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

Status Report
8/30/2006

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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, coordinates the efforts, and maintains the overall program for this proposal. His areas of expertise include energy research, electric system design and operation, engineering, physics, Combined Heat and Power system design and operation, 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 has previously served as principal investigator for three Department of Energy research contracts with budgets totaling over $6.5M. He is currently the principal investigator for projects with a value of ~$2M. He also teaches various courses in Physics and Engineering.
- **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.
- **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.
- **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. Her current interests include modeling of chemical processes and systems.
- **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.
- **Hardarshan Valia** (Ph.D.), President, Coal Science, Inc. Dr. Valia will serve 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.

Initial Scoping Study Completed

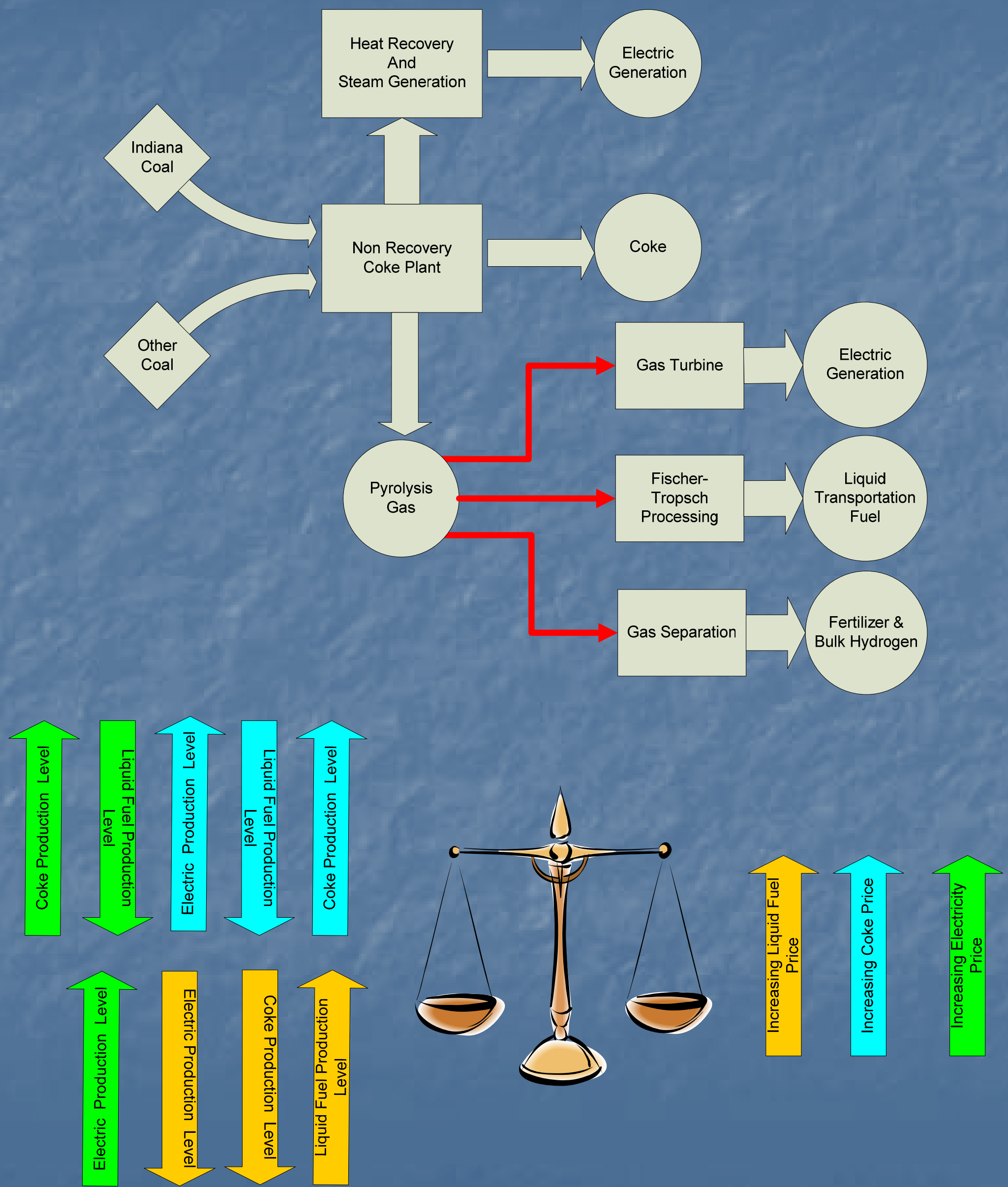
- Results indicated a significant potential to use Indiana coal for the production of coke and electricity
- Preliminary investigation indicates that pyrolysis gas can be used for a Fischer-Tropsch process to produce liquid transportation fuels. Also investigating production of fertilizer and hydrogen

Current Efforts

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

Coke Ovens at Redstone, CO

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.

