Characterization of Indiana’s Coal Resource: Availability of the Reserves, Physical and Chemical Properties of the Coal, and the Present and Potential Uses

Maria Mastalerz, Agnieszka Drobnia, John Rupp, and Nelson Shaffer

Indiana Geological Survey
Indiana University
OBJECTIVES

• Provide assessment how much coal is available for mining
• Characterize quality of coal for those unique properties to utilize it in an efficient and environmentally sound manner;
• Characterize current use of coal;
• Characterize production and use of Coal Combustion Products;
• Characterize limestones and dolomites for Flue Gas Desulphurization
• Provide basis for potential uses of Indiana coals (CBM, CO2 sequestration, non-traditional uses of CCP)
74 pages of text, 102 figures and 67 tables

Resource evaluation for all major coal beds (Danville, Springfield, Seelyville from previous availability work at IGS, Hymera, Houchin Creek, Survant and Colchester – new evaluations, Lower and Upper Blocks and Buffaloville – extents and area available for mining). More than 50 maps of depth, thickness, areas available for underground and surface mining have been generated.

Physical and chemical properties (sulfur, ash, heating value – summaries and maps for major coal beds, ash characteristics, summaries of 35 trace elements – Hg, Se, As, and Cl discussed in more detail).

Utilization (coking properties, SR 64 by Valia and Mastalerz, CBM, CO2 sequestration – DOE-sponsored projects)

Coal Combustion Products from Indiana coals;

Limestones and dolomites for Flue Gas Desulphurization – recent IDOC-funded project to N. Shaffer; and

Summary of the unique properties of Indiana coals.

This document uses all the information that was available to us, both old and the most recent, on Indiana coals.
Coal Production in Indiana 1879-2002

Short Tons

- Underground
- Surface
- Total
<table>
<thead>
<tr>
<th></th>
<th>Illinois</th>
<th>Indiana</th>
<th>W. Kentucky</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mattoon Fm.</td>
<td>Mattoon Fm.</td>
<td>Mattoon Fm.</td>
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<tr>
<td></td>
<td>Bond Fm.</td>
<td>Bond Fm.</td>
<td>Bond Fm.</td>
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<tr>
<td></td>
<td>Patoka Fm.</td>
<td>Patoka Fm.</td>
<td>Patoka Fm.</td>
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<tr>
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<td>Shelburn Fm.</td>
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<tr>
<td></td>
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<td>Danville (VII)</td>
<td>Baker (No.13)</td>
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<tr>
<td></td>
<td>Jamestown</td>
<td>Hymera (VI)</td>
<td>Paradise (no.12)</td>
</tr>
<tr>
<td></td>
<td>Herrin (No.6)</td>
<td>Herrin</td>
<td>Herrin (no.11)</td>
</tr>
<tr>
<td></td>
<td>Springfield (No.5)</td>
<td>Bucktown (Vb)</td>
<td>Springfield (No.9)</td>
</tr>
<tr>
<td></td>
<td>Houchin Creek</td>
<td>Houchin Creek</td>
<td>Houchin Creek</td>
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<tr>
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<td>Survant (IV)</td>
<td>Survant (IV)</td>
<td>Survant (No.8)</td>
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<tr>
<td></td>
<td>Colchester (No.2)</td>
<td>Colchester (IIa)</td>
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<td></td>
<td>Dekoven</td>
<td>Seelyville (III)</td>
<td>Dekoven (No.7)</td>
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</table>
Pennsylvanian System (coal-bearing strata)

Surface Mined Area

Underground Mined Area

100 20 Miles

100 30 Kilometers

Map of southwestern Indiana showing the active coal mines, and mined-out areas.
Availability of Coal Reserves in Indiana

- Indiana had approximately 59.5 billion short tons of original coal resources
- Available for mining is 17.5 billion (~30%)
- Available for surface: ~ 2 billion
  - for underground ~ 16 billion
- Coal produced in Indiana so far: 2,124,417,385 tons (2 billion)
Rate of Recovery

• Continue to mine ~30 million tons per year, all that is available (17 billion tons) is mined in approximately 500 years.
• However, only 2.1 billion is available for surface m. – 70 year supply if surface mined only
• Not more than 20% Indiana production comes from underground mines.
COAL AVAILABILITY

Available Coal Resources =
remaining coal resources –
coal restricted by land use –
coal restricted by technological factors.

