ASSESSMENT OF THE QUALITY OF INDIANA COALS FOR INTEGRATED GASIFICATION COMBINED CYCLE (IGCC) PERFORMANCE; ANALYSIS OF THE EXCISTING DATA AND PROPOSAL OF NEW RESEARCH

FINAL REPORT TO THE CENTER FOR COAL TECHNOLOGY RESEARCH

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INTRODUCTION - PROJECT JUSTIFICATION

Evaluating Indiana coals for IGCC is timely and important:

- **Indiana has significant coal reserves (~57 billion short tons, of which 17.5 billion tons is available for mining). 73% of coal produced in Indiana is used to generate electricity and more than 90% of electricity generated in Indiana comes from coal**

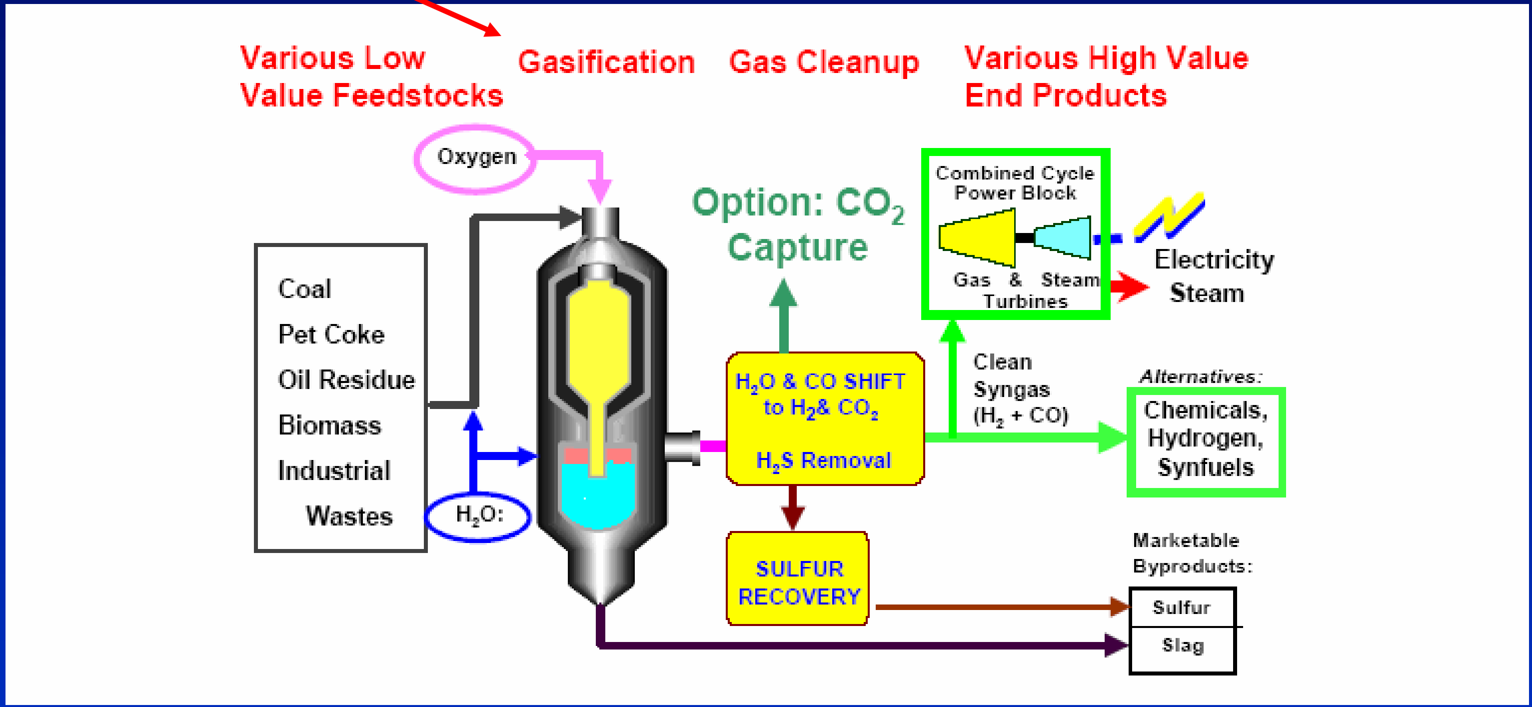
- **Burning Indiana coal causes serious environmental concerns because the majority of Indiana coals have high sulfur content**

- **Integrated Gasification Combined Cycle (IGCC), being one of Clean Coal Technologies, could help Indiana. IGCC can achieve 99% SO_2 removal, removing also Hg and CO_2 upstream of the combustion process**

Gasification:

1) Volatile pyrolysis – fast volatilization and compound degradation;
2) Char gasification

IGCC plant



In the IGCC process, plants turn coal to gas, removing most of the sulfur dioxide and other emissions before the gas is used to fuel a combustion turbine generator. The hot gases are then used to heat steam, driving a steam turbine generator.

PROJECT OBJECTIVES

1. **Identify coal properties that are important for IGCC and assess availability of these types of data for Indiana coal beds.**

2. **Outline future research needed to assess performance of Indiana coal during gasification:**
   a) Propose new laboratory analyses,
   b) Suggest strategy for modeling coal performance in IGCC units.

3. **Identify budgetary needs, time requirements, possible collaborations and sources of matching funds.**

PROJECT TASKS

PROJECT DURATION: MARCH 1 – NOVEMBER 30, 2005

Tasks	Activity	Deadline
Task 1	Identifying properties of major importance to IGCC performance of Indiana coals	April 30
Task 2	Assessing availability of data on coal that are critical for IGCC	June 31
Task 3	Identify areas in which more data are needed	August 31
Task 4	Propose new research and finalizing report	November 30

Task 1:

Identifying properties of major importance to IGCC performance of Indiana coals

1. **We performed intensive literature search on coal gasification from various sources and various countries. Based on the literature, we have identified major projects that are important references. Also based on the literature as well as our own research we have identified several parameters of coal quality that are very important for the performance in an IGCC system.**

2. **We developed summary tables that show how these coal properties influence IGCC behavior and what the requirements are for three types of gasifiers: fixed-bed gasifier, fluidized –bed gasifier, and entrained-flow gasifier.**

3. We visited IGCC plants to get acquainted with the process and the products

Example of a summary table for entrained flow gasifiers.

