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 Drobniak, John Rupp, and Nelson Shaffer

Indiana Geological Survey
Indiana University

Center for Coal Technology Research

Indiana Department of Commerce

OBJECTIVES

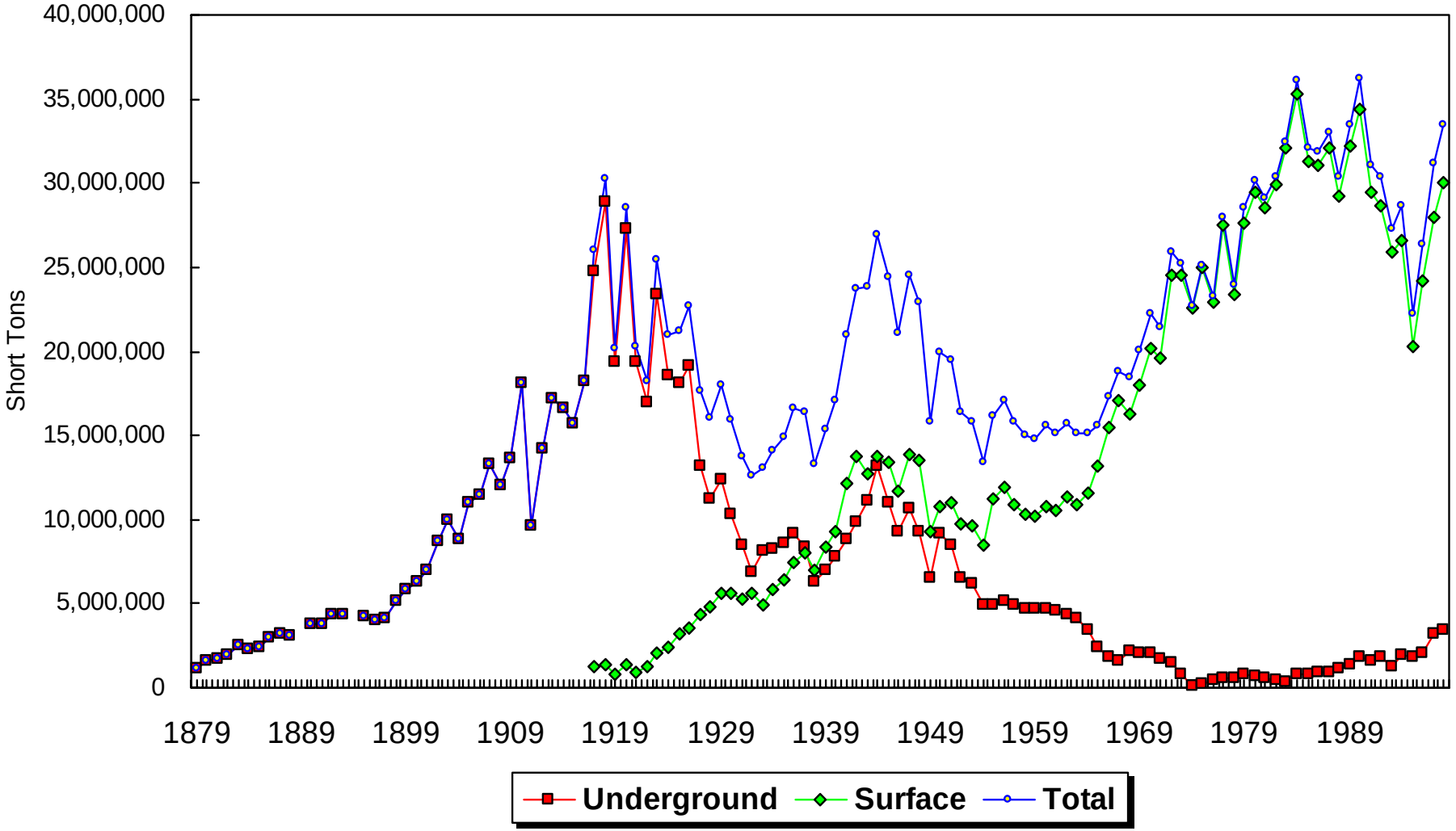
- **Provide assessment how much coal is available for mining**
- **Characterize quality of coal for those unique properties to utilize it in an efficient and environmentally sound manner;**
- **Characterize current use of coal;**
- **Characterize production and use of Coal Combustion Products;**
- **Characterize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

CONTENTS

- **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



Illinois

Group	Formation	Unit
McLeansboro Gp.	Mattoon Fm.	
McLeansboro Gp.	Bond Fm.	
McLeansboro Gp.	Patoka Fm.	
McLeansboro Gp.	Shelburn Fm.	Danville (No.7)
McLeansboro Gp.	Shelburn Fm.	Jamestown
	Carbondale Fm.	Herrin (No.6)
	Carbondale Fm.	Springfield (No.5)
	Carbondale Fm.	Houchin Creek
	Carbondale Fm.	Survant
	Carbondale Fm.	Colchester (No.2)
	Carbondale Fm.	Dekoven
	Carbondale Fm.	Davis
Racoon Creek Group	Tradewater Fm.	Willis
Racoon Creek Group	Tradewater Fm.	Reynoldsburg
Racoon Creek Group	Caseyville Fm.	Gentry

Indiana

Group	Formation	Unit
McLeansboro Gp.	Mattoon Fm.	
McLeansboro Gp.	Bond Fm.	
McLeansboro Gp.	Patoka Fm.	
McLeansboro Gp.	Shelburn Fm.	
Carbondale Group	Dugger Fm.	Danville (VII) ●
Carbondale Group	Dugger Fm.	Hymera (VI) ●
Carbondale Group	Dugger Fm.	Herrin
Carbondale Group	Dugger Fm.	Bucktown (Vb)
Carbondale Group	Petersburg Fm.	Springfield (V) ●
Carbondale Group	Petersburg Fm.	Houchin Creek ●
Carbondale Group	Linton Fm.	Survant (IV) ●
Carbondale Group	Linton Fm.	Colchester (IIIa) ●
Carbondale Group	Linton Fm.	Seelyville (III) ●
Racoon Creek Group	Staunton Fm.	Unnamed Staunton Fm coals
Racoon Creek Group	Brazil Fm.	Minshall / Buffaloville ●
Racoon Creek Group	Brazil Fm.	Upper Block ●
Racoon Creek Group	Brazil Fm.	Lower Block ●
Racoon Creek Group	Mansfield Fm.	Mariah Hill
Racoon Creek Group	Mansfield Fm.	Blue Creek
Racoon Creek Group	Mansfield Fm.	Pinnick
Racoon Creek Group	Mansfield Fm.	St. Meinrad
Racoon Creek Group	Mansfield Fm.	French Lick

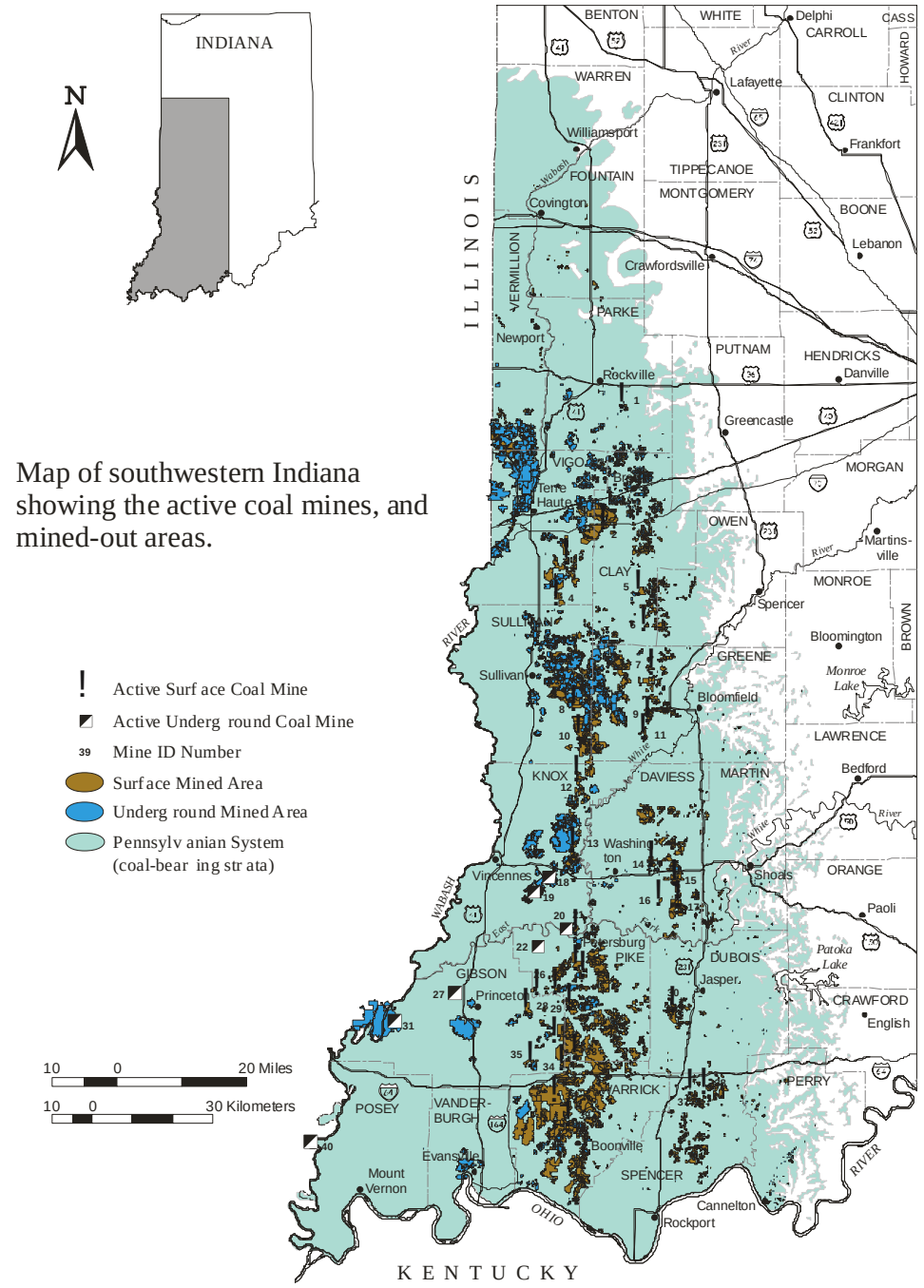
W. Kentucky

Group	Formation	Unit
McLeansboro Group	Mattoon Fm.	
McLeansboro Group	Bond Fm.	
McLeansboro Group	Patoka Fm.	
McLeansboro Group	Shelburn Fm.	Baker (No.13)
McLeansboro Group	Shelburn Fm.	Paradise (no.12)
	Carbondale Fm.	Herrin (no.11)
	Carbondale Fm.	Springfield (No.9)
	Carbondale Fm.	Houchin Creek
	Carbondale Fm.	Survant (No.8)
	Carbondale Fm.	Colchester
	Carbondale Fm.	Dekoven (No.7)
	Carbondale Fm.	Davis (No.6)
Racoon Creek Group	Tradewater Fm.	(Mining City) No.4
Racoon Creek Group	Tradewater Fm.	Empire
Racoon Creek Group	Tradewater Fm.	Lead Creek/Dunbar
Racoon Creek Group	Tradewater Fm.	Elm Lick
Racoon Creek Group	Tradewater Fm.	(Ice House) No.3
Racoon Creek Group	Tradewater Fm.	Foster
Racoon Creek Group	Tradewater Fm.	Amos
Racoon Creek Group	Tradewater Fm.	Bell
	Caseyville	Battery Rock
	Caseyville	Nolin

Series (Pennsylvanian)

Series	Equivalent units
Virg.	(above Mattoon Fm.)
Missourian	Mattoon Fm. – Patoka Fm.
Desmoinesian	Shelburn Fm. – Davis / Seelyville (III), continuing into the upper part of Racoon Creek Group
Atokan	Racoon Creek Group (middle)
Morrowan	Racoon Creek Group (lower) / Caseyville

Pennsylvanian


INDIANA
N
Map of southwestern Indiana showing the active coal mines, and mined-out areas.
! Active Surface Coal Mine
Active Underground Coal Mine
39 Mine ID Number
Surface Mined Area
Underground Mined Area
Pennsylvanian System (coal-bearing strata)
10 0 20 Miles
10 0 30 Kilometers
ILLINOIS
KENTUCKY
BENTON
WHITE
CASS
CARROLL
HOWARD
WARREN
Lafayette
CLINTON
Frankfort
Williamsport
FOUNTAIN
TIPPECANOE
MONTGOMERY
BOONE
Lebanon
Covington
VERMILLION
Crawfordsville
PARKE
Newport
PUTNAM
HENDRICKS
Danville
Rockville
Greencastle
VIGO
Terre Haute
MORGAN
OWEN
Martinsville
CLAY
MONROE
Spencer
SULLIVAN
Bloomington
BROWN
GREENE
Sullivan
Monroe Lake
Bloomfield
LAWRENCE
KNOX
DAVIESS
MARTIN
Bedford
Washington
Vincennes
Shoals
ORANGE
Paoli
Petersburg
PIKE
DUBOIS
Patoka Lake
GIBSON
Princeton
Jasper
CRAWFORD
English
PERRY
WARRICK
POSEY
VANDERBURGH
Boonville
Evansville
SPENCER
Mount Vernon
Cannelton
Rockport
OHIO
RIVER
WABASH
White River

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.

