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

Status Report
12/6/2006

Robert Kramer, Ph.D.
Director, Energy Efficiency and Reliability Center
Purdue University Calumet

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. He also teaches various courses in Physics and Engineering.
- **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. Her current interests include development of nano catalysis and surface chemistry.
- **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. He has worked in the steel industry and is familiar with steel and iron quality and production issues. He has also worked on process costing and economics.
- **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. She is the principal investigator for a $1.29M 21st Century Grant to develop Computational Fluid Dynamic techniques for use in blast furnace operations. She has modeled various industrial systems and has considered energy and process optimization as part of the modeling effort. Recently, she was elected a Fellow of the American Society of Mechanical Engineers.
- **Anita Katti** (Ph.D.), Assistant Professor, Department of Chemistry and Physics, Purdue University Calumet. Dr. Katti has a background in chemical engineering from the pharmaceutical industry.

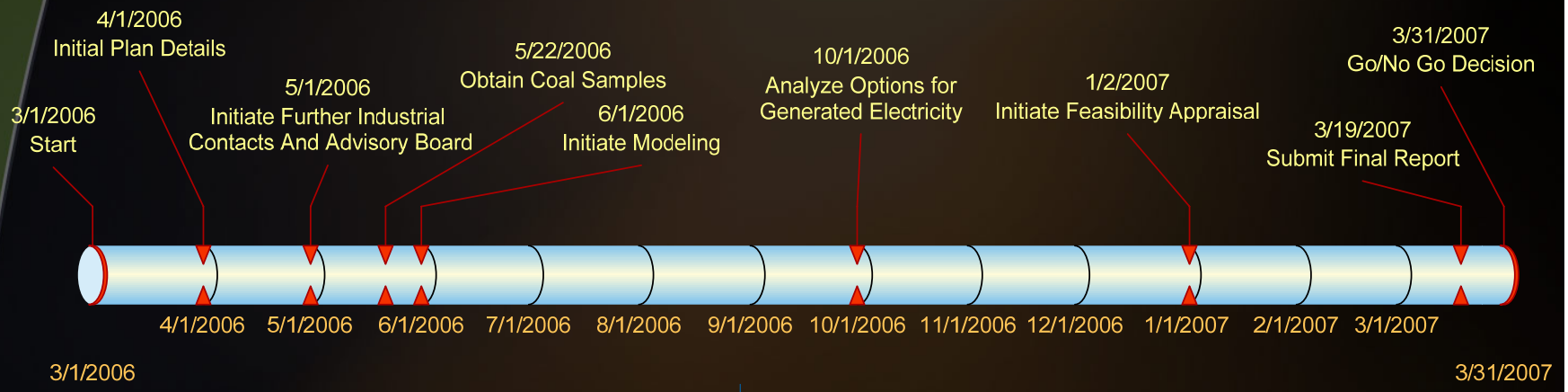
Initial Scoping Study Completed

- **Results indicated a significant potential to use Indiana coal for the production of coke and electricity**
- **Preliminary investigation indicates that pyrolysis gas can be used for a Fischer-Tropsch process to produce liquid transportation fuels. Also investigating production of fertilizer and hydrogen**

Current Efforts

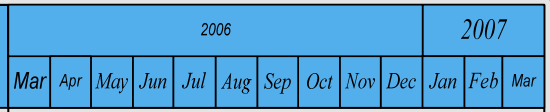
- Process development efforts
  - Computer models
  - Simulation studies
  - Laboratory Tests
- Assembling data for Indiana coal
- Conducting testing of composition of pyrolysis gas from Indiana coal samples
- Developing process concepts
- Blending considerations
- Consider methods to optimize various value streams
- CFD studies to increase usage %
- Preliminary designs for next phase of commercialization
- Seeking funding for next phase