Parameter	Importance	Coal Requirements
Moisture	•influences gasifier efficiency (higher moisture - lower efficiency)	- A range of moisture contents are used
Volatile matter	•influences the extent and rate of gasification reactions	- A range of volatile matter contents are used
Heating value	•determines plant dimensions •influences generation capacity (higher heating value – higher capacity and efficiency)	- A range of heating values are used
Ash content	•influences net cycle efficiency (higher ash –lower efficiency) •influences flux addition rate	<25%
AFT (flow, reduction)	•influence melting ability of discharged slag (it needs to be melted below performance temperature •influences operating costs (higher temperature– higher costs)	<1500ºC
Slag viscosity	viscosity must be sufficiently low to ensure smooth slag flow down the gasifier walls	- Preferred <15Pa.s - Used up to 25 Pa.s
Char reactivity	•influence the extent of carbon conversion (higher reactivity – higher cycle efficiency) •influences oxygen consumption	- A range of reactivities can be used because of higher operational temperature
Sulfur	can cause corrosion of heat exchanger surfaces •influences operating costs (higher sulfur –higher costs)	- Preferred S<1.5%
Nitrogen	•contributes to NOx emissions	
Chlorine	•forming HCl can poison gas cleaning system catalysts •HCl can cause chloride stress corrosion	<0.4% (ad)

IGCC plant visits:
1) Eastman Gasification Plant, Kingsport, Tennessee

Facts:

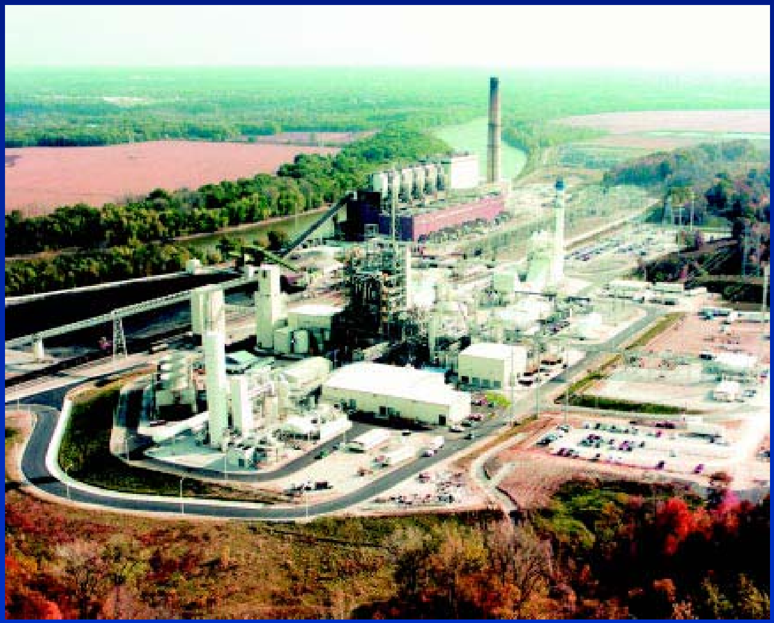
- Funded in 1920 as part of Eastman Kodak, wood to methanol plant
- It was the first commercial U.S. gasification facility in 1983
- 98-99% availability with a spare gasifier; >98% on-stream time since 1984
- Remove >99.9% sulfur and selable elemental sulfur and sulfuric acid
- Low cost vapor-phase removal >95% mercury (on activated carbon) for 22 years
- Low risk option for CO_2 capture, if needed
- Solid residue: vitrous non-reactive material, that of the larger grain size being sold, the smaller grain size is rich in carbon and is land filled

IGCC plant visits:
2) Polk Station Power Plant, Florida

Facts:

•Entrained flow one stage slurry fed gasifier –
GE Texaco Technology
•250MW plant opened in 1996 as DOE IGCC
demonstration project
•Remove >95% sulfur that is recovered as sulfuric acid
•>80% (>90% on-peak) availability with no spare gasifier
•No mercury removal, but low cost vapor-phase removal (like at Eastman) possible if needed
•Low risk option for CO_2 capture, if needed
•Solid residue as a vitrous slag; the larger grain size slag is sold to cement industry, the smaller grain size (rich in carbon) is recycled. Nothing is land-filled.

Plant visits:
3) Wabash River Gasification Plant



Facts:

- **Entrained flow two stage slurry fed gasifier Conoco Technology**
- **260MW plant opened in 1990 as DOE IGCC demonstration project**
- **Remove >95% sulfur that is recovered as sulfuric acid**

- **No mercury removal, but low cost vapor-phase removal possible if needed**

- **Solid residue as a vitrous slag. Currently the feed is 100% petroleum coke of very low mineral matter content and >5% S content. Because such a low MM content, old slag is added to the gasifier.**

Task 2:

Assessing availability of data on coal that are critical for IGCC

- A database in Microsoft Access format has been created.

	Moisture	Fixed C	Volatiles	Ash fusion temp.	Char reactivity	Slag viscosity
Danville	252	131	131	14	0	14
Hymera	135	110	110	0	0	0
Springfield	651	306	306	0	0	1
U. Block	99	82	82	11	0	11
L. Block	156	53	53	14	0	14

Good coverage ⟷ NO DATA

- Maps of selected parameters have been generated

Statistics of selected parameters for four coal beds from Indiana

	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	2095	2540	**2274**	12									1990	2800	**2399**	14
AFTred, soft	2155	2610	**2376**	12			no data				no data		2040	2800	**2445**	14
AFTred, hem	2210	2665	**2435**	12									2080	2800	**2491**	14
AFTred, final	2250	2753	**2502**	12									2170	2800	**2551**	14
Slag viscosity	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

