

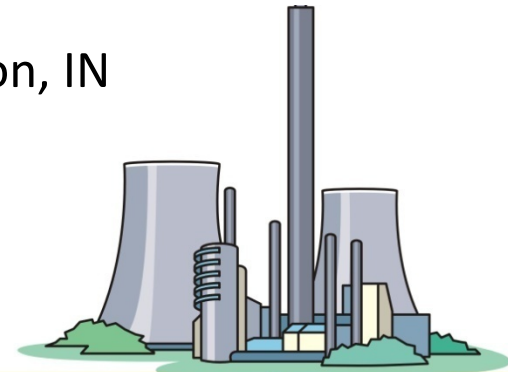
THE POTENTIAL FOR UNDERGROUND COAL GASIFICATION IN INDIANA

Maria Mastalerz, Agnieszka Drobniak, Mary Parke, John Rupp

Indiana Geological Survey, Bloomington, IN



Injection well



Production well



The basics of UCG

- It is *in-situ* gasification of the coal
- Injection and production wells are drilled and linked together in a coal seam.
- Air or oxygen is injected and the coal is ignited in a controlled way.
- The gasification process produces primarily H_2 , CO , CH_4 and CO_2 .
- The produced gas flows to the surface where it is processed and utilized.

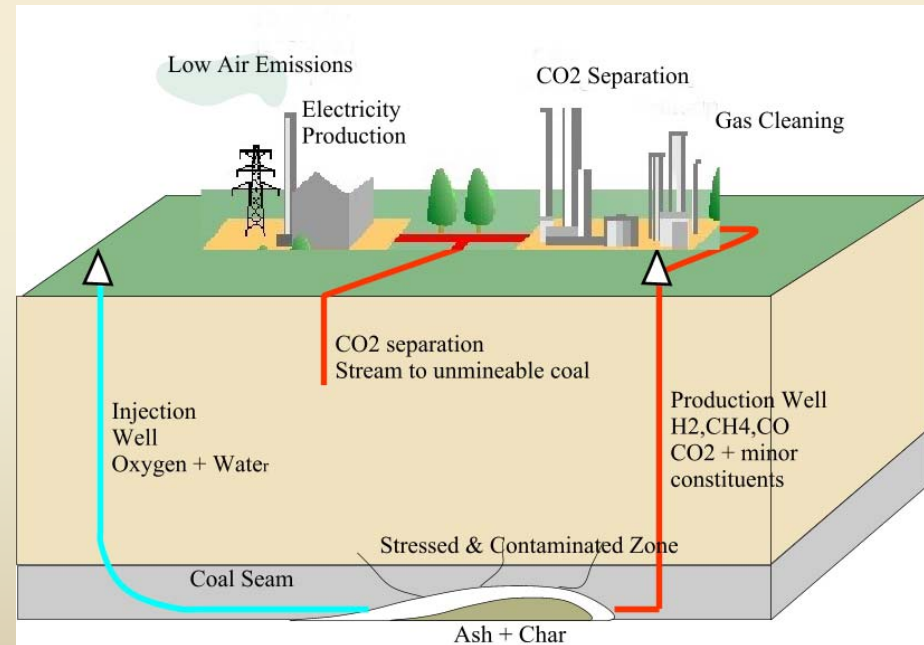
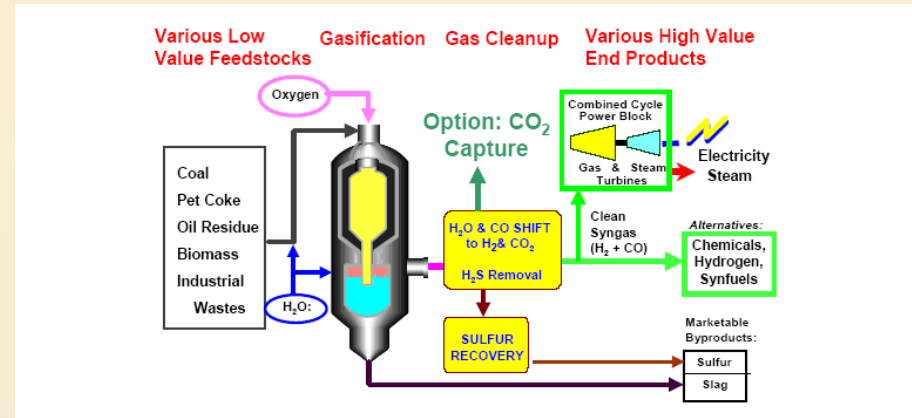


Image: UCG Engineering, Ltd.,
<http://www.coal-ucg.com>

Advantages and Challenges of UCG

- Compared with conventional underground mining and surface gasification, UCG has several advantages and they include:
 - Lower capital costs (no gasifier maintenance)
 - No labor underground
 - Minimal underground technology
 - Increased coal resource utilization
 - No coal or solid wastes at the surface
 - No coal transportation costs
- The main challenge is related to the methods for linking injection and production wells:
 - Hydraulic fracturing and reverse combustion
 - Directional drilling and Controlled Retracting Injection Point (CRIP)

History and Current Status of UCG

- Development of UCG in the Former Soviet Union (five UCG plants in operation in 1960s, one in operation now - Uzbekistan)
- UCG trials, modeling, and development of Controlled Retracting Injection Point (CRIP) technique in the United States (1980s). Rocky Mountain 1 trial – Wyoming 1987-1988, Lawrence Livermore National Laboratory
- Trials and modeling in Western Europe (deep coals, 1990s)
- Experiments in China (abandoned mines, 1980s - present)
- Chinchilla experiment in Australia (Ergo Exergy, 1999-2002)
- Numerous current UCG activities throughout the world (South Africa, New Zealand, and other)
- 1998-2008: Russia and China are the most active countries in UCG development

Determination of Screening Criteria for UCG Feasibility Assessment in Indiana

- The following parameters were considered:

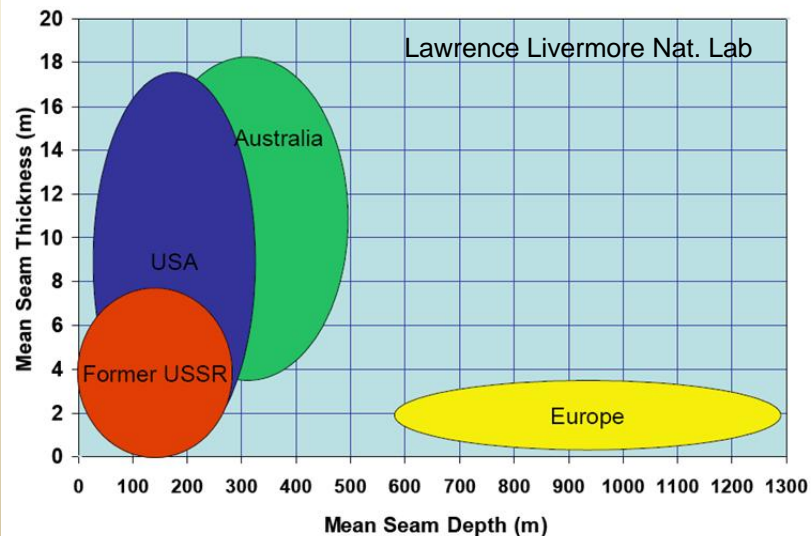
- Thickness of coal seam
- Depth of coal seam
- Coal rank and other properties
- Dip of coal seam
- Water availability
- Amount of coal
- Land-use restrictions

-Coal seam thickness from 0.5 to 30 m
-Dip from 0° to 70°
-Depth from 30 to 800 m
-Calorific value (LHV) from 8.0 to 30.0 MJ/kg (which includes low-quality lignite and bituminous coal)
-Ash content below 60%

- Two have been selected as the most important: thickness of the coal and depth to the coal bed

Criterion #1: Thickness

Thickness	Suitability
> 2.0 m	high
1.5 – 2.0 m	medium
1.0 – 1.5 m	low
< 1.0 m	unacceptable

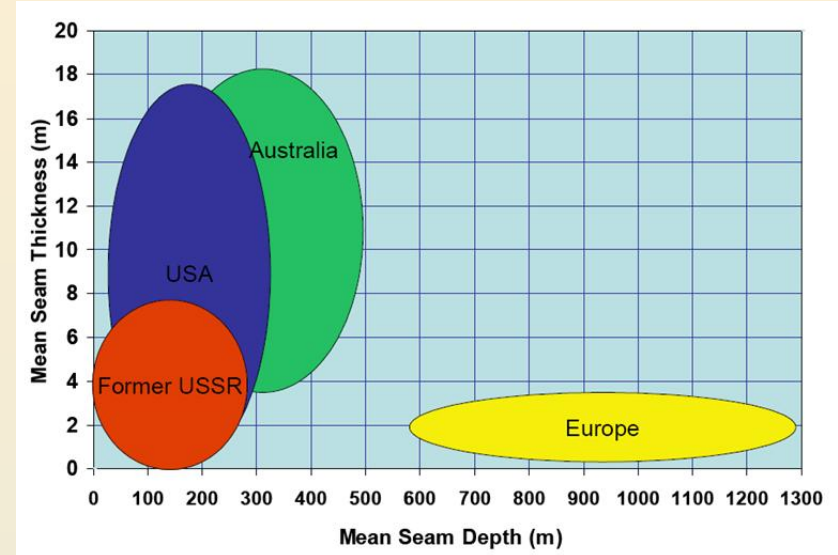


- Coal seam thickness from 0.5 to 30 m
- Dip from 0° to 70°
- Depth from 30 to 800 m
- Calorific value (LHV) from 8.0 to 30.0 MJ/kg (which includes low-quality lignite and bituminous coal)
- Ash content below 60%