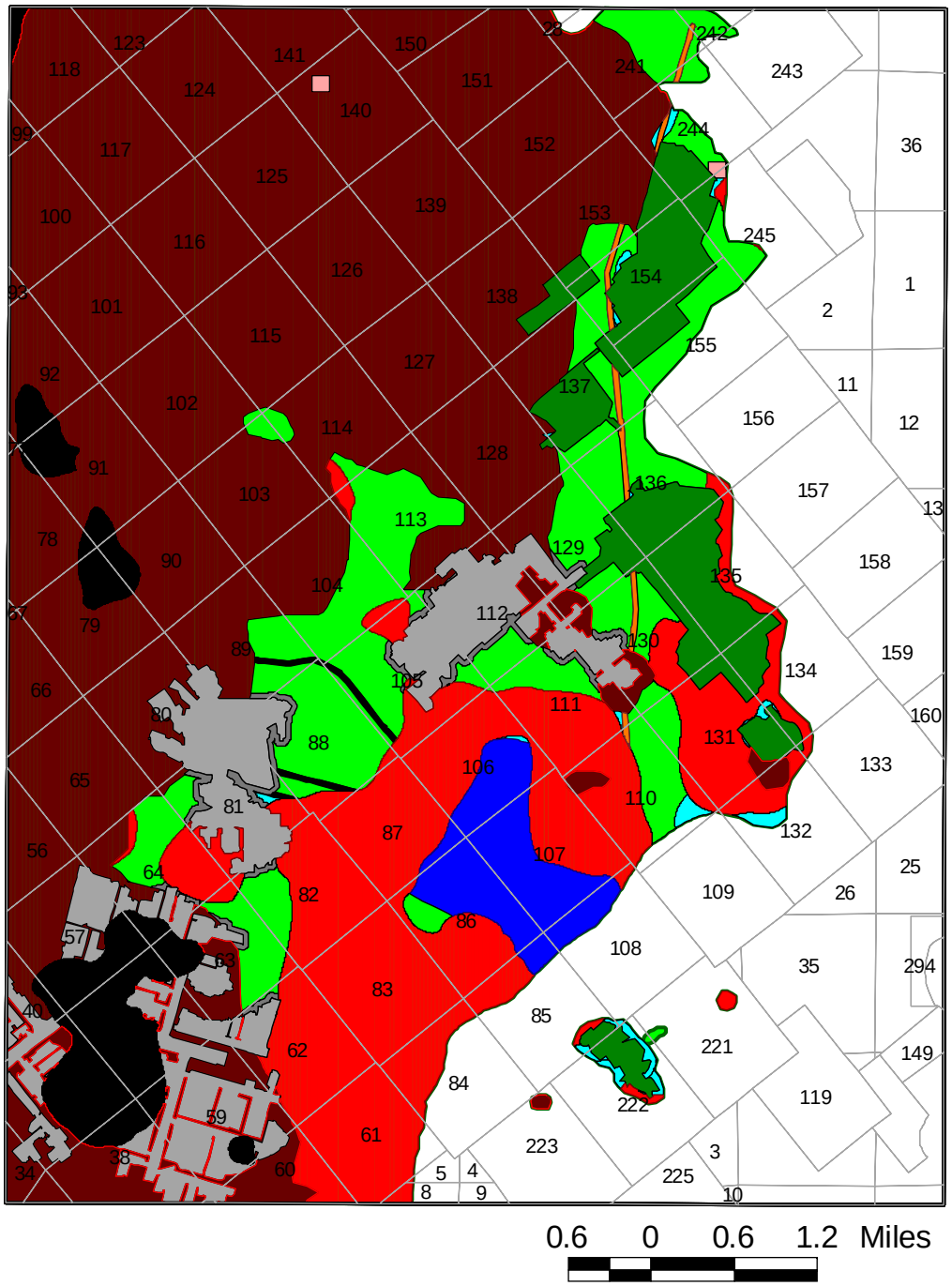
Technology is economically based:

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

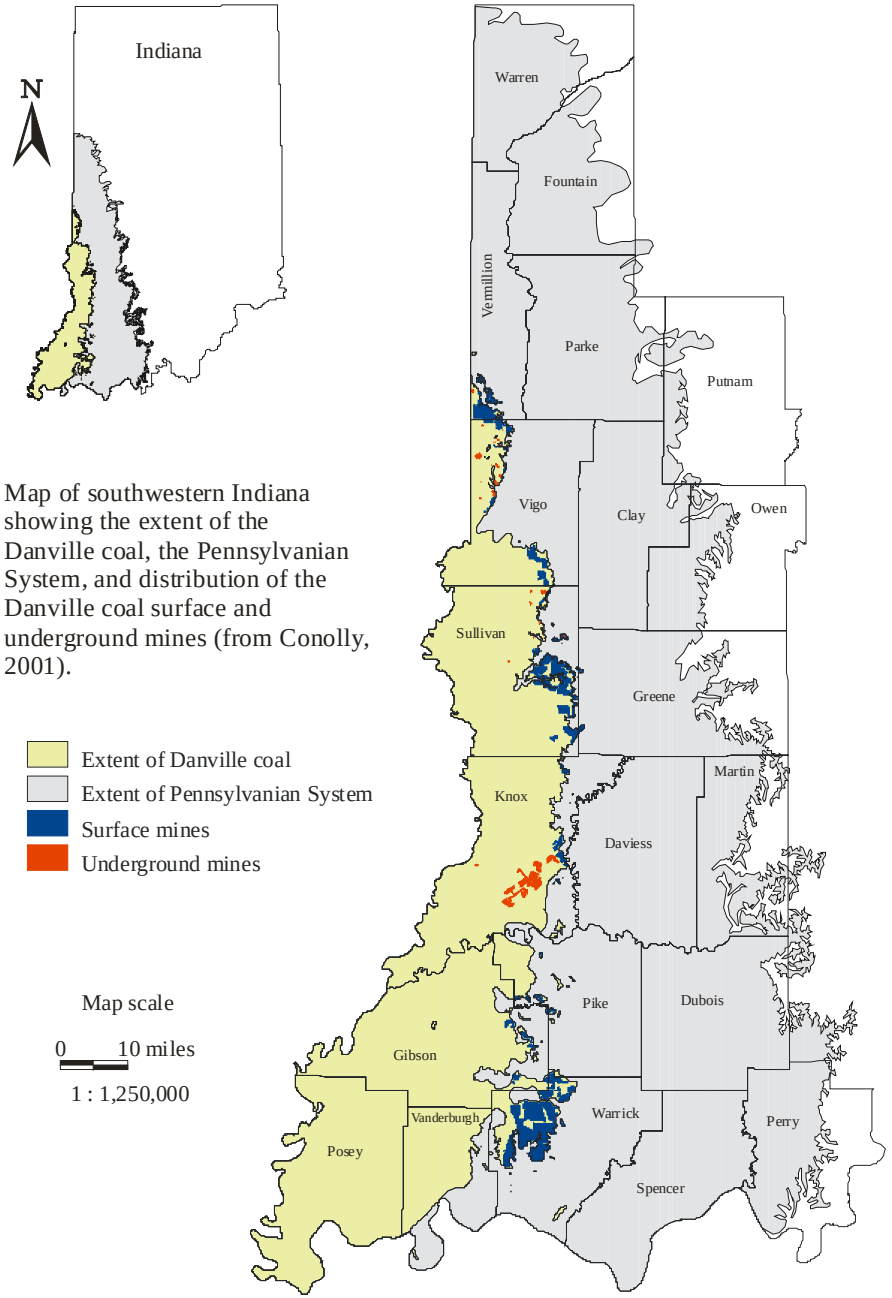


Explanation

- coal available for surface mining
- >200ft deep
- coal eroded
- surface mine
- deep mine
- 200ft buffer around deep mines
- coal <14 inches
- stripping ratio >25:1
- unconsolidated >60ft thick
- towns + 2,640ft buffer
- pipelines + 100ft buffer
- paved roads + 100ft buffer
- mine block too small

Danville coal

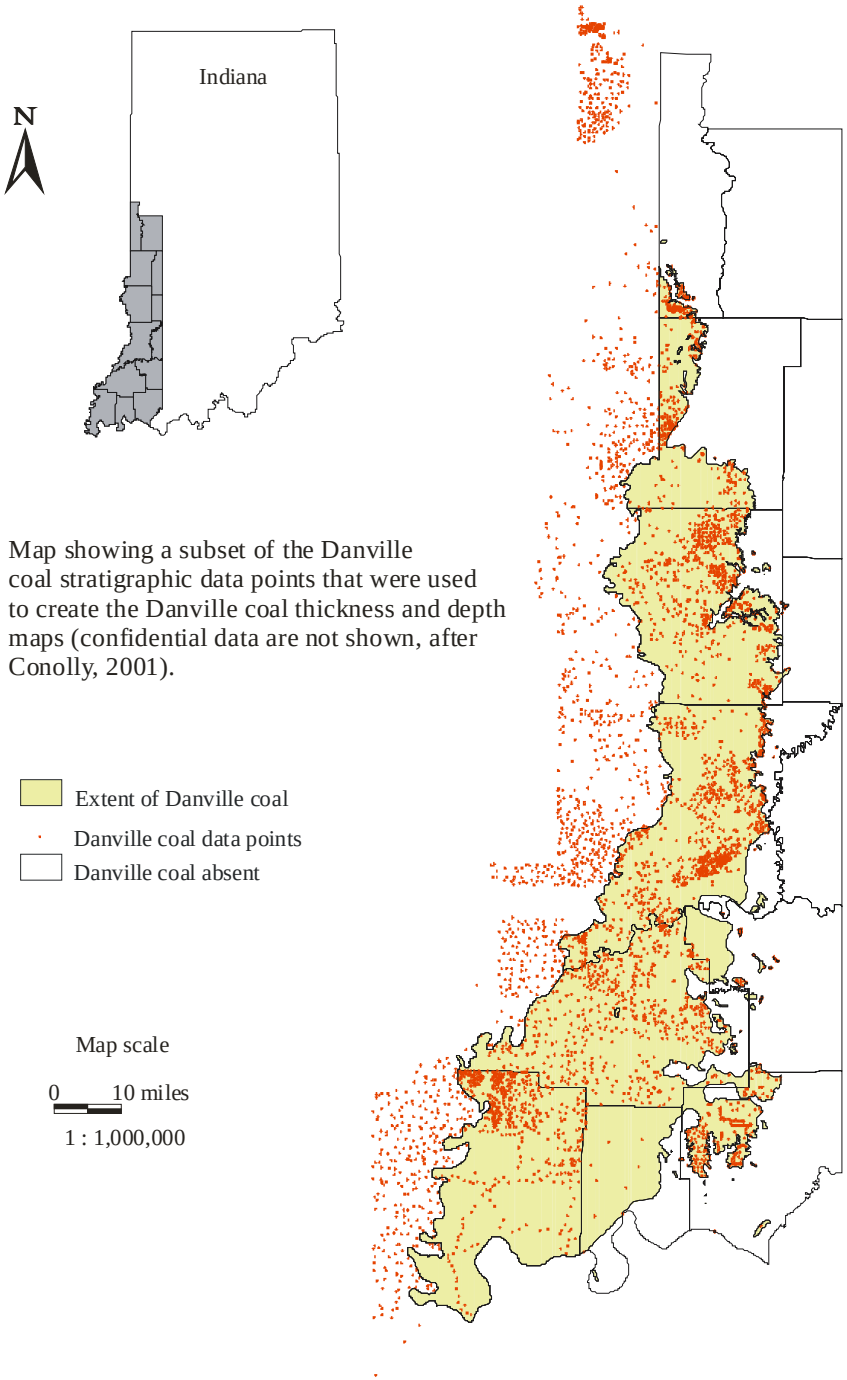
Extent and mined out areas



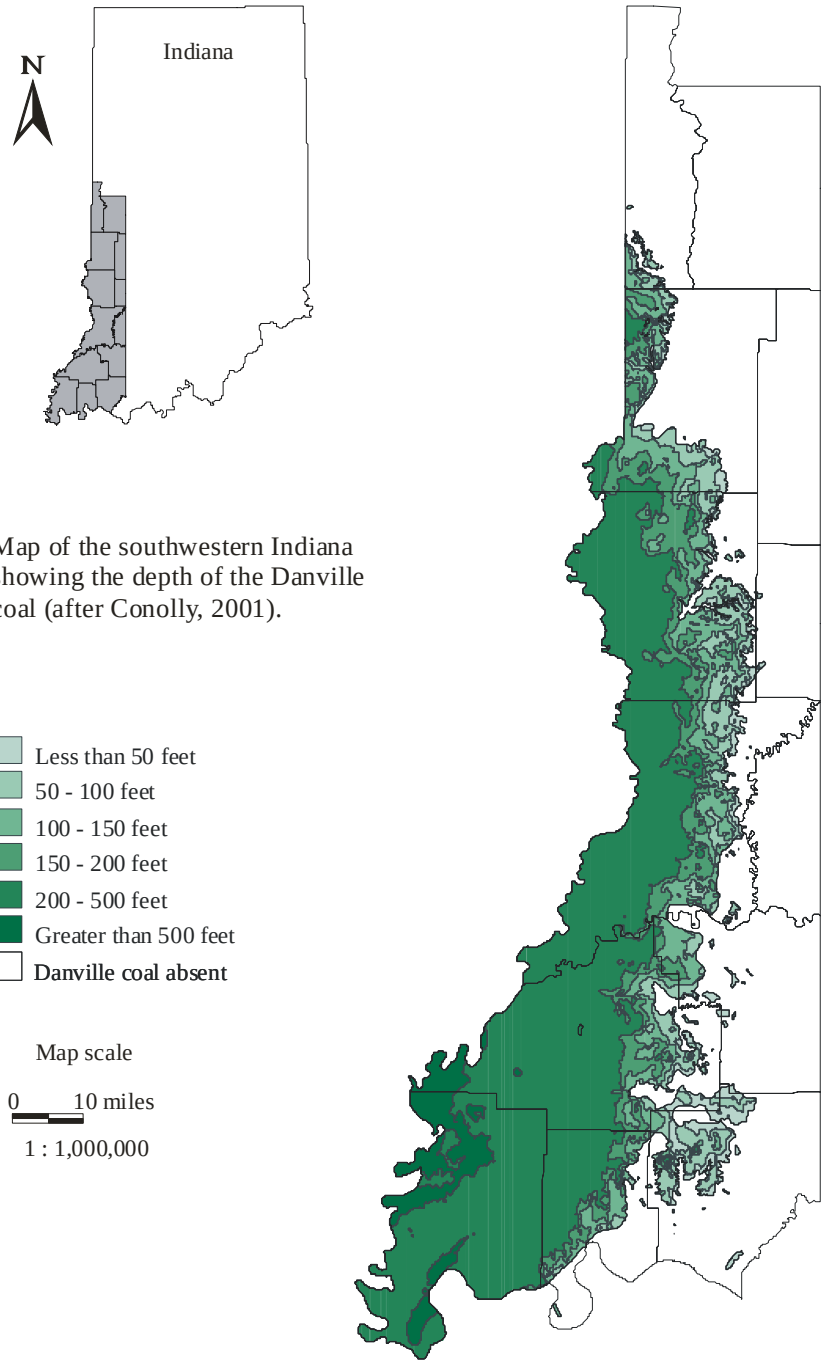
Map of southwestern Indiana showing the extent of the Danville coal, the Pennsylvanian System, and distribution of the Danville coal surface and underground mines (from Conolly, 2001).

Danville coal

Data points used



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).

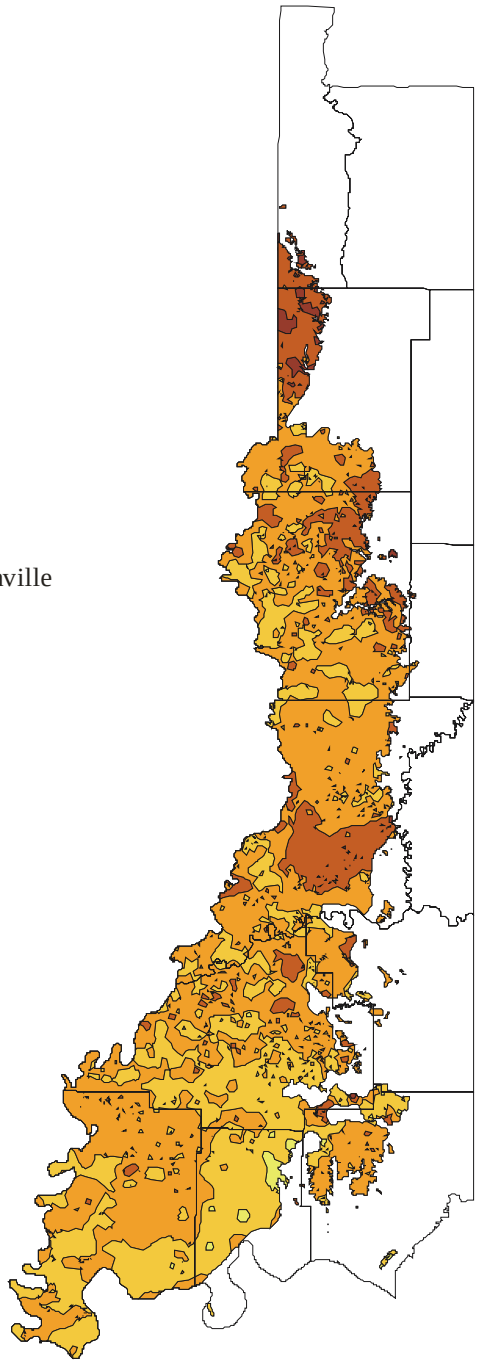


Map of the southwestern Indiana showing the depth of the Danville coal (after Conolly, 2001).