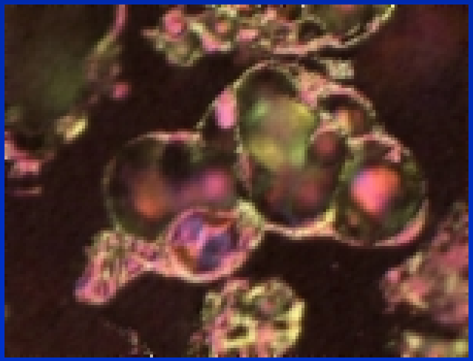
Task 3:

Identify areas in which more data are needed

- **Char reactivity –** important for two-stage gasifiers – no data

Gasification:
1) Volatile pyrolysis – fast volatilization and compound degradation;
2) Char gasification

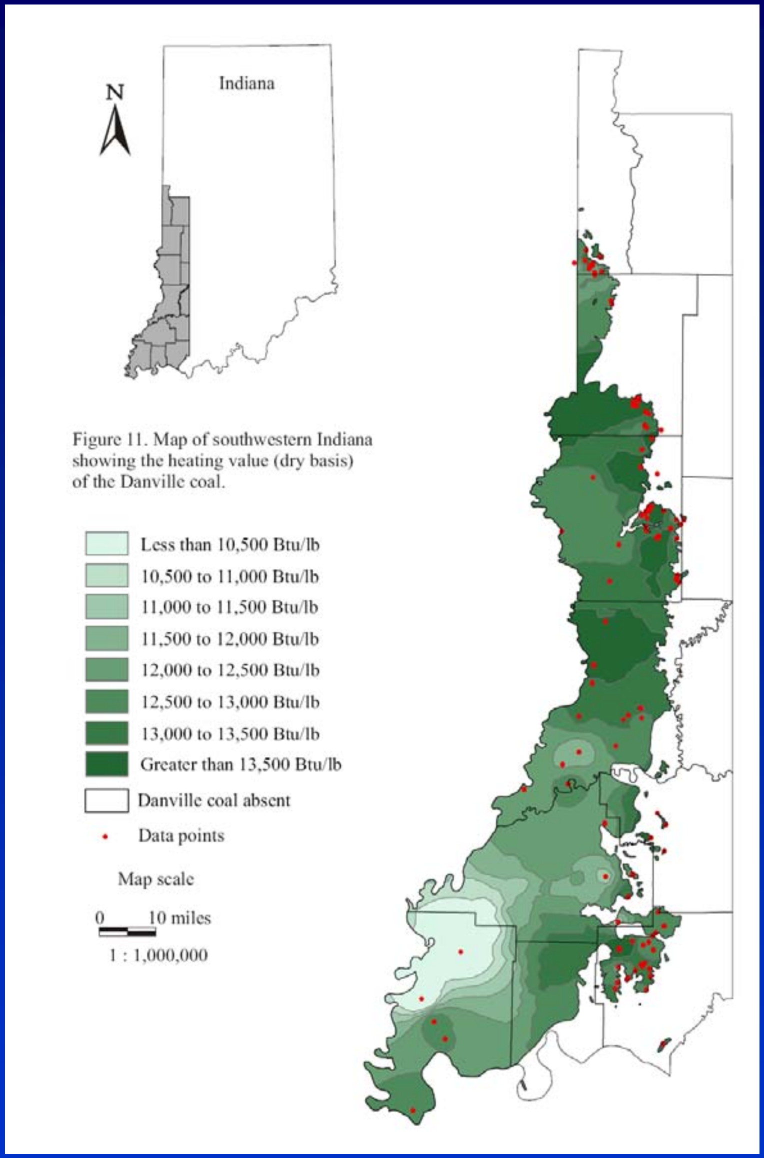
- **Ash chemical compositions** - limited data
- **Slag behavior –** critical for all gasifiers - very few data
- **Chlorine content –** insufficient data to show variability

