Development of Coking/Coal Gasification Concept to Use Indiana Coal for the Production of Metallurgical Coke and Bulk Electric Power

Research Proposal

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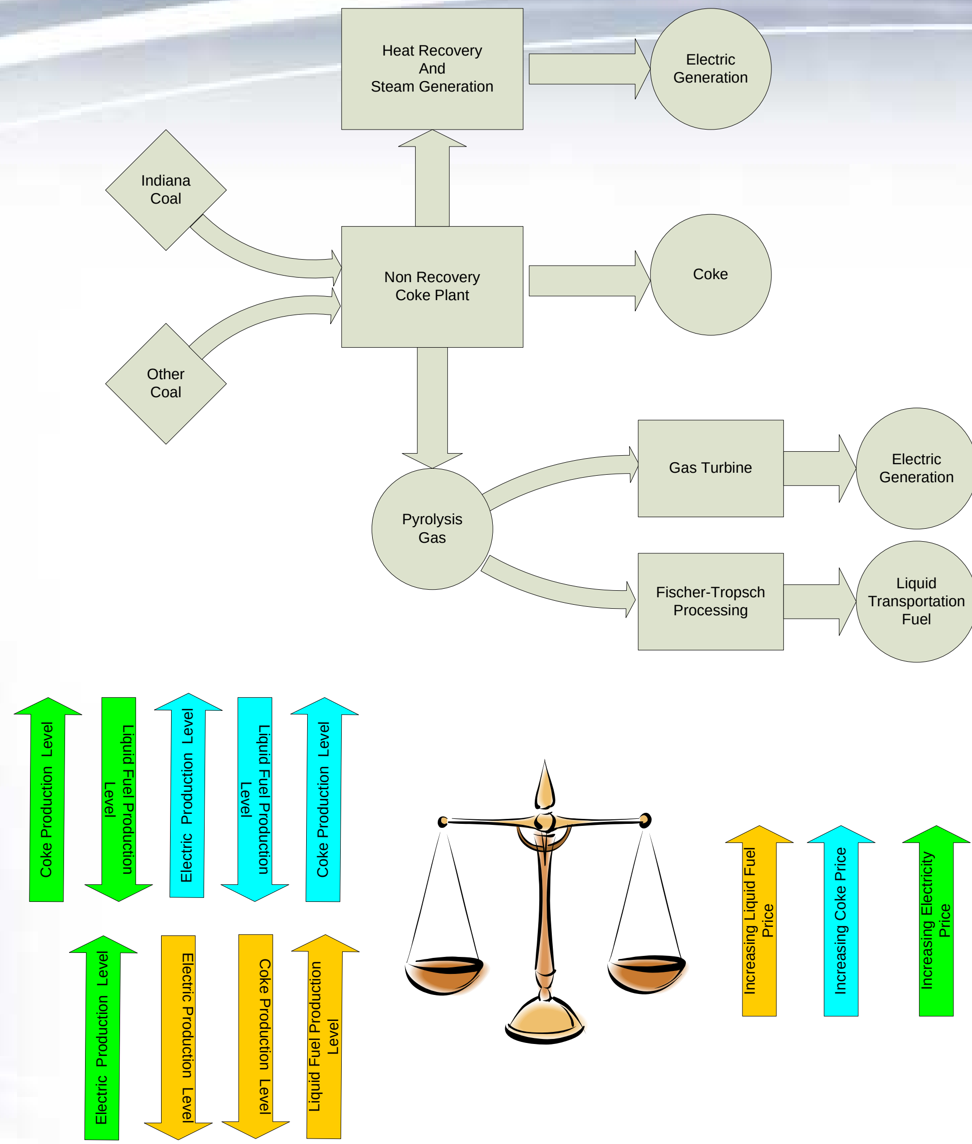
Initial Scoping Study Completed

- Results indicate that there is significant potential to use Indiana coal for the production of coke and electricity
- Preliminary investigation indicates that there is an opportunity to produce a gas stream from the coking process that can be used directly or as part of a Fischer-Tropsch process for the production of liquid transportation fuels.

Next Steps for Developing Technology to Produce Multiple Value Streams from Coking with Indiana Coal

