ASSESSMENT OF THE QUALITY OF INDIANA COALS FOR INTEGRATED GASIFICATION COMBINED CYCLE (IGCC) PERFORMANCE

FINAL REPORT TO THE CENTER FOR COAL TECHNOLOGY RESEARCH
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By

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Project duration – July 1, 2006 –December 31, 2008

The scoping study preceding this project:

1) Identified properties of Indiana coals that are of major importance for IGCC performance (moisture, heating value, mineral matter properties, char reactivity, sulfur, chlorine, etc);

2) Analyzed the availability of data on coal properties needed to assess IGCC performance;

3) Identified the areas in which more data are needed to adequately assess coal performance for IGCC; and

4) Provided a preliminary assessment of Indiana coals for IGCC. (Mastalerz et al, 2005; 2008)

Status of data availability before the project started

	Danville				Hymera				Springfield				Lower Block			
	Min	Max	**Ave**	n	Min	Max	**Ave**	n	Min	Max	**Ave**	n	Min	Max	**Ave**	n
Moisture, ar	1.9	28.2	**11.2**	252	0.8	23.5	**10.26**	135	0.5	34.7	**9.91**	651	0.7	27.1	**13.57**	156
Fixed carbon, dry	32	58.24	**48.43**	131	11.7	54	**46.75**	110	29	70.7	**48.03**	306	35.5	59.5	**50.52**	53
Volatile matter, dry	26.9	46.1	**39.15**	131	15.6	46.8	**38.54**	110	19.9	62	**40.89**	306	33.5	47.5	**38.75**	53
Ash (dry)	4.9	41.1	**13**	254	6.8	72.7	**14.5**	136	4.89	54.21	**12.12**	651	4.1	31	**8.82**	158
Btu (dry)	7651	17314	**13051**	252	2520	13734	**12043**	135	8362	20647	**13229**	651	9677	14726	**13333**	156
AFTred, init Deg F	2095	2540	**2274**	12									1990	2800	**2399**	14
AFTred, soft Deg F	2155	2610	**2376**	12			no data				no data		2040	2800	**2445**	14
AFTred, hem Deg F	2210	2665	**2435**	12									2080	2800	**2491**	14
AFTred, final Deg F	2250	2753	**2502**	12									2170	2800	**2551**	14
Slag viscosity Deg F	2419	2900	**2672**	12							**2460**	1	2155	2900	**2626**	14
Cl (%)	0.01	0.1	**0.03**	24	0.02	0.07	**0.04**	24	0.03	0.24	**0.15**	28	0.01	0.05	**0.02**	28

One of the main recommendations of that study was the necessity to generate more data on mineral matter characteristics.

Objectives of the project

Following that earlier evaluation and recommendations, the main objectives of this study were to:

1) Perform new analyses and integrate them into a coal quality database

2) Map various coal quality parameters;

3) Using several IGCC-important parameters, grade the coals with regard to their suitability for IGCC; and

4) Combine coal quality information with the availability of the coal for surface and underground mining.

Project components

- **New data collection**
  - Mineral matter (ash) composition
  - Ash melting point and slag viscosity
  - Chlorine content of coal
  - Other (Hg, petrographic composition)

- **Data integration and evaluation of the coals for IGCC**

ILLINOIS				INDIANA				W. KENTUCKY				
		Coal Member or Bed	✦			Coal Member	✦			Coal Member or Bed	✦	
McLeansboro Group	Mattoon Fm.			McLeansboro Group	Mattoon Fm.	Cohn		McLeansboro Group	Mattoon Fm.			Virg.
	Bond Fm.				Bond Fm.	Fairbanks			Bond Fm.			Missourian
	Patoka Fm.				Patoka Fm.	Parker Raben Branch Hazelton Bridge Ditney			Patoka Fm.			
	Shelburn Fm.				Shelburn Fm.	Pirtle			Shelburn Fm.			
		Danville	No.7	Carbondale Group	Dugger Fm.	Danville ✦	VII			Baker	No.13	Desmoinesian
		Jamestown				Hymera ✦	VI			Paradise	No.12	
No group name	Carbondale Fm.	Herrin	No.6			Herrin Bucktown	Vb	No group name	Carbondale Fm.	Herrin	No.11	
		Springfield	No.5		Petersburg Fm.	Springfield ✦	V			Springfield	No.9	
		Houchin Creek				Houchin Creek				Houchin Creek		
		Survant			Linton Fm.	Survant	IV			Survant	No.8	
		Colchester	No.2			Colchester	IIIa			Colchester		
		Dekoven								Dekoven	No.7	
		Davis				Seelyville ✦	III			Davis	No.6	
Raccoon Creek Group	Tradewater Fm.			Raccoon Creek Group	Staunton Fm.	Unnamed Staunton Fm. coals		Raccoon Creek Group	Tradewater Fm.	(Mining City)	No.4	
										Empire		
					Brazil Fm.	Minshall / Buffaloville				Lead Creek/Dunbar		Atokan
		Willis				Upper Block				Elm Lick		
						Lower Block						
					Mansfield Fm.	Shady Lane				(Ice House)	No.3	
						Mariah Hill				Foster		
						Blue Creek				Amos		
		Reynoldsburg				Pinnick				Bell		
	Caseyville Fm.	Gentry				St. Meinrad			Caseyville	Battery Rock		Morrowan
						French Lick				Nolin		

✦ Informal name

✦ **Coal beds analyzed**

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

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

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

	DANVILLE				HYMERA				SPRINGFIELD				SEELYVILLE				LOWER BLOCK			
	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n	Min.	Max.	Ave	n
M [weight %, ar]	1.9	28.2	11.3	253	0.8	23.5	10.3	134	0.5	34.7	9.9	654	0.8	29.2	9.9	81	0.7	27.1	13.8	139
A [weight %, dry]	4.9	41.1	13.0	255	6.8	72.7	14.5	135	4.9	54.2	12.2	663	6.7	35.6	14.9	88	4.1	31.0	9.0	148
S [weight %, dry]	0.33	7.62	2.65	163	1.20	5.34	3.10	36	0.30	12.19	3.27	443	2.50	9.84	5.02	28	0.55	7.0	1.36	111
Heat. Value [Btu/lb ,dry]	7651	17314	13050	253	2520	13734	12042	134	8362	20648	13214	663	8494	13810	12149	83	9677	14702	13267	147
FC [weight %, dry]	32.0	58.2	48.4	131	11.7	54.0	46.7	110	29.0	70.7	48.0	308	19.0	61.1	44.4	73	35.5	59.5	52.6	93
VM [weight %, dry]	26.9	46.1	39.1	131	15.6	45.8	38.5	110	19.9	62.0	40.9	308	31.2	65.4	41.4	73	33.5	47.5	38.5	94
Slag viscosity temp. [^oF]	2156	2900	2559	30	2150	2900	2421	15	2150	2720	2345	41	2150	2630	2273	9	2150	2900	2649	38
Cl [weight %]	0.01	0.10	0.03	25	0.02	0.07	0.04	23	0.01	0.24	0.15	31	0.08	0.17	0.11	3	0.01	0.06	0.02	42
SiO_2 [weight %]	31.0	60.0	48.3	34	17.00	55.00	39.13	20	21.0	53.0	38.6	48	19.0	45.0	31.0	14	0.4	61.7	47.2	39
Al_2O_3 [weight %]	14.0	26.0	20.9	34	9.10	28.40	18.00	20	9.2	28.0	18.2	48	8.5	25.0	17.2	14	16.4	34.0	25.3	39
Fe_2O_3 [weight %]	3.5	37.0	16.3	34	4.60	41.00	22.95	20	6.5	49.0	23.3	48	9.2	55.0	35.8	14	3.3	47.2	15.1	39
CaO [weight %]	0.5	10.0	2.9	34	0.43	27.00	4.80	20	0.3	16.0	4.3	48	0.5	8.2	3.1	14	0.5	7.1	1.9	39
MgO [weight %]	0.6	1.7	1.2	34	0.37	1.50	0.85	20	0.3	1.4	0.8	48	0.4	0.9	0.5	14	0.3	1.0	0.6	39
SiO_2/ Al_2O_3	1.75	2.73	2.31	34	1.60	2.93	2.22	20	1.46	2.59	2.16	48	1.44	2.42	1.85	14	0.02	2.52	1.89	39
Fe_2O_3+ CaO [weight %]	4.01	38.50	19.26	34	5.12	42.00	27.75	20	7.60	53.80	27.42	48	10.4	58.0	38.84	14	4.80	47.66	16.51	39
Silica ratio*	0.44	0.92	0.71	34	0.28	0.90	0.58	20	0.30	0.86	0.58	48	0.25	0.80	0.45	14	0.02	0.92	0.73	39
AFTR INIT. [^oF]	2095	2540	2275	12	-	-	-	-	2095	2103	2099	2	-	-	2185	1	1970	2800	2430	28
AFTR SOFT. [^oF]	2155	2610	2375	12	-	-	-	-	2131	2151	2141	2	-	-	2275	1	2040	2800	2477	28
AFTR HEM. [^oF]	2210	2665	2436	12	-	-	-	-	2181	2187	2184	2	-	-	2353	1	2080	2800	2525	28
AFTR FINAL .[^oF]	2250	2735	2502	12	-	-	-	-	2208	2232	2220	2	-	-	2425	1	2170	2800	2558	26
AFTO INIT. [^oF]	2340	2705	2535	12	-	-	-	-	-	-	2528	1	-	-	2668	1	2425	2740	2578	9
AFTO SOFT. [^oF/	2370	2730	2570	12	-	-	-	-	-	-	2576	1	-	-	2701	1	2470	2765	2589	7
AFTO HEM. [^oF]	2395	2765	2594	12	-	-	-	-	-	-	2596	1	-	-	2716	1	2495	2780	2608	7
AFTO FINAL. [^oF]	2415	2795	2626	12	-	-	-	-	-	-	2611	1	-	-	2728	1	2540	2800	2638	7

*$(100SiO_2/[SiO_2+Fe_2O_3+CaO+MgO])$

Evaluation of Indiana coals for IGCC

Evaluation of the coals has been divided into three groups:

1) **Evaluation based on basic coal quality parameters such as heating value, moisture content, ash yield, and sulfur content;**

2) **Evaluation of the ability of coal and coal char to gasify (reactivity); and**

3) **Evaluation of slagging based on mineral matter characteristics.**

Major existing coal-based IGCC plants

Facility	Company	Location	Feedstock	Capacity	Gasifier technology
Willem Alexander Centrale	Nuon	Buggenum The Netherlands	Coal/biomass	253 MW	Shell
Wabash River	SG Solutions	Terre Haute, IN	Coal/pet coke	260 MW	ConocoPhillips
Polk Power Station	Tampa Electric	Mulberry, FL	Coal/pet coke	250 MW	GE Energy
Puertollano	ELCOGAS	Puertollano, Spain	Coal/pet coke	320 MW	Prenflo

Coals best suited for IGCC (slagging gasifiers)

- Low ash content – below 12%

- Low ash fusion temperature (reducing) of <1400°C (2552°F) – guarantees smooth slag flow

- Slag viscosity of <25Pa.s (250 poise) at 1400°C (2552°F) -guarantees smooth slag flow

- A low temperature of critical viscosity <1400°C (2552°F)

- Low or no limestone flux requirements

Coals best suited for IGCC (slagging gasifiers)

- SiO_2/Al_2O_3 ratio of about 2 – minimizes flux requirements and avoids slag crystallization

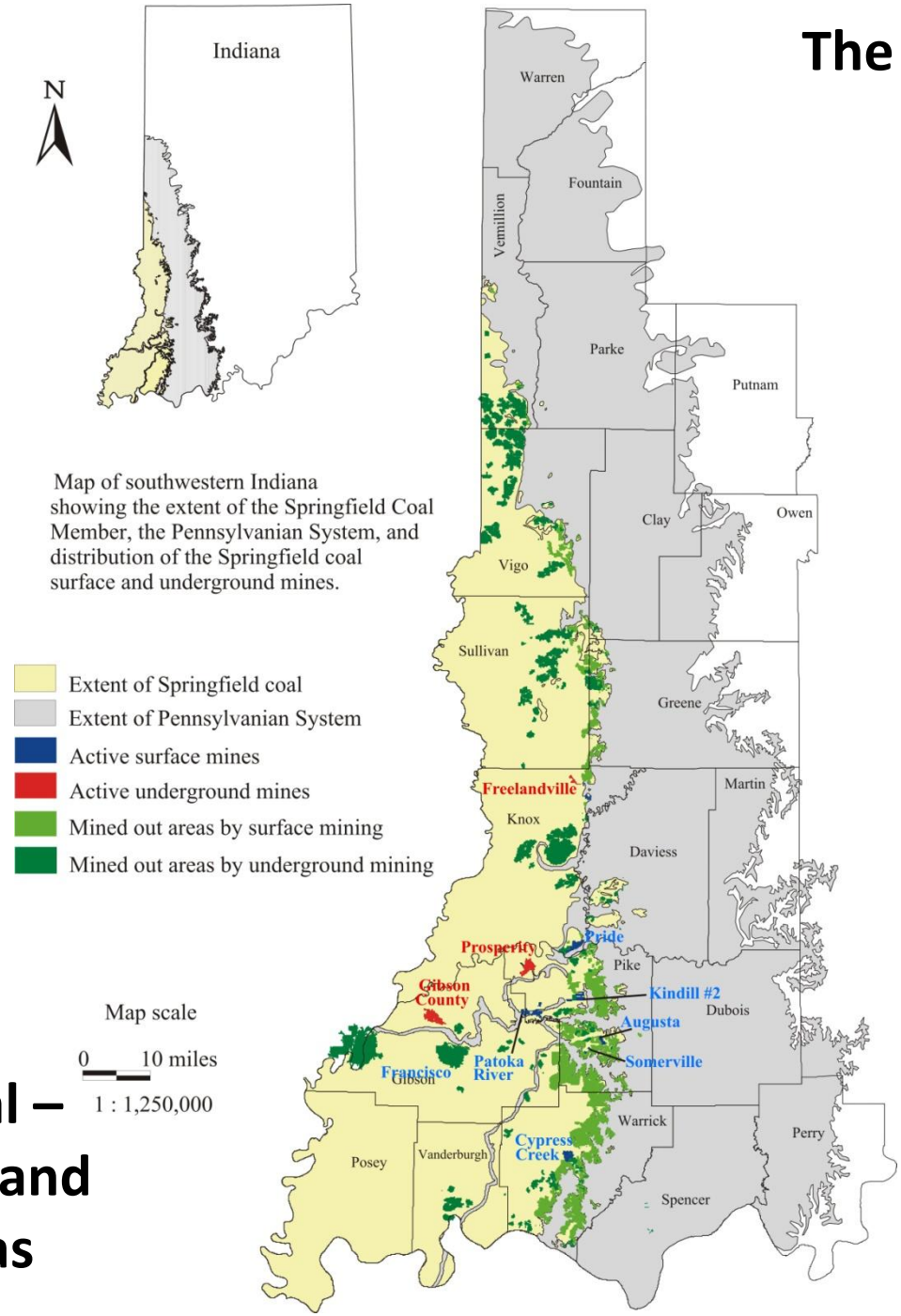
- Fe_2O_3 +CaO content in ash > 15% - gives a chance for zero flux requirement

- A silica ratio ($100SiO_2/[SiO_2+Fe_2O_3+CaO+MgO]$) of <70 – also minimizes flux requirements

Suitability of selected parameters suggested for Indiana coals.

Parameter	Optimal	Remarks
Ash content (%)	less than 12.5	12.5% ash considered less suitable
SiO_2/Al_2O_3	1.9-2.2	<1.9 and >2.2 considered less suitable
Silica ratio	less than 0.70	>0.70 considered less suitable
Fe_2O_3 +CaO (% in ash)	15-35	<15 and >35 considered less suitable
Slag viscosity T (^oF)	less than 2550	>2550 considered less suitable

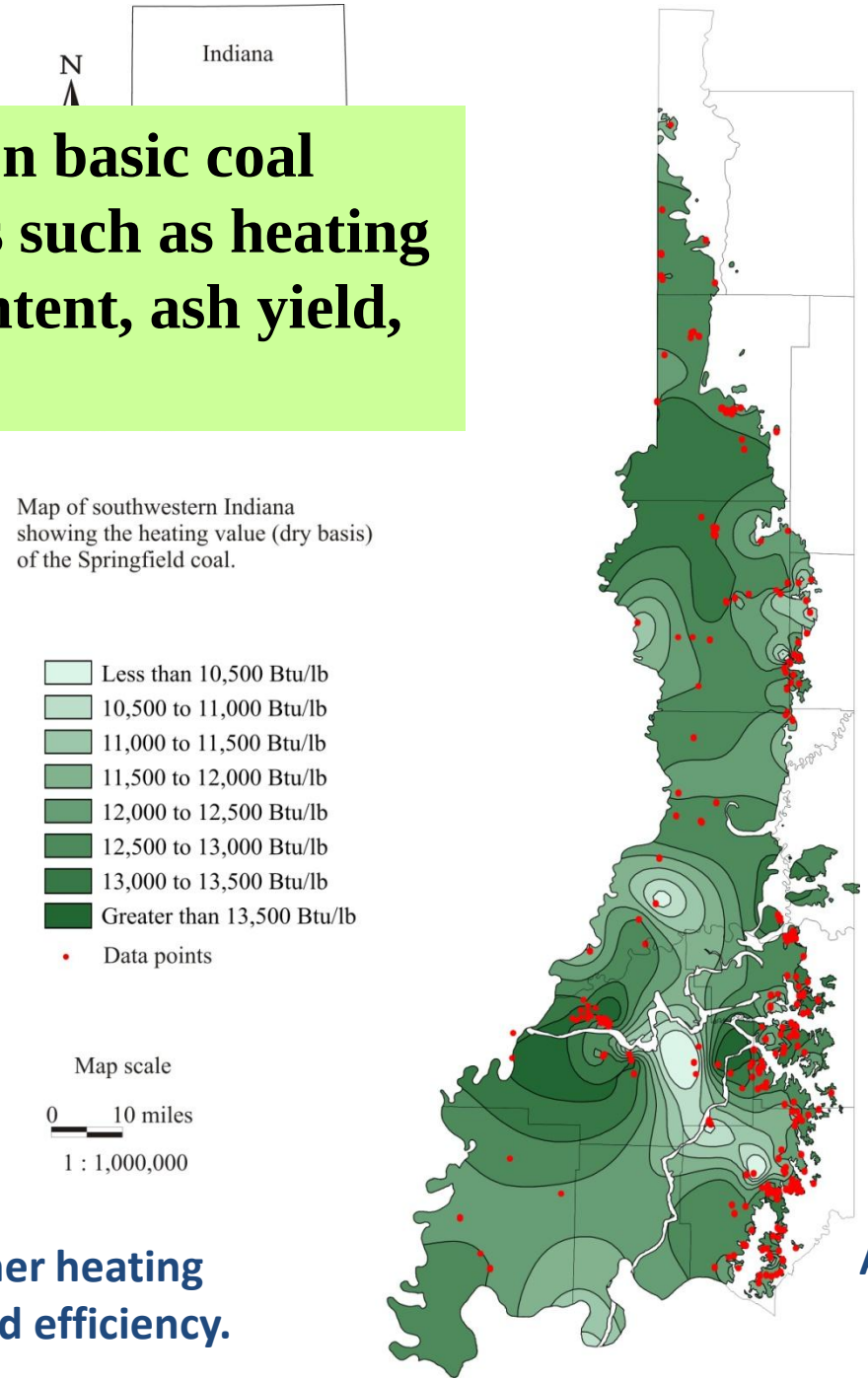
The Springfield Coal



Springfield Coal – Extent, mines, and mined out areas

Springfield Coal -Heating value

Evaluation based on basic coal quality parameters such as heating value, moisture content, ash yield, and sulfur content



Map of southwestern Indiana showing the heating value (dry basis) of the Springfield coal.

Heating value influences generation capacity – higher heating value – higher capacity and efficiency.

A range of heating values used

Springfield Coal – Moisture content

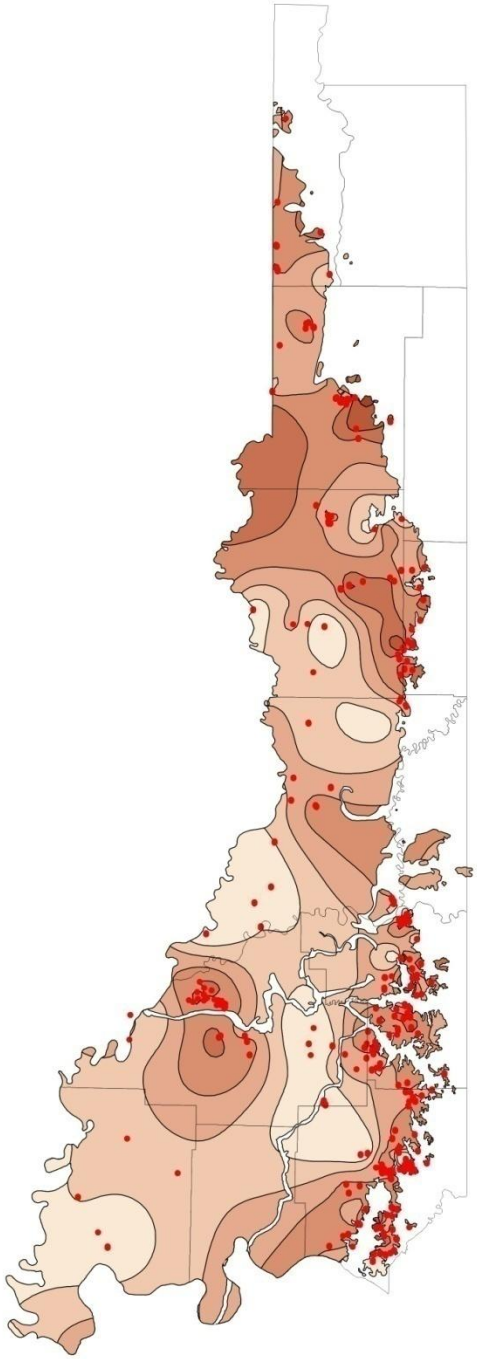
Map of southwestern Indiana showing the moisture content of the Springfield coal.

