

**Development of Coking/Coal Gasification Concept to Use Indiana
Coal for the Production of Metallurgical Coke, Liquid Transportation
Fuels, Fertilizer, and Bulk Electric Power**

Phase II

Final Report

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Executive Summary

Coke is a solid carbon fuel and carbon source produced from coal that is used to melt and reduce iron ore. Although coke is an absolutely essential part of iron making and foundry processes, currently there is a shortfall of 5.5 million tons of coke per year in the United States. The shortfall has resulted in increased imports and drastic increases in coke prices and market volatility. For example, coke delivered 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. This makes clear the likelihood that prices will remain high. This effort that is the subject of this report has considered the suitability of and potential processes for using Indiana coal for the production of coke in a mine mouth or local coking/gasification-liquefaction process. Such processes involve multiple value streams that reduce technical and economic risk. Initial results indicate that it is possible to use blended coal with up to 40% Indiana coal in a non recovery coke oven to produce pyrolysis gas that can be selectively extracted and used for various purposes including the production of electricity and liquid transportation fuels and possibly fertilizer and hydrogen. At present essentially all of the coal used for coke production in Indiana's steel industry is imported from outside Indiana.

Indiana is home to roughly 22% of the domestic base steel production for the United States. One essential raw material needed by this industry is coke. Current 2005 forecasts indicate that the United States will produce 11,500,000 net tons of coke, but will require 17,000,000 net tons for blast furnace, foundry, and related uses.¹ 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. Of this, approximately 8.1 million tons was used for coke production.² Essentially all of this coking coal comes from Kentucky, West Virginia and Virginia.

The significant shortfall of needed coke has placed an enormous strain on Indiana's steel industries. This report describes initial results of the development of a process that can provide at least a partial resolution and/or mitigation of this formidable problem through the use of Indiana coal in a mine mouth or local, environmentally friendly, high efficiency coking/coal gasification facility which would increase coke supply and production, while, at the same time, reducing the cost for Indiana's steel and foundry industry.

The general conclusion of this study is that it is possible to use a blend of Indiana and conventional metallurgical coal to produce coke for use in various industrial applications. In addition, there is also potential to also use gas produced in the coking process for a variety of purposes including production of electricity, liquid transportation fuel, fertilizer, and hydrogen.

The next steps in this effort entail additional laboratory testing of Indiana coals in conjunction with process design efforts. In addition, computer and process models for

the evaluation of coal blending schemes and initial system designs for coking, liquid fuel, and fertilizer production should be further developed.

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Introduction

This effort has considered initial design aspects of a new process for producing coke, which is a solid carbon fuel and carbon source produced from coal that is used to melt and reduce iron ore, in a Multi Purpose facility that uses up to 40% Indiana coal. Currently no Indiana coal is used for coke production. This effort was conducted Energy Efficiency and reliability Center located at Purdue University Calumet in Hammond Indiana with funding from the Center for Coal Technology Research. The team members for this study were:

- Robert Kramer (Ph.D.) (PI) Professor and Director of the Purdue University Calumet Energy Efficiency and Reliability Center. Areas of expertise include energy research, electric system design and operation, energy system optimization, coal/coke gasification and liquid transportation fuel production, 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.
- Chenn Zhou (Ph.D.), Head of Mechanical Engineering Purdue University Calumet. Dr. Zhou is an expert in computational fluid dynamics.
- 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.

A viable supply of iron is one mainstay of economies throughout the world. Issues associated with the supply and price of iron, which is used to produce steel, play either a direct or indirect role in all modern business operations. Indiana is home to approximately 22% of the base steel production for the United States and consequently there is enormous incentive to assure the supply, quality, and price of the raw materials that are used in its production. One of the major components used in the iron making process is coke.

Coke is a solid carbon fuel and carbon source used to melt and reduce iron ore. Coke production begins with pulverized, bituminous coal. In current operations, coal itself can not be used in place of the central placement of coke in a blast furnace because it would not form a permeable bed of sufficient strength and porosity to support the weight of material in the blast furnace.

Coal is fed into a coke oven which is sealed and heated for 14 to 36 hours to about 1100 C (2000 F). Coke is produced by heating particulate coals of very specific properties in a refractory oven in the absence of oxygen (or with limited oxygen at the top of the coal bed in the case of non recovery coke ovens). As temperature increases inside the coal mass, it melts or becomes plastic, fusing together as devolatilization occurs, and ultimately resolidifies and condenses into particles large enough for blast furnace use. During this process, much of the hydrogen, oxygen, nitrogen, and sulfur are released as volatile by-products, leaving behind a partially crystalline and porous carbon product. The quality and properties of the resulting coke is inherited from the selected coals, as well as how they are handled and carbonized in coke plant operations.

Heat is often transferred from one coke oven to another to reduce energy requirements. After the coke is finished, it is moved to a quenching tower where it is cooled with a water spray. Once cooled, the coke is moved directly to an iron melting furnace or into storage for future use. Currently essentially no Indiana coal is used to produce coke.

Coke production is traditionally one of the major pollution sources from steel production. At present there are two main methods of producing coke. First, a recovery process in which the coal is heated in a completely reducing atmosphere and the volatile products are recovered in an associated chemical processing plant. Major issues associated with this process include the complexity of the chemical processing and the production of potentially hazardous compounds. There is also a major concern with the tar that is left after processing. This material is also potentially hazardous and is generally stored on site and thus presents a significant future disposal concern. The complexity of the chemical processing introduces added cost and process operational details that have restricted the use of this option in the past for coking and simultaneous power production.

Air emissions such as coke oven gas, naphthalene, ammonium compounds, crude light oil, sulfur, and coke dust are released from many coke ovens. Emissions control equipment can be used to capture some of the gases and heat can be captured for reuse in other heating processes. But, traditionally, some gases escape into the atmosphere as the coke oven ages. Air and water emissions from coke production can be reduced by using a non-recovery coke battery. In traditional plants, by-products are can be recovered. In non-recovery batteries, pollutants are combusted in the coke oven itself, which is often maintained at a negative pressure. This technique consumes the by-products, eliminating much of the air and water pollution.

In the non recovery process air is introduced above the top of the coke bed in the oven and the volatiles are combusted. The Environmental Protection Agency has stated that new ovens must meet non recovery standards. The hot gases from the oven can then be used in a heat recovery boiler to produce steam and subsequently generate electricity. Relatively small amounts of hydrogen are produced in this process and are recalculated to the bottom of the furnace to provide heat for the process. Figure 1 depicts coke at the conclusion of the coking process in a conventional slot oven. Figure

2 depicts the coke after it has been pushed from a slot oven.³ Figure 3 depicts a non recovery coke oven.⁴



Figure 1: Coke in a Slot Coking Oven



Figure 2: Coke from Slot Oven

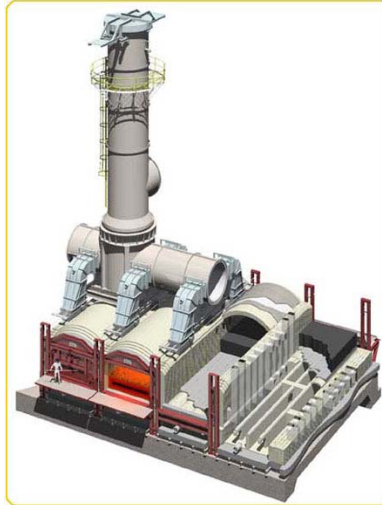


Figure 3: Non Recovery Coke Oven

In the iron making process, iron ore, coke, heated air and limestone or other fluxes are fed into a blast furnace. The heated air causes the coke to combust, which provides the heat and carbon sources for iron production. Limestone or other fluxes may be added to react with and remove the acidic impurities from the molten iron in the form of slag. A typical blast furnace operation indicating the location of the coke is depicted in Figure 4.⁵