- 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

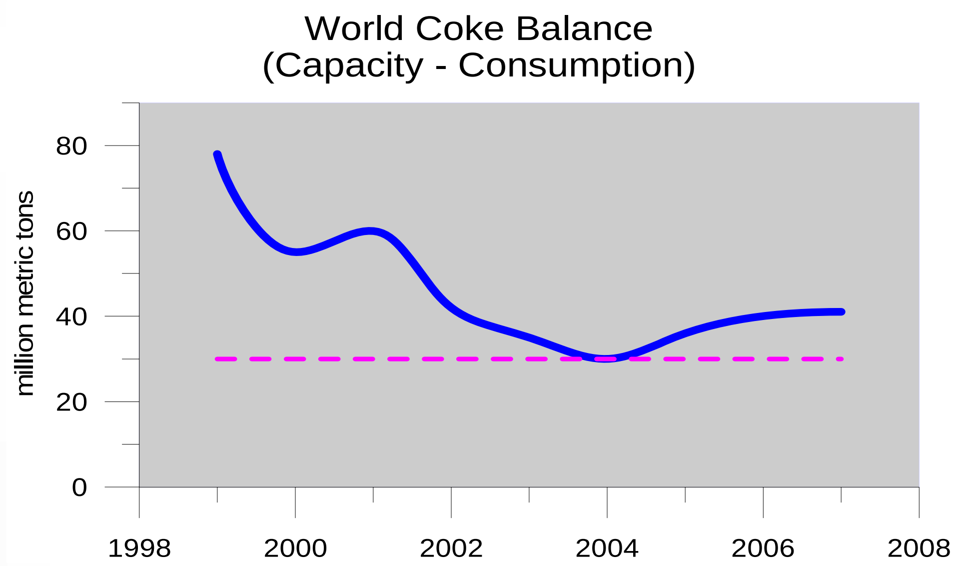
Process Value Streams



Coke is an Essential Part of Iron Making and Foundry Processes

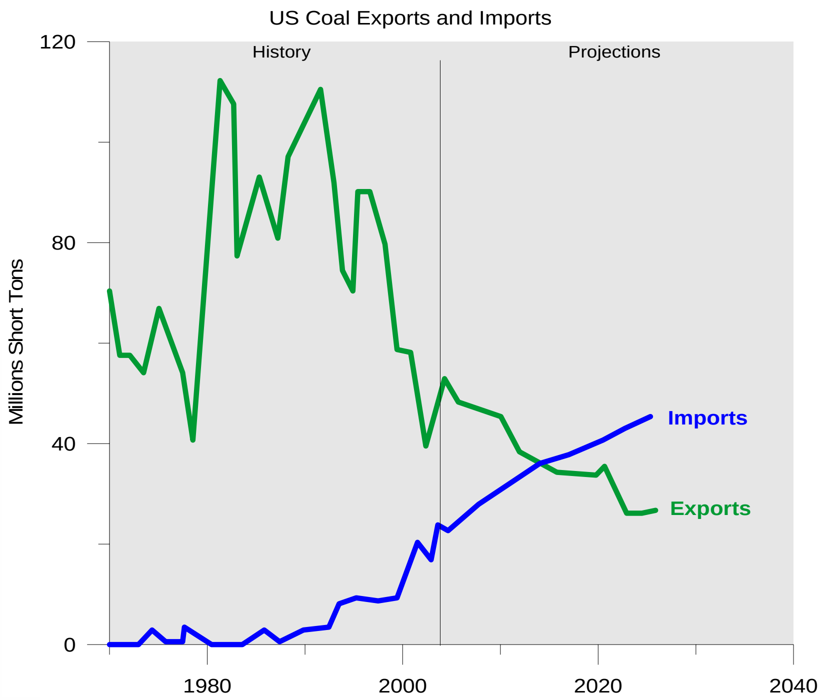
- Currently there is a shortfall of 5.50 million tons of coke per year in the United States.
- Shortfall is being filled by imports, mainly from China and, to a lesser extent, from Japan.
- The result is high volatility in coke prices and a general trend to dramatic price increases.
  - Coke FOB to a 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 Supply and Demand



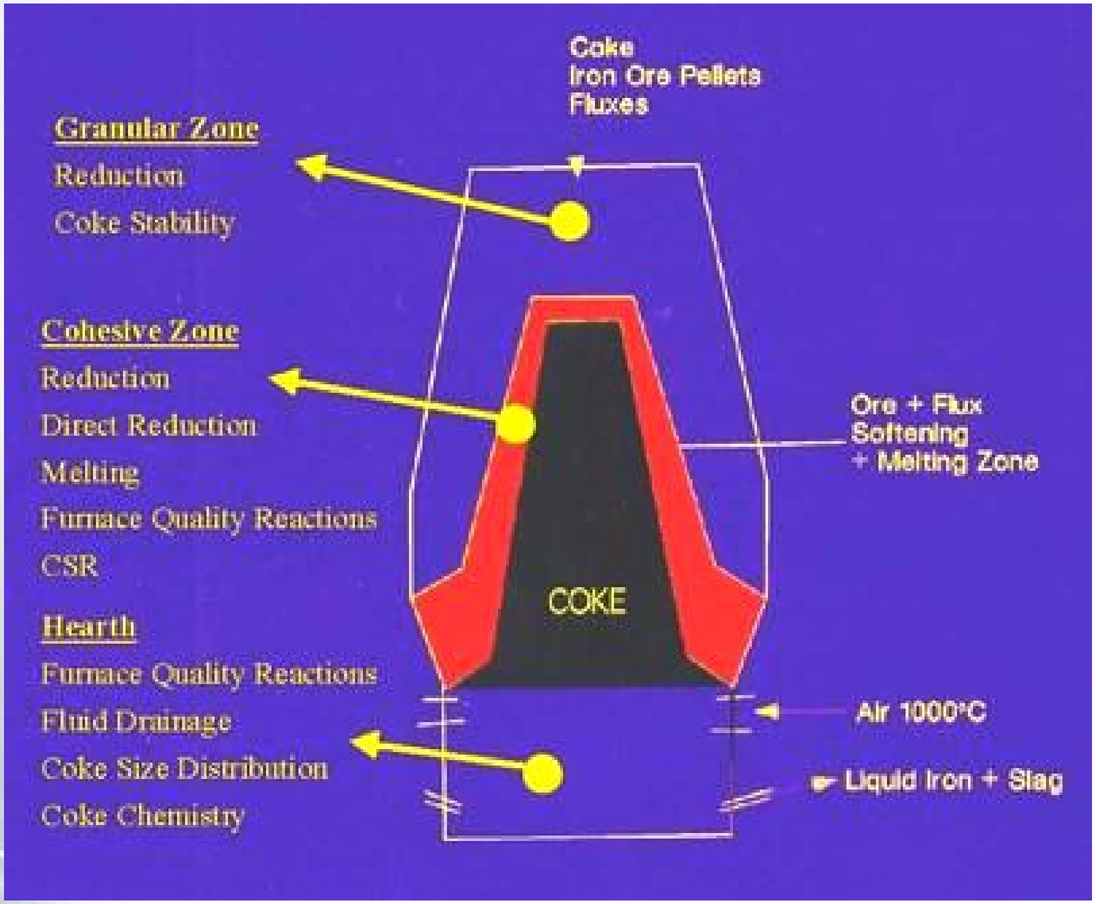
Source: Ludkovsky, G., "Coke Overview at Mittal Steel – Issues and Opportunities", 3rd China International Coking Technology and Coke Market Congress 2005, Beijing, China, Sept. 2005.