Danville coal

Depth to the coal

Map of the southwestern Indiana showing the thickness of the Danville coal (after Conolly, 2001).



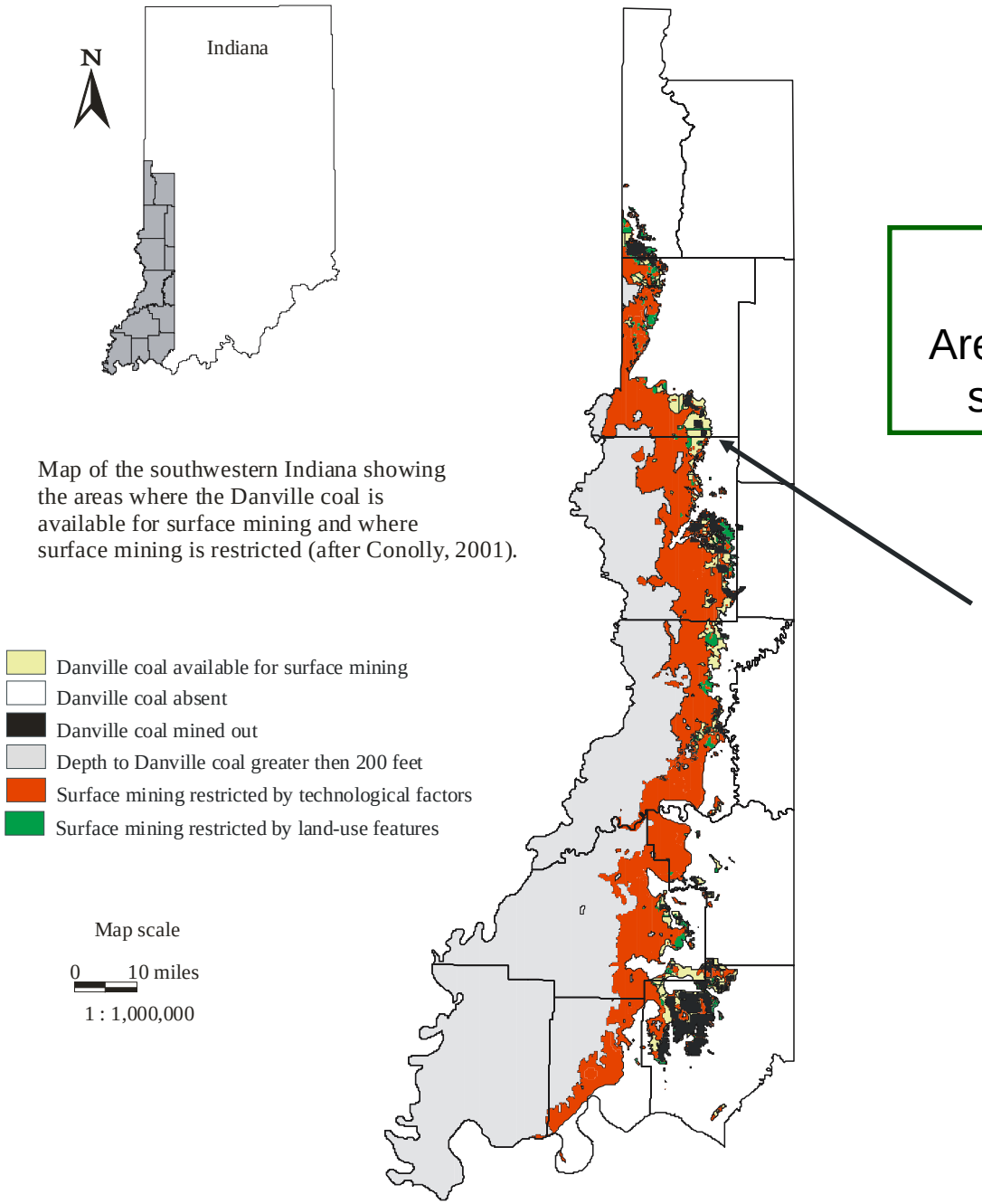
Less than 14 inches
14 - 28 inches
28 - 42 inches
42 - 63 inches
Greater than 63 inches
Danville coal absent

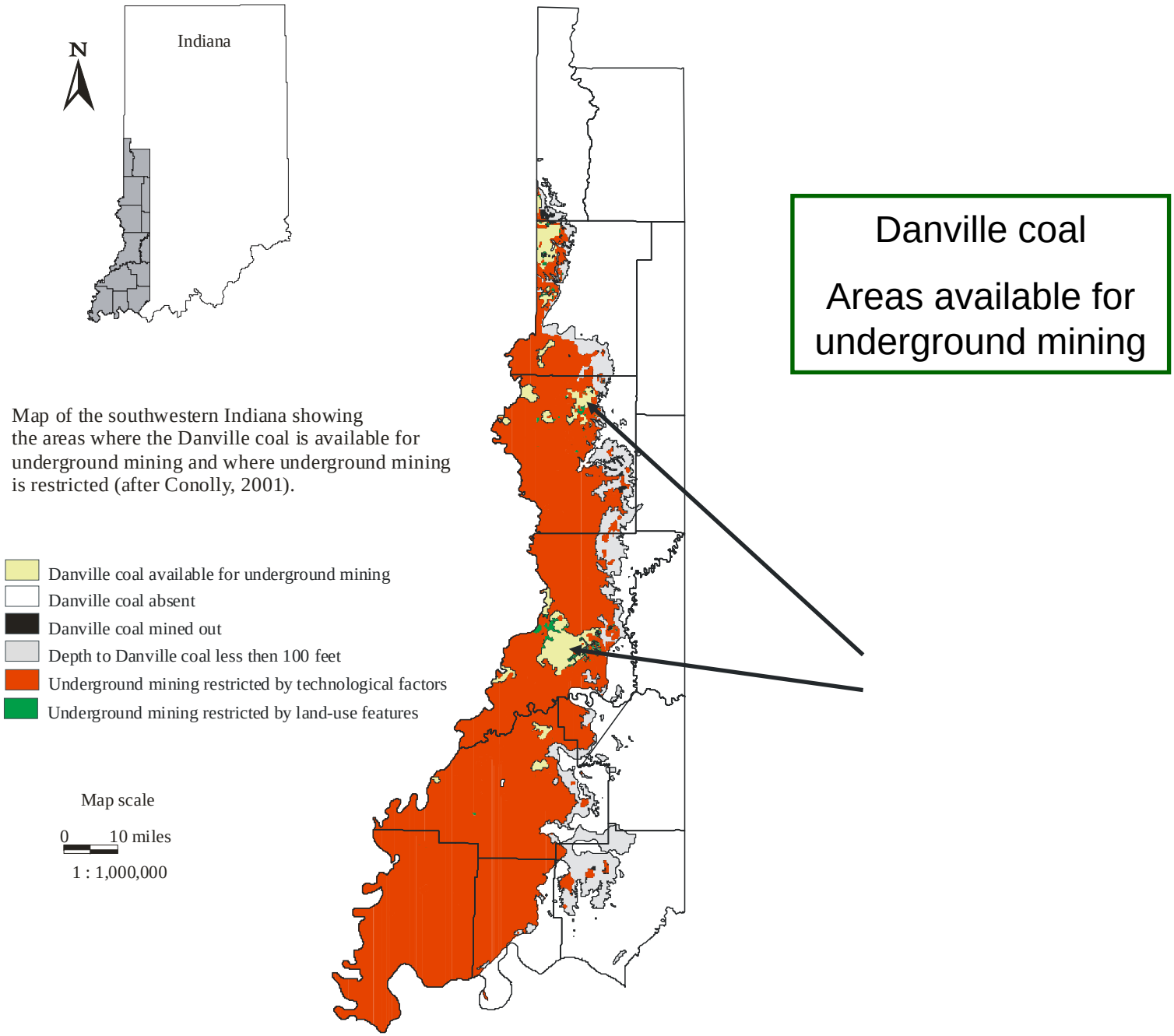
Map scale

0 10 miles

1 : 1,000,000

Danville coal Thickness

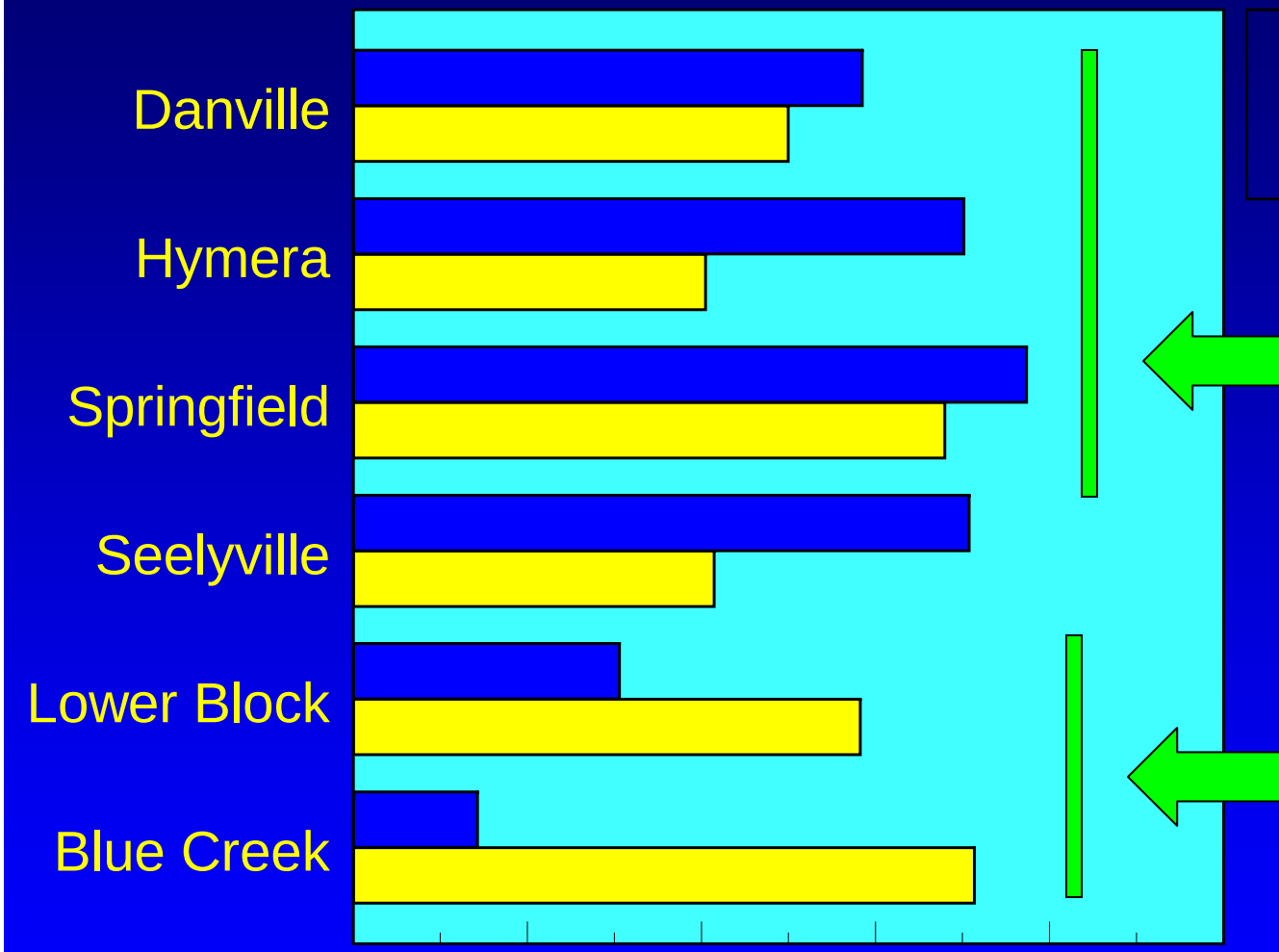

N
Indiana
Danville coal
Areas available for surface mining
Map of the southwestern Indiana showing the areas where the Danville coal is available for surface mining and where surface mining is restricted (after Conolly, 2001).
Danville coal available for surface mining
Danville coal absent
Danville coal mined out
Depth to Danville coal greater then 200 feet
Surface mining restricted by technological factors
Surface mining restricted by land-use features
Map scale
0 10 miles
1 : 1,000,000


Indiana
N
Danville coal
Areas available for underground mining
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).
Danville coal available for underground mining
Danville coal absent
Danville coal mined out
Depth to Danville coal less then 100 feet
Underground mining restricted by technological factors
Underground mining restricted by land-use features
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