<2m – heating value of the gas decreases significantly

Criterion #2: Depth

Depth	Suitability
> 200 m	high ¹
60 - 200 m	adequate
< 60 m	unacceptable ²



- Coal seam thickness from 0.5 to 30 m
- Dip from 0° to 70°
- Depth from 30 to 800 m
- Calorific value (LHV) from 8.0 to 30.0 MJ/kg (which includes low-quality lignite and bituminous coal)
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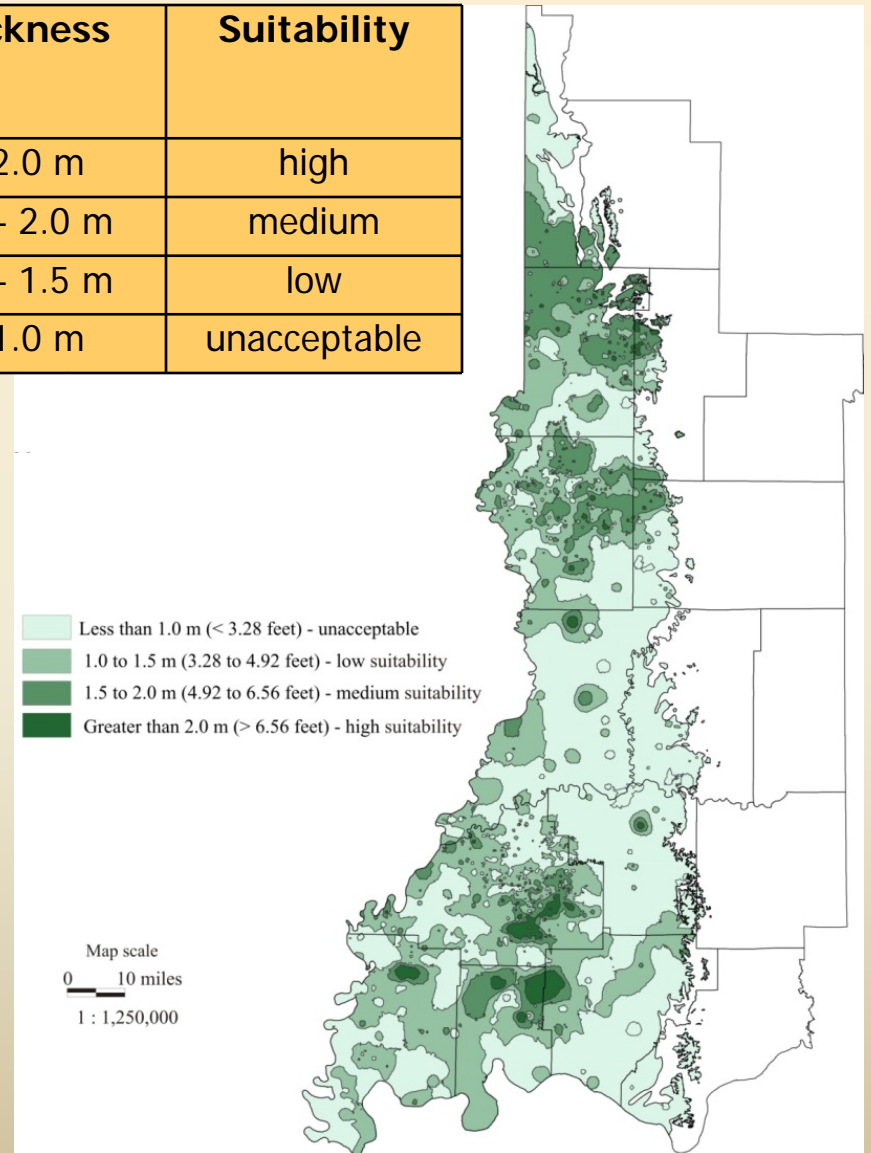
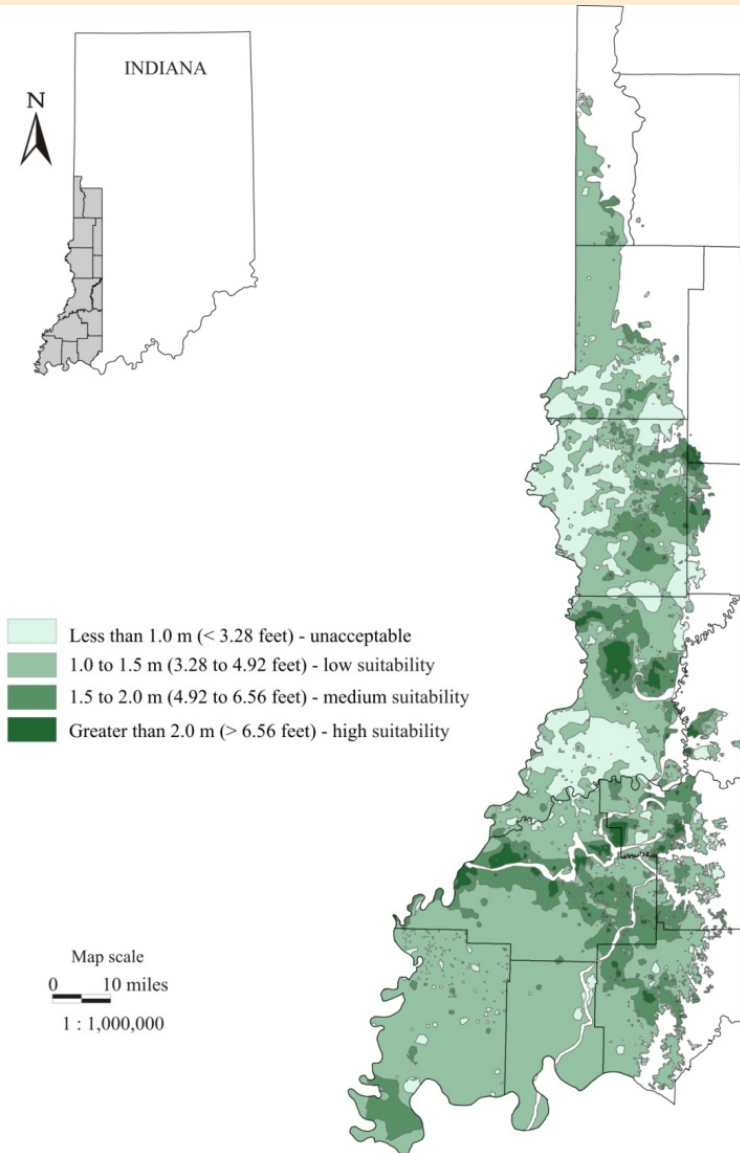
- 1- decrease the risk of subsidence
- 2 -left for surface mining

Criterion: Thickness

Springfield Coal Member

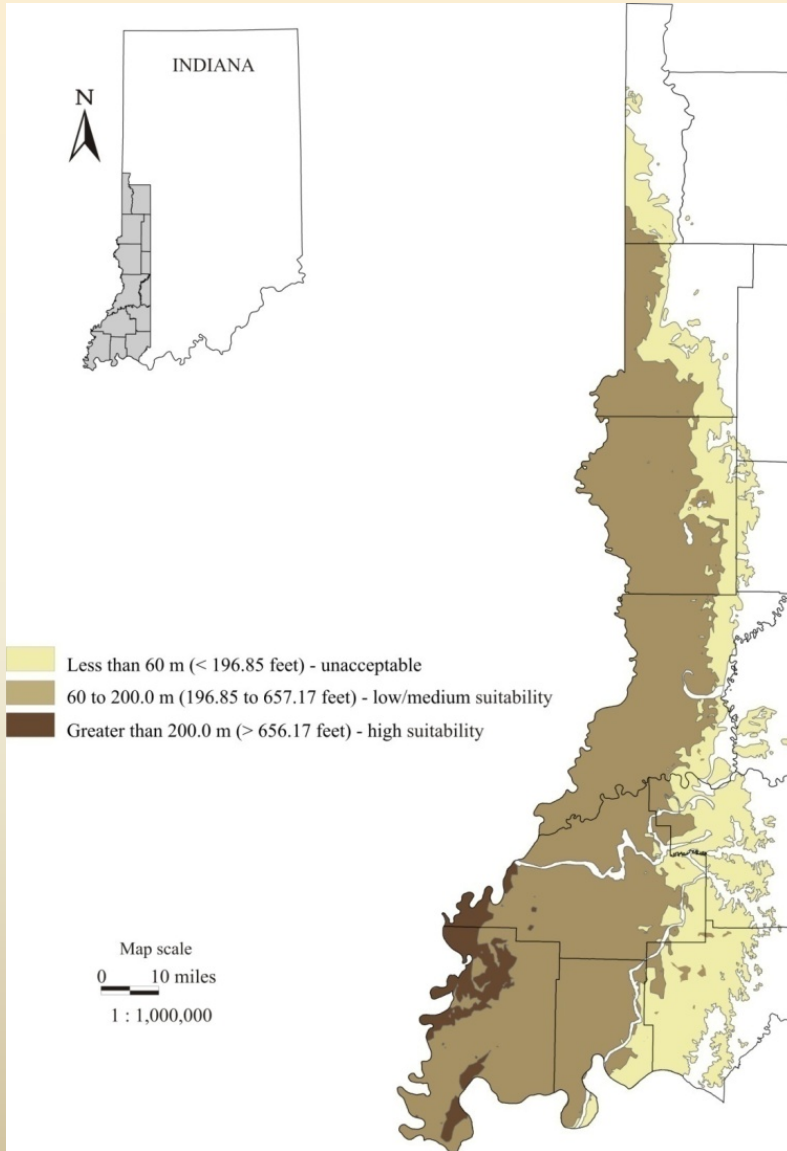
Seelyville Coal Member

Thickness	Suitability
> 2.0 m	high
1.5 – 2.0 m	medium
1.0 – 1.5 m	low
< 1.0 m	unacceptable