US Coal Exports and Imports



Source: Energy Information Administration / International Energy Outlook 2004

Zones of a blast furnace

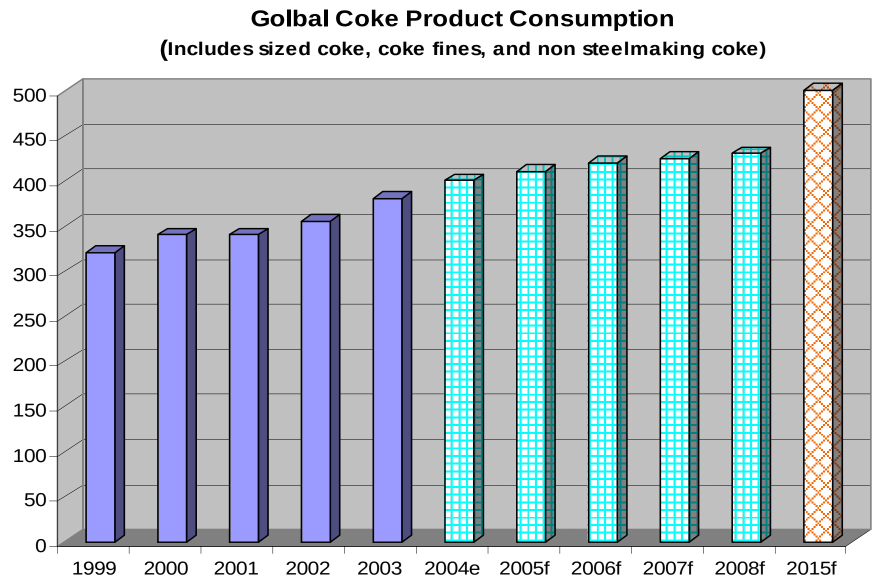


Source:Valia, H., “Coke Production for Blast Furnace Ironmaking”,AISI

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.

Coke Consumption



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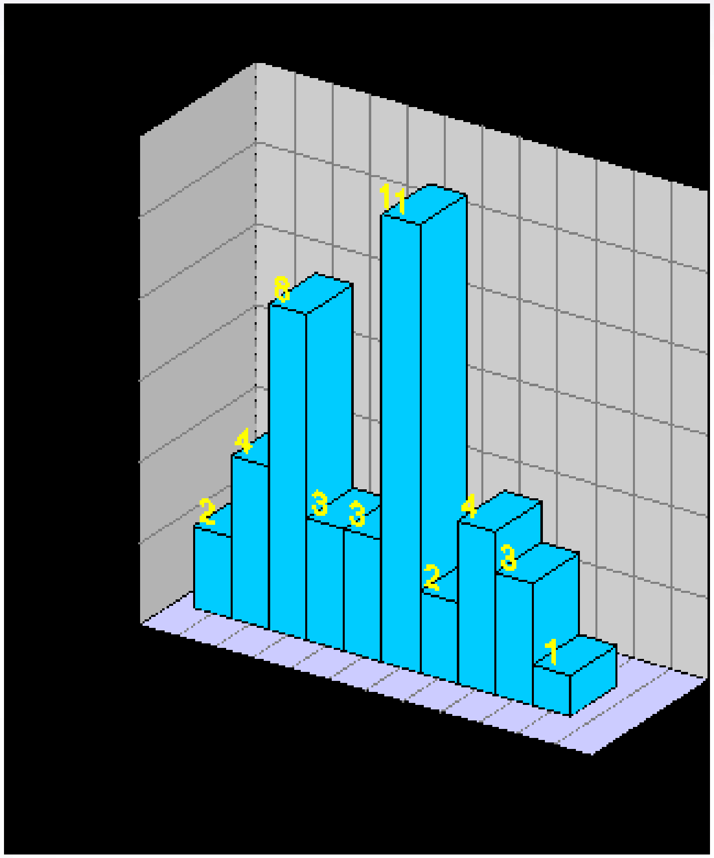
Battery Age



