Coking/Coal Gasification Using Indiana Coal for the Production of Metallurgical Coke, Liquid Transportation Fuels, and Electric Power

Final Report
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Center for Coal Technology Research

Discovery Park
Energy Center

Research Team

- Robert Kramer (Ph.D.) is Director of the Purdue University Calumet Energy Efficiency and Reliability Center. Dr. Kramer serves as the Principal Investigator. His areas of expertise include energy research, electric system design and operation, engineering, physics, Combined Heat and Power systems, environmental engineering, and project management. He has over 30 years of industrial experience in the energy field, most recently as the Chief Scientist for NiSource.
- Libbie Pelter (Ph.D.), Assistant . Professor, Department of Chemistry and Physics, Purdue University Calumet. Dr. Pelter has a background in surface chemistry and catalysis from the petroleum industry.
- Harvey Abramowitz (Ph.D.), Professor, Department of Mechanical Engineering, Purdue University Calumet. Dr. Abramowitz has had extensive experience in metallurgy and steel making processes in general.
- Hardarshan Valia (Ph.D.), President, Coal Science, Inc. Dr. Valia serves as a team member and consultant to the project. He has extensive experience in the steel industry and specifically in the utilization of coal and the coking process. He also has experience with various production and economic aspects of both the coal and steel industry.
- Chenn Zhou (Ph.D.), Head of Mechanical Engineering Purdue University Calumet. Dr. Zhou is an expert in computational fluid dynamics.

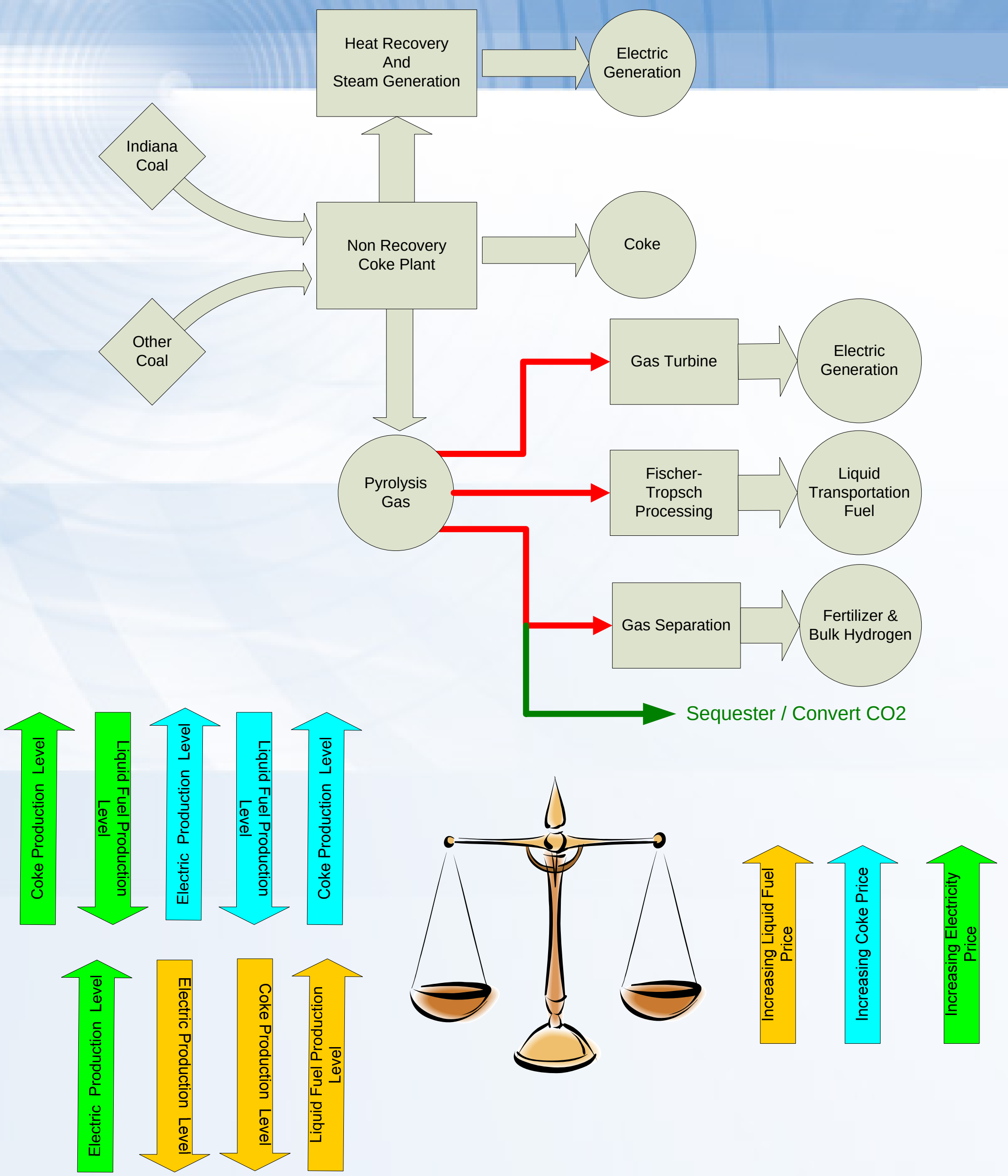
Goals

- Start process development efforts
  - Computer models
  - Simulation studies
- Assemble data for Indiana coal
- Process concepts
- CFD studies to increase usage %
- Blending considerations
- Consider methods to optimize various value streams

Research Plan Results

- Develop initial plan details (Completed)
- Establish new and refine existing interface with industry contacts – Contacts with industrial, governmental, regulatory, technical, and other appropriate sources will be formalized. Communication and information exchange procedures will be established to provide assistance in assuring the success of the project. (Completed)
- Obtain data and models for pyrolysis and Fischer-Tropsch processes. (Completed)
- Obtain coal samples and initiate analysis and evaluation of coking and Fischer-Tropsch processes for producing liquid fuels. (Completed)
- Initiate investigation of using nano catalysist for gas composition changes and Fischer-Tropsch processes. (Completed)
- Initiate non recovery coke oven and pyrolysis modeling. (Completed)
- Perform initial Computational Fluid Dynamics scoping appraisal of influence of produced coke on blast furnace operations. (Completed)
- Analyze the feasibility and options for using or selling generated electricity. (Completed)
- Initiate discussions with coal mine and coke production facilities regarding feasibility of developing a facility. (Completed)
- Determine impact of transportation issues. Coordinate with other studies. (Completed)
- Evaluate economic factors and influence on use of Indiana coal. (Completed)
- Develop process feasibility appraisal. (Completed)
- Make recommendations for a go/no-go decision point for future research. (Completed)
- Prepare final report (will be completed by 9/30/07)

Process Value Streams



Coke is an Essential Part of Iron Making and Foundry Processes

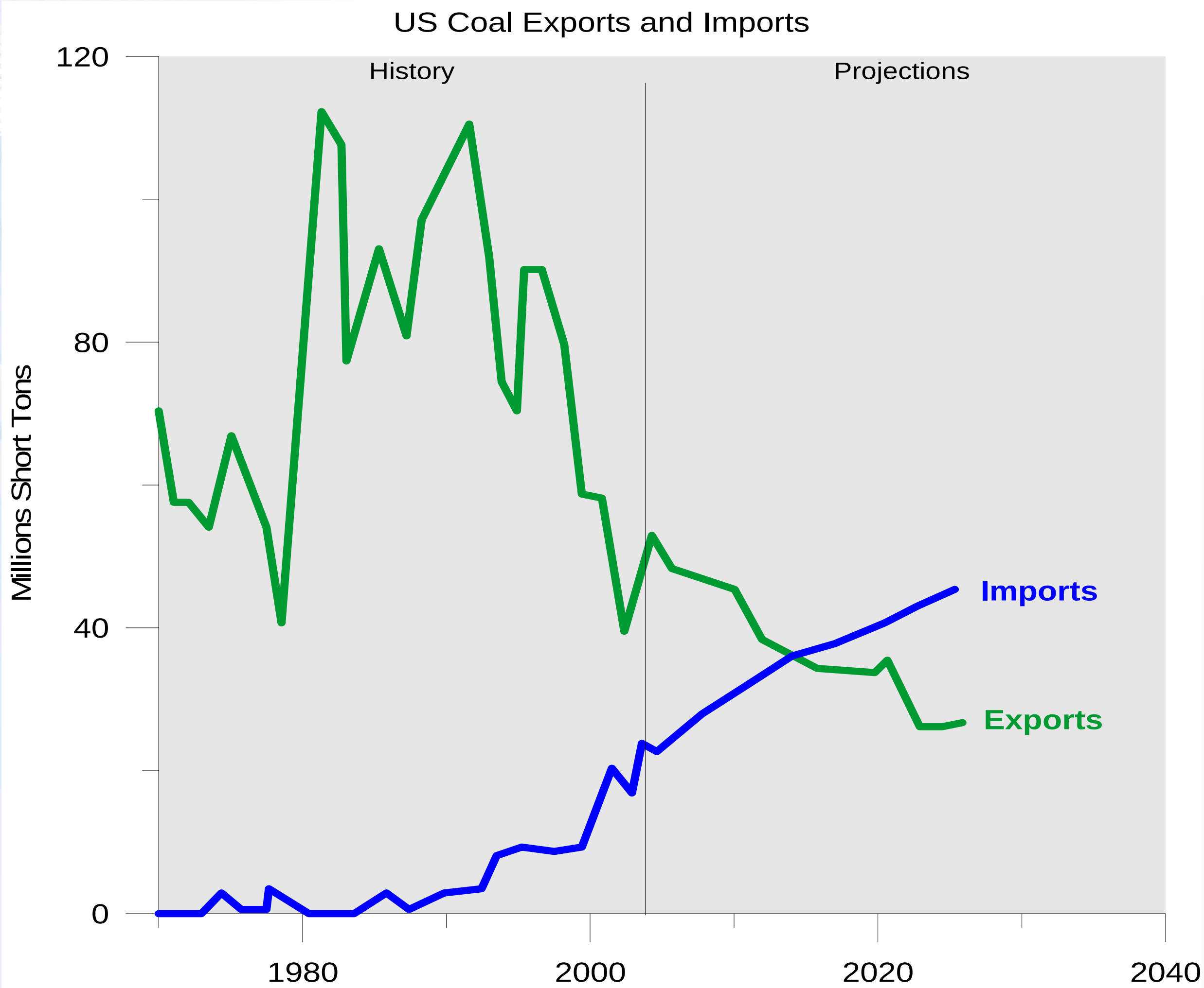
- **Currently there is a shortfall of 5.50 million tons of coke per year in the United States.**
- **Shortfall is being filled by imports, mainly from China and, to a lesser extent, from Japan.**
- **The result is high volatility in coke prices and a general trend to dramatic price increases.**
  - **Coke FOB to a Chinese port in January 2004 was priced at $60/ton, but rose to $420/ton in March 2004 and in September 2004 was $220/ton.**