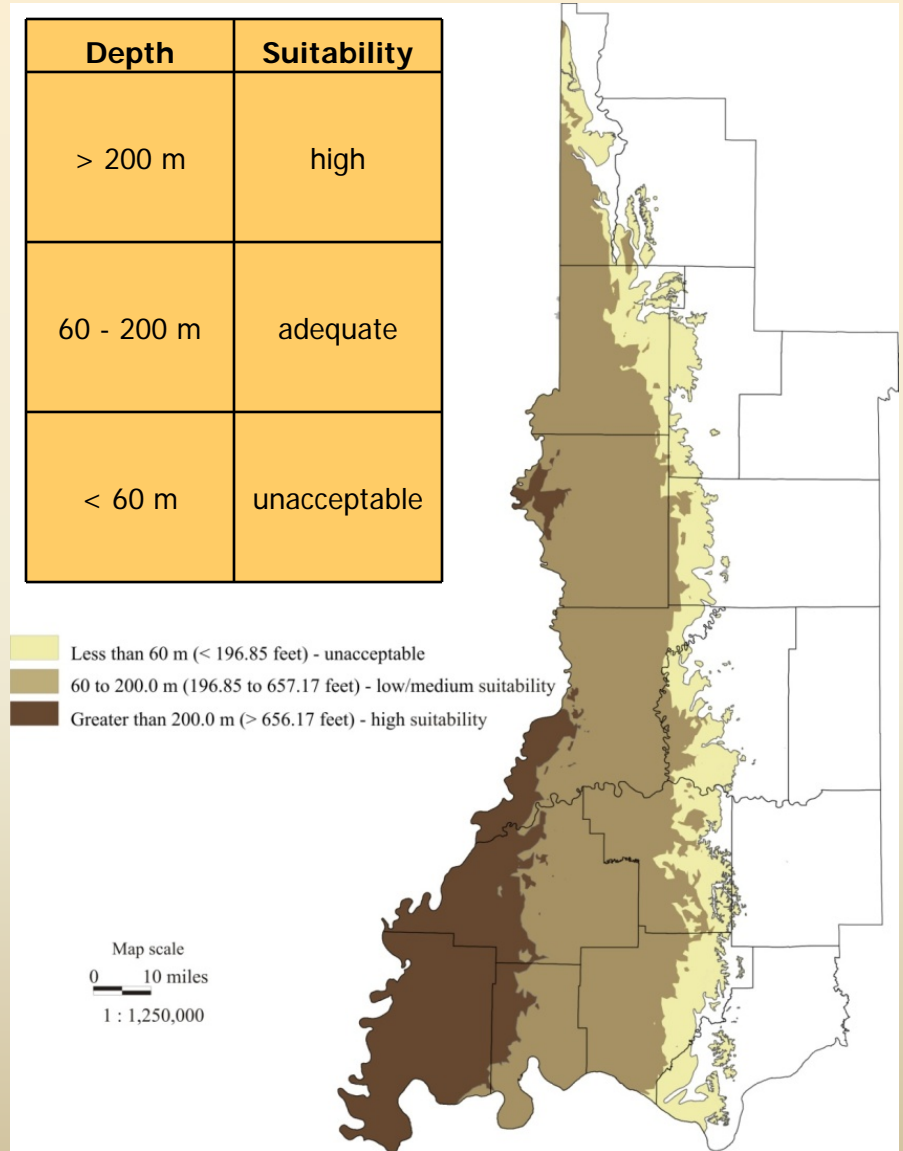


Criterion: Depth

Springfield Coal Member



Seelyville Coal Member



Thickness and Depth

Springfield Coal Member

Thickness	Suitability
> 2.0 m	high
1.5 – 2.0 m	medium
1.0 – 1.5 m	low
< 1.0 m	unacceptable

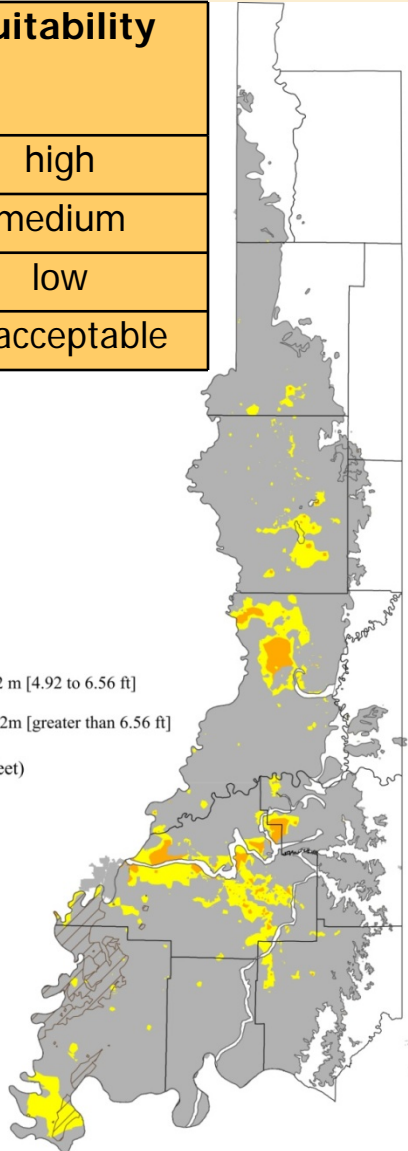
Springfield Coal unavailable for underground gasification (depth less than 200 ft [-60m] or thickness less than 1.5 m or active mining or coal mined out)

Adequate depth and thickness from 1.5 to 2 m [4.92 to 6.56 ft]

Adequate depth and thickness greater than 2m [greater than 6.56 ft]

Depth greater than 200.0 m (> 656.17 feet)

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



Seelyville Coal Member

Depth	Suitability
> 200 m	high
60 - 200 m	adequate
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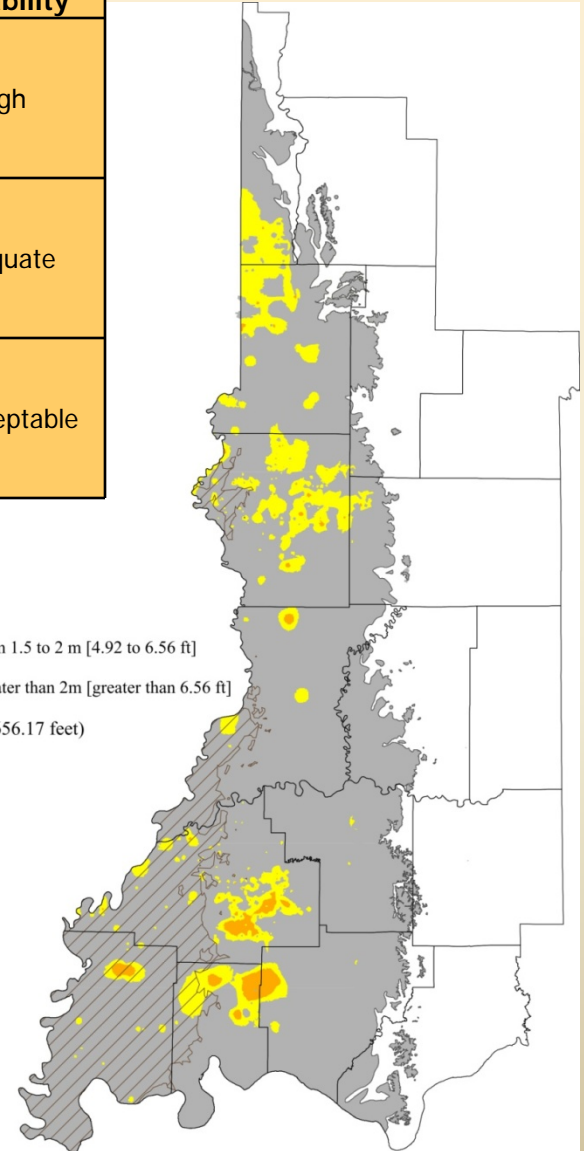
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Depth greater than 200.0 m (> 656.17 feet)

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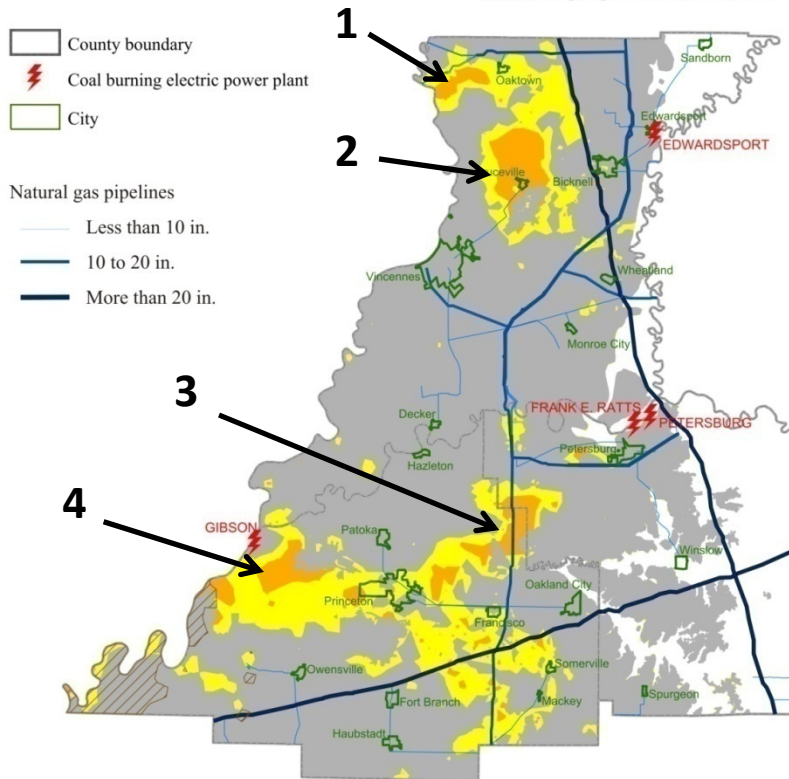
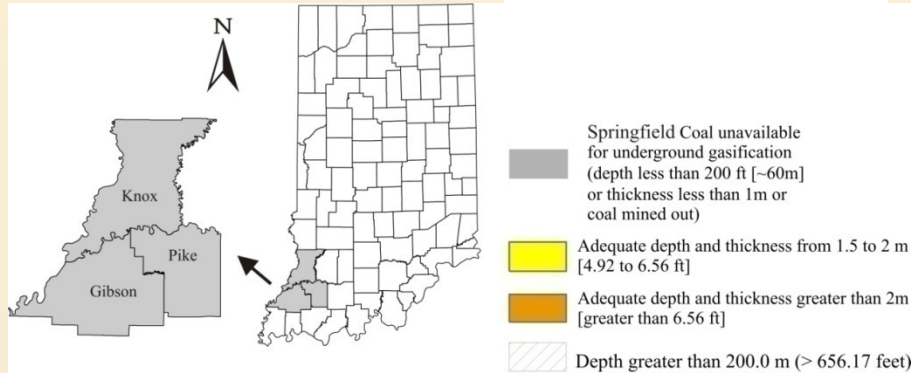


