ABSTRACT

The goal of this project is to develop a technology for producing microengineered adsorbent carbons from Illinois coal and to evaluate the potential application of these novel materials for storing natural gas for use in emerging low pressure, natural gas vehicles (NGV). The focus of the project is to design and engineer adsorbents that meet or exceed the performance and cost targets established for low-pressure natural gas storage materials. Potentially, about two million tons of adsorbent could be consumed in natural gas vehicles by year 2000. If successful, the results obtained in this project could lead to the use of Illinois coal in a growing and profitable market that could exceed 6 million tons per year.

Activated carbon samples were prepared from IBC-106 coal by controlling both the preoxidation temperature and time, and the devolatilization temperature in order to eliminate the coal’s caking behavior. A 4.6 cc pressurized vessel was constructed to measure the Vm/Vs methane adsorption capacity (volume of stored methane at STP per volume of storage container). Several IBC-106 derived activated carbons showed methane adsorption capacities comparable to that of a 1000 m²/g commercial activated carbon. Results indicated that surface area and micropore volume of activated carbons were important physical properties for natural gas storage. Work is in progress to synthesis samples from IBC-106 coal with optimum pore diameter for methane adsorption.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
EXECUTIVE SUMMARY

Background

An adsorbed natural gas (ANG) storage system is being considered as an on-board storage technology for natural gas vehicles (NGV) because it is less expensive, lighter, occupies less space, costs less to refuel, and has much greater storage density at low pressure (< 35 atm) than that of compressed natural gas (CNG) storage (Golovoy, 1983; Wegryn et al., 1992; Nelson, 1993). Carbon-based adsorbents have been found to have the most favorable gas storage density compared to other adsorbents, e.g., zeolites (Golovoy, 1983). A key issue in commercial development of an ANG storage technology is the availability of low cost carbon adsorbents (< $2/lb) with high capacity for methane storage (Nelson, 1993). In addition, advanced cost-effective carbon adsorbents with sieving properties are needed to preferentially remove impurities (CO, CO₂, N₂, C₃-C₄ hydrocarbons) from natural gas. Illinois coal is a low-cost starting material that has the potential of being an ideal precursor for synthesis of carbon-based adsorbents with desirable properties for ANG technology.

NGV are presently being developed by numerous organizations throughout the world in hopes of capitalizing upon their inherent advantages over gasoline and other alternative fuels. To date, NGV have been implemented mainly in the form of high-pressure compressed natural gas retrofit. However, with the development of adsorbed natural gas storage, advancements are now possible in dedicated vehicle technology as opposed to current compressed natural gas technology, which limits market opportunities available to NGV due mainly to safety concerns. Adsorbed NGV (ANGV) operate at 15-30% of the pressure of compressed NGV. In the U.S., the utilization of ANGV in fleet applications will likely be their initial entry point into the marketplace. Fleet vehicles (taxis and buses) usually accommodate high mileage and often refuel at a central location. This allows usage of dedicated natural gas refueling facilities and maximizes the cost savings between gasoline and natural gas. The U.S. DOE recently compiled statistics which showed the potential market for fleet NGV to be tremendous (Biederman et al., 1989). The current number of total fleet automobiles and private and commercial light trucks is 48 million. This is expected to rise to 60 million vehicles by the year 2000. These statistics reflect a growing market potential for ANGV of up to 12 million units. This study also showed that Chicago, Illinois would be the ideal market for fleet vehicles, and deemed the city the prime U.S. location to begin marketing ANGV.

The potential benefit of the development of adsorbed natural gas technology to the Illinois coal industry is significant just taking into account the expected increase in fleet vehicles. If by the year 2000, twelve million fleet ANGV are added and were to carry an average of 300 pounds carbon adsorbent for low pressure natural gas storage, it would necessitate a demand for 3.6 billion pounds of low-cost carbon. If this carbon were to be made of coal, the demand for a suitable coal would be 12 billion pounds assuming that 30% of the coal is utilized in the final product. Thus, 6 million tons of additional coal would be needed. These calculations do not account
for additional demand due to ANGV entering the main marketplace, where over 250 million units are now in operation. If ANGV find entry into this market, it could mean an even greater demand for coal. The results of research directed towards the development of suitable adsorbent carbons from Illinois coal for natural gas storage should be of great interest to the Illinois coal industry. Based on past history of the auto industry, it is reasonable to assume that if a suitable feedstock for a NGV carbon adsorbent is identified, cost conscious auto makers will rush to adopt use of this material for their adsorbed natural gas vehicles.