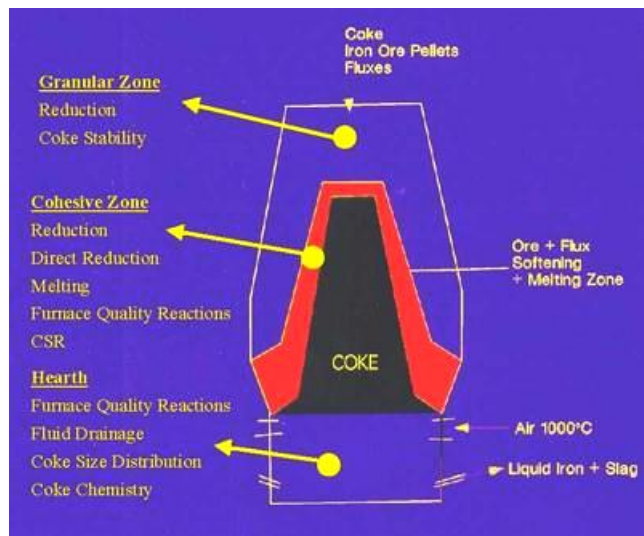


Figure 4: Typical Blast Furnace Zones

Process Description

One key issue in blast furnace iron making is the strength of the coke. The coke produced from Indiana coal has less strength than coke produced from current metallurgical coal sources and consequently is smaller in size. This means that it will be used in upper portions of the blast furnace. Typical characteristics of coke used in blast furnace operations are shown in Table 1.⁶

Physical: (measured at the blast furnace)	Mean	Range
Average Coke Size (mm)	52	45-60
Plus 4" (% by weight)	1	4 max
Minus 1" (% by weight)	8	11 max
Stability	60	58 min
CSR	65	61 min
Physical: (% by weight)		
Ash	8.0	9.0 max
Moisture	2.5	5.0 max
Sulfur	0.65	0.82 max
Volatile Matter	0.5	1.5 max
Alkali (K ₂ O+Na ₂ O)	0.25	0.40 max
Phosphorus	0.02	0.33 max

Table 1: Typical Blast Furnace Coke Characteristics

This report details research that was conducted from March 2006 to the present to determine the viability of using Indiana coal for the production of coke. Specifically, the concept of locating a modified non recovery coking facility at a mine in Indiana or at an existing facility with energy recovery for the generation of electricity was considered. In addition, extension of the technology to include gasification and local power production were also considered. The results of this study indicate that there is a high potential to use Indiana coal for coking as well as other industrial purposes both within and outside Indiana. A flow diagram of the concept is depicted in Figure 5.

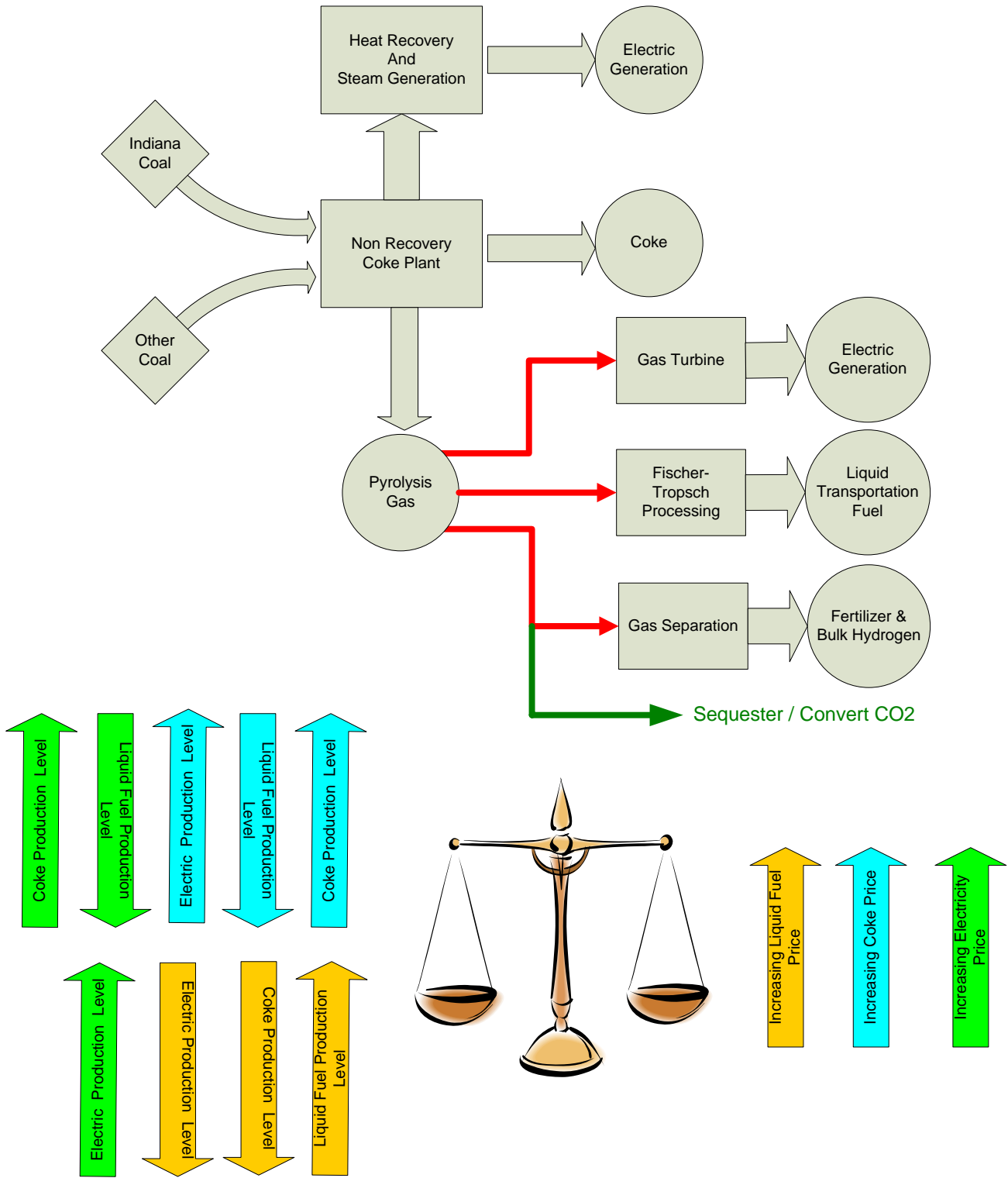


Figure 5: Initial Concept Description

The coal used for the proposed coking process would be a mix of Indiana Brazil Seam or potentially other Indiana coals, as previously identified by the Indiana Geological Survey, blended with other coals to meet metallurgical and emissions requirements. Currently this approach has been used successfully to dramatically increase coke quality. Several steel manufacturers have expressed interest in considering how Indiana coal might be used for various production processes. They also indicate that they have considered and/or are currently considering using Indiana Coal usually at low levels in blends.

Coke produced from Indiana coal has less strength than coke produced from conventional metallurgical coal and this results in coke sizes that fall into two general classes. One class, often referred to as 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. The other class is called coke breeze and is much finer. It is used as a source of carbon in steel making, for palletizing, sintering, as well as in the 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. 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.

An investigation of ways to increase the percentage of Indiana coal used for coke production is under way. One approach is to blend different types of coals until a mixture is obtained that meets the coke quality requirements. Efforts to extend the blending to also consider optimizing the composition of the pyrolysis gas produced in the coking process are also underway. By optimizing both aspects simultaneously it will be possible to obtain coke of acceptable quality for use in blast furnaces and other applications and at the same time obtain a supply of pyrolysis gas that can be used for the production of liquid transportation fuels through the use of the Fischer-Tropsch process, and possibly fertilizer bulk hydrogen.