Other Geospatial Information Used in the Feasibility Analysis

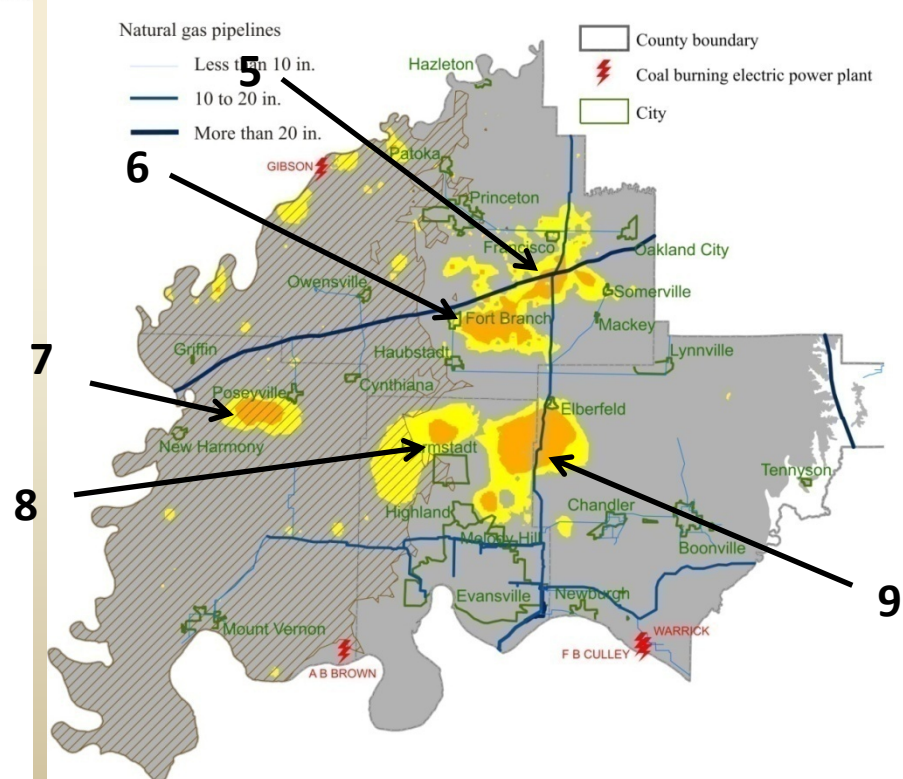
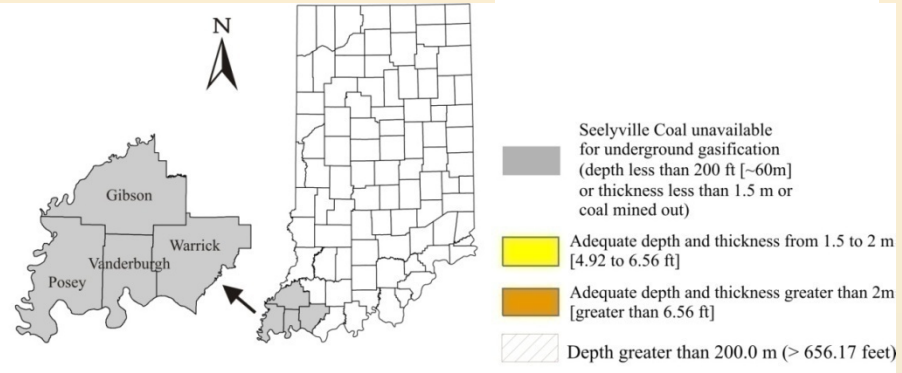
- Infrastructure proximity to
 - Coal-burning power plants
 - Natural gas pipelines
 - Cities
 - Highways
 - Railroads
- Gas markets and length of gas transport
- Same criteria as for underground mining

Thickness, Depth and Infrastructure

Springfield Coal Member



Seelyville Coal Member



Characteristics of Selected Zones

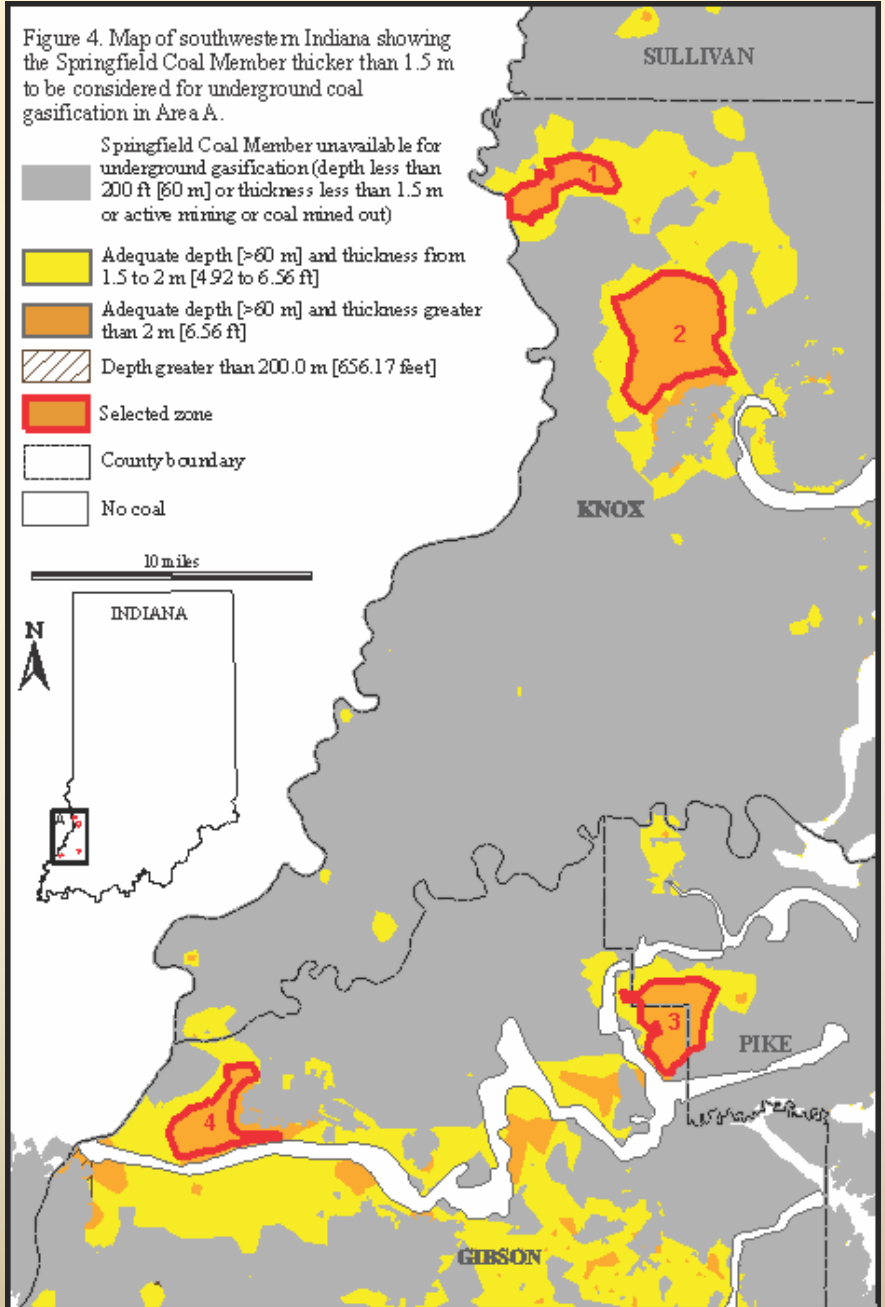
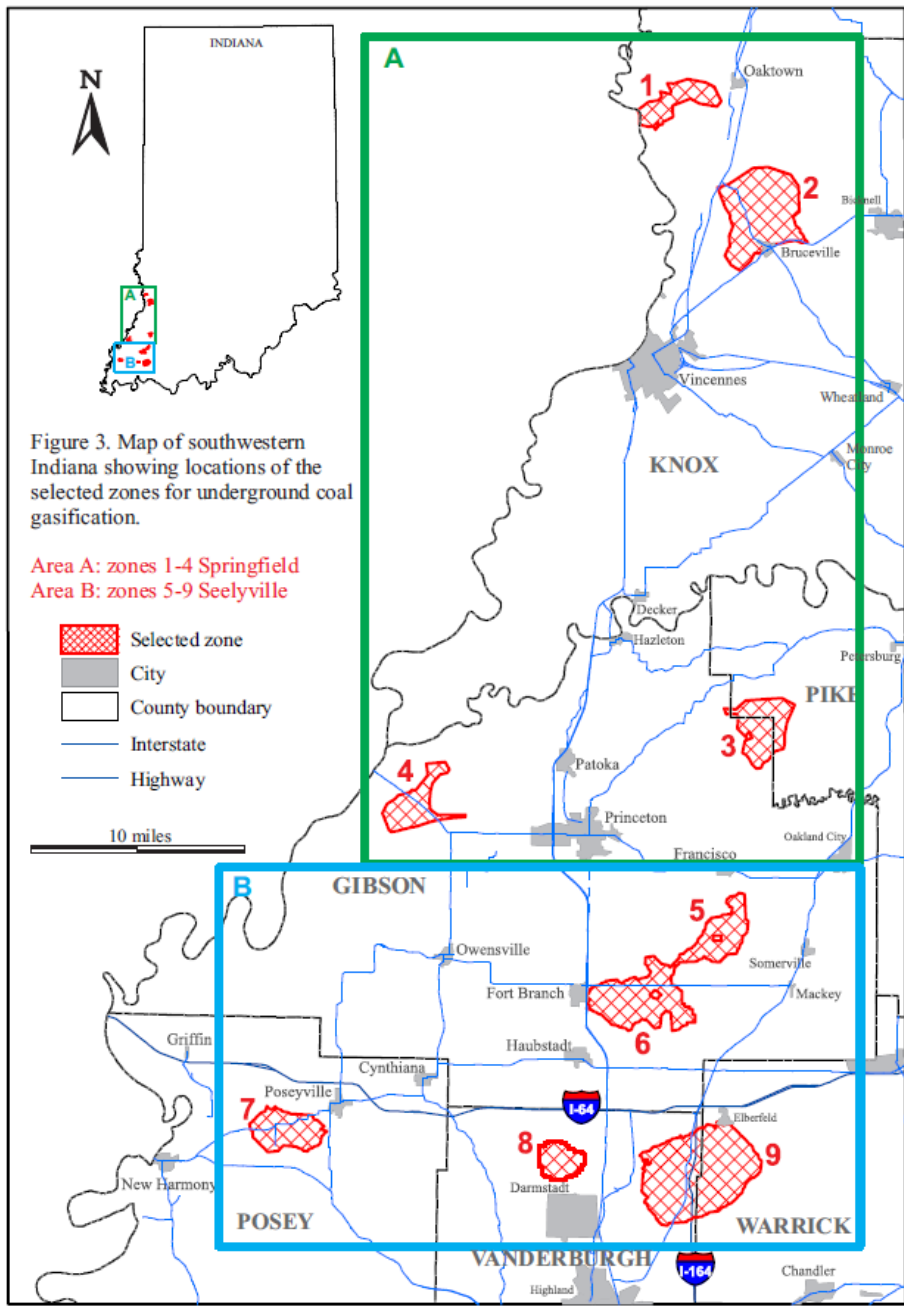
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Mass [10⁶ short tons]	27.7	103.2	53.1	32.4	35.8	75.5	46.2	23.6	182.9
Thickness range [ft]	6.6-7.9	6.6-8.6	6.6-10.3	6.6-7.9	6.6-9.4	6.6-9.2	6.6-11.4	6.6-9.4	6.6-11.3
Depth range [ft]	200-660	200-660	200-660	200-660	200-660	200-660	> 660	200-660	200-660
Moisture range [ar,%]	5-10	5-10	5-7.5	7.5-12.5	< 7.5	5-7.5	5-7.5	7.5-10	7.5-10
Ash range [dry, %]	7.5-12.5	10-15	10-15	5-10	10-15	10-15	7.5-12.5	12.5-15	12.5-20
Sulfur [total, dry, %]	3-4	2-4	3-5	1-3	3-5	2-4	3-4	3-4	2-4
Heating value [dry, 10³ Btu/lb]	12.5- 13.0	12.0- 13.0	11.5- 12.5	13.0- 14.0	11.5- 12.0	11.5- 12.0	12.0- 13.0	11.5- 12.5	11.5- 12.0
Distance to nearest power plant [miles]	14	9.5	10	3	18	17	18	17	17
Distance to nearest pipeline [miles]	1	0	0	7	0	2	3	5	0
Distance to nearest town [miles]	3	0	6.7	5.5	3	2.5	2.2	1.6	2.5