Timeline
Major Milestones

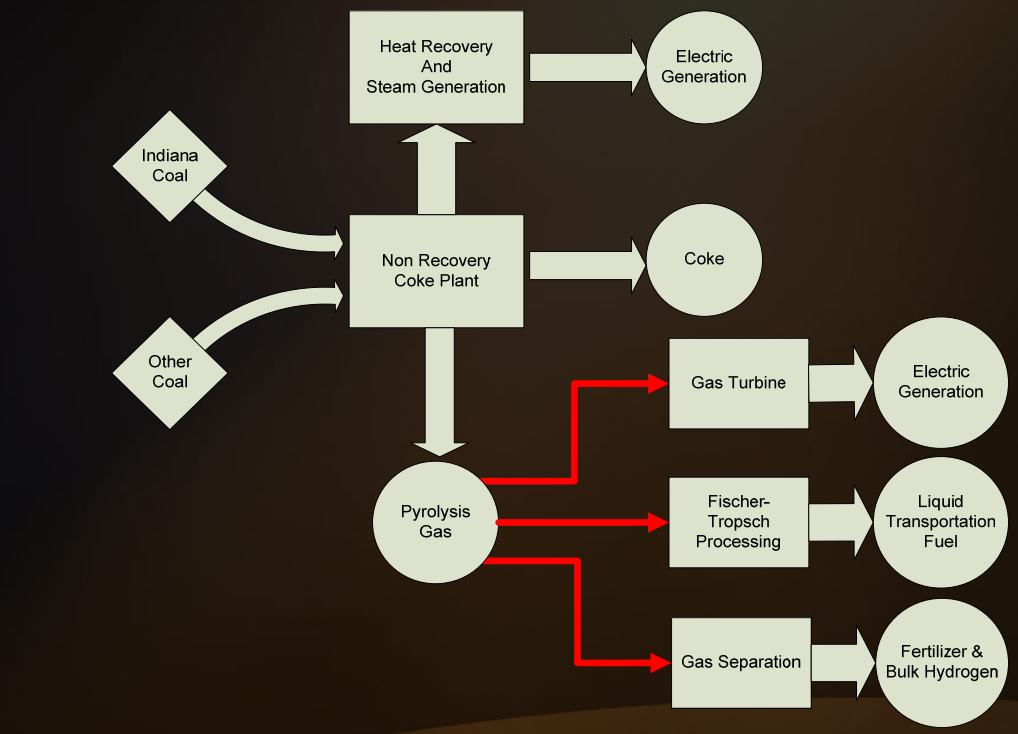


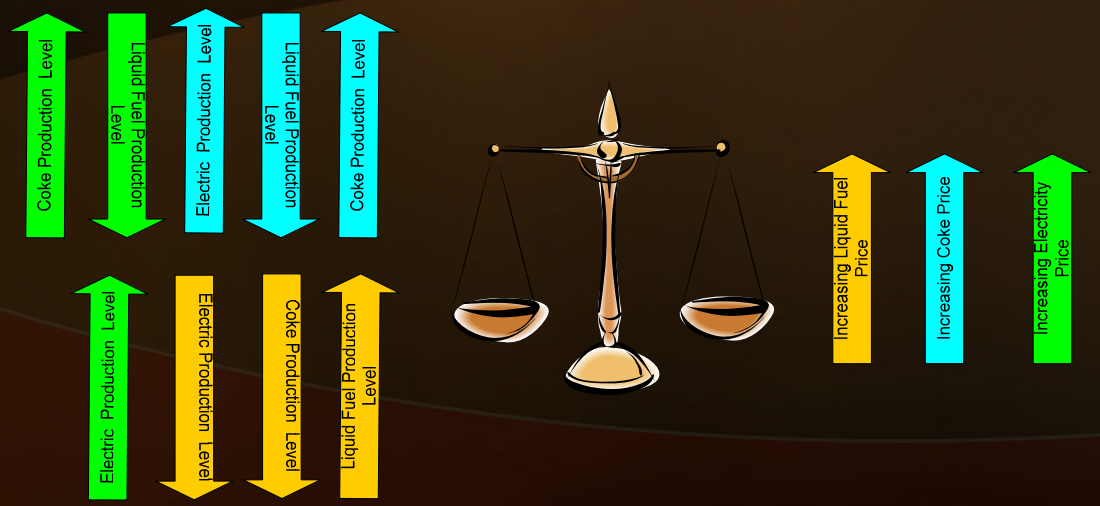
Task Schedule

ID	Task Name	Start	Finish	Duration
1	Develop Initial Plan Details	3/1/2006	3/31/2006	23d
2	Initiate Further Industry Contacts	3/15/2006	5/1/2006	34d
3	Obtain Coal Samples	3/1/2006	5/22/2006	59d
4	Modeling Effort	6/1/2006	2/1/2007	176d
5	Analyze Options for Electricity	6/1/2006	9/29/2006	87d
6	Feasibility Appraisal	1/1/2007	3/16/2007	55d
7	Prepare Final Report	1/1/2007	3/19/2007	56d
8	Go/No Go Decision	3/1/2007	3/30/2007	22d