Coke Oven

Coke Usage is Increasing

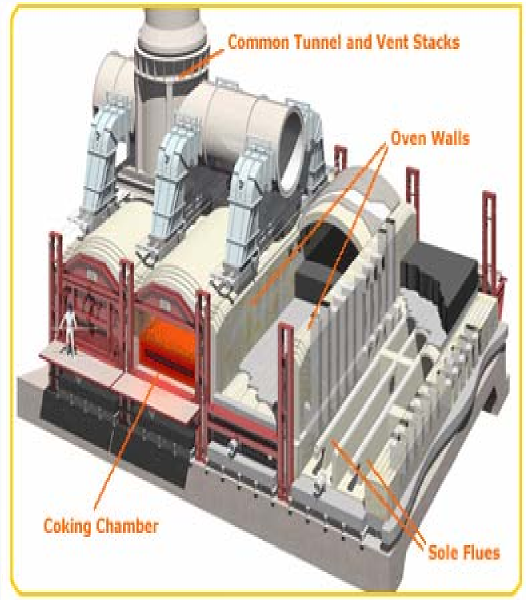
- 2005 forecasts indicate that the US will produce 11,500,000 net tons of coke, but will require 17,000,000 net tons for blast furnace, foundry, and related uses.
  - At present, essentially no Indiana coal is being used for coke production. In 2002, Indiana's steel industry used an estimated 10.7 million tons of coal.
    - 8.1 million tons was used for coke production.
    - Most from West Virginia, Virginia, and Kentucky.

US Coal Exports and Imports



Source: Energy Information Administration / International Energy Outlook 2004

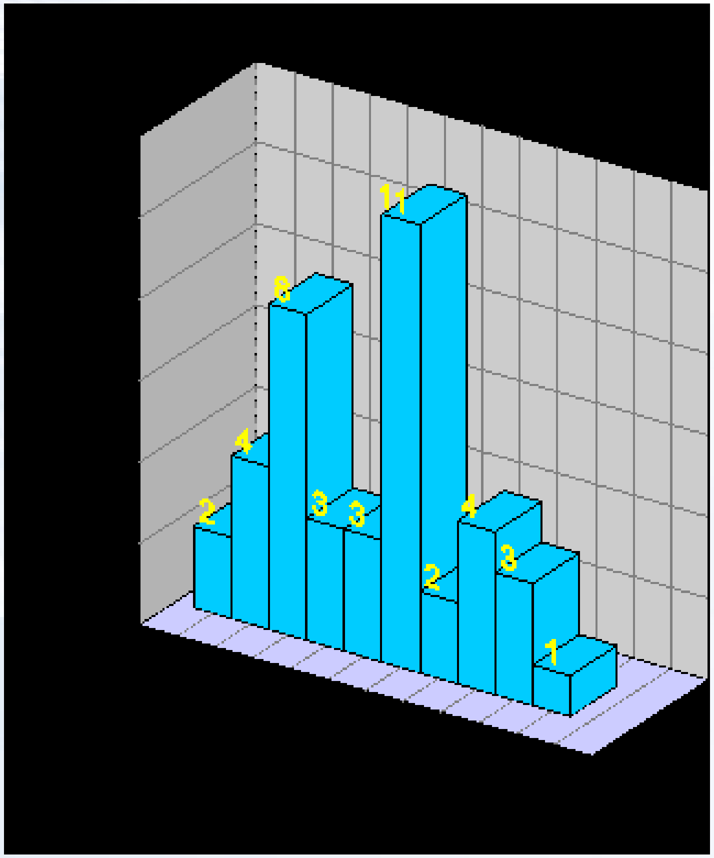
Recovery vs Non Recovery Ovens



Source:
Valia, H., “Coke Production for Blast Furnace Ironmaking”, AISI

Source:
SunCoke Company, Knoxville, Tennessee, http://www.suncoke.com.

Battery Age



Source;
Ludkovsky, G., "Coke Overview at Mittal Steel – Issues and Opportunities", 3rd China International Coking Technology and Coke Market Congress 2005, Beijing, China, Sept. 2005.

Issues With Indiana Coal for Coke

- **Coke produced from Indiana coal has less strength.**
  - Results in coke sizes that fall into two general classes.
    - **Buckwheat or Nut coke, is on the order of 1 inch x ¼ inch as compared to conventional blast furnace coke which is on the order of 1 inch x 4 inches.**
      - **Buckwheat / Nut coke is classically used in the steel industry as a carbon source for electric furnaces, in the production of ferromagnesium and ferrosilicon products, and in the production of elemental phosphorous.**
    - **Coke breeze - much finer.**
      - **Used as a source of carbon in steel making, for palletizing, sintering, elemental production of phosphorous. It can also be made into briquettes and used to feed blast furnaces in combination with iron ore pellets.**
      - **Other industries that use coke breeze include cement, paper, fertilizer, as well as others.**

Zones of a blast furnace

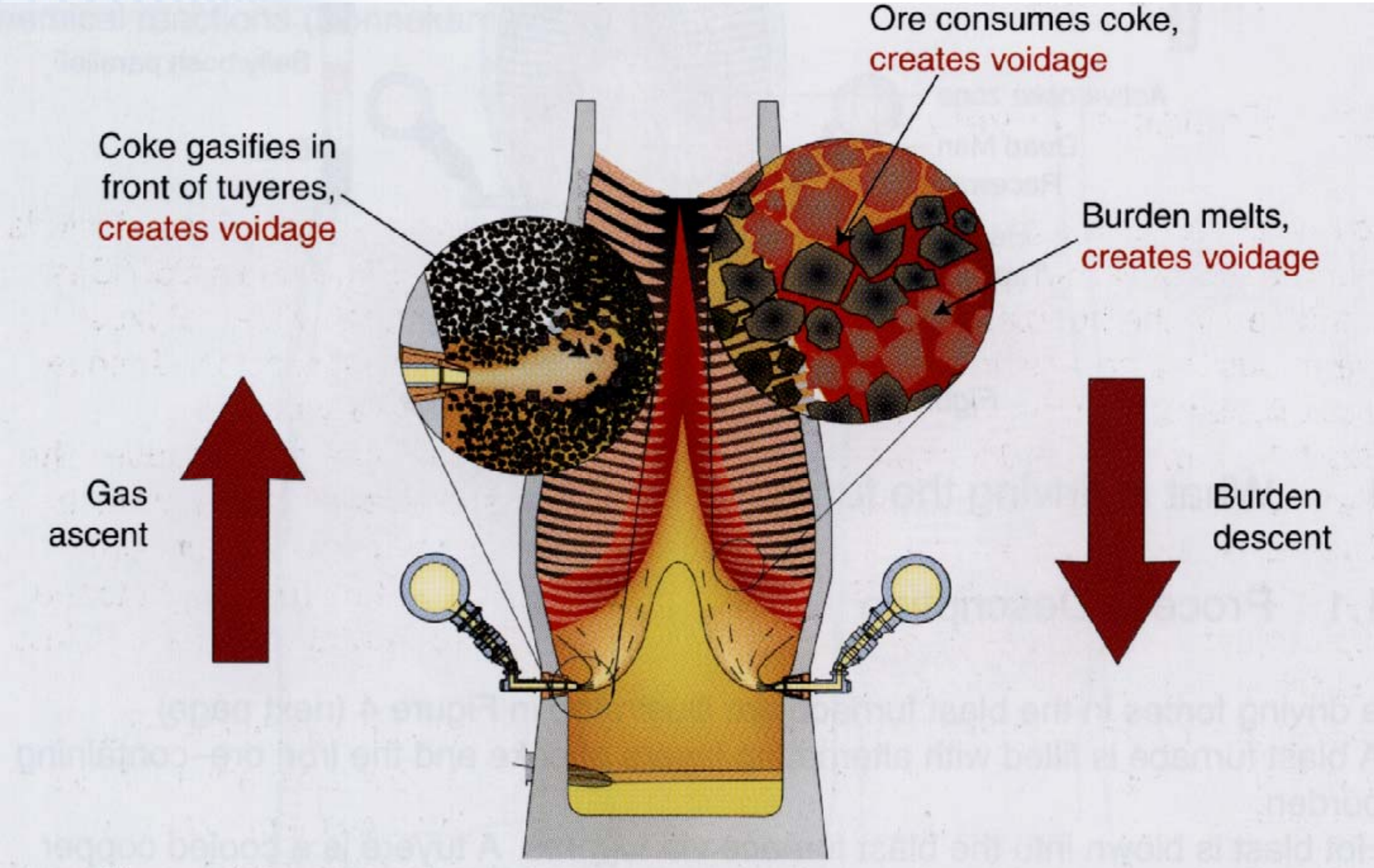


Figure 4: The driving force of a blast furnace: the counter current process creates voidage at the indicated areas causing the burden to descend