Technology is economically based:

- e.g. stripping ratio
- e.g. seam thickness underground
- e.g. coal quality
Map of the Wheatland Quadrangle showing coal available for surface mining and coal restricted from mining

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Legend</th>
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</thead>
<tbody>
<tr>
<td>coal available for surface mining</td>
<td>Green</td>
</tr>
<tr>
<td>&gt;200ft deep</td>
<td>Dark Brown</td>
</tr>
<tr>
<td>coal eroded</td>
<td>Light Green</td>
</tr>
<tr>
<td>surface eroded</td>
<td>Gray</td>
</tr>
<tr>
<td>deep mine</td>
<td>Light Gray</td>
</tr>
<tr>
<td>200ft buffer around deep mines</td>
<td>Medium Gray</td>
</tr>
<tr>
<td>coal &lt;14 inches</td>
<td>Pink</td>
</tr>
<tr>
<td>stripping ratio &gt;25:1</td>
<td>Medium Brown</td>
</tr>
<tr>
<td>unconsolidated &gt;60ft thick</td>
<td>Red</td>
</tr>
<tr>
<td>towns + 2,640ft buffer</td>
<td>Blue</td>
</tr>
<tr>
<td>pipelines + 100ft buffer</td>
<td>Orange</td>
</tr>
<tr>
<td>paved roads + 100ft buffer</td>
<td>Black</td>
</tr>
<tr>
<td>mine block too small</td>
<td>Light Blue</td>
</tr>
</tbody>
</table>

0.6 0 0.6 1.2 Miles
Map of southwestern Indiana showing the extent of the Danville coal, the Pennsylvanian System, and distribution of the Danville coal surface and underground mines (from Conolly, 2001).

- **Map scale:** 1:1,250,000

- **Legend:**
  - Extent of Danville coal
  - Extent of Pennsylvanian System
  - Surface mines
  - Underground mines

**Danville coal Extent and mined out areas**
Map showing a subset of the Danville coal stratigraphic data points that were used to create the Danville coal thickness and depth maps (confidential data are not shown, after Conolly, 2001).
Map of the southwestern Indiana showing the depth of the Danville coal (after Conolly, 2001).

Map scale

0 10 miles
1 : 1,000,000

- Less than 50 feet
- 50 - 100 feet
- 100 - 150 feet
- 150 - 200 feet
- 200 - 500 feet
- Greater than 500 feet
- Danville coal absent
Map of the southwestern Indiana showing the thickness of the Danville coal (after Conolly, 2001).

- Less than 14 inches
- 14 - 28 inches
- 28 - 42 inches
- 42 - 63 inches
- Greater than 63 inches
- Danville coal absent

Map scale
0 10 miles
1 : 1,000,000
Danville coal available for surface mining
Danville coal absent
Danville coal mined out
Depth to Danville coal greater than 200 feet
Surface mining restricted by land-use features
Surface mining restricted by technological factors

Map of the southwestern Indiana showing the areas where the Danville coal is available for surface mining and where surface mining is restricted (after Conolly, 2001).
Map of the southwestern Indiana showing the areas where the Danville coal is available for underground mining and where underground mining is restricted (after Conolly, 2001).

Map scale
0  10 miles
1 : 1,000,000
Physical and Chemical Characteristics of Indiana Coals

• Physical properties
• Coal quality
• Ash chemistry
• Trace elements
• Coal rank and petrographic composition
• Methane and Carbon Dioxide sorption
Quality of Indiana coals - Moisture and BTU

These coals account for about 70% of Indiana coal production.

These coals account for about 30% of Indiana coal production.
Quality of Indiana coal - Sulfur and ash

These coals account for about 70% of Indiana coal production

These coals account for about 30% of Indiana coal production
Map of southwestern Indiana showing the heating value (Btu/lb on dry basis) of the Danville coal.