Preliminary laboratory tests of several Indiana coals were conducted to determine the suitability of Indiana coal for purposes of producing liquid transportation fuels, fertilizer, and hydrogen as part of the coke production process. As the temperature of the coal is increased in the coke production process pyrolysis gas of varying composition is released. In the proposed concept it is anticipated that portions of this gas will be gathered from the coke process at specific temperature ranges with the proper composition for the production of liquid transportation fuels, fertilizer, and hydrogen. Figures 6 and 7 depict test results and show the gas composition from various Indiana coal sample at different temperatures.

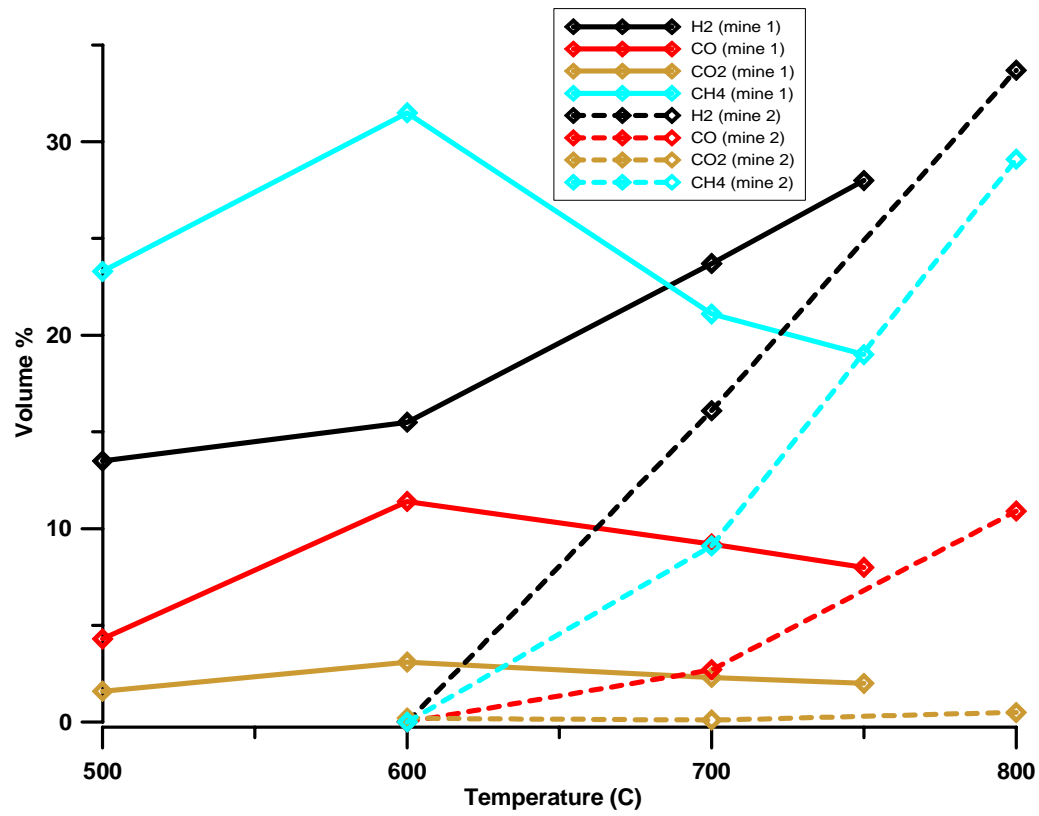


Figure 6: Gas Composition vs. Temperature

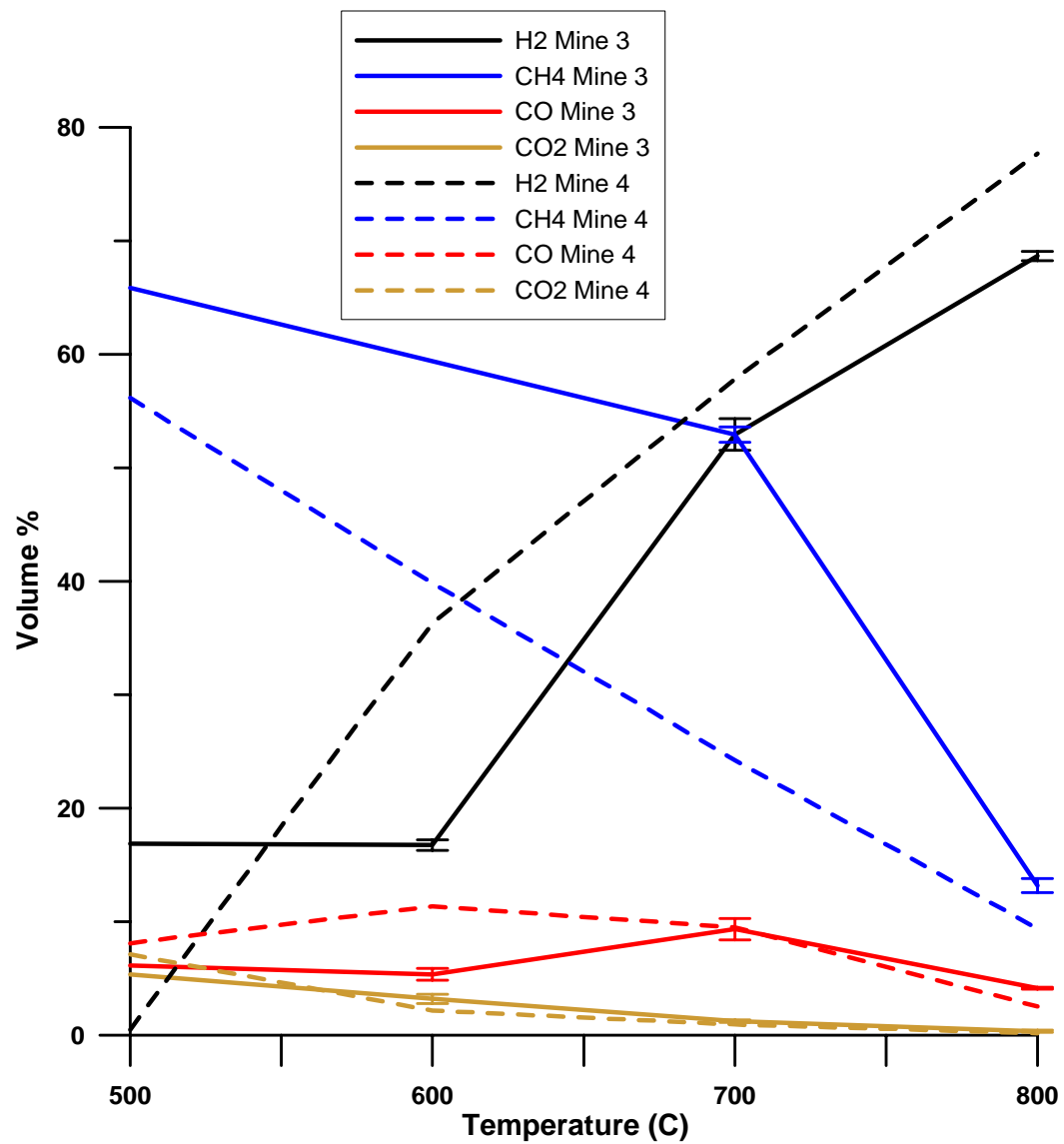


Figure 7: Gas Composition vs. Temperature

The gas from the coal samples was produced in an apparatus developed as part of this effort as depicted in Figure 8.