- 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%
- Data points

Map scale

0 10 miles

1 : 1,000,000

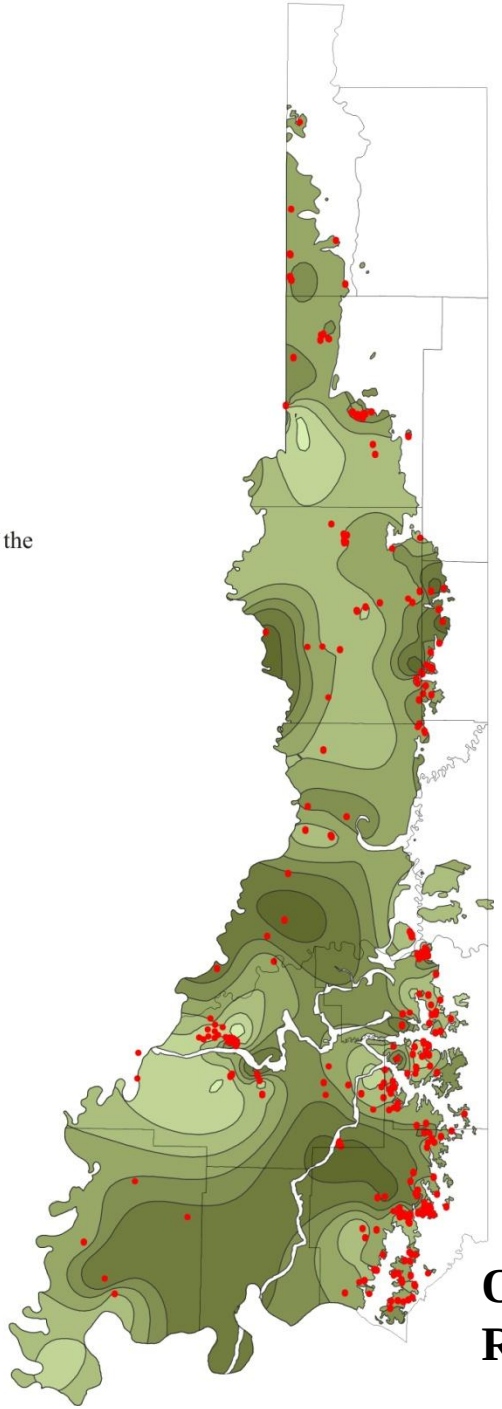


Moisture content influences gasifier efficiency – higher moisture – lower efficiency.

A range of moisture content used

Springfield Coal – Ash content

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



Ash content influences gasifier efficiency – higher ash – lower efficiency. It also influences flux addition rates.

Optimal - less than 12.5%
Required - less than 25%

Springfield Coal – Sulfur content

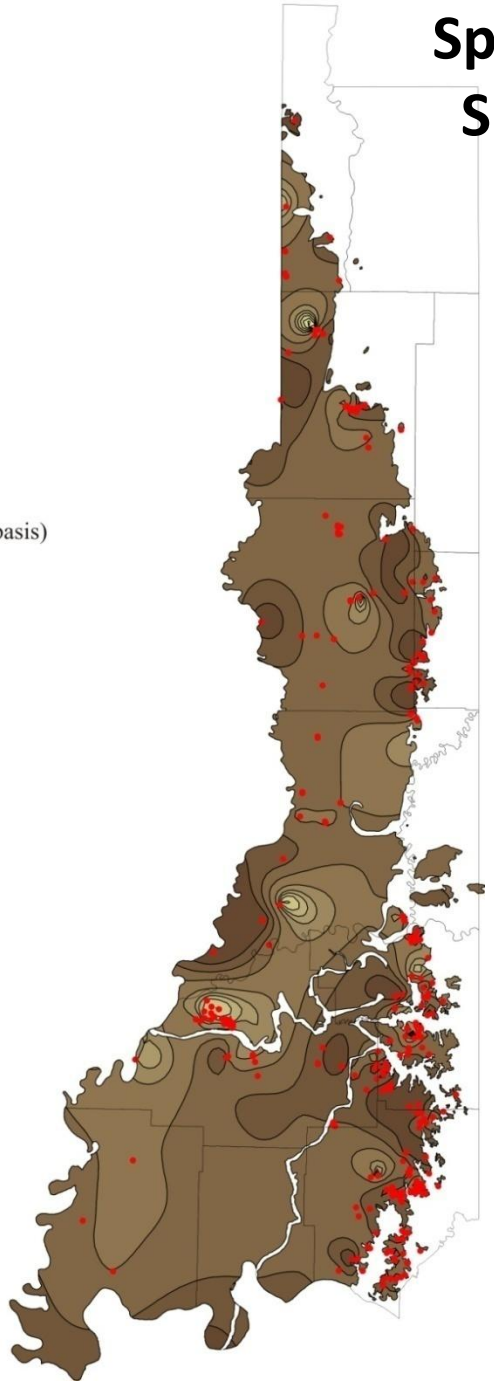
Map of southwestern Indiana showing the total sulfur content (dry basis) of the Springfield coal.

- Less than 0.5%
- 0.50 to 0.75%
- 0.75 to 1.0%
- 1.0 to 1.25%
- 1.25 to 1.5%
- 1.5 to 2.0%
- 2.0 to 3.0%
- 3.0 to 4.0%
- 4.0 to 5.0%
- Greater than 5%
- Data points

Map scale

0 10 miles

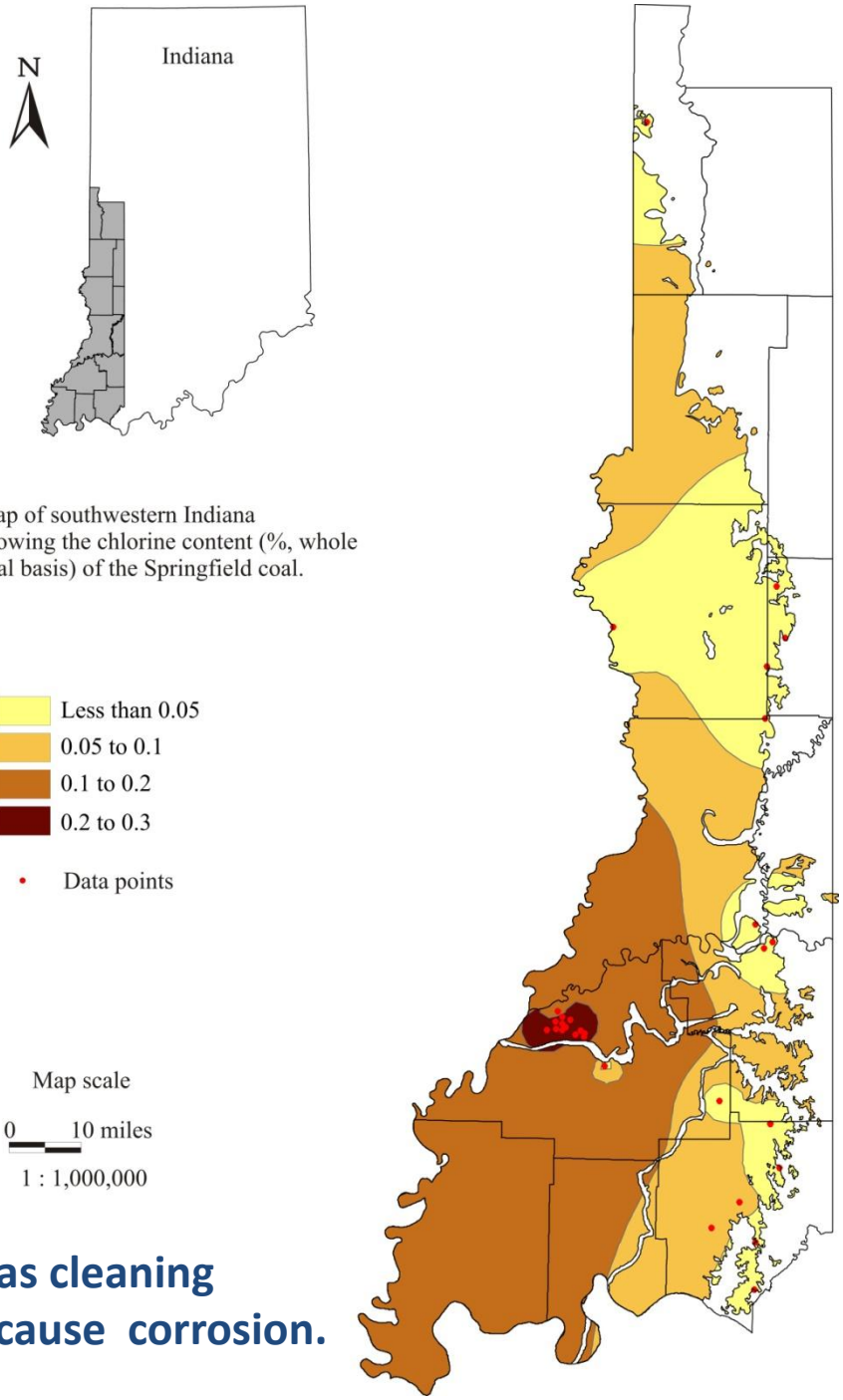
1 : 1,000,000



Preferred – less than 1.5%

Sulfur content can cause corrosion of heat exchanger surfaces and also influences operating costs (higher sulfur – higher costs).

Springfield Coal – Chlorine content



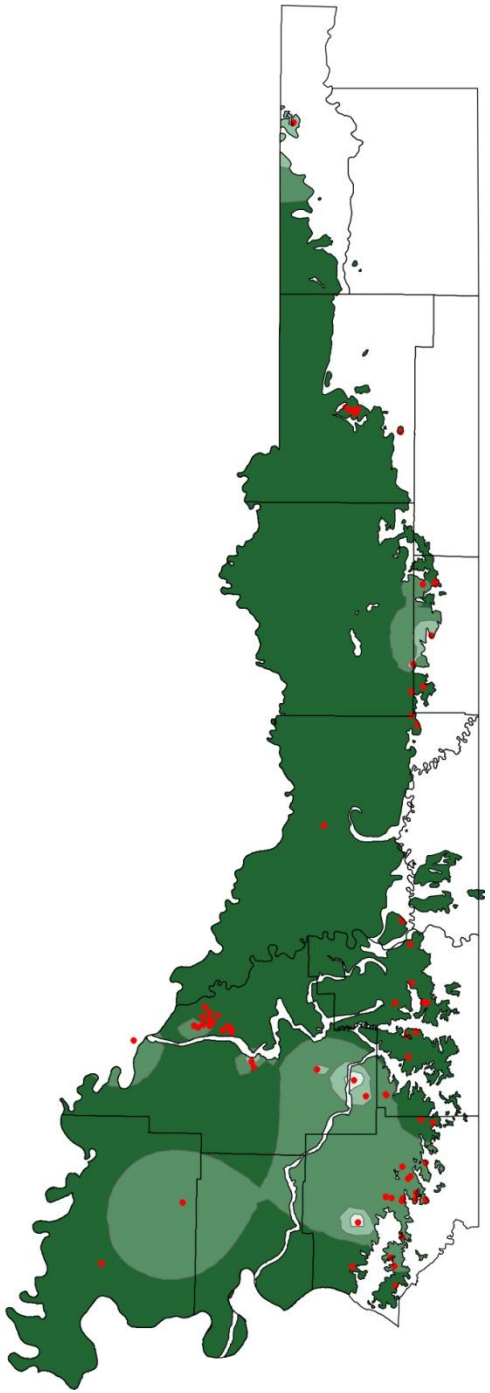
Map of southwestern Indiana showing the chlorine content (%, whole coal basis) of the Springfield coal.

Forming HCl can poison gas cleaning system catalysts and can cause corrosion.

Required - <0.4%
Preferred - <0.2%

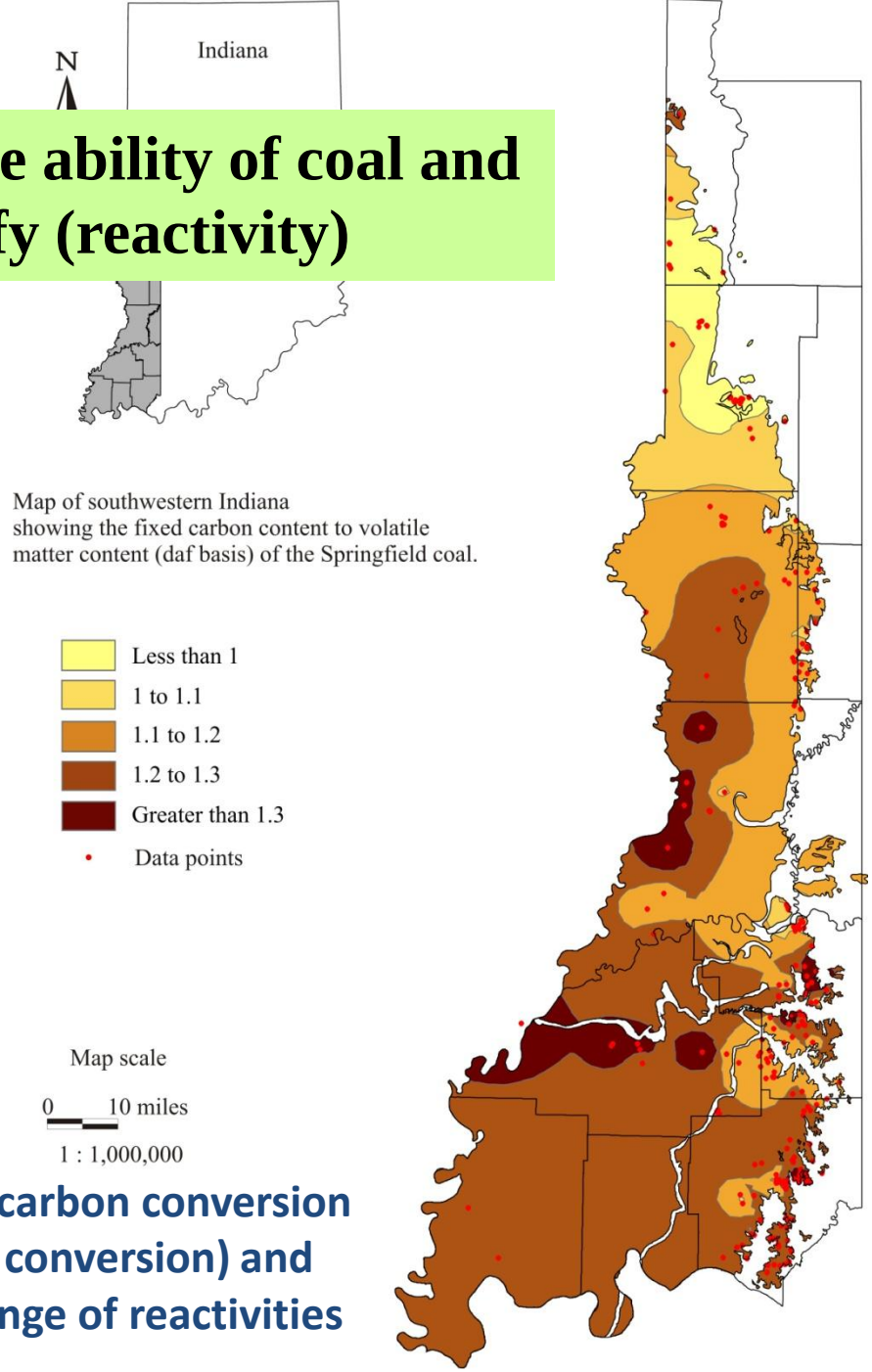
Springfield Coal – Mercury content

Map of southwestern Indiana showing the mercury content (ppm, whole coal basis) of the Springfield coal.



Evaluation of the ability of coal and coal char to gasify (reactivity)

Springfield Coal – Fuel ratio



Higher ratio – Lower reactivity

Char reactivity influences carbon conversion (higher reactivity – higher conversion) and oxygen consumption. A range of reactivities can be used.

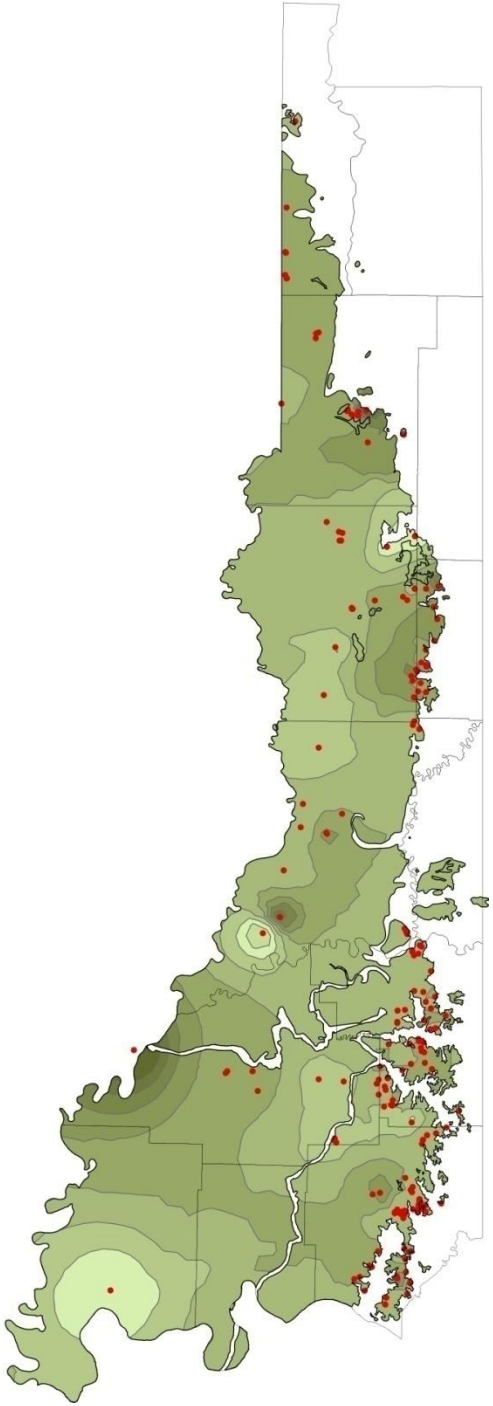
Map of southwestern Indiana showing the O/C value (daf basis) of the Springfield coal.

- Less than 0.15
- 0.15 to 0.20
- 0.20 to 0.25
- 0.25 to 0.30
- 0.30 to 0.35
- 0.35 to 0.40
- 0.40 to 0.45
- 0.45 to 0.50
- Greater than 0.50
- Data points

Map scale

0 10 miles

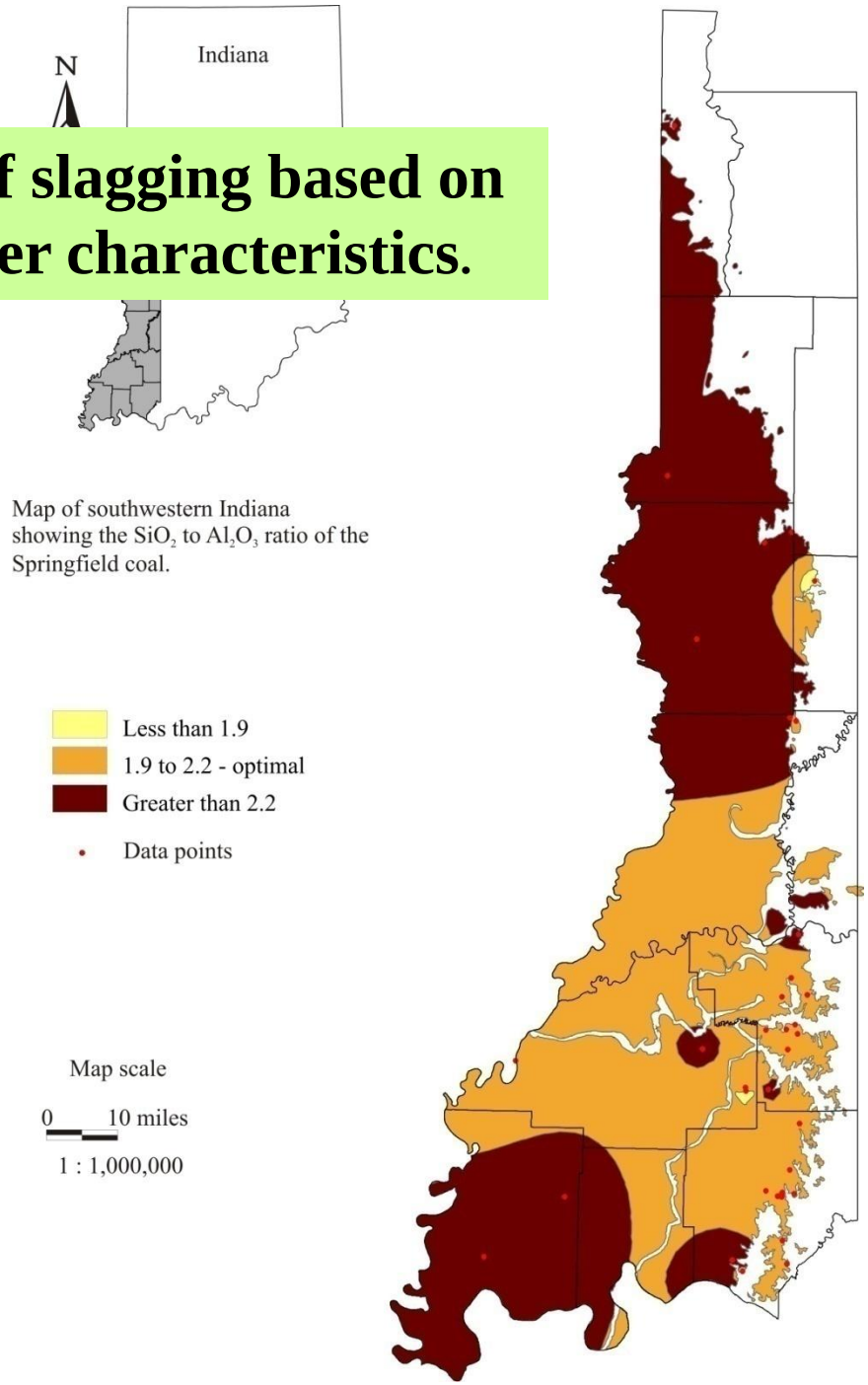
1 : 1,000,000



Higher ratio – Higher reactivity

Springfield Coal – O/C ratio

Evaluation of slagging based on mineral matter characteristics.



Map of southwestern Indiana showing the SiO_2 to Al_2O_3 ratio of the Springfield coal.