Zones of a blast furnace

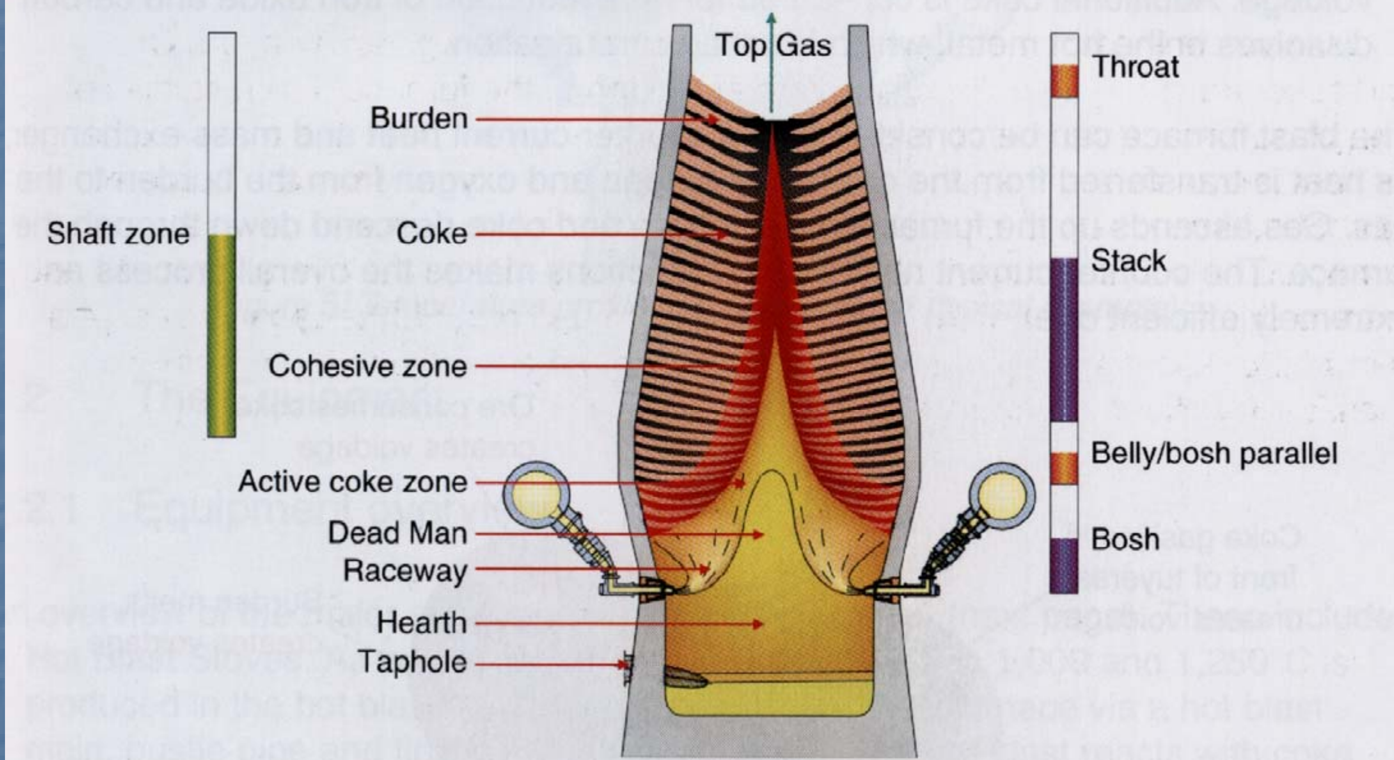


Figure 3: The zones in the blast furnace

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

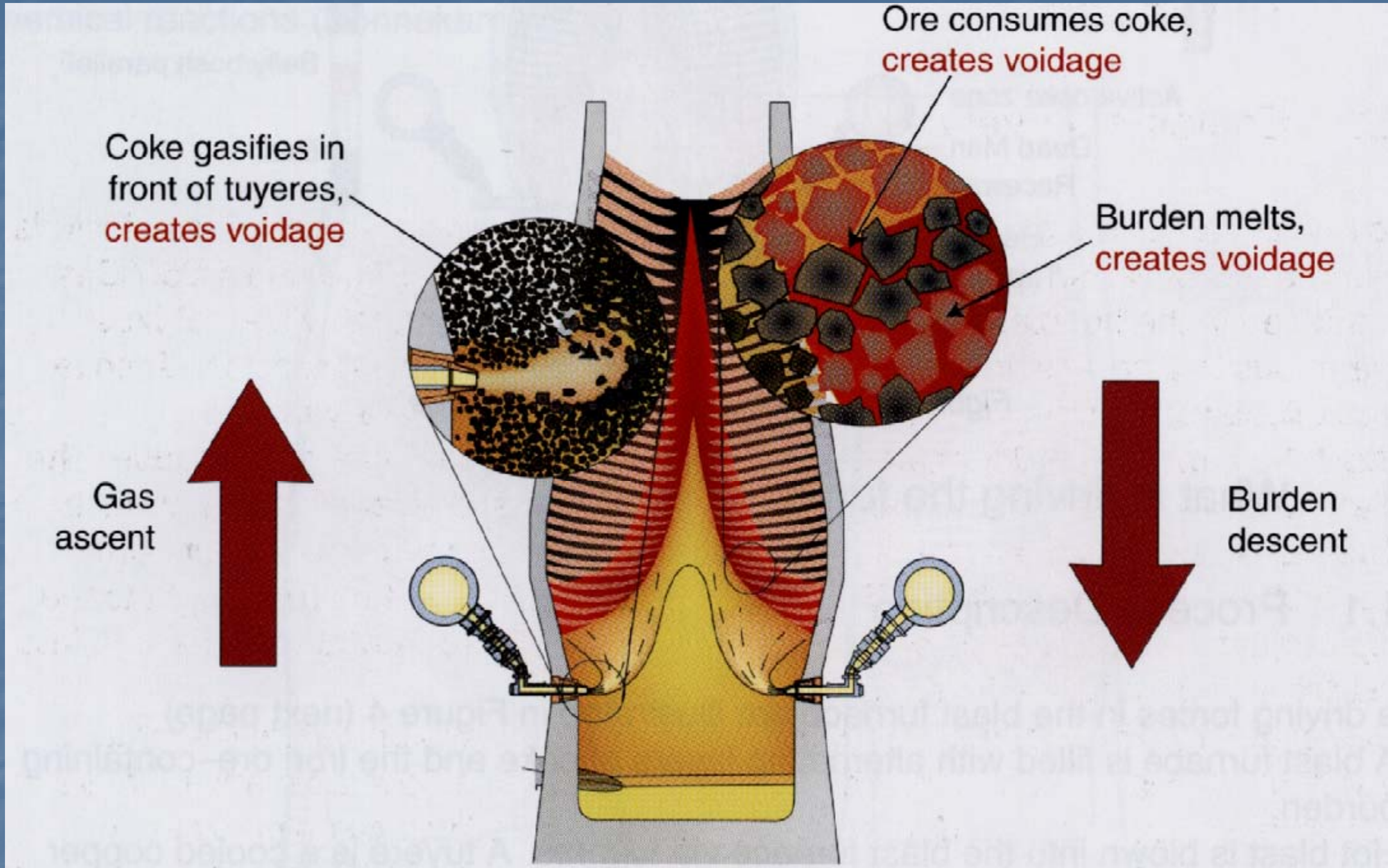


Figure 4: The driving force of a blast furnace: the counter current process creates voidage at the indicated areas causing the burden to descend