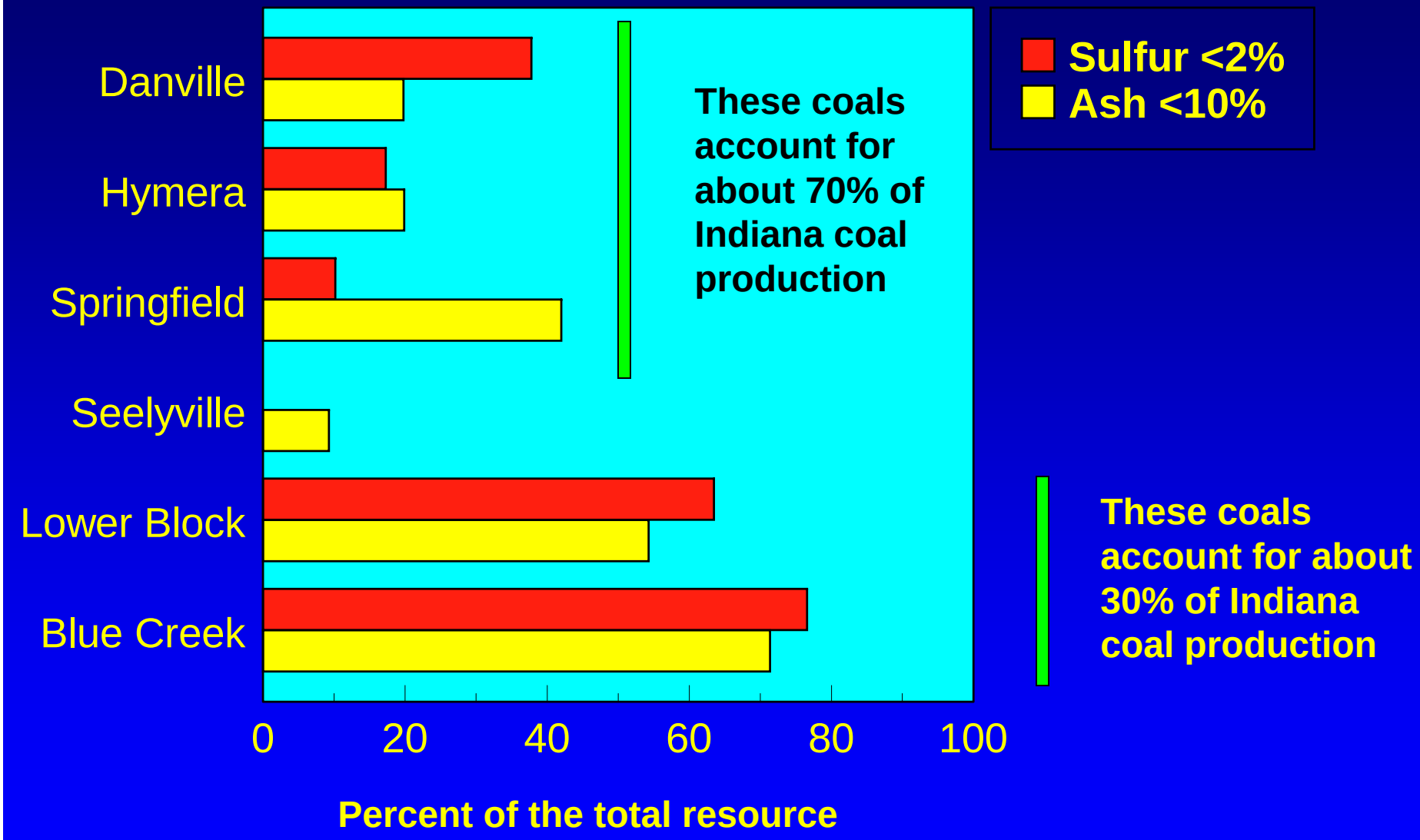


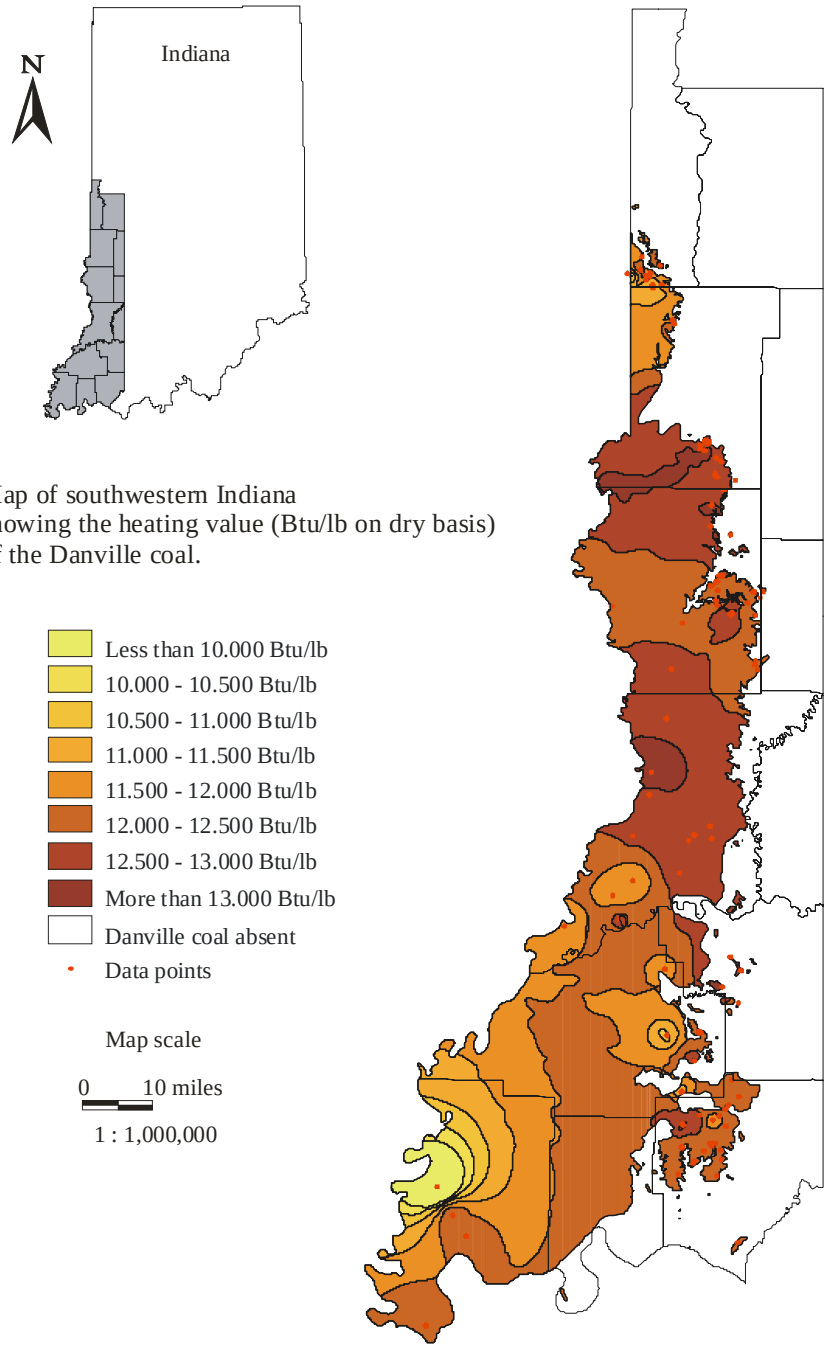
Moisture <12%
Btu>12500

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



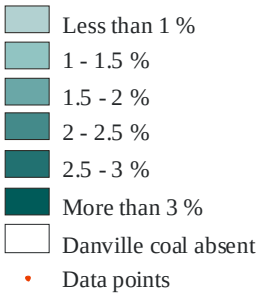


Map of southwestern Indiana showing the heating value (Btu/lb on dry basis) of the Danville coal.

Danville coal

Heating value (Btu/Lb, dry basis)

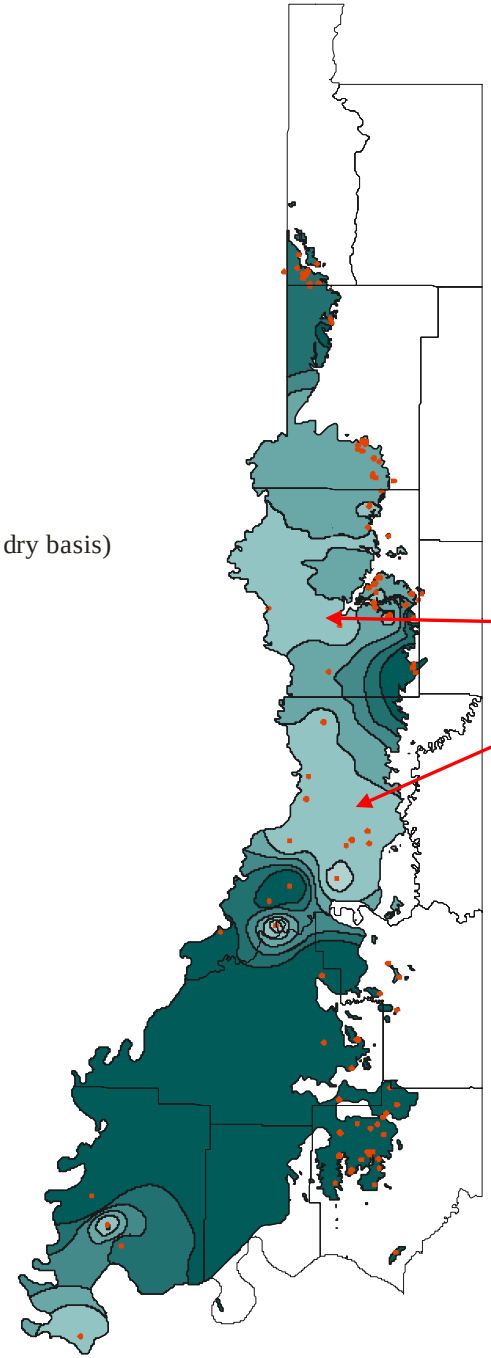
Map of southwestern Indiana
showing the sulfur content (total, dry basis)
of the Danville coal.



Map scale

0 10 miles

1 : 1,000,000

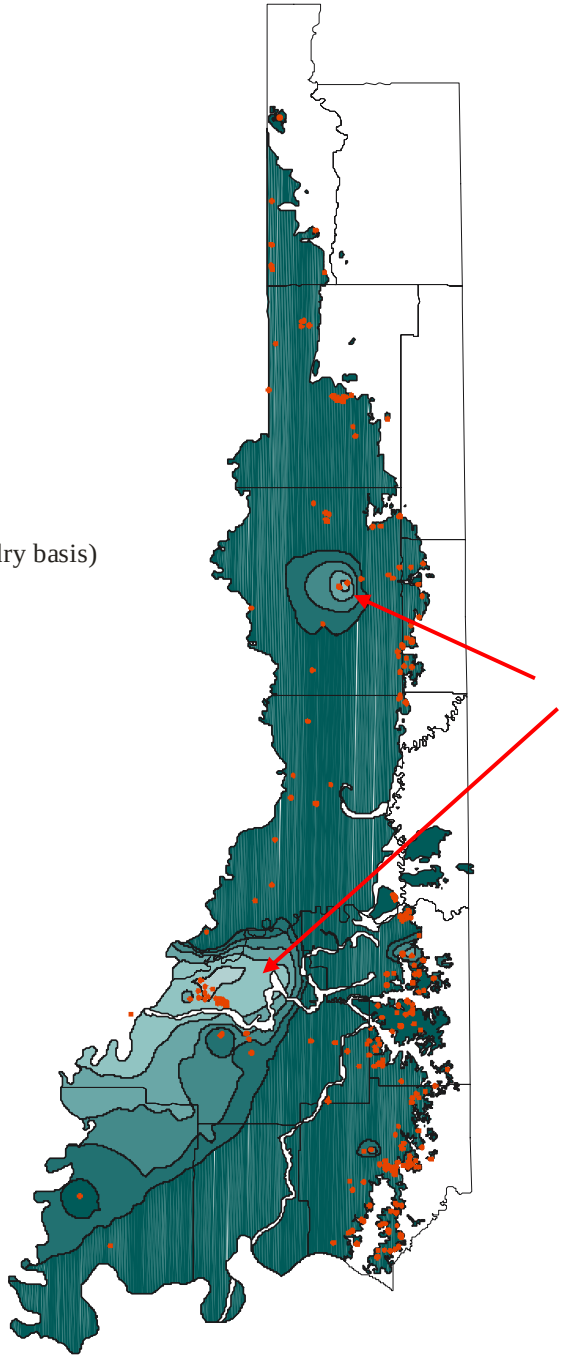


Danville coal

Sulfur content (dry)

Less than
1%

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
- Data points

Map scale

0 10 miles

1 : 1,000,000

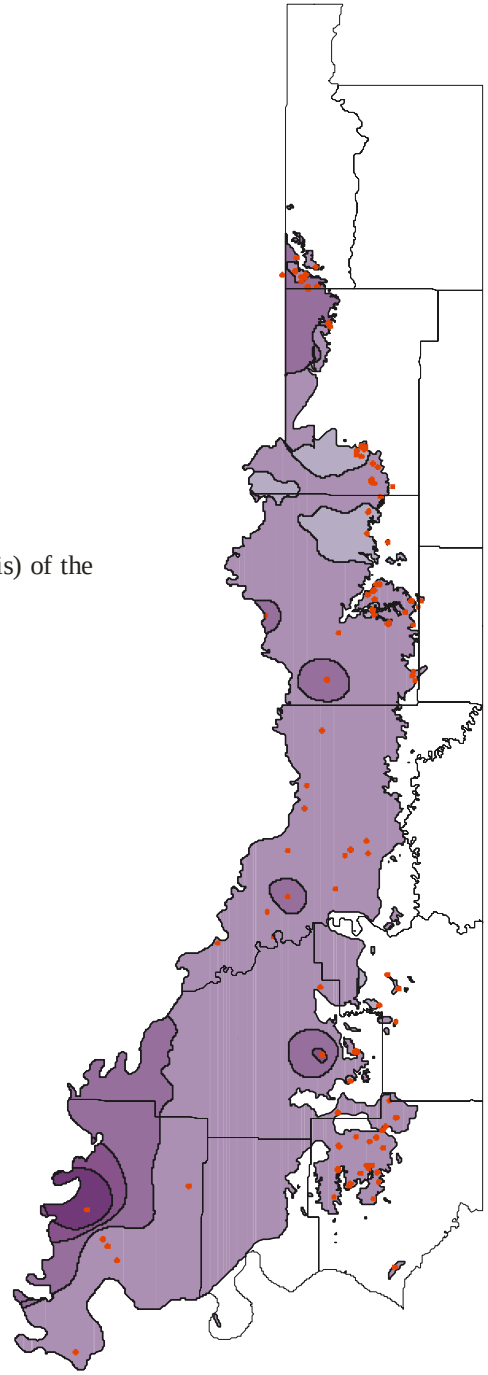
Springfield coal

Sulfur content (dry)

Danville coal

Ash content (dry)

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

MINERAL MATTER IN COAL

Furnace Slagging* Indices

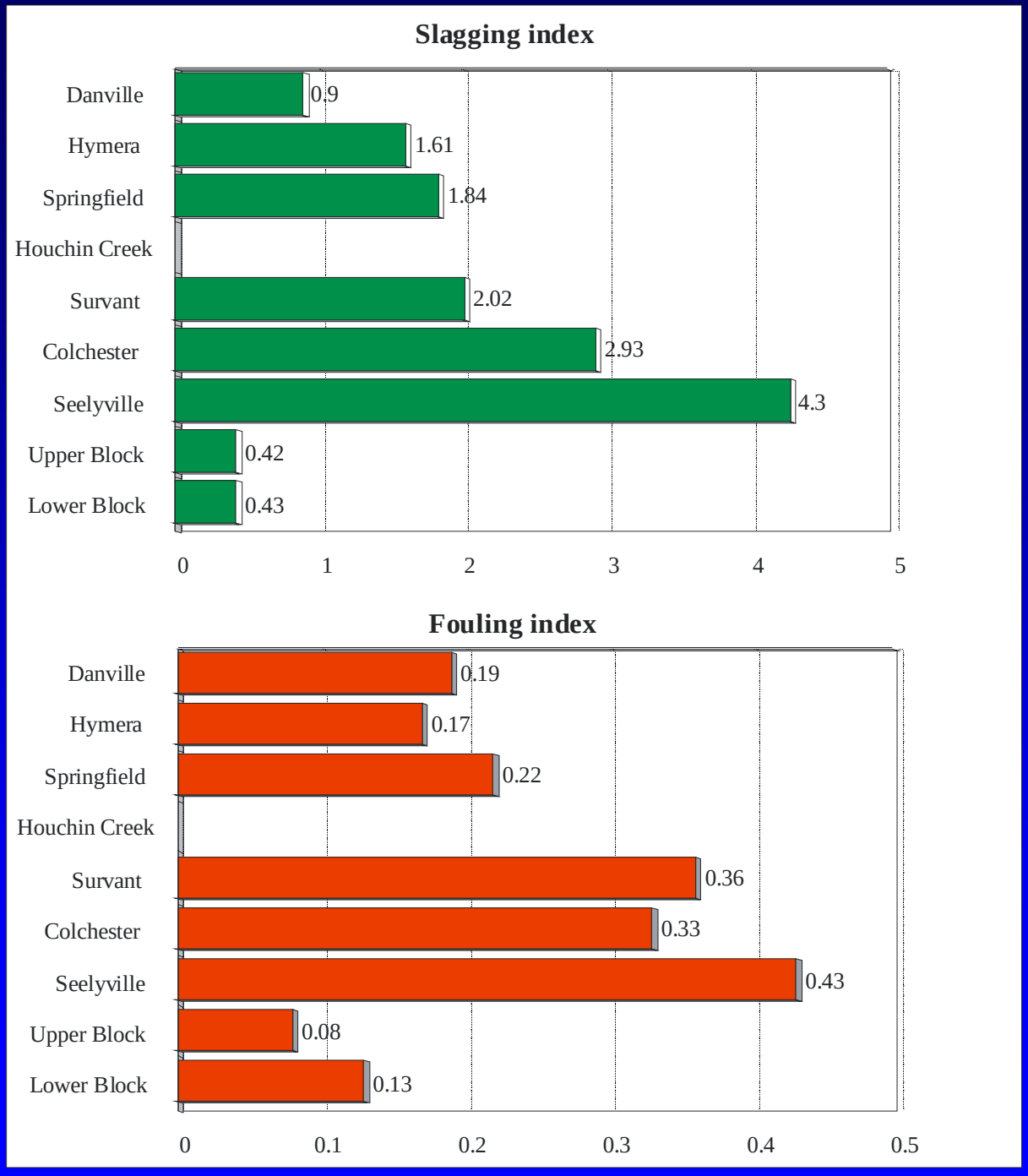
Slagging Index (Base/Acid)*(% Sulfur)	*<0.6*	*low*
	0.6-2	*medium*
	>2	*high*
Base Acid Ratio (Base/Acid)	*<0.5*	*(0.3)*
	dbot	*wbot*
Silica Percentage (SiO_2) (100) / $SiO_2+Fe_2O_3+CaO+MgO$	*<30*	*low*
	30-82	*medium*
	>82	*high*