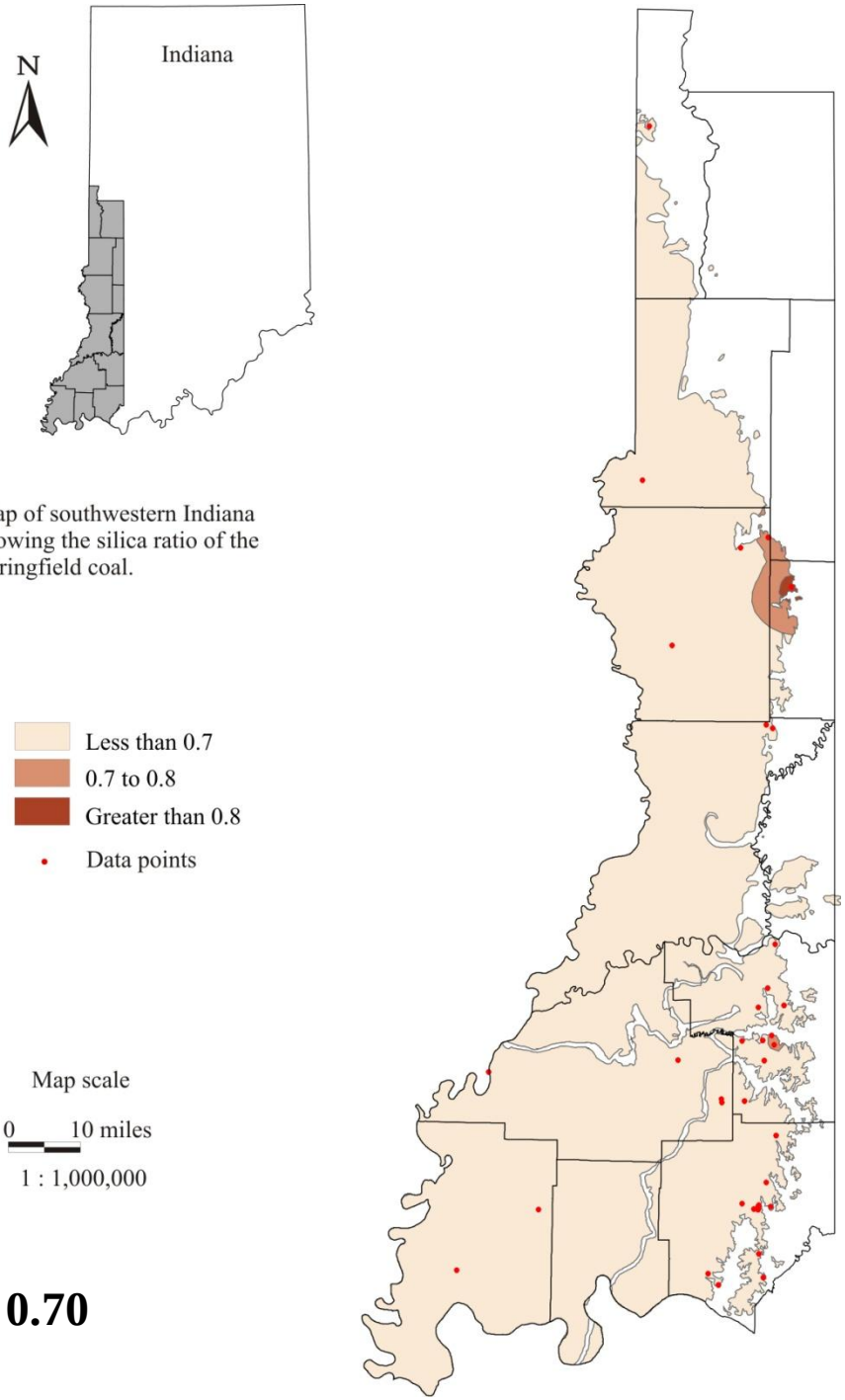
Springfield Coal – SiO_2/Al_2O_3

– minimizes flux requirements and avoids slag crystallization

Optimal : 1.9-2.2

Springfield Coal – silica ratio

minimizes flux requirements

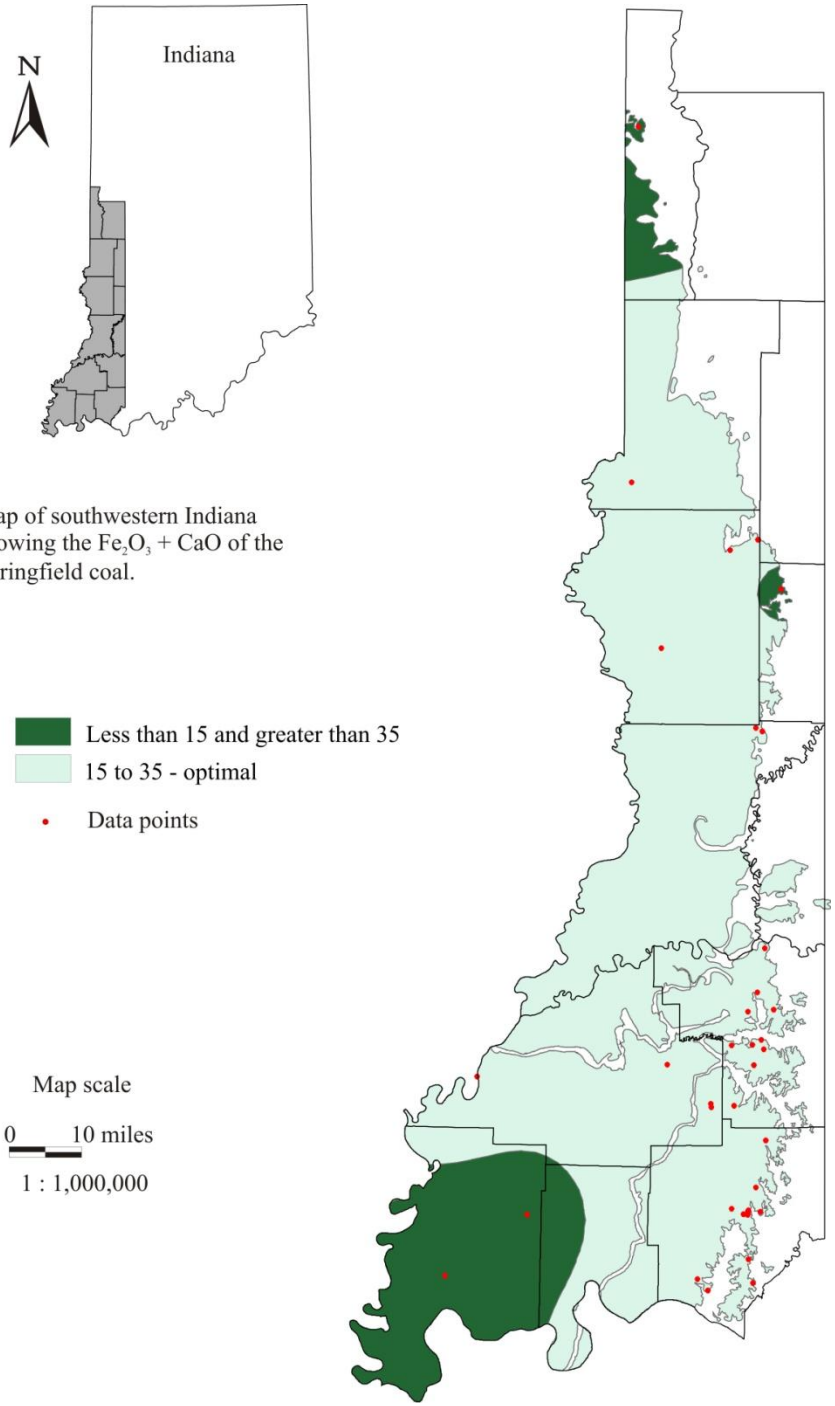


Map of southwestern Indiana showing the silica ratio of the Springfield coal.

Optimal : less than 0.70

$(100SiO_2/[SiO_2+Fe_2O_3+CaO+MgO])$

Springfield Coal – Fe_2O_3+CaO

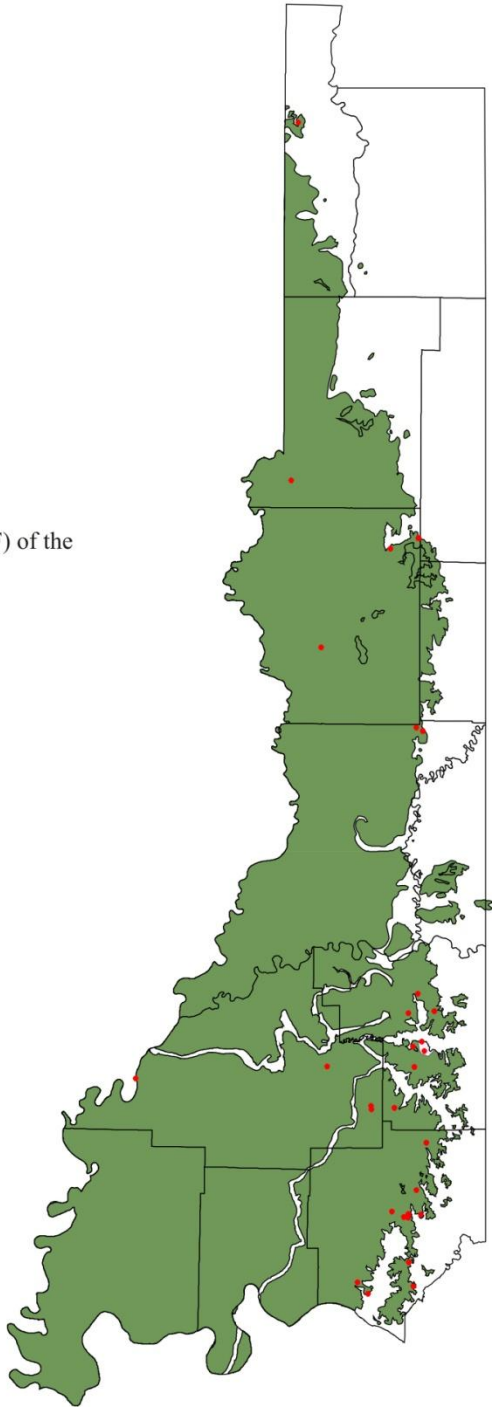


Map of southwestern Indiana showing the Fe_2O_3 + CaO of the Springfield coal.

Optimal: 15-35

Springfield Coal – critical T of slag viscosity

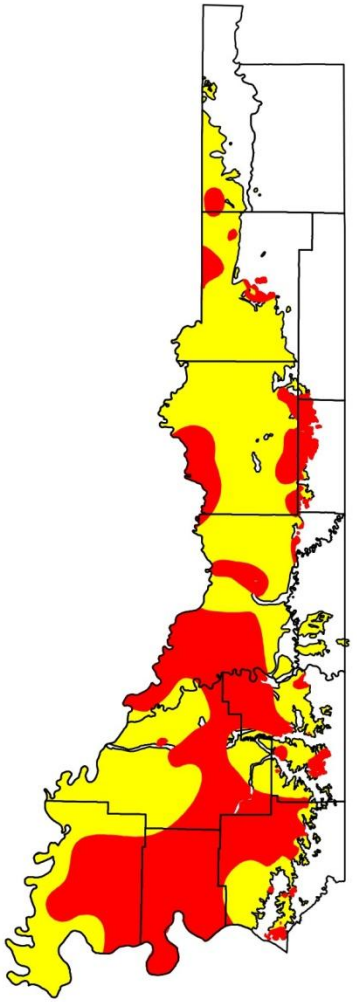
Map of southwestern Indiana showing the critical temperature (in °F) of the slag viscosity of the Springfield coal.

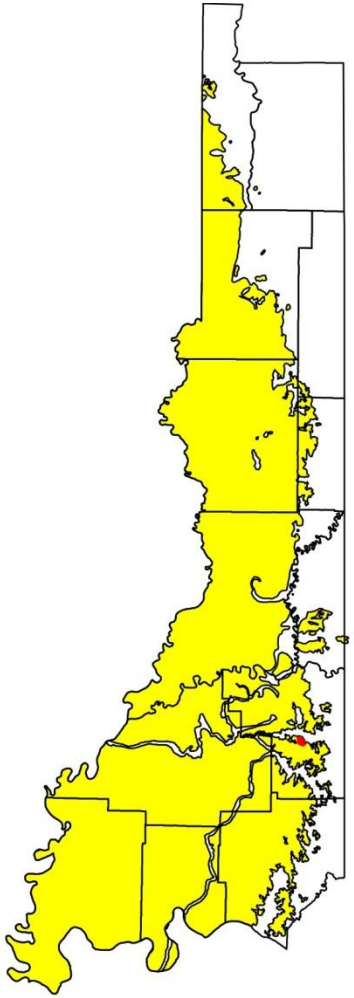


Optimal: less than 2550

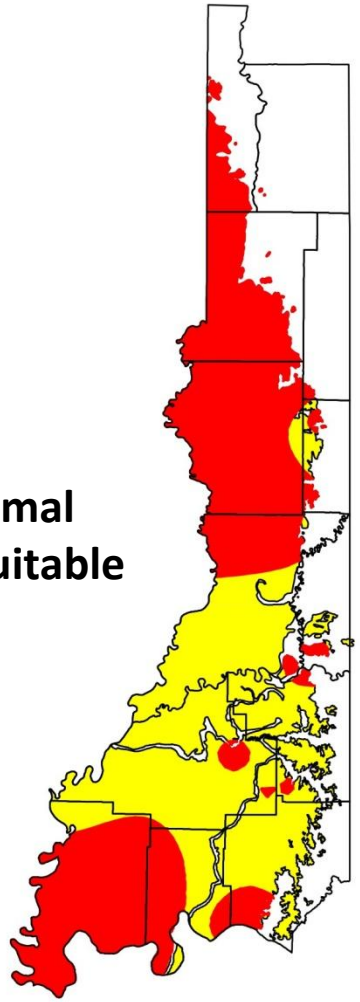
Parameter	Optimal	Remarks
Ash content (%)	less than 12.5	12.5% ash considered less suitable
SiO_2/Al_2O_3	1.9-2.2	<1.9 and >2.2 considered less suitable
Silica ratio	less than 0.70	>0.70 considered less suitable
Fe_2O_3 +CaO (% in ash)	15-35	<15 and >35 considered less suitable
Slag viscosity T (ºF)	less than 2550	>2550 considered less suitable

Maps showing suitability of the Springfield Coal for IGCC





OPT – optimal
LS – less suitable



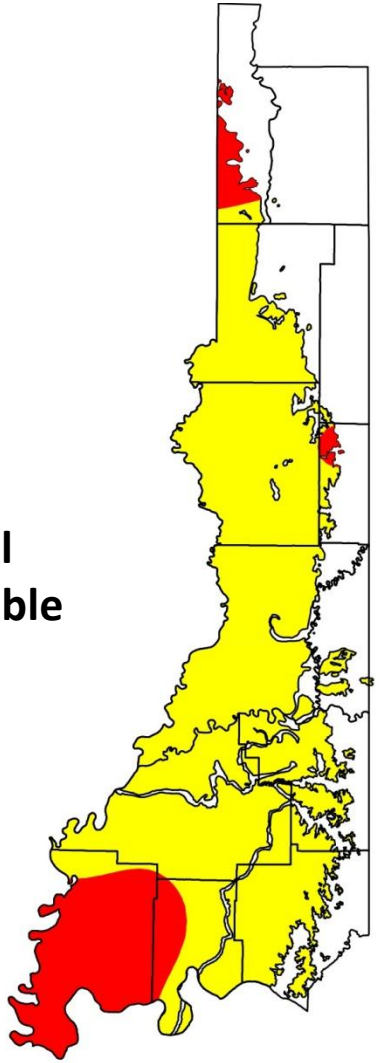
Ash content less than 12.5 % (OPT)
Ash content greater than 12.5 % (LS)

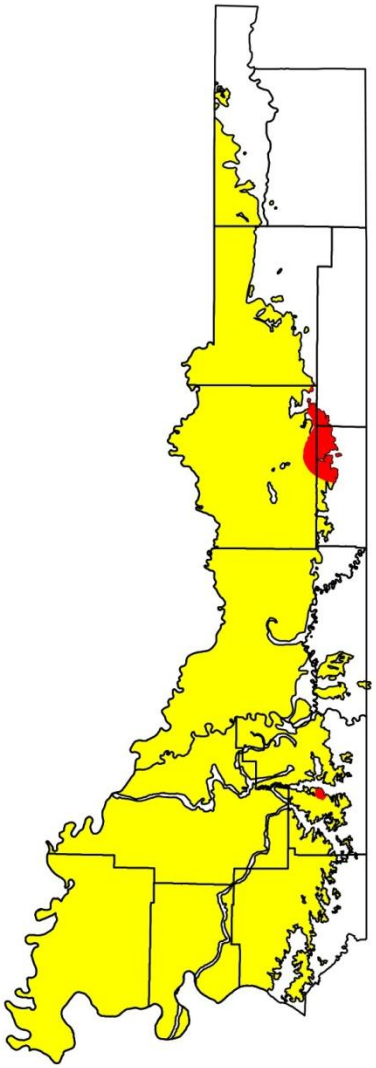
Slag viscosity temp. less than 2550 ^{o}F (OPT)
Slag viscosity temp. greater than 2550 ^{o}F (LS)

SiO_2 to Al_2O_3 ratio from 1.9 to 2.2 (OPT)
SiO_2 to Al_2O_3 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



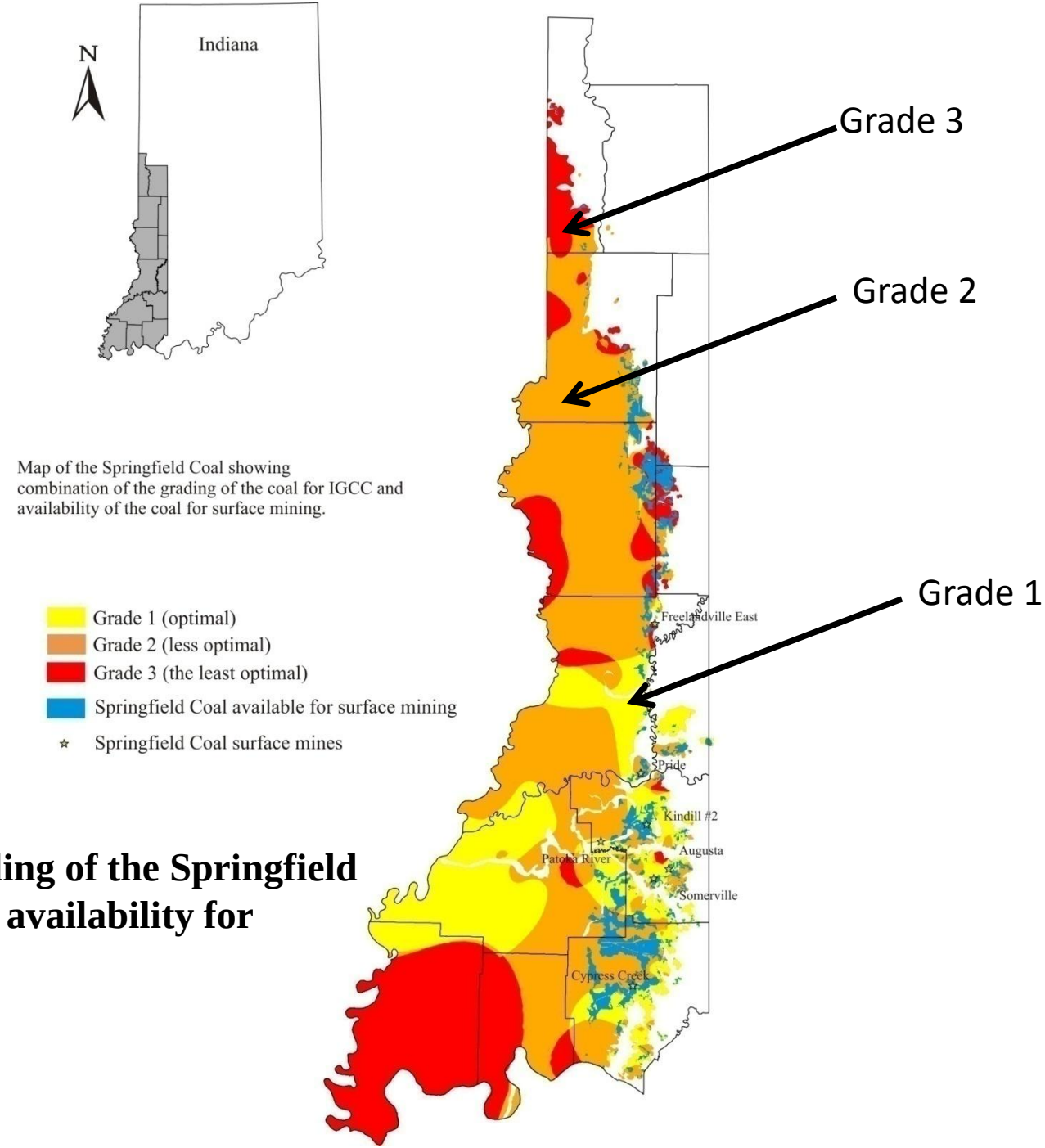


Fe_2O_3 + CaO from 15 to 35 (OPT)

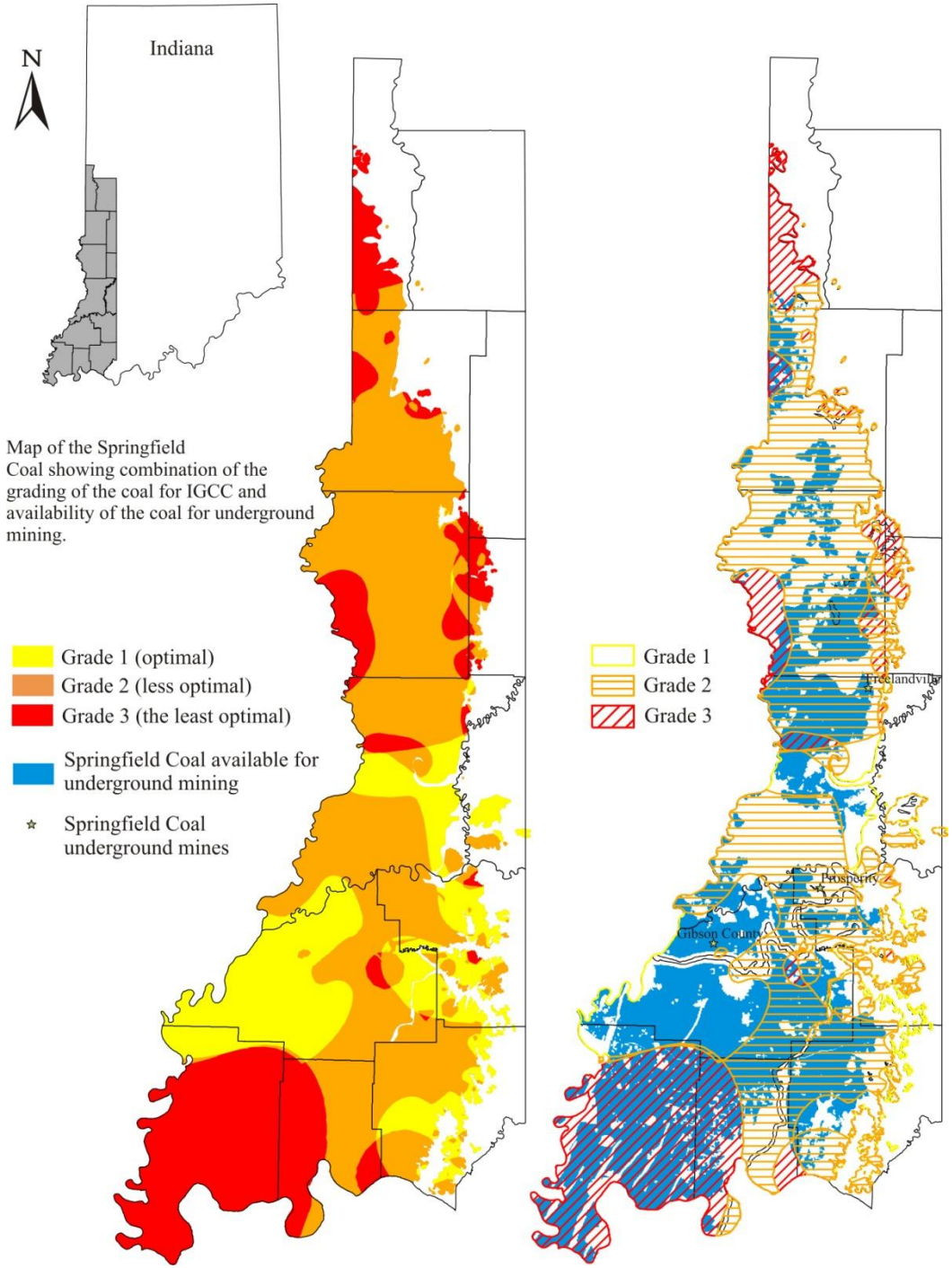
Fe_2O_3 + CaO less than 15 and greater than 35 (LS)