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

Temperature Profile

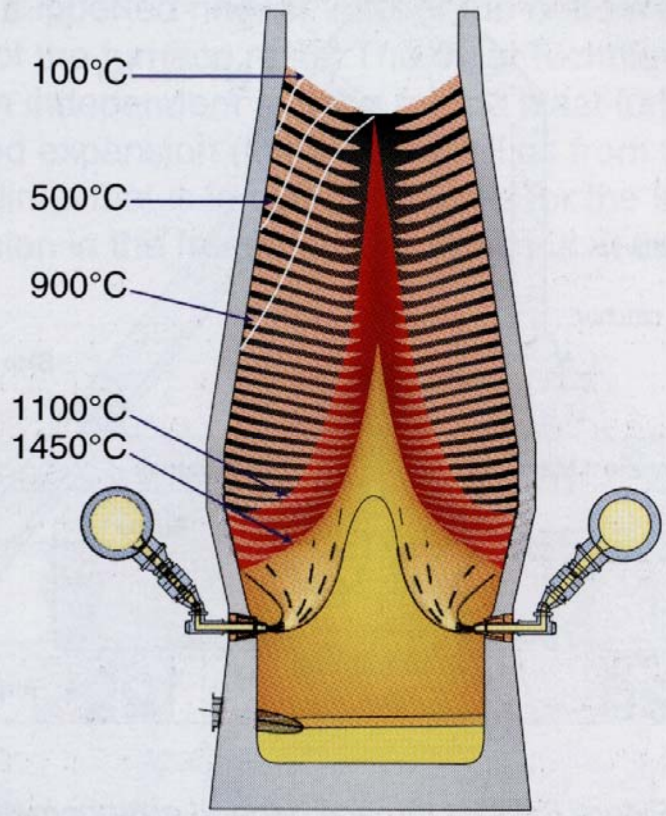
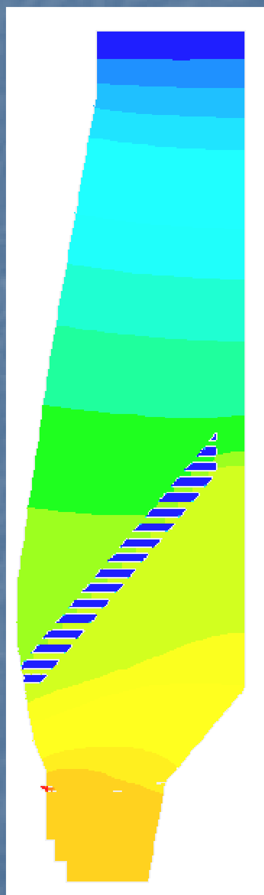


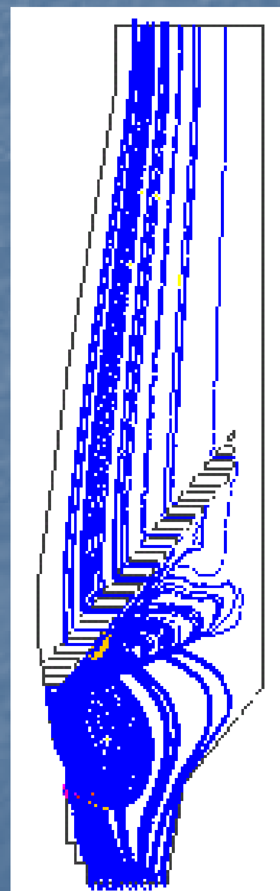
Figure 5: Temperature profile in a blast furnace (typical example)