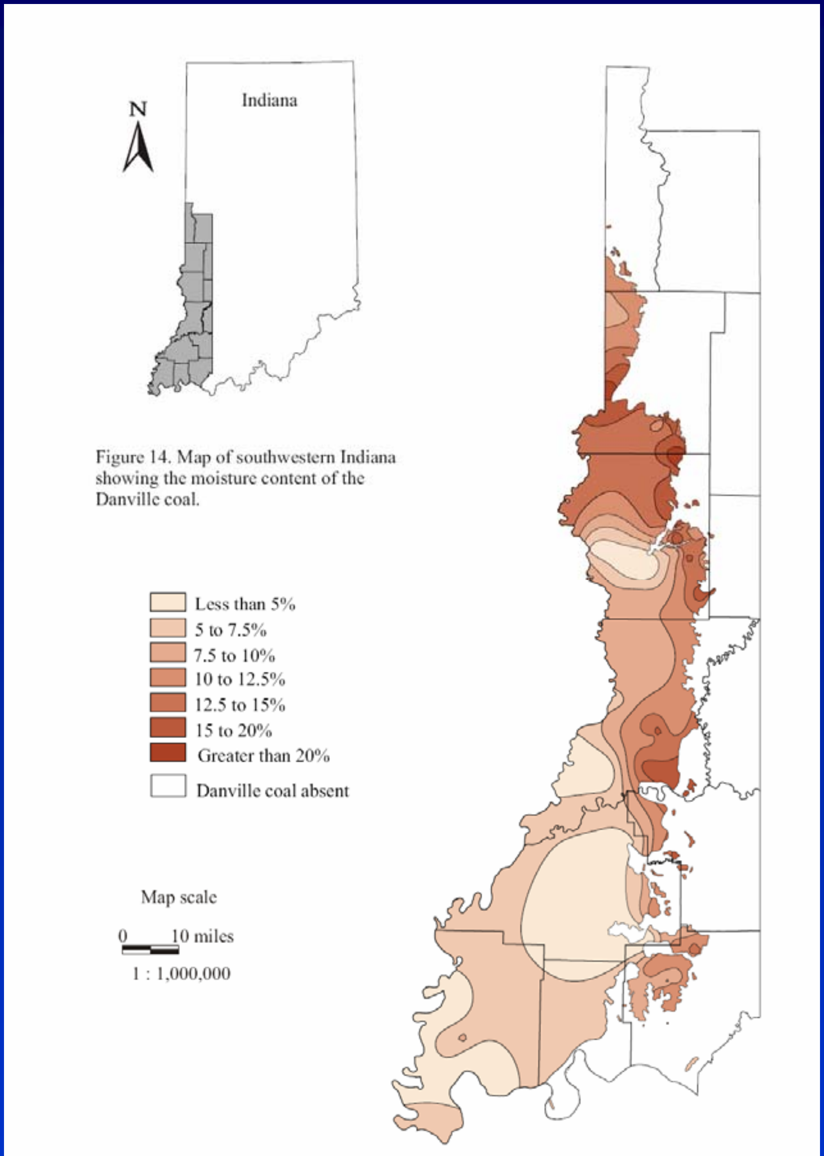


Preliminary evaluation of Indiana coals for IGCC

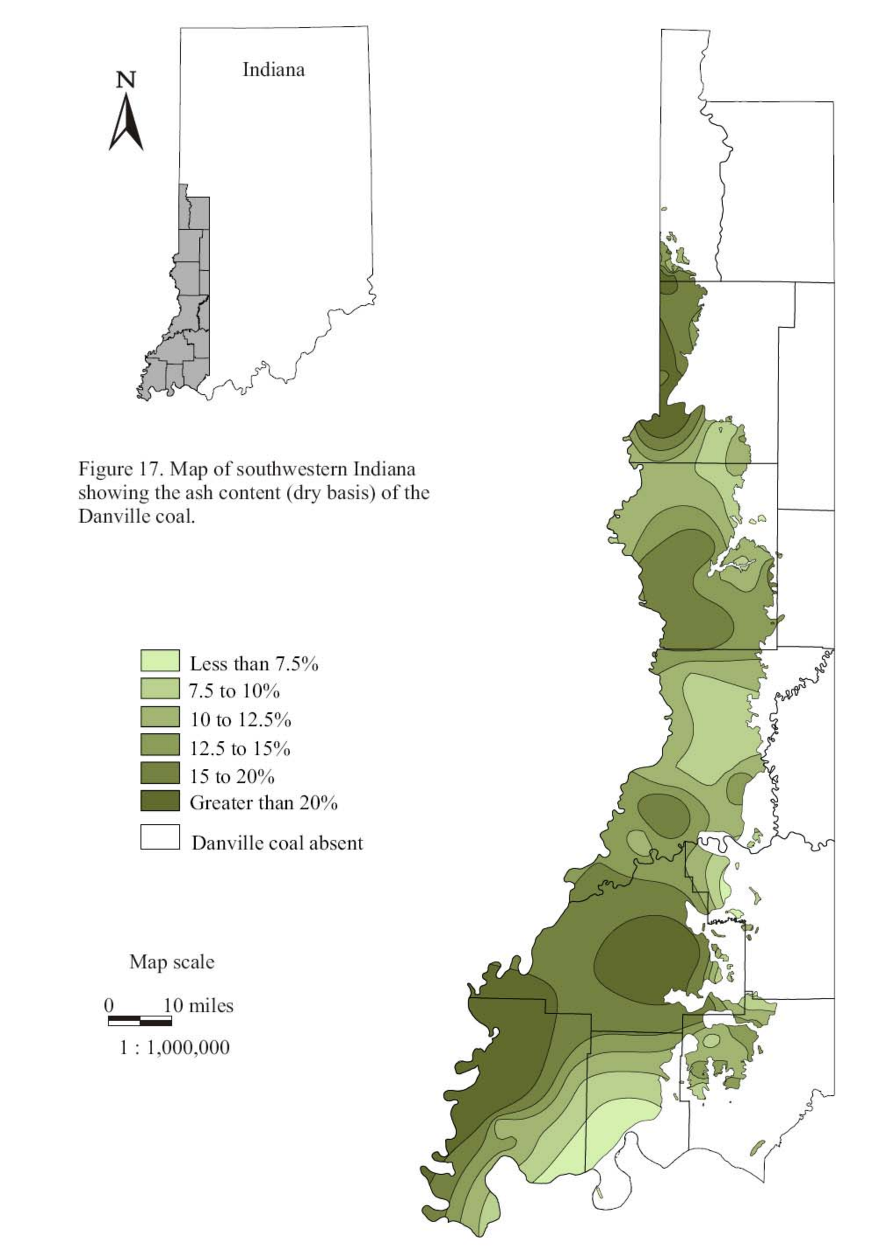
A. Based on coal quality parameters

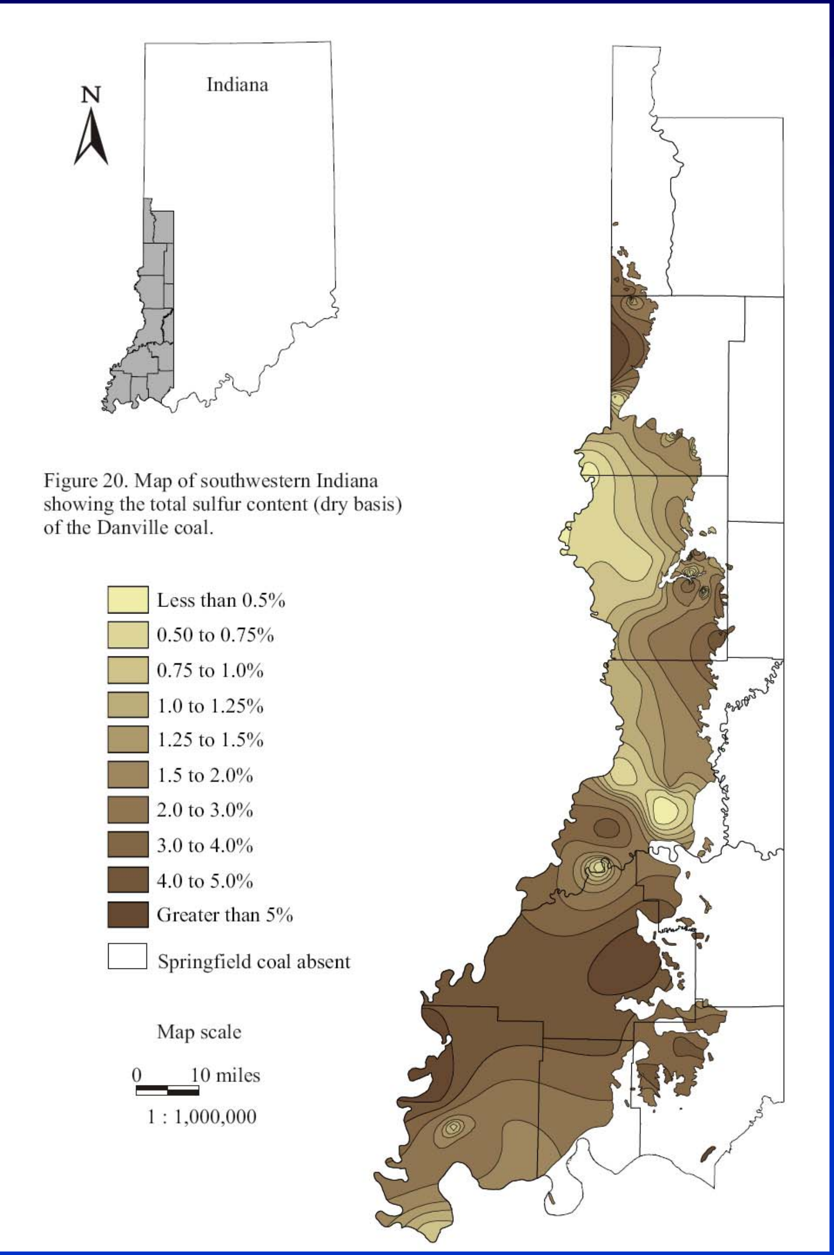
- Heating value
- Moisture content
- Ash yield
- Sulfur content
- Volatile matter content
- Fixed carbon