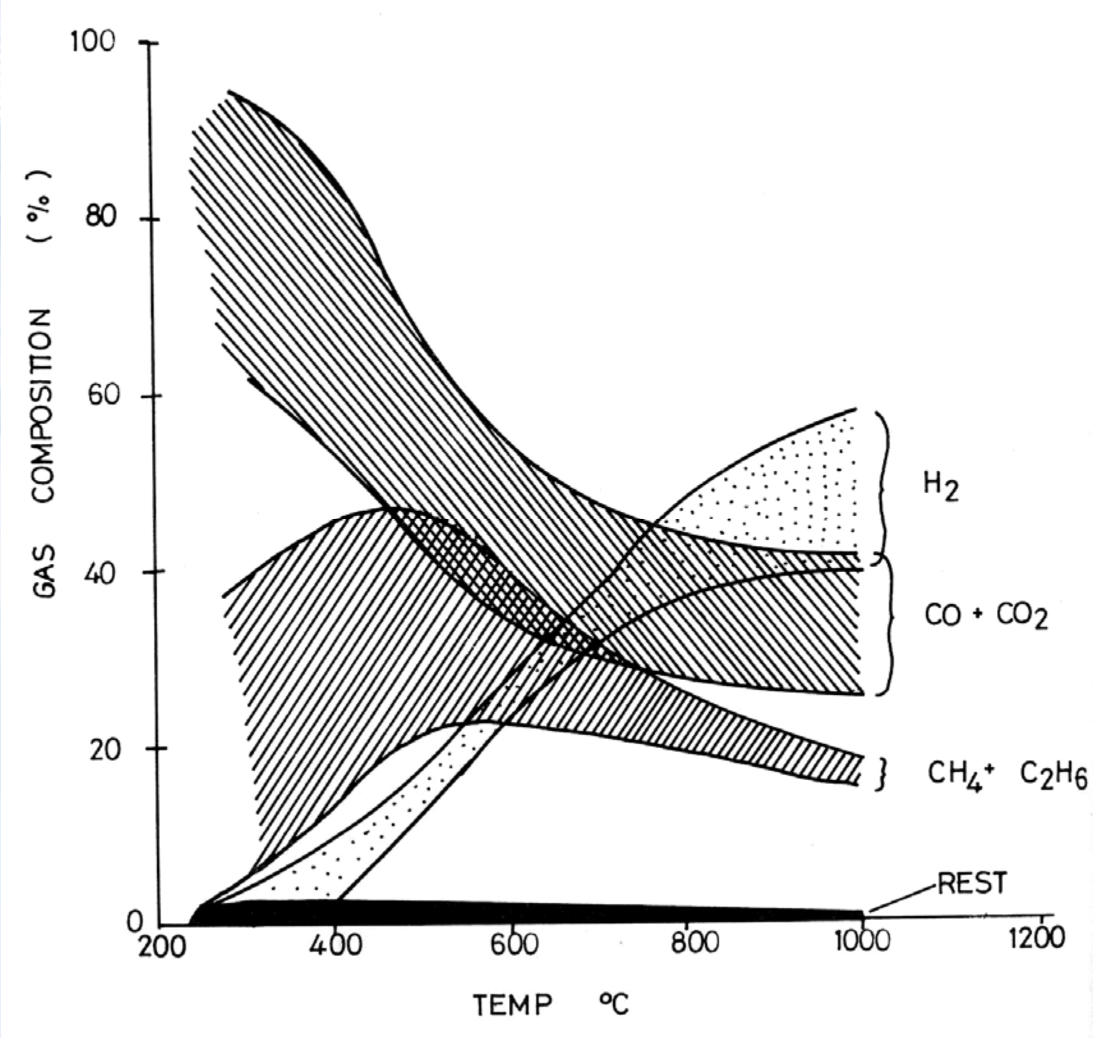
Source: Modern Blast Furnace Ironmaking, Verlag Stahleisen GmbH, 2004

Coke Oven Gas

- One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m^3 of coke oven gas.*

**The Making Shaping and Treating of Steel*, Association of Iron and Steel Engineers, Herbick & Held, Pittsburgh, 1985.

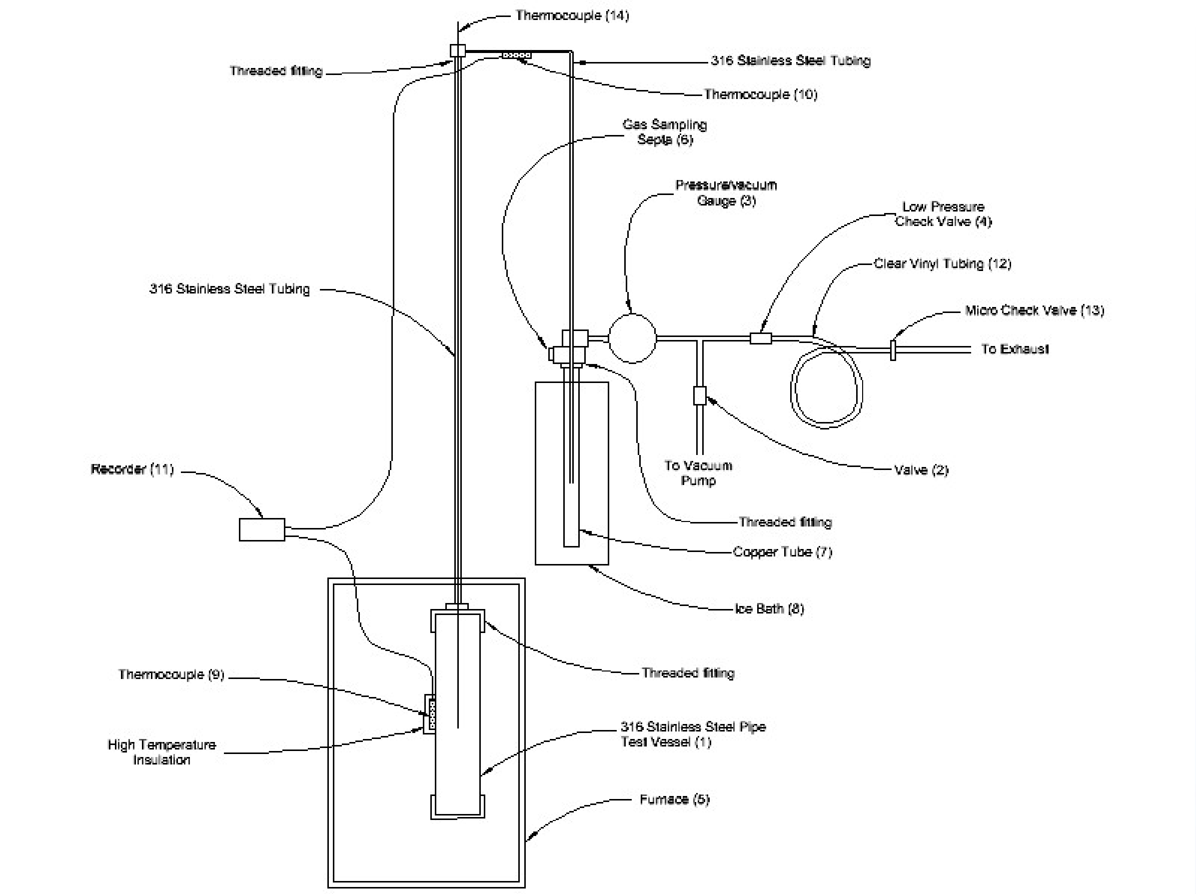
Historic Data:
Pyrolysis Gas Composition vs Temperature



Source:Coal Conversion Technology, Wen,C., Lee, E.