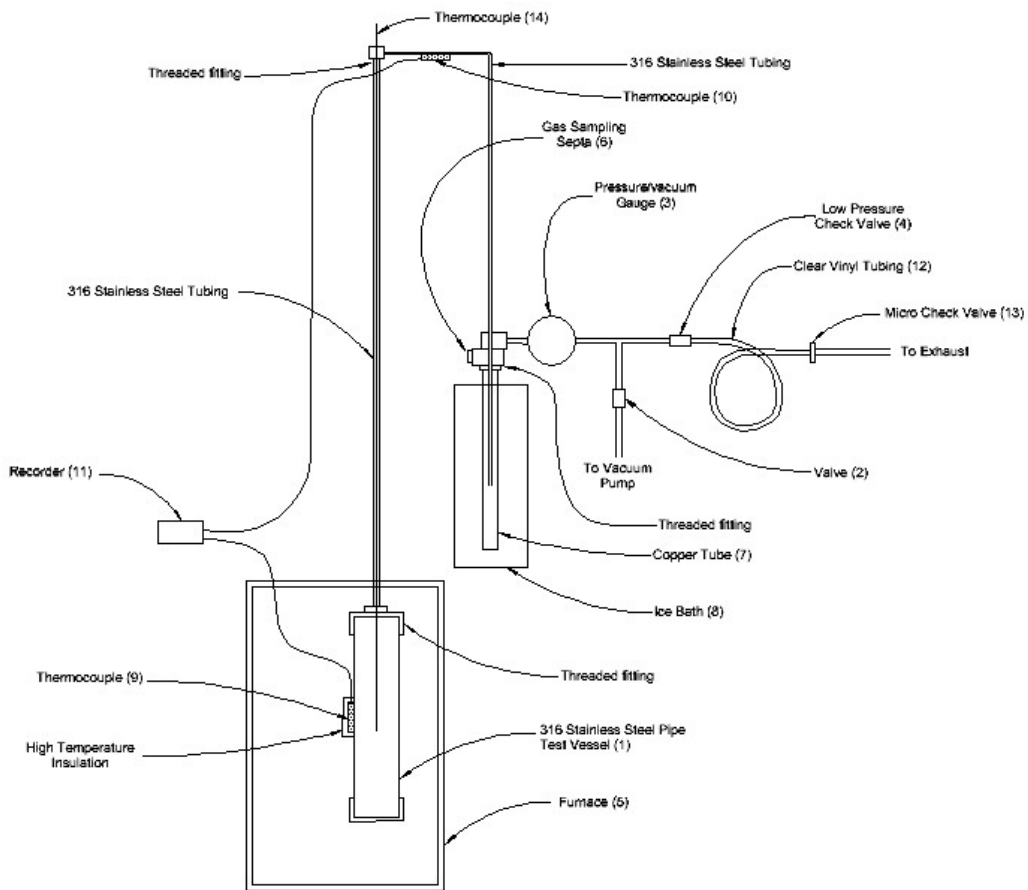


Figure 8: Pyrolysis Gas Apparatus

The gas produced in the apparatus depicted in Figure 8 was analyzed in a gas chromatograph. Samples of chromatograms from the analysis are shown in Figures 9 and 10. Figure 11 shows the results of repeated samples for one pyrolysis sample and indicates that the sampling procedure produces repeatable results.

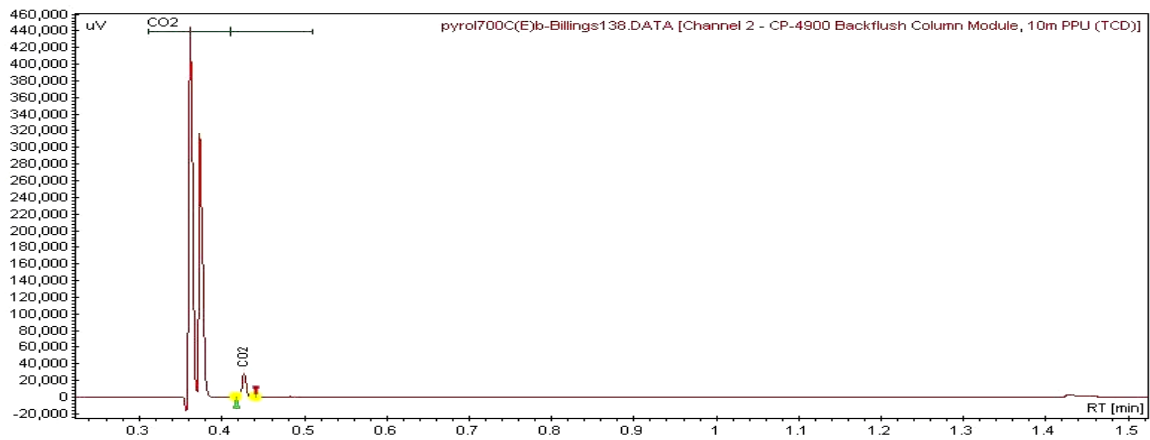
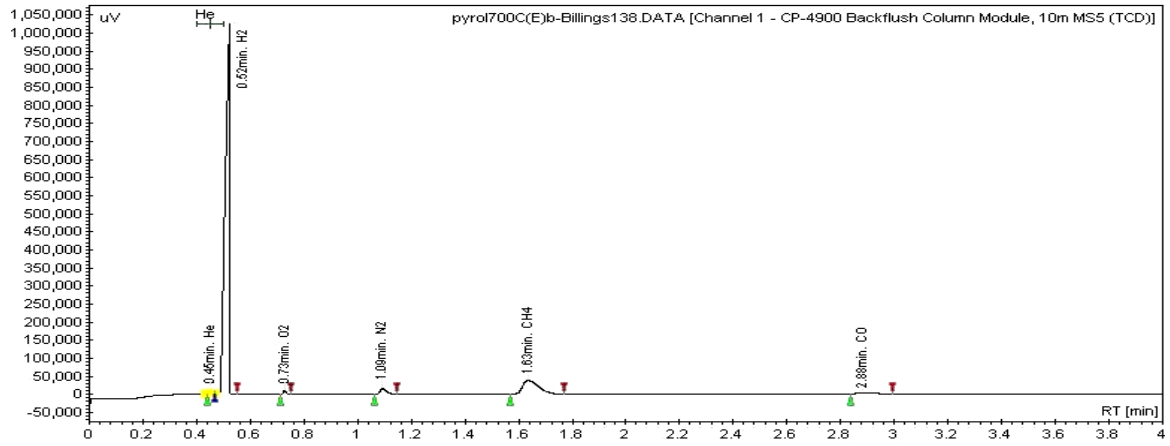