Process Value Streams



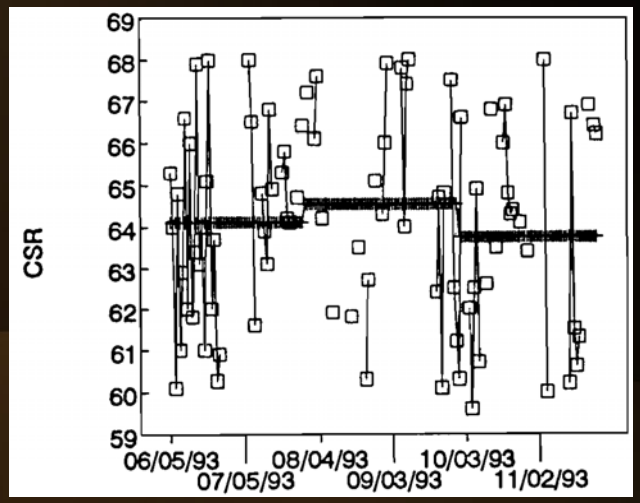


Coal Blending Is Key to Using Indiana Coal For Coke Production

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)	0.82	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

Zones of a blast furnace

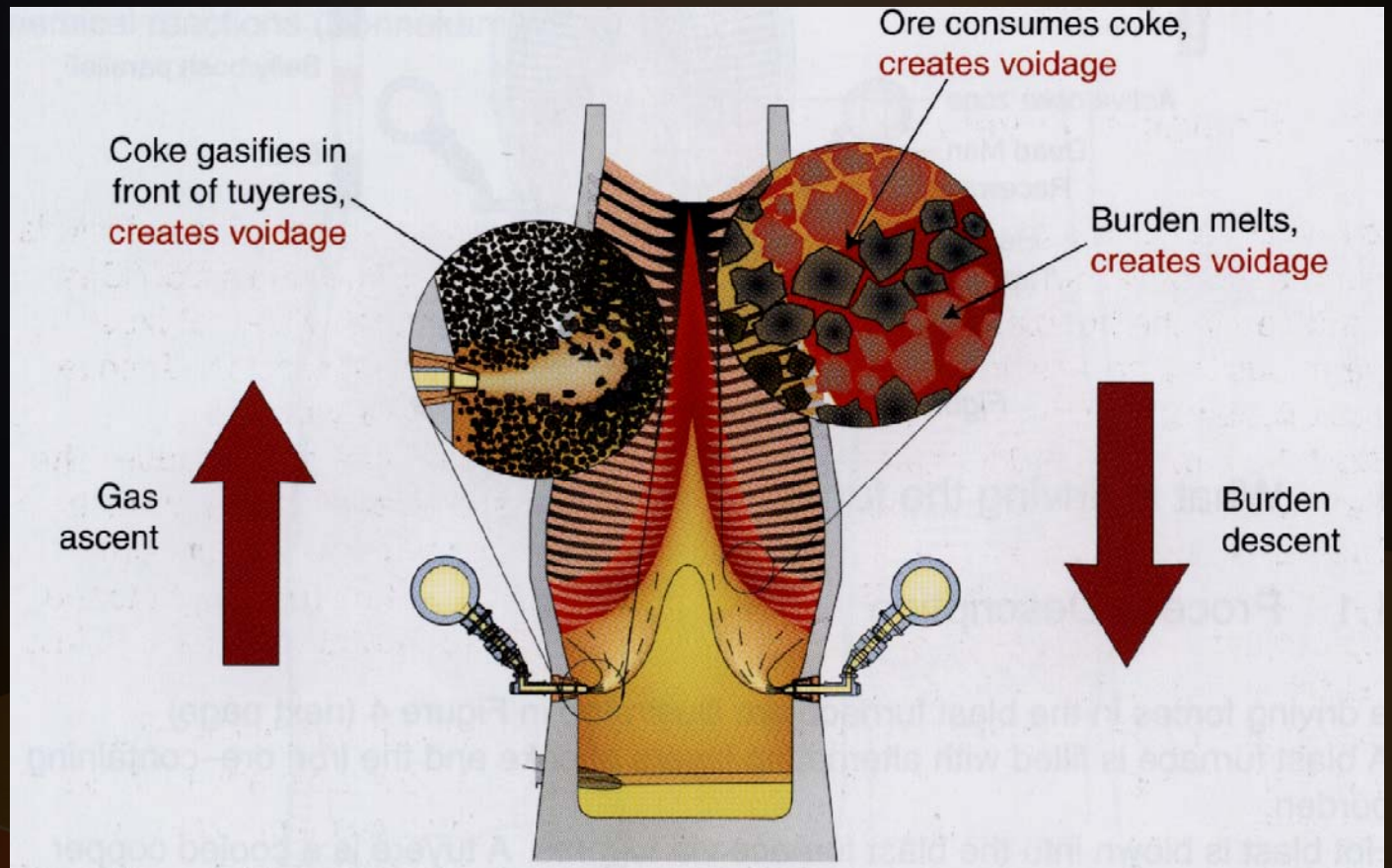
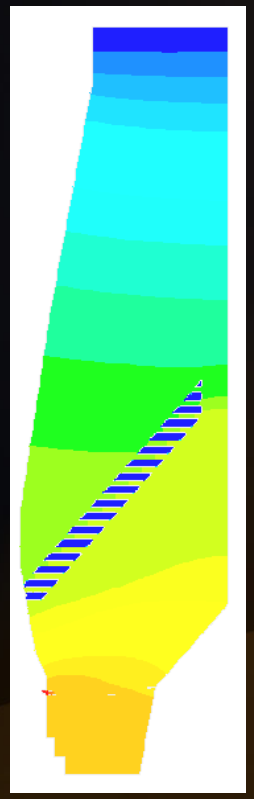


