Coal in Indiana

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Indiana Geological Survey, IU
Some facts about coal in Indiana

• Indiana is among top ten (7) coal producing states, averaging 35,000,000 tons of coal each year;
• About 12-15 coal companies operate ~25 mines;
• Coal industry supports more than 2,500 jobs, adding more than $750 million yearly to Indiana economy;

★ ★ ★

• Indiana uses ~80,000,000 tons of coal a year;
• Close to 90% of electricity in Indiana comes from coal
What is coal?

Coal is a sedimentary rock, composed of lithified plant remains, which has the distinction of being a combustible material.
What is coal?

1) Coal is a function of three distinct processes:
   1) Deposition, preservation, and alteration of organic matter from various kingdoms of life
      • Roots, shoots, seeds, pollen, leaves, etc. of plants
      • Algae
      • Interactions with fungus, bacteria, insects, etc.
   2) Incorporation of mineral matter
   3) Coalification — maturation by heat & pressure over time
      • Heat is generally most important — excessive pressure is inhibitive to the coalification process
      • The level of maturation/coalification is expressed as coal rank
In 2010, Indiana produced 33.72 million tons of coal. In 2011 it was 37.26 million tons. About 56% of production was from approximately 22 surface mines, and 44% was from 6 underground mines.
Indiana coal production 1879-2011
(in short tons -907.2 kg)
Underground coal production
(in % of total)
Coal Consumption in Indiana

Figure 100: Graphs showing the distribution and consumption of coal in Indiana: A. Distribution of Indiana coal; B. Consumption of Indiana coal in Indiana; C. Coal consumption in Indiana; and D. Electric utility use of energy in Indiana.
IMPORT AND EXPORT OF INDIANA COAL
(in thousand short tons)

Source: Energy Information Administration 2004, 2007 and 2010

**Import of coal to Indiana**

- **2004**
  - Total import (red): 31,201
  - Total export (blue): 5,087

- **2007**
  - Total import (red): 33,819
  - Total export (blue): 2,985

- **2010**
  - Total import (red): 33,772
  - Total export (blue): 4,822

**Export of Indiana coal**

- **2004**

- **2007**

- **2010**

Legend:
- **Import 2004**
- **Import 2007**
- **Import 2010**
- **Export 2004**
- **Export 2007**
- **Export 2010**
Distribution of Indiana coal (in thousand short tons)

- Total Indiana production
- Used in Indiana
- Exported to other states
Coal consumption in Indiana 1960-2010

- Total consumption *
- Electricity
- Industrial **
- Residential and commercial ***

Year

[Thousand of short tons]
Coal Geology
<table>
<thead>
<tr>
<th>Illinois</th>
<th>Indiana</th>
<th>W. Kentucky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattoon Fm.</td>
<td>Mattoon Fm.</td>
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<td>Bond Fm.</td>
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<td>Patoka Fm.</td>
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</tbody>
</table>

Pennsylvanian

- **A** low vol. bit.
- **B** medium vol. bit.
- **C** high vol. bit.
- **A** semianthracite
- **B** anthracite
- **C** metanthracite

- **Ro (%)**
  - 0.25 peat
  - 0.38 lignite
  - 0.48 sub-bituminous
  - 1.1 A
  - 1.5 B
  - 1.9 C
  - 2.8 C
  - 5.0 A
### Availability of the Coal

<table>
<thead>
<tr>
<th>Coal Member</th>
<th>Original</th>
<th>Mined-out</th>
<th>Remaining</th>
<th>Restricted</th>
<th>Total Available (remaining minus restricted)</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>5.36</td>
<td>0.83</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>0.92</td>
<td>0.15</td>
<td>0.80</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>0.82</td>
<td>6.93</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>0.20</td>
<td>0.18</td>
</tr>
<tr>
<td>Survant</td>
<td>8.47</td>
<td>0.31</td>
<td>8.17</td>
<td>6.86</td>
<td>1.30</td>
<td>0.22</td>
<td>1.10</td>
</tr>
<tr>
<td>Colchester</td>
<td>5.15</td>
<td>0.001</td>
<td>5.15</td>
<td>4.95</td>
<td>0.20</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>0.29</td>
<td>6.30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>59.53</strong></td>
<td><strong>2.86</strong></td>
<td><strong>56.68</strong></td>
<td><strong>39.13</strong></td>
<td><strong>17.57</strong></td>
<td><strong>2.14</strong></td>
<td><strong>15.92</strong></td>
</tr>
</tbody>
</table>

Note: The sum of coal available for surface and underground mining does not have to equal the total available volume, because some coal may be available for mining by either method.
Figure 1. Availability of Indiana Coal Resources. Based on data in Reference 23.
Depth of the coal

Figure 6. Map of southwestern Indiana showing the depth of the Danville Coal Member. After Conolly and Zlotin (2000).