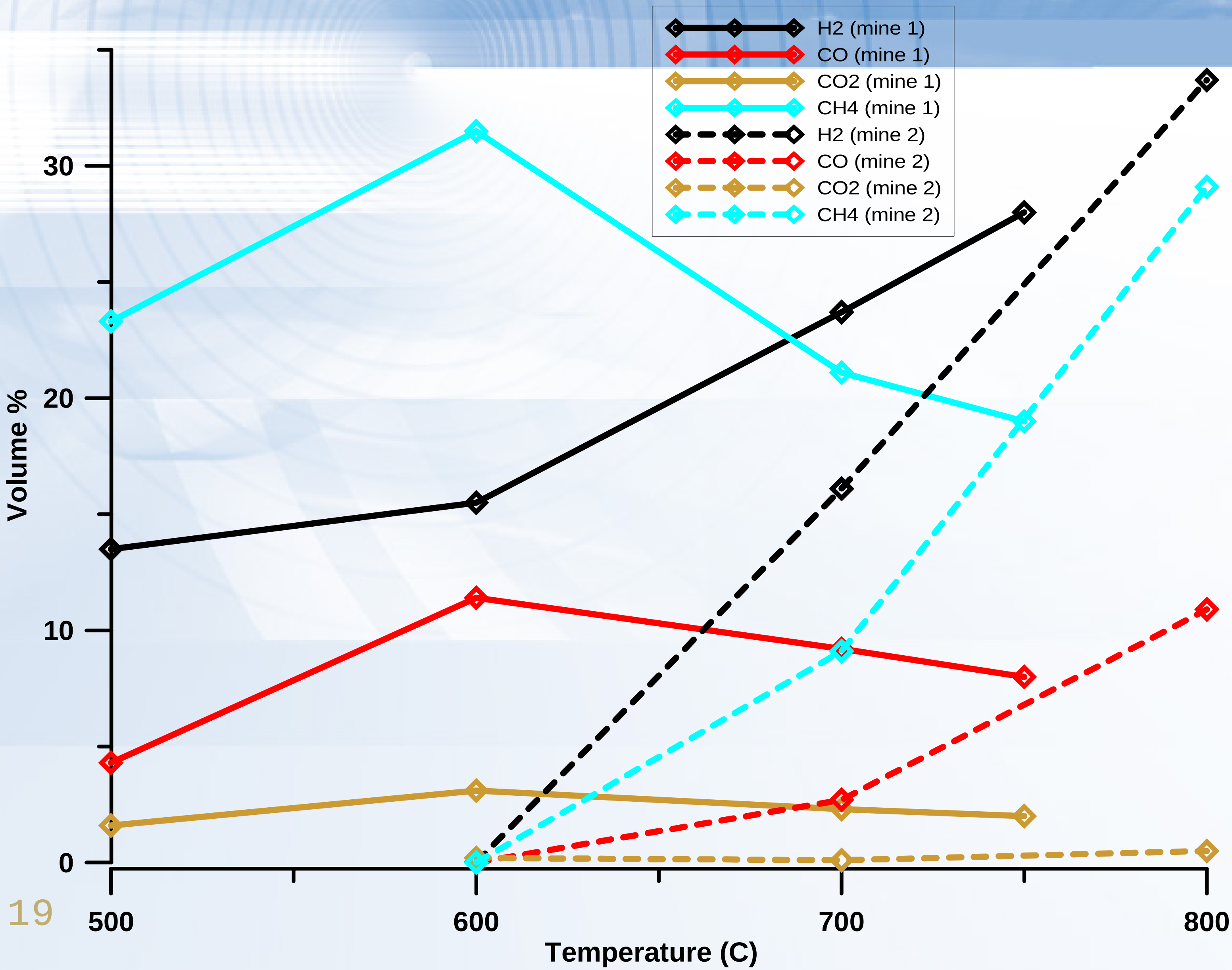
Initial Test Setup

Pyrolysis Test Apparatus

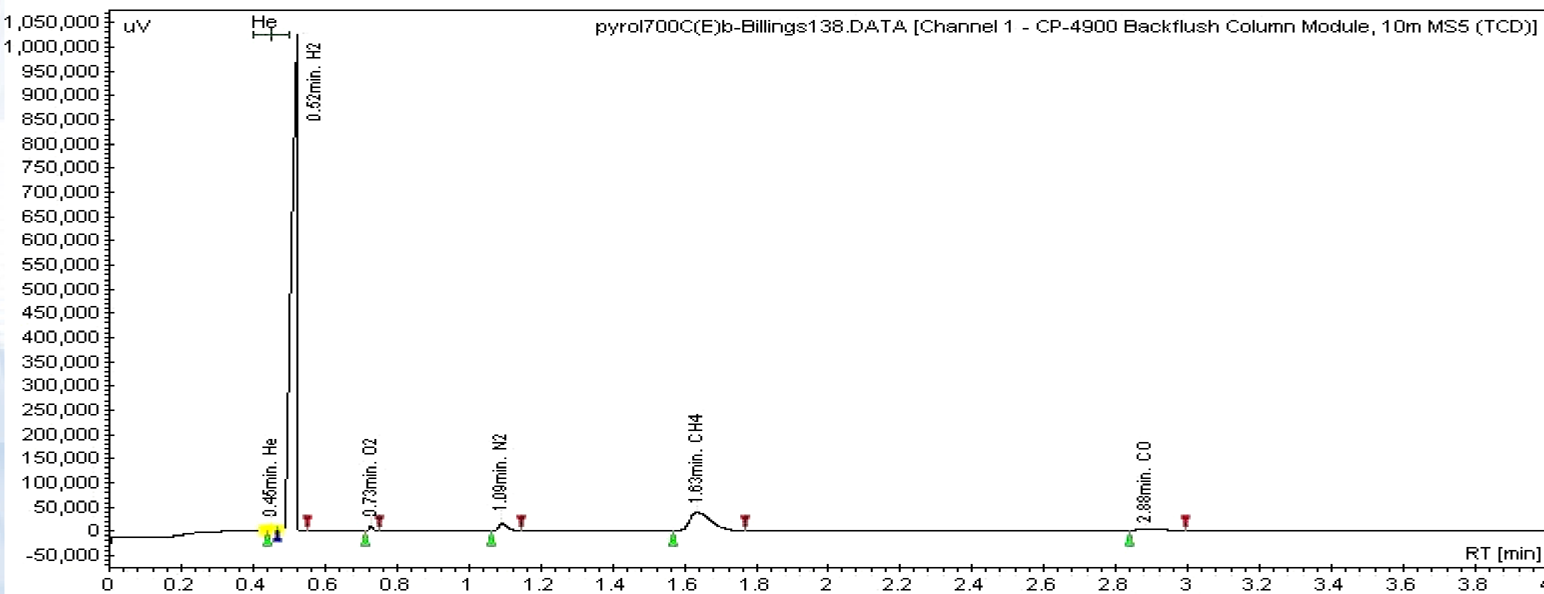


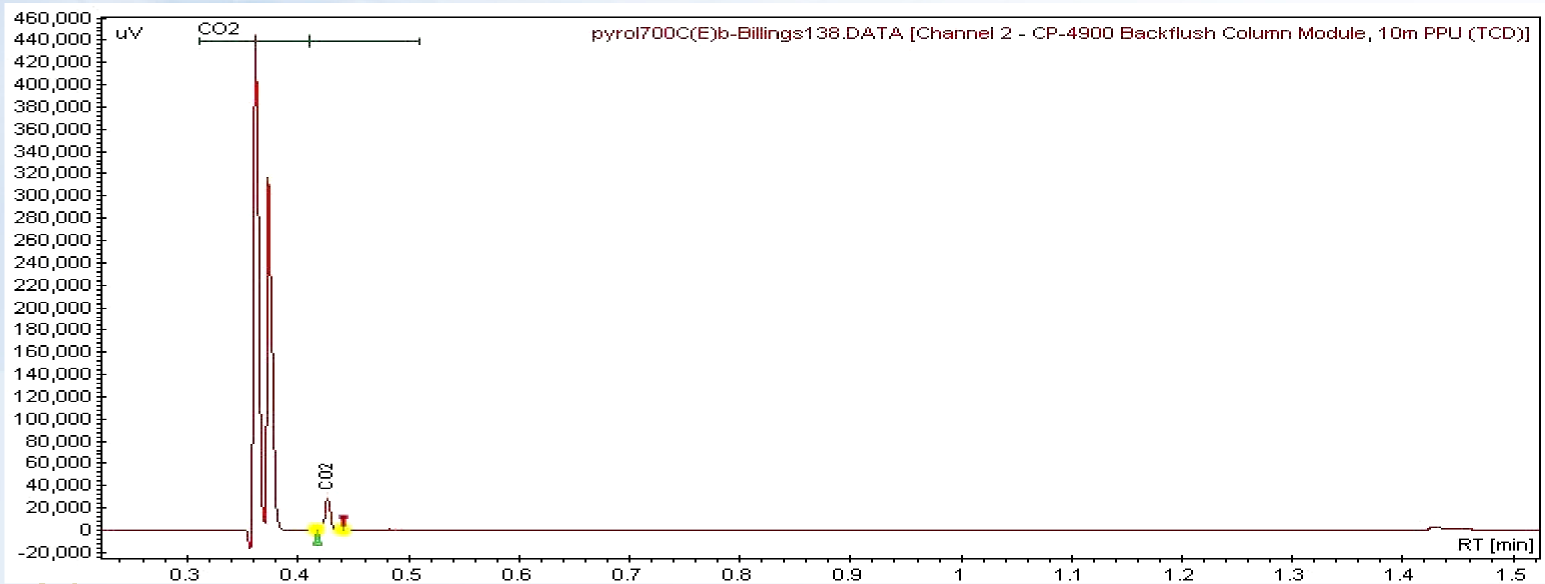
New Design

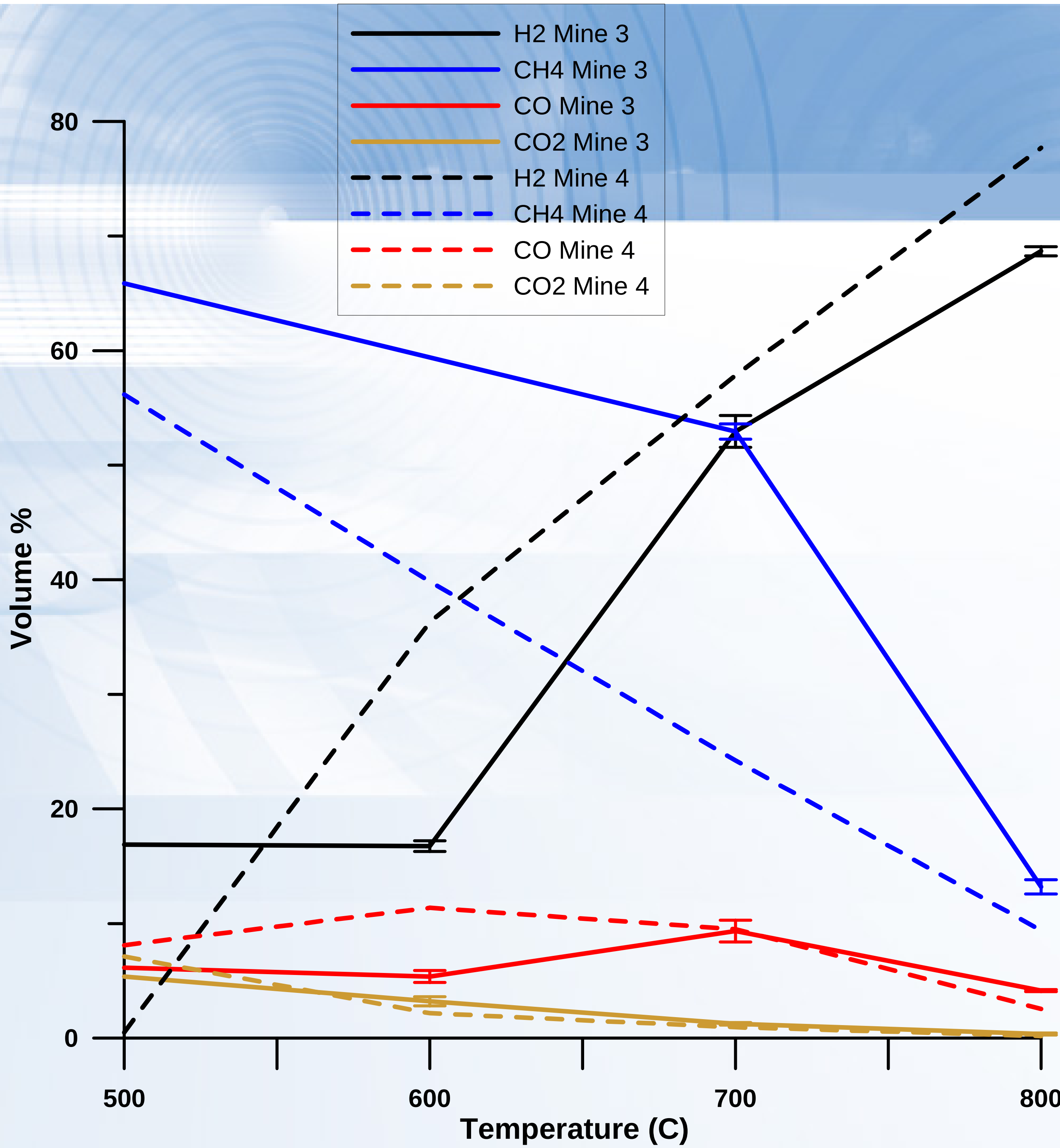
Initial Indiana Coal Test Results

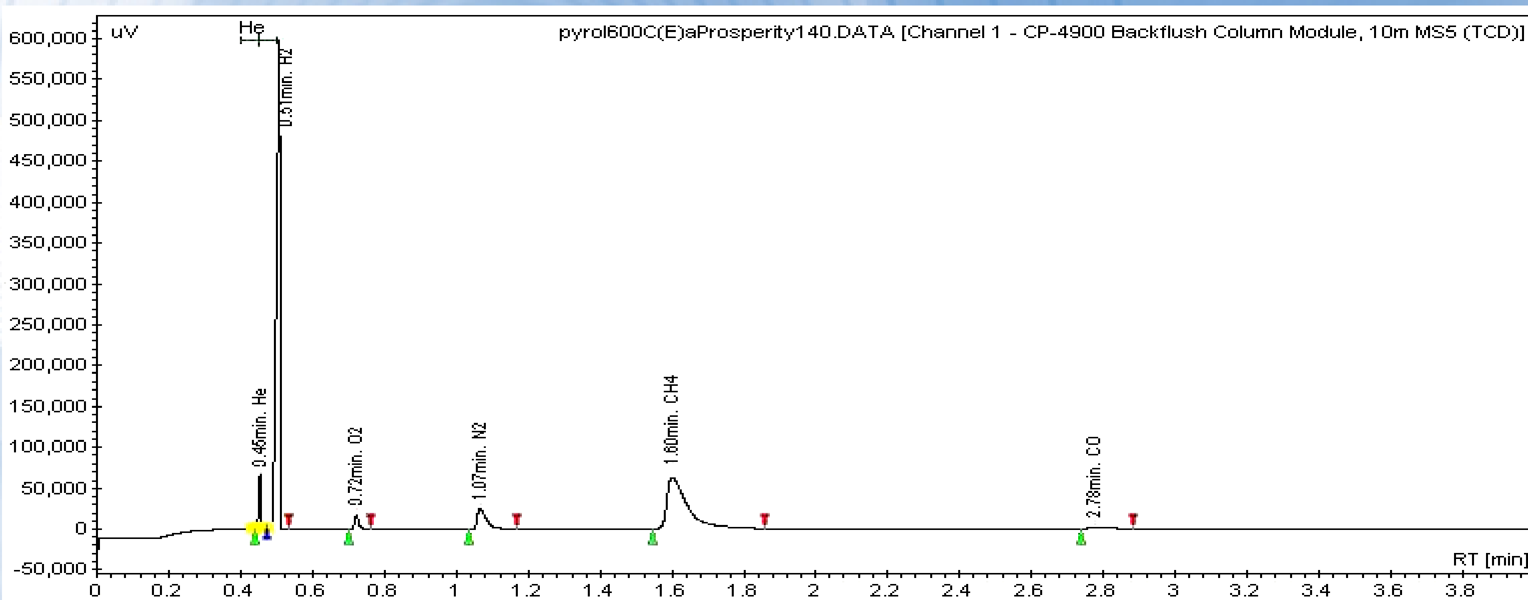


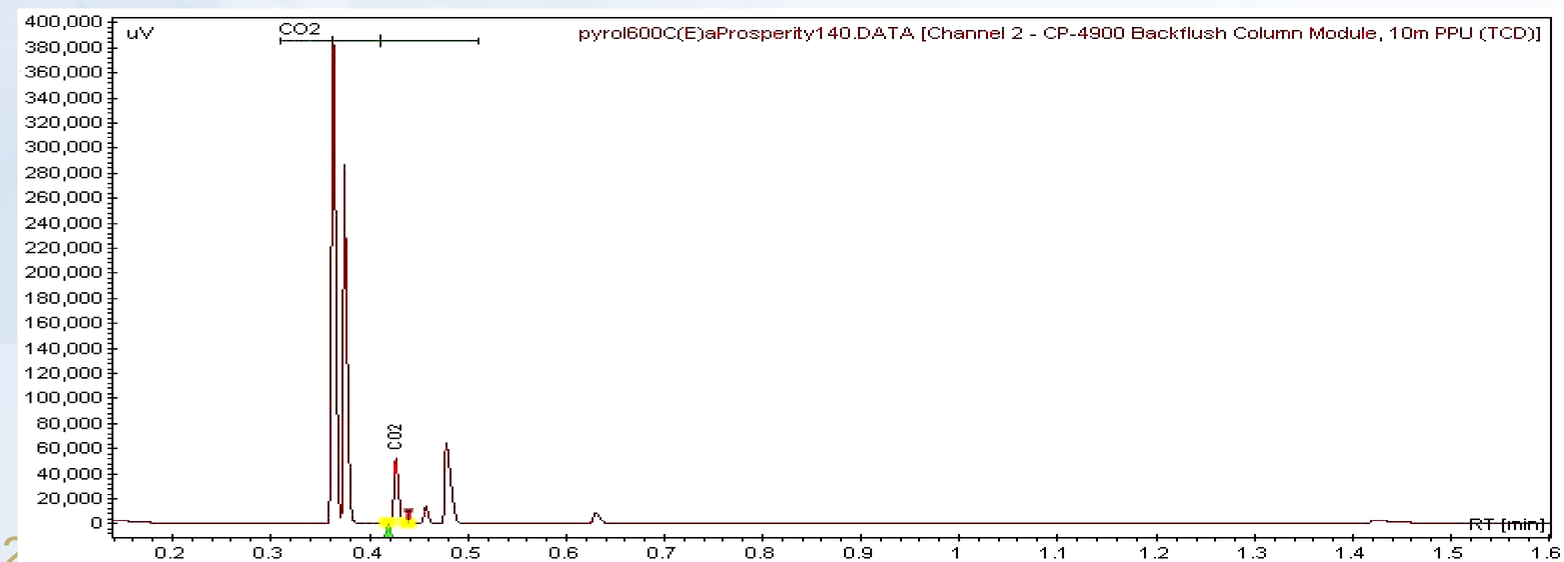
GC

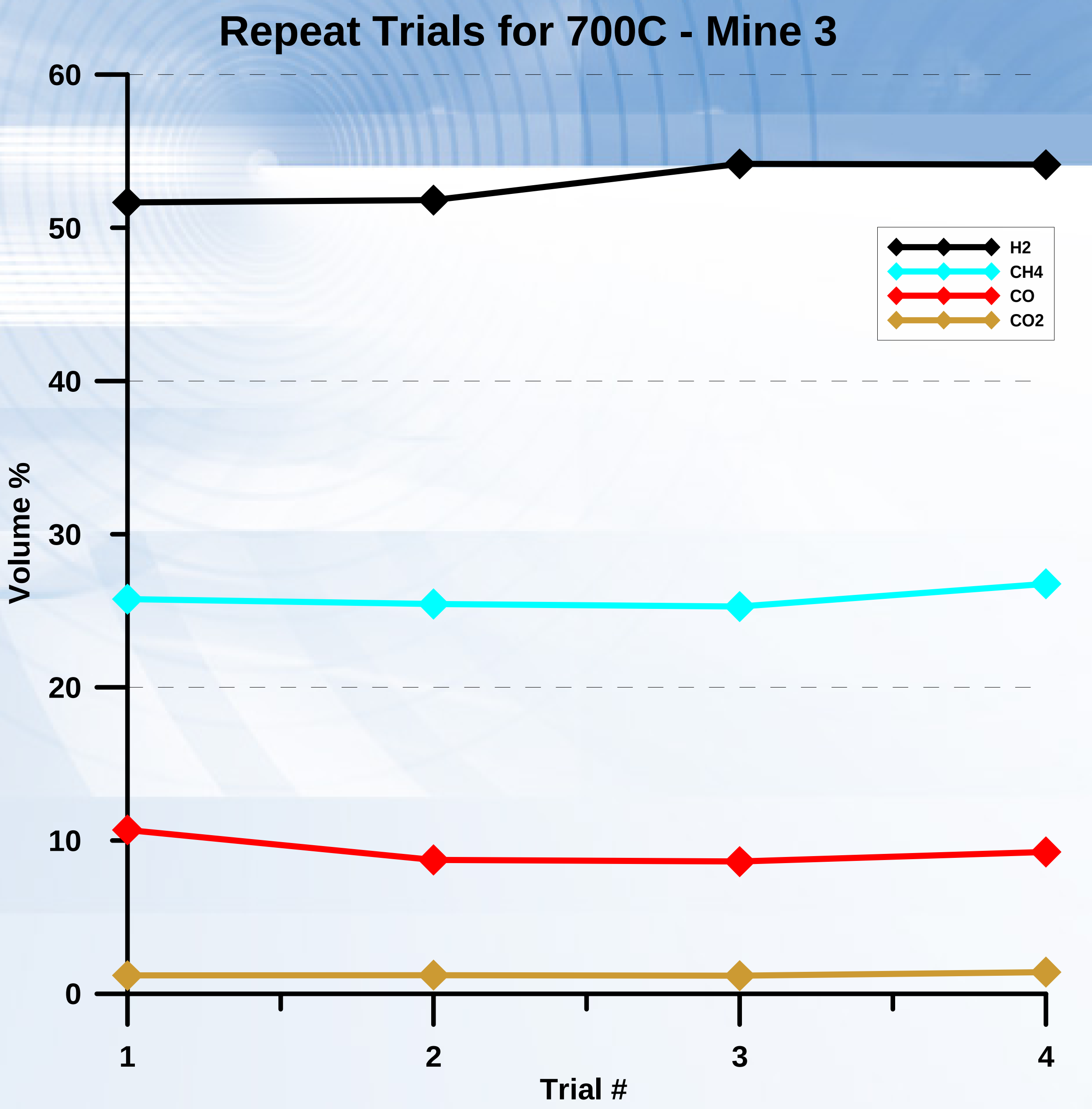

uV
He
pyrol700C(E)b-Billings138.DATA [Channel 1 - CP-4900 Backflush Column Module, 10m MS5 (TCD)]
0.52min. H2
0.45min. He
0.73min. O2
1.09min. N2
1.63min. CH4
2.88min. CO
RT [min]


uV
CO2
pyrol700C(E)b-Billings138.DATA [Channel 2 - CP-4900 Backflush Column Module, 10m PPU (TCD)]
