

**Assessment of the Quality of Indiana Coals for Integrated Gasification
Combined Cycle Performance: Analysis of the existing data and proposal of
new research**

Progress Report – March 1 – May 31, 2005

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1. Importance and justification of the proposed study

There are several reasons to evaluate the applicability of Indiana coals for Integrated Gasification Combined Cycle (IGCC) technology. First, more than 90 percent of Indiana's electricity comes from coal. The overwhelming majority of the coal mined in Indiana (73 percent) is used for generating electricity. Annually, Indiana uses twice as much coal as it produces (70 million short tons used versus 34 million short tons produced). Most of the non-Indiana coal consumed in the state is imported from Wyoming.

Second, Indiana has significant coal reserves; approximately 17.5 billion short tons are available for either surface or underground mining (Mastalerz et al., 2004) which, at the current level of production, can suffice for hundreds of years. However, most Indiana coals are high in sulfur (the average sulfur content for all coal beds is 3.1 percent) and, as such, cause significant SO₂ emissions from power plants upon combustion. Wet scrubbers are used in power plants to reduce these hazardous emissions. In addition, impending mercury regulations for coal-fired power plants from the federal government (EPA, 2000, 2004) will force plants to search for the most efficient and least costly ways to address these issues.

Third, IGCC units are much cleaner than standard power plants; at up to 45 percent efficiency, they can achieve greater than 99 percent SO₂ removal. The technology uses less water and has fewer emissions than a conventional coal-fired power plant with currently required pollution control equipment. Another benefit is the possibility of removing mercury and carbon dioxide upstream of the combustion process at a lower cost than conventional plants. However, the total cost of an IGCC plant is high. At present, IGCC cost projections range from \$1,200 to \$1,400/kW, 10 to 30 percent higher than plants using pulverized coal with wet scrubbers, with similar construction periods. This cost may become attractive, however, when compared with the costs of maintaining old units, especially when additional installations of new pollution control devices become necessary.

Fourth, IGCC is being recognized nationwide as a viable technology. It was stressed as the technology of the future during the recent national Coal 2020 conference in Lexington, Kentucky. Also, Cinergy/PSI, the General Electric Company, and Bechtel Corporation have recently signed a letter of intent to study the feasibility of constructing an IGCC generating station. Edwardsport, Indiana, is one of the places considered for its location (press release of October 26, 2004).

Considering these late developments in clean coal technologies and the fact that IGCC is continuously gaining momentum both nationally and internationally, evaluating Indiana coals with respect to their performance in IGCC systems seems both necessary and of great urgency.

2. Objectives of this study

The principal objective of this scoping study is to outline a new 3-year research program to be conducted on Indiana coal to adequately assess its performance for IGCC. We will outline research areas and specific tests and analyses that are needed, together with the budgetary considerations and identification of matching funds. We will also recommend various models for testing the performance of Indiana coals for IGCC. It is our intent that when this 3-year bench-scale project is completed, adequate information will be available to move to a pilot-scale operation.

In order to propose the new research, we must assess existing data on Indiana coals. Specifically, we will:

1. Identify the properties of Indiana coals that are of major importance for IGCC performance;
2. Assess the availability of data on coal characteristics needed to assess IGCC performance; and
3. Identify areas in which more data are necessary to adequately assess coal performance for IGCC.

This preliminary assessment will provide the basis for the comprehensive evaluation of Indiana coals for IGCC technologies in the future.

3. Activities accomplished to date

Table 1 shows the progress we have made so far. Tasks 1 and 2 have already been completed.