Source;
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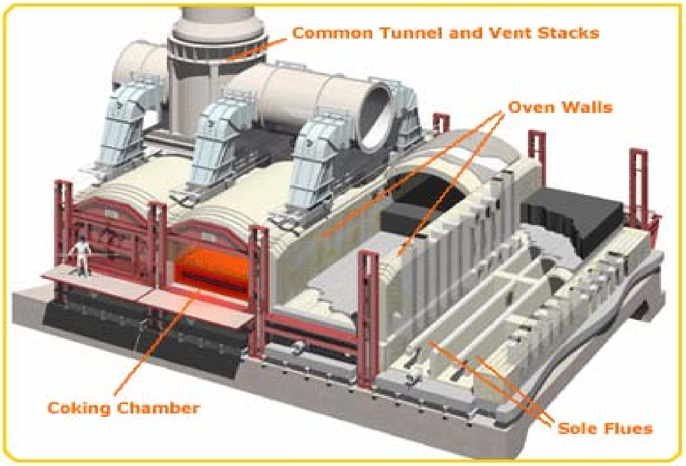
Two Main Methods for Coke Production

- Recovery Process
  - Reducing atmosphere
  - Issues with complexity and gases
  - Issues with waste
  - Combustible gases available for turbine or boiler
  - Byproduct streams
- Non Recovery Process
  - Air introduced to burn off volatiles before they can produce pollutants
  - Heat recovery steam generation for electricity
  - Small amount of H for heating recirculated at bottom
    - Issue is: Can mass flow be modified for a CT?

Recovery vs Non Recovery Ovens



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

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

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.

Test Data

	100% Indiana (Brazil Block Coal)	100% Indiana (Danville, No. 7 coal)
Coke Stability	33	33
Coke Hardness	54	69
CSR*	48	30
Coke size, mm	53	55
Coke yield, %	67.9	67.0
Coking Time, hr	18.6	20.15
Max. Pressure, kpa**	2.07	2.96

(Note: CSR*=Coke strength after reaction with CO2, Max Pressure** = maximum oven wall pressure)

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 m3 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.

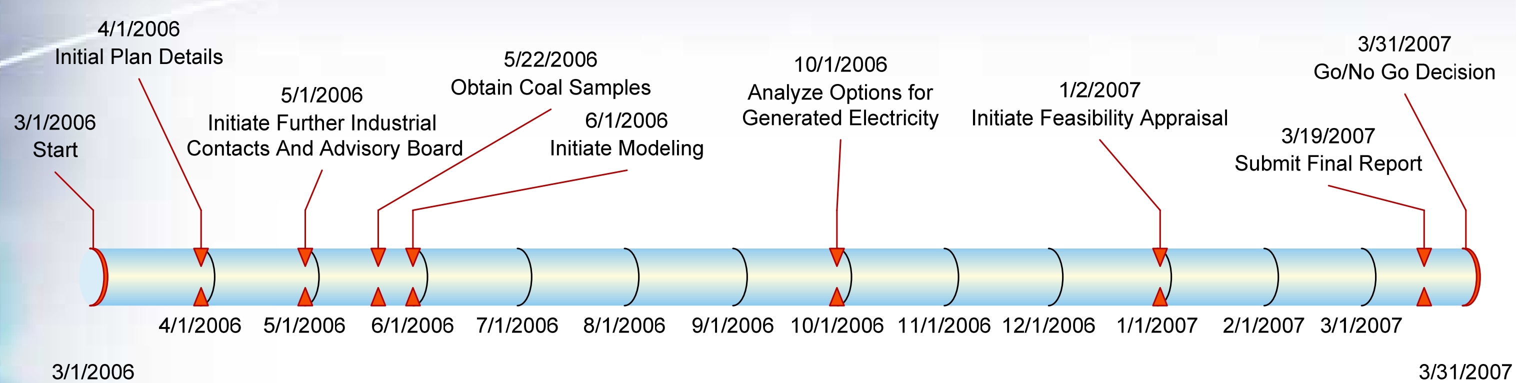
Research Recommendation

- Preliminary results indicate that there is significant benefit to continuing with the current research effort and to consider next steps leading to construction of an industrial test facility should additional analysis and development continue to support the concept.
- Based upon the preliminary results it is recommended that further development of the proposed concept for mine mouth coking/gasification should be initiated and expanded to include consideration of the production of liquid transportation fuels.

Research Plan

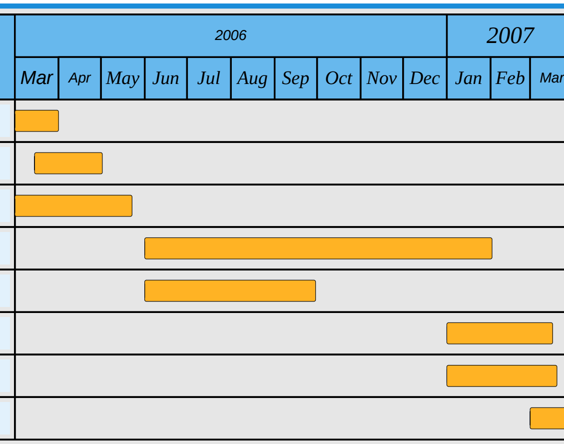
- Develop initial plan details and submit for approval
- Establish new and refine existing interface with industry contacts – Contacts with industrial, governmental, regulatory, technical, and other appropriate sources will be formalized. Communication and information exchange procedures will be established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

