THE POTENTIAL FOR UNDERGROUND COAL GASIFICATION IN INDIANA

Phase II Report to the Indiana Center for Coal Technology Research

Maria Mastalerz, Agnieszka Drobnia, John Rupp
Indiana Geological Survey, Bloomington, IN 47405

Evgeny Shafirovich, Arvind Varma
School of Chemical Engineering, Purdue University, West Lafayette, IN 47907

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1. Introduction

Underground coal gasification (UCG) is a technology that has been known and applied for many years. Its principles, application, advantages, and drawbacks were described in our Phase 1 Report of this project (Shafirovich et al., 2008). That report also indicated the need for careful analysis of Indiana’s geology, coal properties, water resources, etc., to determine the feasibility of employing this technology for Indiana coals.

The main purpose of Phase 2 is the analysis of Indiana’s coal resources to determine suitable UCG locations. This analysis used geologically-related criteria identified and selected in Phase 1. Depth of the coal seam and its thickness were identified as the most important parameters to determine suitability for UCG and these criteria are given in Tables 1 and 2.

Table 1. Recommended seam thickness criteria for selection of Indiana coals.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2.0 m</td>
<td>high</td>
</tr>
<tr>
<td>1.5 – 2.0 m</td>
<td>medium</td>
</tr>
<tr>
<td>1.0 – 1.5 m</td>
<td>low</td>
</tr>
<tr>
<td>&lt; 1.0 m</td>
<td>unacceptable</td>
</tr>
</tbody>
</table>

Table 2. Recommended seam depth criteria for selection of Indiana coals.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 200 m</td>
<td>high</td>
</tr>
<tr>
<td>60-200 m</td>
<td>adequate</td>
</tr>
<tr>
<td>&lt; 60 m</td>
<td>unacceptable</td>
</tr>
</tbody>
</table>
2. Methodology

Two coal beds, the Springfield and the Seelyville, have been analyzed for UCG suitability in this study. These two coals have the largest available resources in Indiana (Table 3) that reside at suitable depth. The Springfield Coal has been of economic importance from the beginning of mining history in the state. In contrast, the Seelyville Coal has not been mined because of inferior quality (high ash, high sulfur, presence of splits), but could possibly be a good candidate for UCG.

Table 3. Summary of available and restricted coal resources for main economic coal beds in Indiana (Mastalerz et al., 2004). Values are in billion short tons.

<table>
<thead>
<tr>
<th>Coal bed</th>
<th>Original</th>
<th>Mined-out</th>
<th>Remaining</th>
<th>Restricted for mining</th>
<th>Total available (Remaining - Restricted)</th>
<th>Available as % of original</th>
<th>Available for surface mining</th>
<th>Available for underground mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danville</td>
<td>6.55</td>
<td>0.36</td>
<td>6.19</td>
<td>5.33</td>
<td>0.83</td>
<td>13.89</td>
<td>0.35</td>
<td>0.52</td>
</tr>
<tr>
<td>Hymera</td>
<td>5.53</td>
<td>0.55</td>
<td>4.98</td>
<td>4.10</td>
<td>0.87</td>
<td>17.47</td>
<td>0.15</td>
<td>0.81</td>
</tr>
<tr>
<td>Springfield</td>
<td>13.31</td>
<td>1.31</td>
<td>12.00</td>
<td>4.65</td>
<td>7.35</td>
<td>61.25</td>
<td>0.82</td>
<td>6.94</td>
</tr>
<tr>
<td>Houchin Creek</td>
<td>5.92</td>
<td>0.0022</td>
<td>5.92</td>
<td>5.56</td>
<td>0.36</td>
<td>6.08</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>Survant</td>
<td>8.47</td>
<td>0.31</td>
<td>8.17</td>
<td>6.86</td>
<td>1.31</td>
<td>16.03</td>
<td>0.22</td>
<td>1.10</td>
</tr>
<tr>
<td>Colchester</td>
<td>5.14</td>
<td>0.001</td>
<td>5.14</td>
<td>4.95</td>
<td>0.19</td>
<td>3.70</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Seelyville</td>
<td>14.61</td>
<td>0.33</td>
<td>14.28</td>
<td>7.68</td>
<td>6.60</td>
<td>46.22</td>
<td>0.30</td>
<td>6.30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>59.53</strong></td>
<td><strong>2.8632</strong></td>
<td><strong>56.68</strong></td>
<td><strong>39.13</strong></td>
<td><strong>17.54</strong></td>
<td><strong>30.95</strong></td>
<td><strong>2.13</strong></td>
<td><strong>15.94</strong></td>
</tr>
</tbody>
</table>

For these two coal beds, a set of maps have been generated, using data from our publicly available stratigraphic database (Mastalerz and Drobnia, 2004) and coal quality database (Mastalerz et al., 2005). For each coal, the following maps have been generated:

1) Map showing the extent of the coal and distribution of surface and underground mines and mined out areas (Figures 1 and 15);
2) Map showing suitability of the coal for UCG based on seam thickness (Figures 2 and 16);
3) Map showing suitability of the coal for UCG based on coal seam depth (Figures 3 and 17);
4) Map showing moisture content of the coal (Figures 4 and 18);
5) Map showing heating value of the coal (Btu/lb, dry basis) (Figures 5 and 19).
For the Seelyville Coal, in addition, a map of the immediate lithologies above the coal has been created (Figure 20). This map, together with moisture content map, helps to address the issue of water availability during UCG operations.

Because depth and thickness are considered the most important criteria in selection of potential UCG sites, these two maps were overlain, providing outlines of the most promising zones.

3. Identification of areas most suitable for UCG

Maps generated for the Springfield Coal are presented in Figures 1-14, whereas maps for the Seelyville Coal are presented in Figures 15-29. For the Springfield Coal, the most UCG suitable areas are in Knox and Gibson Counties (Figures 6-8). For these areas, Figures 9-12 show infrastructure, including roads, railroads, gas pipelines, etc. These elements are important for planning UCG operations and future markets for the gas and, in addition to geological factors, are critical for making selections of the UCG sites. Further, maps of availability of the Springfield Coal for surface mining (Figure 13) and underground mining (Figure 14) are also included in this report. These maps will be helpful at the stage when decisions about traditional mining versus UCG need to be made.

For the Seelyville Coal, areas in Vanderburgh, Warrick, Gibson, and Posey counties are the most suitable (Figures 21-23). For these areas, Figures 24-27 show roads, towns, pipelines, and other elements of infrastructure. Figures 28 and 29 show the availability of this coal for surface and underground mining.

4. The Next Steps

The next step (Phase 3) will analyze the maps generated in Phase 2 showing geologically-related parameters and infrastructure in the most promising areas to select the best locations for potential UCG operations. In particular, product transportation issues will be considered, such as transportation of the produced syngas to the Wabash IGCC power plant and construction of power and chemical plants near selected UCG locations. Special attention will be paid to
environmental aspects, including the risks of groundwater pollution and uncontrolled combustion.

The Final Report, including the list and characteristics of the most promising UCG locations, will be forwarded to CCTR by January 15, 2009. In the final report, the current status of UCG will be described and the feasibility to use UCG in Indiana will be determined, along with the identification of the most promising locations and a list of characteristics for each that allow comparison and selection. As part of this final report, recommendations for follow-up detailed characterization of the sites that have met the screening criteria of this Phase will be itemized. These should include an evaluation of the volumes and geometries of the coals in selected areas, the character of the surrounding or enclosing rock within which the coal resides, the hydrology of the coals and the details of the petrophysical characteristics of the coals as they control the kinetics of the combustion process. Specific investigations related to gasification kinetics of the selected Indiana coals, and modeling of the UCG process, will also be described for the follow-up studies.

References


Figure Captions

Figure 1. Map of southwestern Indiana showing the extent of the Springfield Coal Member, the Pennsylvanian System, and distribution of the Springfield coal surface and underground mines and mined out areas.

Figure 2. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) based on thickness.

Figure 3. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) based on depth.

Figure 4. Map of southwestern Indiana showing moisture content [%] of the Springfield Coal Member.

Figure 5. Map of southwestern Indiana showing heating value [Btu/lb, dry] of the Springfield Coal Member.

Figure 6. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

Figure 7. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

Figure 8. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

Figure 9. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

Figure 10. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

Figure 11. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.
Figure 12. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

Figure 13. Map of southwestern Indiana showing the areas where the Springfield Coal Member is available for surface mining and where surface mining is restricted (after Conolly and Zlotin, 1999).

Figure 14. Map of southwestern Indiana showing the areas where the Springfield Coal Member is available for underground mining and where underground mining is restricted (after Conolly and Zlotin, 1999).

Figure 15. Map of southwestern Indiana showing the extent of the Seelyville Coal Member, the Pennsylvanian System, and distribution of the Seelyville coal surface and underground mined out areas.

Figure 16. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) based on thickness.

Figure 17. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) based on depth.

Figure 18. Map of southwestern Indiana showing moisture content [%] of the Seelyville Coal Member.

Figure 19. Map of southwestern Indiana showing heating value [Btu/lb, dry] of the Seelyville Coal Member.

Figure 20. Map of southwestern Indiana showing the ratio of the thickness (in %) of the fine-grained to coarse-grained sediments occurring in the 30-ft interval above the Seelyville Coal Member.