Table 1. Status of individual tasks of the project.

| Tasks | Activity | Deadline | % completed |
|---------------|---|-----------------|--------------------|
| Task 1 | Identify properties of Indiana coals that are of major importance to IGCC performance | April 30 | 100% |
| Task 2 | Assess availability of coal data that are critical for IGCC | June 31 | 100% |
| Task 3 | Identify areas in which more data are needed | August 31 | 10% |
| Task 4 | Propose new research | November 30 | 5% |

3.1. Identify properties of Indiana coals that are of major importance for IGCC performance (Task 1)

We performed an intensive literature search on coal gasification from various sources and countries. Based on the literature, as well as our own research, we have identified several parameters of coal quality that are very important for the performance in an IGCC system. These include:

- a) **Moisture** influences efficiency of gasification and can determine whether the process must be dry or slurry fed.
- b) **Heating value** influences generation capacity. To obtain the same energy from a lower heating value coal (for example, western coal), a greater tonnage must be gasified.
- c) **Mineral matter properties** such as ash content, ash fusion temperatures (AFT), and slag viscosity have a number of critical effects on an IGCC system. In general, low ash content (<10 percent) coals are preferred for IGCC. Ash fusion temperature is very important, but its influence varies drastically in different plant designs. For example, for entrained flow gasifiers, AFT should be below 1500°C, but for fluidized bed gasifiers, temperatures above 1100°C are preferred.
- d) **Volatile matter and char reactivity** determine the extent and rate of gasification reactions. Coal consumption during gasification consists of two steps: volatile pyrolysis (fast process) and char gasification (slow process). Generally, the higher the char yield and the lower the char reactivity, the longer the time required for complete gasification. ***Therefore, coals that have a low char yield and high char reactivity are generally preferred***, although these requirements vary depending on the gasifier type. Char reactivity, in addition to rank and mineral matter characteristics, depends on maceral composition, with reactivity increasing from inertinite (lowest reactivity) through vitrinite to liptinite (highest reactivity).
- e) ***Sulfur, nitrogen, and chlorine*** are other important parameters.

We also have developed summary tables (Tables 2–4) that show how these coal properties influence IGCC behavior and the requirements for three types of gasifiers:

- 1) fixed-bed gasifiers,
- 2) fluidized-bed gasifiers, and
- 3) entrained-flow gasifiers.

Table 2. Fixed-bed gasifiers

| Parameter | Importance | Coal Requirements |
|-------------------------------|---|--|
| Moisture | <ul style="list-style-type: none"> Influences gasifier efficiency Determines if process must be dry or slurry fed | <ul style="list-style-type: none"> for dry feed – 2% for slurry feed – 10% |
| Volatile matter | <ul style="list-style-type: none"> Determines the extent and rate of gasification reactions | - A range of volatile matter contents are used |
| Heating value | <ul style="list-style-type: none"> Determines plant dimensions Influences generation capacity | - A range of heating values are used |
| Ash content | <ul style="list-style-type: none"> Lowers system efficiency Increases slag production and disposal cost | <15% |
| AFT (flow, Reduction) | <ul style="list-style-type: none"> Influences melting ability of discharged slag (must be melted below performance temperature) | <1400°C |
| Slag viscosity ~1400°C | <ul style="list-style-type: none"> Influences smooth slag flow between packed bed particles (viscosity must be sufficiently low) | <5Pa.s |
| Char reactivity | <ul style="list-style-type: none"> Influences the extent of carbon conversion | - A range of reactivities can be used because of higher operational temperature |
| Sulfur | <ul style="list-style-type: none"> May cause corrosion of heat exchanger surfaces | - Preferred S<1.5% |
| Nitrogen | <ul style="list-style-type: none"> Contributes to NOx emissions | |
| Chlorine | <ul style="list-style-type: none"> May form HCl, which can poison gas cleaning system catalysts May form HCl, which can cause chloride stress corrosion | <0.4% (ad) |