*Slagging – buildup of molten ash in the lower furnace

Furnace Fouling* Indices

- **Fouling Index**
  (Base/Acid) * Na_2O
  - *< 0.2* *low*
  - *0.2 - 0.5* *medium*
  - *> 0.5* *high*
- **Alkalies in Coal**
  (% Ash)*
  (Na_2O + 0.659 K_2O)
  - *< 0.3* *low*
  - *0.3 - 0.5* *medium*
  - *> 0.5* *high*
- **Sodium in Ash**
  % Na_2O
  - *< 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.**

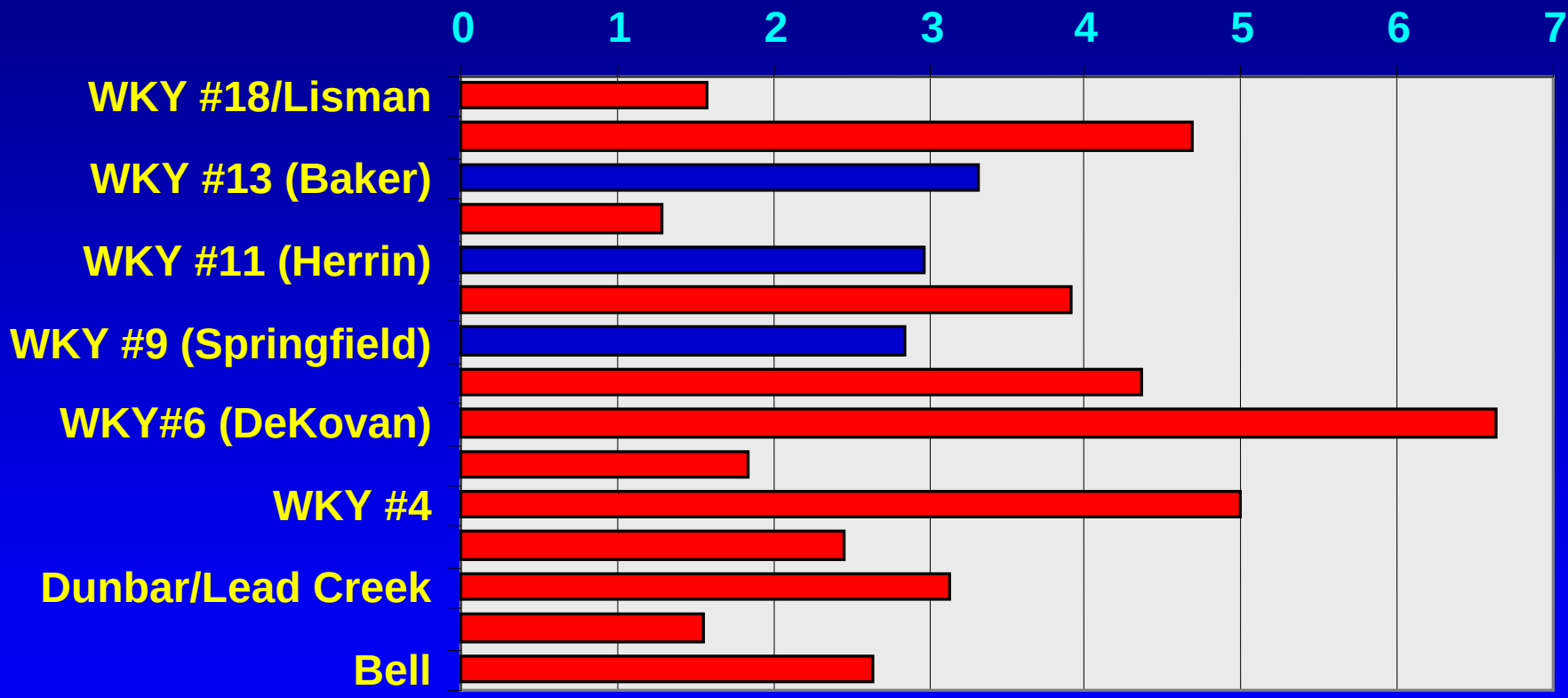


Slagging index – low - below 0.6
medium – 0.6-2.0
high - above 2.0

Fouling index – low - below 0.2
medium – 0.2-0.5
high above 0.5

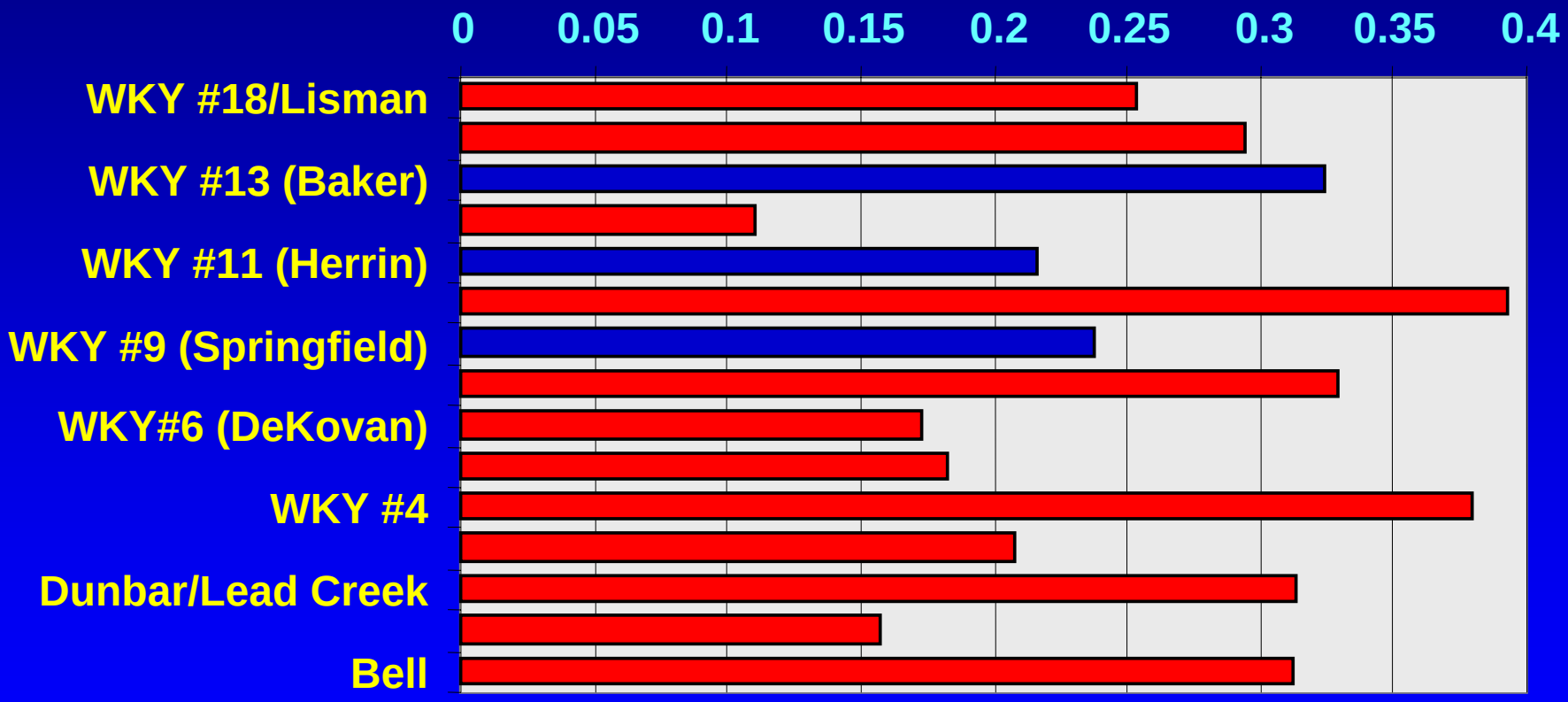
Ash fusion T – low may cause slag deposits

Slagging Index – western Kentucky



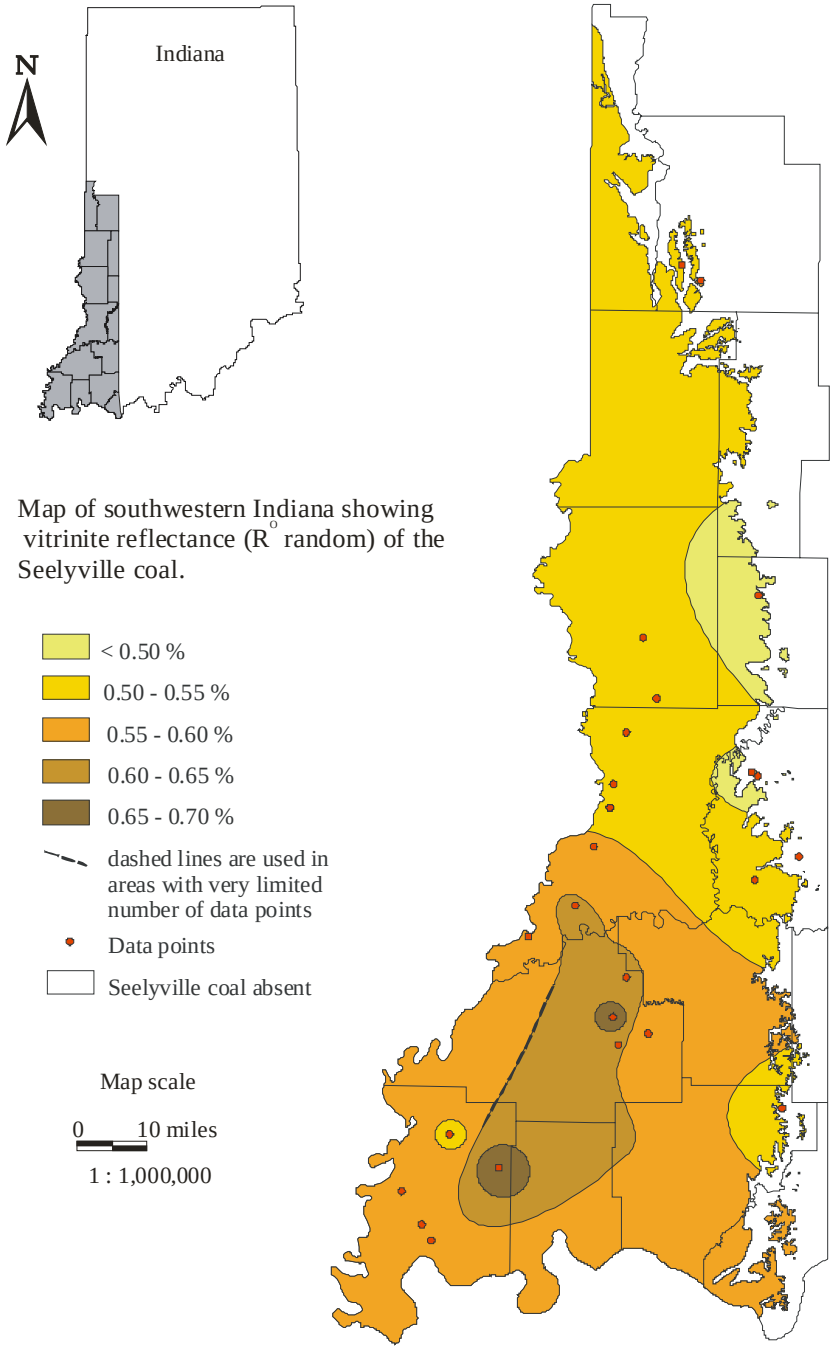
< 0.6 = Low 0.6-2.0 = Medium > 2.0 = High

Fouling Index – western Kentucky



< 0.2 = low 0.2 - 0.5 = moderate >0.5 = high

Coal rank and petrography



Map of southwestern Indiana showing vitrinite reflectance (R^o random) of the Seelyville coal.