Goals and Objectives

The overall goal of this project is to develop a technology for producing microengineered adsorbent carbons from Illinois coal and evaluate the potential application of these novel materials for use in the emerging low pressure ANGV. The focus of the project is to design and engineer adsorbents from Illinois coal that meet or exceed the performance and cost targets established for low-pressure natural gas storage materials.

The project consists of six tasks. In Task 1, chars are prepared from IBC-106 coal in a fixed-bed or a fluidized bed under a wide range of heat treatments and soak times. The pore structure of the chars is tailored for optimum methane storage capacity (about 10-12 Å) via activation in CO₂ or H₂O. Carbon adsorbents with molecular sieve properties will be made by further modifying the pore structure by carbon deposition with CH₄ or by a novel oxygen deposition method. In Task 2, the physical and chemical properties of the products are evaluated to gain additional insight into the fundamentals of preparation and properties of CMS. In Task 3, the methane adsorption capacity (energy storage density) of products and the heat of adsorption will be measured at pressures ranging from 1 to 35 atm with a pressurized thermogravimetric analyzer and by differential scanning calorimetry at the ISGS. Experiments will also be performed at Amoco Research Center (Naperville, IL) with a high pressure volumetric apparatus, designed and constructed for screening adsorbents for ANG, to compare the engineering properties and storage capacity of the adsorbents made from Illinois coal with the commercially available counterparts. In Task 4, the molecular sieve properties of the products are determined by measuring the kinetics of adsorption of O₂, N₂, CO₂, CH₄ and C₂H₆ on chars at 25°C. The ability of the chars to separate impurities from natural gas is tested in an adsorption column/gas chromatography/mass spectrometry system. In Task 5, a process flowsheet for production of adsorbent carbons from Illinois coal suitable for ANGV, is developed, and a technical/economic study is initiated. In Task 6, technical and management quarterly reports are prepared and submitted to the ICCI.
Results and Discussion

Since one of the key issues in commercial development of the ANG storage technology is the availability of low cost adsorbents, the focus of this research is to evaluate potential process schemes that would lower the production cost of the adsorbent carbons.

Coal preoxidation is a necessary and key processing step to manufacture activated carbon/char from Illinois coal. A fundamental study on IBC-106 coal’s caking property was carried out during this reporting period. It was found that the coal’s caking behavior is a function of preoxidation time and devolatilization temperature. The results indicated that the coal preoxidized for a given time period has different caking behaviors at different heat treatment temperatures (HTT). For example, the coal preoxidized at 225°C for 3 h is a noncaking coal at 700°C HTT, but is caking at 850°C. The coal preoxidized for 0.5 h and devolatilized at 400°C for 1 h, had no agglomeration during 850°C steam activation. In other words, IBC-106’s caking can be eliminated by either half hour oxidation at 225°C followed by 400°C devolatilization, or 4-5 hour oxidation at 225°C followed by 850°C devolatilization. The agglomeration or caking behavior was examined by visual observation.

The effect of coal oxidation on carbon surface area and methane adsorption was investigated further by extending the preoxidation time to 9 h. A correlation between surface area of activated carbons and coal preoxidation time at 225°C was observed. The optimum preoxidation time was found to be 4 h. Methane adsorption capacity corresponded well with surface area at various preoxidation time. A sample with the highest Vm/Vs methane adsorption capacity also had the highest surface area and micropore volume.