Figure 21. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

Figure 22. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

Figure 23. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

Figure 24. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) and infrastructure in Gibson, Posey, Vanderburgh and Warrick Counties.
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Figure 28. Map of southwestern Indiana showing the areas where the Seelyville Coal Member is available for surface mining and where surface mining is restricted (after Conolly, 2001).

Figure 29. Map of southwestern Indiana showing the areas where the Seelyville Coal Member is available for underground mining and where underground mining is restricted (after Conolly, 2001).
Figure 1. Map of southwestern Indiana showing the extent of the Springfield Coal Member, the Pennsylvanian System, and distribution of the Springfield coal surface and underground mines and mined out areas.

- **Extent of Springfield coal**
- **Extent of Pennsylvanian System**
- **Active surface mines**
- **Active underground mines**
- **Mined out areas by surface mining**
- **Mined out areas by underground mining**

Map scale:
- 0 miles
- 10 miles
- 1:1,250,000
Figure 2. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) based on thickness.

- Less than 1.0 m (< 3.28 feet) - unacceptable
- 1.0 to 1.5 m (3.28 to 4.92 feet) - low suitability
- 1.5 to 2.0 m (4.92 to 6.56 feet) - medium suitability
- Greater than 2.0 m (> 6.56 feet) - high suitability
Figure 3. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) based on depth.

- Less than 60 m (< 196.85 feet) - unacceptable
- 60 to 200.0 m (196.85 to 657.17 feet) - low/medium suitability
- Greater than 200.0 m (> 656.17 feet) - high suitability
Figure 4. Map of southwestern Indiana showing moisture content [%] of the Springfield Coal Member.

- Less than 5
- 5 to 7.5
- 7.5 to 10
- 10 to 12.5
- 12.5 to 15
- 15 to 20
- Greater than 20

Map scale
0 10 miles
1 : 1,000,000
Figure 5. Map of southwestern Indiana showing heating value [Btu/lb, dry] of the Springfield Coal Member.
Figure 6. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

Springfield Coal unavailable for underground gasification (depth less than 200 m or thickness less than 2 m or active mining or coal mined out)

Thickness greater than 2m (greater than 6.56 ft)

Depth greater than 200.0 m (> 656.17 feet)
Figure 7. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

Springfield Coal unavailable for underground gasification
(depth less than 200 ft [~60m]
or thickness less than 1.5 m or
active mining or coal mined out)

Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]

Adequate depth and thickness greater than 2m [greater than 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

Map scale
0  10 miles
1 : 1,000,000
Figure 8. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG).

- Springfield Coal unavailable for underground gasification (depth less than 200 ft (~60m) or thickness less than 1 m or active mining or coal mined out)
- Adequate depth and thickness from 1 to 2 m [3.28 to 6.56 ft]
- Adequate depth and thickness greater than 2 m [greater than 6.56 ft]
- Depth greater than 200.0 m (> 656.17 feet)
Figure 9. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

- Springfield Coal unavailable for underground gasification (depth less than 200 ft [-60m] or thickness less than 1m or coal mined out)
- Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]
- Adequate depth and thickness greater than 2m [greater than 6.56 ft]

- Depth greater than 200.0 m (> 656.17 feet)

Legend:
- County boundary
- Coal burning electric power plant
- Highway
- Active railroad
- The approved I-69 corridor
- City
Figure 10. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

Springfield Coal unavailable for underground gasification (depth less than 200 ft [~60m] or thickness less than 1m or coal mined out)

Adequate depth and thickness from 1 to 2 m [3.28 to 6.56 ft]

Adequate depth and thickness greater than 2m [greater than 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

County boundary
Coal burning electric power plant
Highway
Active railroad
The approved I-69 corridor
City
Figure 11. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

Springfield Coal unavailable for underground gasification (depth less than 200 ft [~60m] or thickness less than 1m or coal mined out)

- Adequate depth and thickness greater than 2m [greater than 6.56 ft]
- Depth greater than 200.0 m (> 656.17 feet)

Legend:
- County boundary
- Coal burning electric power plant
- City

Natural gas pipelines
- Less than 10 in.
- 10 to 20 in.
- More than 20 in.
Figure 12. Map of southwestern Indiana showing suitability of the Springfield Coal Member for underground gasification (UCG) and infrastructure in Knox, Pike, and Gibson Counties.