Figure 20. Map of southwestern Indiana showing the depth of the Springfield Coal Member. After Conolly and Zlotin (1999).
Thickness of the coal

Figure 7. Map of southwestern Indiana showing the thickness of the Danville Coal Member. Modified from Conolly and Zlotin (2000).

Figure 21. Map of southwestern Indiana showing the thickness of the Springfield Coal Member. After Conolly and Zlotin (1999).
Availability of the coal

Danville Coal Member total original surface-minable resources
2.64 billion short tons (Bt)

- Thick unconsolidated material: 0.205 Bt (8%)
- Block size / configuration: 0.036 Bt (<1%)
- Land-use restrictions: 0.11 Bt (4%)
- Mined: 0.35 Bt (13%)
- Available for surface mining: 0.35 Bt (13%)
- Stripping ratio: 1.917 Bt (61%)

Danville Coal Member total original underground-minable resources
5.53 billion short tons (Bt)

- Thin bedrock cover: 0.243 Bt (4%)
- Block size / configuration: 0.12 Bt (2%)
- Land-use restrictions: 0.05 Bt (1%)
- Mined: 0.07 Bt (1%)
- Available for underground mining: 0.52 Bt (9%)

Springfield Coal Member total original surface-minable resources
4.14 billion short tons (Bt)

- Block size / configuration: 0.38 Bt (9%)
- Land-use restrictions: 0.64 Bt (15%)
- Available for surface mining: 0.62 Bt (20%)
- Stripping ratio: 1.26 Bt (38%)

Springfield Coal Member total original underground-minable resources
11.7 billion short tons (Bt)

- Block size / configuration: 0.61 Bt (5%)
- Land-use restrictions: 0.31 Bt (3%)
- Mined: 0.74 Bt (6%)
- Available for underground mining: 6.93 Bt (60%)

Near Galatia Channel: 0.31 Bt (3%)
Thin bedrock cover: 0.65 Bt (7%)
Seam <42 inches thick: 1.73 Bt (15%)
Coal properties

The properties of coal are function of:

1) The composition of organic fraction
2) The composition of non-organic (mineral matter)
3) The coalification level – the coal rank
## Classification of Coals by Rank

<table>
<thead>
<tr>
<th>Class/Group</th>
<th>Fixed Carbon Limits (dry, mineral matter free, %)</th>
<th>Volatile Matter Limits (dry, mineral matter free, %)</th>
<th>Gross Caloric Value Limits (moist, mineral matter free)</th>
<th>Agglomerating Character</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equal or greater than</td>
<td>Less than</td>
<td>Greater than</td>
<td>Equal or less than</td>
</tr>
<tr>
<td>Anthracitic:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meta-anthracite</td>
<td>98</td>
<td>92</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>Anthracite</td>
<td>92</td>
<td>92</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Semianthracite</td>
<td>86</td>
<td>92</td>
<td>8</td>
<td>18</td>
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<tr>
<td>Bituminous:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Low volatile bituminous coal</td>
<td>78</td>
<td>86</td>
<td>14</td>
<td>22</td>
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<tr>
<td>Medium volatile bituminous coal</td>
<td>69</td>
<td>78</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td>High volatile A bituminous coal</td>
<td>...</td>
<td>69</td>
<td>31</td>
<td>...</td>
</tr>
<tr>
<td>High volatile B bituminous coal</td>
<td>...</td>
<td>...</td>
<td>13,000^c</td>
<td>...</td>
</tr>
<tr>
<td>High volatile C bituminous coal</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Subbituminous:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbituminous A coal</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Subbituminous B coal</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Subbituminous C coal</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Lignitic:</td>
<td></td>
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<tr>
<td>Lignite A</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Lignite B</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

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**Notes:**

A This classification does not apply to certain coals.

B Moist refer to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

C Megajoules per kilogram.

D If agglomerating, classify in low volatile group of bituminous class.

E It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in the high volatile C bituminous group.

F Coals having 80% or more fixed carbon on the dry, mineral matter free basis shall be classified according to fixed carbon, regardless of gross caloric value.

G Editorially corrected.
Physical and Chemical Characteristics of Coal

- Physical properties
- Coal quality
- Ash chemistry
- Trace elements
- Coal rank and petrographic composition
- Methane and Carbon Dioxide sorption
Sulfur content (weight %)

Figure 61. Map of southwestern Indiana showing the sulfur content (total S, dry basis) of the Danville Coal Member.

