvent to be tested is initially charged to the mixing chamber and heated to operating temperature. Wet peat is injected into the mixing chamber through the feed chute. Agitation in the mixing chamber ensures intimate peat-solvent
Table 1. Summary of Potential Solvent Data For Peat Dewatering

<table>
<thead>
<tr>
<th>SOLVENT</th>
<th>Mixture Temp (High), °F</th>
<th>Solubility, wt% at 100°F, wt%</th>
<th>Solubility, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Butyl Alcohol</td>
<td>257</td>
<td>67.6</td>
<td>21.4</td>
</tr>
<tr>
<td>Isobutyl Alcohol</td>
<td>270</td>
<td>55.0</td>
<td>18.4</td>
</tr>
<tr>
<td>Phenol</td>
<td>151</td>
<td>50.8</td>
<td>33.0</td>
</tr>
<tr>
<td>Amyl Alcohol</td>
<td>360</td>
<td>42.7</td>
<td>10.0</td>
</tr>
<tr>
<td>Furfural</td>
<td>248</td>
<td>39.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Methyl Ethyl Ketone</td>
<td>284</td>
<td>36.0</td>
<td>10.6</td>
</tr>
<tr>
<td>Aniline</td>
<td>320</td>
<td>32.0</td>
<td>5.9</td>
</tr>
<tr>
<td>o-Toluidine</td>
<td>400</td>
<td>25.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Diethyl Ketone</td>
<td>400</td>
<td>25.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Benzene</td>
<td>400</td>
<td>4.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2. Laboratory Test Results For Phase-Separation Time and Soak Tests

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Minimum Solvent Required to Soak Peat (85% H2O), lb/lb</th>
<th>Peat-Solvent Phase Separation Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Butyl Alcohol</td>
<td>0.98</td>
<td>50.0</td>
</tr>
<tr>
<td>Isobutyl Alcohol</td>
<td>0.66</td>
<td>60.0</td>
</tr>
<tr>
<td>Phenol</td>
<td>2.14</td>
<td>*</td>
</tr>
<tr>
<td>Amyl Alcohol</td>
<td>0.72</td>
<td>50.0</td>
</tr>
<tr>
<td>Furfural</td>
<td>2.24**</td>
<td>*</td>
</tr>
<tr>
<td>MEK</td>
<td>0.84</td>
<td>20.0</td>
</tr>
<tr>
<td>Aniline</td>
<td>0.90</td>
<td>*</td>
</tr>
<tr>
<td>o-Toluidine</td>
<td>0.84</td>
<td>*</td>
</tr>
<tr>
<td>DEK</td>
<td>0.72</td>
<td>Instantaneous</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.78</td>
<td>Instantaneous</td>
</tr>
</tbody>
</table>

* No separation.

** No clear layer visible.
Figure 2 Solvent Dewatering Bench-Scale Unit
contacting. At the end of the test, the agitation is stopped, and the peat is allowed to flow into the settling section. After the peat has settled, excess solvent is cooled and collected in the separation chamber.

The peat from the settling section is analyzed for residual water content. The solvent in the separation chamber is analyzed for water extracted from the peat.

PRESENT RESULTS

A total of 37 solvent extraction dewatering runs using 5 different organic solvents and 3 different peats (Minnesota, North Carolina, and Maine) have been conducted over a range of temperatures and residence times. A summary of the range of operating conditions used in these tests is presented in Table 3. The results of the tests are presented with a discussion of the suitability of each solvent for the dewatering application.

Table 3. Range of Operating Conditions for Bench-Scale Solvent Extraction Dewatering Tests with Minnesota Peat

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Temp, °F</th>
<th>Residence Time, min.</th>
<th>Solvent Used, lb/lb water</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-butanol</td>
<td>100-275</td>
<td>10-90</td>
<td>2.8-40</td>
</tr>
<tr>
<td>Amyl alcohol</td>
<td>293-304</td>
<td>10-90</td>
<td>5.1-7.0</td>
</tr>
<tr>
<td>MEK</td>
<td>272-304</td>
<td>10-90</td>
<td>6.9-7.2</td>
</tr>
<tr>
<td>DEK*</td>
<td>295-311</td>
<td>10-60</td>
<td>6.9-7.1</td>
</tr>
<tr>
<td>Benzene</td>
<td>198-404</td>
<td>10-90</td>
<td>62.2-155</td>
</tr>
</tbody>
</table>

* Also used with North Carolina and Maine Peats.
By examining the solid/solvent product from the slurry settling section after the runs, it was evident that several of the solvents significantly altered the physical condition of the peat. The most active solvent in this regard was n-butanol, which appeared to break down the peat to such an extent that no solvent/peat interface could be observed. Amyl alcohol and MEK both reacted with peat, although not to the extent that the n-butanol did. In addition to reacting with the peat, MEK also has a high solubility in water at low temperatures (19.7 wt% at 100°F), which means that a substantial amount of makeup MEK would be needed in a process or a significant recovery from water would be necessary. Of the two solvents that did not appear to react appreciably with the peat, benzene has a much lower affinity for water than DEK and one would require substantially more of it to remove the same amount of water. Therefore, on this basis, DEK appears to be the most promising candidate solvent. These statements are summarized in Table 4.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Extent of Solvent-Peat Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEK</td>
<td>Very Low</td>
</tr>
<tr>
<td>Benzene</td>
<td>Low</td>
</tr>
<tr>
<td>MEK</td>
<td>Moderate</td>
</tr>
<tr>
<td>Amyl Alcohol</td>
<td>Moderate</td>
</tr>
<tr>
<td>n-Butanol</td>
<td>Very High</td>
</tr>
</tbody>
</table>

Dewatering tests using each of the five selected water-saturated solvents were also conducted to determine the relative dewatering characteristics of each solvent. The tests were conducted at a nominal temperature of 300°F and for a 10-minute residence time. The results of the tests are shown in Table 5.
Table 5. Results of Solvent Runs With Minnesota Peat
(81.5% Moisture, T=300°F, Saturated Solvents, RT=10 min)

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Phase Separation</th>
<th>Pressing Feed Moisture</th>
<th>Total Removed, %</th>
<th>Feed Moisture Removed, % Water in Peat, Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>18.9</td>
<td>69.4</td>
<td>88.3</td>
<td>28.9</td>
</tr>
<tr>
<td>DEK</td>
<td>68.1</td>
<td>17.8</td>
<td>85.9</td>
<td>46.3</td>
</tr>
<tr>
<td>MEK</td>
<td>48.2</td>
<td>25.7</td>
<td>73.9</td>
<td>58.5</td>
</tr>
<tr>
<td>Amyl Alcohol</td>
<td>62.7</td>
<td>20.2</td>
<td>82.2</td>
<td>47.7</td>
</tr>
<tr>
<td>n-Butanol</td>
<td>64.1</td>
<td>7.7</td>
<td>71.8</td>
<td>52.1</td>
</tr>
</tbody>
</table>

The results show that benzene removed approximately 90% of the water from the peat, while DEK and amyl alcohol removed nearly 85% of the water. MEK and n-butanol removed approximately 75% and 70% of the water, respectively.

On the basis of these tests, benzene appears to remove the water better than DEK. However, note that most of the water was removed in the pressing step for benzene. With DEK, the bulk of the water in the peat was removed in the phase separation step, which is more desirable.

In order to determine the relative dewatering characteristics of different peats, tests using water-saturated and recycled DEK were conducted in Minnesota, North Carolina, and Maine peats. These tests were conducted at a nominal temperature of 300°F and for residence times of 10 and 60 minutes. The results of these tests are presented in Table 6.

The results show that the water-saturated DEK removed 85.9% of the water from the Minnesota peat, 87.6% of the water from the North Carolina peat, and 75.5% of the water from Maine peat at the conditions used. For all of the peats, most of the water was removed in the phase-separation step. The weight percent water remaining in the peats after solvent dewatering was approximately 50% for all three peats.
The results show that recycling the DEK reduced the amount of water removed from the three peat types. Accordingly, the amount of water remaining in the peat also increased with recycling. The decrease in water removal efficiency with recycling was most significant for the tests with Maine peat. Water removed decreased from 75.5% with saturated DEK to 52.5% with Recycle II solvent. The water removal was least affected by recycling for the North Carolina peat. The weight percent water remaining in the peats after dewatering with recycled DEK ranged from 63.3% in the Minnesota peat to 71.5% in the Maine peat.