Favorable BTU and moisture content





Favorable ash and ideal sulfur content

Preliminary evaluation of Indiana coals for IGCC

B. Based on char reactivity

(conversion of the char per time unit)

-**Fuel ratio** - ratio between Fixed carbon and Volatile matter

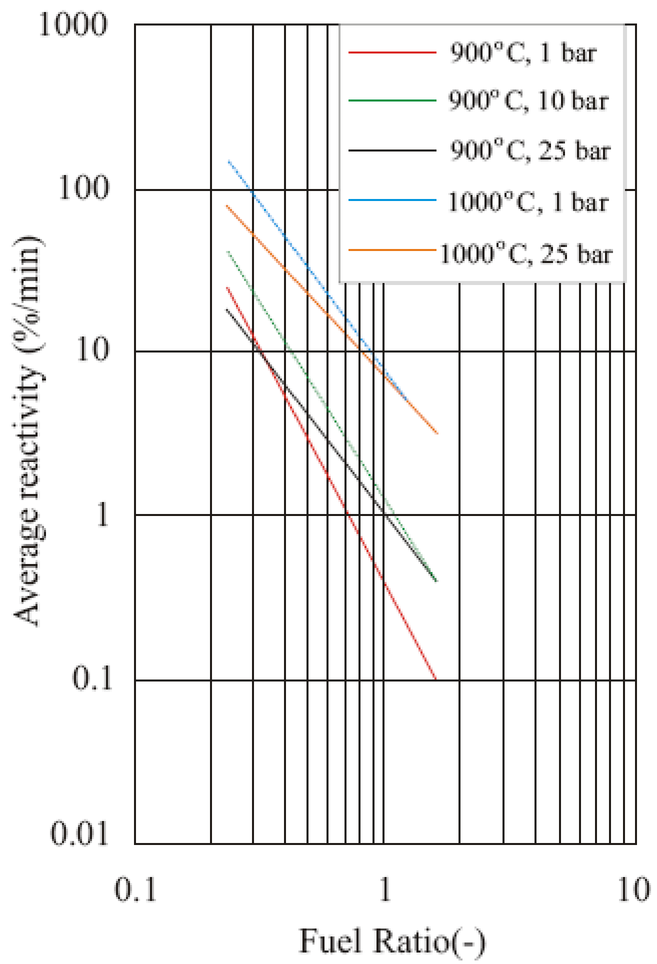
Char reactivity (%/min) = 1.92×10^{12} *exp (-33260/Temperature, K)* (Pressure, bar)$^{0.011}$ *(Fuel ratio-)$^{-1.22}$

- **Oxygen to carbon ratio**

Char reactivity (%/min) = 2.70×10^{14} *exp(-34452/Temperature, K)* (Pressure, bar)$^{0.012}$ * (O/C, mol/mol)$^{2.26}$