Figure 4: The driving force of a blast furnace: the counter current process creates voidage at the indicated areas causing the burden to descend

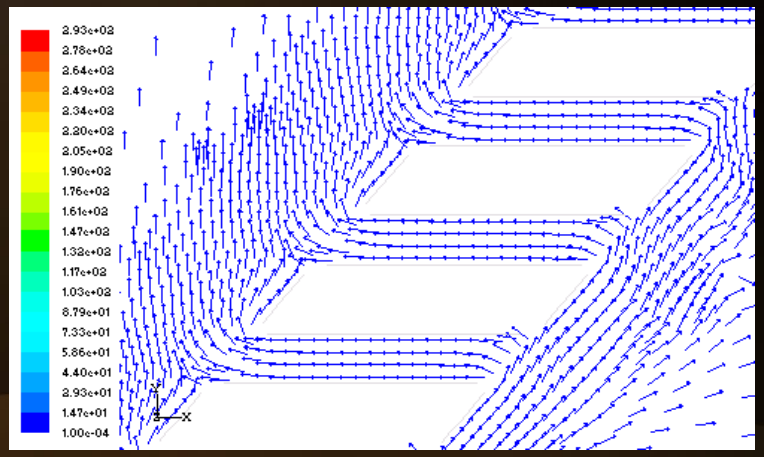
Source: Modern Blast Furnace Ironmaking, Verlag Stahleisen GmbH, 2004