Table 6. RESULTS OF SOLVENT EXTRACTION DEWATERING TESTS WITH DEK AND PEATS FROM MINNESOTA, NORTH CAROLINA, AND MAINE

<table>
<thead>
<tr>
<th>Peat (% moisture)</th>
<th>Solvent</th>
<th>Phase Separation</th>
<th>Pressing</th>
<th>Total Water Removed, %</th>
<th>Water in Dewatered Peat, Wt%</th>
<th>Residence Time, Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota (81.5)</td>
<td>DEK (Sat)</td>
<td>68.1</td>
<td>17.8</td>
<td>85.9</td>
<td>46.3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle I</td>
<td>12.9</td>
<td>68.5</td>
<td>81.4</td>
<td>49.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle II</td>
<td>24.5</td>
<td>44.5</td>
<td>69.0</td>
<td>63.3</td>
<td>60</td>
</tr>
<tr>
<td>North Carolina (85)</td>
<td>DEK (Sat)</td>
<td>65.5</td>
<td>22.1</td>
<td>87.6</td>
<td>53.3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle I</td>
<td>49.8</td>
<td>28.0</td>
<td>77.8</td>
<td>68.8</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle II</td>
<td>22.9</td>
<td>57.1</td>
<td>80.0</td>
<td>67.1</td>
<td>60</td>
</tr>
<tr>
<td>Maine (85)</td>
<td>DEK (Sat)</td>
<td>74.4</td>
<td>1.1</td>
<td>75.5</td>
<td>53.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle I</td>
<td>43.1</td>
<td>11.1</td>
<td>54.2</td>
<td>67.9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Recycle II</td>
<td>31.6</td>
<td>20.9</td>
<td>52.5</td>
<td>71.5</td>
<td>60</td>
</tr>
</tbody>
</table>

Results were also obtained with a series of solvent runs on Minnesota peat. Both water-saturated and recycle tests were made at residence times of 10 to 60 minutes. The runs were conducted with Minnesota peat at a nominal temperature of 300°F. The results of these tests are shown in Table 7.

The results of these tests show that benzene removed approximately 83% to 94% of the water in the feed peat. In all 3 tests, most of the water was removed from the peat in the mechanical dewatering pressing step. In the water-saturated test, 18.9% of the water was removed in the phase-separation step and 69.4% in the pressing step. When the benzene was recycled, however, no water was removed in the phase-separation step.
<table>
<thead>
<tr>
<th>Solvent</th>
<th>Phase Separation</th>
<th>Pressing</th>
<th>Total</th>
<th>Water in Peat Peat, Wt%</th>
<th>Residence Time, min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene (Saturated)</td>
<td>18.9</td>
<td>69.4</td>
<td>88.3</td>
<td>28.9</td>
<td>10</td>
</tr>
<tr>
<td>Recycle I</td>
<td>-1.0</td>
<td>95.0</td>
<td>94.0</td>
<td>32.4</td>
<td>10</td>
</tr>
<tr>
<td>Recycle II</td>
<td>-3.7</td>
<td>86.4</td>
<td>82.7</td>
<td>36.4</td>
<td>60</td>
</tr>
<tr>
<td>DEK (Sat)</td>
<td>68.1</td>
<td>17.8</td>
<td>85.9</td>
<td>46.3</td>
<td>10</td>
</tr>
<tr>
<td>Recycle I</td>
<td>12.9</td>
<td>68.5</td>
<td>81.4</td>
<td>49.5</td>
<td>10</td>
</tr>
<tr>
<td>Recycle II</td>
<td>24.5</td>
<td>44.5</td>
<td>69.0</td>
<td>63.3</td>
<td>60</td>
</tr>
<tr>
<td>MEK (Sat)</td>
<td>48.2</td>
<td>25.7</td>
<td>73.9</td>
<td>58.5</td>
<td>10</td>
</tr>
<tr>
<td>Recycle I</td>
<td>18.5</td>
<td>41.4</td>
<td>59.9</td>
<td>62.7</td>
<td>10</td>
</tr>
<tr>
<td>Recycle II</td>
<td>20.2</td>
<td>60.7</td>
<td>80.9</td>
<td>49.9</td>
<td>60</td>
</tr>
<tr>
<td>Amyl Alcohol (Sat)</td>
<td>62.6</td>
<td>20.2</td>
<td>82.8</td>
<td>47.7</td>
<td>10</td>
</tr>
<tr>
<td>Recycle I</td>
<td>16.2</td>
<td>90.9</td>
<td>74.7</td>
<td>49.6</td>
<td>10</td>
</tr>
<tr>
<td>Recycle II</td>
<td>21.2</td>
<td>44.7</td>
<td>65.9</td>
<td>64.2</td>
<td>60</td>
</tr>
<tr>
<td>n-Butanol (Sat)</td>
<td>64.1</td>
<td>7.7</td>
<td>71.8</td>
<td>52.1</td>
<td>10</td>
</tr>
<tr>
<td>Recycle I</td>
<td>48.8</td>
<td>6.8</td>
<td>56.6</td>
<td>64.4</td>
<td>10</td>
</tr>
<tr>
<td>Recycle II</td>
<td>45.9</td>
<td>1.6</td>
<td>47.5</td>
<td>70.7</td>
<td>60</td>
</tr>
</tbody>
</table>
The amount of water remaining in the peat after the solvent-extraction treatment was 28.9% for the water-saturated benzene test, 32.4% for the first recycle benzene test, and 36.4% for the second recycle benzene test. This indicates that a recycle solution appears to be less effective in removing water than a water-saturated solution.

The results also tend to indicate that increasing the residence time from 10 to 60 minutes does not increase the water removal from the peat. Indeed, the percentage of water remaining in the peat was highest in the run with the 60-minute residence time. However, this may have been due to the condition of the benzene recycle containing increased amounts of dissolved organics.

The results of the tests conducted with water-saturated and recycled DEK showed that 69% to 86% of the water was removed from the feed peat. With the recycled solutions, more water was removed during phase separation than during pressing. The amount of water remaining in the peat was higher than that achieved with benzene, ranging from 46.3 to 63.3 weight percent.

With the other three solvents tested, the amount of water removed from the peat with water-saturated solvent ranged from 71.8% to 82.8%. Except for the results of the MEK tests, recycling the solvent tended to decrease the water removal efficiency. Accordingly, the water remaining in the peat also increased with recycling, except for the results of the MEK tests.

A comparison of the actual percentage of water removed from the peat for solvent amounts which theoretically would remove 100% of the water from the peat is shown for three benzene and DEK runs in Table 8. Based on these results, it appears that the benzene and DEK extracted, respectively, 88.3% and 85.9% of the water theoretically possible.

PRELIMINARY ECONOMIC EVALUATION

Based on the results of the solvent extraction dewatering tests conducted with Minnesota peat and diethyl ketone, we have prepared a preliminary process flow
Table 8. Percent Water Removal At Solvent Amounts Theoretically Predicted To Remove 100% of the Water
(T = 300°F)

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Theoretical Solvent Required to Remove 1 lb of Water, lb-solvent/lb-water</th>
<th>lb-solvent added to water in peat</th>
<th>Feed Moisture Removed, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-Saturated Benzene</td>
<td>61.9</td>
<td>66.0</td>
<td>88.3</td>
</tr>
<tr>
<td>Benzene Recycle I</td>
<td>63.9</td>
<td>65.8</td>
<td>94.0</td>
</tr>
<tr>
<td>Benzene Recycle II</td>
<td>67.6</td>
<td>63.4</td>
<td>82.7</td>
</tr>
<tr>
<td>Water-Saturated DEK</td>
<td>6.5</td>
<td>5.7</td>
<td>85.9</td>
</tr>
<tr>
<td>DEK Recycle I</td>
<td>7.4</td>
<td>5.9</td>
<td>81.4</td>
</tr>
<tr>
<td>DEK Recycle II</td>
<td>6.6</td>
<td>5.9</td>
<td>69.0</td>
</tr>
</tbody>
</table>
diagram for a dewatering plant producing 2.75 million lb/hr of 35 weight percent moisture peat and estimated the process economics. This quantity of dewatered peat is required for a plant producing 250 billion Btu per day of SNG from peat.