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

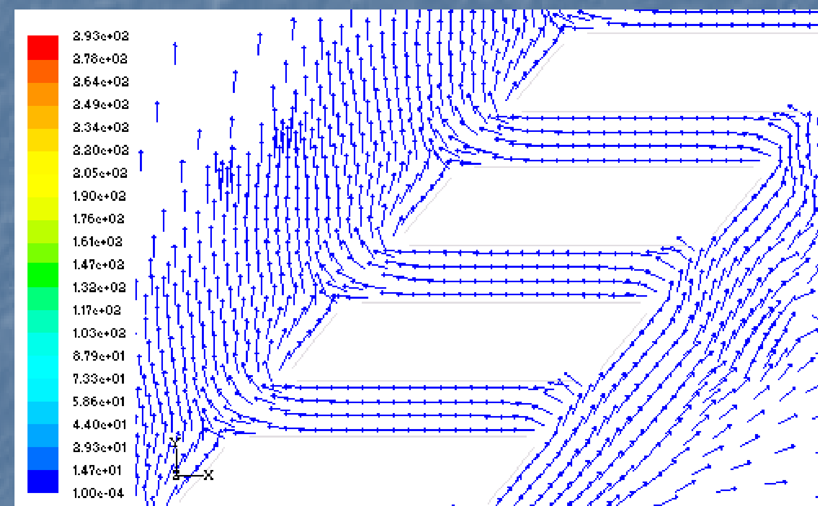
Preliminary CFD Results



Pressure



Streamlines

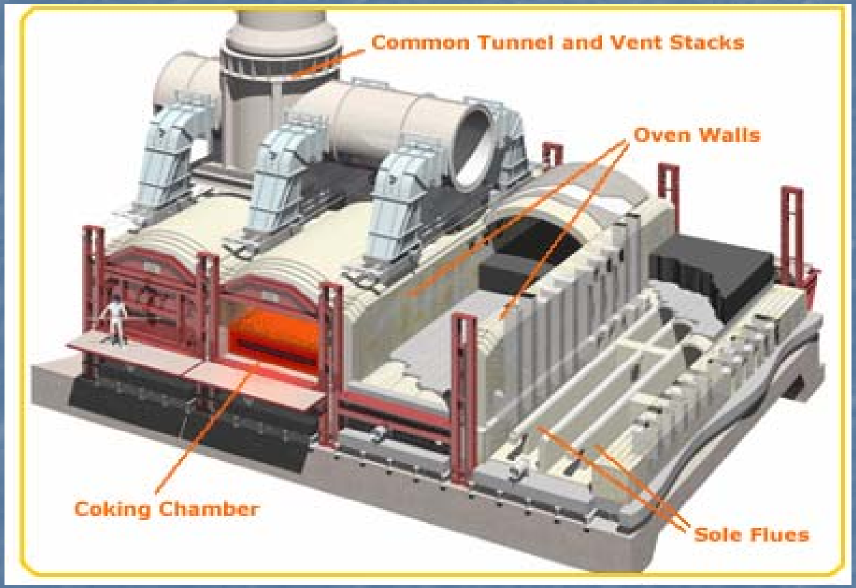


Velocity Vectors

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 and Virginia.