The Vm/Vs methane adsorption capacities of carbons from Illinois coal, measured at 500 psig, ranged from 51 to 73 cm³/cm³. An activated carbon made from the coal sample which has been preoxidized prior to devolatilization step had a comparable methane storage capacity to that of BPL. Samples prepared from IBC-106 without the preoxidation step showed lower capacity than that of BPL.

Table 1. lists production conditions, surface area, and methane adsorption capacity of selected samples prepared during this reporting period.

Work is currently in progress to produce activated carbon samples with optimum pore size diameter and internal surface area. These samples are prepared at activation temperatures that results in slow char burn-off rate in order to develop a more uniform pore structure (narrower pore size distribution) while increasing the internal surface area of the char. The goal is to synthesis an activated carbon from IBC-106 coal with the majority of its pores in the range of 10-12 Å. The optimum pore size for methane storage has been reported to be about 11.4 Å, i.e., three methane molecular width.
Table 1. List of selected activated carbons produced from Illinois coal

<table>
<thead>
<tr>
<th>Carbon #</th>
<th>Production conditions *</th>
<th>Coal weight loss (daf), wt%</th>
<th>Carbon surface area (dry), m²/g</th>
<th>CH₄ adsorption at 500 psig g/g</th>
<th>Bulk density g/cm³</th>
<th>CH₄ adsorption at 500 psig cm³/cm³</th>
<th>Micropore volume cm³/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n400(1)850(1.5)</td>
<td>75.8</td>
<td>897</td>
<td>0.0424</td>
<td>0.33</td>
<td>50.6</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>225(2)400(1)850(2)</td>
<td>78.3</td>
<td>970</td>
<td>0.0497</td>
<td>0.38</td>
<td>62.7</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>225(3)400(1)850(2)</td>
<td>77.7</td>
<td>978</td>
<td>0.0479</td>
<td>0.39</td>
<td>57.2</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>225(4)400(1)850(2)</td>
<td>76.9</td>
<td>1037</td>
<td>0.0541</td>
<td>0.44</td>
<td>67.3</td>
<td>0.374</td>
</tr>
<tr>
<td>5</td>
<td>225(5)400(1)850(2)</td>
<td>77.3</td>
<td>932</td>
<td>0.0474</td>
<td>0.45</td>
<td>62.8</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>225(6)400(1)850(2)</td>
<td>79.9</td>
<td>961</td>
<td>0.0478</td>
<td>0.43</td>
<td>64.4</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>225(3)400(1)825(3)</td>
<td>76.9</td>
<td>1056</td>
<td>0.0509</td>
<td>0.44</td>
<td>73.3</td>
<td>0.408</td>
</tr>
<tr>
<td>BPL</td>
<td>Commercial carbon</td>
<td>-</td>
<td>883</td>
<td>0.0505</td>
<td>0.46</td>
<td>67.3</td>
<td>0.429</td>
</tr>
</tbody>
</table>

* Oxidation °C (h) devolatilization °C (h) activation °C (h); "n": non-oxidation
OBJECTIVES

The overall goal of this two-year project is to develop a technology for producing microengineered carbon adsorbents from Illinois coal and to evaluate the potential application of these materials for use in the emerging low pressure natural gas vehicle (NGV). The main objective of the proposed research is to synthesize microengineered adsorbents, from Illinois coal, suitable for use in ANGV which meet the following criteria: a) natural gas storage density of > 150 V/V compared to current 100-120 V/V; b) lower adsorbent cost (< $2/lb). Another important objective is to develop an adsorbent carbon with sieving properties to be used in a guard bed system for controlling the adsorbable contaminants present in natural gas (C₂-C₄ hydrocarbons, N₂, CO₂, odorant, water). The tasks of the project are:

Task 1. Adsorbents are prepared from IBC-106 coal in a fixed-bed or a fluidized-bed reactor under a wide range of heat treatment and activation conditions. The pore structure of the chars is tailored for optimum methane storage capacity (about 10-12 Å) via chemical activation with KOH or activation in CO₂/H₂O. The pore structure may be further modified by carbon deposition with CH₄ to achieve proper molecular sieving properties.