Briefly, peat containing 70% moisture is mixed with recycled and makeup solvent to yield a slurry containing about 5% dry solids. This feed is preheated by heat exchange with hot extract and steam to the 300°F extraction temperature. The reactor effluent is centrifuged to separate the major part of the solvent-water phase. The peat-containing phase is flashed into a tank feeding directly into the produce press, releasing the remainder of the extract phase and yielding the 35% moisture product. The liquid-vapor stream from the flash and pressing operation is condensed and cooled by heat exchange with cold feed slurry. After heat exchange, the recycle solvent streams are cooled to 75°F by refrigerated 50°F coolant. About 97% of the solvent lost is carried out with the dewatered peat product being conveyed to the SNG plant. It will appear in the condensate from either the gasifier or the CO-shift effluent.

The sensitivity of the dewatering costs to the percent solvent recovery is shown in Figure 3. Increasing the solvent recovery from 95% to 100% decreases the dewatered product cost from about $3.00/million Btu to about $1.50/million Btu. The base case cost of diethyl ketone is taken to be about $6.80/gal, or about $1/pound. The sensitivity of the dewatering cost to the solvent cost is shown in Figure 4 for two solvent recovery efficiencies. The dewatering cost is much more sensitive to the solvent cost for the case with 95% solvent recovery efficiency. This is because the solvent makeup requirement is five times higher in the former than in the latter case.

The dewatering cost is not very sensitive to feed peat cost. A 30¢/million Btu change in the cost of feed peat changes the dewatering cost only by about 1.8%. The sensitivity of the dewatering cost to feed moisture content greater than 70 weight percent was not determined. However, each increment of moisture requires a similar multiplier for the additional solvent required.
DEK @ $6.80/GAL.
(BASE CASE)

Figure 3 Sensitivity of Dewatering Cost to Solvent Recovery
Figure 4 Sensitivity of Watering Cost to Solvent Cost
The total plant investment and total capital requirements have been estimated to be $594 million and $814 million, respectively. The solvent extraction dewatering process based on diethyl ketone does not appear to be economically competitive with other methods of peat dewatering at the present time.

CONCLUSIONS

- Solvent extraction dewatering can remove up to 90% of the water in peat
- Based on the tests conducted, DEK and benzene appear to dewater peat better than the other solvents tested
- A preliminary economic evaluation of solvent extraction dewatering of peat with DEK shows that the cost of this type of dewatering method is not currently competitive with other peat dewatering methods.

FUTURE WORK

Because all of the objectives of the task have been completed, no future work is planned.
QUESTIONS AND ANSWERS

Q: In the economic evaluation, have you got any idea as to at what point, after how many cycles, you have to replace the solvent? Did you include any evaluation of that?

A: There is a provision for solvent makeup. Approximately one-half the cost of dewatering is for makeup solvent.

Q: Is that the difference between 95 and 100% recovery?

A: Yes.

Q: But you did show that in at least many of those solvents you had a degradation of the solvent quality over a period of time.

A: That is one reason why diethyl ketone was selected for the process design. It reacts very little with the peat, whereas methylethyl ketone did disrupt some of the peat substance. Each solvent would have been deteriorated in proportion to the extent that it disrupts the peat.

Q: If one were to thermally dry the peat after it comes out of the solvent extraction unit, how much solvent would be recovered in that drying operation downstream? Was that solvent included in the percent solvent recovered?

A: It was estimated that approximately 85% of the solvent loss that was presented in the economic evaluation case did go out with the dewatered, pressed peat. The other 15% went out with the water streams that would be recovered in some type of distillation system. The solvent in the peat that is fed to a gasification system would be evaporated and recovered downstream in the product gas cleanup train.
Q: How much were you losing with the peat and how much were you losing with the water? Is it roughly 85 and 15 percent?

A: Yes.
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PEAT DEWATERING

Andrew Allen
First Colony Farms
BACKGROUND

The sod peat harvesting program at First Colony Farms is designed to develop a practical cost-efficient, environmentally acceptable means of producing a high grade fuel peat at or around 30% moisture from the highly decomposed and woody peats similar to those found in coastal areas of North Carolina.

OBJECTIVES

1. To determine the production rates of the sod peat harvesting equipment during varying climatic and seasonal conditions and to develop a balanced sod production methodology from bog preparation through stockpiling of harvested sod peat.

2. To determine the drying characteristics of sod peat and the parameters affecting sod peat dewatering, including the following:
   a. Diameter and geometry of sods
   b. Weather conditions
   c. Solar radiation
   d. Handling and stockpiling

3. To determine the cost in dollars per million Btu's to produce and stockpile sod peat in a balanced peat program.

4. To extrapolate the results of the First Colony sod peat project to sod production in other areas of the United States.

TECHNICAL PROGRESS

First Colony Farms has been studying and evaluating various methods of peat production over the last several years. One of these, the sod peat method, involves the mechanical removal of wet peat from the bog and its extrusion onto the bog surface where it is left to air dry.
Sod peat harvesting can be divided into distinct operations that include initial bog preparation, production, loading and stockpiling, and annual bog preparation.

The initial bog preparation phase includes activities such as grinding of surface vegetation, ditching, augering, fining milling, fine grading, installation of drainage structures, and road construction. It is essential that the surface of the bog be well graded and sloped to prevent any ponding of precipitation so that drying will be enhanced or accelerated.

The production of sod peat is accomplished with the quadruple head sod extruder attached to the 450 H.P. Base Unit. This unit cuts four 1-3/4 inch wide slots by approximately 14 inches deep in the bog surface. The wet raw peat taken from these slots is thrown up to the extruder chamber and pushed out through an orifice approximately 4 inches in diameter. The extruded peat, called sod, then falls to the bog surface where it is left to dry to 30% moisture prior to harvesting. The ideal moisture content at the time of production is approximately 65%. This can be accomplished by varying the depth of cut in the bog surface, thus varying the moisture content of the raw peat.

After the peat sods have dried to 30% moisture, which takes an average of 10-12 days, it is then windrowed into long ridges, picked up with the loading unit, and transported to the stockpile area by carts.

FUTURE WORK

First Colony will continue with the program in progress to determine the above objectives.
QUESTIONS AND ANSWERS

Q: Have you had any problems with heating or combustion in storage piles?

A: No, we have not. We thought at first this may be a problem and we monitored the stockpiles for about two years by setting temperature probes in the piles and actually checking the temperature of the pile during various times of the year.

We have never had a pile get above about 115°F for either sod or milled peat.

Q: I couldn't help but notice that there was a great deal of fugitive emissions, perhaps from some of the crumbling of the sods. Do you foresee that as a constraint or a problem in this method of harvesting?

A: There are some fugitive emissions. I don't know if I would call it a great deal. I think it may depend on the eye of the beholder.

We do have some emissions into the air. It is fairly localized. It falls out within a few hundred feet of the source. And, of course, we are currently working within our property. The nearest property line to our current operation is about 3,000 feet. So we would not anticipate any emissions actually leaving our property at all.

Q: Have you monitored these?

A: No. But we are currently in the midst of setting up a program that would monitor this.
Q: Could you go into maybe a little bit of what your typical harvesting cycle is through the year and maybe what problems you have had in different time periods, in the winter months? What is typical harvesting?

A: Generally we would begin bog preparation in the winter months. By that I mean we would begin our initial clearing and grinding, and we would begin our initial ditching operations, sloping, and actual fine-grading operations. So that by the spring we would have these fields ready to produce.

We would begin production by about mid March, depending again on how soon the spring happens to break for us. We are waiting primarily for enough sunshine and temperature to actually begin drying the peat.

In the case of a sod program, we would anticipate that we would get from 10 to 15 cycles per year—again, that is dependent upon weather—but from 10 to 15 cycles of production per year per field, which would carry us through about mid November. At the end of November we would go back into what we would call bog preparation, or annual bog preparation, which would be a resloping, regrinding of the surface, an over-all dressing up of the fields, and cleaning of the ditches and canals in preparation for the following season.

Q: What would you expect to be your yield in terms of tons per acre per year and have you got any feeling for what you would translate that into in terms of depth?

A: We are currently getting about 1.2 inches depletion per pass with this unit. Over-all production per acre I'm guessing right now, but I think it is going to probably be about 20 to 30 tons per acre per pass.
Q: What do you do with surficial runoff? Do you contain it? What methods do you use and what problems have you encountered in this area?

A: These fields that we are working are divided up by V ditches into approximately ten-acre cuts. They are 165 feet wide and half-mile in length. The V ditches provide surface drainage for us only, since the bog itself is very colloidal in nature and we get practically zero flow of water out of the bog and into the ditches. But we do need to maintain a very smooth and dry surface in order to get the full benefit from the sun and the wind drying.