Table 3. Fluidized-bed gasifiers

| Parameter | Importance | Coal Requirements |
|------------------------------|---|--|
| Moisture | <ul style="list-style-type: none"> Influences gasifier efficiency (higher moisture - lower efficiency) | - A range of moisture contents are used |
| Volatile matter | <ul style="list-style-type: none"> Determines the extent and rate of gasification reactions | - A range of volatile matter contents are used |
| Heating value | <ul style="list-style-type: none"> Determines plant dimensions Influences generation capacity (higher heating value = higher capacity and efficiency) | - A range of heating values are used |
| Ash content | <ul style="list-style-type: none"> Influences net cycle efficiency Influences flux addition rate | <40% |
| AFT (flow, reduction) | <ul style="list-style-type: none"> Influences operations | >1100°C; Since mineral matter is expelled as ash, it is important that AFT is higher than operation temperature for the ash particles not to become sticky and agglomerate |
| Slag viscosity | <ul style="list-style-type: none"> Not much of concern | |
| Char reactivity | <ul style="list-style-type: none"> Influences carbon conversion | - Low reactivity chars not suitable because of low carbon conversion at relatively low temperature |
| Sulfur | <ul style="list-style-type: none"> Can cause corrosion of heat exchanger surfaces | - Preferred S<1.5% |
| Nitrogen | <ul style="list-style-type: none"> Contributes to NOx emissions | |
| Chlorine | <ul style="list-style-type: none"> May form HCl, which can poison gas cleaning system catalysts May form HCl, which can cause chloride stress corrosion | <0.4% (ad) |

Table 4. Entrained-flow gasifiers

| Parameter | Importance | Coal Requirements |
|------------------------------|--|---|
| Moisture | <ul style="list-style-type: none"> Influences gasifier efficiency (higher moisture = lower efficiency) | - A range of moisture contents are used |
| Volatile matter | <ul style="list-style-type: none"> Influences the extent and rate of gasification reactions | - A range of volatile matter contents are used |
| Heating value | <ul style="list-style-type: none"> Determines plant dimensions Influences generation capacity (higher heating value = higher capacity and efficiency) | - A range of heating values are used |
| Ash content | <ul style="list-style-type: none"> Influences net cycle efficiency (higher ash = lower efficiency) influences flux addition rate | <25% |
| AFT (flow, reduction) | <ul style="list-style-type: none"> Influences melting ability of discharged slag (must be melted below performance temperature) Influences operating costs (higher temperature = higher costs) | <1500°C |
| Slag viscosity | <ul style="list-style-type: none"> Influences slag flow | <ul style="list-style-type: none"> Preferred <15Pa.s Used up to 25 Pa.s; viscosity must be sufficiently low to ensure smooth slag flow down the gasifier walls |
| Char reactivity | <ul style="list-style-type: none"> Influences extent of carbon conversion (higher reactivity = higher cycle efficiency) Influences oxygen consumption | - A range of reactivities may be used because of higher operational temperature |
| Sulfur | <ul style="list-style-type: none"> May cause corrosion of heat exchanger surfaces Influences operating costs (higher sulfur = higher costs) | - Preferred S<1.5% |
| Nitrogen | <ul style="list-style-type: none"> Contributes to NO_x emissions | |
| Chlorine | <ul style="list-style-type: none"> May form HCl, which can poison gas cleaning system catalysts May form HCl, which can cause chloride stress corrosion | <0.4% (ad) |

3.2. Assess the availability of data on coal characteristics needed to assess IGCC performance (Task 2)

We have prepared a database of Indiana coal characteristics that are of primary importance to IGCC. The Microsoft ACCESS database includes many parameters, some of which (for example, moisture content, ash yield, and heating value) contain a great deal of data for all major Indiana coal beds. For selected coal characteristics, maps have been generated to document the character of lateral variability. Examples of such maps of moisture and ash content for the Danville and Springfield Coal Members are presented in Figures 1 through 4.

For some parameters, for example, ash fusion temperatures, ash viscosity, or char reactivity, data are sparse to nonexistent (Table 5).