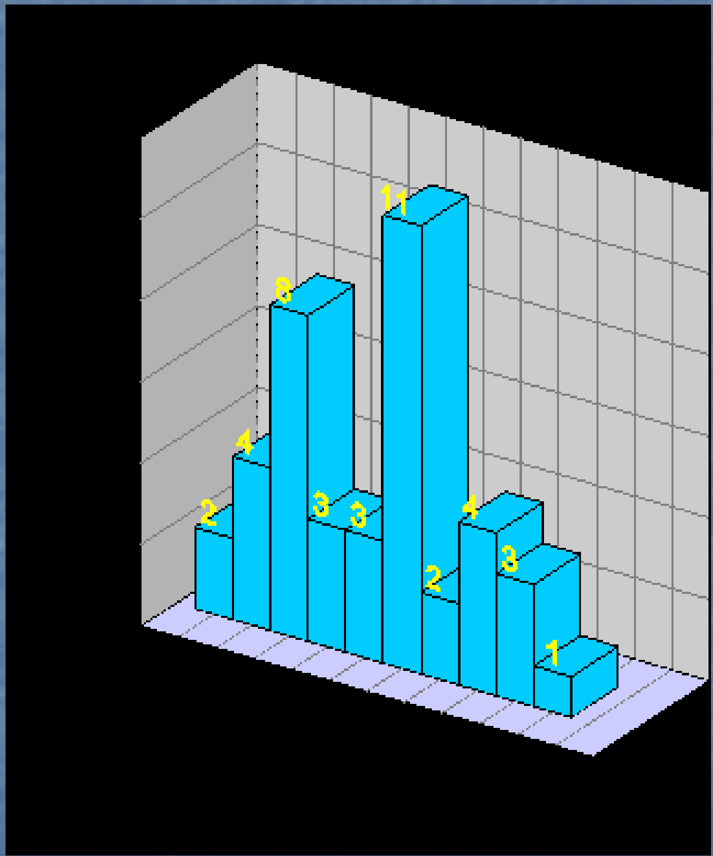
Recovery vs Non Recovery Ovens



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

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

Battery Age



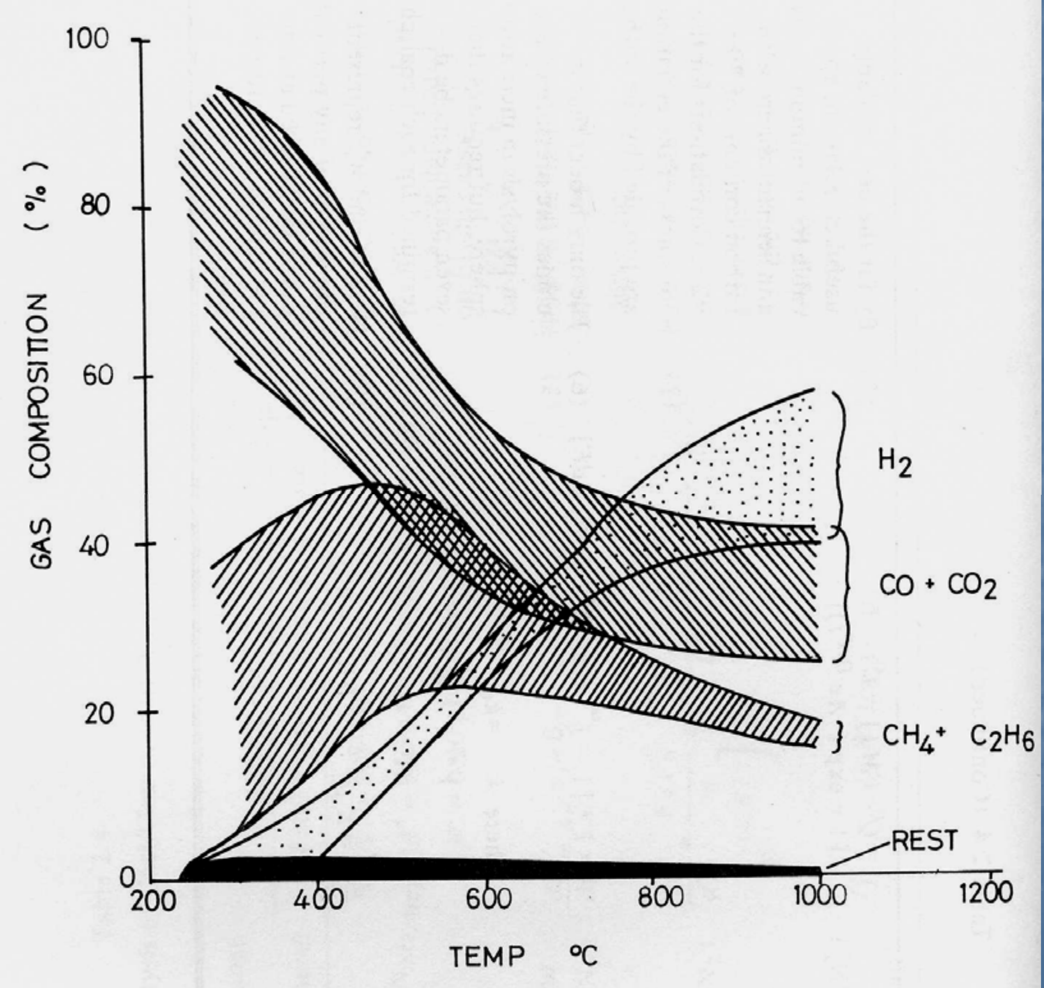
Source;
Ludkovsky, G., “Coke Overview at Mittal Steel – Issues and Opportunities”, 3rd China International Coking Technology and Coke Market Congress 2005, Beijing, China, Sept. 2005.

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.

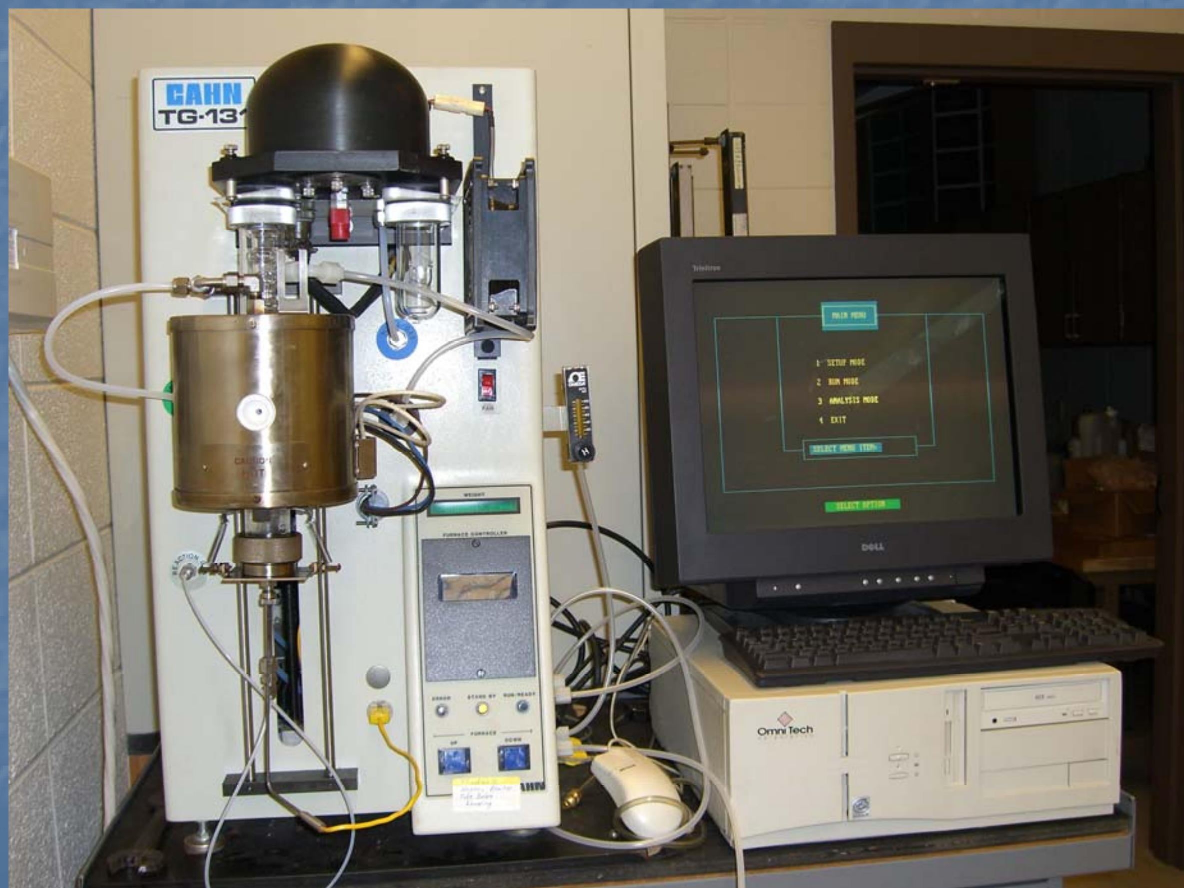
Slow Pyrolysis Gas Composition vs Temperature