Task 2. Adsorbents are characterized for their physical and chemical properties, including N₂-BET and CO₂ surface area, porosity and pore size distribution and bulk density, to gain insight into the fundamentals of preparation and the properties of products.

Task 3. Molecular sieve properties of selected products are determined by measuring the kinetics of adsorption of O₂, N₂, CO₂, CH₄ and C₂H₄ on chars at 25°C. The ability of the chars to separate impurities from natural gas is tested in an adsorption column/mass spectrometry system.

Task 4. Methane adsorption capacity (energy storage density) of products and the heat of adsorption are measured at pressures ranging from 1 to 35 atm. High-pressure methane capacities of products is determined with a high-pressure volumetric adsorption apparatus at Amoco Corporation and results are compared with commercial products tested for ANG.

Task 5. A process flowsheet for production of microengineered adsorbents from Illinois coal is developed. A technical and economic study as well as a market analysis will be initiated.

Task 6. Technical and management quarterly reports are prepared and submitted to ICCI.
INTRODUCTION

Carbon-based adsorbents have been found to have the most favorable gas storage density compared to other adsorbents, e.g., zeolites (Golovoy, 1983). In ANGV applications, the storage volume is often limited (gas tank). Thus for adsorbents with the same capacity per unit mass, the one having the greater packing density in the storage vessel will result in a greater storage capacity. However, adsorbents with lower packing density, but greater capacity per unit mass, may have greater storage capacities. Matranga et al. (1992) performed Monte Carlo calculations to simulate the adsorption of natural gas on carbon. Adsorption isotherms, storage capacity, and isosteric heats of adsorption were determined from model simulations and compared with experimental data. Their model simulations predicted a maximum storage capacity at 35 atm of $244\, V/V$ for monolithic carbon and $169\, V/V$ for pelletized carbon. (The standard terminology for natural gas storage capacity is $V/V$ or volume of stored material at STP per volume of storage container.) Generally, two approaches are taken to optimize storage capacity using carbon adsorbents. An adsorbent with a high mass uptake but low density, such as the Amoco KOH type carbons, can be treated with binder and compacted to improve packing density and thus increase volumetric storage capacity. On the other hand, a high density but low microporosity carbon can be activated in an attempt to increase the microporosity, and thus storage capacity. However, this will be at the expense of decreasing density. For natural gas storage, macroporosity in carbons is undesirable. Amoco type carbons have large macropore volumes which still exist after compaction. This results in reduced volumetric storage capacity. Conventional activation of coal-derived carbons by air, carbon dioxide or steam, also results in macropore formation. Therefore, to minimize macropore formation and increase gas storage capacity, new or modified methods for the preparation of both types of carbons must be found.

EXPERIMENTAL PROCEDURES

Coal Preparation
The adsorbent carbons produced in this work were prepared from an Illinois Basin Coal, IBC-106. Twenty pounds of this coal was obtained from the coal bank located at the ISGS. The parent coal was subjected to a step-wise grinding and sieving technique which involved grinding the sample in a rock mill and a Homes mill in order to reduce its particle size from -8 mesh to -20+100 mesh. Size range of -20+100 mesh is considered as that of Granular Activated Carbon. About 20 aliquot of $\sim 5$ grams coal sample was prepared by riffling from a 5 pounds portion of the fresh ground coal.

Carbon Production
An oxidation-pyrolysis-gasification reactor system assembled during the first reporting period was used for char production experiments. In a typical run, the sample holder was filled with about 5 gm coal and the sample was placed into the reactor tube, the air flow was set at 1 liter/min and the furnace was set to 225°C. Under these
conditions, the gas temperature above the boat was about 225-250°C. After a pre-determined oxidation time, the gas stream was switched from air to nitrogen at 1 liter/min. The reactor was purged with nitrogen for at least five minutes. In the devolatilization step, the reaction temperature was increased to 425°C and was hold for 30 minutes to one hour (desired devolatilization time). In the gasification step, the nitrogen flow rate was reduced to 0.5 liter/min and the peristaltic pump was turned on with a water flow rate of 22 cc/min (desired water flow rate to produce 50% steam in nitrogen gasification gases). The furnace was set to 800-850°C and hold at this temperature for the desired period of activation time. After the completion of the activation step, the reactor was cooled under a nitrogen purge to the ambient temperature and the sample was stored in a glass bottle.