← Springfield →

← Seelyville →

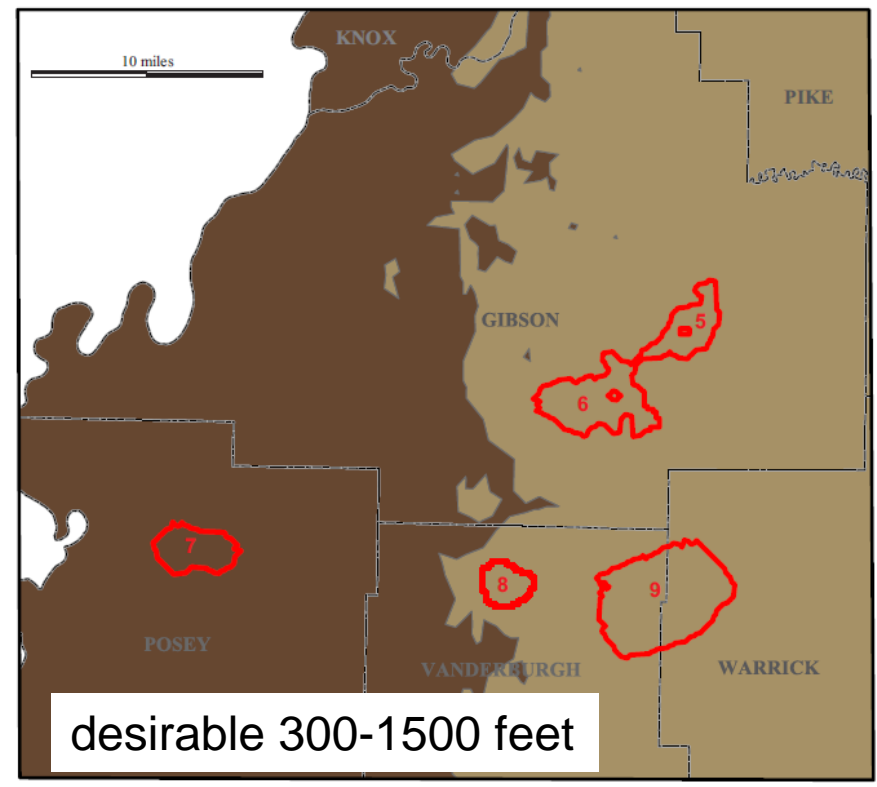
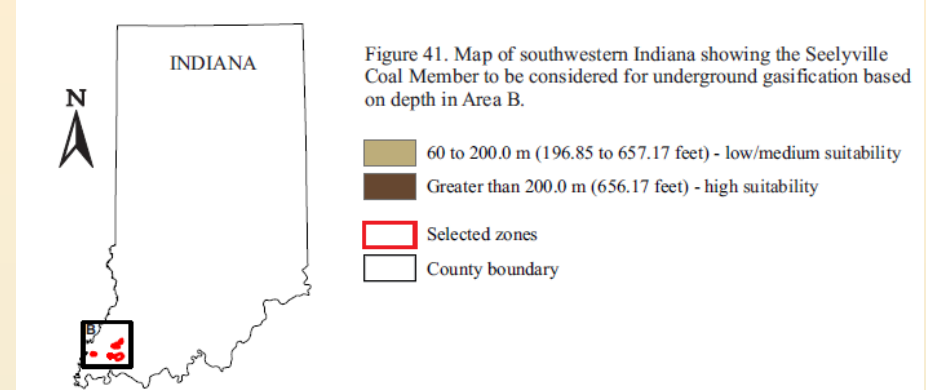
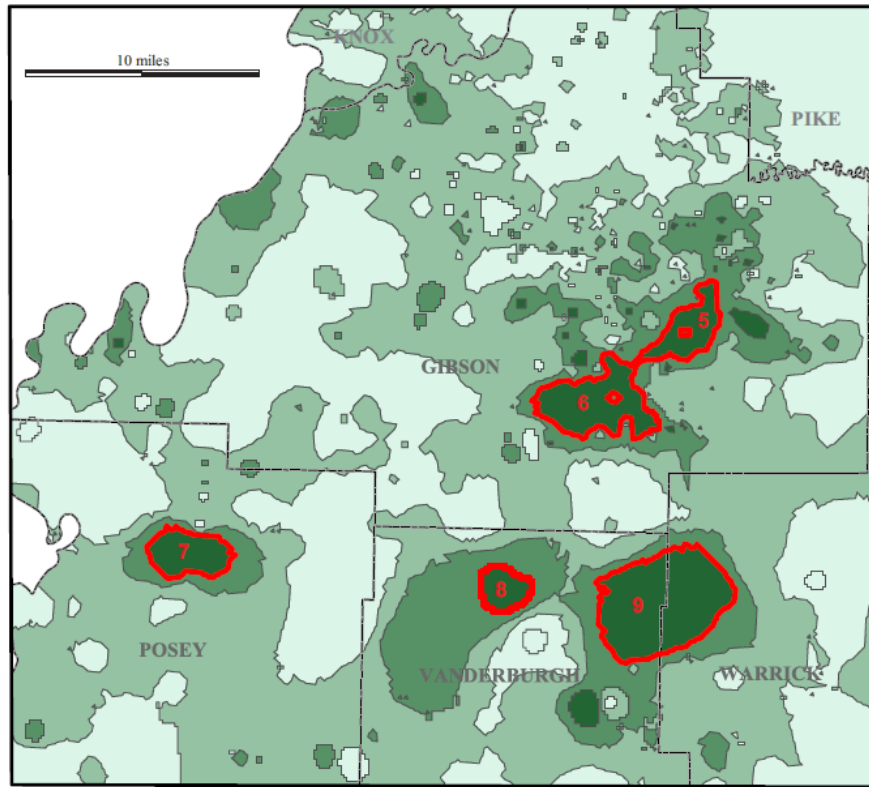
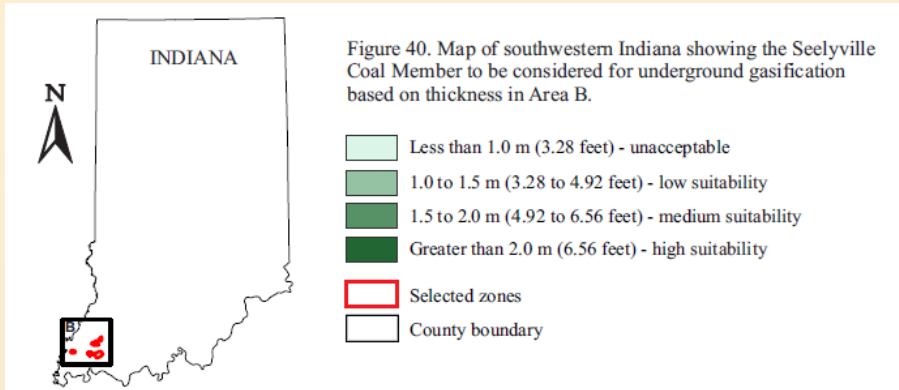
33*10⁶ tons – for 20 years of operation of 300 MW UCG-based power plant