The surface runoff is, again, caught by the V ditches and carried to the canals. At each end of the V ditches we provide a silt screen to trap any sedimentation that may want to flow out to the canals, and then the canals drain south to the river. But we hope to trap that prior to leaving the bog, because we need the material for fuel as well, and we certainly don't want to pollute the streams.

Q: Have you set up any monitoring practices on the streams to insure water quality?

A: Yes. We are currently engaged in a study, actually being done by North Carolina State University, to monitor the water flow off the land as far as quantity and quality.

They have been doing this on some of the other areas of our property for the last ten years, and now they are taking the areas of our peat mine and studying the areas of nonproduction, production, silt screening versus non-silt screens.
Q: I'm kind of curious as to how many inches of rain you have down there a year. And do you see any threshold on the amount of rain that would make this solar drying infeasible?

A: We currently average between 50 and 55 inches of rain per year. We have about 35 inches of evaporation a year. So we are having more runoff than we are evaporation.

But, no, I don't envision that the rain will cause us any more delay than a day or two, unless we hit a very long wet season, and that, of course, is not really something that we can expect to happen.

We have weather data for the last six years based on our own weather station. And then we go back as far as 20, 30, 40 years based on some other stations in the neighborhood, and we have projected the overall harvesting days, based on the long-range weather patterns. We don't anticipate any problems, but there are days when you can't produce, obviously.

Q: My impression is that you have had substantial experience or testing with milled peat and sod peat. Have you investigated full face harvesting, even on paper?

A: Only very limitedly. We actually tried a hydraulic method at one time. That particular experiment failed, primarily because of the wood content of the peat that the unit that we were using was not capable of handling.

This is something that we may get into later, but right now we have no plans in our present program to look at it.
Q: Again it is my impression, and I wish you would correct me if I'm wrong, that of the milled peat and the sod peat, your preference at the moment appears to be sod peat, with no question about it.

A: Well, we are looking very strongly at both means. You can't really produce sod without producing milled peat, because of the configuration of that cutting wheel, and once it cuts below the bottom of the bog you are increasing your ash content.

On the other hand, you can produce milled peat without sod peat. We are currently evaluating both programs. We have customers, or potential customers, who would like some of each. And, of course, we are in the business to make a profit, in the long run. So we want to provide something we can sell.

Q: Does humidity affect the drying at all? For example, if you have a 80% humidity day, does it dry more slowly?

A: Yes. Eastern North Carolina is very humid, especially in the summer. But we have measured temperatures on the surface of the bog at about 130° in the warmer summer months, and the wind and the temperature, I think, are the two biggest variables for it. This is what we really need: high temperature and wind to remove that moisture.

Now, I am sure the humidity plays in there, but I think over-all, it would be on the rate of drying.

Q: Would you be kind enough to expand on your experience with land reclamation?

A: Yes. We have three areas from which we have stripped the peat. These areas are about four miles apart, so that we have a varying bog condition. We removed an average of 5.5 feet of peat off of one, which is more in the center
of the bog; we removed an average of about 42 inches off of the westernmost edge of the bog, which is up in the shallow edges of the bog. We have planted the first site for five years now. We have had an average crop production in corn yields of 150 bushels per acre or thereabout, and an average soybean production of about 50 bushels per acre. We also planted small green milo one season and we had about 76 bushels per acre of milo. And all of these averages are above the average of the total area that we are currently farming in.

There is nothing really magic about this soil underneath. It is a very high-organic, high-mineral-content soil. It is actually a mixture of both. There is a very distinct layer between the peat layer and the transition, as we call it. It is an ideal farming soil. It would be ideal for tree production.

We would anticipate maybe some of both, farming and tree production. We are looking at, in this particular case, an average elevation of 14.5 feet in the bog that we are currently working, which is about 32,000 acres. We would remove, say, 5.5 feet, we would be left with an elevation of around nine feet, which we could drain through the existing canal system. And we really think we are in a pretty good spot there as far as land reclamation is concerned.

Q: I'm trying to get a feel for what you think would be a lower threshold for economic viability of the sod peat method. How many acres would you have to clear a year?

A: It goes back to your rate of production. We are currently working on some modifications that we hope are going to increase production on this particular unit. But based on what we know now, if you were to base it on, say, an 800,000-ton-a-year operation, you would probably be looking at about 15 to 1800 acres that you would be working. That is net acres. And that is assuming ten passes or ten cycles per year per field.
Q: And you are going to have to deal with that order of magnitude? You couldn't have a smaller operation that was maybe one order of magnitude less than that?

A: You could certainly drop that back. That would be an 800,000 ton a year operation. Depending on the quantity you wanted to produce, you could certainly cut that back in size.

Q: How many machines would you need for the example you have given, of the type you are using for the 800,000 ton a year production?

A: In extruders, you are probably looking at 20 to 24 units.

Q: Generally, what is the percentage of nonusable area that goes into ditches and transportation systems in the field? 10%, 5%?

A: Ultimately almost all of that will be used. When you are ditching, you are taking the material out of the ditch and putting it on the surface and using it.

In a ten-acre cut, your effective mining area is going to be about nine acres, which includes the area beneath the stockpile. And, of course, each year your stockpile is removed and you also harvest below that.
DEVELOPMENT OF CONCEPTUAL DESIGNS FOR PEAT PRODUCTION SYSTEMS

Contract No. DE-AC01-80ET-14104

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

In recent years, because of the decline in global reserves of oil and natural gas, there has been an increasing interest in alternative energy sources. One of these sources is peat.

The use of peat as a fuel is nothing new, at least not in the U.S.S.R., Finland, Germany, Holland, and Ireland. However, it is virtually unexploited in this country; but of late we have seen a dramatic increase in the interest in peat as an energy source. The bulk of recent peat-related research has revolved around the question of how to convert peat into usable energy. Unfortunately, very little research and development work has been done on the extraction and harvesting of peat. This program hopes to contribute to the solution of that issue.

ES.1.1 Objective of the Program

It is clear that, in order for peat to become a major source of energy, it must be competitive with other fuels that it could replace. Each fuel has a factor that most heavily contributes towards its cost; for example, costs related to mineral rights, physical extraction, transportation, cleaning, storage, etc. The major problem with peat is that in its natural occurrence it consists of between 70 and 97 percent water.

Much research has been conducted to process peat in its wet state, or to find methods that will economically reduce the water content in peat to increase its energy density (see Figure ES-1). Depending on the ultimate use of the peat, it can be presented for future processing with water contents ranging from 50 to 95 percent. Thus, if peat were used in the Wet Air Oxidation (WAO) steam generation process, peat with 90 to 95 percent water will be entirely cost-competitive with the best of modern conventional steam generating equipment using dry coal.* If, on the other hand, peat is to be used in a conventional (though

modified) boiler, using the direct combustion system, then peat should be delivered to the plant at as low a moisture content as possible. Solar drying will reduce moisture content to approximately 35 percent. Preferably, one wants to reduce this even more through secondary drying.

![Graph showing moisture levels in peat]

FIGURE ES-1. - Moisture levels in peat.

The issue is, of course, to create the most efficient heat conversion system, to arrive at an arrangement that results in the lowest cost per million Blu.

It is easy to become entangled in this web of economic analyses. Therefore, we will define the objective of this program as stipulated by the Contract: "... the development of conceptual designs for peat production systems capable (either as single or multiple units on the same site) of supplying the tonnages (3,000,000 tons of dried peat from a single site) required for utilization of
peat in direct combustion." Through this definition, we are now able to crystallize the requirements and constraints for this program:

a. Final product to be suitable for direct combustion. Consequently we will assume that it is necessary to reduce the water content to at most 50 percent. Thus, no matter how we harvest, the peat will have to be dried by whatever means before it enters the power plant.

b. Tonnages required are 3,000,000 tons of dried peat per year, at 50 percent moisture by weight.

c. One or more units may be used produce the above tonnages.

The above requirements give us considerable leeway in our conceptual designs and several options will be presented in a later section.

ES.1.2 Geographical Areas Covered

Peat is a surface deposit; as such, the access to peat is heavily dictated by topography, climate, hydrology, ecosystems, etc. Whereas the chemical composition of peat falls within a well-defined range (depending on the degree of carbonization), the physical properties may vary considerably from place to place and they are an important parameter in the design of peat production equipment.