Table 5. Data availability for selected coal properties for Indiana coal beds.

| | Moisture | Fixed carbon | Volatile matter | AFT | Slag viscosity | Char reactivity |
|-------------|----------|--------------|-----------------|-----|----------------|-----------------|
| Danville | 149 | 116 | 116 | 12 | 12 | 0 |
| Hymera | 119 | 102 | 102 | 0 | 0 | 0 |
| Springfield | 320 | 280 | 280 | 0 | 1 | 0 |
| U. Block | 120 | 76 | 76 | 11 | 10 | 0 |
| L. Block | 142 | 50 | 50 | 15 | 15 | 0 |

3.3. Identify areas in which more data are necessary to adequately assess coal performance for IGCC (*Task 3*)

The analysis of the database indicates that gaps exist in the parameters of ***char reactivity and slag behavior***; these and related properties must be emphasized in any further research assessing IGCC performance of Indiana coals. We will continue to research this topic in the next stage of the project.

4. Next steps

- Visit Eastman (Tennessee) and Wabash River (Indiana) Gasification plants.
- Propose additional tests and analyses that must be conducted on Indiana coal to adequately assess coal performance for IGCC (completing Task 4).
- Create a model of the IGCC performance of Indiana coals (Task 4).

REFERENCES

- EPA, 2000. Regulatory finding on the emissions of hazardous air pollutants from electric utility steam generating units. U.S. Federal Register 65 (245), p. 79825-79831.
- EPA, 2004. Mercury. <http://www.epa.gov/mercury>, accessed on March 9, 2004.
- Mastalerz, M., Drobnik, A., Rupp, J., and Shaffer, N., 2004. Characterization of Indiana's coal resource: Availability of the reserves, physical and chemical properties of the coal, and present and potential uses. IGS Open-File Study 04-02, 74 p.



Figure 1. Map of southwestern Indiana showing the moisture content of the Danville coal.