Silica ratio less than 0.7 (OPT)

Silica ratio greater than 0.7 (LS)

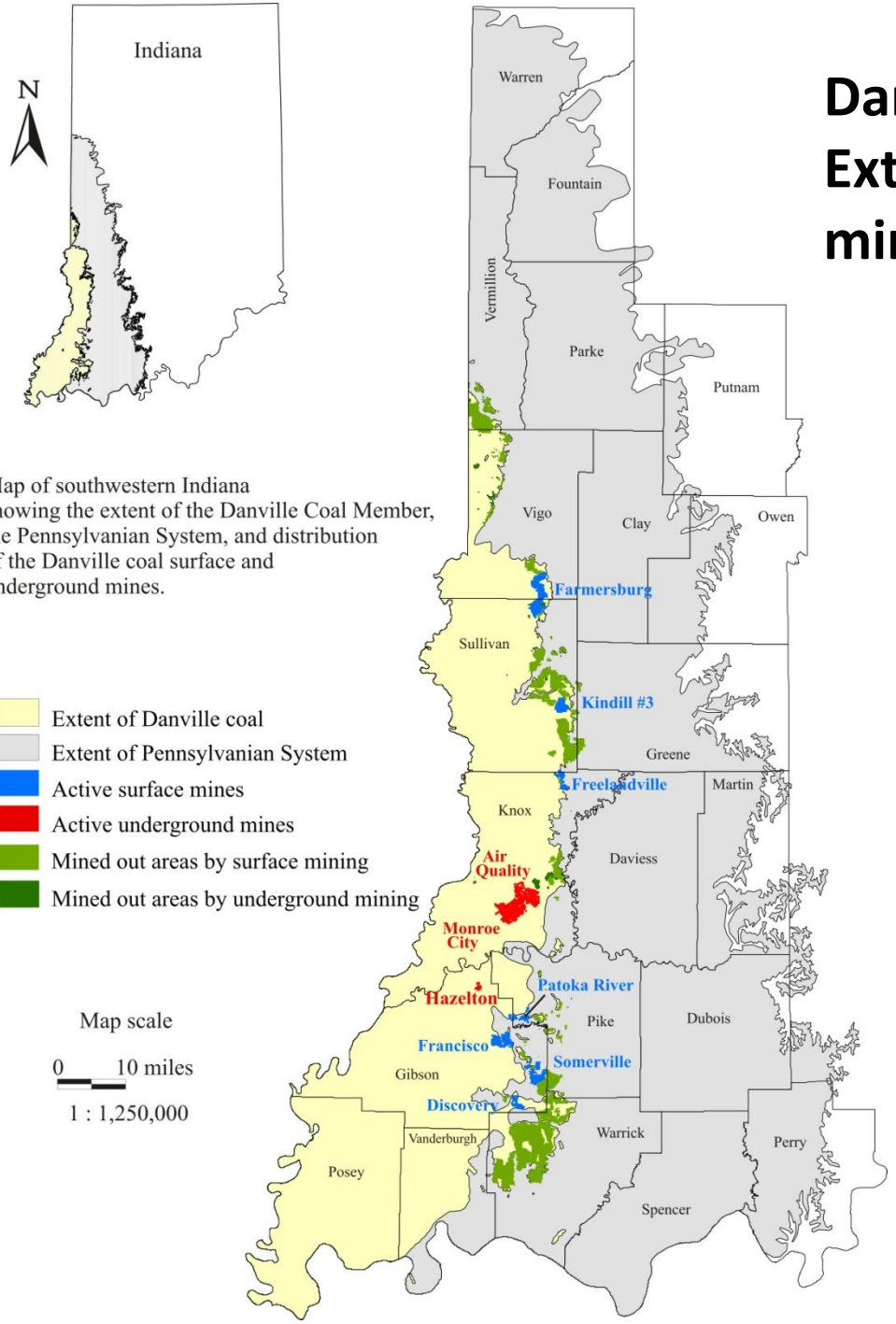


Maps showing grading of the Springfield Coal for IGCC and availability for surface mining



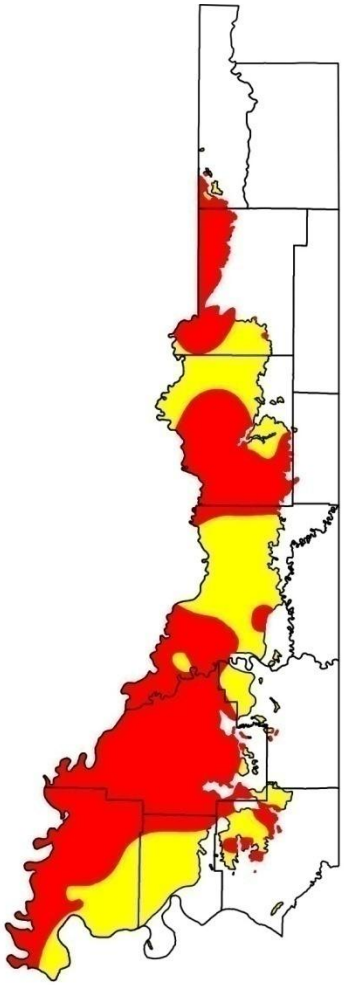
Combination of grading and availability for underground mining of the Springfield Coal

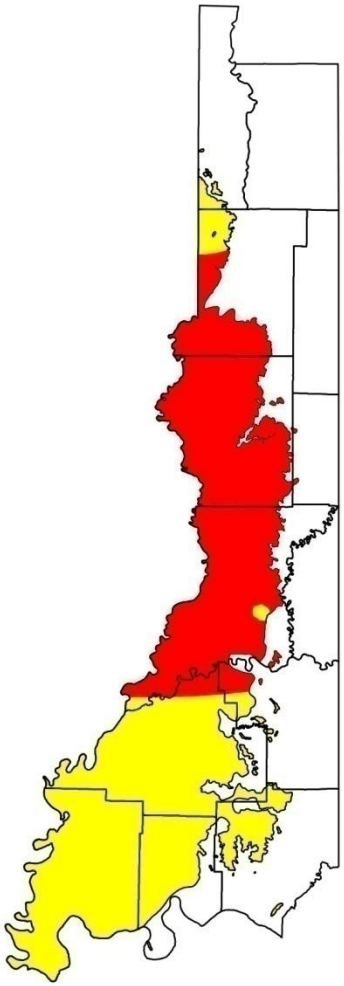
Danville Coal – Extent, mines, and mined out areas



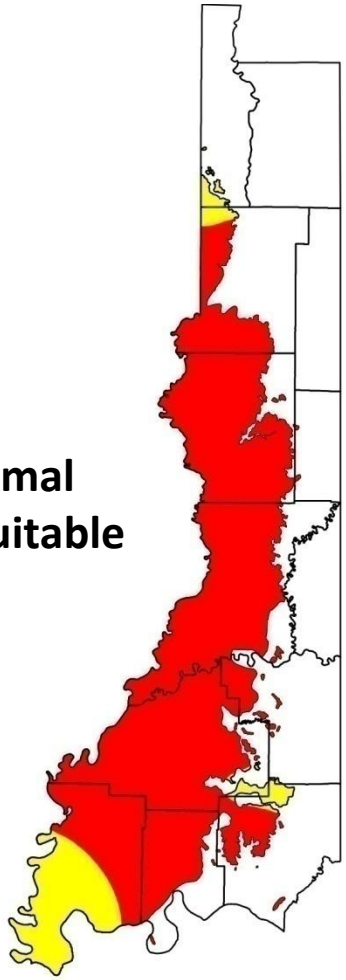
Map of southwestern Indiana showing the extent of the Danville Coal Member, the Pennsylvanian System, and distribution of the Danville coal surface and underground mines.

Maps showing suitability of the Danville Coal for IGCC





OPT – optimal
LS – less suitable



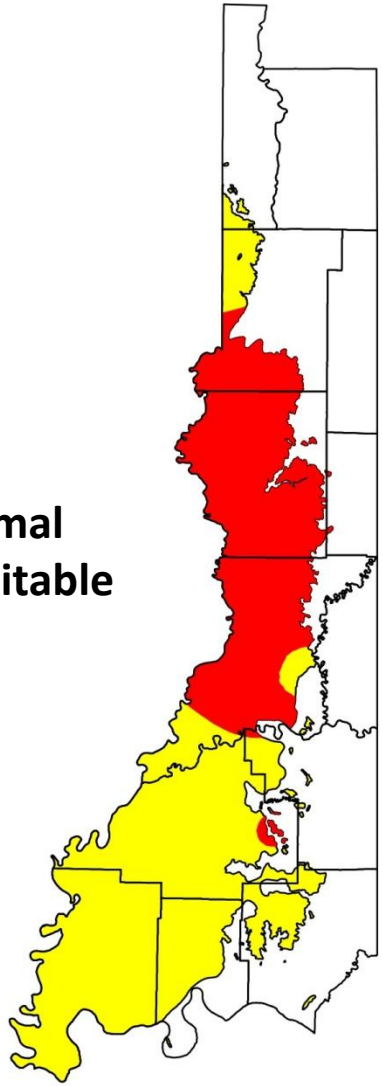
Ash content less than 12.5 % (OPT)
Ash content greater than 12.5 % (LS)

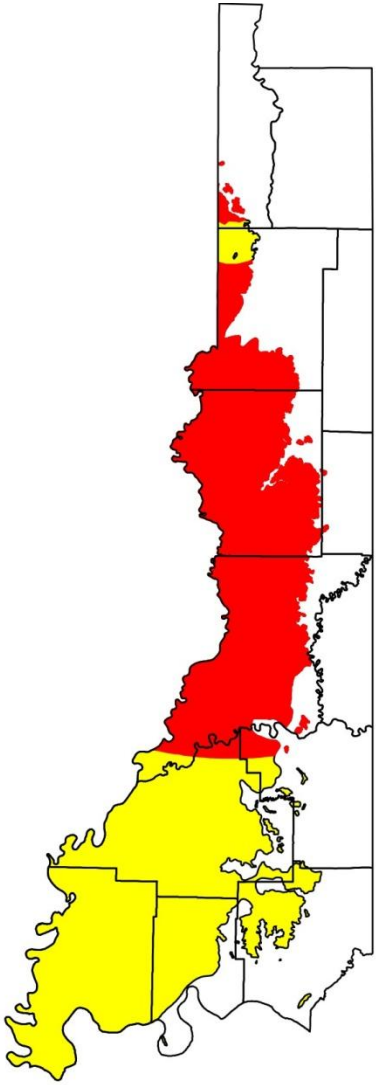
Slag viscosity temp. less than 2550 ^{O}F (OPT)
Slag viscosity temp. greater than 2550 ^{O}F (LS)

SiO_2 to Al_2O_3 ratio 1.9 to 2.2 (OPT)
SiO_2 to Al_2O_3 ratio greater than 2.2 (LS)

Maps showing suitability of the Danville Coal for IGCC

OPT – optimal
LS – less suitable





Fe_2O_3 + CaO from 15 to 35 (OPT)

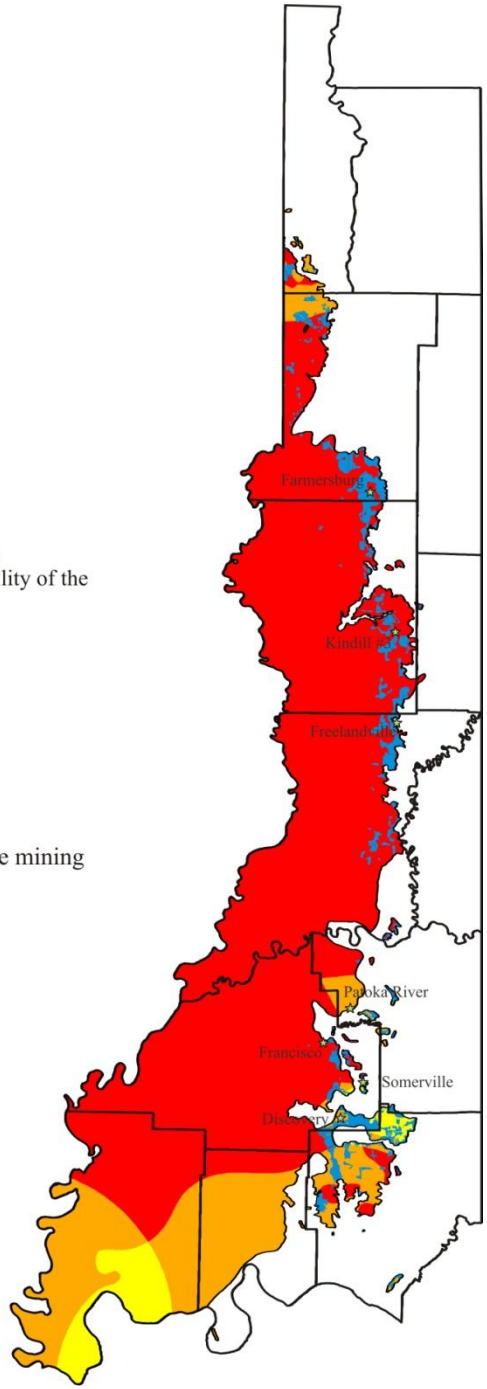
Fe_2O_3 + CaO less than 15 and greater than 35 (LS)

Silica ratio less than 0.7 (OPT)

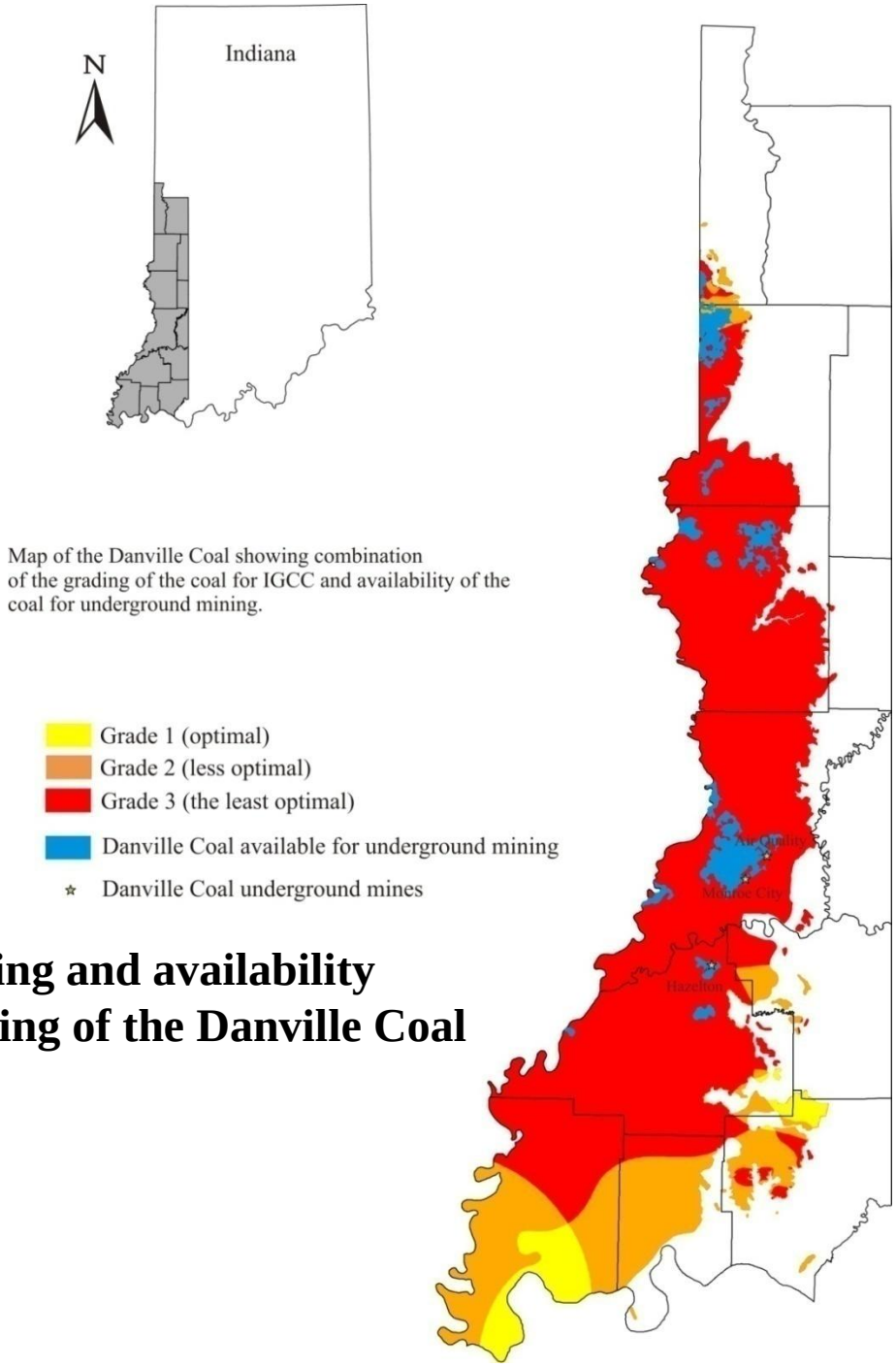
Silica ratio greater than 0.7 (LS)

Map of the Danville Coal showing combination of the grading of the coal for IGCC and availability of the coal for surface mining.

- Grade 1 (optimal)
- Grade 2 (less optimal)
- Grade 3 (the least optimal)
- Danville Coal available for surface mining
- Danville Coal surface mines

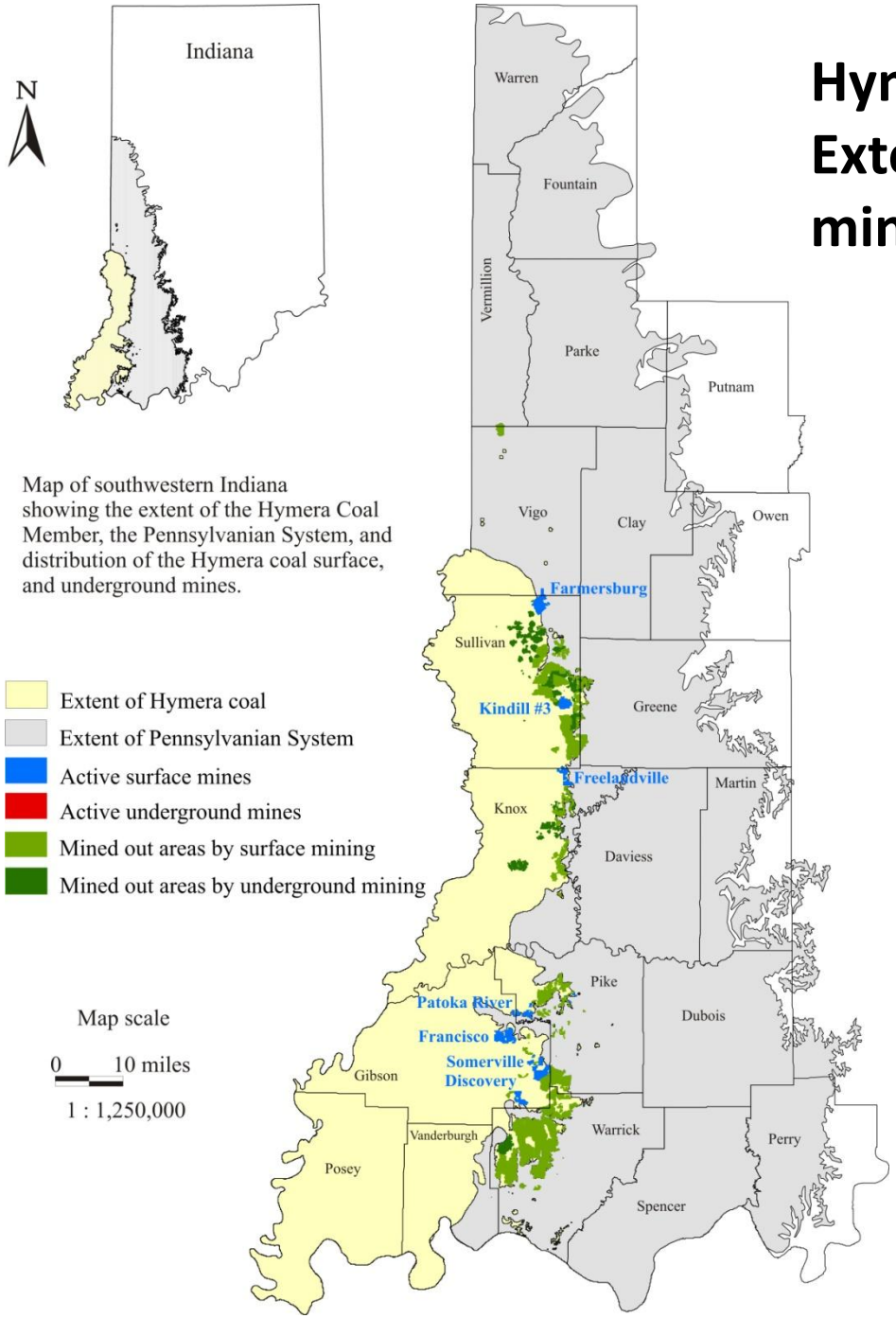


Maps showing grading of the Danville Coal for IGCC and availability for surface mining