In compliance with the Statement of Work, we have concentrated our efforts on peat harvesting in the states of Alaska, Florida, and Minnesota. These three areas were selected because, in the United States, they also typify three different types of deposits in widely varying climates.
ES.1.3 The Approach of Foster-Miller Associates, Inc. (FMA) to the Harvesting Problem

FMA's approach to the development of a large-scale harvesting system was to "start from scratch."

First of all, we performed a literature search, which provided us with between one and two hundred titles, directly or indirectly relevant to our program effort.

We then set out to look at the peat reserves in question. Through these visits we gained first-hand knowledge of the physical characteristics of the peat, the topography, and climatological conditions in these three states. Discussions with geologists, horticulturalists, soil scientists, environmentalists, energy directors and local entrepreneurs provided us with a clear picture of what was to be done and within which context the work for this program was to be performed. (We were surprised to find that no other research and development house involved in peat production system development had been in touch with any of the state officials we contacted.)

Finally, we gathered catalogues and spec sheets of peat production related hardware that we knew was available from overseas sources, mainly the U.S.S.R, Finland, and Ireland. North American suppliers of fuel grade peat production equipment are virtually nonexistent.

Some of the European peat production hardware is currently being used at First Colony Farms (FCF) in North Carolina, and may be applicable to this program, but one has to realize that:

a. There is a greater diversity in the physical characteristics of North American peat bogs than there seems to be in Europe.

b. There is a wider spectrum of climatological conditions to be considered, varying from the subtropics in Florida to the Alaskan permafrost.
c. None of the presently available equipment can handle the large volumes as a single unit. It is conceivable, however, that a number of these smaller units operating together could produce the required tonnages.

The next step will be to develop several peat production concepts that, if deemed economically viable, may be developed into preliminary peat production designs.

ES.2 PRODUCTION COST GUIDELINES

In order for peat to ever become a significant energy contributor, it will have to be competitive with other energy sources. To establish the full matrix of fuel-cost comparisons is an immense task, the magnitude of which falls beyond the scope of this program. The economics of fuel-source selections cannot be dealt with on a generalized scale. Even such basic parameters as Btu-value, moisture content, and requirements for conformation to environmental legislation may vary significantly from one geographical area to the next. In the following subsections we will survey the principal characteristics of several energy sources and will then gradually begin to concentrate on the comparison of peat versus coal, two major energy sources in which the United States is self-sufficient. We have attempted to present our analysis in such a way that anyone interested in comparing peat with sources other than coal can do so readily.

ES.2.1 User Cost of Various Energy Sources

There is one common denomination that can be used to compare various energy sources, that is its cost per million Btu. Such a comparison leaves out possible side effects that may detrimentally affect its application. In some instances, the expense to correct those side-effects may be substantial to the point that the energy source becomes noncompetitive. In other instances, environmental or political issues may exclude a source altogether. In this report we will limit ourselves to consideration of parameters that are quantifiable, and we have opted to exclude the cost of such intangibles as environmental impacts (excluding reclamation cost), alternate uses, ash disposal costs, etc.
A survey was initiated to obtain current costs and usage of various fossil heat energy sources for the three typical areas: Alaska, Florida, and Minnesota. The results are presented in Table ES.1. It can be seen from the part of Table ES.1 relating to Minnesota that coal is the predominant fossil energy source in this state at a current cost of $1.07/10^6$ Btu. The majority of this coal is surfaced, mined and delivered under long-term contract.

In Florida coal costs are higher ($1.84/10^6$ Btu) and coal accounts for only 26 percent of the fossil fuel burned for electric power generation. The majority of the remainder is accounted for by the use of oil at a significantly higher cost ($4.08/10^6$ Btu).

Comparable statistics were not available for Alaska, though the data in Table ES.2 allows a rough comparison. It is apparent that in urban centers, such as Anchorage, gas at a cost of $0.88/1000$ ft$^3$ is very competitive, while in remoter area costs of light oil used for power generation approach $13.51/10^6$ Btu. Table ES.3 shows costs of alternative fuel such as wood chips.

<table>
<thead>
<tr>
<th>Table ES.2 Fossil Fuel Costs - Alaska*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>0.85</td>
</tr>
</tbody>
</table>

ES.2.2 Cost Surveys Performed by Others

FMA is not the only company that performed fuel-peat cost surveys. Direct cost comparison is not realistic, because the data are derived from different production processes, in bogs with widely varying characteristics. Moreover, much of the data applies to foreign producers where peat's competitors (coal, oil, natural gas) command prices that are much higher than in the United States.

* Personal Communication with Mr. Dave Resnell of the Alaska Division of Energy Power Development
Table ES.1. Fossil Fuel-Usage and Cost - Minnesota and Florida

<table>
<thead>
<tr>
<th></th>
<th>Total Btu (x10^6)</th>
<th>Percent of total Btu</th>
<th>Average delivered price $/10^6 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Oil</td>
<td>Gas</td>
</tr>
<tr>
<td>Minnesota</td>
<td>22,566</td>
<td>21,816</td>
<td>233</td>
</tr>
<tr>
<td>Florida</td>
<td>63,938</td>
<td>16,606</td>
<td>32,632</td>
</tr>
</tbody>
</table>

Sources: U.S. Department of Energy Publications:

- Electric Power Monthly - November 1980
- Cost and Quality of Fuels for Electric Utility Plants - October 1980
Table ES.3. Other Fuels Used For Steam-Electric Generation*

<table>
<thead>
<tr>
<th>Type</th>
<th>Btu/lb</th>
<th>Tons burned</th>
<th>Average delivered price $/10^6 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood chips</td>
<td>4,757</td>
<td>7,300</td>
<td>1.702</td>
</tr>
<tr>
<td>Refuse</td>
<td>7,500</td>
<td>1,000</td>
<td>2.411</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>14,000</td>
<td>31,000</td>
<td>0.72 to 1.32</td>
</tr>
</tbody>
</table>

Still, to provide a frame of reference we are presenting the production cost for fuel-grade peat as obtained from several literature sources.

ES.2.2.1 Finnish Production Costs

According to a report that was presented by PERTTI HARMÉ of the Ministry of Trade and Industry,** consumer prices of fuels in Finland, as per May 1980, were as follows:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Price</th>
<th>Price/effective heat value of fuel $/10^6 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy fuel oil</td>
<td>196</td>
<td>5.07</td>
</tr>
<tr>
<td>Light fuel oil</td>
<td>298</td>
<td>8.79</td>
</tr>
<tr>
<td>Coal (on coast)</td>
<td>63</td>
<td>2.64</td>
</tr>
<tr>
<td>Milled peat</td>
<td>8.0</td>
<td>2.34</td>
</tr>
<tr>
<td>Sod peat</td>
<td>12.5</td>
<td>2.64</td>
</tr>
<tr>
<td>Peat briquette</td>
<td>85</td>
<td>4.89</td>
</tr>
<tr>
<td>Chipped wood</td>
<td>14.5</td>
<td>3.52</td>
</tr>
</tbody>
</table>

* Sources: See Table ES.2

Disregarding cost associated with the actual fuel-burning process, one can see from the price per megawatt-hour tabulation that peat is competitive with coal and that, compared with other fuels, it is at the bottom of the price-ladder.

Thus, the price (not necessarily the cost) for fuel-grade peat in Finland is:

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Price per 10^6 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Milled peat</td>
<td>$2.34/10^6 Btu</td>
</tr>
<tr>
<td>b. Sod peat</td>
<td>$2.64/10^6 Btu</td>
</tr>
</tbody>
</table>

ES.2.2.2 Irish Production Cost

In their 34th Annual Report, Bord na Mona reported the following power plant production figures and the prices of their milled and sod peat.