CO2
RT [min]


H2 Mine 3
CH4 Mine 3
CO Mine 3
CO2 Mine 3
H2 Mine 4
CH4 Mine 4
CO Mine 4
CO2 Mine 4
80
60
40
20
0
Volume %
500
600
700
800
Temperature (C)


pyrol600C(E)aProsperity140.DATA [Channel 1 - CP-4900 Backflush Column Module, 10m MS5 (TCD)]
uV
He
0.45min. He
0.51min. H2
0.72min. O2
1.07min. N2
1.60min. CH4
2.78min. CO
RT [min]


pyrol600C(E)aProsperity140.DATA [Channel 2 - CP-4900 Backflush Column Module, 10m PPU (TCD)]
uV
CO2
CO2
RT [min]

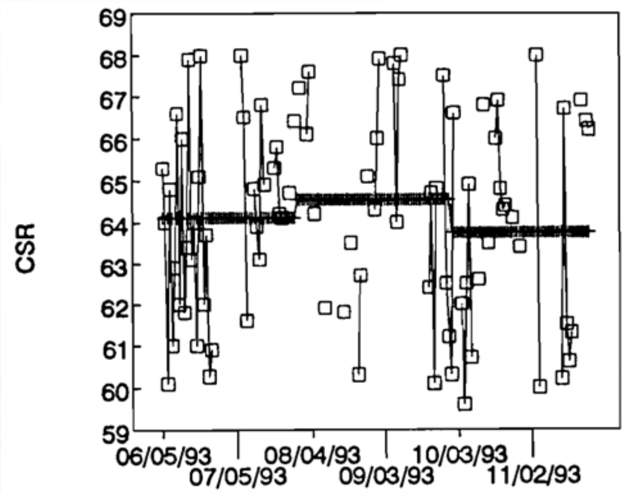

Repeat Trials for 700C - Mine 3
Volume %
0
10
20
30
40
50
60
Trial #
1
2
3
4
H2
CH4
CO
CO2