Preliminary CFD Results



Pressure

Streamlines

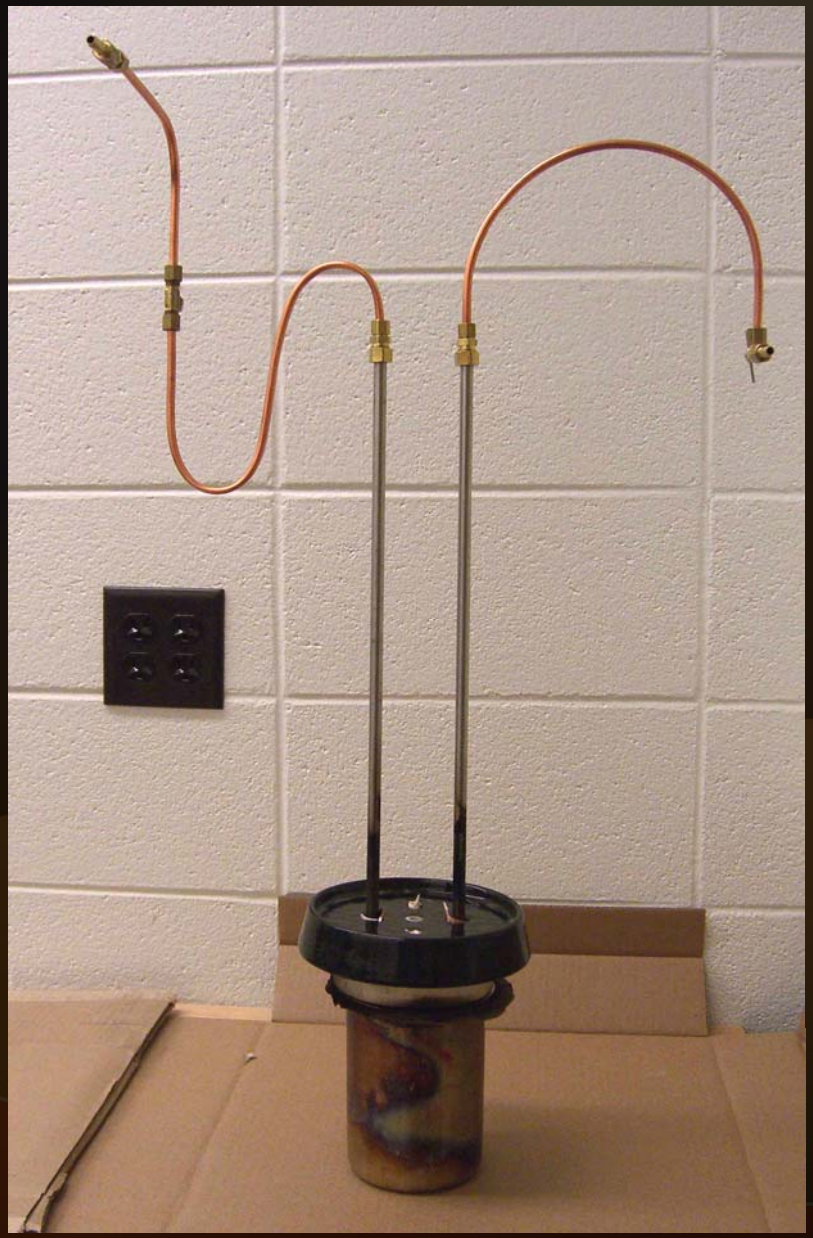


Velocity Vectors

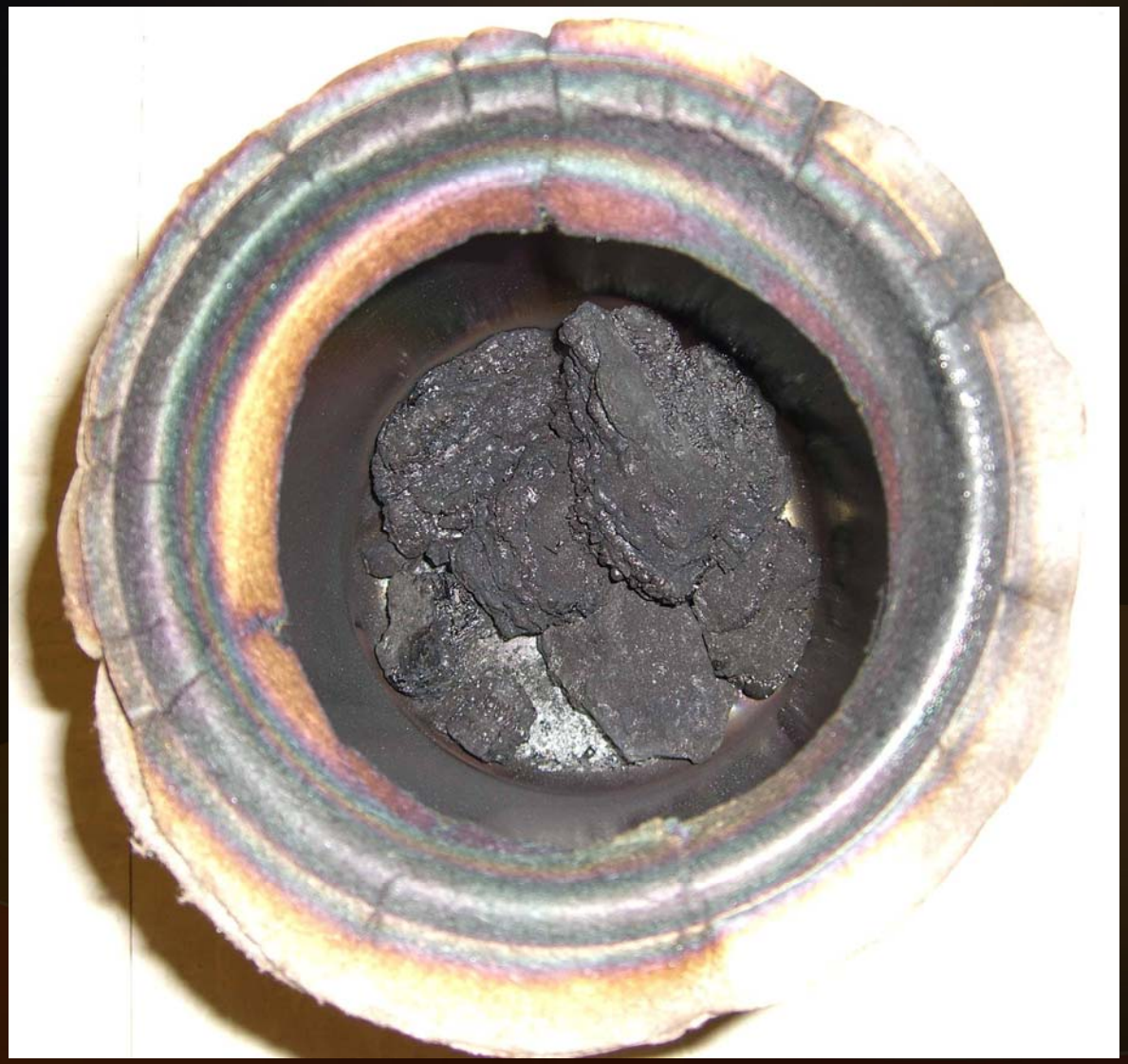
Coke Oven

Initial Test Setup

Initial Pyrolysis Test



Post Initial Test



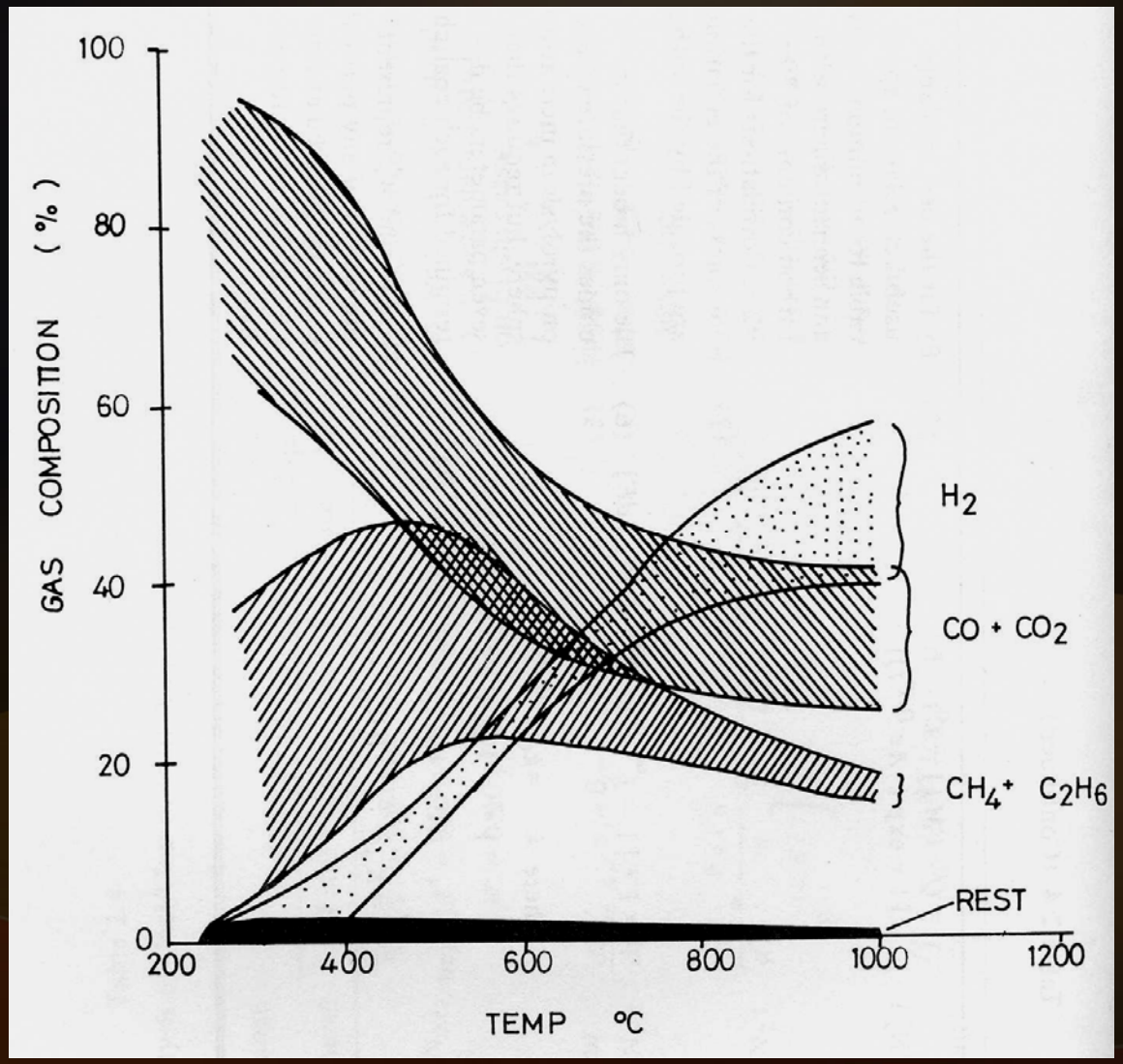
New Pyrolysis Design

Coke Oven Gas

- **In a recovery coke oven, typically the coke oven gas has a composition of 58% hydrogen, 26% methane, 5.5% nitrogen, 