Figure 9: Gas Chromatogram

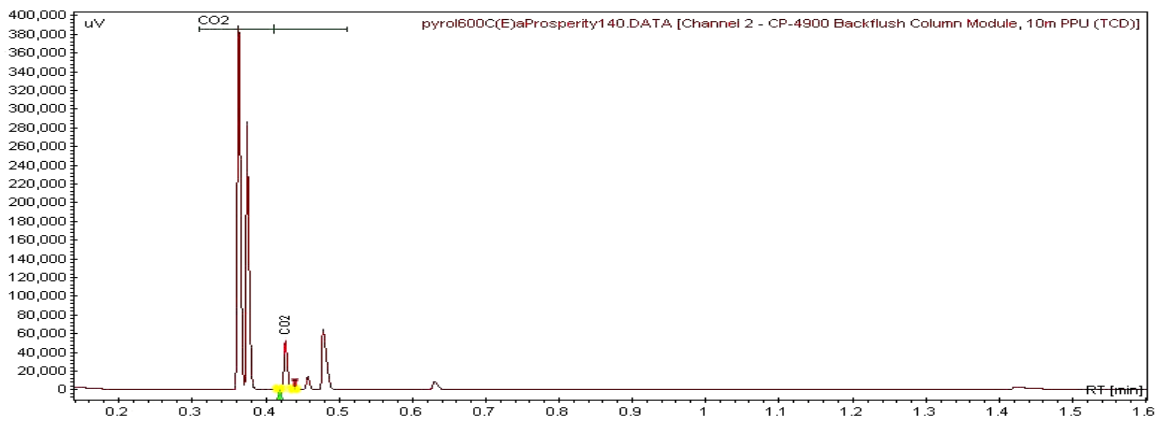
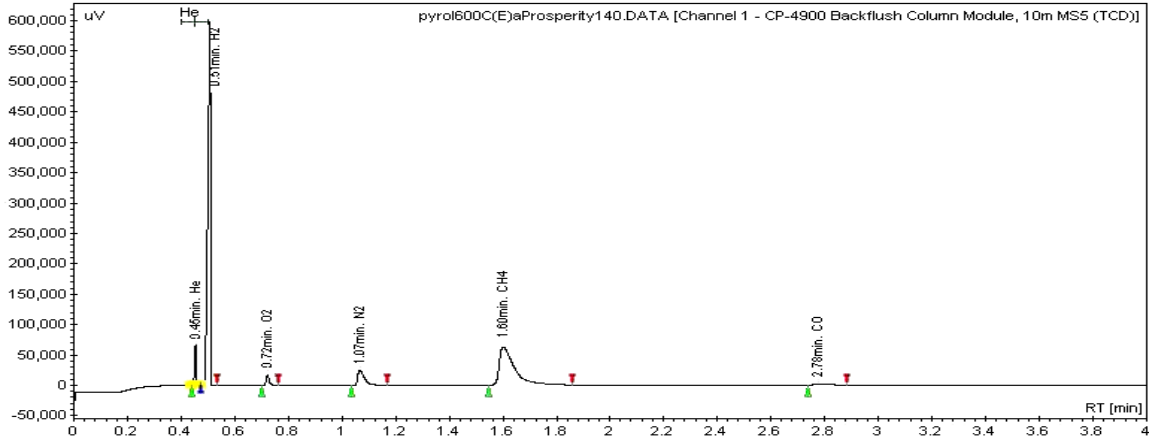


Figure 10: Gas Chromatogram

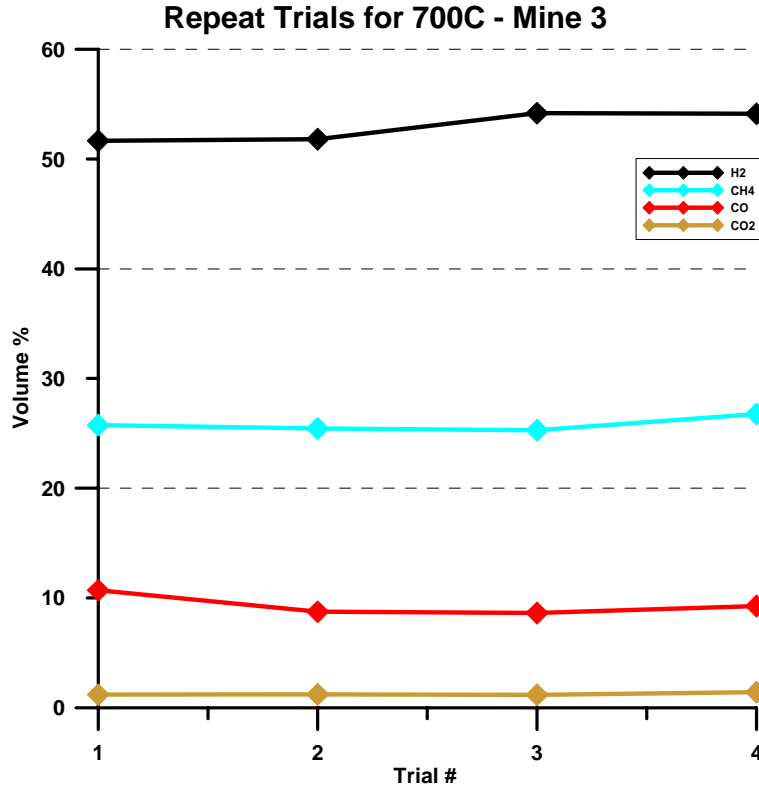


Figure 11: Repeated GC Trial

A metallurgically compatible sample of Indiana Brazil seam coal was obtained from Solar Sources. This coal was analyzed by the coke laboratory at US Steel in Gary, Indiana. Results of this analysis are shown in Table 2.* As can be observed from the data in this table, this particular coal when blended with other metallurgic coal would be suitable for blast furnace coking purposes.

* The assistance of Solar Sources in obtaining the sample and US Steel in performing the analysis was extremely helpful to this effort and is greatly appreciated.

Purdue Coal Sample 7-20-2005	%
Moisture Content	2.38
Size Analysis	
+ 1- ¼ "	8.8
+ 1"	15.8
+ ¾"	25.9
+ ½ "	40.1
+ ¼ "	59.6
+ 1/8 "	12.9
Mean size	1.44
Proximate Analysis	
Volatile Matter	37.08
Fixed Carbon	53.62
Ash	9.30
Sulfur Content, % Dry	0.76
Oxidation Test (% Trans.)	97.0
Petrographic Analysis	
V-Types	
3	0.4
4	11.5
5	55.0
6	33.0
7	0.1
RO	0.57

Table 2: Indiana Coal Test Results

To better characterize Indiana coal it is recommended that additional analysis should be performed in the next phase of this effort. Additional tests that have been identified for such a characterization are depicted in Table 3. Additional tests may be necessary as the process is developed further.

I.	Proximate Analysis
	a. Moisture
	b. Volatile matter
	c. Fixed carbon
	d. Ash
	e. Sulfur
	f. BTU/lb (heating value)
	g. Free swelling index
II.	Ultimate Analysis
	a. Carbon
	b. Hydrogen
	c. Nitrogen
	d. Oxygen
	e. Chlorine
III.	Ash Chemistry
	a. SiO_2
	b. Al_2O_3
	c. Fe_2O_3
	d. CO
	e. MgO
	f. K_2O
	g. P_2O_5
	h. Na_2O
IV.	Rheological Properties
	a. Gieseler Plastometry (fluid characteristics)
	b. expansion and contraction
	c. Sole heat oven test (SHO)
V.	Petrographic Tests
	a. Petrographic composition of coal
	b. Rank determination by reflectance
	c. Fluorescence analysis

Table 3: Future Coal Tests

In addition to the nature of the gas produced during the coke process it is also crucial that the produced coke meet standards for its use in blast furnace or other applications.

One method to obtain the proper coke properties is through the blending of various types of coal.

An example of three types of coal blends used by the Japanese Steel Industry in 1975 for coke production is depicted in Figure 12.⁷

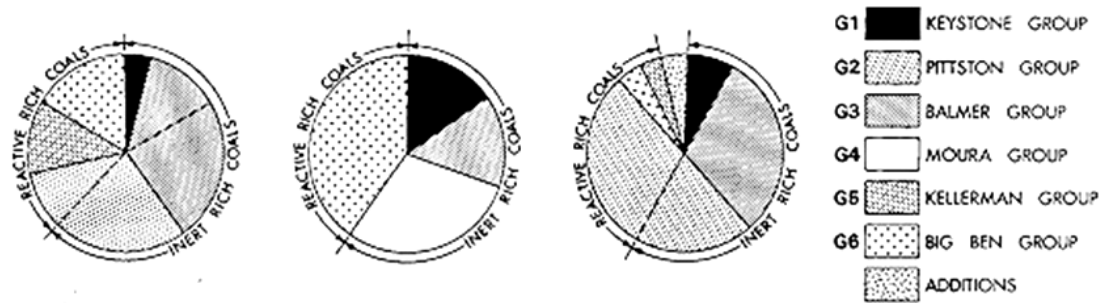


Figure 12: Coking Coal Blend Example

One way to rank coals is by the amount of volatile matter they contain. At the simplest level, mid-range prime coking coals will produce the best coke and the farther a particular coal is away from prime coking coal, the less suitable it is. Coke from high volatile coals tends to be too weak and reactive to be used in the blast furnace. Also, carbonizing low volatile coals can produce unacceptably high pressures on oven walls for slot ovens.