Coal Blending Is Key to Using Indiana Coal For Coke Production

Table VII: Analytical data for selected Indiana-Illinois coals

	Coal A	Coal B	Coal C	Coal D	Coal E
Petrography					
T. Inerts(%)	18.91	23.38	22.22	10.82	10.22
O. Inerts(%)	15.03	18.63	19.29	6.21	6.82
Exinite (%)	12.80	8.0	11.40	4.20	4.20
Reflectance(%)	0.56	0.55	0.63	0.58	0.65
Inert Index	0.84	1.11	0.96	0.43	0.37
Rank Index	2.54	2.43	2.57	2.45	2.52
P. Stability	12(33)	4	11(25)	19(33)	25(31)
USSCBI	0.84	1.09	0.97	0.44	0.38
USSSI	2.57	2.49	2.62	2.48	2.54
USS P.Stab.	21	17	24	5.22	4.49
Chemistry					
V.M.(%,db)	37.5	36.3	37.0	36.50	35.80
F.C.(%,db)	55.6	54.9	58.0	55.40	58.40
Ash(%,db)	7.0	8.8	5.0	8.1	5.8
Sulfur(%,db)	0.62	0.75	0.86	0.86	1.04
FSI	1.5	1.0	4.0	2.0	2.0
Alkali Index	0.78	0.85	0.92	1.53	1.33
Phophorus(%)	0.043	0.037	0.005	0.007	0.009
Rheology					
F.Range(Deg.C)	64	52	54	53	41
M.F.(ddpm)	48	30	24	5	3
P. CSR	50(48)	43	42(46)	35(30)	28(27)

Blend of 23% Indiana coal - 37% Eastern High Volatile (EHV) coal - 40% Eastern Medium Volatile (EMV) coal

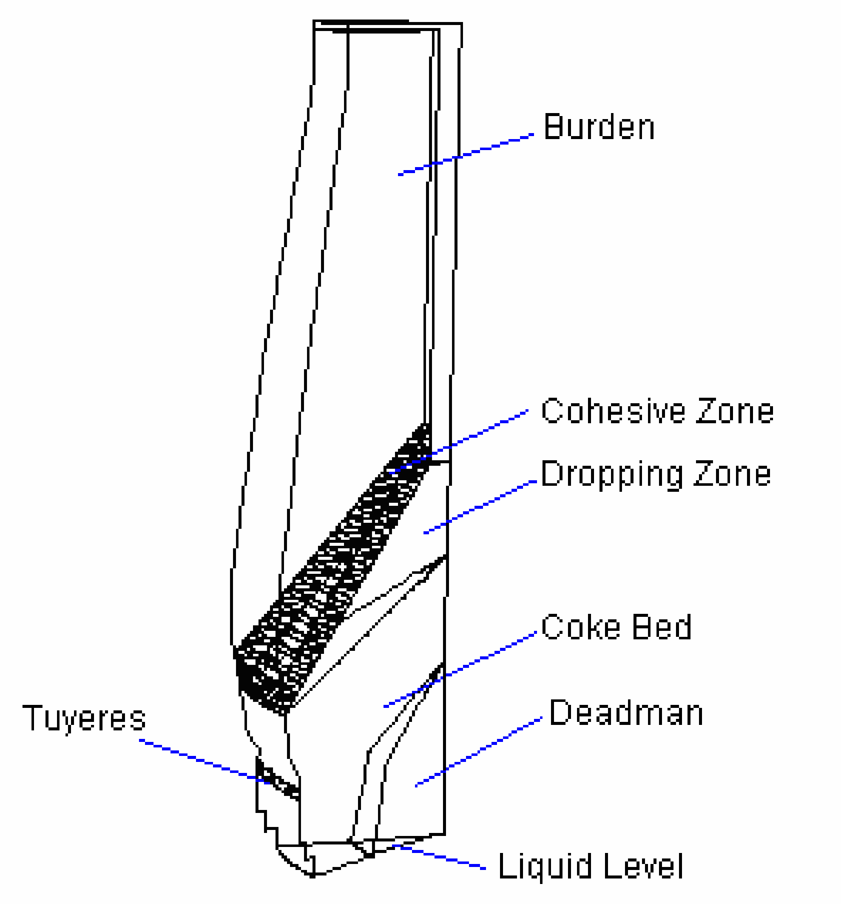


Source: Use Of Reverts And Non-Coking Coals
In Metallurgical Cofemaking, H.S. Valia and W. Hooper,
1994 Iron Making Conference Proceedings

Economic and Quality Process Optimization

- Develop model for blending coals in way that maximizes Indiana/Illinois Basin coal percentage (minimizes cost) within constraints
  - Maintain acceptable CSR levels
  - Produce pyrolysis gas streams at various temperatures that have composition suitable for producing Fischer Tropsch liquids, fertilizer, and bulk hydrogen
  - Electricity production
- Use the Model to formulate the design for a multipurpose coking facility that maximizes value for the entire process while meeting operating requirements
- Continue development of new approach to using nut coke in blast furnace operations that maximizes use of Indiana/Illinois Basin coal

CFD Model



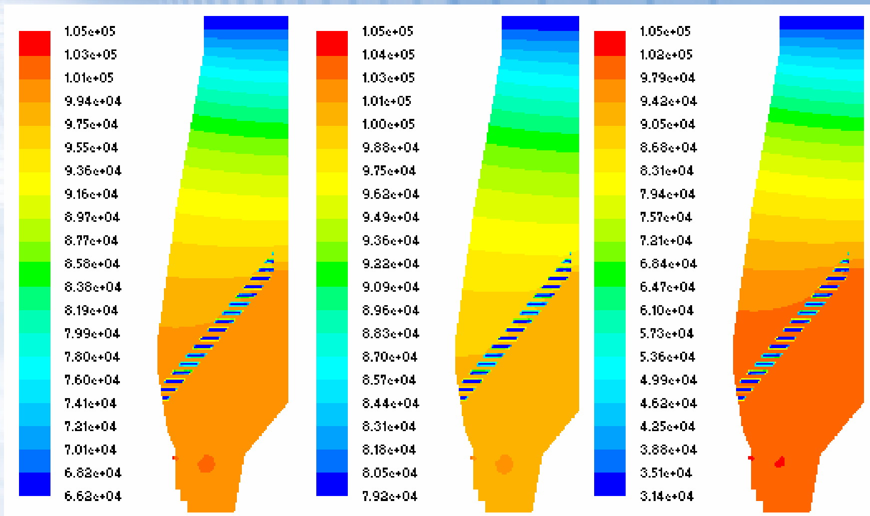
Cohesive zone: 34 alternating layers of coke and ore,
Ore layer's porosity: is assumed as zero (ore starts fusing and melting in the cohesive zone),

Coke bed porosity in the cohesive zone is 0.5. Burden: one zone with effective porosity of 0.41.

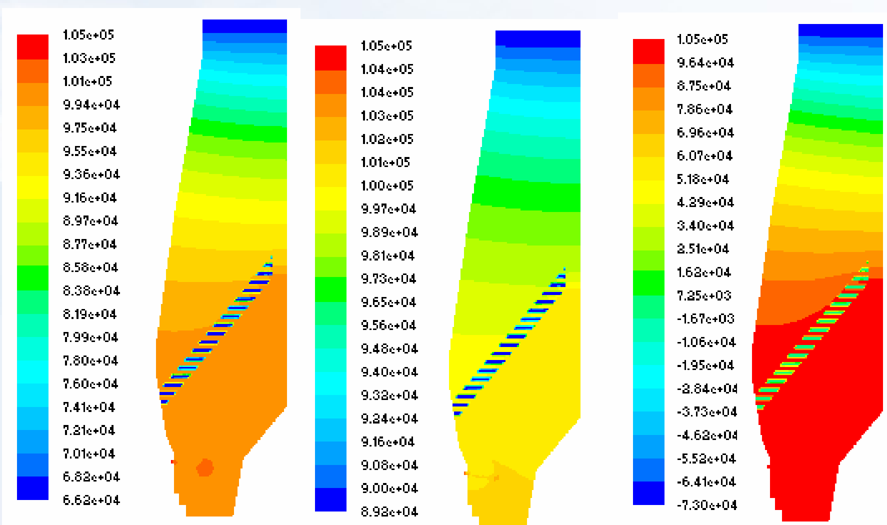
Test Cases

Case	Ore Porosity	Ore Diameter	Coke Porosity	Coke diameter
1	0.35	0.012	0.5	0.0380
2	0.35	0.02	0.5	0.0380
3	0.35	0.006	0.5	0.0380
4	0.35	0.012	0.5	0.0600
5	0.35	0.012	0.5	0.0200
6	0.35	0.012	0.3	0.0380
7	0.35	0.012	0.65	0.0380
8	0.5	0.012	0.5000	0.0380
9	0.2	0.012	0.5000	0.0380