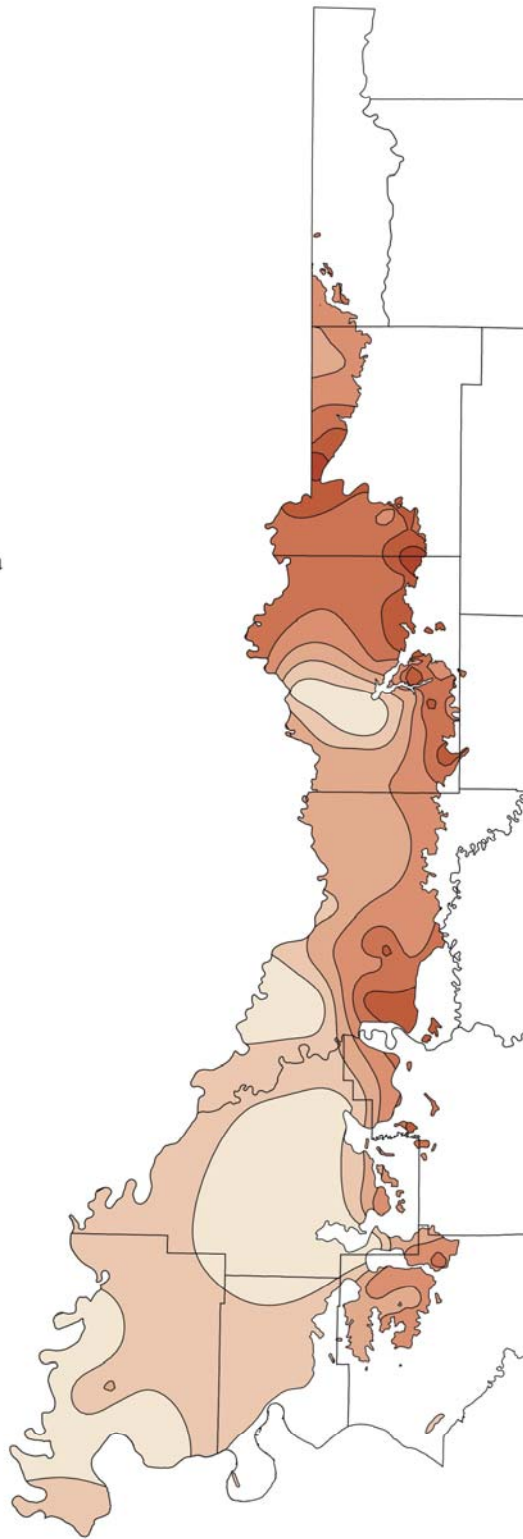
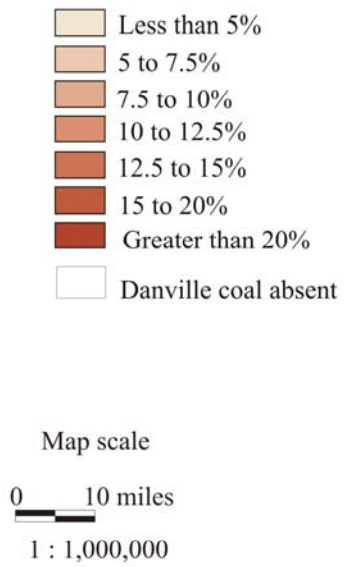
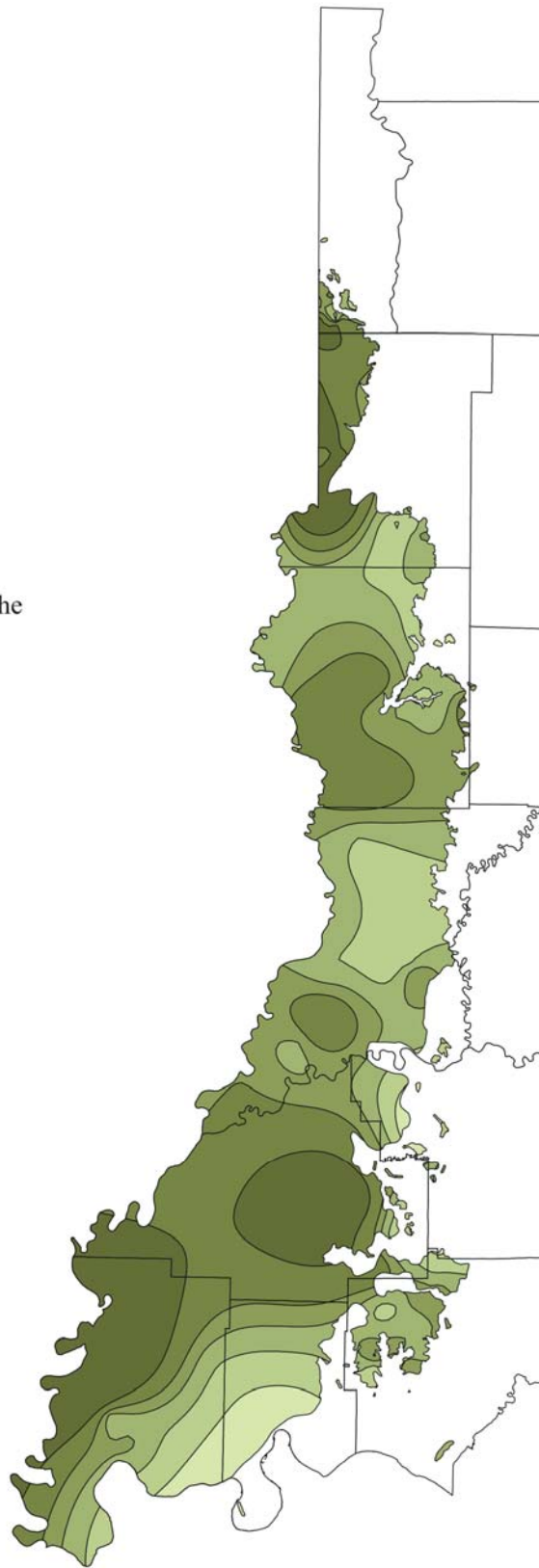
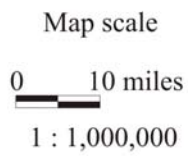
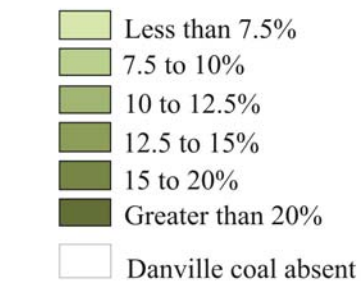




Figure 2. Map of southwestern Indiana showing the ash content (dry basis) of the Danville coal.