2.25% acetylene, 2% carbon dioxide, 6% carbon monoxide, and .25% oxygen.**
- **One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m^3 of coke oven gas.**

Source:
Coke Oven Flow Gas Measurement, General Electric Industrial Sensing, Application Note 930-095B, March, 2005.
The Making Shaping and Treating of Steel, Association of Iron and Steel Engineers, Herbick & Held, Pittsburgh, 1985.

Slow Pyrolysis Gas Composition vs Temperature



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

Current GC for Gas Analysis

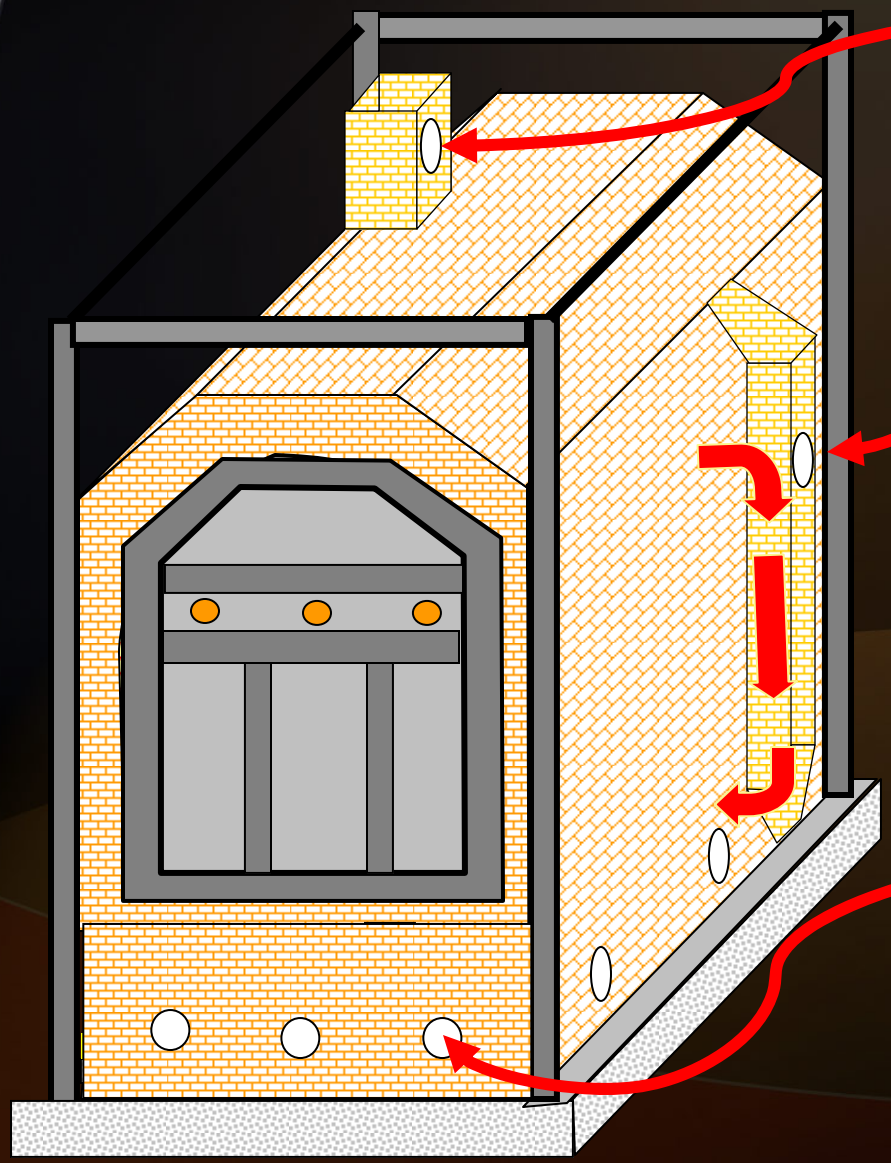
GC for Next Testing Stage

Next Phase Issue

- **There is an opportunity to significantly accelerate the testing program and the development of test capability for the production of liquid transportation fuels**
- **This will also facilitate blending tests leading to increased usage of Indiana Coal**