Carbon Characterization

Single-point BET surface areas of the carbons were determined from nitrogen (77 K) adsorption data obtained with a Monosorb flow apparatus (Quantachrome Corp.). Multi-point BET surface areas and micropore volumes of two selected products were calculated using t-plot (for micropore volume) based on the nitrogen adsorption isotherm \( p/p_0 \): 0.0011-1) measured with a volumetric adsorption apparatus (Micromeritics). These measurements were performed at the University of Illinois' Material Reserch Laboratory. Screening tests were performed with a pressurized thermogravimetric analyzer (Spectrum Research and Engineering) to measure the methane adsorption capacity (g/g) of the carbon products at pressures up to 500 psig. A 4.6 cc pressurized vessel was constructed during this reporting period to measure the Vm/Vs methane adsorption capacity (cm³/cm³).

RESULTS AND DISCUSSION

Table 1 lists a number of activated carbons produced from IBC-106 under various conditions. The single point BET surface areas and methane adsorption capacity (g/g) values of these samples were reported in the previous report. A commercial activated carbon, BPL manufactured by Calgon Carbon Corp., was selected as a reference adsorbent. The Vm/Vs methane adsorption capacities of carbons from Illinois coal, measured at 500 psig, ranged from 51 to 73 cm³/cm³. These values are comparable to that of BPL. Figure 1 shows the methane adsorption isotherms (0 to 500 psig) for BPL and two selected carbon products. It is noted that the activated carbon (#4) made from the coal sample which has been pre-oxidized prior to devolatilization step has a comparable methane storage capacity to that of BPL. Carbon (#1) prepared from IBC-106 without the preoxidation step showed lower capacity.

Devolatilization is considered to be a necessary step in creating cross link creation within the coal's network. It has been recognized that following the preoxidation step
Figure 1. Methane adsorption isotherms for BPL and selected carbons from Illinois coal (Carbons #1 and #4)

Figure 2. Effect of devolatilization temperature on surface area and methane adsorption of coal carbons
Table 1. List of selected activated carbons produced from Illinois coal

<table>
<thead>
<tr>
<th>Carbon #</th>
<th>Production conditions *</th>
<th>Coal weight loss (daf), wt%</th>
<th>Carbon surface area (dry), m²/g</th>
<th>CH₄ adsorption at 500 psig g/g</th>
<th>Bulk density g/cm³</th>
<th>CH₄ adsorption at 500 psig cm³/g</th>
<th>Micropore volume cm³/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n400(1)850(1.5)</td>
<td>75.8</td>
<td>897</td>
<td>0.0424</td>
<td>0.33</td>
<td>50.6</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>225(2)400(1)850(2)</td>
<td>78.3</td>
<td>970</td>
<td>0.0497</td>
<td>0.38</td>
<td>62.7</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>225(3)400(1)850(2)</td>
<td>77.7</td>
<td>978</td>
<td>0.0479</td>
<td>0.39</td>
<td>57.2</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>225(4)400(1)850(2)</td>
<td>76.9</td>
<td>1037</td>
<td>0.0541</td>
<td>0.44</td>
<td>67.3</td>
<td>0.374</td>
</tr>
<tr>
<td>5</td>
<td>225(6)400(1)850(2)</td>
<td>77.3</td>
<td>932</td>
<td>0.0474</td>
<td>0.45</td>
<td>62.8</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>225(9)400(1)850(2)</td>
<td>79.9</td>
<td>961</td>
<td>0.0478</td>
<td>0.43</td>
<td>64.4</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>225(3)400(1)825(3)</td>
<td>76.9</td>
<td>1056</td>
<td>0.0509</td>
<td>0.44</td>
<td>73.3</td>
<td>0.408</td>
</tr>
<tr>
<td>BPL</td>
<td>Commercial carbon</td>
<td>-</td>
<td>883</td>
<td>0.0505</td>
<td>0.46</td>
<td>67.3</td>
<td>0.429</td>
</tr>
</tbody>
</table>