Pressure Loss

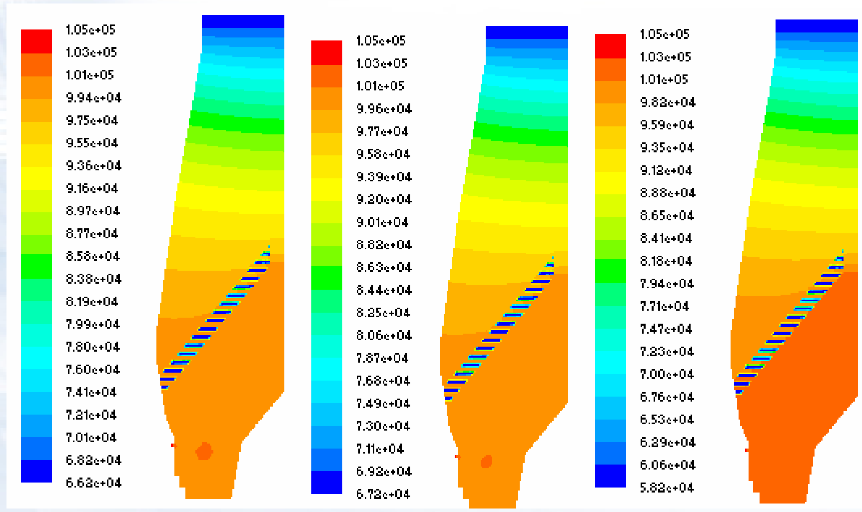


(a) Ore Dia = 0.012m (b) Ore Dia = 0.02m (c) Ore Dia = 0.006m

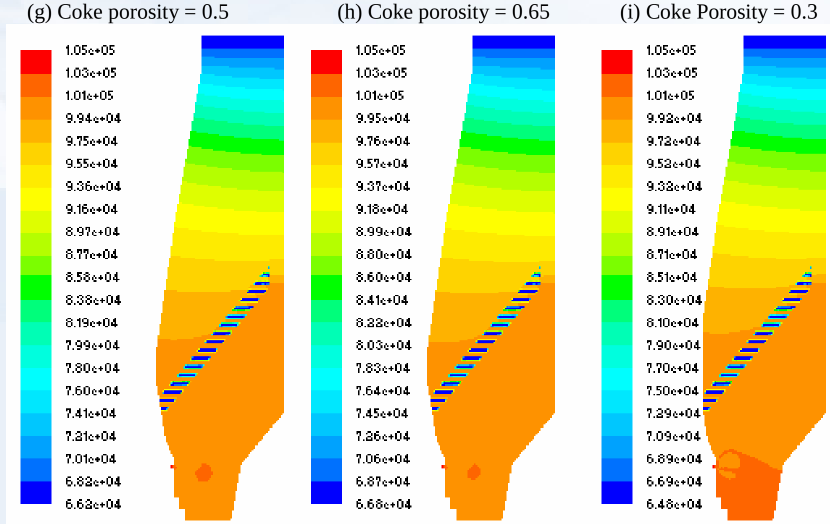


(d) Ore Porosity = 0.35 (e) Ore Porosity = 0.5 (f) Ore Porosity = 0.2

Pressure Loss

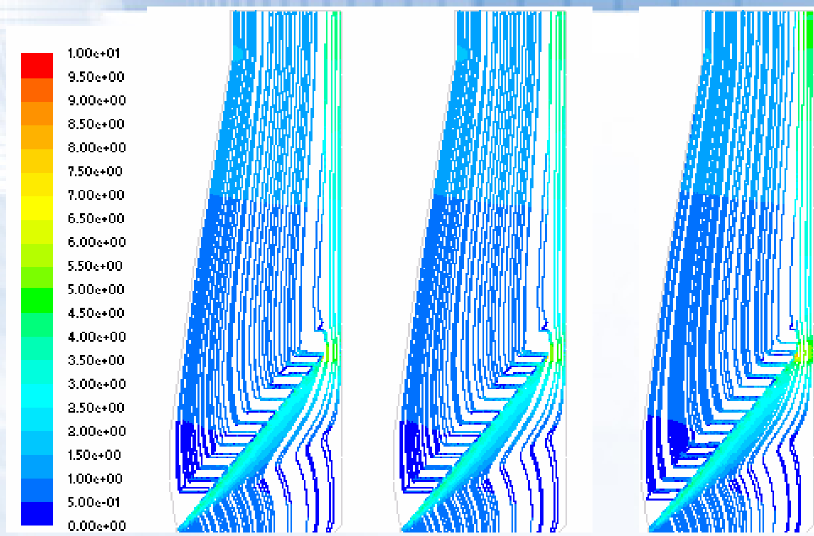


(g) Coke porosity = 0.5 (h) Coke porosity = 0.65 (i) Coke Porosity = 0.3

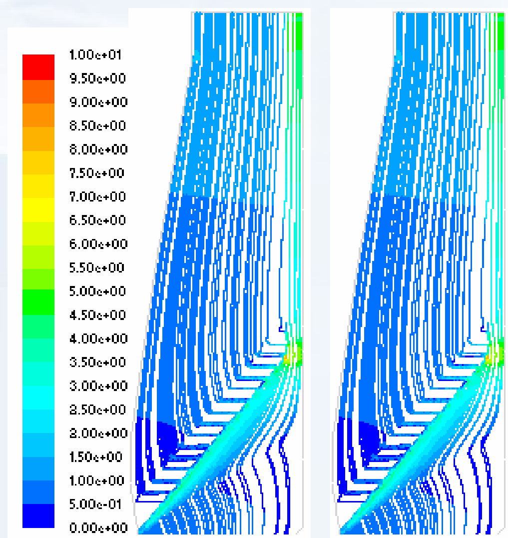


(g) Coke dia = 0.038m (h) Coke dia = 0.06m (i) Coke dia = 0.02

Path Lines

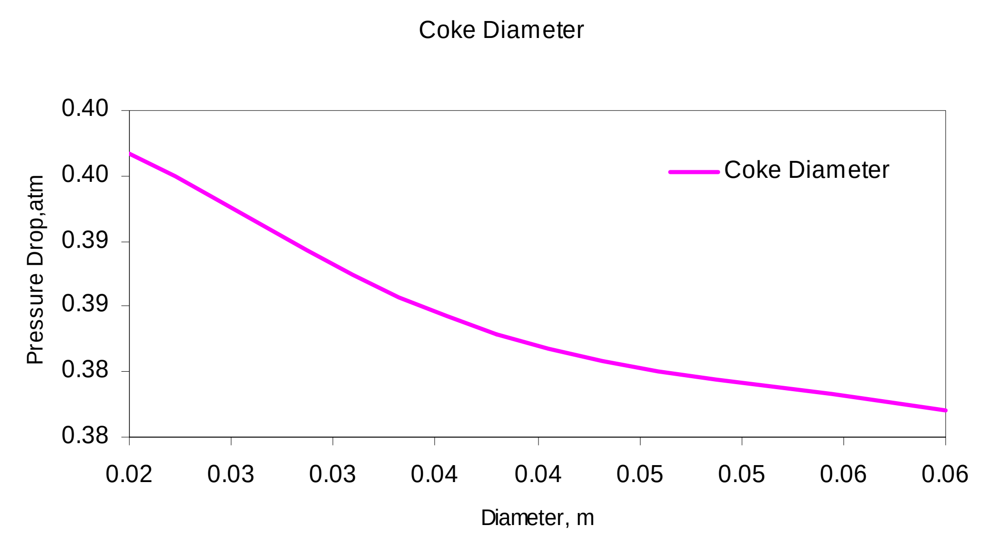


(a)Coke dia – 0.038m, Porosity – 0.5 (b) Coke dia – 0.02m (c) Coke dia – 0.06m

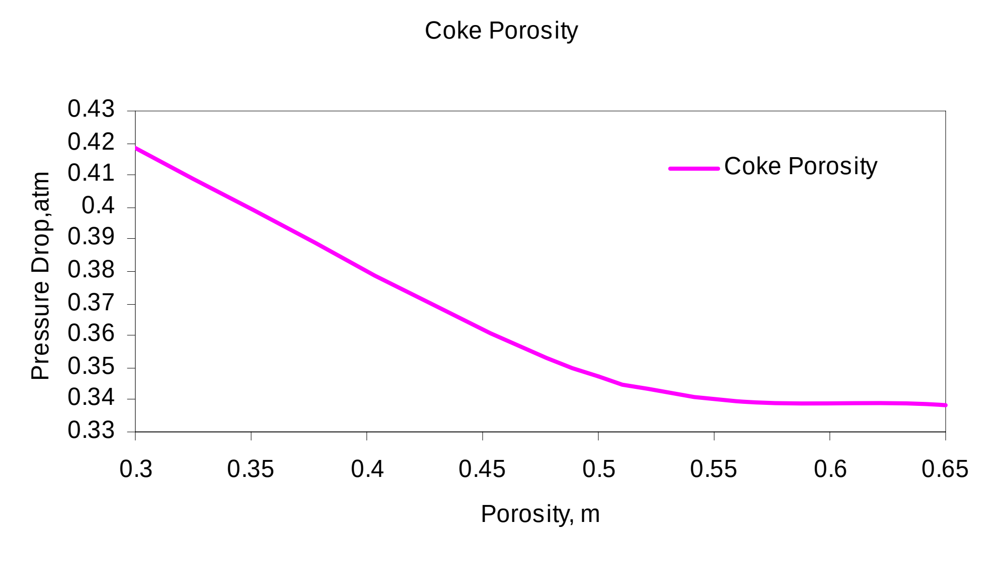


(d) Porosity – 0.3 (e) Porosity – 0.65

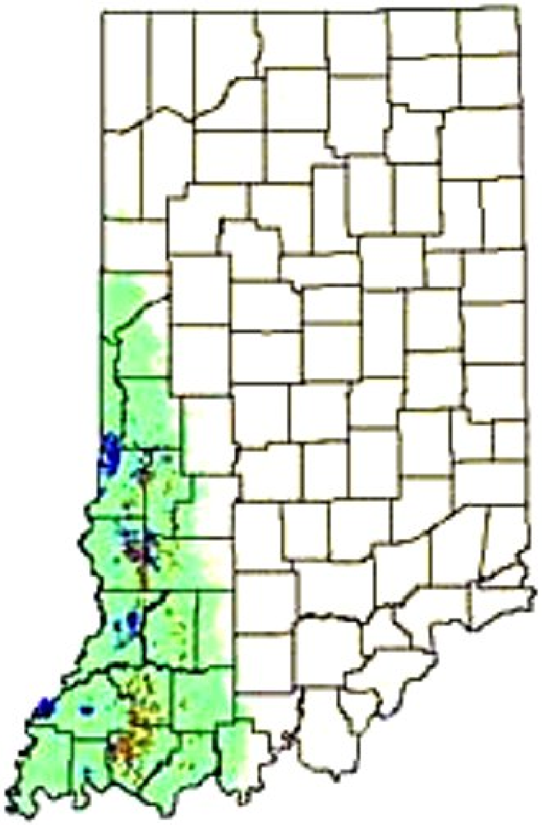
Pressure Drop vs Coke Diameter



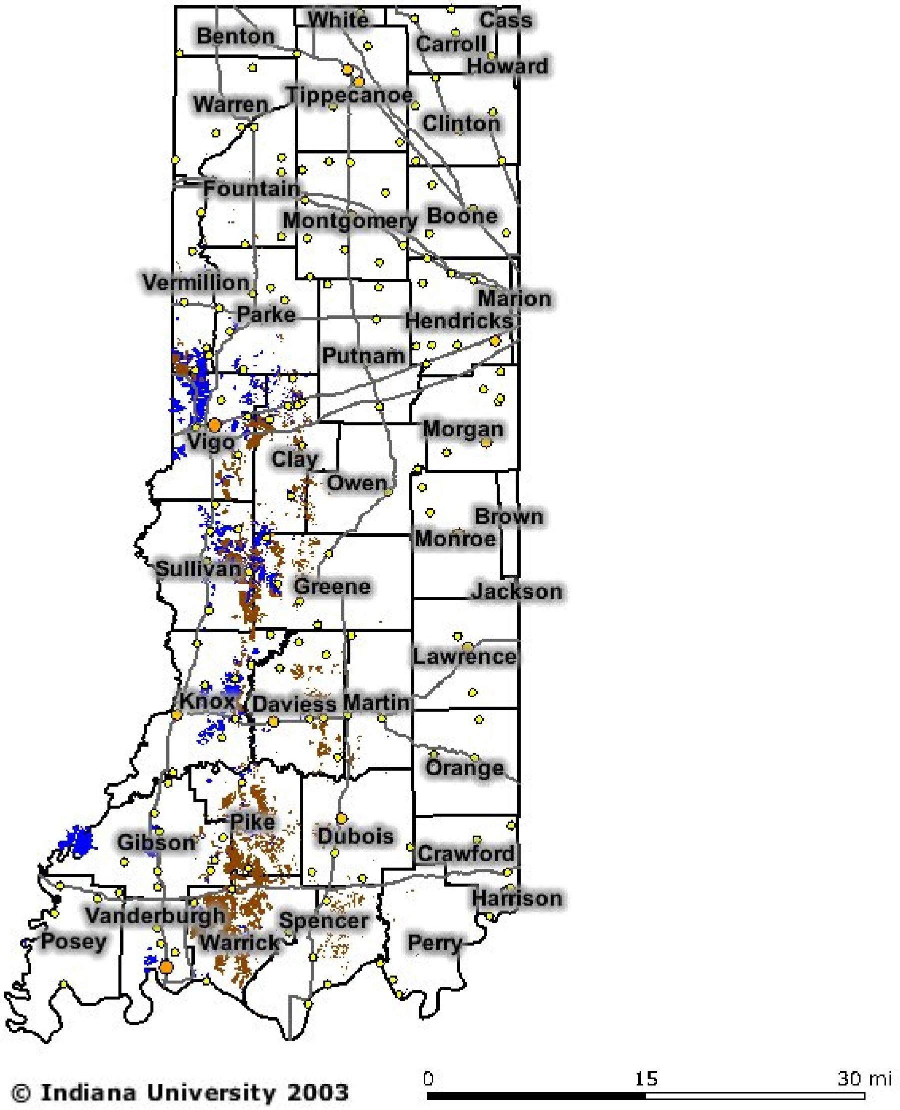
Pressure Drop vs Coke Porosity



Transportation Issues

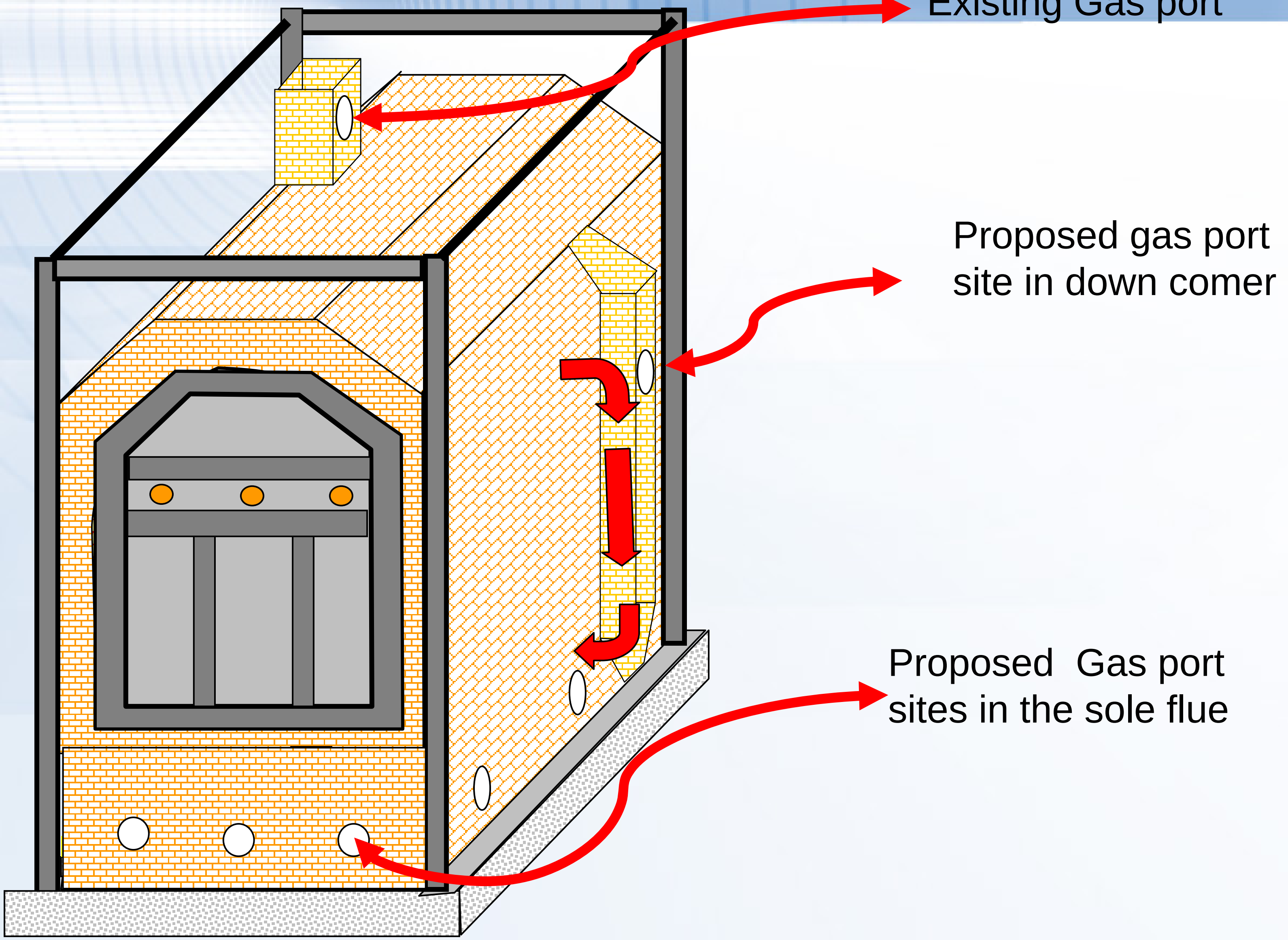


Index map of Indiana showing the coal-bearing rocks of the Pennsylvanian System in green, underground coal mines in blue, and surface coal mines in brown.



CSL Pilot Oven

CSL Pilot Oven



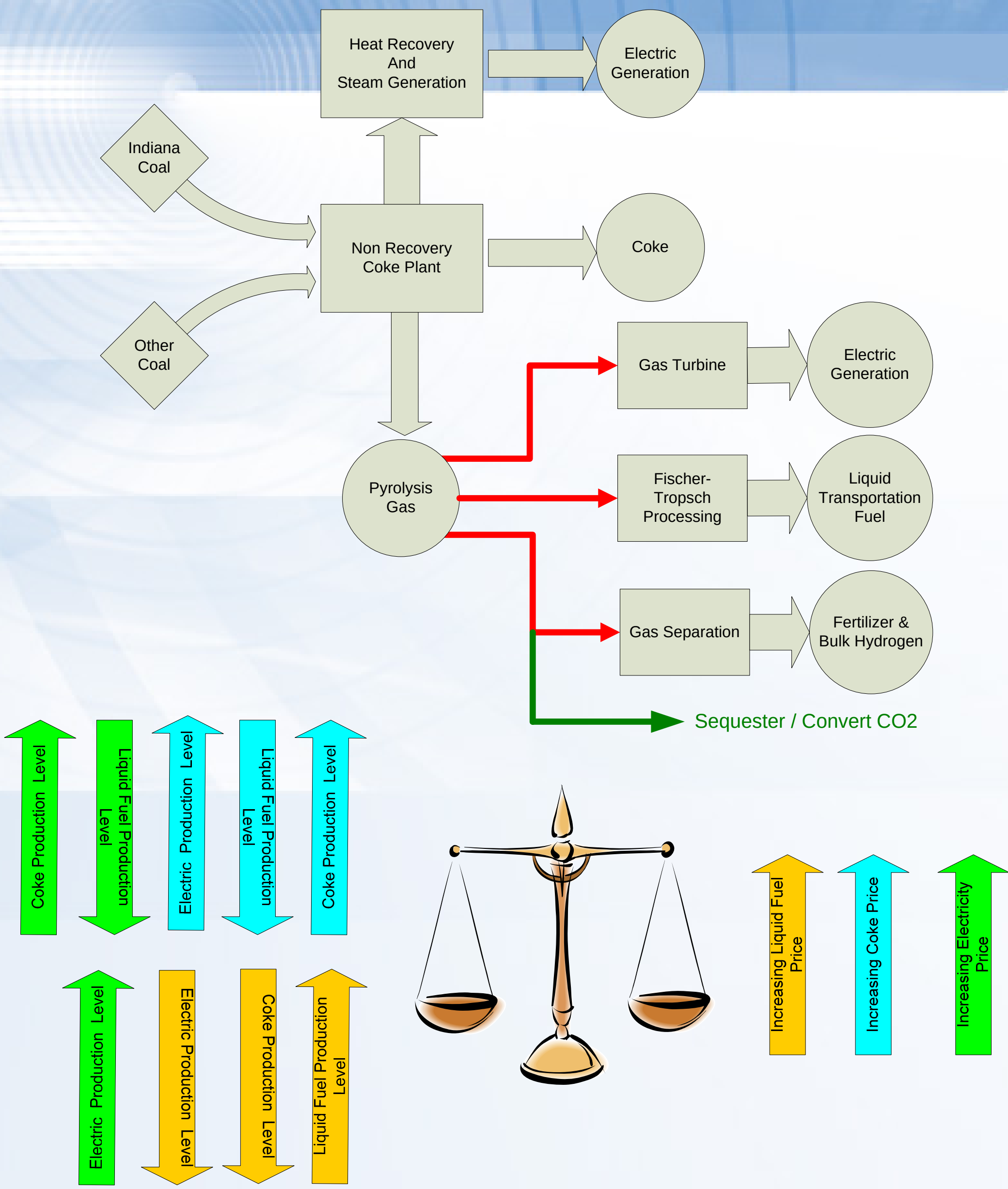
Research Recommendation

- Results indicate that there is significant benefit to continuing with the current research effort and to consider further development of processes that will lead to construction of an industrial test facility.
- Based upon the preliminary results it is recommended that further development of the proposed concept for using Indiana Coal for coking/gasification should be initiated and expanded to include development of an optimized coal blending scheme that maximizes coke and pyrolysis gas properties for use in Fischer Tropsch production of liquid transportation fuels, fertilizer and low grade hydrogen gas.
- Industrial process testing should be initiated when funding is available.

Future Work Objectives

- Phase 2 can be started in 2007
- Additional funding required
- Ongoing discussions with potential industrial collaborators
- Develop optimization model for minimizing cost by maximizing Indiana/Illinois Basin coal use, coke properties, and value streams
- Obtain more test data for coal samples
- Start one ton oven testing
- Fischer-Tropsch unit design, construction, and installation
- Fertilizer concept development and testing
- Bulk H concept development and testing
- Consider environmental issues in more detail
- Continue discussions for potential commercialization at mine mouth (or other) multipurpose coke facility

Process Value Streams



Thank You !

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