CSL Non Recovery Coke Simulator

CSL non recovery pilot oven



Slow Pyrolysis Gas Production Rate

$$\frac{dV}{dt} = \frac{K_0 V_0}{m'} 10^{\left[-\frac{E}{RT} - \frac{K_0 R T^2}{mE} e^{-\left(\frac{E}{RT}\right)}\right]}$$

(1975 data)

m' = heating rate = $\frac{dT}{dt}$

V = volume of any particular gas released at time t (not total volatiles)

K_0 = rate constant for release of a particular component, including tar, sec^{-1}

E = activation energy kJ/mol

R = gas constant, kJ/mol °K

m = order of reaction

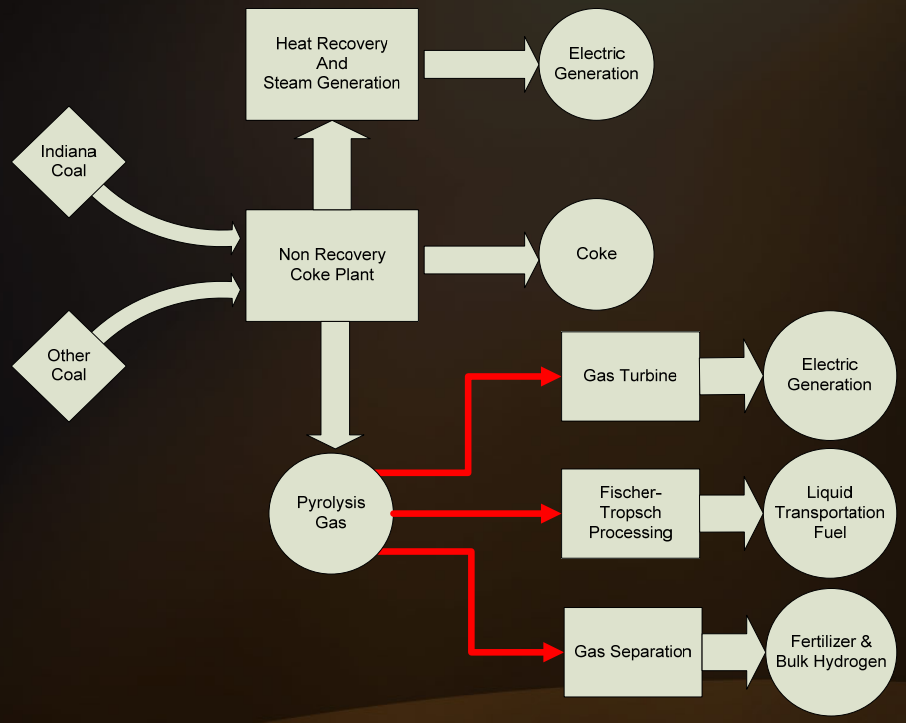
Gas	K_0	E
H_2	20	22.3
CH_4	1.67×10^5	31.0
CO_2	550	19.5
CO	55	18.0

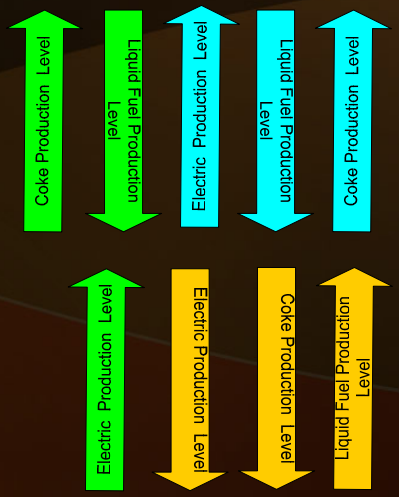
Source:Coal Conversion Technology, Wen,C., Lee, E.

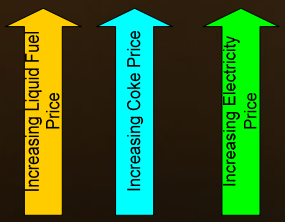
Phase 2 Issues

- Phase 2 can be started in 2007.
- Additional funding required (~$1,200,000)
- Duct work, piping, controls, expanded monitoring equipment
- Advanced Process Testing
- Fischer-Tropsch unit design, construction, and installation
- Fertilizer concept testing
- Bulk H concept testing
- Expanded environmental licensing required.

Process Value Streams







Thank You !

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