More detailed evaluation of selected areas

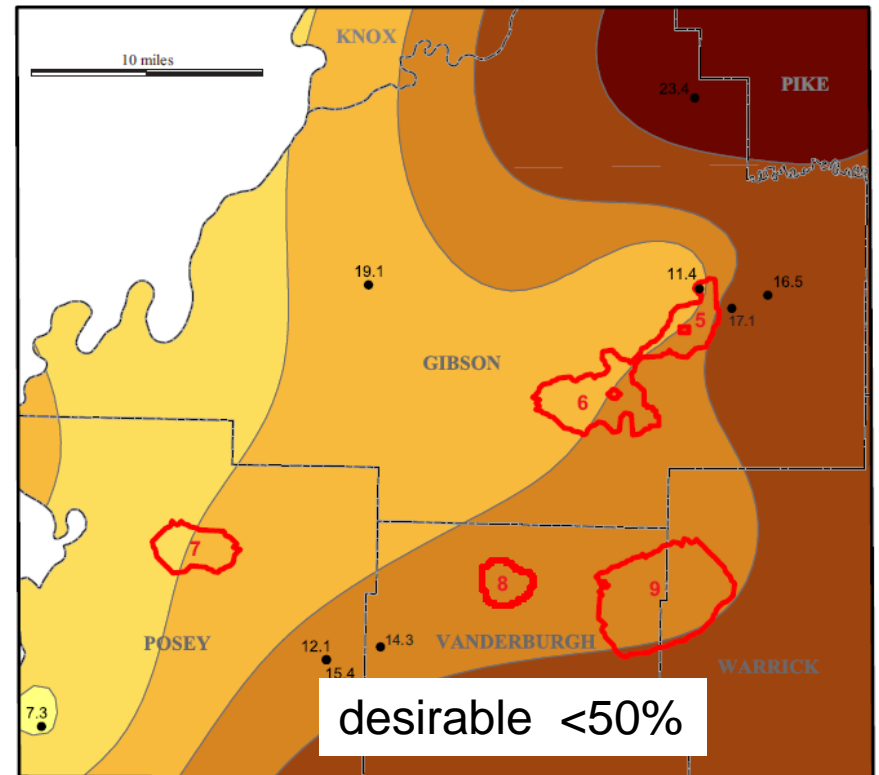
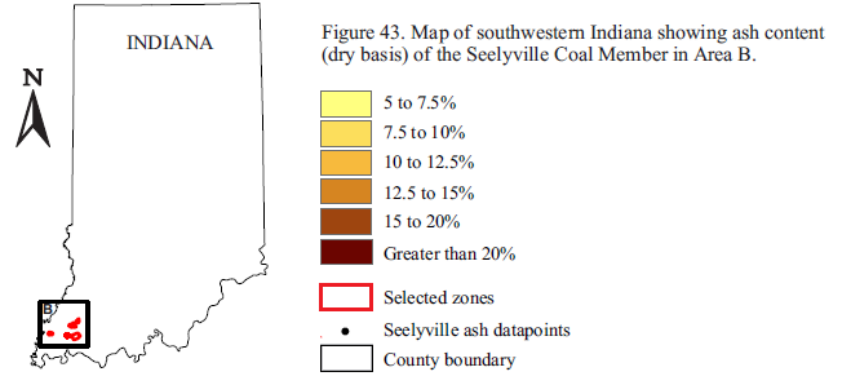
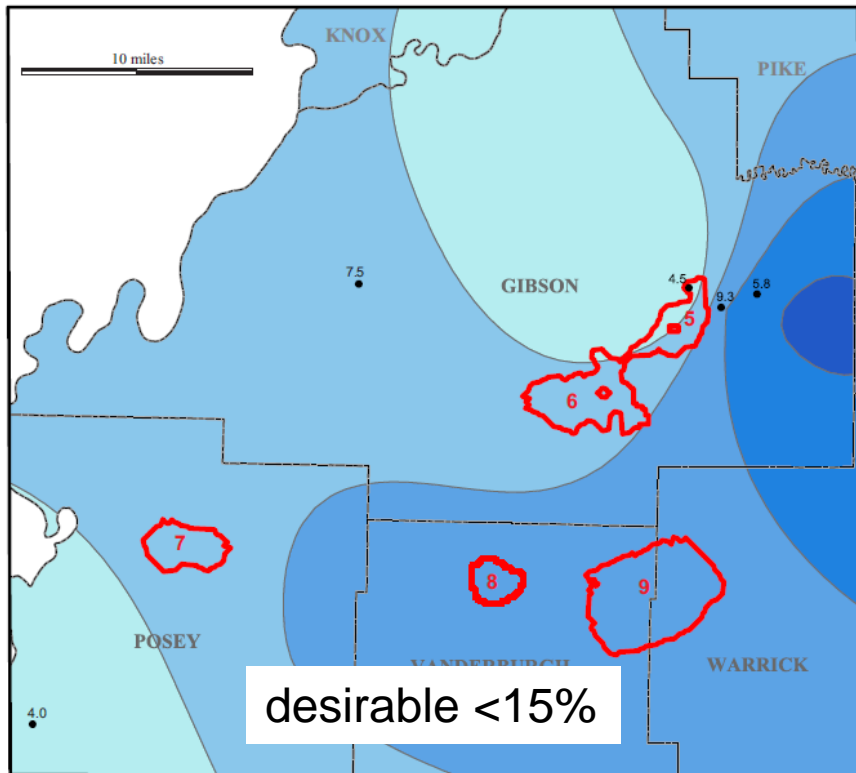
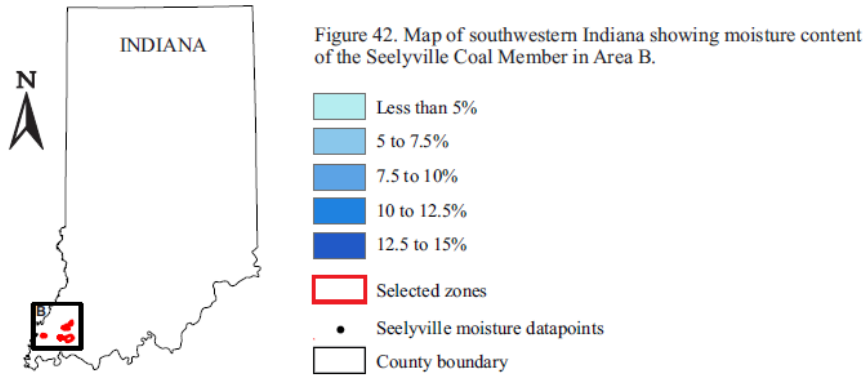


Parameter	Desired value	Imperial units and comments
Coal thickness (m)	1.5-15.0	5-50 ft
Thickness variation (% of seam thickness)	<25	
Depth (m)	92 -460	300-1,500 ft
Dip (degrees)	0-70	Technology dependent
Dip variation (degrees/31m, 100 feet)	<2	For directionally drilled wells
Single parting thickness (m)	<1	<3 ft
Total parting thickness (% of seam thickness)	<20	
Fault displacement (% of seam thickness)	<25	
Fault density (Number of faults/31 m)	<1	number of faults/100 ft
Coal rank	≤bituminous	If bituminous, FSI should be low
Coal moisture (wt %)	<15	
Ash content (wt %)	<50	
Coal sulfur (wt %)	<1	
Thickness of consolidated overburden (m)	>15	>50 ft
Seam permeability (mD)	50-150	
Immediate overburden permeability (mD)	<5	15 m (50 ft) above the seam
Distance to nearest overlying water-bearing unit (m)	>31	>100 ft
Coal aquifer characteristics	confined	
Nearest producing well completed in coal seam (km)	>1.6	>1 mile
Available coal resources (10^6 m ³)	15.4	~543×10 ⁹ cubic ft for 20-year-long operation

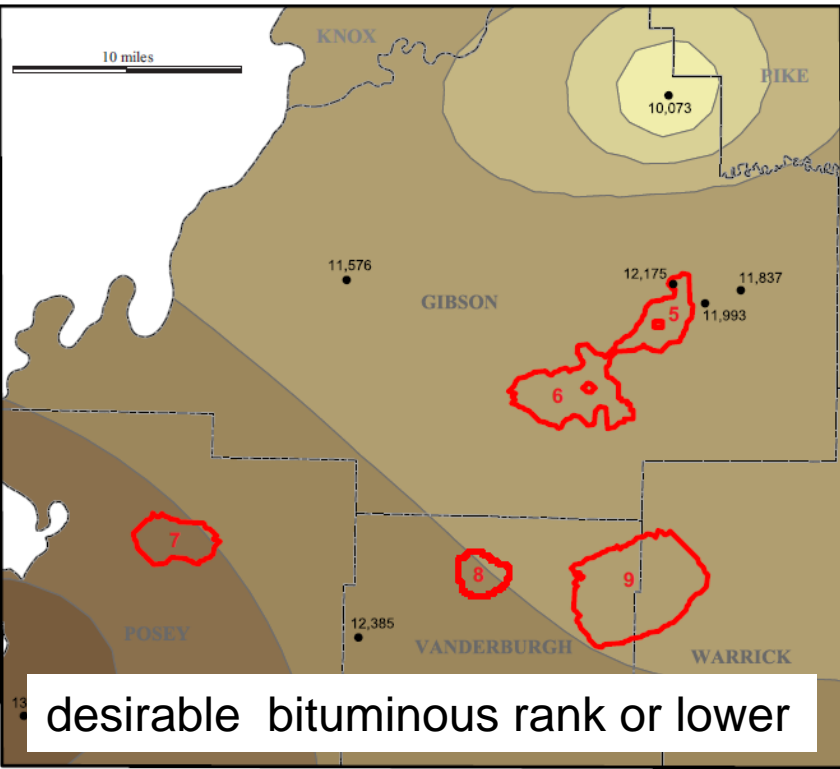
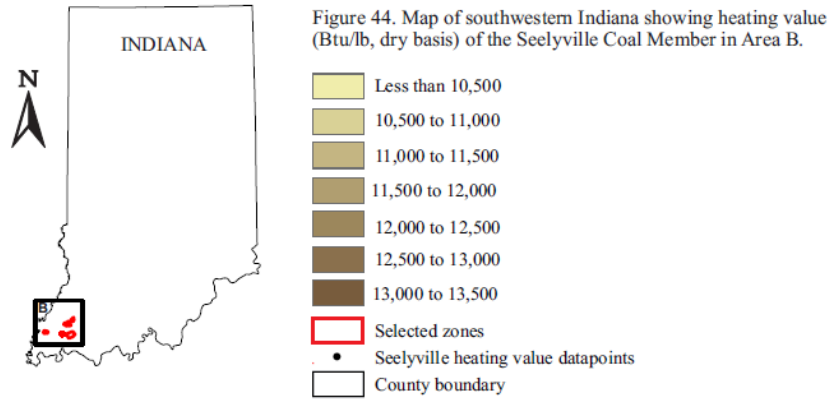
Thickness and depth of selected areas