Figure 65. Map of southwestern Indiana showing the sulfur content (total S, dry basis) of the Springfield Coal Member.
Sulfur content (lb/mln Btu)

Figure 62. Map of southwestern Indiana showing the sulfur content as lb/million Btu of the Danville Coal Member. Values of 0.6 and lower indicate compliance coal.

Figure 63. Map of southwestern Indiana showing the sulfur content as lb/million Btu of the Springfield Coal Member. Values of 0.6 and lower indicate compliance coal.
Heating value (Btu/lb)
During coal combustion mercury is volatilized and large part of it is captured in fly ash and some part is emitted to the atmosphere.

Mercury directly emitted from power plants generally is NOT considered harmful.

But in the natural environment Hg can go through a series of chemical transformations that convert elemental Hg to a highly toxic form – methylmercury – that is concentrated in fish and birds.

Mercury enters the food chain.

Cases of mercury poisoning have been documented in people who eat contaminated fish for prolonged periods (?).
Coal combustion vaporization

Hg\textsuperscript{0} (g)

Catalytic Oxidation

Hg\textsuperscript{2+} (g)

Chlorination

HgCl\textsubscript{2} (g)

Sorption

Hg (p) species

Ash formation

HgCl\textsubscript{2}, HgO, HgSO\textsubscript{4}, HgS

Fate of Hg in combustion

Combustion

Post-combustion
A large portion of Hg is associated with pyrite. Hg content is reduced during washing by 55%.
Mercury in Indiana coals

- Danville
- Hymera
- Springfield
- Seelyville
- Upper Block

Mercury (ppm)
Mercury concentration in in-ground coal on an equal-energy basis (lb/ 10^{12} Btu).

In Indiana
X = 9.2 raw
5.2 float
Trace elements: Chlorine

Figure 21. Map of southwestern Indiana showing the chlorine content (% whole coal basis) of the Springfield coal.

Table 28 A. Chlorine content (% whole coal basis) of Indiana coal members; n = number of samples

<table>
<thead>
<tr>
<th>Coal Member</th>
<th>Avg.</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darville</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.10</td>
<td>28</td>
</tr>
<tr>
<td>Hymera</td>
<td>0.04</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>25</td>
</tr>
<tr>
<td>Bucktown</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Springfield</td>
<td>0.15</td>
<td>0.08</td>
<td>0.01</td>
<td>0.24</td>
<td>30</td>
</tr>
<tr>
<td>Houchin Creek</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suvant</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colchester</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seelyville</td>
<td>0.08</td>
<td>0.01</td>
<td>0.08</td>
<td>0.09</td>
<td>3</td>
</tr>
<tr>
<td>Staunton</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>2</td>
</tr>
<tr>
<td>Minshall/Bufaloville</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.04</td>
<td>6</td>
</tr>
<tr>
<td>Upper Block</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
<td>21</td>
</tr>
<tr>
<td>Lower Block</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.09</td>
<td>30</td>
</tr>
<tr>
<td>Marlah Hill</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.04</td>
<td>2</td>
</tr>
<tr>
<td>Blue Creek</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnamed Mansfield</td>
<td></td>
<td>no data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Avg. for all coals</strong></td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td>144</td>
</tr>
</tbody>
</table>
The concentrations of numerous trace elements decrease significantly as a result of washing.
## Mineral matter in coal

<table>
<thead>
<tr>
<th>Total coal alkali</th>
<th>( %Na_2O + 0.6589(%K_2O) \times 90 \text{ ash/100} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total base</td>
<td>( Fe_2O_3 + CaO + MgO + K_2O + Na_2O )</td>
</tr>
<tr>
<td>Base/acid ratio</td>
<td>( \frac{(Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}{(SiO_2 + TiO_2 + Al_2O_3)} )</td>
</tr>
<tr>
<td>Silica/alumina ratio</td>
<td>( \frac{SiO_2}{Al_2O_3} )</td>
</tr>
<tr>
<td>Silica ratio</td>
<td>( \frac{SiO_2}{(SiO_2 + Fe_2O_3 + CaO + MgO)} )</td>
</tr>
<tr>
<td>Slagging index</td>
<td>( \text{Base/acid ratio} \times %S )</td>
</tr>
<tr>
<td>Fouling index</td>
<td>( \text{Base/acid ratio} \times \text{Na}_2\text{O} )</td>
</tr>
</tbody>
</table>
Mineral matter in coal – parameters significant for Integrated Gasification Combined Cycle (IGCC)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimal</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content (%)</td>
<td>less than 12.5</td>
<td>12.5% ash considered less suitable</td>
</tr>
<tr>
<td>SiO₂/Al₂O₃</td>
<td>1.9-2.2</td>
<td>&lt;1.9 and &gt;2.2 considered less suitable</td>
</tr>
<tr>
<td>Silica ratio</td>
<td>less than 0.70</td>
<td>&gt;0.70 considered less suitable</td>
</tr>
<tr>
<td>Fe₂O₃ +CaO (% in ash)</td>
<td>15-35</td>
<td>&lt;15 and &gt;35 considered less suitable</td>
</tr>
<tr>
<td>Slag viscosity T (°F)</td>
<td>less than 2550</td>
<td>&gt;2550 considered less suitable</td>
</tr>
</tbody>
</table>
Maps showing suitability of the Springfield Coal for IGCC