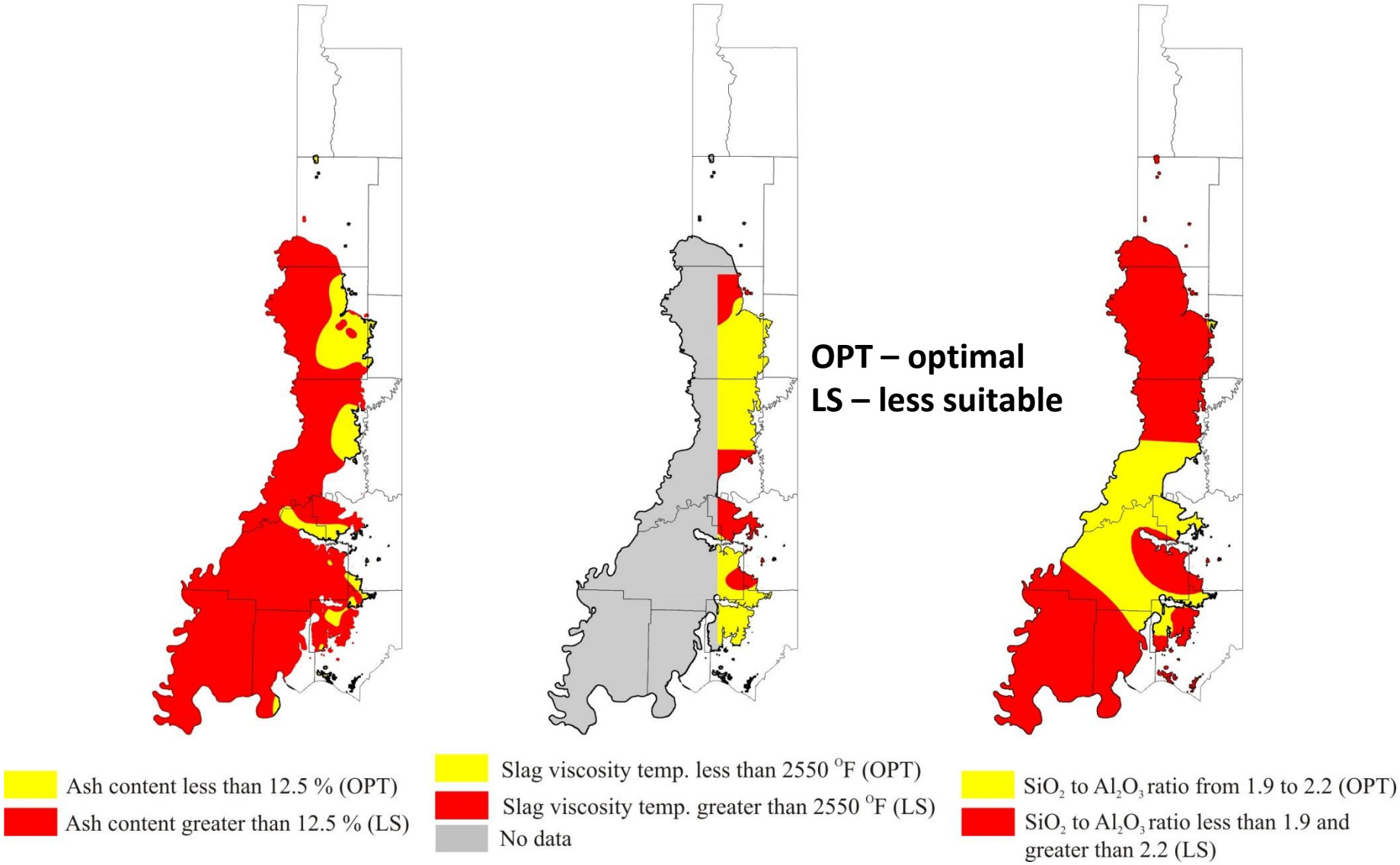
Combination of grading and availability for underground mining of the Danville Coal

Hymera Coal – Extent, mines, and mined out areas



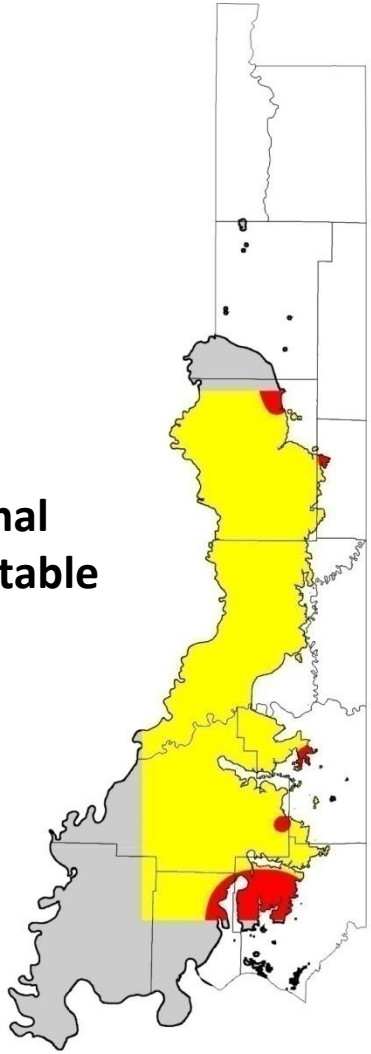
Map of southwestern Indiana showing the extent of the Hymera Coal Member, the Pennsylvanian System, and distribution of the Hymera coal surface, and underground mines.

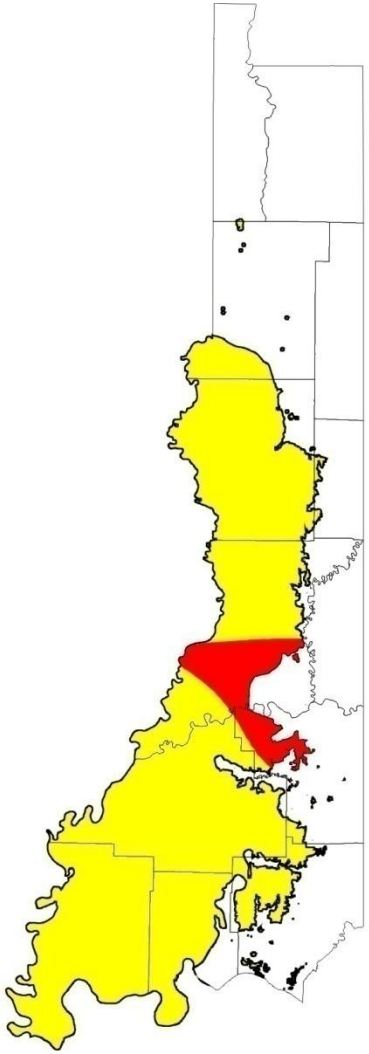
Maps showing suitability of the Hymera Coal for IGCC



Maps showing suitability of the Hymera Coal for IGCC

OPT – optimal
LS – less suitable





Fe_2O_3 + CaO from 15 to 35 (OPT)

Fe_2O_3 + CaO less than 15 and greater than 35 (LS)

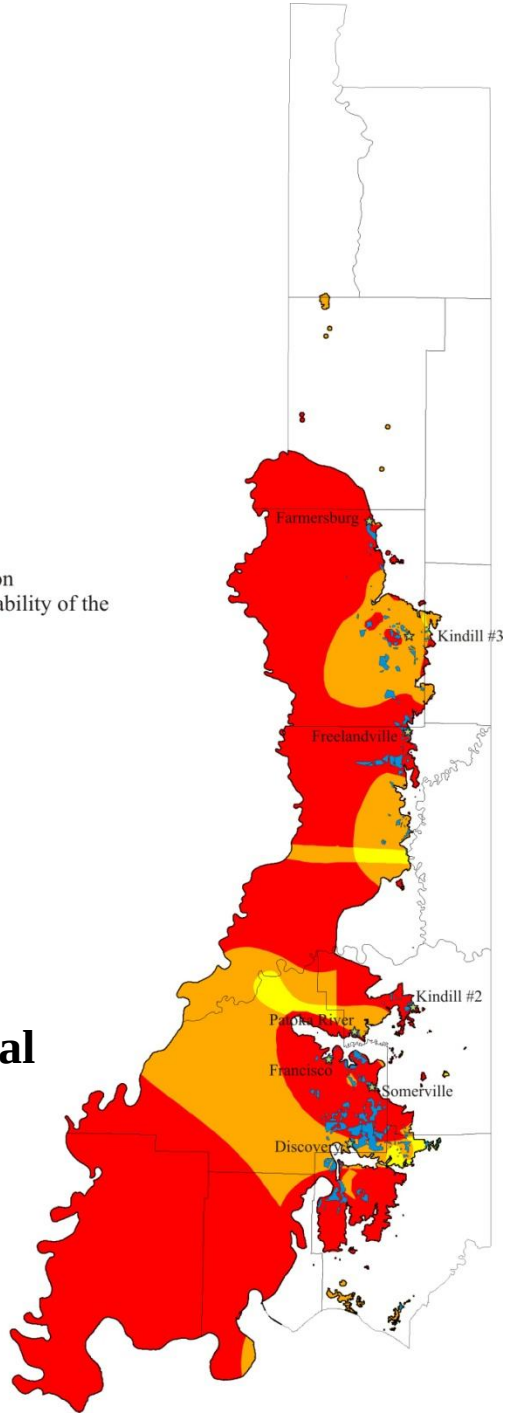
No data

Silica ratio less than 0.7 (OPT)

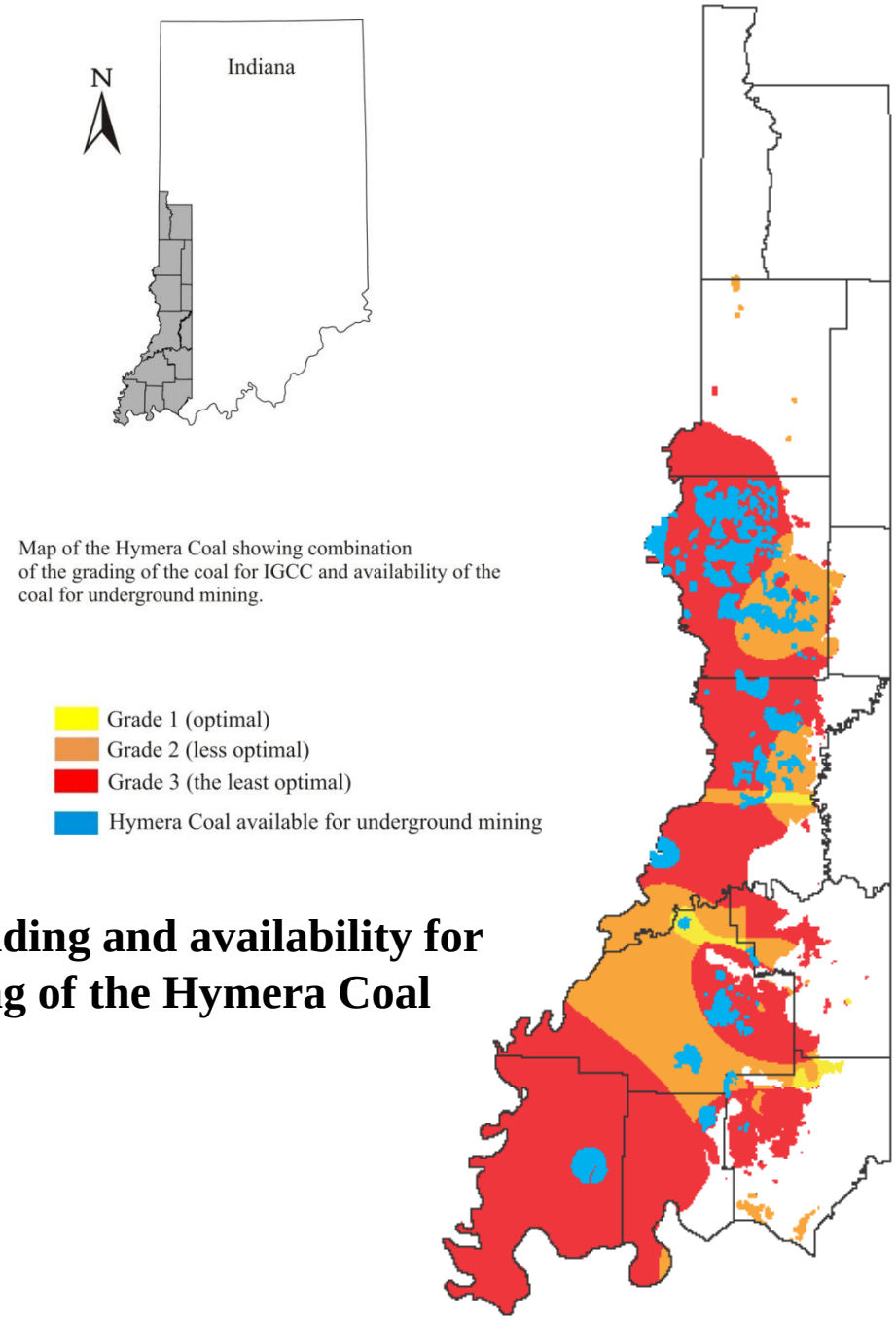
Silica ratio greater than 0.7 (LS)

Map of the Hymera Coal showing combination of the grading of the coal for IGCC and availability of the coal for surface mining.

Grade 1 (optimal)
Grade 2 (less optimal)
Grade 3 (the least optimal)

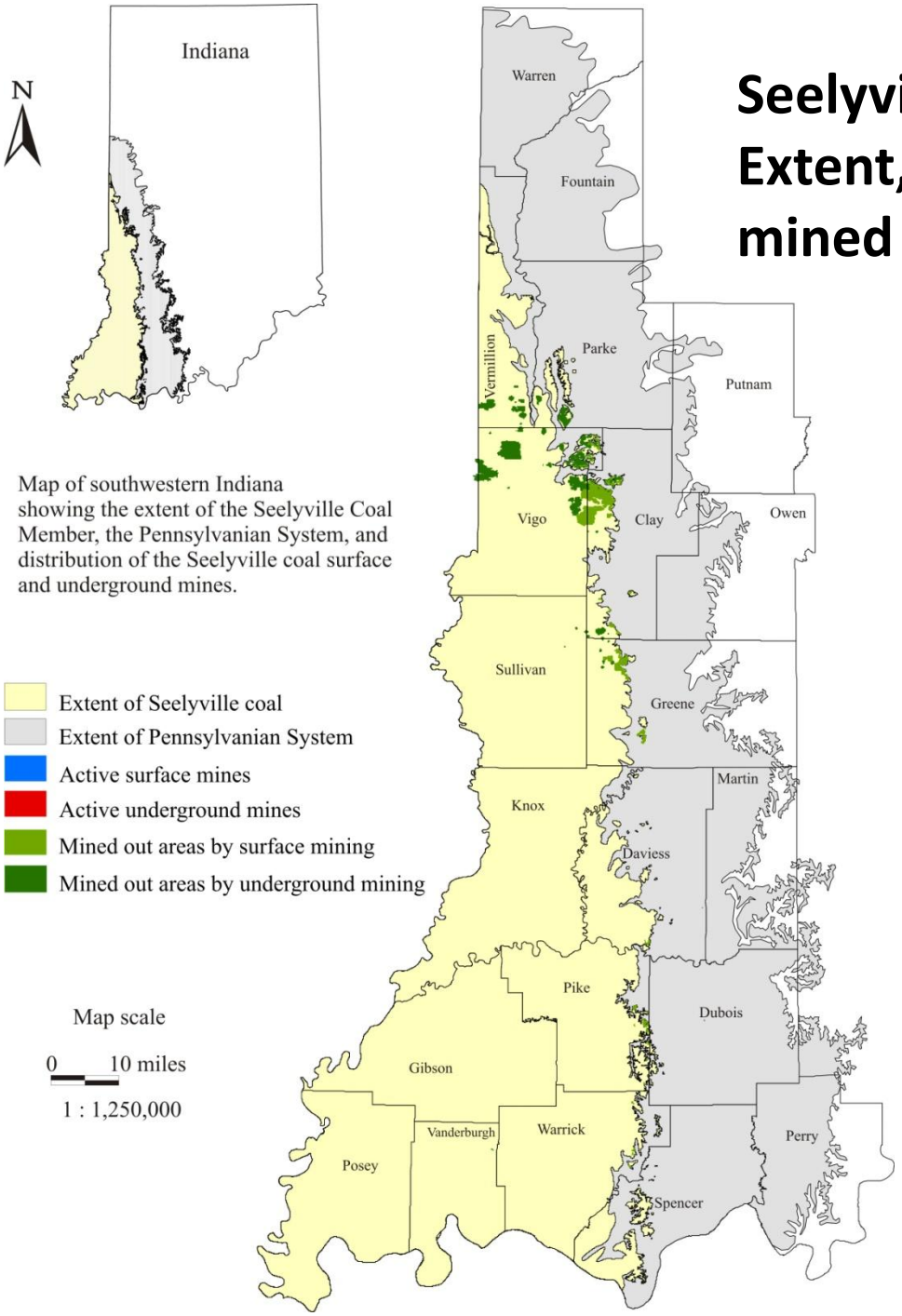


Maps showing grading of the Hymera Coal for IGCC and availability of the coal for surface mining



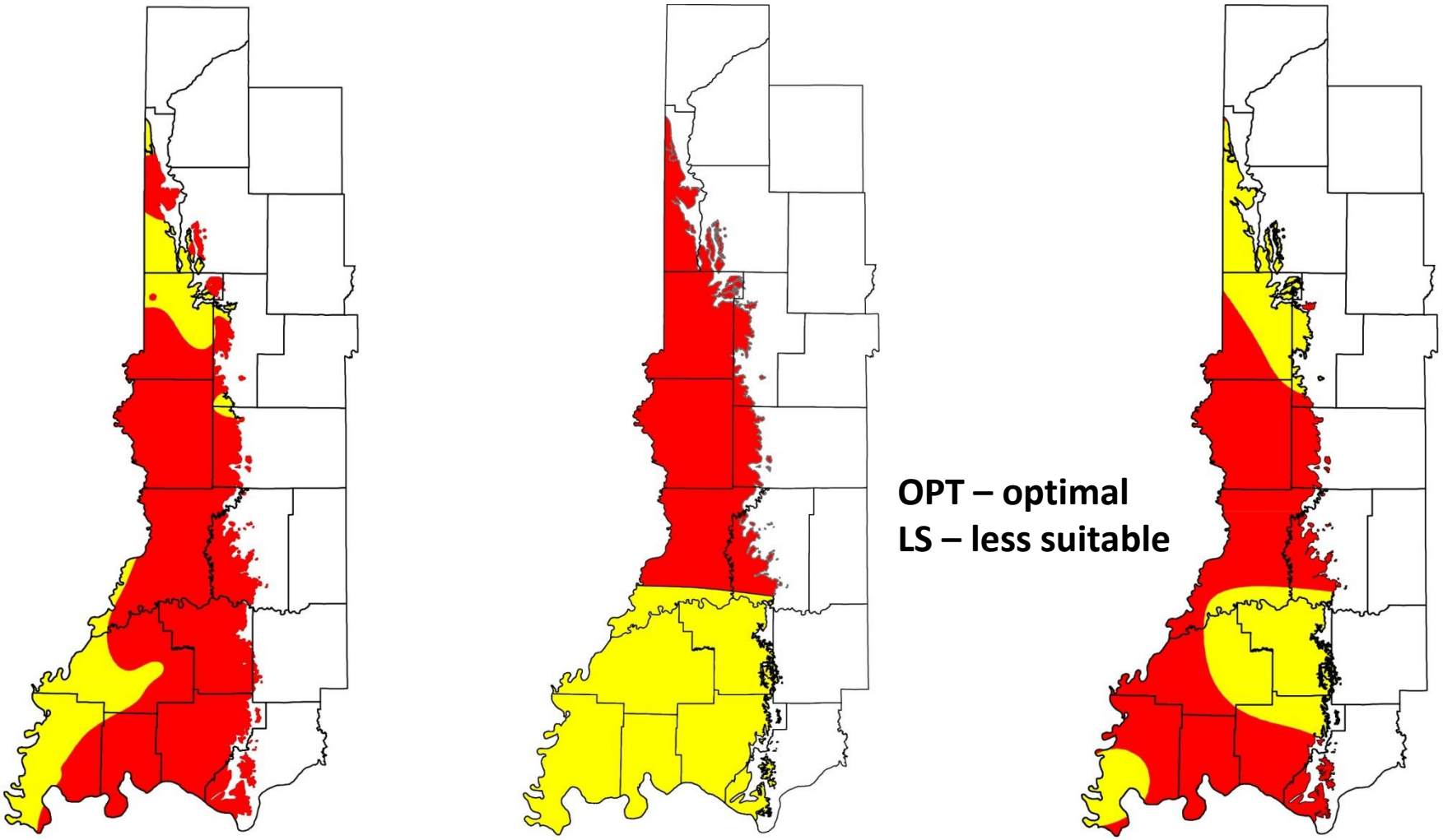
Combination of grading and availability for underground mining of the Hymera Coal

Seelyville Coal – Extent, mines, and mined out areas



Map of southwestern Indiana showing the extent of the Seelyville Coal Member, the Pennsylvanian System, and distribution of the Seelyville coal surface and underground mines.