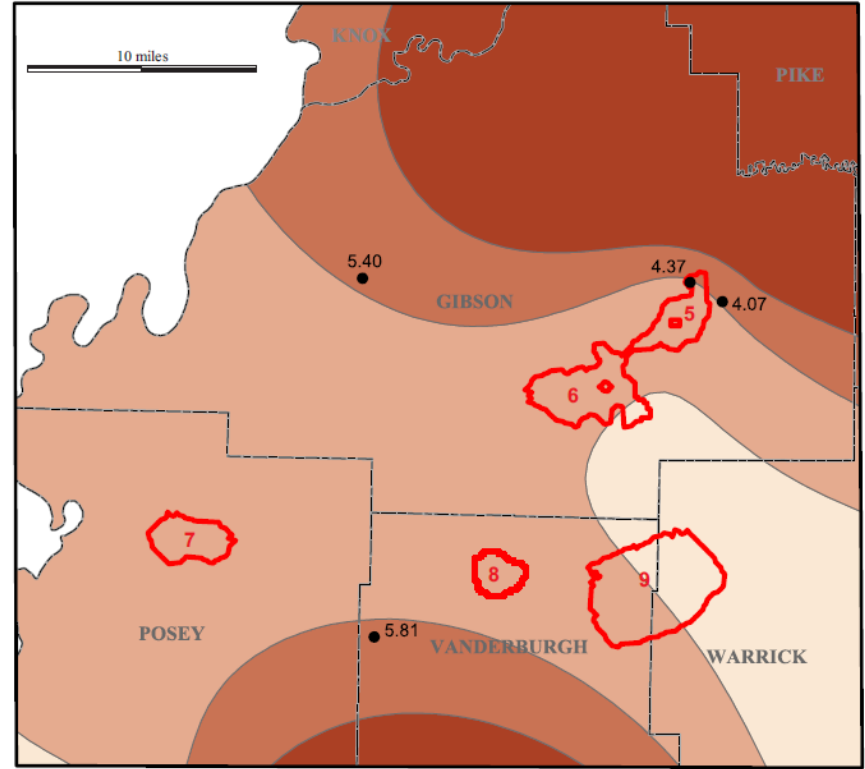
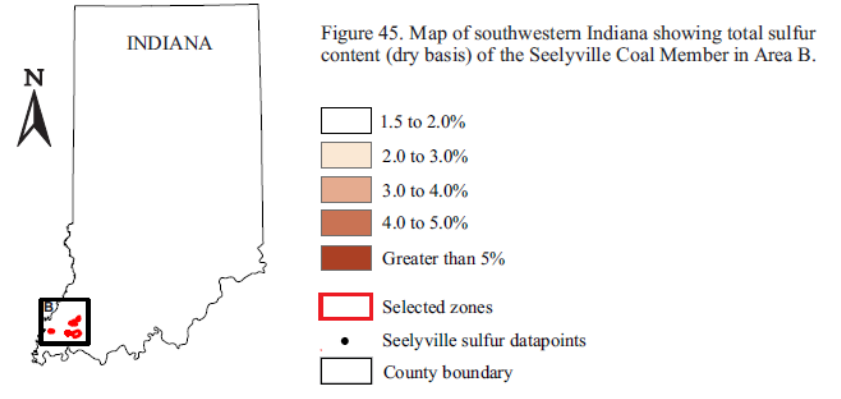
Moisture and ash content of selected areas

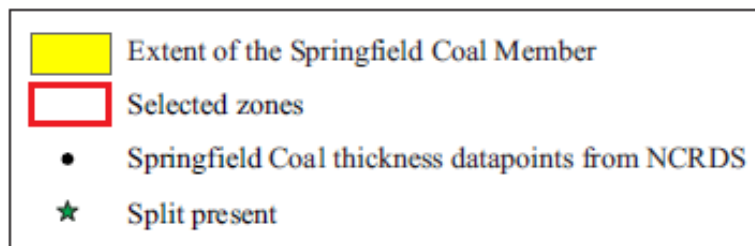
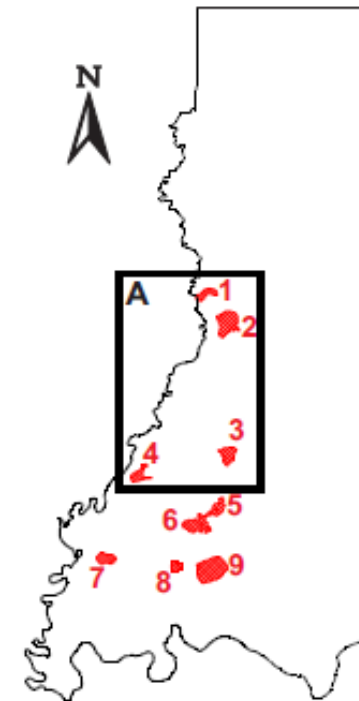
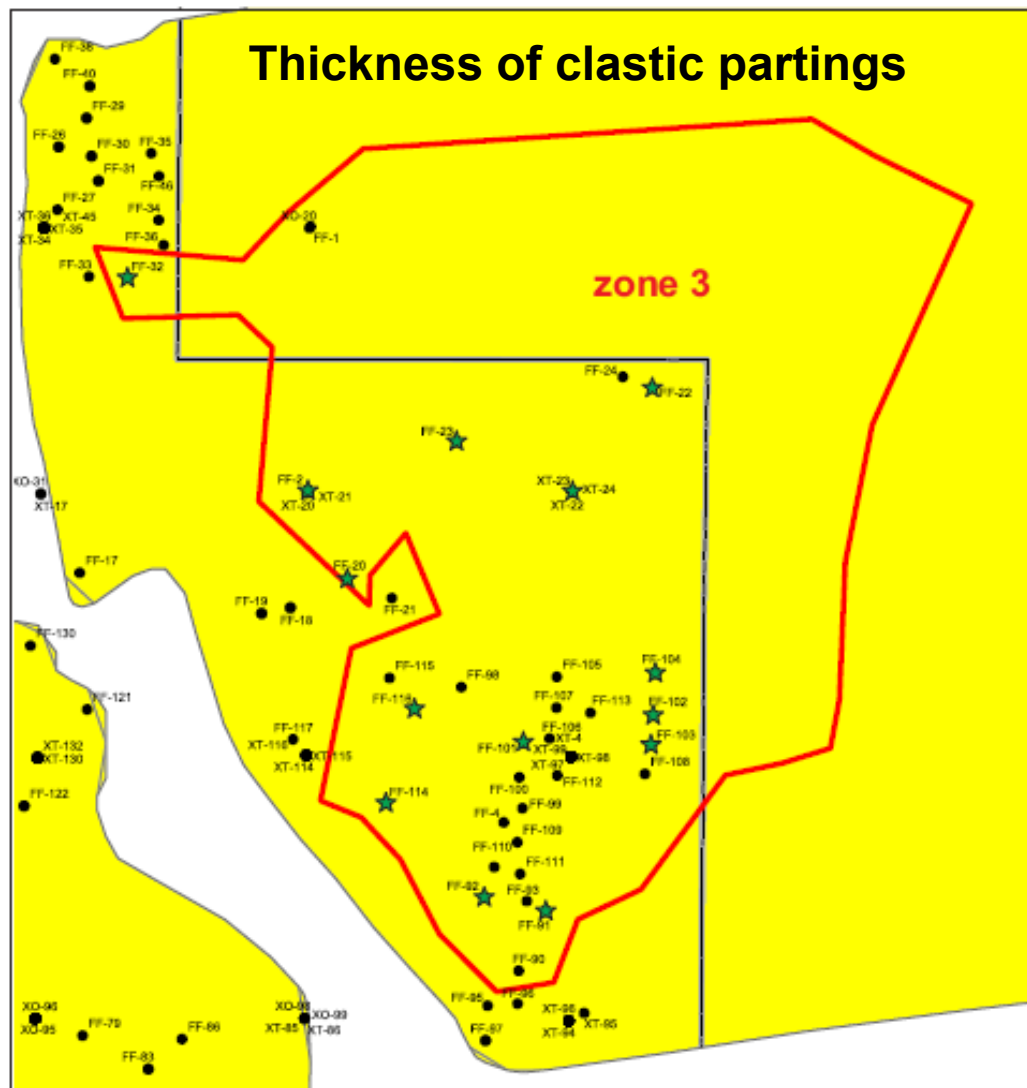