Zevenhoven and Hupa, 1997

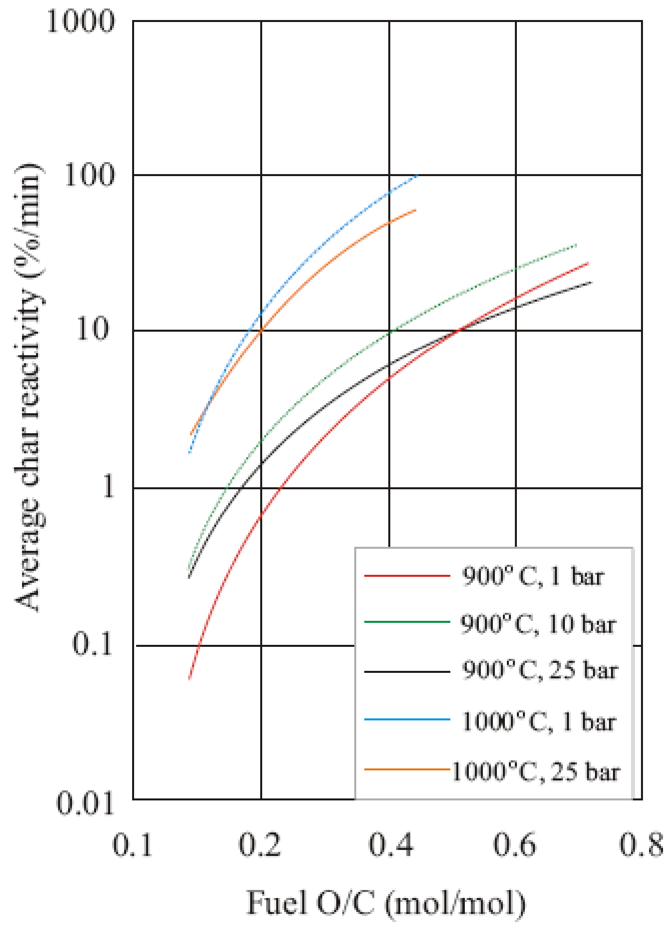
Higher fuel ratio - lower reactivity



Zevenhoven and Hupa, 1997

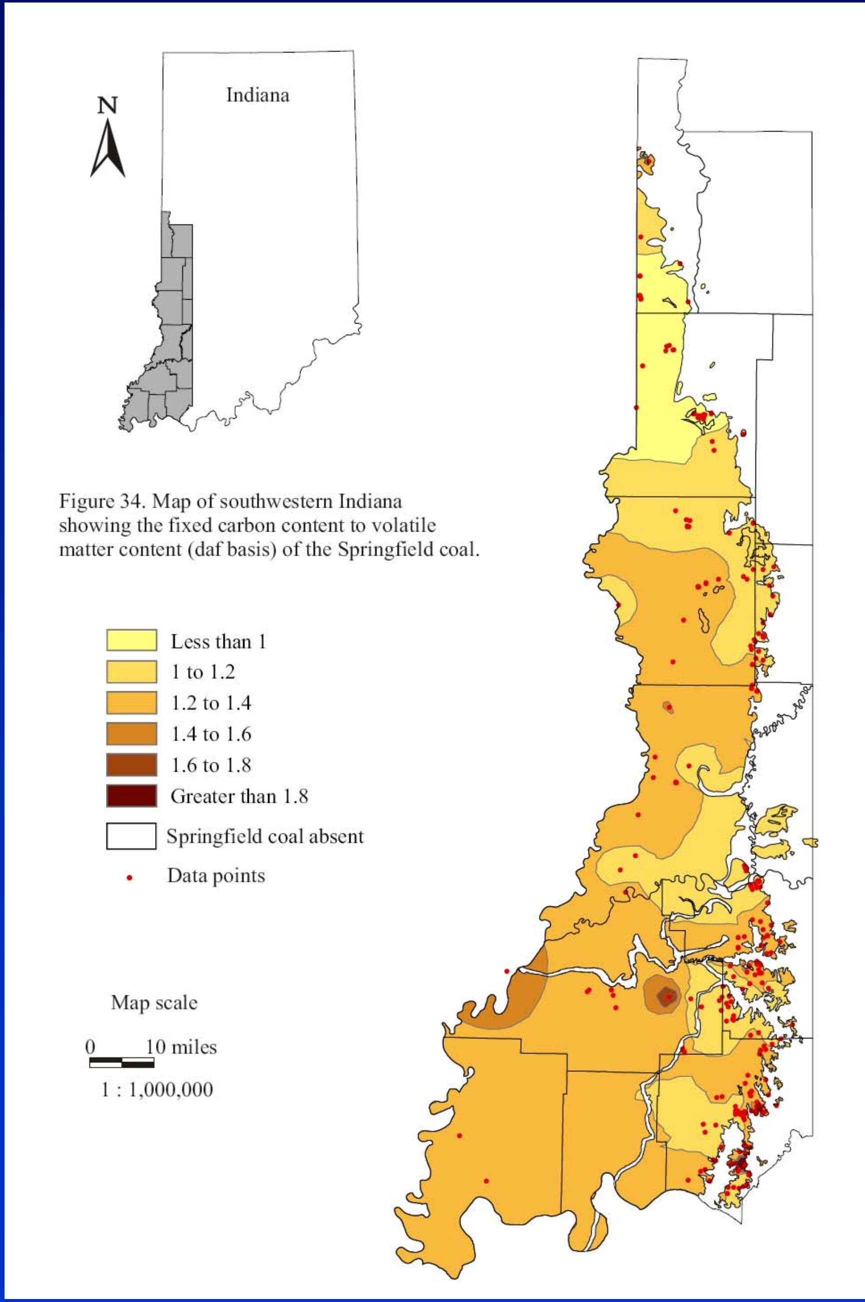
<u>Fuel ratio</u> - ratio between Fixed carbon and Volatile matter