* Oxidation °C (h) devolatilization °C (h) activation °C (h); "n": non-oxidation

in production of activated carbon from a caking coal, devolatilization at intermediate temperatures is favored to efficiently create new cross links within coal's network, hence to preserve its microporosity (Sun, 1993). Carbon #1 produced without the preoxidation step showed lower surface area and methane adsorption capacity (Table 1), as caking destroys microporosity by structural realignment. Figure 2 shows the effect of devolatilization temperature on surface area and methane adsorption capacity of two carbon sets produced with devolatilization at 400 and 500°C, respectively. Both carbon sets had the same preoxidation time (3 h) and the same activation temperature (850°C). It appears that a lower devolatilization temperature leads to slightly higher surface area and methane adsorption capacity. Note that during char activation the maximum methane adsorption capacity corresponds well with the maximum surface area.

Coal preoxidation is a necessary and key processing step to manufacture activated carbon/char from Illinois coal. A fundamental study on IBC-106 coal's caking property was carried out during this reporting period. Based on an earlier study (Sun, 1993), the effect of coal oxidation on coal's caking behavior was investigated. It was found that the coal's caking behavior is a function of its oxidation time and devolatilization temperature. Figure 3 shows that a coal oxidized for a given time period has different caking behaviors at different heat treatment temperatures (HTT), e.g., the coal oxidized for 3 h is a noncaking coal at 700°C HTT, but is caking at 850°C. It is also interesting to note that the coal oxidized for 0.5 h and devolatilized at 400°C for 1 h, had no agglomeration during 850°C steam activation. In other words, IBC-106’s caking can be eliminated by either half hour oxidation at 225°C followed by 400°C devolatilization, or 4-5 hour oxidation at 225°C followed by 850°C devolatilization. The agglomeration or caking behavior was examined by visual observation.
Figure 3. Effect of coal oxidation time and devolatilization temperature on caking property of IBC-106 coal.

Figure 4. Effect of pre-oxidation time on surface area and methane adsorption of Carbons #1-6.
The effect of coal oxidation on carbon surface area and methane adsorption was investigated further by extending the oxidation time to 9 h. Figure 4 illustrates a correlation between surface area of Carbons #1-6 and coal preoxidation time at 225°C. The optimum preoxidation time appears to be 4 h. Again, methane adsorption capacity corresponds well with surface area at various preoxidation time. Carbon #7, the sample with the highest Vm/Vs methane adsorption capacity produced in this period, was activated at 825°C. Table 1 shows that this sample also has the highest surface area and micropore volume.

The BET (multi-point) surface areas for BPL (the commercial carbon), Carbon #4 and Carbon #7 are 1112, 1107 and 1158 m²/g, respectively.

Four additional carbon products were made with 4-4.5 hour activation at 800°C. The BET surface area, micropore volume and pore size distribution of these samples are currently being measured. The purpose of lowering the activation temperature further is to develop a more uniform pore structure (narrower pore size distribution) while increasing the internal surface area. In these runs the char with the majority of pores in the range of 10-12 Å. The optimum pore size for methane storage has been reported to be about 11.4 Å, i.e., three methane molecular width.

CONCLUSIONS AND RECOMMENDATIONS

A number of activated carbon samples were prepared from IBC-106 coal with methane adsorption capacities comparable to that of a commercial activated carbon. These initial results are encouraging when considering the possibility of pelletizing the treated samples. Carbon densification is expected to increase the Vm/Vs methane adsorption by 20 to 40% (Sejnoha et al., 1994). It was concluded that surface area and micropore volume are important physical properties for natural gas storage. To produce an activated carbon with desired physical properties from IBC-106 coal, it is critical to eliminate coal’s caking behavior by controlling both the preoxidation temperature and time, and the devolatilization temperature.