- Less than 10,000 Btu/lb
- 10,000 - 10,500 Btu/lb
- 10,500 - 11,000 Btu/lb
- 11,000 - 11,500 Btu/lb
- 11,500 - 12,000 Btu/lb
- 12,000 - 12,500 Btu/lb
- 12,500 - 13,000 Btu/lb
- More than 13,000 Btu/lb
- Danville coal absent
- Data points

Map scale

0 10 miles
1 : 1,000,000
Map of southwestern Indiana showing the sulfur content (total, dry basis) of the Danville coal.

- Less than 1%
- 1 - 1.5%
- 1.5 - 2%
- 2 - 2.5%
- 2.5 - 3%
- More than 3%
- Danville coal absent
- Data points

Map scale
0 - 10 miles
1 : 1,000,000
Map of southwestern Indiana showing the sulfur content (total, dry basis) of the Springfield coal.

- Less than 1%
- 1 - 1.5%
- 1.5 - 2%
- 2 - 2.5%
- 2.5 - 3%
- More than 3%
- Springfield coal absent

Map scale
0 - 10 miles
1 : 1,000,000

Data points
Map of southwestern Indiana showing the ash content (dry basis) of the Danville coal.

- Less than 5%
- 5 - 10%
- 10 - 15%
- 15 - 20%
- 20 - 25%
- More than 25%
- Danville coal absent
- Data points

Map scale
0 10 miles
1 : 1,000,000

Danville coal
Ash content (dry)
### Furnace Slagging* Indices

- **Slagging Index** *(Base/Acid)* (% Sulfur)
  - < 0.6 \textit{low}
  - 0.6-2 \textit{medium}
  - > 2 \textit{high}

- **Base Acid Ratio** *(Base/Acid)*
  - < 0.5 \textit{dbot} (0.3) \textit{wbot}

- **Silica Percentage** *(SiO₂) (100) / SiO₂+Fe₂O₃+CaO+MgO*
  - < 30 \textit{low}
  - 30-82 \textit{medium}
  - > 82 \textit{high}

*Slagging – buildup of molten ash in the lower furnace*
# Furnace Fouling Indices

- **Fouling Index (Base/Acid) \( \times \) Na\(_2\)O**
  - \(< 0.2\) low
  - \(0.2 - 0.5\) medium
  - \(> 0.5\) high

- **Alkalies in Coal (% Ash)\(^*\) (Na\(_2\)O + 0.659 K\(_2\)O)**
  - \(< 0.3\) low
  - \(0.3 - 0.5\) medium
  - \(> 0.5\) high

- **Sodium in Ash % Na\(_2\)O**
  - \(< 0.5\) low
  - \(0.5 - 1\) medium
  - \(> 1.0\) high

- **Chlorine in Coal % Cl**
  - \(< 0.1\) low
  - \(0.1 - 0.3\) medium
  - \(> 0.3\) high

\(^*\)fouling – buildup on upper furnace.
### Slagging index

- **Danville**: 0.9
- **Hymera**: 1.61
- **Springfield**: 1.34
- **Houchin Creek**: 2.02
- **Survant**: 2.93
- **Colchester**: 4.3
- **Seelyville**: 4.3
- **Upper Block**: 0.42
- **Lower Block**: 0.43

**Legend**:
- Slagging index – low - below 0.6
- medium – 0.6-2.0
- high - above 2.0

### Fouling index

- **Danville**: 0.19
- **Hymera**: 0.17
- **Springfield**: 0.22
- **Houchin Creek**: 0.36
- **Survant**: 0.33
- **Colchester**: 0.43
- **Seelyville**: 0.43
- **Upper Block**: 0.08
- **Lower Block**: 0.13

**Legend**:
- Fouling index – low - below 0.2
- medium – 0.2-0.5
- high above 0.5

**Note**: Ash fusion T – low may cause slag deposits
Slagging Index – western Kentucky

- WKY #18/Lisman
- WKY #13 (Baker)
- WKY #11 (Herrin)
- WKY #9 (Springfield)
- WKY #6 (DeKovan)
- WKY #4
- Dunbar/Lead Creek
- Bell