<table>
<thead>
<tr>
<th>Type of Peat</th>
<th>Harvest Tonnes</th>
<th>Irish Pound/tonne</th>
<th>United States $/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milled Peat</td>
<td>2,403,320</td>
<td>5.15</td>
<td>7.96</td>
</tr>
<tr>
<td>Sod Peat</td>
<td>313,119</td>
<td>10.08</td>
<td>13.57</td>
</tr>
</tbody>
</table>

Assuming that the peat contains 50 percent moisture, has a density of 22 lb/ft^3, and has a Btu value of 4500 Btu/lb, the production of Irish peat translates into the following prices:

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Price per 10^6 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Milled peat</td>
<td>$0.88/10^6 Btu</td>
</tr>
<tr>
<td>b. Sod peat</td>
<td>$1.73/10^6 Btu</td>
</tr>
</tbody>
</table>

ES.2.2.3 Canadian Production Costs

Several Canadian institutions performed feasibility studies of fuel peat operations. In one of them, milled peat feeds a 120 MW power plant (using 1 million tons of peat per year). Estimates in 1979 project a cost of Canadian $1.15/10^6 Btu*. Correcting for inflation and currency exchange rate, this results in a cost of United States $1.20 (1-1/2 years inflation) x $0.84 (exchange rate) x $1.15 = United States $1.16/10^6 Btu.

ES.2.2.4 United States Production Costs

Production costs for a United States operation have been estimated by Bechtel Engineering and Wheelabrator.

In 1978 Bechtel performed a study for a 6 million ton/year operation*. Their finding was a cost of $0.75/10^6 Btu for peat with a 35 to 50 percent moisture content. Adding 30 percent for inflation over 2-1/2-year results in a 1981 equivalent of $0.98/10^6 Btu.

Finally, FCF is trying to find clients for whom they could produce fuel peat. Official costs are not available but it is thought that customers would like to see prices in the $1.15 to $1.25/10^6 Btu range.

ES.2.3 Conclusion

Data regarding the cost to produce fuel grade peat is not always readily available, or may not be available in a format that allows direct comparison with competitive fuels in the United States.

Current practices and estimates have resulted in the following cost ranges for fuel-grade peat:

- a. Milled peat $0.88 to $2.34/10^6 Btu
- b. Sod peat $1.73 to $2.64/10^6 Btu
- c. Wet harvesting $0.50/10^6 Btu (This excludes dewatering costs)

Any new system should certainly be able to produce peat within the above ranges; the operator who can produce peat at the lowest cost will dominate the market. However, in order for peat to be competitive with other energy sources, it has to be produced at costs below those listed in Tables ES.1 and ES.2.

Upon completion of the production systems, an economical analysis of each system will be made to verify that indeed they conform to the above cost restraints.
Since this program requires the development of peat production systems, we have addressed several basic issues dealing with the planning of a bog as well as the equipment required in the production cycle. In Figure ES-2, we have generated a model for the planning of the bog. At some point, the decision will be made to indeed go ahead with the development of the bog. In our program, where we are dealing with the development of production systems for direct combustion, a choice will have to be made for either the dry harvesting or the wet harvesting method. The methods of operation and the required equipment are presented in Figure ES-3 and ES-4 respectively.

In the following subsections, we will describe the approaches to bog development and the methods of production in detail.

In the previous subsections, we have reviewed the current peat production systems and harvesting techniques. We have gone into great detail to identify the steps and equipment required to successfully complete the harvest cycle. None of the previous production methods is applicable to all peat bogs. Climate, hydrology, bog characteristics, ecological restraints, and many other factors will decide which system is best suited in a particular application. Moreover, the following observations and generalizations can be made:

a. If properly applied, the existing peat production systems produce peat-fuel at prices that are competitive with other fuels.

b. Peat production equipment is available and does perform satisfactorily.

c. Much of the equipment, especially in the milled-peat process, has been around for decades, and has been perfected through the years.

d. Alternative methods have been looked at by foreign peat producers, but milled-peat or sod-peat production systems have survived as the most economical.
Figure ES-2: Planning the Development of a Bog
Figure ES-3 Dry Harvesting Method

- Milled Peat Method
  - Ditching
  - Profiling
  - Milling
  - Harrowing
  - Ridging
  - Harvesting
  - Stockpiling
  - Loading and Transport

- Sod Peat Method
  - See Figure

Equipment Used in Finnish Practices
- Ditching Machine
- Ditch Miller
- Tractor Digger
- Screw Leveler
- Milling Mill
- Harrowing Spoon Harrower
- Ridging Lineal Ridger
- Harvesting Bog Trailer
- Stockpiling Special Loaders

Equipment Used in Irish Practices
- Cuthbertson Plow
- Tractor Disc Ditcher
- Levelers Bulldozers Offset Mill
- Milling Drums Half-Track Tractors
- Spoon Harrow Tractor
- Ridger
- Harvester
- Articulated Roller
- Ground Spiral Bucket Elevator Wagons Locomotives

Equipment Used in Practices of FCF
- Screw Auger Dragline
- Dozer Scourifer Mill Base Unit Horizontal Auger
- Milling Drums
- Spoon Harrow
- Windrower
- Drum Loader Vacuum Loader Carts

*Equipment Terminology as provided by users; follow-on communication may simplify issue.

a) Milled Peat Method
b) SOD PEAT METHOD

Figure ES-3 Dry Harvesting Method (Continued)
Figure ES-4 Wet Harvesting Method

- **Wet Harvesting Method**
  - **Slurry Pond Method**
    - Dredging
      - Peat Slurry Preparation
        - Slurry Transport
          - Dewatering
            - Equipment Used:
              - Barge
                - Hover Barge
                - Backhoe
                - Cutterhead
              - Hopper
                - Water Jets
                - Radar Screen
                - Slurry Tank
              - Slurry Pump
                - Slurry Pipe
              - Settling Basin
                - Screens
                - T.R. VARI-NIP Press
                - Drying Plant

- **Hydro-peat Method**
- **Slurry Ditch Method**
On the other hand, there are several drawbacks that limit the size or the full potential of these systems. Consider the dry harvesting methods:

a. Extensive preproduction drainage systems have to be installed.

b. The production cycle is comprised of a large number of operations, making it labor-intensive.

c. It is entirely weather-dependent for the drying process.

d. As a rule, the harvest season is limited because of climatic conditions.

e. Large drying areas are required; so much of the productive bog will be covered with peat left to dry.

f. There are no single-site operations producing 3,000,000 tons of dried peat (50 percent moisture content) per year.

g. In order to reduce moisture content for increased Btu value, secondary drying is desirable.

With regards to the slurry harvesting techniques, it has the following advantages:

a. No major preparations are required.

b. The area disturbed at one time is relatively small.

c. With the exception of the dewatering plant, system components are simple and proven.

d. This technique is largely weather independent.

But there are also disadvantages that cannot be overlooked:

a. The system requires large amounts of water.
b. Economical dewatering systems for large volumes have yet to be developed.

c. Much of the slurried peat may pass screens, or any other dewatering mechanism, in a colloidal state, posing two problems, low efficiency and environmental considerations.

We feel that any large-scale peat production system will have to address these issues. Advantage should be taken of those operational aspects that have proven to be reliable, efficient, and (cost-) effective. Conversely, one should try to eliminate, circumvent, and improve upon those operations that do not permit the systems to achieve their full potential. Furthermore, entirely new systems may be developed on these premises. That is what this program is all about.

ES.4 PERFORMANCE SPECIFICATIONS

Production of 3,000,000 tons of peat per year (at 50 percent moisture content by weight) requires large systems. Since peat in its natural state has a moisture content of between 90 and 95 percent, the in situ weight to be removed annually becomes on the order of 15,000,000 tons. Assuming that the wet density of peat is 60 lb/ft³, one has to excavate

\[
\frac{15,000,000 \text{ tons/year } \times 2,000 \text{ lb/ton}}{60 \text{ lb/ft}^3} = 5 \times 10^8 \text{ ft}^3
\]

of wet peat. Assuming also, at this point, that the operation works two shifts, that is, 16 hr/day, 7 days/week, 365 days/year, one can develop a basic idea of the order of magnitude of such a system. Any of the numbers thus generated can later be "massaged" to reflect actual conditions. Thus, the above system would have the following characteristics:

a. Assuming a 7-ft thick peat deposit, the area to be excavated is 1640 acres/year.

b. Total volume of the dried peat at 50 percent moisture content is \(1 \times 10^8\) ft³ or a cube with sides of 464 ft length or an area of one acre piled almost a half-mile high.
c. In the sod-peat mining method, where drying takes approximately 10 days, 36 harvests can be collected. Assuming the peat left to dry on the land to be 6 inches thick with a 50 percent packing density, one can see that the area covered with drying peat is $5 \times 10^8$ ft$^3$/36 harvests x 0.5 ft thickness x 0.5 packing density = $5.55 \times 10^7$ ft$^2$ = 1275 acres = 2.0 mi$^2$.

d. In the case of wet harvesting, with 1-1/2 percent solids in the slurry, the amount of water pumped through the system is phenomenal. Assuming the dry weight of peat to be 15 lb/ft$^3$, one can calculate the volume of water pumped: $6.6 \times 10^9$ ft$^3$ of water/year.