Maps showing suitability of the Seelyville Coal for IGCC

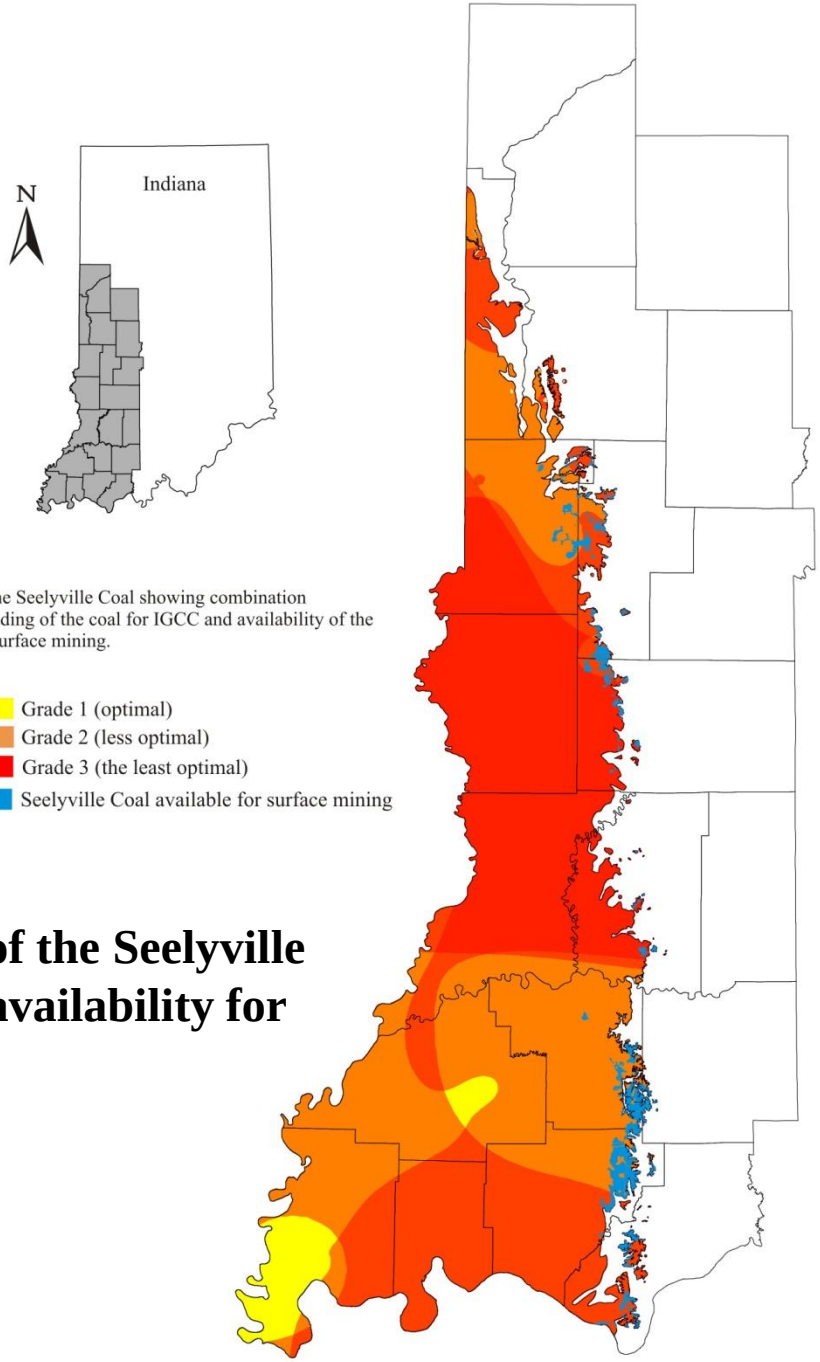


OPT – optimal
LS – less suitable

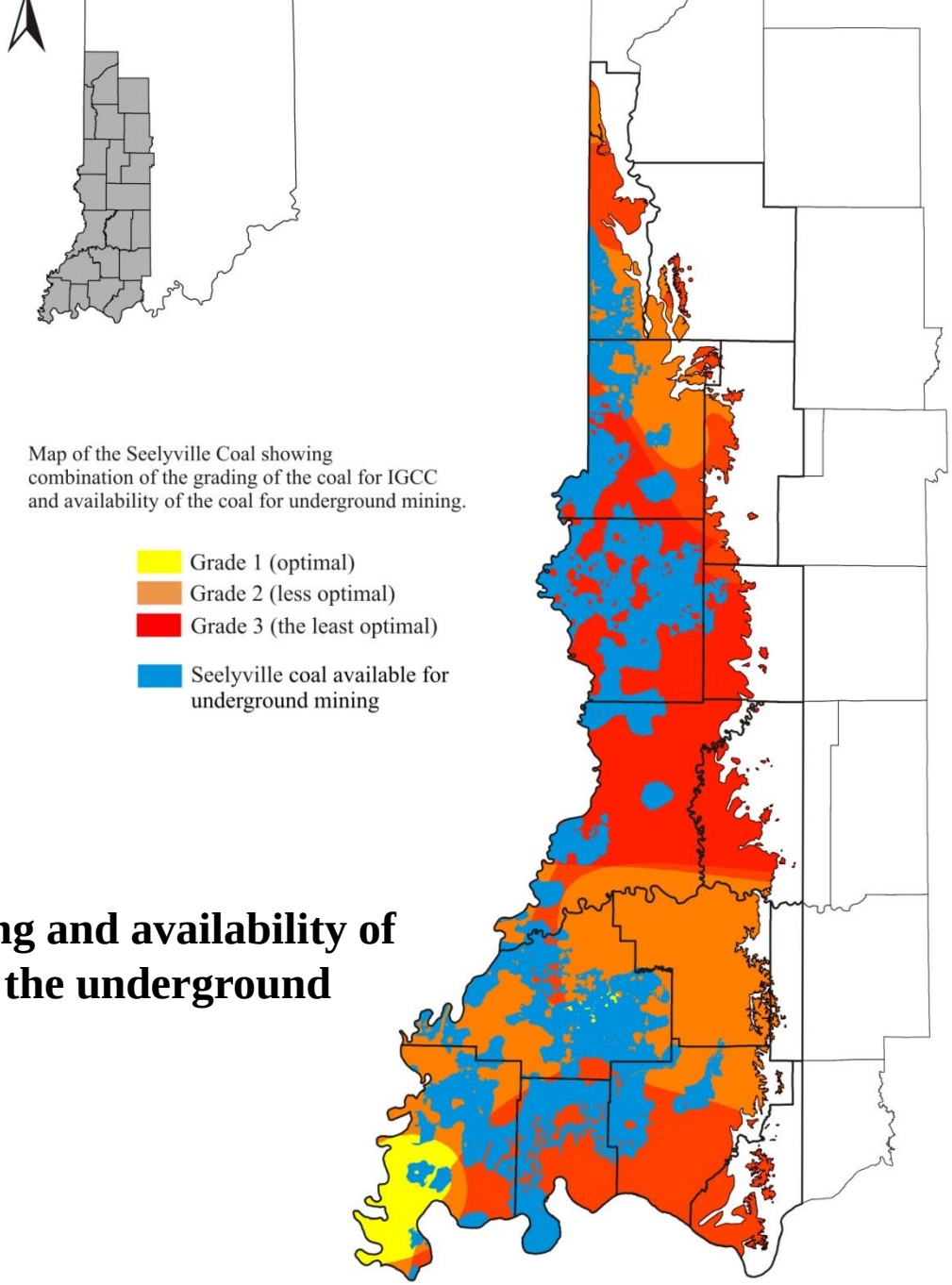
Ash content less than 12.5 % (OPT)
Ash content greater than 12.5 % (LS)

SiO_2 to Al_2O_3 ratio from 1.9 to 2.2 (OPT)
SiO_2 to Al_2O_3 ratio less than 1.9 and greater than 2.2 (LS)

Fe_2O_3 + CaO from 15 to 35 (OPT)
Fe_2O_3 + CaO less than 15 and greater than 35 (LS)



Maps showing grading of the Seelyville Coal for IGCC and its availability for surface mining



Combination of grading and availability of the Seelyville Coal for the underground mining

Summary and conclusions

- The overall objective of this study was to evaluate Indiana coals for use in IGCC technologies. Specific aims included: 1) generating new analyses on coals and integrating them into a coal quality database; 2) mapping various coal quality parameters; 3) using several IGCC-important parameters, grading the coals with regard to their suitability for IGCC; and 4) combining coal quality information with the availability of the coal for surface and underground mining. Four coal beds are targeted in this study: the Danville, Hymera, Springfield, and Seelyville Coal Members.

- This study includes an analysis of coal properties that are of major importance to IGCC technology and requirements with regard to these properties in all three types of gasifiers: fixed-bed, fluidized-bed, and entrained flow. The properties identified as having major impact on gasification process are, among others, heating value, moisture content, and ash content. An updated database of coal properties important for IGCC is available with the final report.

Summary and conclusions

- Assessment of Indiana coals for IGCC is accomplished based on the analysis of: 1) basic coal quality parameters such as heating value, moisture content, ash yield, and sulfur content; 2) ability of coal and coal char to gasify (reactivity); and 3) mineral matter characteristics.

- Basic coal quality characteristics such as heating value, moisture content, and ash content indicate that Indiana coals are a good feedstock for gasification. High sulfur content of the majority of Indiana coals does not create a problem because in IGCC plants sulfur is transformed into sulfuric acid and high purity elemental sulfur, both profitable products. Chlorine content in the coals studied is usually well below the IGCC-preferred 0.2% level, except some areas in the Springfield coal, where at places is a little higher but still below 0.3%. Chlorine content below 0.4% is required for gasification.

Summary and conclusions

- Since no direct reactivity measurements were available, coal/char reactivity proxies such as fuel ratio (a ratio of fixed carbon and volatile matter) and O/C ratio were used to evaluate reactivity. The analysis indicates that the Danville Coal and the Springfield Coal will be more reactive than the Hymera Coal. Reactivity of coal/char is more important in gasifiers with two-step char conversion, such as the one used at Wabash Valley Gasification Plant, than in one stage gasifiers where gasification is a faster process.

- Mineral matter characteristics are very important in entrained-flow slagging gasifiers. Entrained-flow slagging gasifiers are the most common gasifier types in IGCC technologies worldwide, including the US and, therefore, evaluation of mineral matter properties and prediction of its behavior in the gasifier is of fundamental importance.

Summary and conclusions

- Grading of coals for IGCC was accomplished by mapping the distribution of selected parameters, overlying the maps, and outlining the areas with the best characteristics (Grade 1) and less desirable characteristics (Grade 2 and 3). Maps of coal grading were combined with maps of availability for the surface and underground mining. In the **Danville Coal**, the best coals (Grade 1 and 2) available by surface mining methods occur in Warrick, Pike, and northern Vigo Counties. The coal available by underground methods is dominantly of Grade 3, except in northern Pike County where there is coal of Grade 2. In the **Hymera Coal**, most of the coal available both for surface and underground mining is represented by Grade 3 and 2. In the **Springfield Coal**, the best coal for IGCC available by surface methods occur in Pike and Warrick Counties and there are large areas of excellent quality coal (Grade 1 and 2) available by underground methods. In the **Seelyville Coal**, Pike, Vigo, and Warrick Counties contain Grade 1 and 2 coals available for surface mining and coals of Grade 1, 2, and 3 are available for underground mining in several counties.

Summary and conclusions

- For Indiana coals, we recommend two main blending strategies if improvement in slagging characteristics is required: a) blending low SiO_2/Al_2O_3 coals (<1.6) with high SiO_2/Al_2O_3 coals to yield of SiO_2/Al_2O_3 of 1.0-2.2; and b) blending high flux (Fe_2O_3+CaO) coals with a lower flux coals to yield Fe_2O_3+CaO content about 15-20%

- Although the evaluation of Indiana coals presented in this report is particularly suitable for entrained-flow slagging gasifiers, generated data and coverages can be valuable for other coal-processing technologies as well. By concentrating on the evaluation based on mineral matter characteristics, but including evaluation of the coal/char reactivity as well as analysis of coal quality parameters, this study can be used to guide the selection of coals for other gasification technologies as well as other clean coal technologies.

Associated Maps

Map 1. Drobniak, A., Shaffer, K., Mastalerz, M., 2006. ***Coal Supply and Demand in Indiana***, IGS Miscellaneous Map 72

Map 2. Drobniak, A., Mastalerz, M., and Shaffer, K., 2006. ***Coal, Electricity, and Gas Transportation Systems in Indiana***. IGS Open-File Study 06-03.

Map 3. Drobniak, A., Rupp, J., Mastalerz, M., and Shaffer, K., 2007. ***Conceptual Carbon Management Strategies in Indiana,*** Open File Study 07-01.

Map 4. Drobniak, A., Pfitzer, C., Mastalerz, M. 2007. ***Indiana Railroad System***, Open File Study 07-04.

For further information contact:
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611 North Walnut Grove Avenue
Bloomington, IN 47405
http://gis.indiana.edu/

COAL SUPPLY AND DEMAND IN INDIANA

Compiled by Agnieszka Drobniak, Maria Mastalerz and Kathryn Shaffer

Edition 1 - May 2006

Figure 1. Generalized stratigraphic section showing approximate vertical relations of coals in Indiana

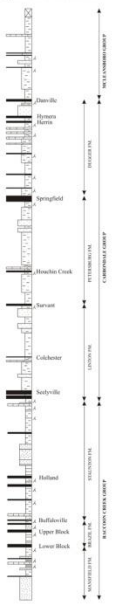


Table 1. Lithostratigraphy of the Pennsylvanian System in Indiana (modified from Mastalerz and Harper, 1998, and the Tristate Committee on Correlation of the Pennsylvanian System in the Illinois Basin, 2001). The table shows major coal beds.

Illinois		Indiana		W. Kentucky	
Modesto Fm.		Modesto Fm.		Modesto Fm.	
Bond Fm.		Bond Fm.		Bond Fm.	
Patoka Fm.		Patoka Fm.		Patoka Fm.	
Shelbyville Fm.	Danville (No.7) Seelyville	Shelbyville Fm.	Danville (VII) Seelyville	Shelbyville Fm.	Baker (No.11) Danville (No.12)
	Herrin (No.6)		Herrin (VI) Houchin Creek		Herrin (No.11)
	Springfield (No.5)		Springfield (V)		Springfield (No.9)
Carbondale Fm.	Houchin Creek	Carbondale Fm.	Houchin Creek	Carbondale Fm.	Houchin Creek
	Survant		Survant (IV)		Survant (No.6)
	Colchester (No.2) Dekoven Davis	Staunton Fm.	Colchester (III)a	Staunton Fm.	Colchester (No.2) Dekoven (No.4) Davis (No.5)
			Seelyville (III)		
		Brazil Fm.	Coniferous Sandstone Fm. crush	Brazil Fm.	Offering (Clay) No.4 Fraser
			Minshall - Buffaloville (II)		Local Crush Shoshoni
Mansfield Coal Group	Staunton Fm.	Mansfield Coal Group	Upper Block	Mansfield Coal Group	Elm Lick
	Willis		Lower Block		
			Mansfield (Hill Bluff Clay) Creek		(Sol Hoard) No.3 Kopper Kettle (Bell)
Brazil/Tradewater Group	Reynolsburg	Tradewater Fm.	Francisco (I) Mariaville	Tradewater Fm.	Battery Rock Nodus
	Gossett		French Lick		

Legend

- Active surface and underground mines
- Active surface mines areas
- Active underground mines areas
- Mined out areas
- Coal burning electric power plants
- Coal burning electric power plants with scrubbers
- Active railroads
- Interstates
- Highways
- Rivers
- Lakes
- Cities
- County boundary

Bedrock systems

- Pennsylvanian
- Mississippian
- Devonian-Mississippian
- Devonian
- Silurian
- Ordovician

Table 2. Summary of available and restricted coal resources for main economic coal beds in Indiana (in billion short tons)

Coal bed	Original	Mined out	Remaining[1]	Restricted	Total available (Remaining, Restricted)	Available as % of original	Available for surface mining	Available for underground mining
Danville	6.55	0.36	6.19	3.33	9.52	145.27	0.25	3.52
Hymera	5.53	2.05	4.08	4.15	8.23	148.81	0.42	7.81
Springfield	13.21	1.31	12.00	4.65	7.35	55.25	0.82	6.94
Houchin Creek	5.92	0.0022	5.92	3.36	6.58	6.68	0.16	0.17
Survant	8.47	0.31	8.17	8.86	1.31	16.63	0.22	1.10
Colchester	14.81	0.23	14.58	7.65	8.93	60.31	0.35	8.58
Seelyville	14.81	0.33	14.25	7.95	8.68	46.22	0.35	8.33
	68.83	2.6632	66.68	39.13	17.34	38.98	2.13	15.94

[1] Following currently used criteria (Mastalerz et al., 2004, Int'l J Coal Geol, 59:43).

COAL PRODUCTION IN INDIANA
Total: 34,063,000Short Tons

Table 3. Active surface mines in Indiana as of February 2006

ID	Company / Surface Mine Name	County	Year opened	2004 Production (1,000 short tons)
	B. B. Mining, Inc.			
1	Kiron	Knox	1996	230
	Black Beauty Coal Company			
2	Discovery #1, Gamaville South Pit	Gibson	1993	1,830
3	Farmersburg #1, South Pit	Sullivan, Vigo	1996	4,268
4	Francisco	Gibson	1996	2,133
5	Hoosier Mine, Jenny Pit[1]	Clay	2001	
6	Miller Creek, Sugar Ridge[1]	City	2001	860
7	Miller Creek, Knox Pit			
8	Somerville Central, Somerville Central	Gibson	1996	5,371
9	Somerville East[1]	Pike	1996	
10	Viking, Corning Pit	Daviess	1995	1,462
	Black Beauty Coal Company			
11	Hansons Mine[1]	Sullivan	2005	
	Knox Mining, Inc.			
12	Knox #1, Willow Church Pit[1]	Pike	1974	1,203
13	Knox #3, Pennsylvania Pit[1]	Sullivan	1987	535
	Solar Sources, Inc.			
14	Carlisle, Carlisle	Daviess	1979	2,198
15	Carmichael, Midway II Pit[1]	Daviess	1979	
16	Lewis, Lewis	Clay, Vigo	2001	417
	Triad Mining, Inc.			
17	Augusta	Pike	2002	616
18	Augusta South[1]	Pike	2002	
19	Freelandville	Knox	1996	311
20	Freelandville	Knox	1996	409
21	Freelandville, East Pit	Knox	1996	462
22	Oakville	Fountain	1996	1,139
23	Patoka River	Gibson, Pike	1996	756
	Vigo Coal Company, Inc.			
24	Carrens Creek	Warrick	1998	1,202
25	Rangeline[1]	Warrick	2001	38
				Total 24,834

Source: Indiana Coal Council

[1] Not in production
[2] No production reported for 2004
[3] Closed and sold in 2004; 1996 lessee under new ownership
[4] Permit issued, but no production reported; reserve production is not in the 2006 COAL PRODUCTION IN INDIANA table
[5] In progress operation
[6] Permit issued, but not in production
[7] Includes 3 underground mines
[8] Production includes some strip mining production

Table 4. Active underground mines in Indiana as of February 2006

ID	Company / Underground Mine Name	County	Year opened	2004 Production (1,000 short tons)
	Black Beauty Coal Company			
26	Air Quality	Knox	1983	1,715
27	Air Quality Underground	Gibson	2003	361
	Fire Sar Mining, Inc.			
28	Prosperity	Pike	2000	2,345
	Hoosier Energy Coal, LLC			
29	Gibson County	Gibson	2000	2,978
	Solar Sources, Inc.			
30	Oaklands[1]	Knox	1994	894
	Sunrise Coal, LLC			
31	Houston[2]	Greene	2005	
	Triad Mining, Inc.			
32	Freelandville Underground[3]	Knox	2001	444
	White River Coal, Inc.			
33	Hazleton	Gibson	2002	713
				Total 10,040

[1] Not in production
[2] No production reported for 2004
[3] Closed and sold in 2004; 1996 lessee under new ownership
[4] Permit issued, but no production reported; reserve production is not in the 2006 COAL PRODUCTION IN INDIANA table
[5] In progress operation
[6] Permit issued, but not in production
[7] Includes 3 underground mines
[8] Production includes some strip mining production

Figure 2. Export of Indiana coal to other states and import of coal from other states to Indiana (2004, Thousand Short Tons)

COAL DISTRIBUTION IN INDIANA
Total: 65,744 Thousand Short Tons

Table 5. Coal both produced and used in Indiana (2004, Thousand Short Tons)

Method of Transportation	Electricity Generation	Coke Plants	Industrial Plants (Except Coke)	Residential and Commercial	Total
Railroad	16,194	-	10,438	-	26,632
Railroad	537	-	-	-	537
River	537	-	-	-	537
Truck	-	-	-	1,115	1,115
Tramway, Conveyor, and Slurry Pipeline	732	-	2,574	-	3,306
Truck	4,315	-	5,280	508	10,103

Table 6. Coal imported to Indiana from other states (2004, Thousand Short Tons)

Method of Transportation	Electricity Generation	Coke Plants	Industrial Plants (Except Coke)	Residential and Commercial	Total
Total	10,890	6,996	330	38	18,254
Railroad	9,578	6,996	330	38	16,942
River	1,312	-	-	-	1,312
Tramway, Conveyor, and Slurry Pipeline					
Truck	800	-	282	11	1,159

Table 7. IMPORT of coal into Indiana (2004, Thousand Short Tons)

State of Origin by Method of Transportation	Electricity Generation	Coke Plants	Industrial Plants (Except Coke)	Residential and Commercial	Total
Alabama					314
Railroad	-	314	-	-	314
Illinois	87	-	-	-	87
Railroad	87	-	-	-	87
Illinois	4,391	-	190	-	4,581
Railroad	3,000	-	-	-	3,000
River	392	-	-	-	392
Truck	1,391	-	190	-	1,581
Kentucky Total	1,347	158	129	42	1,676
Railroad	87	125	129	42	383
River	270	-	11	-	281
Truck	-	33	189	-	222
Eastern Kentucky	90	158	176	-	424
Railroad	90	125	129	-	344
River	-	-	47	-	47
Truck	-	33	-	-	33
Western Kentucky	258	-	23	-	281
Railroad	87	-	-	-	87
River	171	-	11	-	182
Truck	-	-	12	-	12
Ohio	5,711	-	-	-	5,711
Railroad	5,711	-	-	-	5,711
Ohio	391	-	-	-	391
Railroad	321	-	-	-	321
River	70	-	-	-	70
Pennsylvania Total	1,195	-	-	91	1,286
Railroad	1,195	-	-	91	1,286
River	154	-	-	-	154
Truck	-	-	-	15	15
Pennsylvania	-	-	-	15	15
River	-	-	-	15	15
Truck	-	-	-	-	-
Wyoming	1,746	-	-	-	1,746
Railroad	1,600	-	-	-	1,600
River	146	-	-	-	146
Virginia	1,398	1,397	94	-	2,889
Railroad	1,398	1,397	94	-	2,889
West Virginia Total	148	4,998	43	13	5,202
Railroad	148	4,998	43	13	5,202
West Virginia	79	704	22	-	805
Railroad	79	704	22	-	805
Southern	49	-	-	-	49
Railroad	49	-	-	-	49
Southern	19	4,998	43	13	5,038
Railroad	19	4,998	43	13	5,038
River	154	-	-	-	154
Truck	-	-	-	61	61
Total	14,002	-	-	-	14,002
Railroad	14,002	-	-	-	14,002
Total	23,009	5,944	539	20	31,511
Railroad	21,696	5,944	539	20	28,199
River	1,312	-	-	-	1,312
Tramway, Conveyor, and Slurry Pipeline	-	-	-	-	-
Truck	800	-	282	11	1,159

Table 8. EXPORT of coal out of Indiana (2004, Thousand Short Tons)

State of Destination by Method of Transportation	Electricity Generation	Coke Plants	Industrial Plants (Except Coke)	Residential and Commercial	Total
Alabama	238	-	-	-	238
Railroad	238	-	-	-	238
Florida	81	-	-	-	81
River	81	-	-	-	81
Illinois	349	-	47	14	410
Railroad	349	-	-	-	349
River	152	-	46	-	198
Truck	200	-	1	14	215
Iowa	-	-	45	-	45
River	-	-	45	-	45
Kentucky	1,757	-	1,137	34	2,928
Railroad	550	-	-	-	550
River	1,207	-	-	-	1,207
Truck	200	-	1,137	34	1,371
Michigan	12	-	-	-	12
Great Lakes	12	-	-	-	12
Minnesota	81	-	-	-	81
Railroad	81	-	-	-	81
Mississippi	5	-	-	-	5
River	5	-	-	-	5
Missouri	-	-	138	-	138
River	-	-	133	-	133
Truck	-	-	5	-	5
Nebraska	88	-	-	-	88
Railroad	88	-	-	-	88
Ohio	122	-	-	-	122
River	122	-	-	-	122
Pennsylvania	-	-	33	-	33
River	-	-	33	-	33
Tennessee	-	-	-	20	20
River	-	-	-	20	20
Wisconsin	315	-	142	-	457
Railroad	142	-	142	-	284
River	173	-	-	-	173
Unknown State	-	-	-	-	-
Unknown	-	-	-	-	-
Total	3,389	-	1,539	76	4,967
Great Lakes	12	-	-	-	12
Railroad	360	-	142	-	1,132
River	1,412	-	-	20	1,607
Tramway, Conveyor, and Slurry Pipeline	-	-	-	-	-
Truck	200	-	1,146	40	1,393
Unknown	-	-	-	-	-

* Quantity is less than 500 short tons or percent is less than .05
** Includes distributions to Unknown consumers
*** Includes distributions to Unknown consumers, exports of metallurgical coal(Ky), The category "Industrial Plants" includes coal distributed to synthetic fuel plants that transform coal into synthetic coal and thus substitute in a fuel-to-fuel ratio. Coal used in the production of synthetic fuel is not counted as coal. Coke plants are not included in this table. Coke plants have been added to the "Industrial Plants" category. Source: Energy Information Administration, Form EIA-6A, "Coal Distribution Report." Reproduced by permission.