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



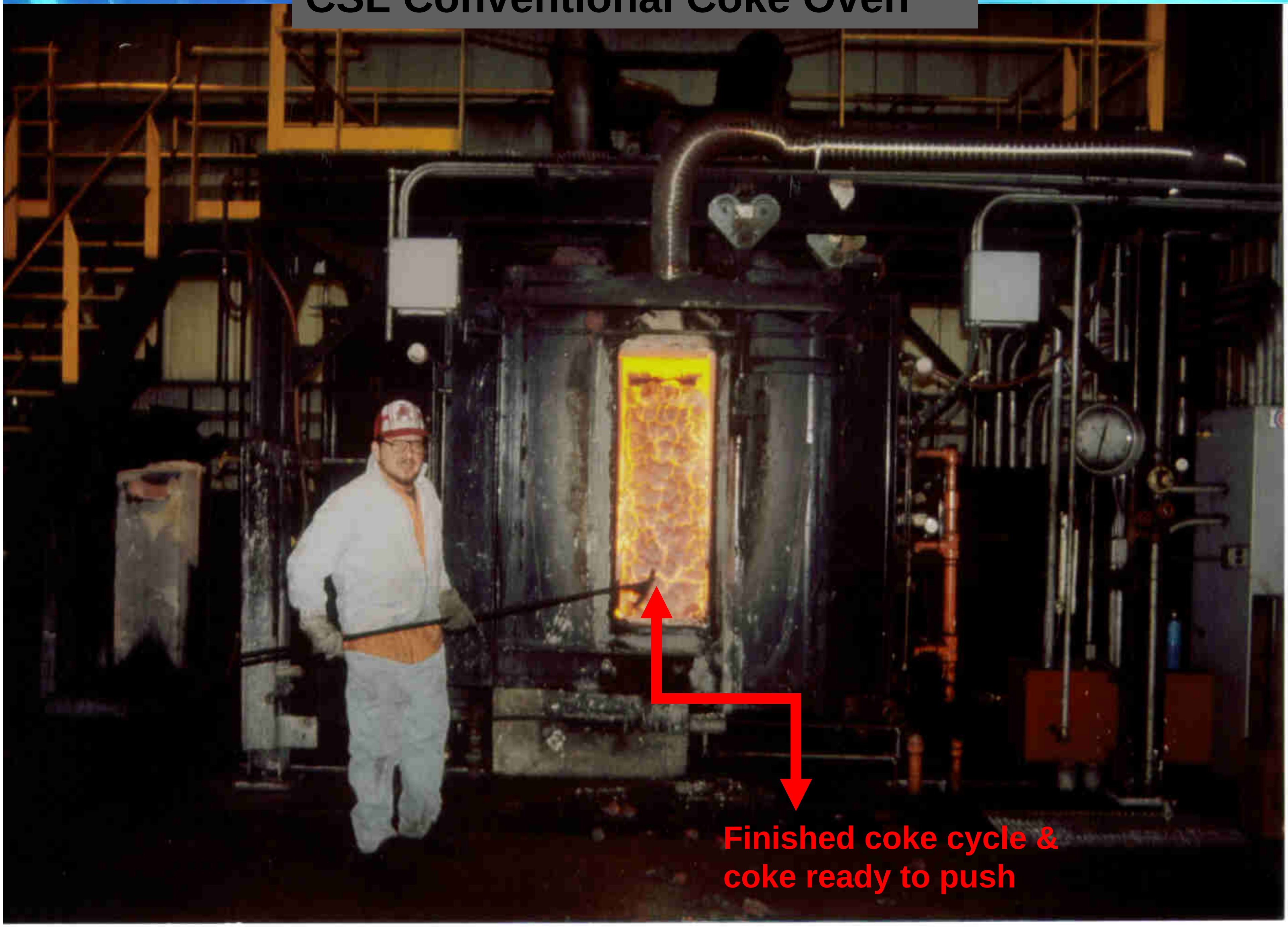
Research Team

- **Robert Kramer** (Ph.D.) is Director of the Purdue University Calumet Energy Efficiency and Reliability Center. Dr. Kramer will serve as the Principal Investigator, coordinate the efforts, and maintain 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 $1.5M. 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 Peltier** (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.

New Opportunity (Phase 2)

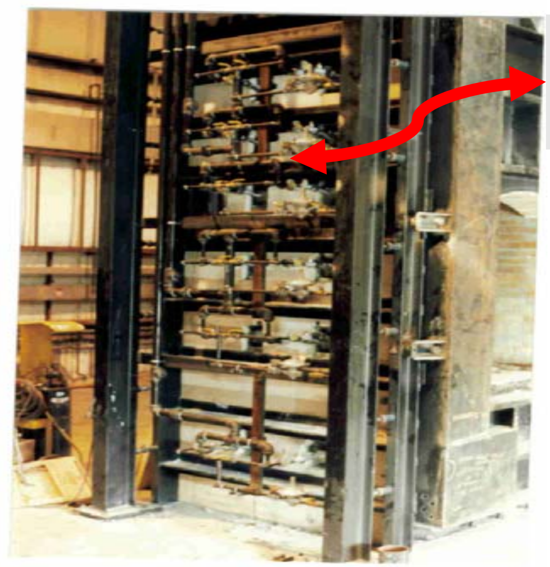
- There is an opportunity to significantly accelerate the testing program and the development of test capability for the production of liquid transportation fuels
- This will also facilitate blending tests leading to increased usage of Indiana Coal