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

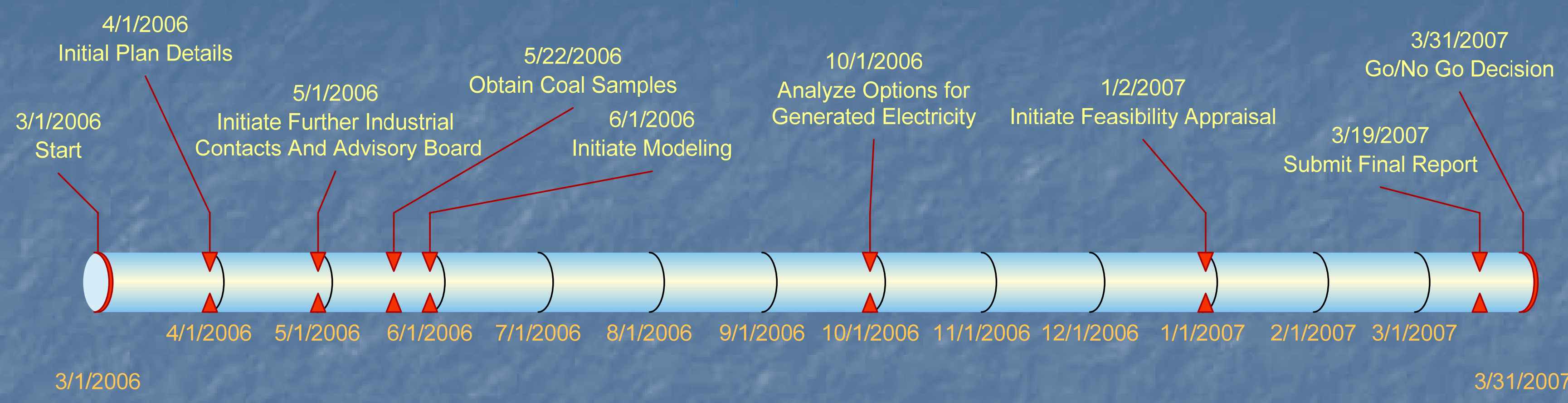
Test Furnace

TGA



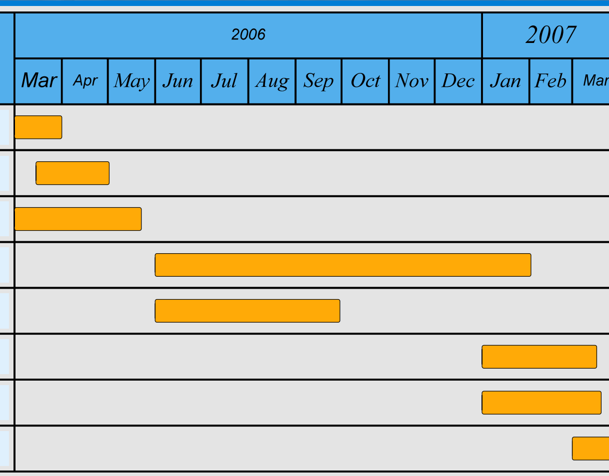
GC for Gas Analysis

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

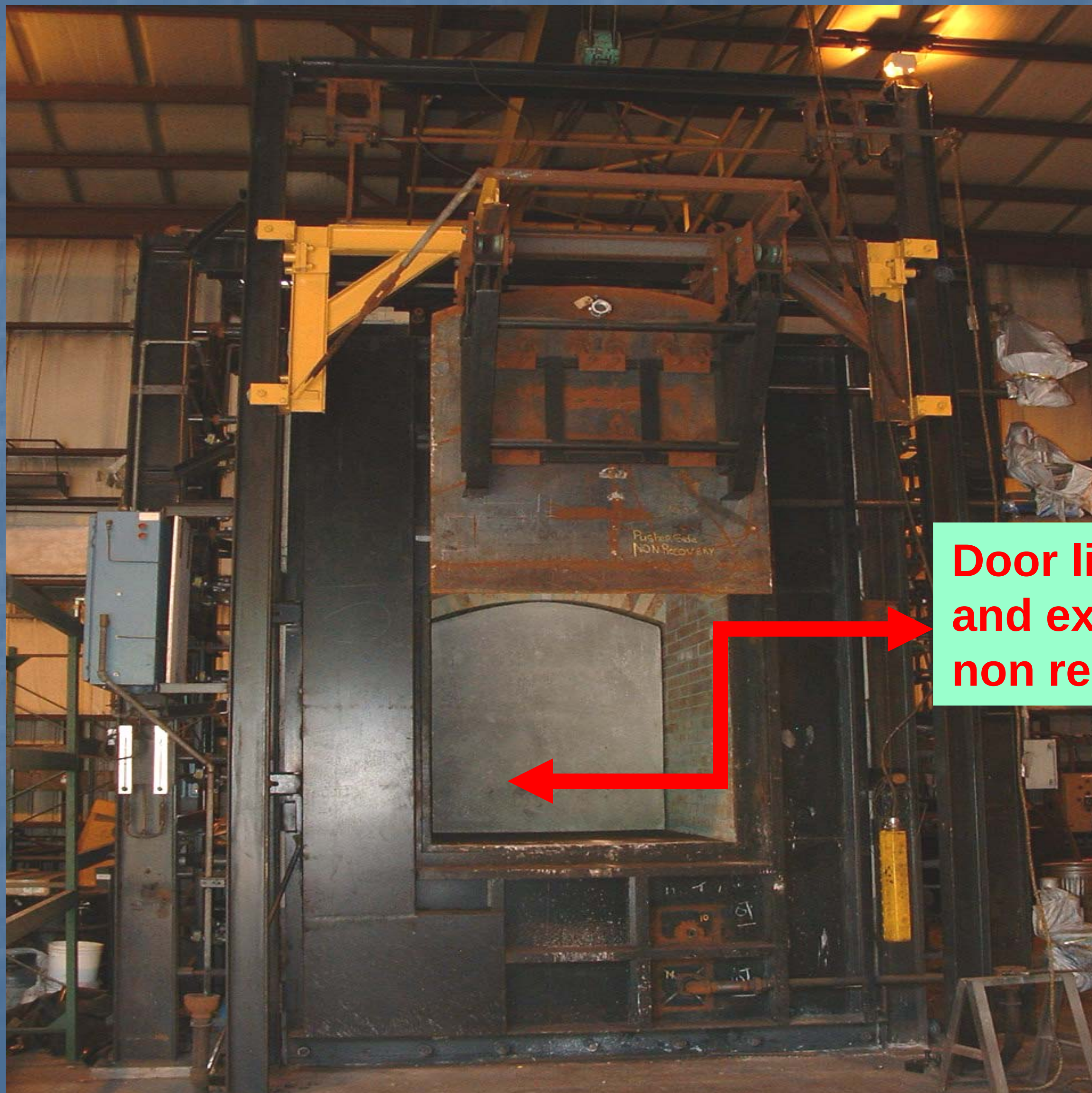


Next Phase Issue

- 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