When coal is viewed under a microscope, it can be seen to be composed of three main components, or macerals, analogous to the minerals found in rocks.⁸ The first of these, vitrinite, softens on heating. It in association with the other components, liptinite and inertinite, forms the coke matrix. These components reflect light at different intensities. In general, the reflectance of the vitrinite is a measure of the rank of the coal and is inversely proportional to the volatile matter content. Usually a coal blend for blast furnace coke should have a reflectance between 1.25% and 1.35%. The reflectance of coals blends tends to vary linearly, but having the average reflectance of a blend in this range is not sufficient to assure that the produced coke will have the desired qualities. For this reason the reflectance distribution is considered.

If the reflectance values from a sample are plotted in a histogram, it is desirable to have a distribution that resembles a normal distribution with not too large a standard deviation. Unacceptable distributions have large standard deviations or have multiple peaks.⁹ Attempts at using simple linear programming models to determine coal blends for coking have produced varying results due to the complexity of the coking process.¹⁰ Modeling must also consider other characteristics such as dilatation and fluidity, which provide empirical measures of the extent of softening and fusion on heating, in the blending process.

Due to the physical characteristics of Indiana coal¹¹, the coke produced will tend to be of a smaller size, but there are many opportunities to use this type of coke in blast furnace and other operations. Concerns with the relative strength of the coke produced from Indiana coal can be reduced by carefully blending various types of coal. Through blending many potential issues with coke characteristics can be reduced or eliminated. Classically, coal blending for coke production has been considered to contain a level of “art” to the process. The research team for the proposed project has had considerable experience in customizing coal blends used for coking processes in operating industrial coke production facilities. This experience will be a valuable attribute in customizing the process to maximize the use of Indiana coal. The research team will develop blending models and/or recommendations that will help to increase the use of Indiana coal for industrial purposes. The nature of the coal blend for the current proposal would be a function of the coking process detail and will require additional research to determine the optimal values.

Two examples of coke quality produced via pilot oven carbonization using Indiana coal are given in the Table 4:

	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)

Table 4. Examples of Coke Quality

Another approach to increasing the percentage of Indiana coal for coke production involves locating that coke in upper regions of the blast furnace where higher reactivity is less of a concern. In this region there is also less mechanical pressure on the individual pieces of coke since there is less material above it. This would allow coke of reduced strength to be readily used in this region. Figure 13 depicts various zones and layering for a typical blast furnace. Methods to use coke produced with a enhanced blend of Indiana coal in the upper coke layers is currently under development.

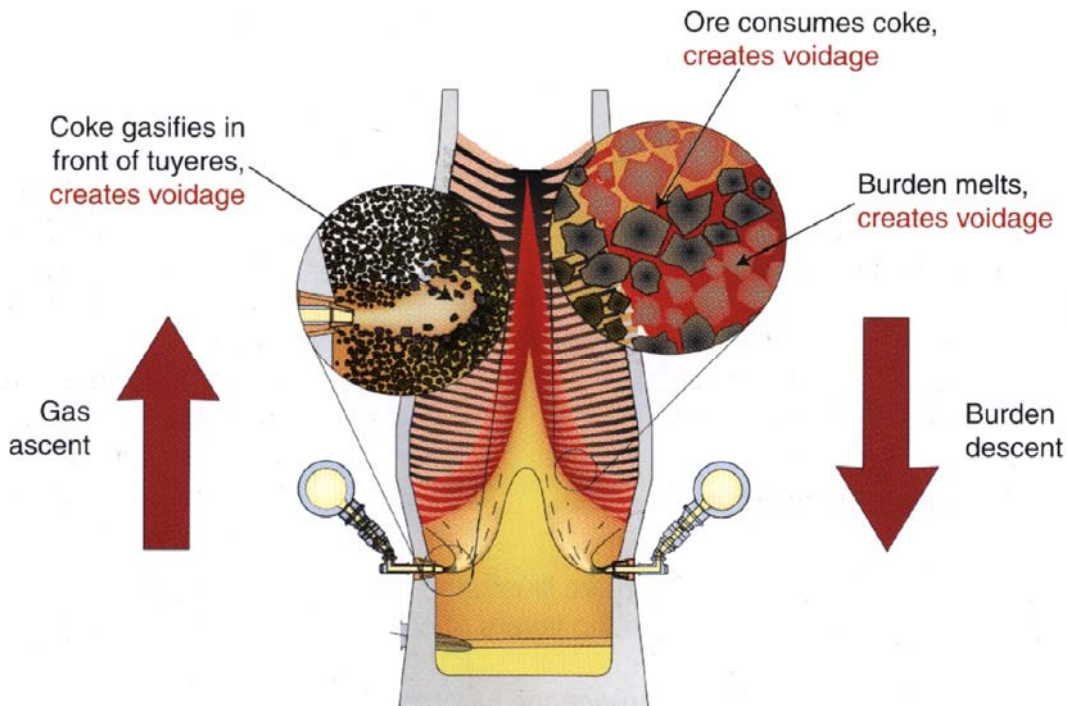


Figure 13: Blast Furnace Zones¹²

Research efforts regarding blast furnace Computational Fluid Dynamics (CFD) at Purdue University Calumet will be leveraged to provide additional support for this proposal. The use of CFD analysis will assist in maximizing the applicability and value of coke generated from Indiana coal. A blast furnace located in Northwest Indiana was modeled and the influences in changes in the coke properties resulting from the use of Indiana coal were considered on an exploratory basis.

The geometry considered is depicted in Figure 14. The cohesive zone was modeled with 34 alternating layers of coke and ore. The ore layer's porosity is assumed to be zero since the ore starts fusing and melting in the cohesive zone. The coke bed porosity in the cohesive zone is 0.5. The burden is treated as one zone with an effective porosity of 0.41. Various cases were run to find the effect of the ore and coke porosity, and ore and coke particle diameters. These cases are listed in Table 5.

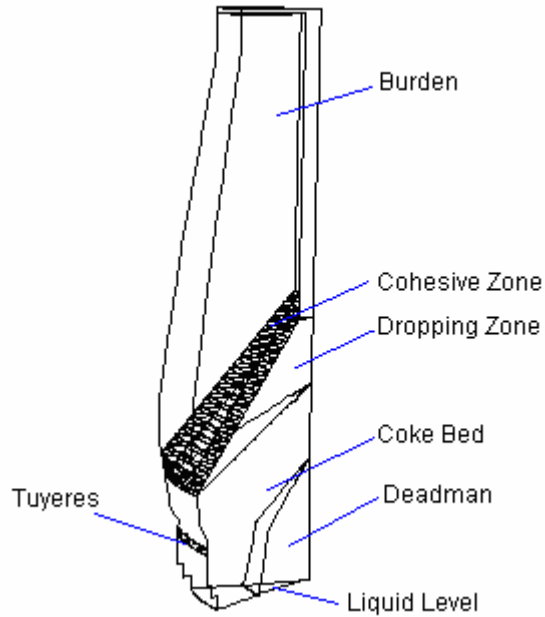


Figure 14: Model Geometry

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

Table 5: Cases Considered

The velocity profile was similar for all the cases as shown in Figure 15. From Figure 2 it can be observed that the velocity decreases as we move away from the tuyere due to the effect of the porous zone in coke bed. The gas flow is primarily upward. The velocity is uniform in the other zones of the blast furnace.