CSL Conventional Coke Oven



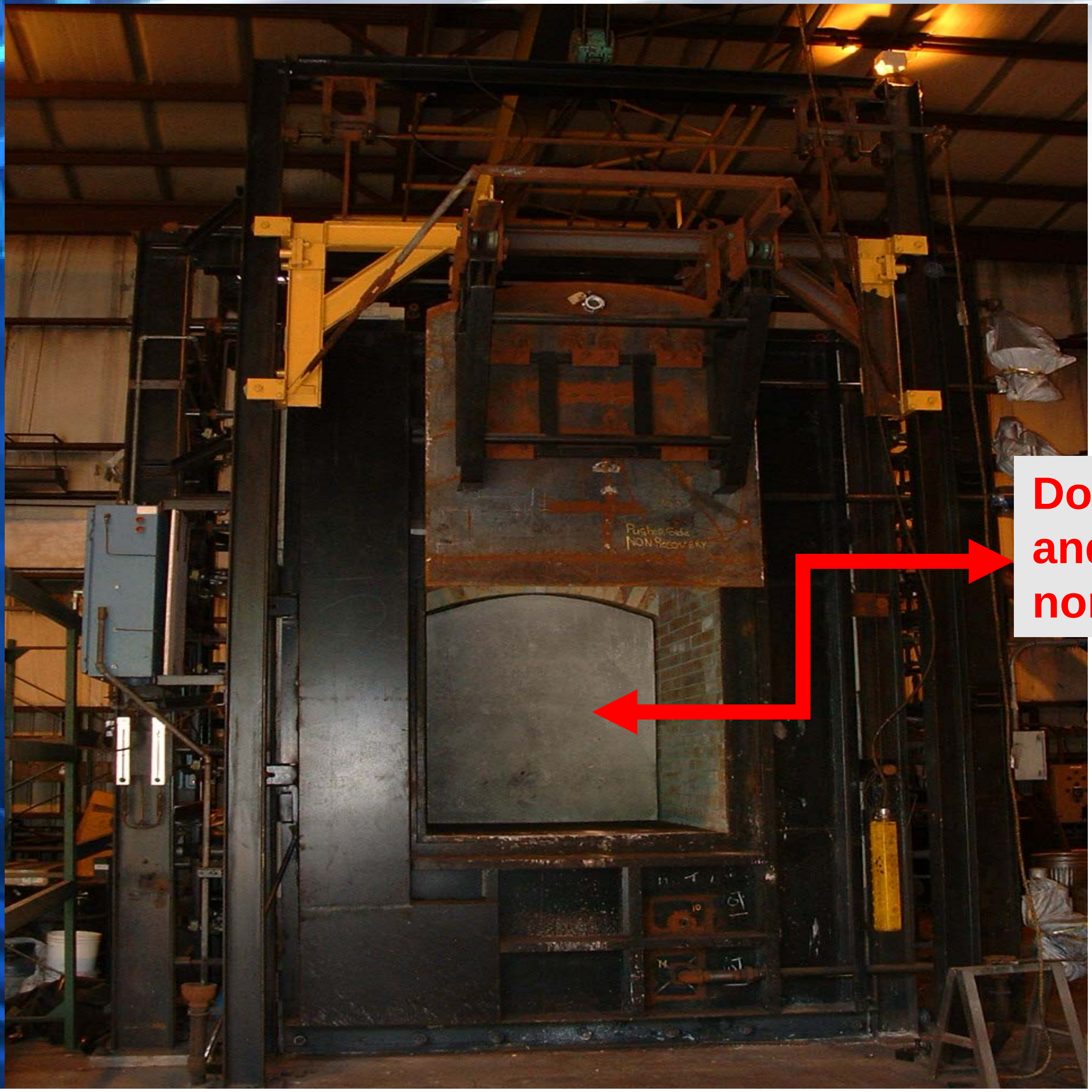
CSL non recovery coke simulator construction in summer 1991