< 0.6 = Low  0.6-2.0 = Medium  > 2.0 = High
Fouling Index – western Kentucky

- WKY #18/Lisman
- WKY #13 (Baker)
- WKY #11 (Herrin)
- WKY #9 (Springfield)
- WKY#6 (DeKovan)
- WKY #4
- Dunbar/Lead Creek
- Bell

< 0.2 = low  0.2 - 0.5 = moderate  >0.5 = high
Map of southwestern Indiana showing vitrinite reflectance ($R_v$ random) of the Seelyville coal.

Indiana coals are of high-volatile bituminous rank

- C – Ro 0.47-0.57%
- B – Ro 0.57-0.71%
- A – Ro 0.71-1.1%

Coal rank and petrography

Seelyville coal
Vitrinite reflectance
Maceral composition (A, in volume %) and palynology (B) of the Upper Block coal in Daviess County.
Trace elements in Indiana coals

- Danville
- Hymera
- Springfield
- Seelyville
- Upper Block

Mercury (ppm)
Map of southwestern Indiana showing the mercury content of the Danville coal.

- Less than 0.05 ppm
- 0.05 - 0.10 ppm
- 0.10 - 0.15 ppm
- More than 0.15 ppm
- Danville coal absent
- Data points

Map scale:
- 0 miles
- 10 miles
- 1 : 1,000,000
Map of southwestern Indiana showing the mercury content of the Springfield coal.

- Less than 0.05 ppm
- 0.05 - 0.10 ppm
- 0.10 - 0.15 ppm
- 0.15 - 0.20 ppm
- 0.20 - 0.25 ppm
- 0.25 - 0.30 ppm
- More than 0.30 ppm
- Springfield coal absent
- Data points

Map scale:
- 0 - 10 miles
- 1 : 1,000,000
Mercury concentration in in-ground coal on an equal-energy basis (lb/10^{12} Btu).

In Indiana
X=9.2 raw
5.2 float

EXPLANATION
- Coal areas with less than 30 samples
- > 5 & ≤10 lb Hg/10^{12} Btu
- > 10 & ≤15 lb Hg/10^{12} Btu
- > 15 & ≤20 lb Hg/10^{12} Btu
- > 20 lb Hg/10^{12} Btu

\[ x = \text{Mean} \]
\[ n = \text{Number of samples} \]
Regulatory approaches

• Bituminous – 2/TBtu
• Subbituminous 5.8/TBtu
• Lignite – 9.2/TBtu

• MACT – Compliance data – 08
The concentrations of numerous trace elements decrease significantly as a result of washing. In this report we have comparison between raw and washed coal for trace elements as well as sulfur and ash.
Seelyville coal may contain 1.5 to 3.0 Tcf of gas (Drobniak et al., 2002)
CO₂ sequestration

At pressure of 400 psi, Indiana coal beds can accommodate 560-790 Scf/ton CO₂

Our coal can accommodate ~4.8 times more CO₂ than CH₄
Utilization

- Electricity generation
- Steel industry
  - Coke blends
  - Pulverized coal injection
  - CBM
  - CO₂ sequestration
- Unconventional uses (gasification, liquefaction)
Indiana coal and steel industry

• Coking blends – fluidity, plasticity, reactive/inert ratio, etc. – Brazil Formation coals have superior coking properties

• Pulverized coal injection (PCI) – good coals are those that have high combustibility and replace more coke – high replacement ratio (RR).