Many other "vital statistics" could be generated, but they will still be based on the previously established assumptions.

ES.5 FUTURE PROGRAM WORK

We have reached the point in this program where sufficient background data have been gathered to propose new systems. In these new systems, advantage will be taken of the positive aspects of presently available equipment, while eliminating those aspects that are obviously inefficient or impractical.

Presently we are concentrating on several distinctly different concepts:

- A modified dry harvesting concept (Figure ES-5). In this approach we are making use of the currently available implements, developed for both milled-peat and sod-peat harvesting. However, we are replacing a vast array of tractors, trucks, carts, etc., with a simple rail-mounted bridge structure that can accommodate the entire spectrum of implements, materials handling equipment and bog maintenance hardware. All components are electrically driven.

- Concepts making a full face cut. Several approaches are being taken and we will propose them later in the program.

- Wet harvesting concepts utilizing the deep milling techniques recently developed.
Figure ES-5 Modified Dry Harvesting Concept
QUESTIONS AND ANSWERS

Q: Did you find anyone who had used drainage tile for aiding in the dewatering or lowering of the water level within bogs for dry harvesting?

A: No. I have not. (Speaker's Note: This question was misunderstood: Drainage tiles are being used e.g., at Bord Na Mona in the Irish bogs.)

Q: I am aware of a deep milling operation, and I have heard from people in Sweden about that. Have you investigated that?

A: I had a slide of it. You may recall that fairly large wheel which was cutting these trenches. That machine is being used for deep milling because it does cut about 40 centimeters deep.

Q: Did I understand correctly from one of your slides that you were going to use the waste heat from the power plant to dewater the slurried peat?

A: As a concept, yes. I was not too familiar at this point with the latest in the dewatering research. There are a number of options that could be used there, I think.

Q: I would be very surprised if there was enough waste heat in any typical power plant to come anywhere near supplying the energy required to dewater the slurry.

We had looked into the possibility of reducing the moisture content from 50 to 40%. But do you have any idea what the heat load would be to dewater a 98.5%-moist slurry?

A: No, not off hand. However, the energy required to remove the heat is twice that of the formation of the peat in the first place, and I meant the waste heat to only supplement the primary heat input.
We were not asked to go into the detail of the dewatering process. I don't think at this point we are advocates of the wet harvesting system in a slurry system because of the dewatering problems.

Q: Another question refers to the three million tons per year requirement. You said that the equipment isn't available.

A: Not as a single unit.

Q: Why does it have to be a single unit? Because that is about a 200 megawatt power plant, and there is no problem with that. Finland has several power plants that are between 150 and 250 megawatts, counting electric power generation and district heating, and they seem to have no problem at all furnishing the feed requirements.

A: No. You're hitting a good point. When we started this program, we had performed quite a bit of engineering work on large bucket-wheel excavators. It always seems very attractive to come up with one machine that can do everything. So that would seem like a very elegant system. However, when you get down to the basics of economics and practicality, in peat harvesting, one large machine is simply not a viable option. And, like you say, a large number of smaller machines, as used in Ireland and in some other places, can produce peat economically and competitively with other sources. Indeed, the only reason why we considered a one-machine system is because we were asked to do that.

Q: Another question relates to the wet harvesting. You said that the components for wet harvesting are commercially available?

A: The equipment for dry harvesting is available, but for wet harvesting I'm talking about the major components. They are very simple basically, for instance, the barges and cutter heads are used in dredging operations.
Q: Is this the operation you have concluded is the best? There are a number of wet harvesting techniques that you didn't touch upon.

A: That's right. Our program is getting into that right now.

Q: And you are aware that, at Vancouver, Western Peat is harvesting and dewatering peat for horticultural purposes?

A: Yes.

Q: So they are not as concerned about optimizing the wet harvesting. They want something that is proven and that will give them the material they need and they send it into a natural gas-fired furnace to further dewater it. But it is a relatively small capacity.

A: It's about a tenth of what we are doing, yes.

Q: I was just wondering how you eliminated the other possibilities. The barge is really the schematic that you had up there, which is very similar to Western Peat's. But what about some of the other options? Why did you eliminate those?

A: I didn't eliminate them. I said some of the other options we are looking at are, for instance, twin augers, advancing screw augers, which would provide the traction for any vehicle that had to operate in a very wet bog and as it advanced would slice itself through the peat, which is one of the better harvesting options that we have.

Another option is a series of smaller bucket-wheel excavators, that produce three million tons; or a not too large bucket-wheel excavator that could take a full face cut.
At this point we are getting into the analysis of these various systems. As I said, we started this program in November 1980 and it will not be completed until early 1982.

Q: What tasks do you have? You have obviously finished your literature survey. Now what are you supposed to be doing? The next time we meet, what can we expect to hear from you as far as a recommendation?

A: The next time we meet, we will have gathered all the engineering data on peat. And I must say that engineering data on peat, dealing with such topics as shear strength and physical characteristics, are hardly available especially when one becomes site-specific but we are digging that out right now. Based on that data we will have as complete a set of input parameters as possible on coefficients of traction, shear strength to cut through the peat en bloc, or the rolling resistance for a vehicle that might want to travel on peat itself, items of that nature.

When I come back in six months from now, I will have for you a number of conceptual designs of systems that should be workable.

Q: Wet systems or dry systems?

A: Both wet and dry.

Q: Because the dry systems are available now. First Colony Farms just went out and bought them. Are you going to do something that will improve upon the current technology?

A: That is what we are trying to do. I guess at this point we know the advantages of existing systems and their disadvantages, and from this point on we hope to improve upon them.
Q: I think just from a point of order standpoint, in the future it would be useful not to use hydraulic dredging and wet harvesting synonymously. Because hydraulic dredging is a possible method of wet harvesting. But it is probably not the best method and it is certainly not the only method. And so I think it would be very useful not to use those synonymously in the future. I think you made a statement that you concentrated primarily on dry harvesting methods because you felt that the dewatering techniques for wet harvesting were not readily available. And I think that wet carbonization and possibly several other techniques are certainly available. Effective wet harvesting techniques can be used for a variety of end uses, including gasification, wet carbonization for direct solid fuel use, and a number of others, biogasification or what-have-you.

A: I agree with you fully. No, I am not disagreeing with you at all.

Q: Why wasn't that part of your contract? That is a viable dewatering option and it is a great fuel for direct combustion.

A: Well, let me put it, without trying to be rude, that that is the way the contract was formulated. And I guess we will be pointing out in a final report the viability of a hydraulic harvesting system for wet combustion. But, strictly speaking, we are to develop peat production system concepts for direct combustion.

Q: What about briquetting or pelletizing? Because the techniques you are looking at require that you build a power plant near the bog. Now, a lot of power plants are in existence and you want to take the peat that you harvest, whether you chemically modify it, as in wet carbonization, or you pelletize it and thereby concentrate it. But you are eliminating from consideration power plants that are in existence that are more than about 50 miles away from the bog site. Were you supposed to look only at in situ peat combustion?
A: No. Those are certainly possibilities. But that is not what we were requested to do.

Those are things that certainly have to be considered at this point.

Q: I guess I am having trouble figuring out what you were requested to do. Was it in situ?

A: No. It is the production of peat at 50% moisture for direct combustion in a power plant. Remember, our program calls for the development of peat production systems capable of producing 3,000,000 tons of peat. The 50% moisture content only quantifies the volume to be excavated. The drying process is, strictly speaking, not our concern, although we realize it is the most important issue in the production of fuel-grade peat.

Q: As a suggestion, I think it might be worthwhile to look at some of the Proceedings and to study very hard the projects that are under way as part of the over-all program -- wet carbonization included. And also some of the foreign technology that I realize you probably haven't had time to look at yet, like the pellets and the briquetting which would enable you to transport the peat perhaps economically further than the 50 miles away from the plant site and which could very easily be used for direct combustion, because you are going to be very limited with the things you are looking at. With wet harvesting especially, if you are much more than ten miles away from the harvesting site, it is just not going to be economically feasible. I mean they eliminated a water/lignite slurry for that very reason, and lignite is much more energy-concentrated than peat is. These are just meant to be positive points of feedback, of things for you to consider in order to look at all possible combustion scenarios.