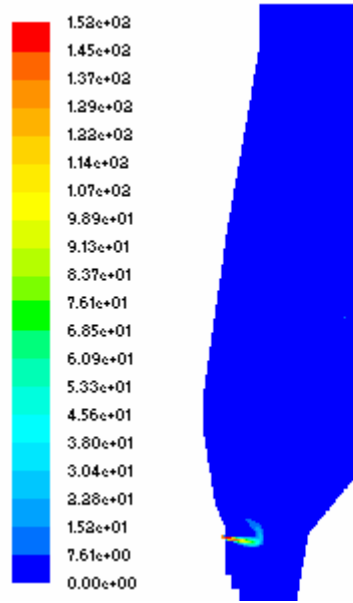
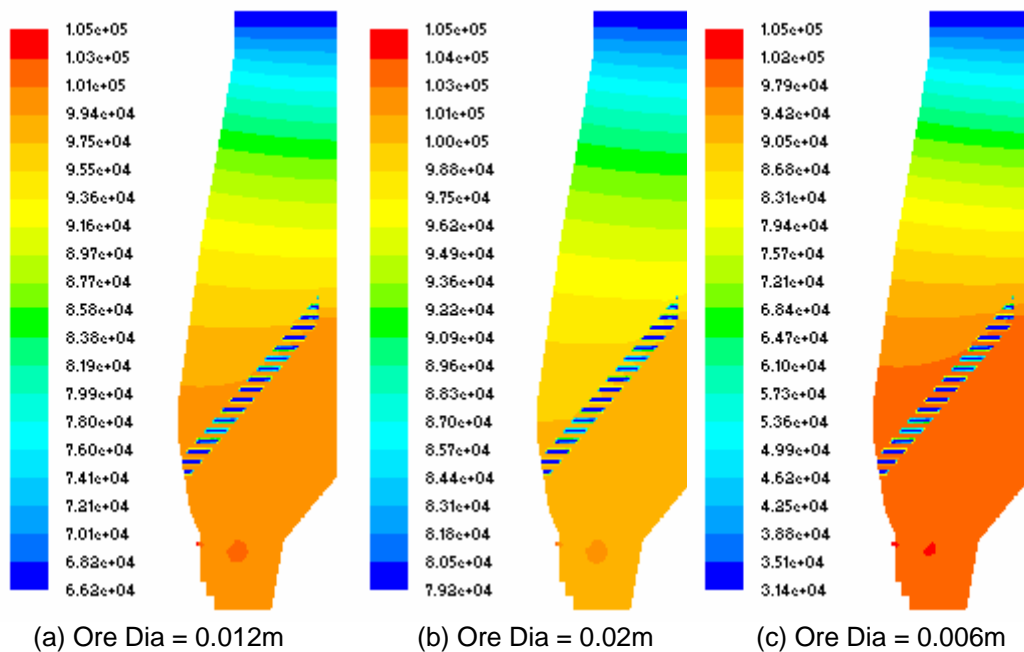
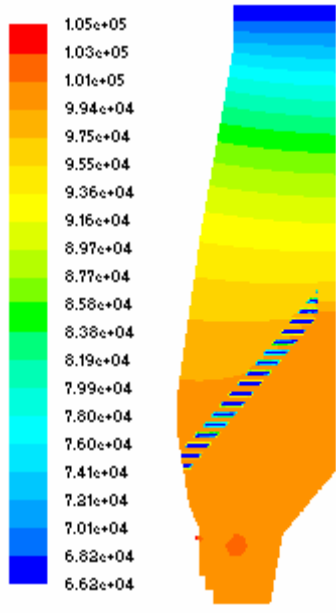


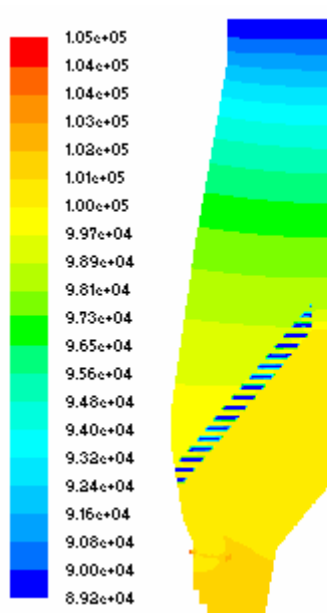
Figure 15: Velocity profile

The pressure drop for the different cases is depicted in Figure 16. It can be observed that as the ore diameter, ore porosity, coke diameter and coke porosity increases, the pressure drop from the tuyere level to the top of the furnace decreases. The effect of the ore layer is more dominant as the ore layer thickness is higher than the coke layer thickness.