• Significant proportion of Indiana coals have high RR

Valia and Mastalerz, 2004. IGS Special Report 64.
Non-coking, but some good for PCI e.g. Danville coal

Superior coking properties
Lower Block coal

240 micrometers
Indiana Limestones and Dolomites for FGD

- Specific gravity, grindability, acid solid residue
- Mineralogy
- Chemical composition
- Reactivity

Excellent sources of limestone for FGD applications exist in Indiana
<table>
<thead>
<tr>
<th>Sample</th>
<th>SO$_2$ Removal (percent)</th>
<th>Reagent Rate (pounds/min x 10^4)</th>
<th>Utilization (S:Ca Ratio)</th>
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<tr>
<td>Bainbridge Unit 1-3</td>
<td>88.9</td>
<td>1.199</td>
<td>93.1</td>
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<tr>
<td>Bainbridge Unit 1-4</td>
<td>89.4</td>
<td>1.123</td>
<td>93.0</td>
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<td>Bainbridge Unit 4</td>
<td>89.7</td>
<td>1.094</td>
<td>92.9</td>
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<td>Bloomington Bench II</td>
<td>89.1</td>
<td>1.105</td>
<td>93.0</td>
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<td>Bloomington Bench I</td>
<td>88.1</td>
<td>1.081</td>
<td>93.5</td>
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<td>Campbellsburg</td>
<td>93.2</td>
<td>1.186</td>
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<td>1.128</td>
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<td>1.109</td>
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<td>Mill Town Unit 2ABCD</td>
<td>93.1</td>
<td>1.124</td>
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<td>Orleans (A)</td>
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<td>1.070</td>
<td>92.9</td>
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<td>Temple Unit Bench III</td>
<td>98.3</td>
<td>1.206</td>
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From Shaffer and Sadowski, 2000
### Indiana Coal Combustion Products Totals in 1999

<table>
<thead>
<tr>
<th>Product</th>
<th>Tons Produced</th>
<th>Tons Reused</th>
<th>Percent Reused</th>
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</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>3,287,072</td>
<td>1,130,152</td>
<td>34%</td>
</tr>
<tr>
<td>FGD Materials</td>
<td>3,779,295</td>
<td>1,839,141</td>
<td>49%</td>
</tr>
<tr>
<td>Bottom Ash</td>
<td>1,162,642</td>
<td>497,420</td>
<td>43%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,229,009</strong></td>
<td><strong>3,466,713</strong></td>
<td><strong>42%</strong></td>
</tr>
</tbody>
</table>


Disposal in coal mines – currently ~ 1 million tons a year (Division of Reclamation)
Unconventional applications

- Low-grade ore
- Carbon whiskers
- Composites
- Fullerenes
Coal availability studies show:

- 17-18 billion short tons of coal are available for mining (surface and underground) in Indiana.
- At current production rate, this reserve would last for more than 500 years.
  - But this can only be accomplished by a significant increase in the percentage produced by underground mining.
  - Production using current practices (80% surface - 20% underground) will last only 100 years.
Indiana coals, being part of the Illinois Basin, have many common characteristics with the coals of Illinois and western Kentucky.

- Similar coalification level; high volatile bituminous rank dictates such properties as calorific value, moisture, carbon content, etc.
- High volatile bituminous rank: very suitable for combustion, but also useful for gasification or liquefaction because of their reactivity.
Indiana coals (and those of the entire Illinois Basin) have good heating value.

- Better than most Western coals but lower than Appalachian coals.
- Compared to western coals, we need to burn less Indiana coal to get the same amount of energy.
Most of Indiana coal is high in sulfur

- Significant portions of the Danville and the Brazil Fm. coals are low-sulfur compliance coals.
- Illinois and western Kentucky do not have this low sulfur resource.
- Availability of good quality limestones (for FGD) close to our power plants helps utilize high sulfur coals.
Trace elements in Indiana coals are usually on the low side for Illinois Basin coals and low in other elements in comparison with Western coals.

Mercury is generally low. Washing results in significant reduction not only of sulfur but numerous trace elements as well.
There is an increasing interest in CBM and CO$_2$ sequestration potential of Indiana coals. Previous and current projects provide more data and indicate some potential areas. More research needed.
ACKNOWLEDGMENTS

To the Center for Coal Technology Research and Indiana Department of Commerce for sponsoring the project.

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Maria Mastalerz, Agnieszka Drobiak, John Rupp, and Nelson Shaffer

Indiana Geological Survey
Indiana University
611 North Walnut Grove
Bloomington, IN 47405-2208

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