A: I am very much aware of what you are saying. I don't necessarily disagree. But you may be hinting at a wider range of possibilities than just direct
combustion. All I'm saying at this point is that we are pursuing production systems that will result in peat that can be further processed to be used in the direct combustion process.

Q: I have one other question for you relating back to the Western Peat operation. What were you referring to when you talked about the inefficiencies?

A: I was referring to statements that I got from Charlie Carncross of Western Peat, who told me that in the screen that he is using and in the Ingersoll Rand press that he is using, as much as, I think it was 65 or 70% of the peat in very fine form is transported back to the bog and is not captured. But then, again, it doesn't bother him that much because he is looking for fibrous horticultural peat in the first place.

Q: I have a question on how you can equate the costs for wet harvesting versus the cost for milled and sod peat on a per-million-Btu basis. You had a slide there where you tell about the production costs per million Btu's for milled and sod peat and then for wet harvesting. And I wonder how you can equate the two.

A: It's hard. At this point there is very little cost data available or data that is made public knowledge. And I think I did say that when I pointed to the 50 cents.

Q: What I am saying is how do you get a figure for wet harvesting that is even comparable for a product that is already at the 50% level of moisture? You see, in the wet harvesting you have got to include drying or something to get it down to the 50%.

A: Those are numbers that I got through a literature survey. The 50 cents to me seems to be extremely low, actually unrealistic. But that is all that is available, furthermore it only referred to the actual harvesting, excluding dewatering and drying.
Q: I think your figure on Western Peat Moss maybe is reversed. The figure that I had obtained from them was that they pump about 1.5% solids in the slurry going in. With the same amount of water, they have about 1/2 of 1% of colloidal material going back to the bog, which would give you two-thirds efficiency, rather than one-third.

A: Okay. I will check my source.

Q: You have talked about dry harvesting and wet harvesting methods. There is an in-between method of as-is harvesting with mechanical dewatering or some type of dewatering. In other words, you don't have to use a water slurry to mine the peat, you don't have to use slurry transport to get it out of the bog. There are other methods. That is one of the methods being considered on the Minnegasco feasibility study. There are two dry harvesting methods, milled peat and sod peat. Anything which is not dry harvesting, which is not relying on solar drying, but which may rely on some drainage, I would consider in the wet category and it going to produce peat at greater than 35 or 50% moisture content.

In that respect there are pieces of commercially available equipment which are used for dry harvesting and can be used for wet harvesting. You don't just wait for it to dry. I.e., milling equipment. You know, even the shallow millers which will take a ten or 12-inch cut produce about 2,000 wet tons or about 200 dry tons of peat per hour. So you are talking about machines that have, in a ten-hour working day, 2,000 dry tons of capacity for a machine commercially available today. It is just that one does not leave that peat in the field at that point to dry. You don't use it as a bog prep machine, you use it as your production machine. Commercially available equipment. All that one needs in conjunction with that is conveying equipment, which also of course, is relatively well developed.

So I think there is a lot of equipment available if one is not trying to do all of the drying in the field. And then there are other methods of drying, such as mechanical or carbonization to do additional dewatering out of the field.
A: There is more equipment available than I have shown. I have looked at the proceedings of previous conferences, and not too much seems to have been said about peat harvesting. Many of the Conferences seem to have dealt almost exclusively with Gasification or Liquefaction and very little with peat harvesting.

I have tried at least to sketch what is presently available. And maybe at the next meeting when we elaborate on new systems, we will know against what background we will have developed these systems.

But there is a lot more equipment available in Sweden and Germany, as well.
CLOSING REMARKS

Dr. Melvyn Kopstein
Manager
DOE Peat Development Program
CLOSING REMARKS

Dr. Melvyn J. Kopstein: Environmental and Socio-Economic Impact Assessment

Over the last day and a half you have heard a lot of presentations in the areas of gasification and dewatering and resource estimation and just now on harvesting. The two parts of the peat program that have not been touched upon yet are environmental impact assessment and socio-economic impact assessment.

These are the two non-technical areas of peat utilization in the United States which are critical and which must be addressed prior to the large-scale utilization of peat in this country. And, during each of the past two conferences that my office has sponsored, we have heard from the UOP/SDC group on the environmental issues associated with peat utilization and from Radian Corporation on the socio-economic issues associated with peat utilization.

Three scales of development were considered by these two organizations. One would be a small power plant, in the neighborhood of one to ten megawatts. The second, or intermediate, scale of magnitude would be about 100 to 200 megawatts in capacity. And the third being what is generally considered a commercial scale gasification facility, which is about 250-billion-Btu-per-day output. Radian and UOP/SDC did an excellent job of identifying the issues associated with the utilization of peat by each of these three possible scenarios. No attempt was made to mitigate or to assess these issues. We felt that this was a starting point, to at least identify what would have to be looked at as part of an over-all environmental impact assessment and an over-all socio-economic impact assessment.

That was what my program refers to as Phase I of each of these two areas. Phase II relates back to performing programmatic, environmental, and socio-economic impact assessments. And I have been promising for about the last six months that there would be an announcement in the Commerce Business Daily about an opportunity pertaining to performance of each of these two impact assessments.
I am happy to say, to at least restore some of my credibility, that about three weeks ago there was an announcement in the CBD about a competitive RFP to perform a programmatic environmental impact assessment. There has been no such announcement concerning socio-economics at this point, but we are expecting that within about two or three months -- this one is lagging considerably behind the environmental -- a similar opportunity will be announced in the CBD to perform a programmatic socio-economic impact assessment.

Understandably, I can't go into very much detail about these, due to the competitive natures of the procurement. But I did at least want to take this opportunity to explain to you where we stood in each of these procurements and to let you know that DOE still considers the environmental and socioeconomics areas to be critical. And even though we don't have any contracts let at this point, we will continue in the future to diligently pursue and try to determine what the environmental and socio-economic impacts are of peat utilization.

At this point, even though the program is only looking at gasification as an end use for peat, the results from these studies will extrapolate toward applications such as beneficiation, which is an enhancement of the peat energy content, wet carbonization, liquids production, or direct combustion for rural home heating. All of these end uses for peat will still have to consider the environmental impacts of their implementation.

So, I am hopeful that the results from the environmental impact assessment will go a long way towards demonstrating DOE's intent to rigorously pursue this important area. I hope, parallel effort in socioeconomic impact assessment will be commenced in the near future.
QUESTIONS AND ANSWERS

Q: I was wondering, besides the environmental impact statement, are there any plans in the future for DOE to do any work looking at technology development for reclamation of peat-mined lands?

A: Yes. First we will do the assessments for environment and socio-economics and at some later date we will determine whether an Environmental Impact Statement itself should be performed.

But, as far as your specific question on reclamation, there are a number of reclamations we are considering, one of which was an excellent recommendation by your Fish and Wildlife Service. Bob Hayden and Jay Bassin, who aren't here today, suggested that peat be converted from a No. 7 wetland to a higher grade wetland in order to make the land available for more useful applications in a noncommercial sense, say as more of a recreation area or land that is much more amenable to wildlife.

I have had some preliminary discussions with Bob Hayden and Jay Bassin about it and we have talked about an inter-agency agreement. But until the details of my budget are worked out, it is difficult, if not impossible, to have substantive discussions.

The commercial reclamation scenarios that are commonly considered in the United States and abroad relate back to the fertility of reclaimed peat lands. If you leave about a foot towards the bottom of the bog and you mix it with a mineral sublayer, it has been shown that, at least for the crops tested, the productivity is greater than in land that has been previously nurtured for years and years to maximize the outputs. I am referring to crops like sorghum and soybeans and blueberries.

In Finland, they have an experimental station for forestry and they found that peat ash is an excellent fertilizer for the growth of trees. So this is another possibility. Another reclamation possibility, which is also in
the commercial area, is in energy farms such as the growth and harvesting and utilization of cattails.

So I think DOE is considering a number of possible reclamation options, ranging from the commercial exploitation and socio-economic advantage of the land after the peat has been harvested and the energy sold over the useful plant life to the noncommercial things that the Fish and Wildlife Service has suggested that would be perhaps more palatable to them or a little bit easier for society to accept.

So we are interested and we are going to pursue these applications and these reclamation options, as well as any others that should crop up that appear to be environmentally acceptable and economically feasible.