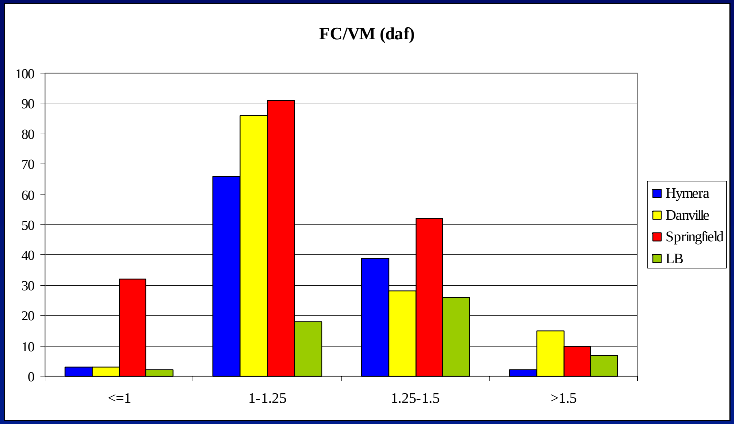
Higher O/C ratio – higher reactivity

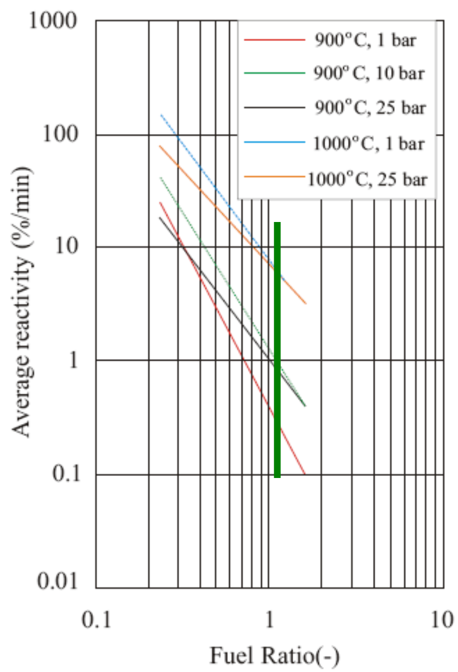


Zevenhoven and Hupa, 1997

Fuel ratio

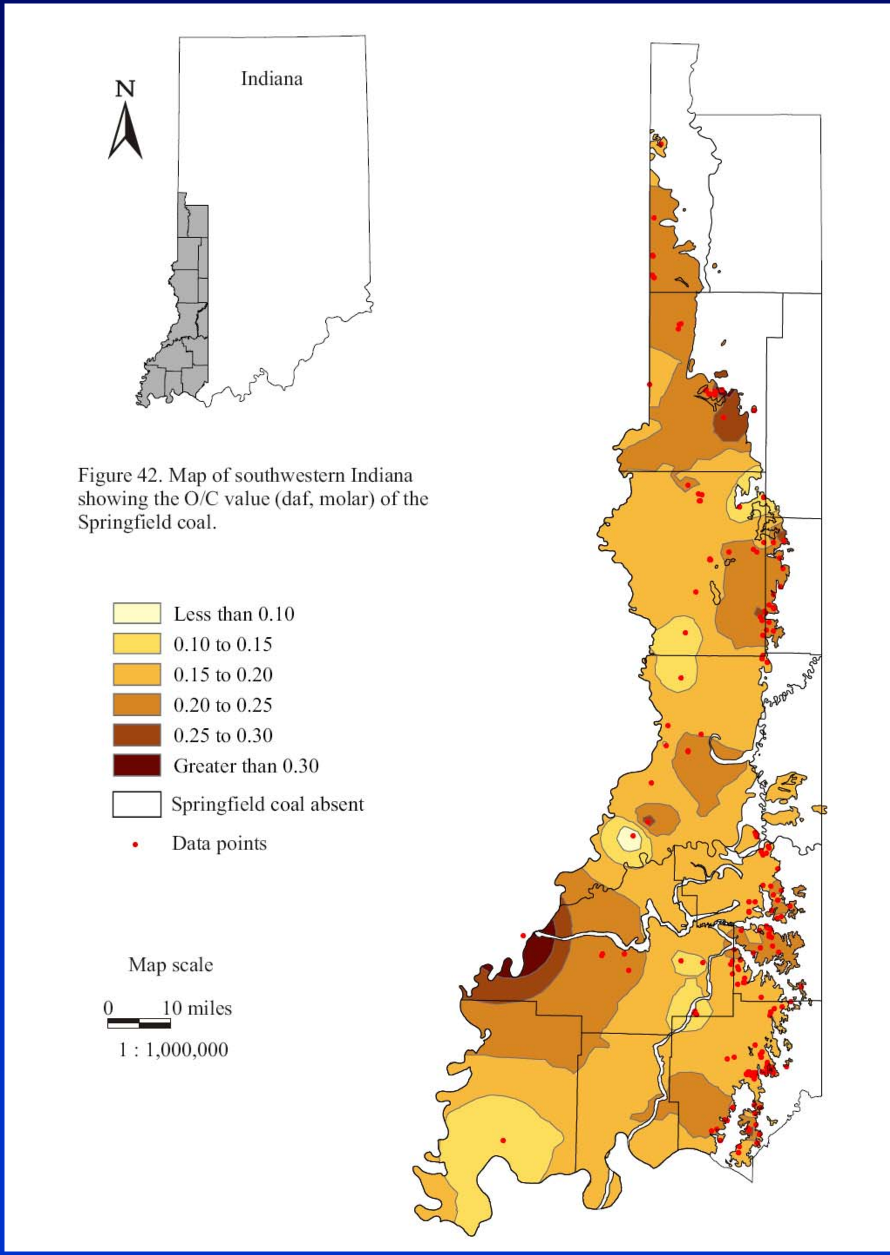


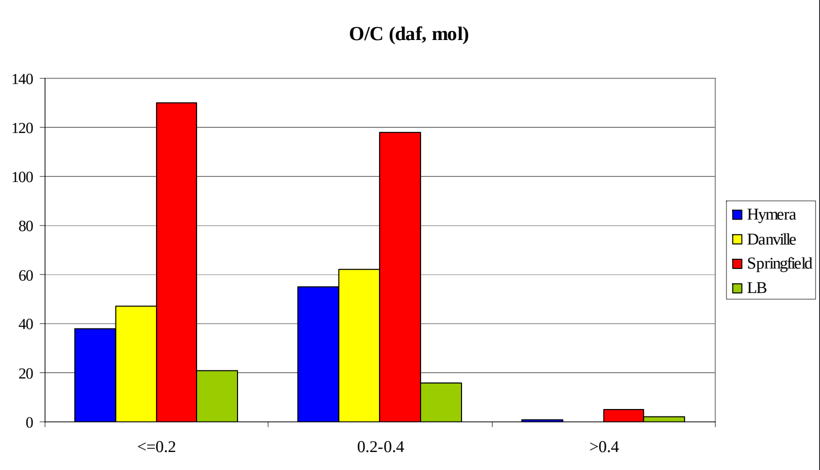


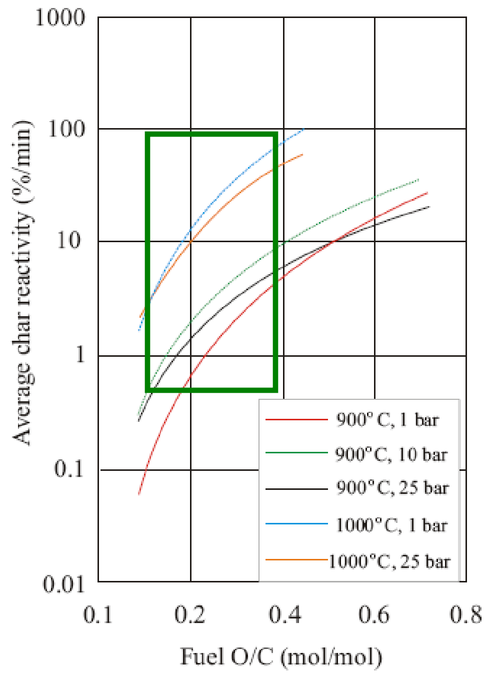


Higher fuel ratio - lower reactivity

O/C ratio







Higher O/C ratio – higher reactivity

Summary of preliminary evaluation of Indiana coals for IGCC

- Btu, moisture, ash, sulfur – good to very favorable
- Reactivity – no direct data but fuel ration and O/C ratio suggest adequate reactivity
- **Slag behavior - ?????? – insufficient data on ash chemical composition and ash fusion temperatures**
- **Slag properties???**