Indiana coals are of high-volatile bituminous rank

C – Ro 0.47-0.57%

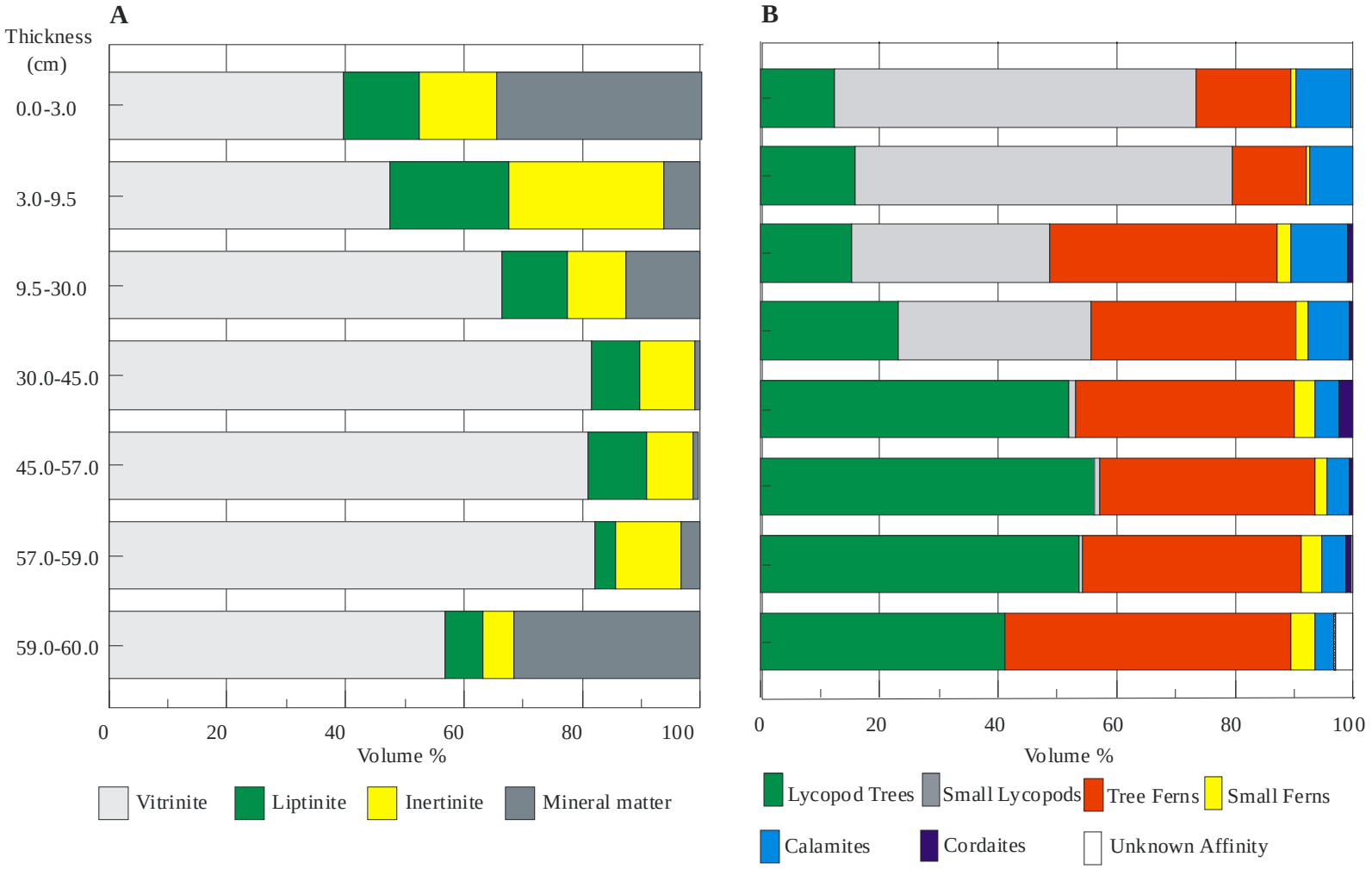
B – Ro 0.57-0.71%

A – Ro 0.71-1.1%

Seelyville coal

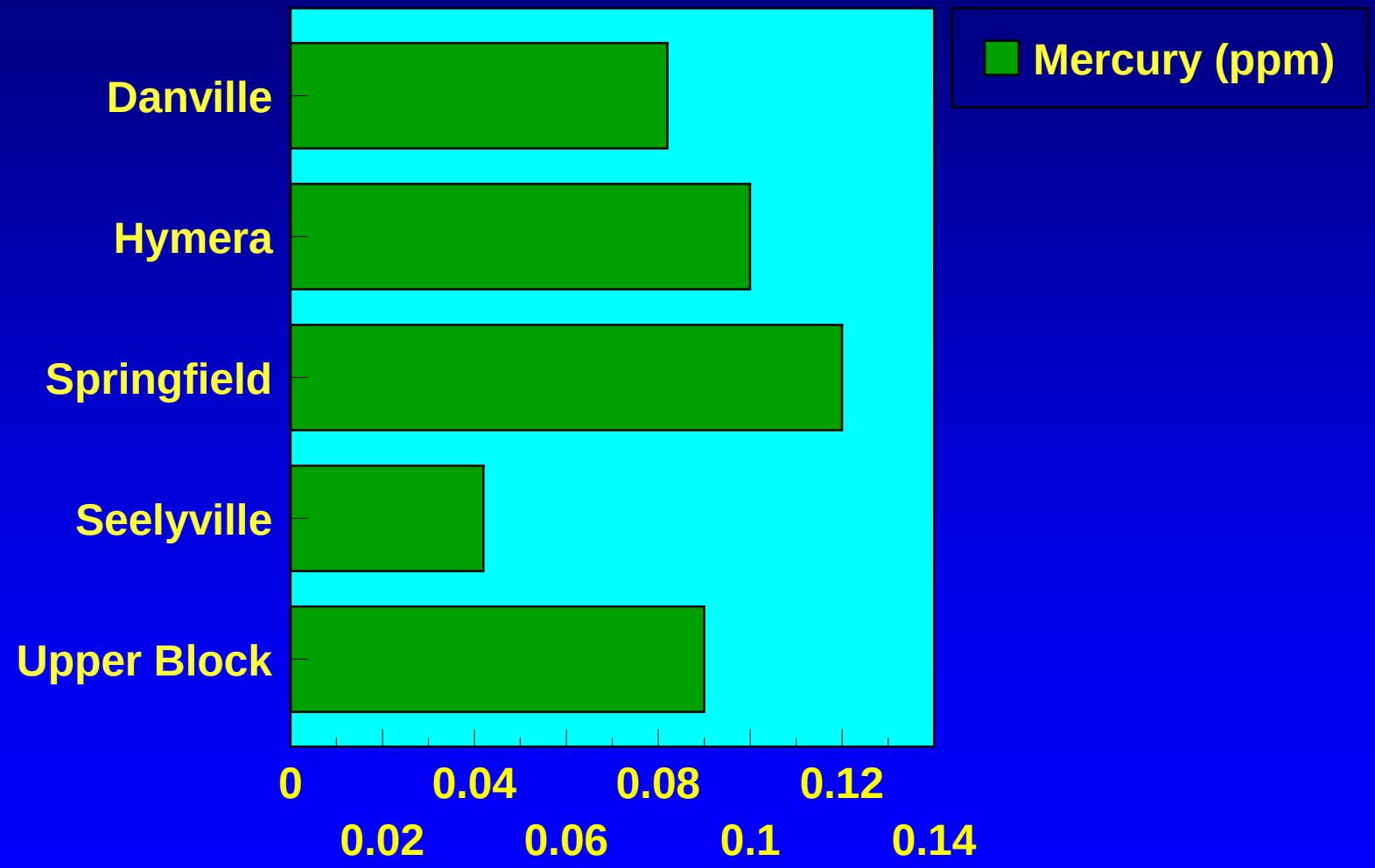
Vitrinite reflectance

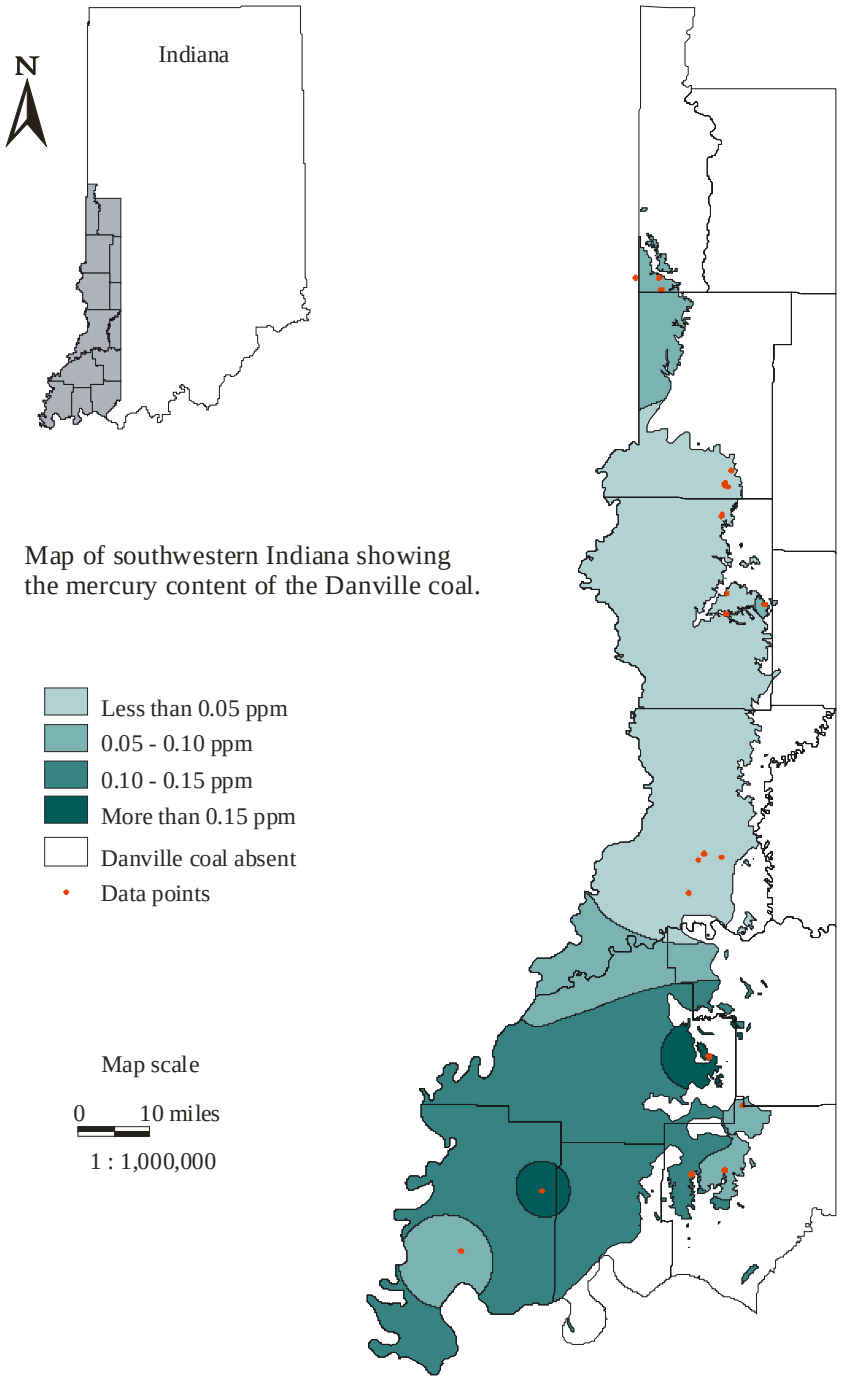
Petrography and palynology



Maceral composition (A, in volume %) and palynology (B) of the Upper Block coal in Daviess County.

Trace elements in Indiana coals

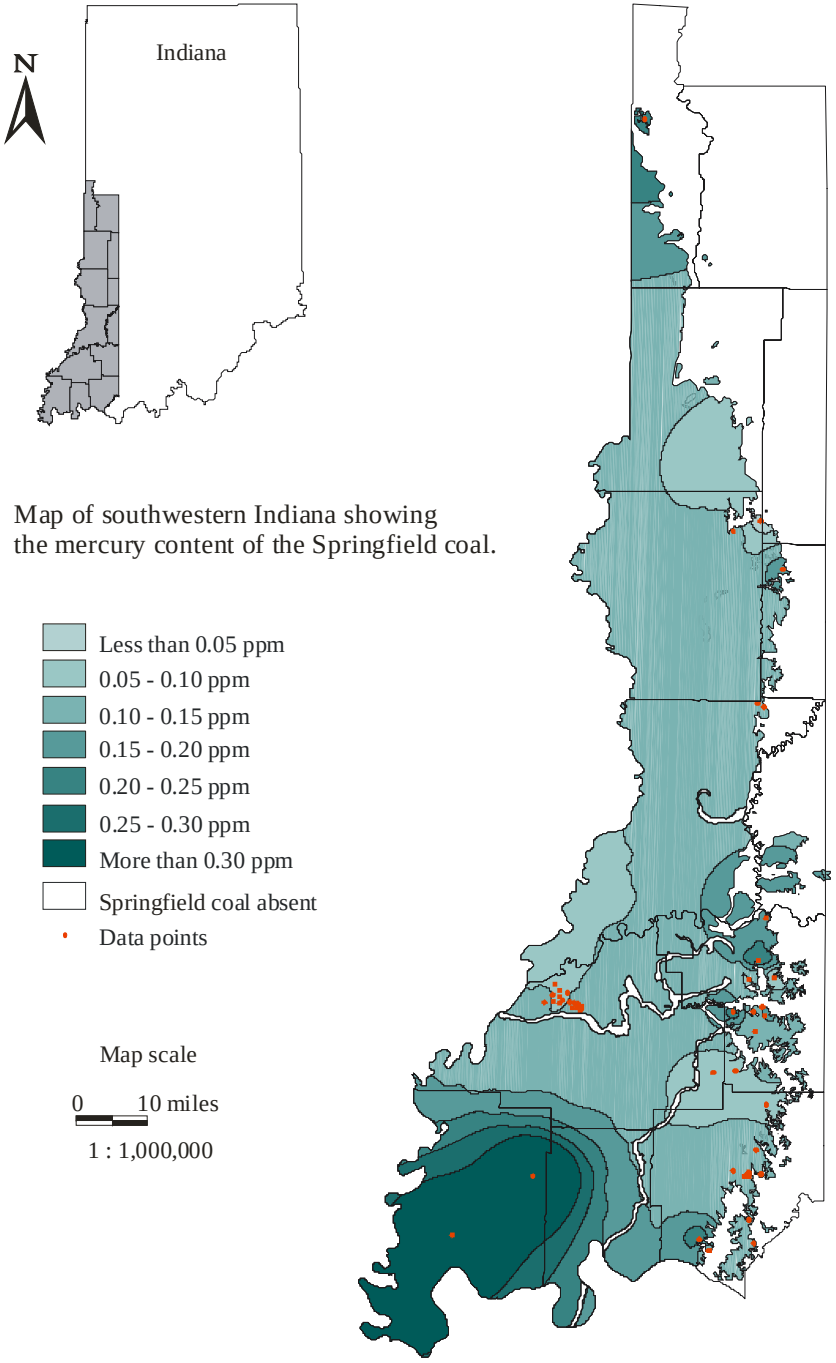




Map of southwestern Indiana showing the mercury content of the Danville coal.