Heating value and sulfur content of selected areas



desirable bituminous rank or lower





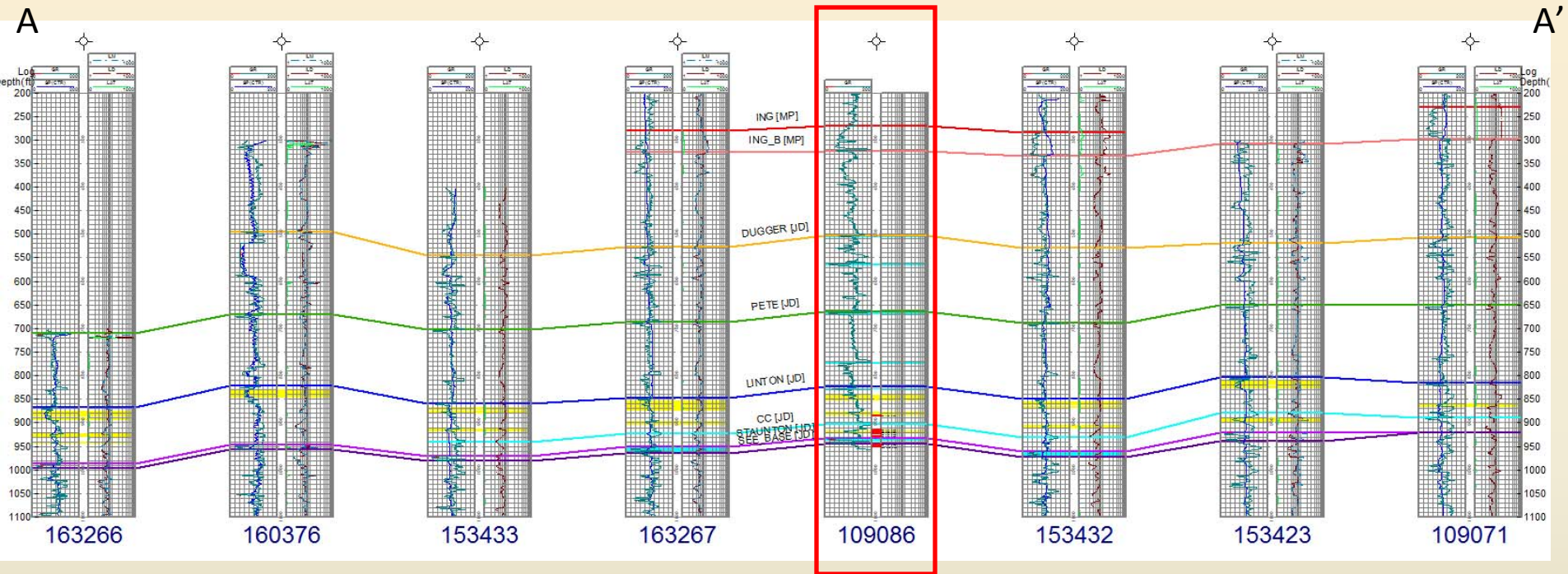
Single parting thickness (m)	<1
Total parting thickness (% of seam thickness)	<20

Well ID	Top [ft]	Bottom [ft]	Thc. [ft]	Lithology	Notes	Parting thicker than 3.28 ft (1m)	Total coal thc.	Total splits thc.	% of coal
FF-32	321.5	327.5	6.0	COAL					
FF-32	327.5	328.9	1.4	No record	Parting	NO	7.42	1.42	83.9
FF-32	328.9	330.4	1.4	COAL					
FF-22	367.8	369.3	1.4	COAL					
FF-22	369.3	370.7	1.4	No record	Parting	NO	7.42	1.42	83.9
FF-22	370.7	376.7	6.0	COAL					
FF-23	317.5	318.9	1.4	COAL					
FF-23	318.9	320.9	2.0	No record	Parting	NO	9.84	2.00	83.1
FF-23	320.9	329.4	8.4	COAL					
FF-20	257.4	258.8	1.4	COAL					
FF-20	258.8	260.2	1.4	No record	Parting	NO	7.42	1.42	83.9
FF-20	260.2	266.2	6.0	COAL					
FF-116	230.0	231.5	1.5	COAL					
FF-116	231.5	233.0	1.5	No record	Parting	NO	7.50	1.50	83.3
FF-116	233.0	239.0	6.0	COAL					
FF-114	270.0	271.5	1.5	COAL					
FF-114	271.5	273.0	1.5	No record	Parting	NO	5.5	1.5	78.6
FF-114	273.0	277.0	4.0	COAL					
FF-92	218.0	219.4	1.4	COAL					
FF-92	219.4	220.8	1.4	No record	Parting	NO	8.4	1.4	85.6
FF-92	220.8	227.8	7.0	COAL					
FF-91	214.8	216.3	1.4	COAL					
FF-91	216.3	217.7	1.4	No record	Parting	NO			
FF-91	217.7	224.7	7.0	COAL			9.8	2.8	77.6
FF-91	224.7	226.1	1.4	No record	Parting	NO			
FF-91	226.1	227.5	1.4	COAL					
FF-102	273.0	274.5	1.5	COAL					
FF-102	274.5	278.5	4.0	No record	Parting	YES	7.0	4.0	63.6
FF-102	278.5	284.0	5.5	COAL					
FF-103	227.0	229.5	2.5	COAL					
FF-103	229.5	232.5	3.0	No record	Parting	NO	8.5	3.0	73.9
FF-103	232.5	238.5	6.0	COAL					
FF-104	260.0	262.0	2.0	COAL					
FF-104	262.0	267.0	5.0	No record	Parting	YES			
FF-104	267.0	270.0	3.0	COAL			6.5	6.5	50.0
FF-104	270.0	271.5	1.5	No record	Parting	NO			
FF-104	271.5	273.0	1.5	COAL					
XT-20	258.0	259.5	1.5	COAL					
XT-20	259.5	261.0	1.5	No record	Parting	NO	7.5	1.5	83.3
XT-20	261.0	267.0	6.0	COAL					
XT-23	318.0	319.5	1.5	COAL					
XT-23	319.5	321.5	2.0	No record	Parting	NO	10.0	2.0	83.3
XT-23	321.5	330.0	8.5	COAL					
FF-101	267.0	270.0	3.0	COAL					
FF-101	270.0	274.0	4.0	No record	Parting	YES	9.0	4.0	69.2
FF-101	274.0	280.0	6.0	COAL					

- Single parting thickness < 1m

- Total parting thickness < 20% of the seam thickness

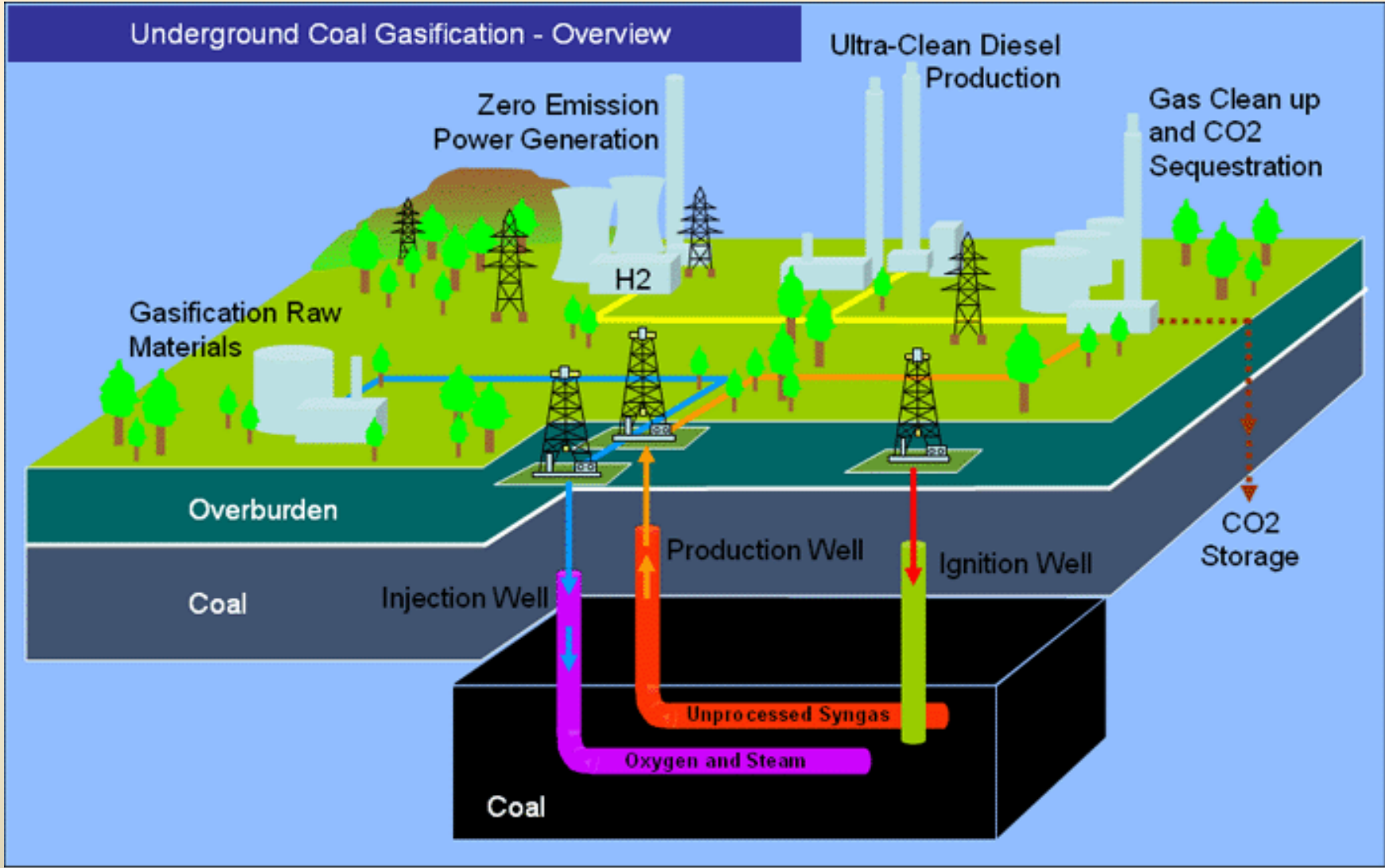
Wells with Gamma Ray Logs



- Picks on key horizons
- Blue highlights are coal
- Yellow highlights are potential porous zones (aquifers?)
- Red lines on depth track in well 109086 mark sample depths and porosity, permeability values

Follow-up Work

- Follow-up detailed characterization and evaluation of the selected localities includes:
 - Studies on the influence of the chemical and petrophysical characteristics of the coals and associated rocks on the kinetics of the UCG process.
 - Determination of the geomechanical properties of the overlying rock (risk of subsidence).
 - Evaluation of the hydrology of the coals and surrounding rocks
 - Site-specific modeling of the UCG process with a focus on the environmental aspects (groundwater contamination).
 - Economic analysis, including capital, operational and environmental costs.
- Collaboration with Lawrence Livermore National Laboratory (LLNL).



Funding was provided by the Indiana Center for Coal technology Research