Barriers to using Indiana coal in IGCC

The main barriers are the same as those for using IGCC technologies and building new IGCC plants in general, and, among others, include:

- 1) High capital cost,
- 2) Unfamiliarity of the technology to utilities (IGCC plants are more chemical plants than boilers),
- 3) Relatively long time to gain full plant capacities (this, however changes with experience)
- 4) Reliability concerns,
- 5) Project financing – bankers need guarantees or assurance that gasifiers will perform well,
- 6) Economic uncertainties – tax incentives, multi-pollutant legislations, and
- 7) Public perception about any new coal-using power plants

Barriers to using Indiana coal in IGCC

The barriers that are specific or related to the properties of Indiana coals and that might prevent potential IGCC plants from selecting Indiana coal as IGCC feedstock include:

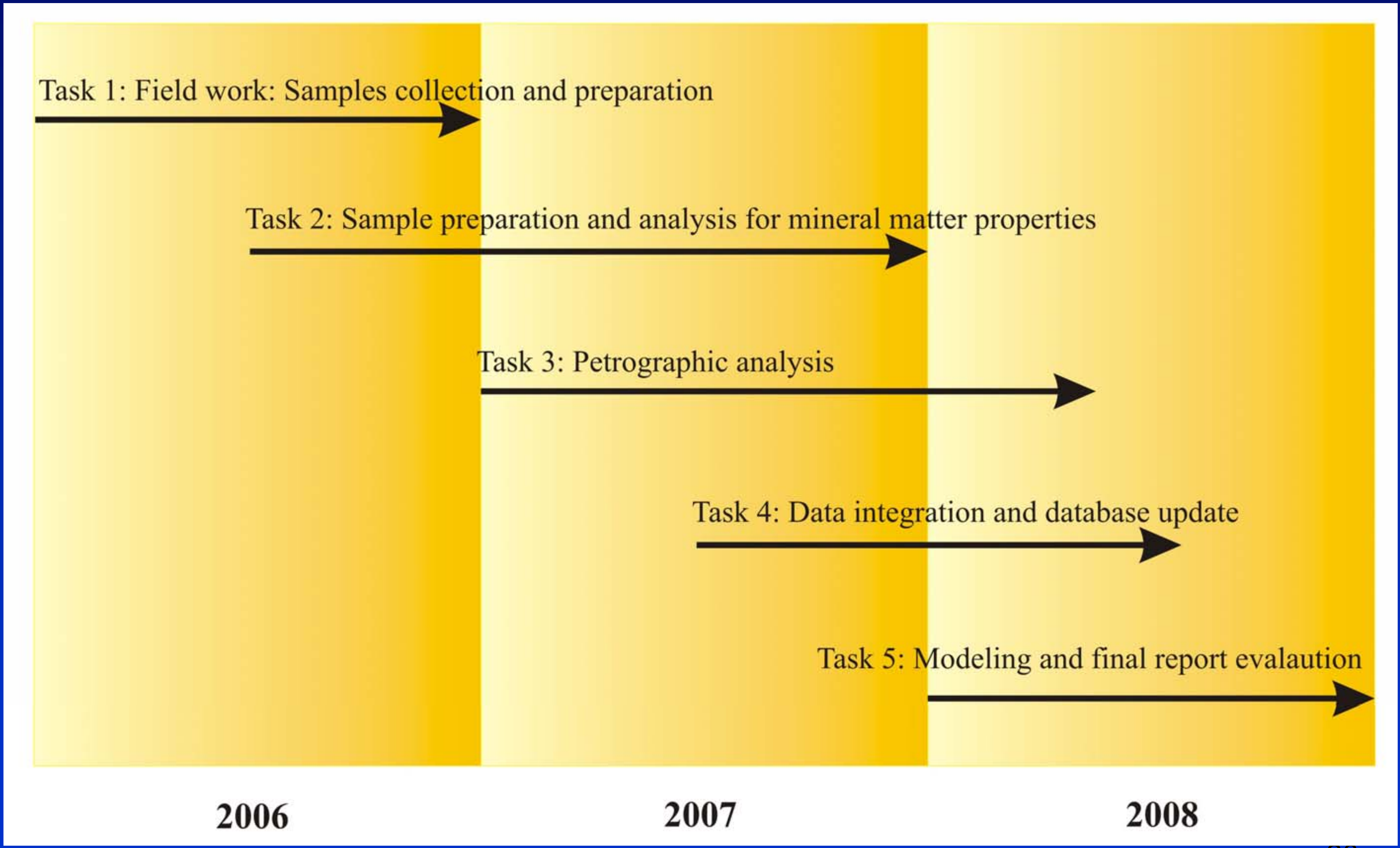
- Insufficient information about ash characteristics such as ash composition and ash melting properties and, consequently, difficulty of predicting slag behavior in a gasifier;
- Insufficient information about chlorine content of Indiana coals. There is a perception that Indiana coals, similar to some Illinois coals, are high in chlorine. This does not appear to be the case, but not enough data are available to disprove it, and
- Price of the coal

Task 4:

Propose new research to provide a comprehensive evaluation of Indiana coals for IGCC

- Mineral matter (ash) composition
- Ash melting point and slag viscosity
- Petrographic composition
- Chlorine in Indiana coals
- Modeling of IGCC performance of Indiana coals

Tasks and milestones



ACKNOWLEDGMENTS

- Center for Coal Technology Research