Danville coal

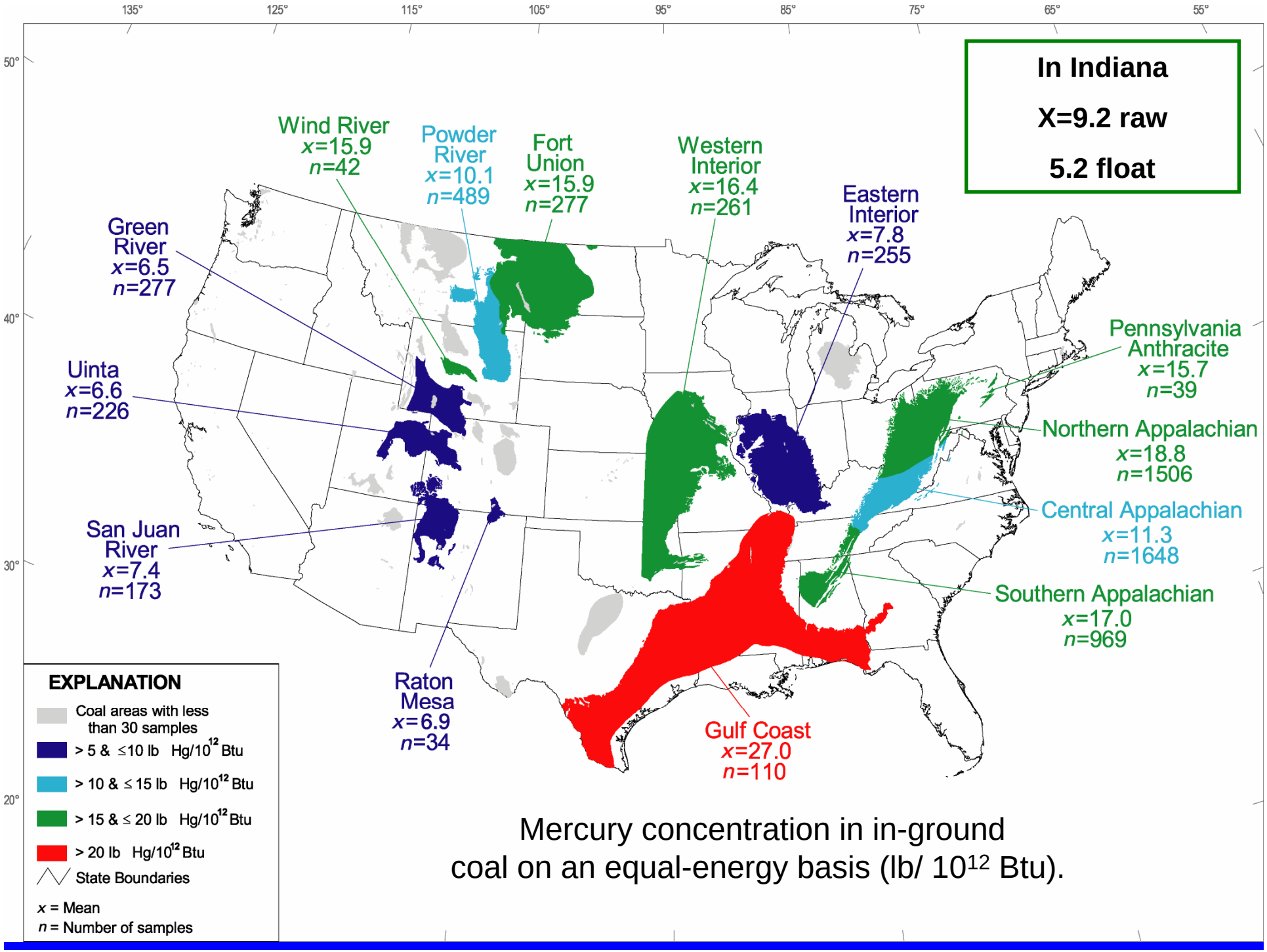
Mercury content (ppm)



Map of southwestern Indiana showing the mercury content of the Springfield coal.

Springfield coal

Mercury content (ppm)



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

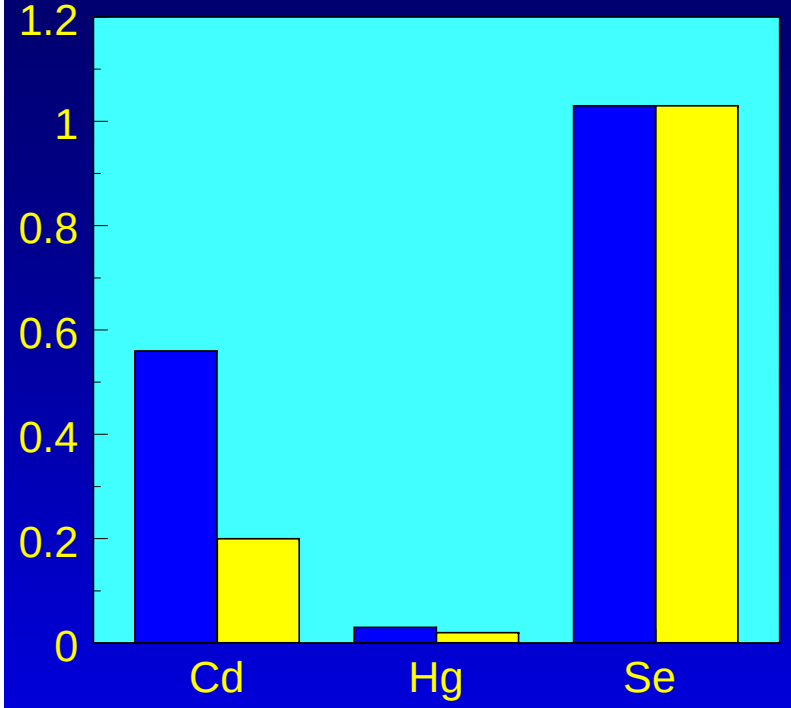
Regulatory approaches

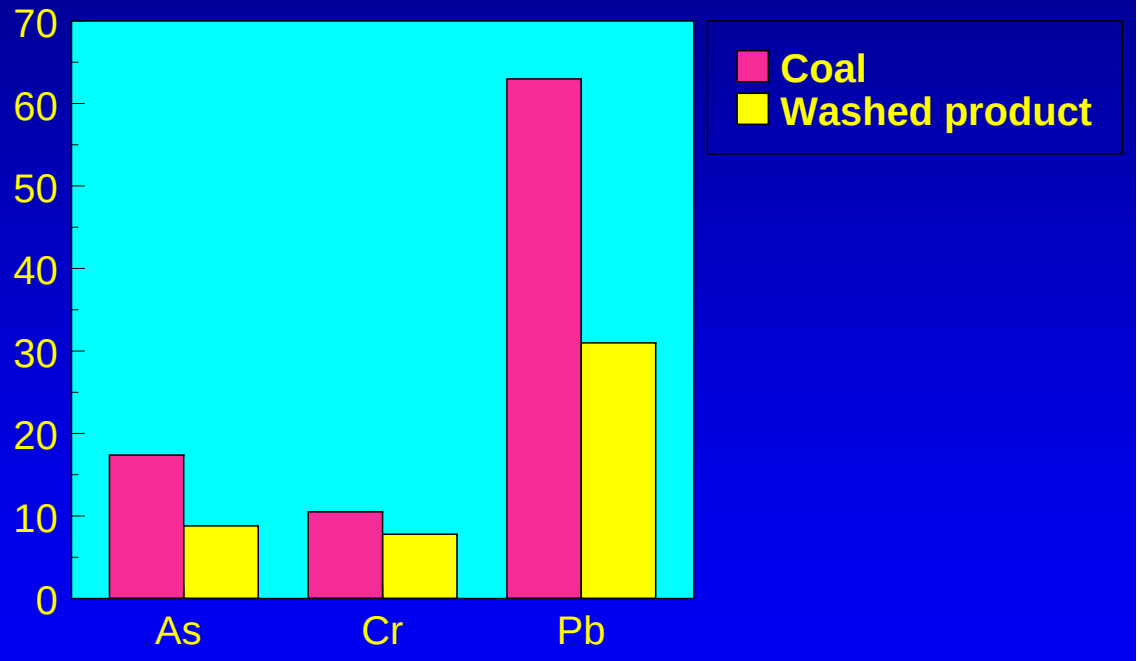
- Bituminous – 2/TBtu
- Subbituminous 5.8/TBtu
- Lignite – 9.2/TBtu

- MACT – Compliance data – 08

Danville Coal

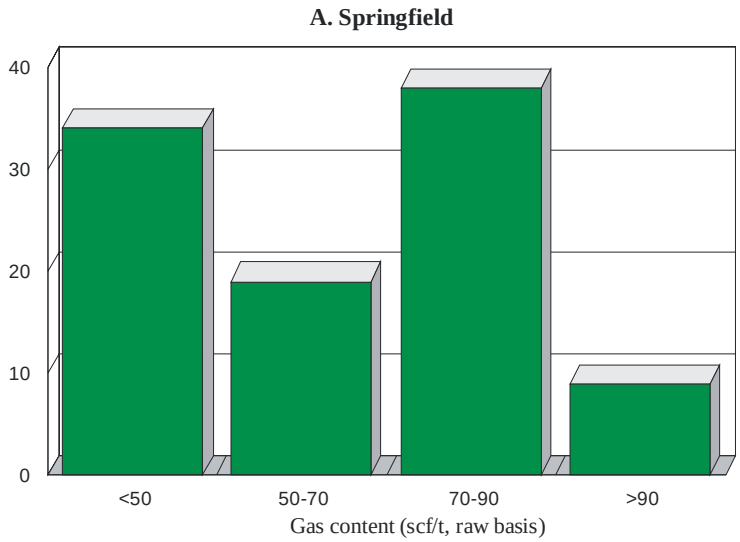
In ppm, whole coal basis

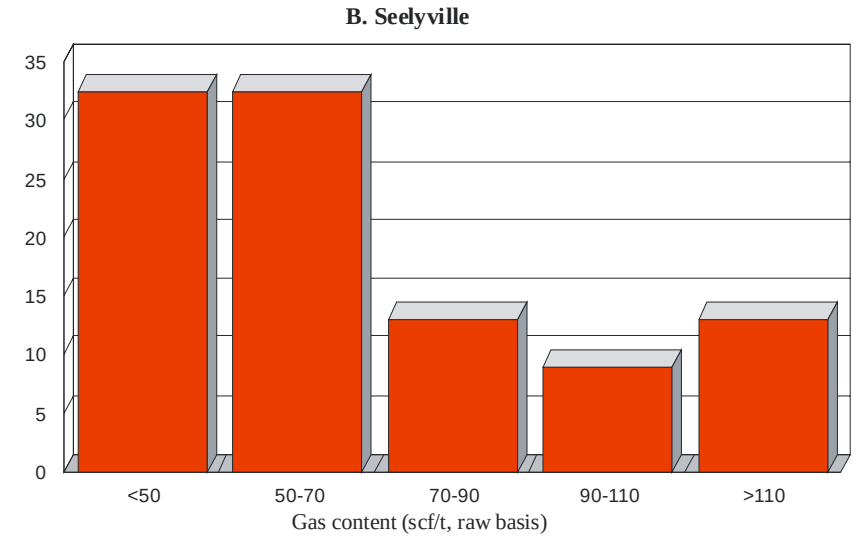




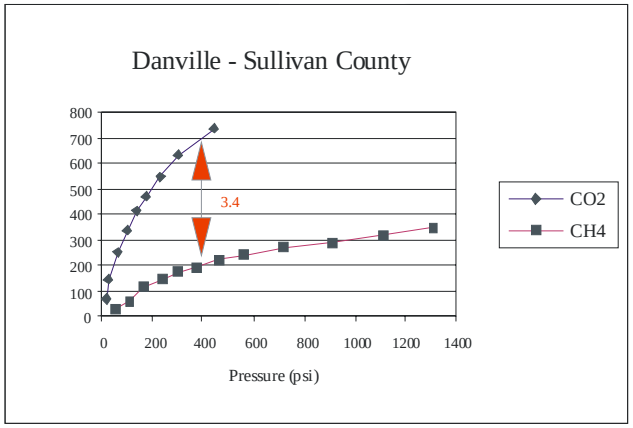
The concentrations of numerous trace elements decrease significantly as a result of washing. In this report we have comparison between raw and washed coal for trace elements as well as sulfur and ash.

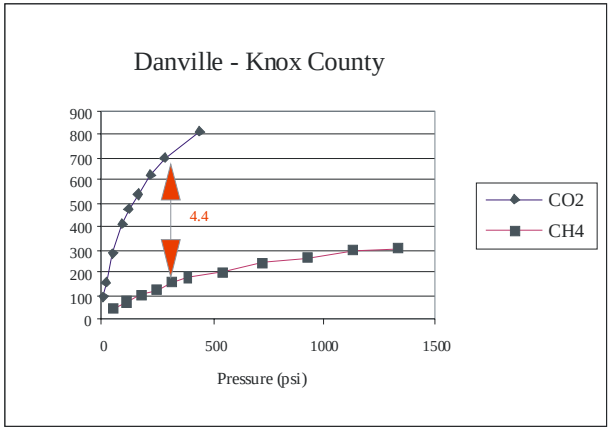
Coalbed Methane

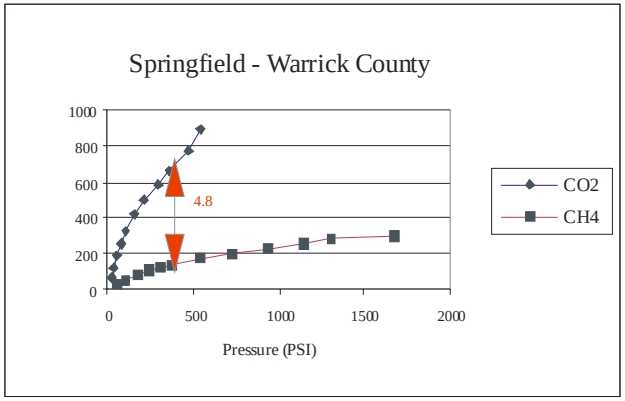


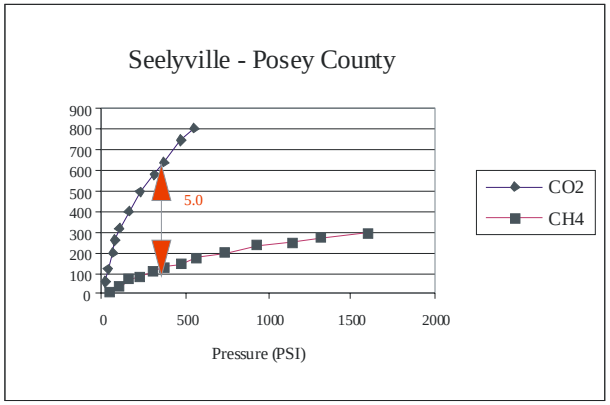


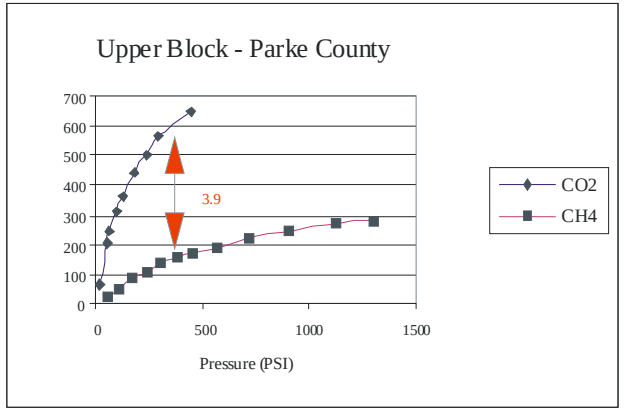
Seelyville coal may contain
1.5 to 3.0 Tcf of gas
(Drobniak et al., 2002)