Completed brick work
& steel superstructure



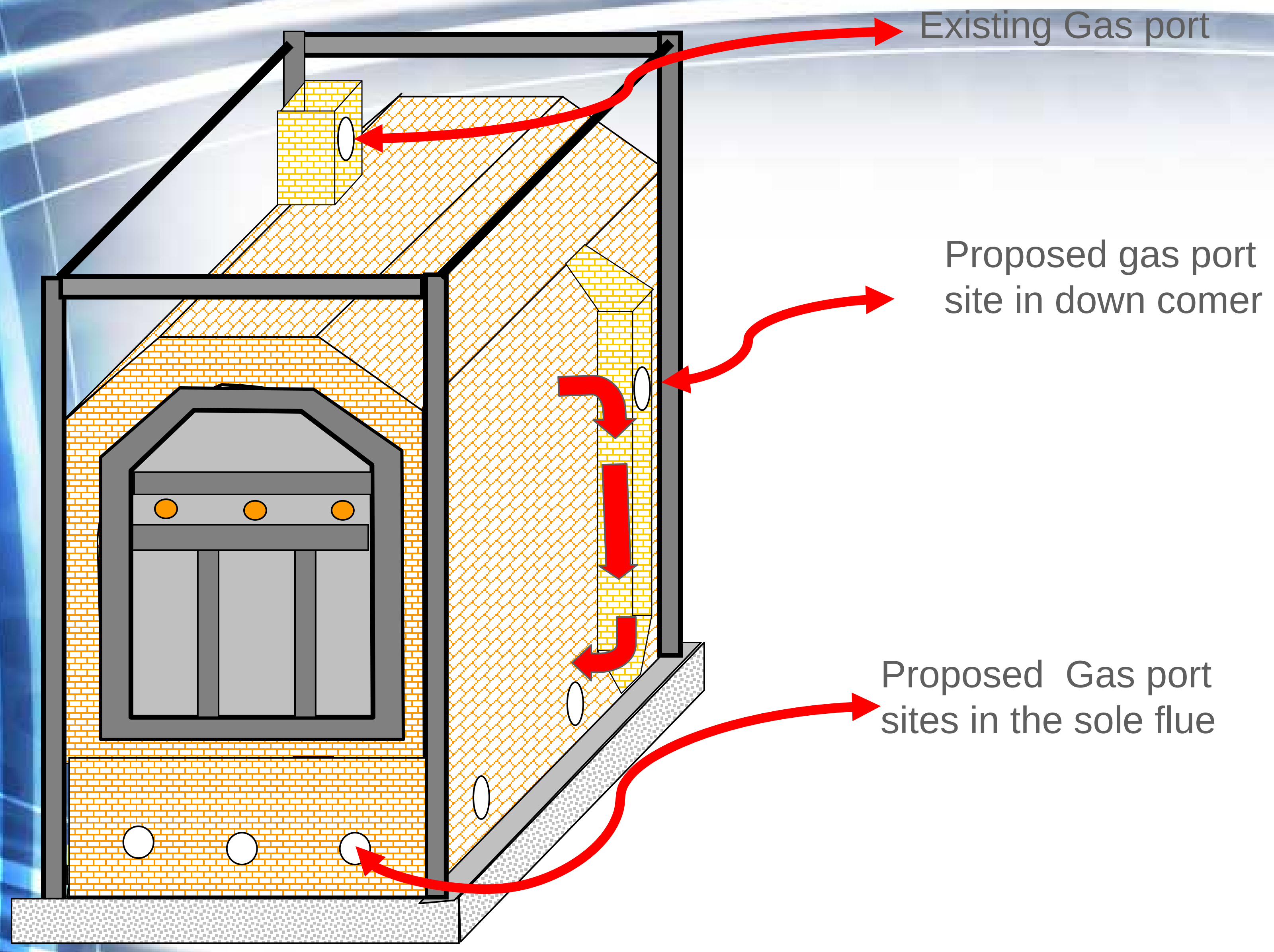
Heating manifold and wall thermocouples

CSL Non Recovery Coke Simulator



Door lifting mechanism and exposed interior of non recovery oven

CSL non recovery pilot oven



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

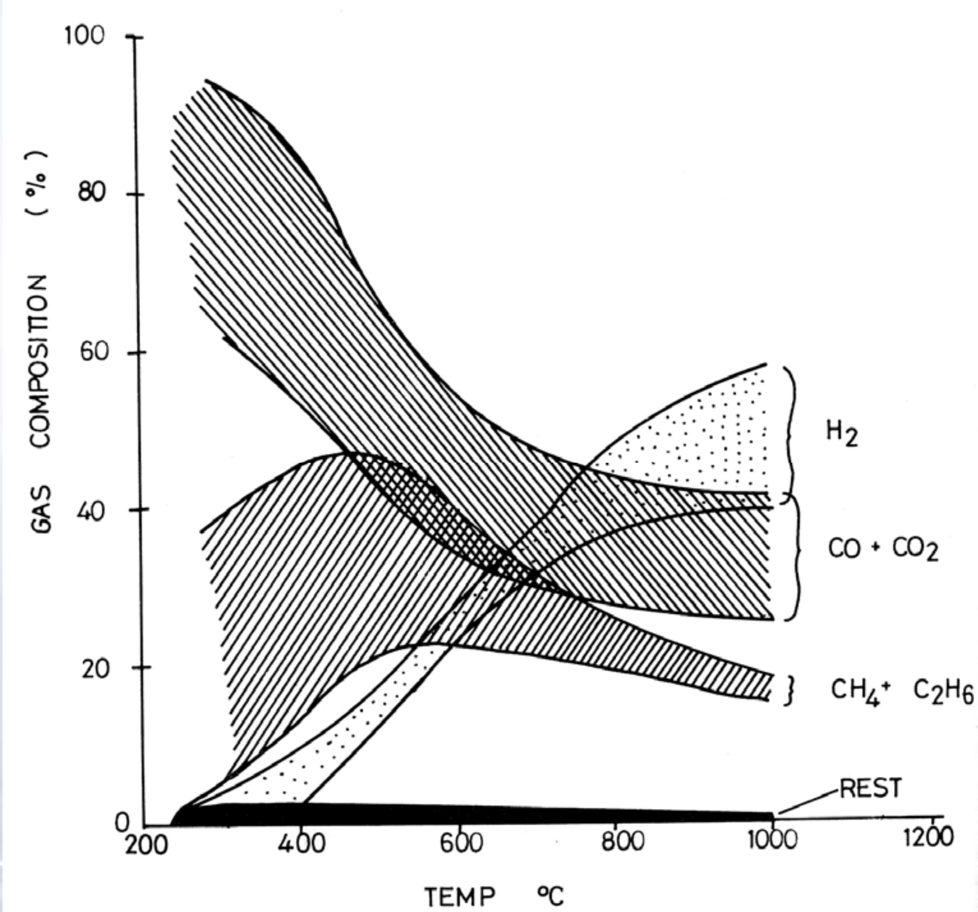
R = gas constant, kJ/mol °K

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.

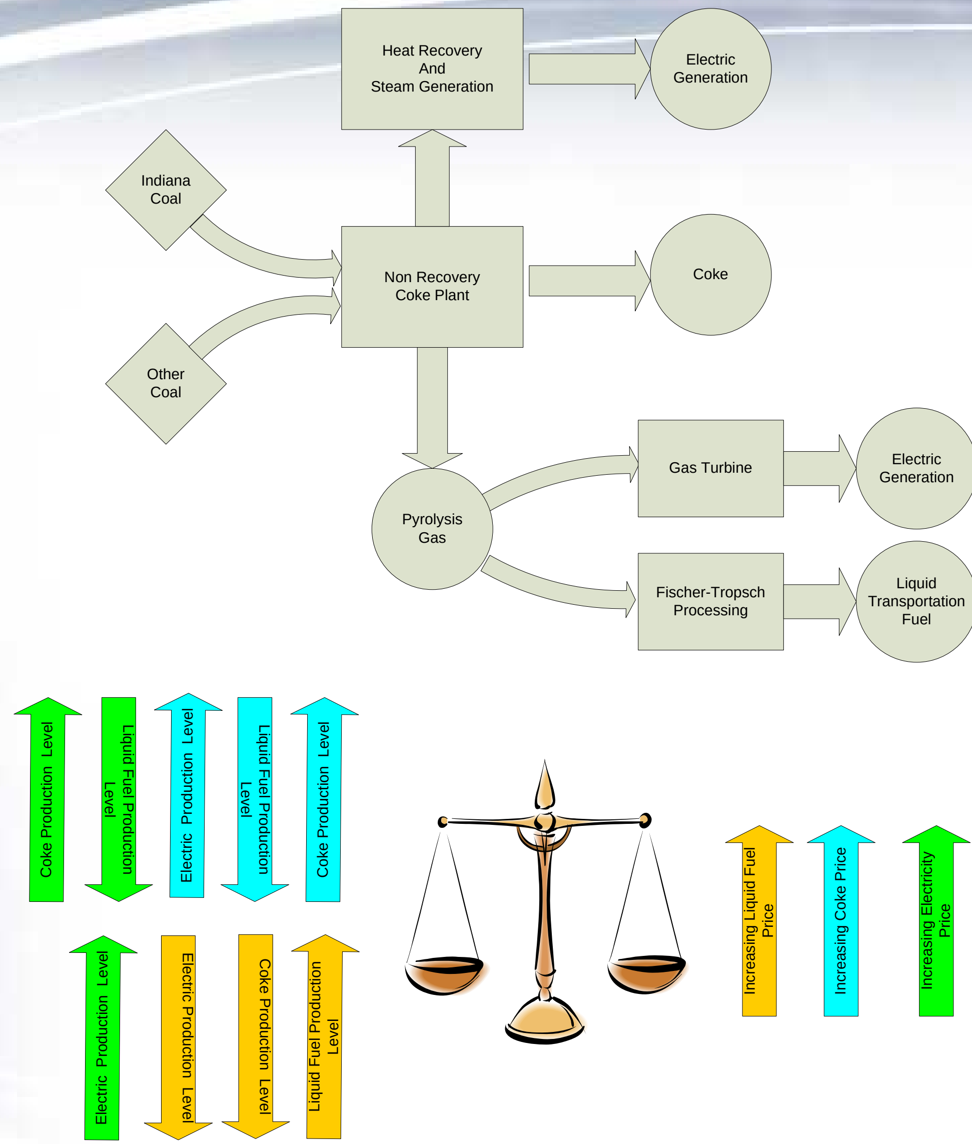
Pyrolysis Gas Composition vs Temperature



Phase 2 Timing Issues

- Phase 2 can be started this Summer for small amount of money for duct ports in walls (~$25K). Expanded environmental licensing required later.
- Duct work piping, controls, and Fischer-Tropsch unit can be added later.
- Estimate 15-40 gallons of Fischer-Tropsch liquid per day at peak.

Process Value Streams



Revised Research Recommendation

- Preliminary results indicate that there is significant benefit to continuing with the current research effort and to consider next steps leading to construction of an industrial test facility should additional analysis and development continue to support the concept.
- Based upon the preliminary results it is recommended that further development of the proposed concept for mine mouth coking/gasification should be initiated and expanded to include consideration of the production of liquid transportation fuels. <u>Preliminary work for test facility ports should be done now.</u>

Thank You !

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