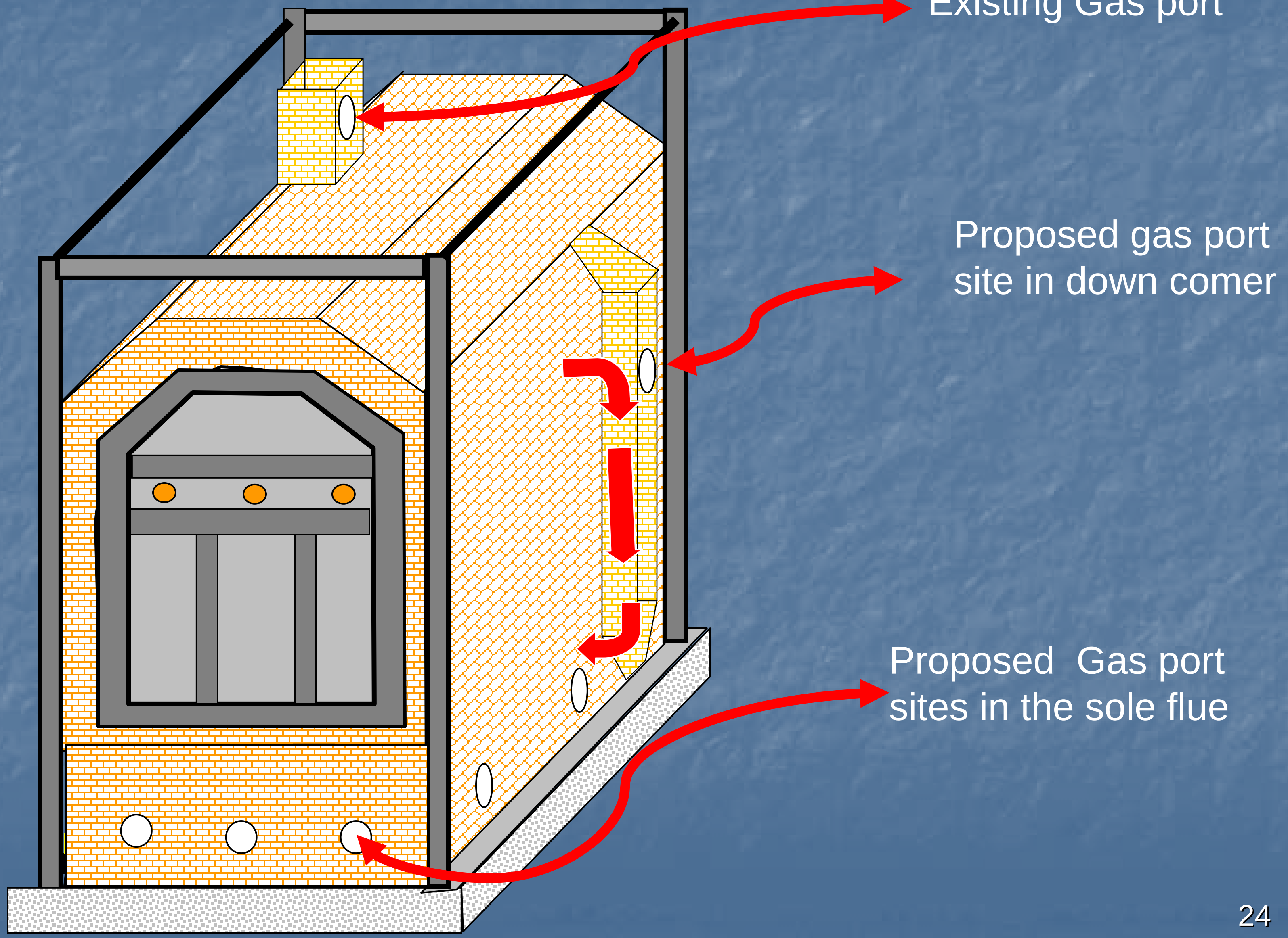
CSL Conventional Coke Oven

CSL Non Recovery Coke Simulator



Door lifting mechanism and exposed interior of non recovery oven

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

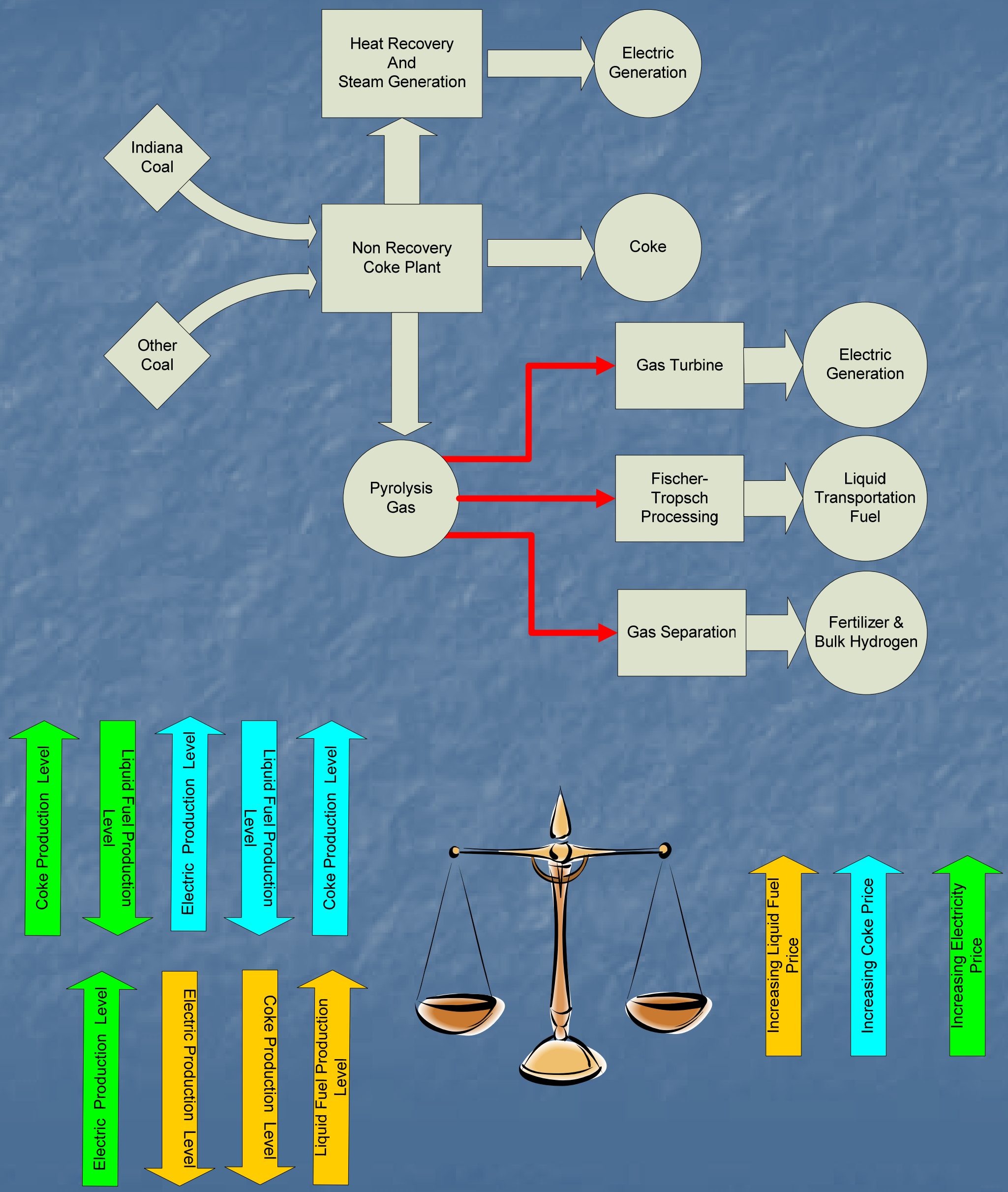
Gas	K_0	E
H_2	20	22.3
CH_4	1.67×10^5	31.0
CO_2	550	19.5
CO	55	18.0

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

Phase 2 Issues

- Phase 2 can be started in 2007.
- Additional funding required (~$950,000)
- Duct work, piping, controls, expanded monitoring equipment,
- Fischer-Tropsch unit design, construction, and installation.
- Expanded environmental licensing required.

Process Value Streams



Thank You !

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