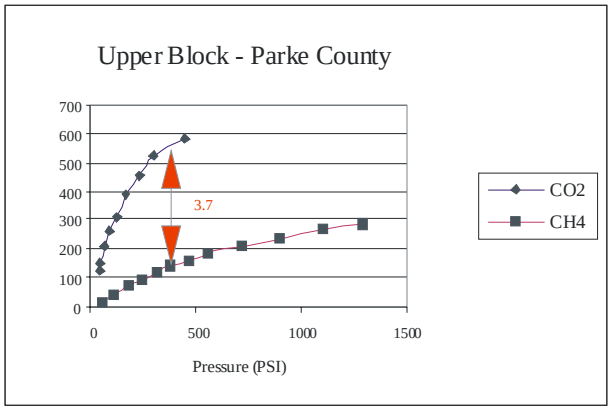












CO_2 sequestration

At pressure of 400 psi, Indiana coal beds can accommodate 560-790 Scf/ton CO_2

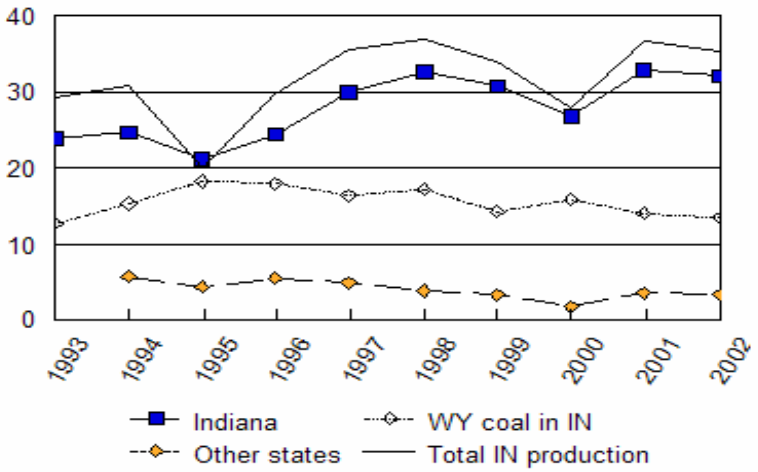
Our coal can accommodate ~4.8 times more CO_2 than CH_4

Utilization

- Electricity generation
- Steel industry
  - Coke blends
  - Pulverized coal injection
  - CBM
  - CO_2 sequestration
- Unconventional uses (gasification, liquefaction)

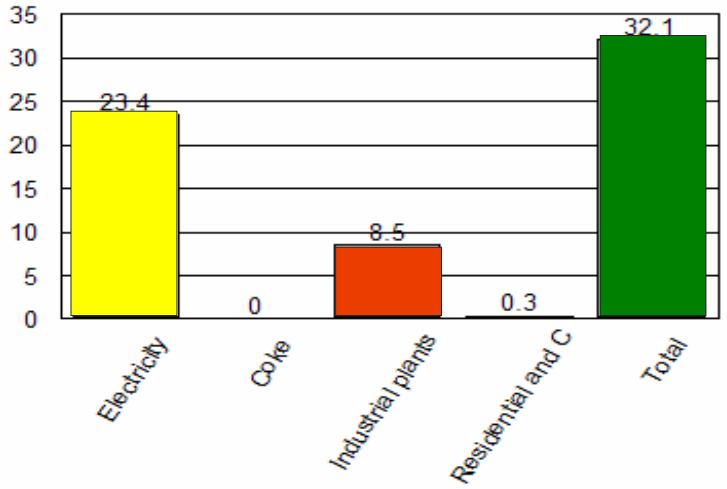
A

Distribution of Indiana coal (in million short tons)



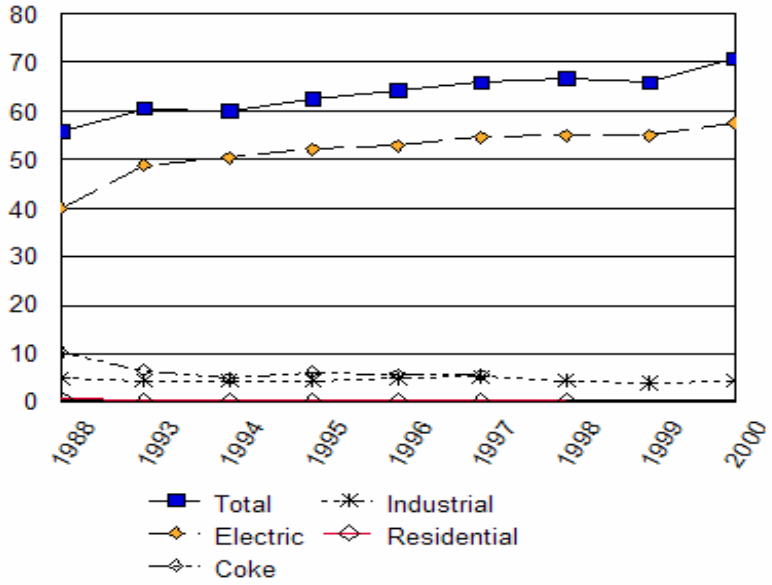
B

Consumption of Indiana coal in IN in 2002 (in million short tons)



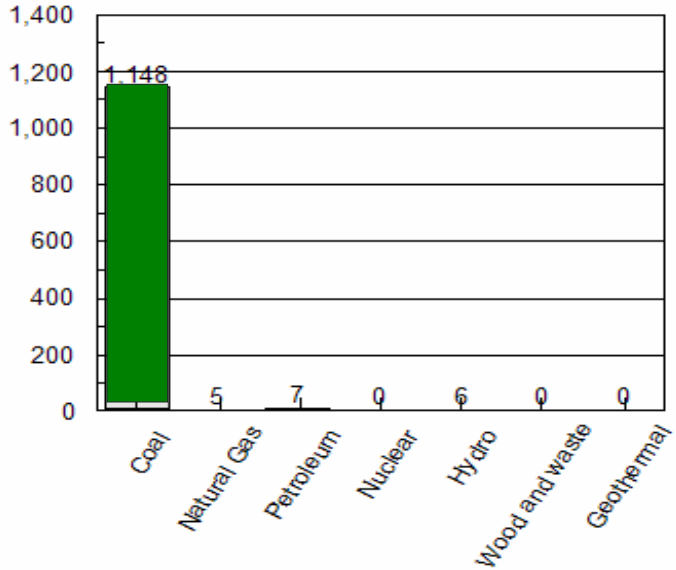
C

Coal consumption in Indiana (in million short tons)



D

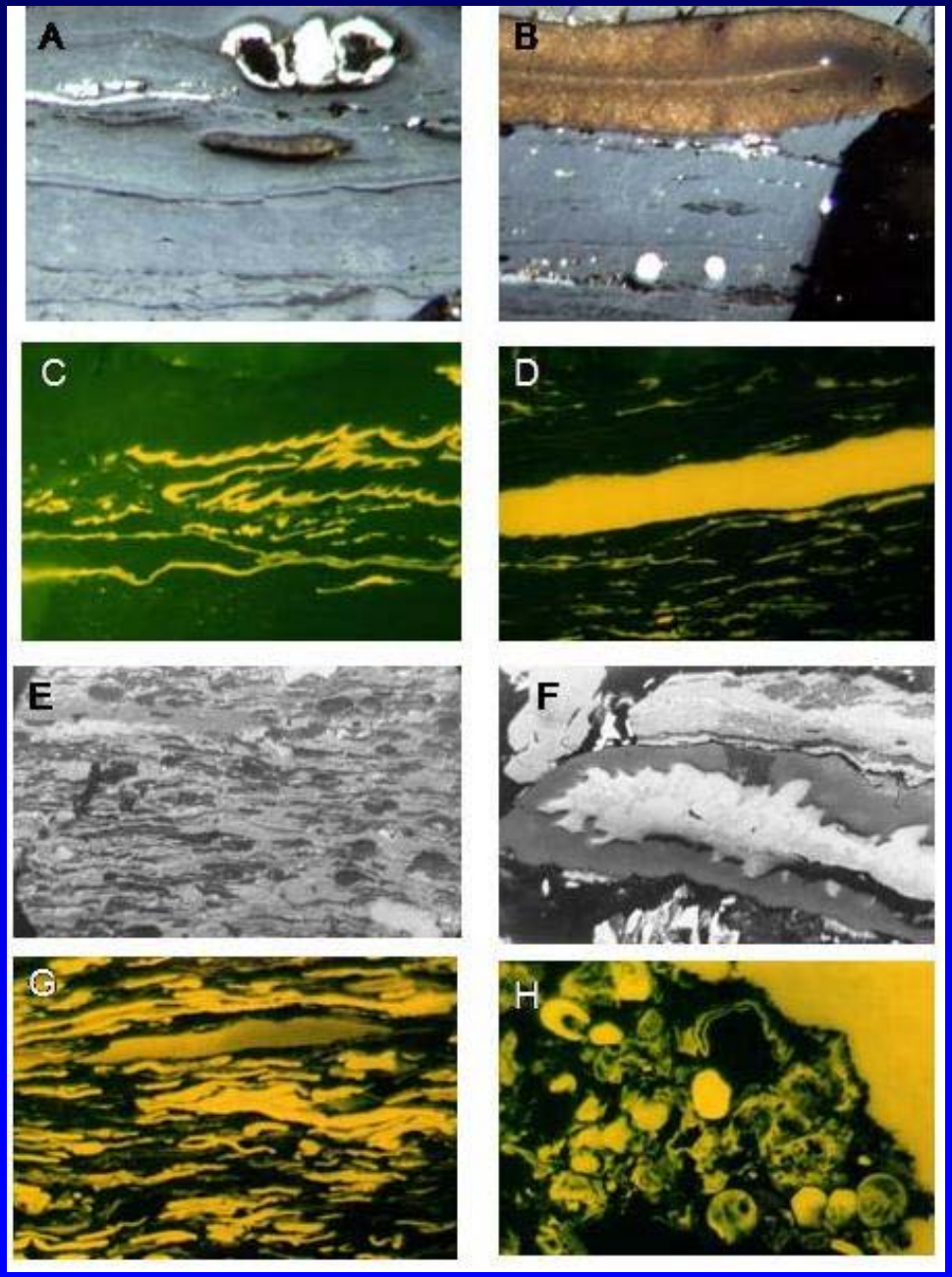
Electric utility use of energy in Indiana (in trillion Btu)



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

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

Sample	SO_2 Removal (percent)	Reagent Rate (pounds/min x104)	Utilization (S:Ca Ratio)
Bainbridge Unit 1-3	88.9	1.199	93.1
Bainbridge Unit 1-4	89.4	1.123	93.0
Bainbridge Unit 4	89.7	1.094	92.9
Bloomington Bench II	89.1	1.105	93.0
Bloomington Bench I	88.1	1.081	93.5
Campbellsburg	93.2	1.186	92.3
Cloverdale (III) Triplicate	91.3	1.128	92.6
Cloverdale Bench II	89.7	1.106	92.9
Cloverdale Bench (II) Duplicate	89.2	1.124	93.0
Cloverdale Unit Bench I	88.9	1.109	93.1
Columbus	no data		
Gosport	90.0	1.084	92.8
Mill Town Bench IV	93.7	1.132	92.3
Mill Town Bench II	89.4	1.077	93.0
Mill Town Bench I	91.1	1.109	92.6
Mill Town Unit 2ABCD	93.1	1.124	92.3
Orleans (A)	89.8	1.070	92.9
Orleans Unit X	89.8	1.075	92.9
Orleans Unit Y	89.9	1.106	92.8
Paoli Cave Stone	98.3	1.365	91.2
Pipe Creek Jr.	89.9	1.099	92.8
Putnamville Unit 1	89.7	1.096	92.9
Temple Unit Bench III	98.3	1.206	91.3

from Shaffer and Sadowski, 2000

Coal Combustion Products

Indiana Coal Combustion Products Totals in 1999

Product	Tons Produced	Tons Reused	Percent Reused
Fly ash	3,287,072	1,130,152	34%
FGD Materials	3,779,295	1,839,141	49%
Bottom Ash	1,162,642	497,420	43%
Total	8,229,009	3,466,713	42%

Source: Indiana Legislative Services Agency Office of Fiscal and Management Analysis -- Fiscal Impact Statement for SB 417.

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

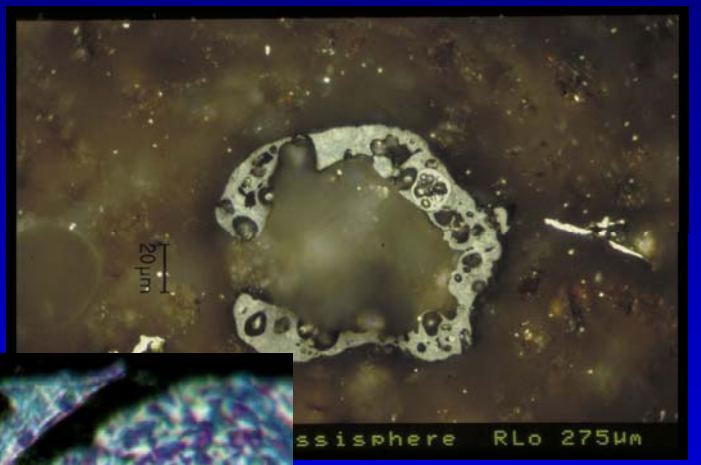
Unconventional applications

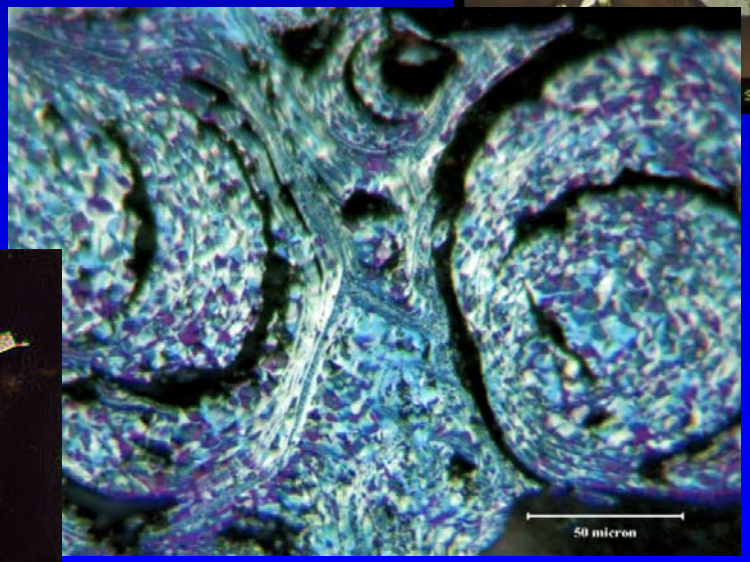
-Low-grade ore

-Carbon whiskers

-Composites

-Fullerenes





SUMMARY: Availability

- Coal availability studies shows:
  - 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.

SUMMARY: Basinwide Characteristics

- 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.

SUMMARY: Heating Value

- 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.

SUMMARY: Sulfur Content

- 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.

SUMMARY: Trace Elements

- 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 sulfur but numerous trace elements as well.

SUMMARY: Alternative Uses

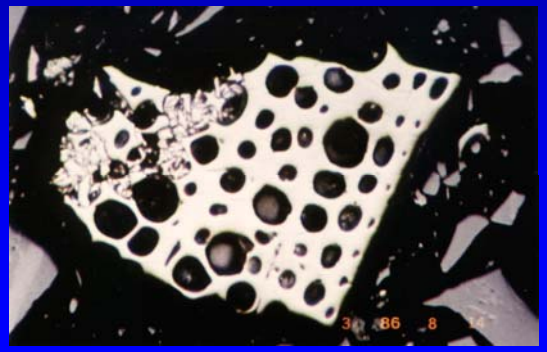
- There is an increasing interest in CBM and CO_2 sequestration potential of Indiana coals
- Previous and current projects provide more data and indicate some potential areas
- More research needed

ACKNOWLEDGMENTS

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

To industrial cooperators in Indiana for assistance and access to coal mines, especially to Black Beauty Coal Company for financial support and coal quality analyses.

To our colleagues: Phil Ames, Kathy Shaffer, Paul Irwin, Sally Letsinger, Rachel Walker, and Amy Foster



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 Drobniak, John Rupp, and Nelson Shaffer

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

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