- Springfield Coal unavailable for underground gasification (depth less than 200 ft [-60m] or thickness less than 1m or coal mined out)
- Adequate depth and thickness from 1.0 to 2 m [3.28 to 6.56 ft]
- Adequate depth and thickness greater than 2 m [greater than 6.56 ft]
- Depth greater than 200.0 m (> 656.17 feet)

Legend:
- County boundary
- Coal burning electric power plant
- City

Natural gas pipelines:
- Less than 10 in.
- 10 to 20 in.
- More than 20 in.
Springfield coal available for surface mining
Springfield coal mined out
Depth to coal greater than 200 feet
Surface mining restricted by land-use features
Surface mining restricted by technological factors

Figure 13. Map of southwestern Indiana showing the areas where the Springfield Coal Member is available for surface mining and where surface mining is restricted (after Conolly and Zlotin, 1999).
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- Extent of Seelyville coal
- Extent of Pennsylvanian System
- Mined out areas by surface mining
- Mined out areas by underground mining

Map scale
0 10 miles
1 : 1,250,000
Figure 16. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) based on thickness.

- Less than 1.0 m (< 3.28 feet) - unacceptable
- 1.0 to 1.5 m (3.28 to 4.92 feet) - low suitability
- 1.5 to 2.0 m (4.92 to 6.56 feet) - medium suitability
- Greater than 2.0 m (> 6.56 feet) - high suitability

Map scale
0 10 miles
1 : 1,250,000
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Less than 60 m (< 196.85 feet) - unacceptable
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Figure 21. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

- Grey: Seelyville Coal unavailable for underground gasification (depth less than 200 m or thickness less than 2 m or active mining or coal mined out)
- Orange: Thickness greater than 2m (greater than 6.56 ft)
- Diagonal: Depth greater than 200.0 m (> 656.17 feet)

Map scale
0 10 miles
1 : 1,000,000
Figure 22. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

Seelyville Coal unavailable for underground gasification (depth less than 200 ft [~60m] or thickness less than 1.5 m or active mining or coal mined out)

- **Yellow**: Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]
- **Orange**: Adequate depth and thickness greater than 2m [greater than 6.56 ft]
- **Shaded**: Depth greater than 200.0 m (> 656.17 feet)

Map scale
- 0 10 miles
- 1 : 1,000,000
Figure 23. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification.

- Adequate depth and thickness greater than 2 m (depth less than 200 ft [~60 m] or thickness less than 1 m or coal mined out)
- Adequate depth and thickness from 1 to 2 m (3.28 to 6.56 ft)
- Adequate depth and thickness greater than 2 m (greater than 6.56 ft)
- Depth greater than 200.0 m (> 656.17 feet)
Figure 24. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) and infrastructure in Gibson, Posey, Vanderburgh and Warrick Counties.

Seelyville Coal unavailable for underground gasification (depth less than 200 ft (~60m) or thickness less than 1.5 m or coal mined out)

Adequate depth and thickness greater than 2m (greater than 6.56 ft)

Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

County boundary
Coal burning electric power plant
Interstate
Highway
Active railroad
The approved I-69 corridor
City
Figure 25. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) and infrastructure in Gibson, Posey, Vanderburgh and Warrick Counties.

Seelyville Coal unavailable for underground gasification (depth less than 200 ft [~60m] or thickness less than 1m or coal mined out)

Adequate depth and thickness greater than 2m [greater than 6.56 ft]

Adequate depth and thickness from 1 to 2 m [3.28 to 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

- County boundary
- Coal burning electric power plant
- Interstate
- Highway
- Active railroad
- The approved I-69 corridor
- City
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Seelyville Coal unavailable for underground gasification (depth less than 200 ft (~60m) or thickness less than 1.5 m or coal mined out)

Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]

Adequate depth and thickness greater than 2m [greater than 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

Natural gas pipelines
- Less than 10 in.
- 10 to 20 in.
- More than 20 in.

County boundary
Coal burning electric power plant
City
Figure 27. Map of southwestern Indiana showing suitability of the Seelyville Coal Member for underground gasification (UCG) and infrastructure in Gibson, Posey, Vanderburgh and Warrick Counties.

- Adequate depth and thickness greater than 2m [greater than 6.56 ft]
- Adequate depth and thickness from 1 to 2 m [3.28 to 6.56 ft]
- Adequate depth and thickness less than 2m [less than 6.56 ft]
- Depth less than 200 ft (~60m) or thickness less than 1m or coal mined out

Natural gas pipelines:
- Less than 10 in.
- 10 to 20 in.
- More than 20 in.

Coal burning electric power plant
City
County boundary
Figure 28. Map of southwestern Indiana showing the areas where the Seelyville Coal Member is available for surface mining and where surface mining is restricted (after Conolly, 2001).
Figure 29. Map of southwestern Indiana showing the areas where the Seelyville Coal Member is available for underground mining and where underground mining is restricted (after Conolly, 2001).

- Yellow: Seelyville coal available for underground mining
- Black: Seelyville coal mined out
- Light grey: Depth to Seelyville coal less then 100 feet
- Dark red: Underground mining restricted by technological factors
- Green: Underground mining restricted by land-use features

Map scale

0 10 miles
1 : 1,000,000