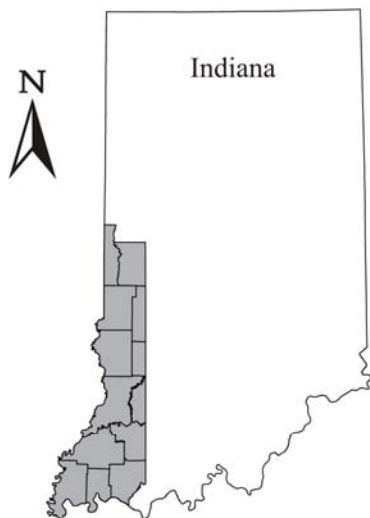


Figure 3. Map of southwestern Indiana showing the moisture content of the Springfield coal.

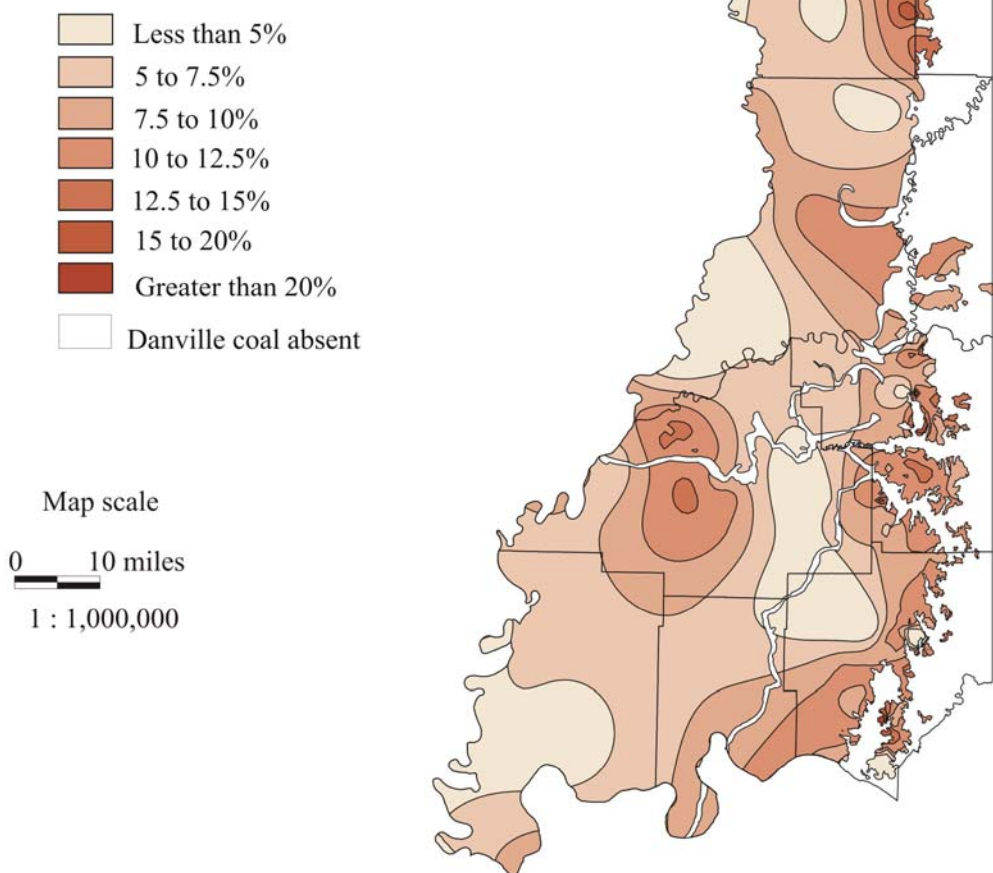




Figure 4. Map of southwestern Indiana showing the ash content (dry basis) of the Springfield coal.