DISCLAIMER STATEMENTS


(A) Makes any warranty of representation, express or implied, with respect to the accuracy, completeness, or usefulness of the
information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Department of Energy. The news and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Department of Energy.

Notice to Journalists and Publishers: If you borrow information from any part of this report, you must include a statement about the DOE and Illinois cost-sharing support of the project.
REFERENCES


Lizzio, A. A., Rostam-Abadi, M., 1993. Production of Carbon Molecular Sieve from


PROJECT MANAGEMENT REPORT
March 1 through May 31, 1995

Project Title: **NOVEL CARBONS FROM ILLINOIS COAL FOR NATURAL GAS STORAGE**

<table>
<thead>
<tr>
<th>DOE Cooperative Agreement Number:</th>
<th>DE-FC22-92PC92521 (Year 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICCI Project Number:</td>
<td>94-1/4.2B-6M</td>
</tr>
<tr>
<td>Principal Investigator:</td>
<td>Massoud Rostam-Abadi, ISGS</td>
</tr>
<tr>
<td>Other Investigators:</td>
<td>Jian Sun, Anthony A. Lizzio, ISGS</td>
</tr>
<tr>
<td>Project Manager:</td>
<td>Daniel Banerjee</td>
</tr>
</tbody>
</table>

COMMENTS
## Expenditures - EXHIBIT B

Cumulative Projected and Estimated Expenditures by Quarter

<table>
<thead>
<tr>
<th>Quarter*</th>
<th>Types of Cost</th>
<th>Direct Labor</th>
<th>Fringe Benefits</th>
<th>Materials and Supplies</th>
<th>Travel</th>
<th>Major Equipment</th>
<th>Other Direct Costs</th>
<th>Indirect Costs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1, 1994 to</td>
<td>Projected</td>
<td>4,967</td>
<td>1,244</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>3,720</td>
<td>1,043</td>
<td>11,474</td>
</tr>
<tr>
<td>Nov. 30, 1994</td>
<td>Estimated</td>
<td>3,200</td>
<td>460</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>300</td>
<td>446</td>
<td>4,906</td>
</tr>
<tr>
<td>Sep. 1, 1994 to</td>
<td>Projected</td>
<td>9,934</td>
<td>2,488</td>
<td>1,500</td>
<td>0</td>
<td>0</td>
<td>7,450</td>
<td>2,137</td>
<td>23,509</td>
</tr>
<tr>
<td>Feb. 28, 1995</td>
<td>Estimated</td>
<td>6,000</td>
<td>860</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>950</td>
<td>831</td>
<td>9,141</td>
</tr>
<tr>
<td>Sep. 1, 1994 to</td>
<td>Projected</td>
<td>14,934</td>
<td>3,632</td>
<td>2,500</td>
<td>0</td>
<td>0</td>
<td>14,885</td>
<td>3,595</td>
<td>39,546</td>
</tr>
<tr>
<td>May 31, 1995</td>
<td>Estimated</td>
<td>13,600</td>
<td>3,406</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>2000</td>
<td>1951</td>
<td>21,456</td>
</tr>
<tr>
<td>Sep. 1, 1994 to</td>
<td>Projected</td>
<td>19,868</td>
<td>4,977</td>
<td>3,000</td>
<td>0</td>
<td>0</td>
<td>17,042</td>
<td>4,489</td>
<td>49,376</td>
</tr>
<tr>
<td>Aug. 31, 1995</td>
<td>Estimated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Cumulative by Quarter
COST BY QUARTER - EXHIBIT C

NOVEL CARBONS FROM ILLINOIS COAL FOR NATURAL GAS STORAGE

Projected Expenditures Actual Expenditures

Total ICCI Award $49,376
Milestones:

A. Preparation of carbon adsorbents (Task 1)
B. Physical and chemical characterization (Task 2)
C. Methane working capacity/heat of adsorption (Task 3)
D. Molecular sieve properties (Task 4)
E. Technical/economic/market studies (Task 5)
F. Reports (Task 6)