Table 9. Investor-owned, cooperative, and municipal coal-burning electric power plants

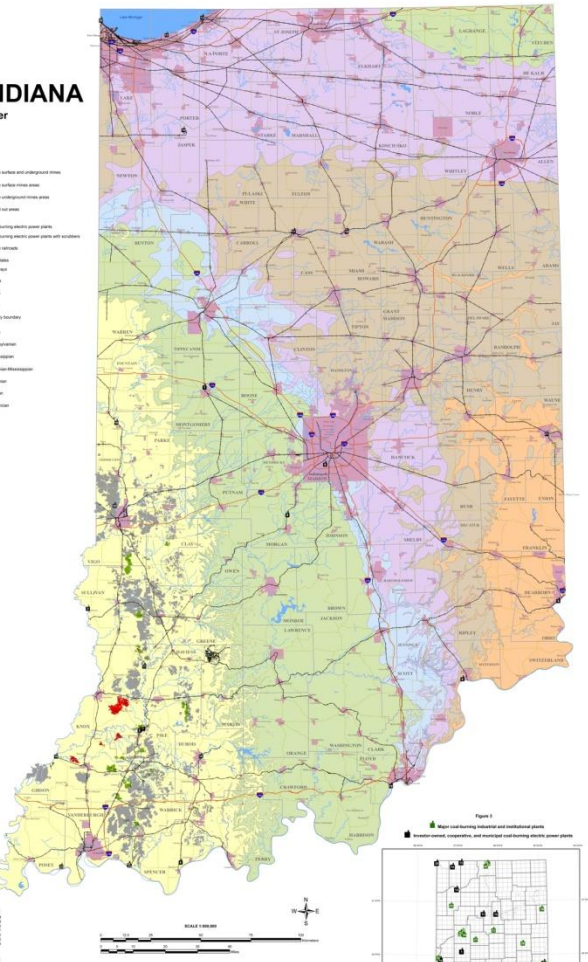
ID	Company / Plant Name	County	Generating Capacity (MW)[1]	Coal burned in 2004 (1,000 tons)[2]	Origin of coal received in 2004 (1,000 tons)[3] Indiana	Illinois Basin (Western, Eastern)	Eastern	Western
	Crawfordsville Electric Light & Power Co.							
1	Crawfordsville	Montgomery	23	24				
	Hoosier Energy R.E.C.Inc.							
2	Frank E. Ratts	Pike	234	719	720			
3	Merom	Sullivan	1,080	3,494	3,494			
	Indiana Michigan Power Co.							
4	Rockport	Spencer	2,660	9,027	450		237	1,113
5	Tanners Creek	Dearborn	1,301	2,261	32	166	1,741	326
	Indiana Kentucky Electric Corp.							
6	Clifty Creek	Jefferson	1,304	4,486		117	1,537	3,411
	Indianapolis Power & Light Co.							
7	Eagle Valley	Pike	1,073	5,014	4,919			
8	Eagle Valley (formerly Petersburg)	Morgan	392	1,796	1,796			
9	Perkins Street (formerly Edwin W. Stout)	Marion	558	1,871	1,862	9		
	City of Jasper							
10	Jasper	Dubois	13	37				
	City of Logansport							
11	Logansport	Cass	42	151				
	Northern Indiana Public Service Co.							
12	Bailly[4]	Porter	618	1,424	255	1,071	78	
13	Michigan City	La Porte	540	1,539			154	1,384
14	R. M. Schahfer	Jasper	1,040	3,024		1,367	774	2,903
	City of Peru							
15	Peru	Miami	25	17				
	PSI Energy Inc.							
16	Cayuga	Vermillion	1,092	3,180	1,601	1,579		
17	Gallagher[5]	Clark	140	392	392			
18	Gibson[5]	Gibson	1,140	3,250	1,251	1,929		
19	R. Gallagher[5]	Floyd	600	1,511	1,529	19	171	
20	Wabash River	Vigo	323	1,000	1,000	0		
	City of Richmond							
21	Whitewater Valley[6]	Wayne	54	208	38		207	
	Southern Indiana Gas & Electric Co.							
22	A. B. Brown[5]	Posey	531	1,083	1,083			
23	F. B. Culley[5]	Warrick	475	1,246	1,247			
	Southern Indiana Gas & Electric Co. and Alcoa							
24	**Generating Inc.**							
25	Warrick	Warrick	782	2,937	927			
	State Line Energy LLC							
26	State Line Energy	Lake	513	1,024				

[1] Source: U.S. DOE, U.S. Federal Energy Regulatory Commission (FERC). Existing generating plants as of January 1, 2001.
[2] Source: Indiana Department of Environmental Management (IDEM), Office of Air Management, Annual Emission Inventory Database.
[3] Data from (2)-(5), (8)-(9) and (12)-(26) are based on Indiana Department of Environmental Management (IDEM) Annual Emission Inventory Database. Data available only for plants with generating capacity greater than 50 MW. Data unavailable for Duke Energy, Tanners Creek. The plant utilizes western coal and all electricity is used in the Chicago, IL area.
[4] Bailly Station
[5] Plants with scrubbers
[6] Plant with cofiring
[7] "Origin" also includes Eastern Kentucky coal from unspecified counties. Could be Interior or Eastern coal.

Figure 3

Major coal-burning industrial and institutional plants

Investor-owned, cooperative, and municipal coal-burning electric power plants



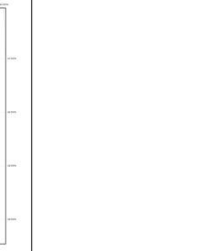


Table 10. Major coal-burning industrial and institutional plants

ID	NAME	County	City	Tons of Coal/2004
27	A.E. Staley Sagamore Operation	Tippecanoe	Lafayette	67,644
28	AGC Division - Alcoa Power Generating	Warrick	Newburgh	2,004,391
29	Bayer Corp. Elkhart Plant	Elkhart	Elkhart	39,000
30	Bunge North America(East), L.L.C.	Adams	Decatur	96,211
31	C.C. Perry K Steam Plant	Marion	Indianapolis	134,675
32	Cargill Corn Milling Div.	Tippecanoe	Lafayette	0
33	Colonial Brick Corp.	Vanderburgh	Evansville	4,892
33	DaimlerChrysler Corp Transmission Plant	Howard	Kokomo	25,698
34	Dow AgroSciences LLC - Tippecanoe	Tippecanoe	Lafayette	38,000
35	Eli Lilly & Company - Tippecanoe Labs	Tippecanoe	Lafayette	58,555
36	F.Jasper 11th Ave.	Dubois	Jasper	193
37	F.Jasper Main St.	Dubois	Jasper	16,000
38	GE Plastics Mt. Vernon Inc	Posey	Mount Vernon	225,485
39	Griffin Industries, Inc. - Newberry	Greene	Newberry	6,865
40	Hoosier Energy Service Corp.	Monroe	Bloomington	2,475
41	Indiana Veneer Corp.	St. Joseph	Mishawaka	11,846
42	International Paper Co.	Vigo	Terre Haute	77,472
43	Jasper Chair Co.	Dubois	Jasper	118
44	Jasper Wood Prod.	Dubois	Jasper	42
45	K.I.C. Inc. - Plant 1	Dubois	Jasper	1,000
46	Keller Manufacturing Co., Inc.	Harrison	Corydon	555
47	Kimball International	Dubois	Jasper	118
48	Kimball Office Furniture	Daviess	Washington	120,000
49	Muscatatuck State Hospital & Training	Jennings	Butlerville	1,072
50	New Energy Corp.	St. Joseph	South Bend	115,799
51	Nucor Steel Indiana (CSI)	Clark	Jeffersonville	21,000
52	Pfizer Inc.	Vigo	Terre Haute	21,108
53	Purdue University - Wade Utility Plant	Tippecanoe	West Lafayette	180,184
54	Rexam Beverage Can Co.	Posey	Mt. Vernon	29,000
55	Saint Joseph's College	Jasper	Rensselaer	2,812
56	Tate & Lyle: Lafayette South	Tippecanoe	Lafayette	86,922
57	University Of Notre Dame Du Lac	St. Joseph	Notre Dame	75,344

Source: Indiana Department of Environmental Management (2004)

PREPARATION OF THIS MAP WAS FUNDED BY THE INDIANA CENTER FOR COAL TECHNOLOGY RESEARCH

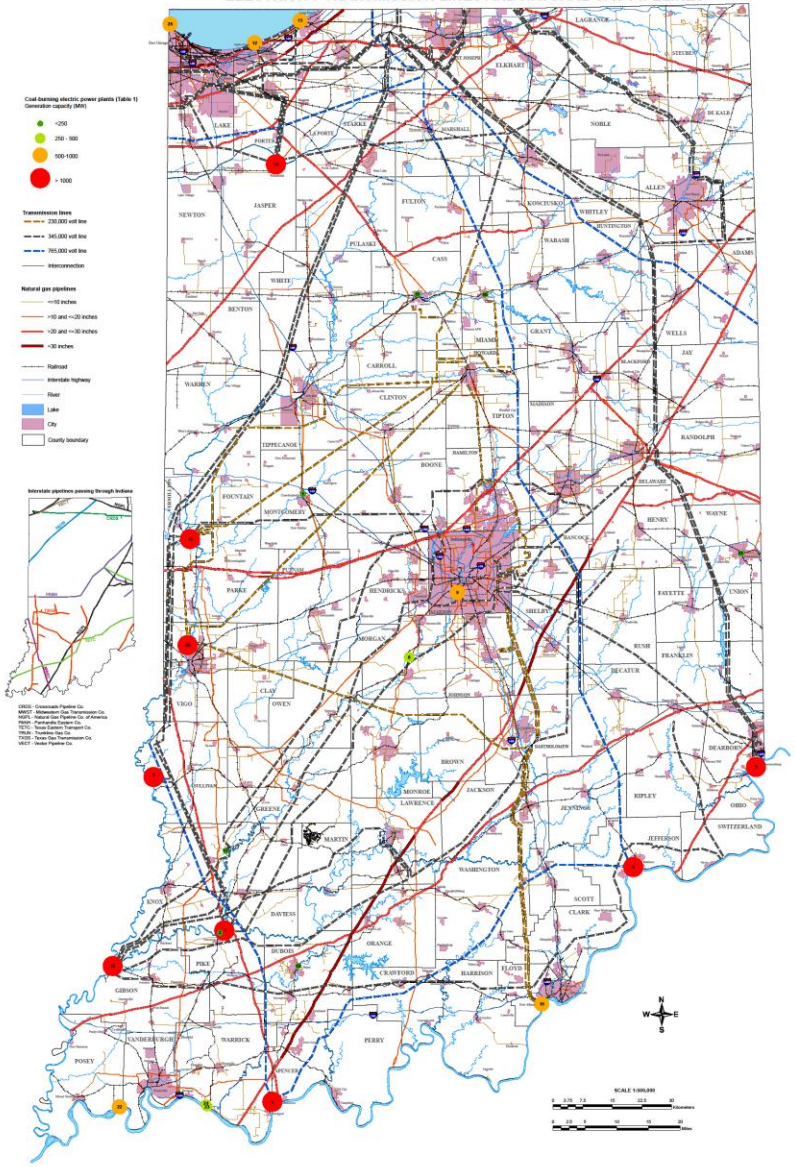
Coordinate system: UTM NAD83 Zone 16

COAL, ELECTRICITY, AND GAS TRANSPORTATION SYSTEMS IN INDIANA

Compiled by Agnieszka Drobniak, Maria Mastalerz and Kathryn Shaffer

May 2006

ELECTRICITY TRANSMISSION LINES AND NATURAL GAS PIPELINES



SURFACE AND UNDERGROUND COAL MINES

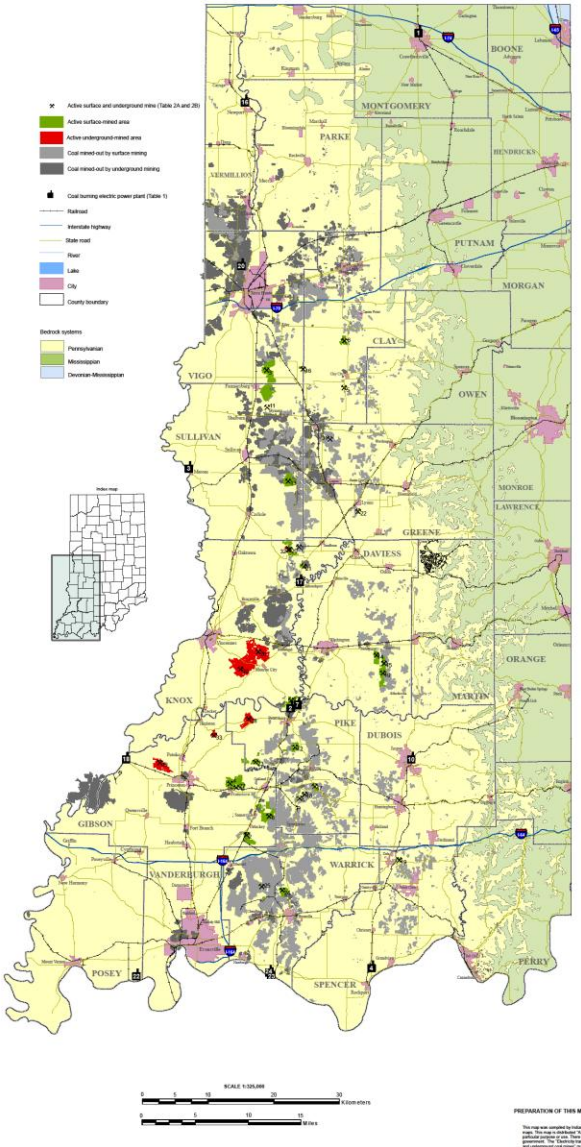


Table 1. Investor-owned, cooperative, and municipal coal-burning electric power plants

ID	Company / Plant Name[1]	County	Generation Capacity (MW)[2]
	Cinergy/Cincinnati Gas & Light & Power Co.		
1	Cayuga	Montgomery	22
	Hoosier Energy/R.E.C.I. Inc.		
2	Frank E. Ratts	Pike	234
3	Merom	Sullivan	1,000
	Indiana Michigan Power Co.		
4	Rockport	Spencer	2,600
5	Tanners Creek	Dearborn	1,021
	Indiana Kentucky Electric Corp.		
6	Clifty Creek	Jefferson	1,304
	Indianapolis Power & Light Co.		
7	Petersburg	Pike	1,613
8	Eagle Valley (formerly Pritchard)	Morgan	382
9	Harding Street (formerly Elmer W. Stout)	Marion	858
	City of Jasper		
10	Jasper 2	Dubois	15
	City of Logansport		
11	Logansport	Cass	43
	Northern Indiana Public Service Co.		
12	Bailly	Porter	610
13	Dunlap City	La Porte	340
14	R. M. Schahfer	Jasper	1,944
	City of Peru		
15	Peru	Miami	30
	PSI Energy Inc.		
16	Cayuga	Vermillion	1,062
17	Clifty Creek	Knox	713
18	Gibson	Gibson	3,340
19	Tanners Creek	Dearborn	1,000
20	Wabash River	Vigo	1,165
	City of Richmond		
21	Whitewater Valley	Wayne	64
	Southern Indiana Gas & Electric Co.		
22	A. B. Brown	Posey	531
23	F. B. Culley	Warrick	415
	Southern Indiana Gas & Electric Co. and Alcoa Generating Corp.		
24	Warrick	Warrick	742
	State Line Energy LLC		
25	State Line Energy	Lake	513

[1] Source: U.S. DOE, Energy Information Administration (EIA), Electric power industry 2004 data, Utility data, Table 2. Plant data, Table 2.
[2] Net generation, 2003 (Coal, natural gas, petroleum coke, fuel oil and burning other fuels at mixed fuel plant, other fossil-fuelled energy sources).

Table 2A. Active surface mines in Indiana as of February 2006

ID	Company / Surface Mine Name	County	Year opened
	A. B. Mining, Inc.		
1	Dogwood	Knox	1990
	Black Beauty Coal Company		
2	Dreyerburg #1, Somerville South Pit	Gibson	1993
3	Cannerburg #1, South Pit	Sullivan, Vigo	1996
4	Francisco	Gibson	1996
5	Francisco, Jordan Pit	Gibson	2000
6	Miller Creek, Sugar Ridge[1]	Clay	2001
7	Miller Creek, Knox Pit	Clay	2001
8	Somerville #1, Somerville Central	Gibson	1996
9	Stanford, Pike Pit	Pike	1996
10	Viking, Canning Pit	Daviess	1995
	Coal Field Development Company		
11	Carlisle Mine	Sullivan	2000
	Knox Mining, Inc.		
12	Knox#2, White Church Pit[2]	Pike	1974
13	Knox#3, Mt. Olive Pit[2]	Sullivan	1987
	Solar Sources, Inc.		
14	Cannelburg	Daviess	1979
15	Cannelburg, Midway II Pit[3]	Daviess	1979
16	Midway	Clay, Vigo	2001
	Triad Mining, Inc.		
17	Augusta	Pike	2002
18	Augusta South	Pike	2002
19	Fort Branch	Gibson	1995
20	Freelandville	Knox	1995
21	Freelandville, East Pit	Knox	1995
22	Oaklands	Gibson	1995
23	Patoka River	Gibson, Pike	1995
	Vigo Coal Company, Inc.		
24	Cypress Creek	Warrick	1995
25	Hangover[4]	Warrick	2001

Table 2B. Active underground mines in Indiana as of February 2006

ID	Company / Underground Mine Name	County	Year opened
	Black Beauty Coal Company		
26	Dogwood Underground	Knox	1993
27	Francisco Underground	Gibson	2003
	Five Star Mining, Inc.		
28	Prosperity	Pike	2000
	Gibson County Coal, LLC		
29	Gibson County	Gibson	2000
	Solar Sources, Inc.		
30	Oaklands	Knox	1994
	Sunrise Coal, LLC		
31	Howesville	Greene	2000
	Vigo Coal Company		
32	Freelandville Underground	Knox	2001
	White River Coal, Inc.		
33	Hazleton	Gibson	2003

Source: Indiana Department of Natural Resources, Division of Reclamation, 2005.
[1] In reclamation.
[2] Closed and sold in 2004.
[3] Closed and sold in 2004. Still leased under mine ownership.
[4] Closed and sold in 2004. Still leased under mine ownership. Resume production in the late 2006.
[5] Mined-out underground.
[6] Mined-out underground.

INDIANA GEOLOGICAL SURVEY
OPEN-FILE STUDY 06-03

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PREPARATION OF THIS MAP WAS FUNDED BY THE INDIANA CENTER FOR COAL TECHNOLOGY RESEARCH

Coordinate system: UTM 83 Zone 16

"Electricity transmission lines and natural gas pipelines" map is intended for use only at the published scale of 1:500,000. The "Surface and underground coal mines" map is intended for use only at the published scale of 1:325,000. A detailed on-the-ground survey and historical analysis of a single site may differ from this map.

Transmission lines modified after Indiana Electric Association, June 1, 1995.