- OPT – optimal
- LS – less suitable

- Ash content less than 12.5 % (OPT)
- Ash content greater than 12.5 % (LS)
- Slag viscosity temp. less than 2550 °F (OPT)
- Slag viscosity temp. greater than 2550 °F (LS)
- SiO₂ to Al₂O₃ ratio from 1.9 to 2.2 (OPT)
- SiO₂ to Al₂O₃ ratio less than 1.9 and greater than 2.2 (LS)
Maps showing suitability of the Springfield Coal for IGCC

OPT – optimal
LS – less suitable

Yellow: $\text{Fe}_2\text{O}_3 + \text{CaO}$ from 15 to 35 (OPT)
Red: $\text{Fe}_2\text{O}_3 + \text{CaO}$ less than 15 and greater than 35 (LS)

Yellow: Silica ratio less than 0.7 (OPT)
Red: Silica ratio greater than 0.7 (LS)
Maps showing grading of the Springfield Coal for IGCC and availability for surface mining.
Combination of grading and availability for underground mining of the Springfield Coal
Underground Coal Gasification (UCG)

- It is *in-situ* gasification of the coal.
- Injection and production wells are drilled and linked together in a coal seam.
- Air or oxygen is injected and the coal is ignited in a controlled way.
- The gasification process produces primarily H$_2$, CO, CH$_4$ and CO$_2$.
- The produced gas flows to the surface where it is processed and utilized.
Coalbed gas content

Figure 35. Map of southwestern Indiana showing the gas content (scf/ton, raw basis) of the Seelyville Coal Member.

Figure 36. Histograms showing coalbed gas content in the A. Springfield Coal Member; and B. Seelyville Coal Member.
16S rRNA study of coal water and methanogenic enrichment: dominant methanogen - CO$_2$/H$_2$ utilizing *Methanocorpusculum*

Strąpoć et al., 2008, AEM
CO₂ sequestration

- CO₂ storage from 1.6 to 4.6 billion t (1.8 to 5.1 billion tons) in Illinois Basin coal

- 90 mln tons of CO₂ storage in Indiana (~3%)

- 164 mln tons a year from stationary sources in Indiana

- Gibson Station emits ~ 22 mln CO₂ a year (3100 MW capacity) – 660 mln for 30 years

- Edwardsport Gasification – 4.5 mln a year (630 MW capacity) – 150 mln for 30 years
70-280 billion m³ (2.4-9.8 tcf) of CH₄ is potentially recoverable as a result of CO₂ ECBM practices in the Illinois Basin.

Total recoverable ECBM and CO₂ storage per acre of the coal increases towards the deeper areas of the basin, where there are more coal seams and the total coal thickness is largest.

~0.15 tcf of CH₄ in Indiana.
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 mining – 70 year supply if surface mined only

- Currently ~44% Indiana production comes from underground mines.
Thank you
### Regulations
- Cross-State Air Pollution Rule
- Utility MACT Rule
- GHG NSPS for Coal Plants
- Coal Ash
- Cooling Water Intake Structures

### Projected Impacts

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Projected Power Plant Closures

[Map showing projected power plant closures with various States highlighted and GW values indicated]
Coal Plant Build-Out Ending

- Surge of New Coal Plant Construction is Coming to an End
  - Started in 2003 after the jump in gas prices
  - 21 GW of new capacity from 2005 to 2014 operating or under construction
  - ~ 4 GW not under construction may be built

Status of New Coal-Fired Plants

- Possible
- Probable
- Construction
- Operating

MW

0
1,000
2,000
3,000
4,000
5,000
6,000

2000
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018