MAJOR POINT SOURCES OF CO_2 EMISSIONS AND CONCEPTUAL GEOLOGICAL SEQUESTRATION STRATEGIES IN INDIANA

Compiled by Agnieszka Drobniak, Kathryn Shaffer, John Rupp, and Maria Mastalerz

MAJOR SOURCES OF CO_2 EMISSIONS (METRIC TONS/YEAR)

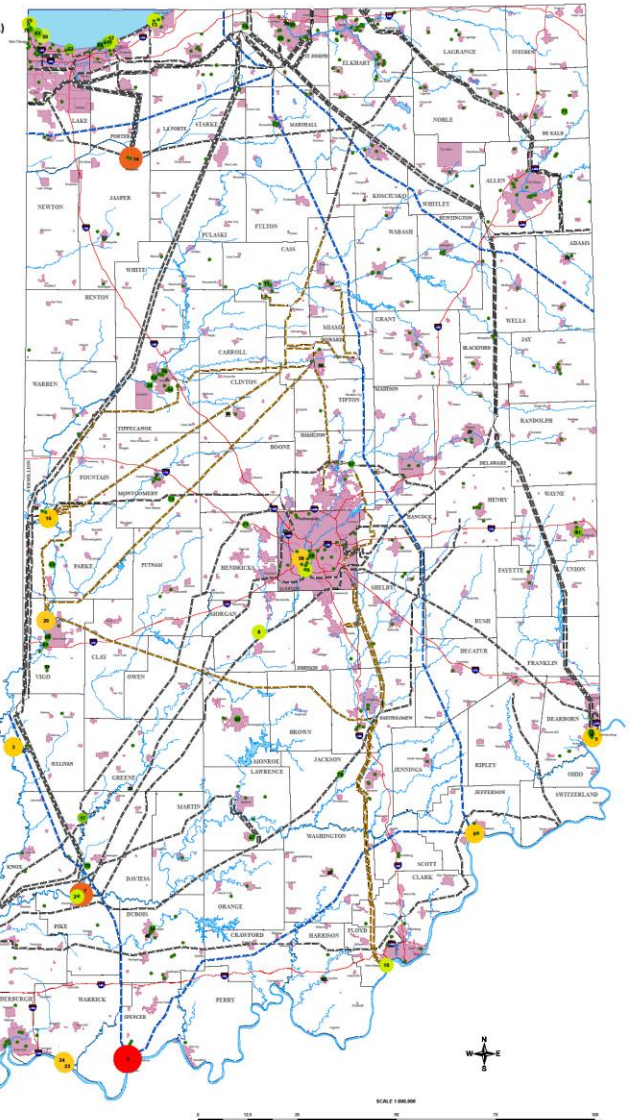
- Less than 100,000
- 100,000 to 500,000
- 500,000 to 1,000,000
- 1,000,000 to 5,000,000
- 5,000,000 to 10,000,000
- 10,000,000 to 15,000,000
- More than 15,000,000

Transmission line capacity
(line capacity smaller than 230,000 volt is not included)

- 765,000 volt
- 345,000 volt
- 230,000 volt
- Interconnection

Other

- Interstate highway
- Rivers
- Lakes
- Municipalities
- County boundaries



MAJOR SOURCES OF CO_2 EMISSIONS [in metric tons]

(1 metric ton = 1.102 short ton)

1) Coal-burning facilities:

a) Electric power plants

ID	Company / Plant Name[1]	County	Generation capacity (MW)[2]	CO_2 emissions (metric tons/year)[3]
	Cloverdale Electric Light & Power Co.			
1	Cloverdale	Montgomery	25	67,076
	Hoosier Energy REC Inc.			
2	Frank E. Ratts	Pike	234	1,497,883
3	Merom	Sullivan	1,080	6,135,071
	Indiana Michigan Power Co.			
4	Rockport	Spencer	2,600	15,193,730
5	Tanners Creek	Dearborn	1,021	3,547,559
	Indiana Kentucky Electric Corp.			
6	Clifty Creek	Jefferson	1,304	7,479,077
	Indianapolis Power & Light Co.			
7	Petersburg	Pike	1,073	11,484,794
8	Perry K (formerly Pritchard)	Marion	32	1,000,128
9	Harding Street (formerly Elmer W. Stout)	Marion	868	5,057,120
	City of Jasper			
10	Jasper 2	Dubois	15	100,659
	City of Logansport			
11	Logansport	Cass	43	276,501
	Northern Indiana Public Service Co.			
12	Bailly	Porter	618	3,933,084
13	Michigan City	LaPorte	469	2,986,000
14	R. M. Schahfer	Jasper	1,044	10,076,556
	City of Peru			
15	Peru	Miami	35	46,670
	Duke Energy Indiana			
16	Cayuga	Vermillion	1,062	6,383,760
17	Cinergy Gallagher	Clark	113	653,087
18	Gibson	Gibson	3,340	19,006,600
19	R. Gallagher	Floyd	600	3,138,287
20	Wabash River	Vigo	1,165	4,556,369
	City of Richmond			
21	Whitewater Valley	Wayne	64	828,284
	Southern Indiana Gas & Electric Co.			
22	A. B. Brown	Posey	531	2,804,506
23	F. B. Culley	Warrick	415	3,080,630
	Southern Indiana Gas & Electric Co. and Alcoa Generating Corp.			
24	Warrick	Warrick	742	6,175,675
	State Line Energy LLC			
25	State Line Energy	Lake	613	3,117,786
	SUBTOTAL		21,062	110,004,410

b) Industries and institutions

ID	Company Name[4]	County	City	CO_2 emissions (metric tons/year)[5]
26	A.E. Staley Sugarcane Operation	Tippecanoe	Lafayette	165,147
27	Ball State University	Delaware	Muncie	75,607
28	Bunge North America (East), LLC	Adams	Decatur	96,207
29	C.C. Perry II Steam Plant	Marion	Indianapolis	389,518
30	Cargill Corn Milling, Inc.	Vermillion	Clinton	0
31	Colonial Brick Corp.	Vermillion	Cayuga	13,403
32	Daimler/Chrysler Corp. Transmission Plant	Howard	Kokomo	70,405
33	Eli Lilly & Company - Clinton Labs	Vermillion	Clinton	171,850
34	Eli Lilly & Company - Tippecanoe Labs	Tippecanoe	Lafayette	105,868
35	Fairfax Power Plant	Marion	Indianapolis	0
36	Frito-Lay, Inc.	Clinton	Frankfort	46,828
37	GE Plastics Mt. Vernon Inc.	Posey	Mount Vernon	628,748
38	Griffin Industries, Inc. - Newberry	Greene	Newberry	27,627
39	Holy Cross Services Corp.	St. Joseph	Notre Dame	7,607
40	Indiana University	Monroe	Bloomington	180,231
41	International Paper Co.	Vigo	Terre Haute	212,252
42	Jasper Chair Co.	Dubois	Jasper	322
43	Jasper Wood Prod.	Dubois	Jasper	115
44	Jofco Pt 1 & 2	Dubois	Jasper	540
45	Kimball Manufacturing Co., Inc.	Dubois	Jasper	1,338
46	Kimball International	Dubois	Jasper	323
47	Lehigh Cement Company	Lawrence	Mitchell	357,158
48	Methodist State Hospital & Training	Jennings	North Vernon	1,107
49	New Energy Corp.	St. Joseph	South Bend	317,207
50	Pennsylvania LGA	Daviess	Lawrenceburg	153,629
51	Pfizer, Inc.	Vigo	Terre Haute	57,639
52	Purdue University - Water Utility Plant	Tippecanoe	West Lafayette	493,851
53	Rockport Cogeneration	Spencer	Rockport	1,000
54	Tate & Lyle, Lafayette South	Tippecanoe	Lafayette	232,860
55	University Of Notre Dame Du Lac	St. Joseph	Notre Dame	299,166
	SUBTOTAL			4,002,942

2) Major natural-gas burning sources (greater than 100,000 metric tons/year)[6]

ID	Company Name[4]	County	CO_2 emissions (metric tons/year)[5]
56	Duke Energy - Wabash River	Vigo	6,153,539
57	SIGECO - F.B.Culley Generating Station	Warrick	6,088,515
58	Daimler/Chrysler Corporation Foundry	Marion	5,468,668
59	Hoosier Energy, LLC	Lake	1,041,348
60	Indiana Gas Company	Floyd	1,000,000
61	ISG Burns Harbor, LLC	Porter	726,326
62	US Steel Corp. Gary Works	Lake	707,971
63	Whiting Clean Energy, Inc.	Lake	510,084
64	ArcelorMittal USA (Indiana Harbor West)	Lake	502,019
65	Cinergy - Madison Plant	Jefferson	483,214
66	Portside Energy Corporation	Porter	213,023
67	Duke Energy - Noblesville	Hamilton	206,182
68	Mount Sugar Creek, LLC	Vigo	155,985
69	Duke Energy - Cayuga	Vermillion	153,563
70	Grain Processing Corporation	Clarke	100,075
71	Steel Dynamics - Iron Operations	De Kalb	173,060
72	Nucor Steel Corp	Montgomery	143,029
73	Arcelor Inc. - Warrick Operations	Warrick	140,223
74	PSEG Lawrenceburg Energy Company, Inc.	Dearborn	116,602
75	Cinergy - Gibson	Gibson	114,852
76	Ute Tax Ute Kokomo Combined	St. Joseph	108,148
77	Steel Dynamics, Inc. (SDI) Bar Products	Hendricks	105,524
	SUBTOTAL OF LISTED		26,304,583
	ALL NATURAL-GAS BURNING SOURCES		30,402,977

3) Major wood-burning sources (greater than 100,000 metric tons/year)[6]

ID	Company Name	County	CO_2 emissions (metric tons/year)[5]
78	Rose Acre Farms, Inc., Soybean Processing	Jackson	557,892
	ALL WOOD-BURNING SOURCES		621,604

Emission sources	CO_2 emissions (metric tons/year)
Coal-burning electric power plants	110,004,410
Major coal-burning industrial and institutional plants	4,052,962
Natural-gas industrial generators	30,402,977
Wood-burning industries	621,834
Oil-burning industries[7]	96,949
TOTAL	**153,659,138**

1 U.S. Federal Energy Regulatory Commission (FERC), Existing generating plants as of January 1, 2005, unpublished data.
2 Megawatt-data include coal-burning units, but not solid-burning other fuels, therefore, these numbers may not match used fuelers published elsewhere.
3 U.S. Environmental Protection Agency (EPA) emissions data (EPA, 2006). Where emissions data is unavailable through that source, they are calculated using emission factor (EPA, 1998c) and consumption data (Indiana Department of Environmental Management, unpublished data).
4 Indiana Department of Environmental Management, unpublished data.
5 Where emissions data is unavailable through EPA, they are calculated using emission factor (EPA, 1998c) and consumption data (Indiana Department of Environmental Management, unpublished data).
6 Includes top 25 CO_2-emitters by volume of emissions. Total number of natural-gas burning sources in the state is 417.
7 Calculated from Indiana Department of Environmental Management data.
8 Calculated from Indiana Department of Environmental Management natural gas consumption data using an EPA emission factor (EPA, 1998c).
9 Major CO_2-emitter by volume of emissions. Total number of heavy-wood-burning sources in the state is 31.
10 Calculated from Indiana Department of Environmental Management wood-burning consumption data using an EPA emission factor (EPA, 1998c).
11 Calculated from Indiana Department of Environmental Management fuel oil consumption data using an EPA emission factor (EPA, 1998c).

CONCEPTUAL GEOLOGICAL SEQUESTRATION STRATEGIES FOR CO_2 IN INDIANA

Potential geological sequestration includes four options:

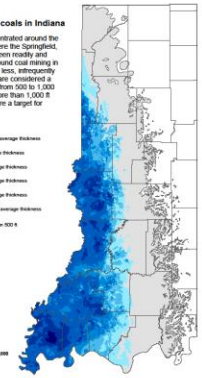
1) Adsorption within coal seams that are too deep or too inferior in quality to mine;
2) Isolation in mature or depleted oil and natural gas reservoirs;
3) Storage in deep, saline-water-filled formations;
4) Adsorption in organic-rich shales.

Further evaluation to determine ability of these four conceptual geological sequestration strategies is ongoing.

1) CO_2 storage potential for major coals in Indiana

Coal mining in Indiana has been concentrated around the eastern margin of the Illinois Basin where the Springfield, Danville, and other coal seams have been readily and economically accessed. Most underground coal mining in Indiana has been at depths of 300 ft or less, infrequently to 500 ft. Coals from 1.5 to 3.5 ft thick are considered a target for CO_2 sequestration at depths from 500 to 1,000 ft. Additionally, all coals at depths of more than 1,000 ft are considered unminable, and therefore a target for sequestration.

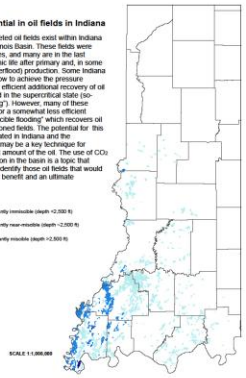
- Less or equal 0 ft cumulative average thickness
- >0 to 10 ft cumulative average thickness
- >10 to 15 ft cumulative average thickness
- >15 to 20 ft cumulative average thickness
- >20 to 25 ft cumulative average thickness
- Greater than 25 ft cumulative average thickness
- Area excluded, depth less than 500 ft



2) CO_2 storage potential in oil fields in Indiana

Many mature and depleted oil fields exist within Indiana and the surrounding Illinois Basin. These fields were developed over decades, and many are in the last phases of their economic life after primary and, in some cases, secondary (waterflood) production. Some Indiana fields may be too shallow to achieve the pressure necessary for the most efficient additional recovery of oil in which CO_2 is injected in the supercritical state (so-called "miscible flooding"). However, many of these fields are appropriate for a somewhat less efficient process termed "immiscible flooding" which recovers oil otherwise left in abandoned fields. The potential for this process is being evaluated in Indiana and the surrounding basin and may be a key technique for recovering a significant amount of the oil. The use of CO_2 to enhance oil production in the basin is a topic that needs further study to identify those oil fields that would offer both an economic benefit and an ultimate repository for CO_2.

- Predominantly immiscible (depth <2,500 ft)
- Predominantly near-miscible (depth <2,500 ft)
- Predominantly miscible (depth >2,500 ft)



3) CO_2 storage potential in the Mt. Simon sandstones in Indiana

The CO_2 sequestration option having the largest potential volume among the four geologic strategies is injection into deep saline-water-filled formations. These reservoirs or aquifers are typically composed of porous and permeable sandstone overlain by thousands of feet of impermeable shale and other sedimentary rock. The water in some of these formations, at depths of 3,000 to 5,000 ft, has two to three times the salinity of seawater and is not usable as a potable water resource. Many of the large natural gas storage fields located within the basin already use these units for the storage of gas. Injection of CO_2 into these formations, where it would be contained in the same manner that natural gas and oil have been contained for millions of years, offers enormous sequestration potential. One of the major geologic units potentially suitable for CO_2 sequestration is the Mt. Simon Sandstone, a rock unit that underlies much of the Illinois Basin. The geology of the Mt. Simon makes it an excellent storage unit and the cap-rock seal of the Eau Claire Shale has proven its performance as a seal containing natural gas.

Depth [ft]

- Less or equal 3,000
- >3,000 to 4,000
- >4,000 to 5,000
- >5,000 to 6,000
- >6,000 to 7,000
- >7,000 to 8,000
- >8,000 to 9,000
- >9,000 to 10,000
- >10,000 to 11,000
- >11,000 to 12,000
- >12,000 to 13,000
- >13,000 to 14,000
- >14,000 to 15,000
- Greater than 15,000

4) CO_2 storage potential in New Albany Shales in Indiana

Some of the shales in Indiana are very rich in organic material, hence the name "black" shales. The organic matter in these shales has the potential to adsorb CO_2 in the same manner as organic matter in coal beds. Because these shales are hundreds of feet thick and lie at great depths, they serve as an additional option for carbon sequestration. And in a similar manner as injection into coal beds, the potential exists for producing additional natural gas or methane as the CO_2 is injected.

Thickness [ft]

- Less or equal 100
- >100 to 150
- >150 to 200
- >200 to 250
- >250 to 300
- Greater than 300
- Area excluded, depth less than 500 ft
- 2,500 ft depth contour line

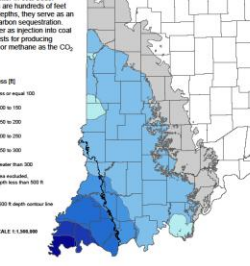


Table showing semi-quantitative estimates of CO_2 storage capacities [metric tons].

	Low estimate	Most probable estimate	High estimate
Major coal beds[1]	77,190,900	185,767,000	307,418,000
Oil fields[1]	15,306,979	30,613,956	48,024,955
Mt. Simon Sandstone[2]	15,209,300,000	38,023,250,000	60,837,200,000
New Albany Shales[3]	6,825,000,000	7,800,000,000	12,675,000,000

1 Values for sequestration capacity in coals and oil fields were calculated using methods reported in the Midwestern Geological Sequestration Consortium Phase 1 investigation (2005).

2 Values for sequestration capacity in saline aquifers were calculated using the standardized methods as reported in the 2008 report by the Capacity and Fairways Subgroup of the Geologic Working Group of the DOE Carbon Sequestration Regional Partnerships. Values for x = 1%, 2.5% and 4% for low, most probable, and high estimates, respectively.

3 Values for sequestration capacity in shales were calculated using methods reported in Solano-Acosta and others (2004). Values for solfrac = 30, 50 and 80 for low, most probable, and high estimates respectively.

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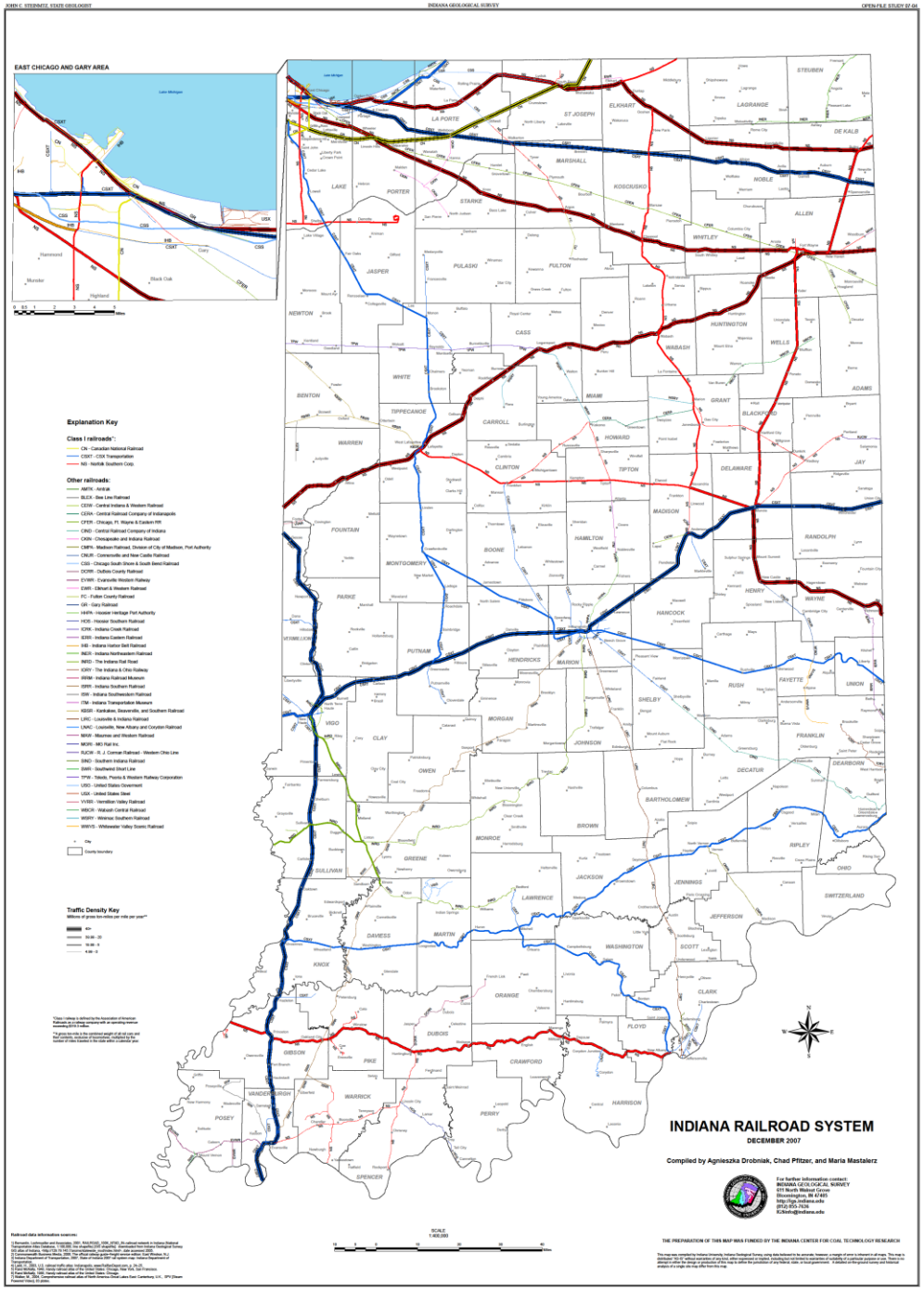
Coordinate system: UTM NAD83 Zone 16


JOHN C. STEINMITZ, STATE GEOLOGIST
INDIANA GEOLOGICAL SURVEY
OPEN-FILE STUDY 07-04
EAST CHICAGO AND GARY AREA
Explanation Key
Class I railroads*:
CN - Canadian National Railroad
CSXT - CSX Transportation
NS - Norfolk Southern Corp.
Other railroads:
AMTK - Amtrak
BLEX - Bee Line Railroad
CERW - Central Indiana & Western Railroad
CERA - Central Railroad Company of Indianapolis
CFER - Chicago, Ft. Wayne & Eastern RR
CIND - Central Railroad Company of Indiana
CKIN - Chesapeake and Indiana Railroad
CMPA - Madison Railroad, Division of City of Madison, Port Authority
CNUR - Connersville and New Castle Railroad
CSS - Chicago South Shore & South Bend Railroad
DCRR - DeBoss County Railroad
EVWR - Evansville Western Railway
EWR - Elkhart & Western Railroad
FC - Fulton County Railroad
GR - Gary Railroad
HHPA - Hoosier Heritage Port Authority
HOS - Hoosier Southern Railroad
ICRR - Indiana Creek Railroad
IERR - Indiana Eastern Railroad
IHB - Indiana Harbor Belt Railroad
INER - Indiana Northeastern Railroad
INRD - The Indiana Rail Road
IORY - The Indiana & Ohio Railway
IRRM - Indiana Railroad Museum
ISRR - Indiana Southern Railroad
ISW - Indiana Southwestern Railroad
ITM - Indiana Transportation Museum
KBSR - Kankakee, Beaverville, and Southern Railroad
LRC - Louisville & Indiana Railroad
LNAC - Louisville, New Albany and Corydon Railroad
MWR - Miami-see and Western Railroad
MCRR - MG Rail Inc.
RJCW - R. J. Corman Railroad - Western Ohio Line
SIND - Southern Indiana Railroad
SWR - Southwind Short Line
TPW - Toledo, Peoria & Western Railway Corporation
USG - United States Government
USX - United States Steel
VVRR - Vermilion Valley Railroad
WBCR - Wabash Central Railroad
WSRY - Wildwood Southern Railroad
WWVS - Whitewater Valley Scenic Railroad
City
County boundary
Traffic Density Key
Millions of gross ton-miles per mile per year**
50.00 - 20
19.99 - 5
4.99 - 0
*Class I railway is defined by the Association of American Railroads as a Class I railway with an operating revenue exceeding $272.2 million.
** A gross ton-mile is the combined weight of all rail cars and locomotives in a train multiplied by the number of miles. The number of miles traveled in the state within a calendar year.
INDIANA RAILROAD SYSTEM
DECEMBER 2007
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SCALE
1:400,000


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