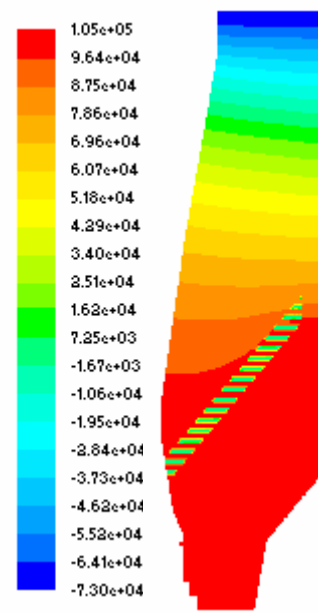




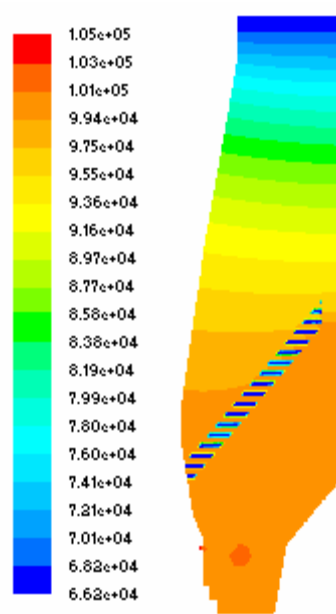
(d) Ore Porosity = 0.35



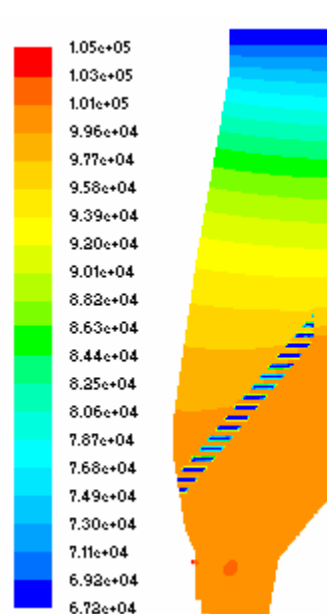
(e) Ore Porosity = 0.5



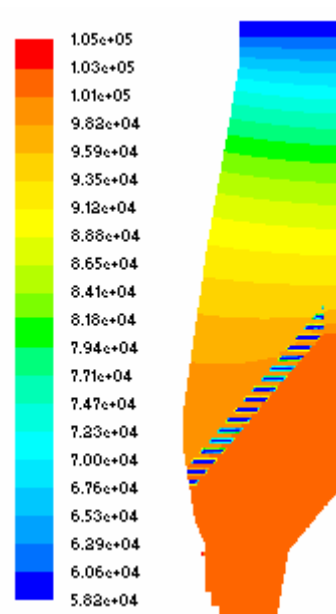
(f) Ore Porosity = 0.2



(g) Coke porosity = 0.5



(h) Coke porosity = 0.65



(i) Coke Porosity = 0.3

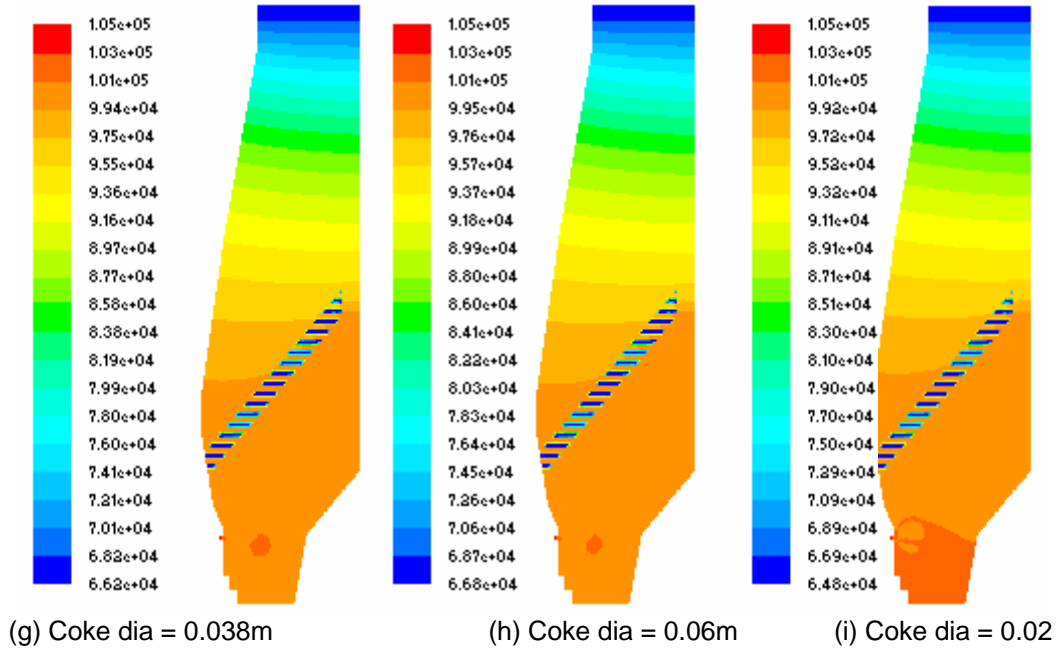
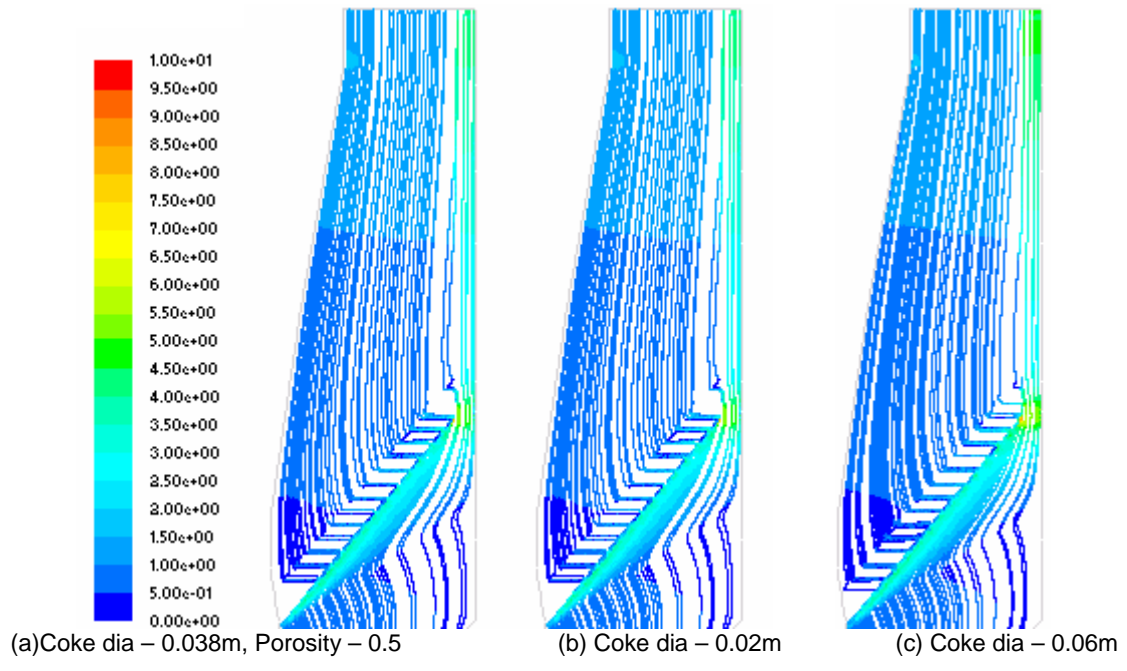


Figure 16: Pressure loss

Gas flow streamlines colored by velocity magnitude are depicted in Figure 17. The gas velocity is higher in the region of the chimney. The velocity is similar for most of the cases considered.



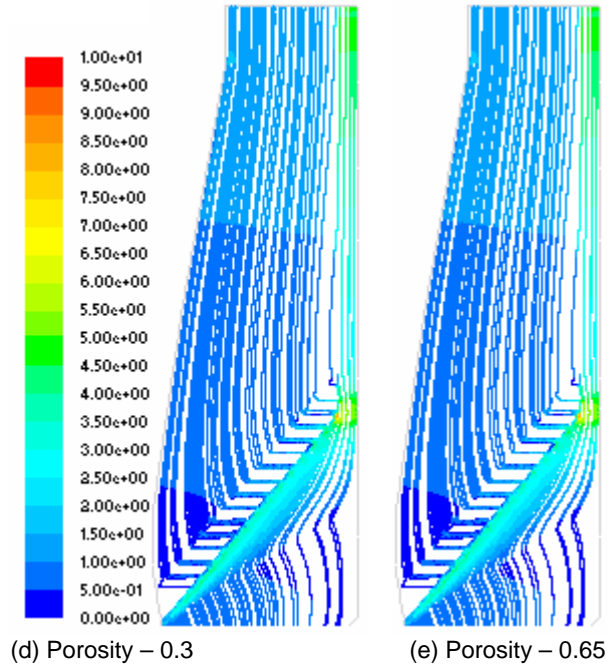


Figure 17: Flow lines for various coke properties

The effect of the coke diameter in the burden is depicted in Figures 18-21. As coke diameter increases, the pressure drop decreases mainly due to the increased inertial and viscous resistance to the gas flow. The same is true for the effect of coke bed porosity and the ore diameter and porosity. The effective gas porosity or gas permeability of the burden decreases in all the cases and leads to reduced pressure drop in all the modeled cases.

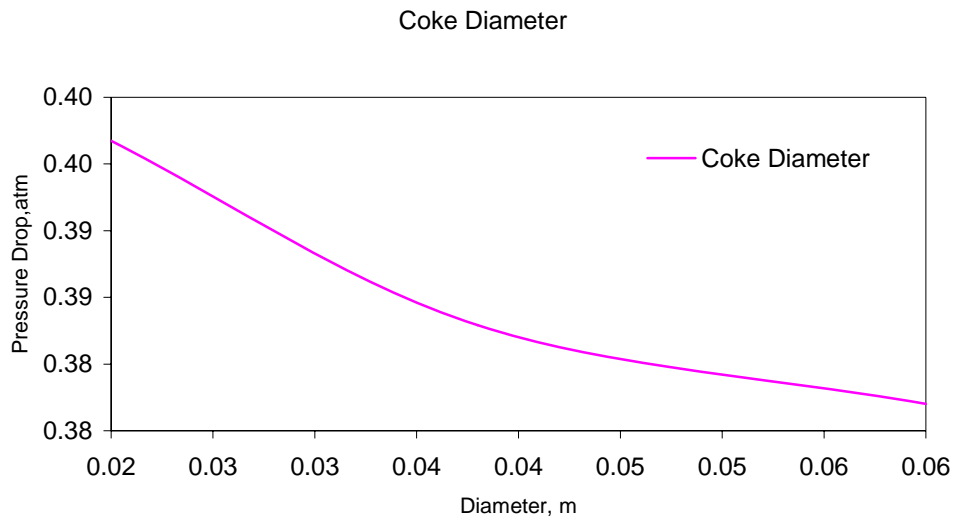


Figure 18: Pressure drop vs Coke Diameter

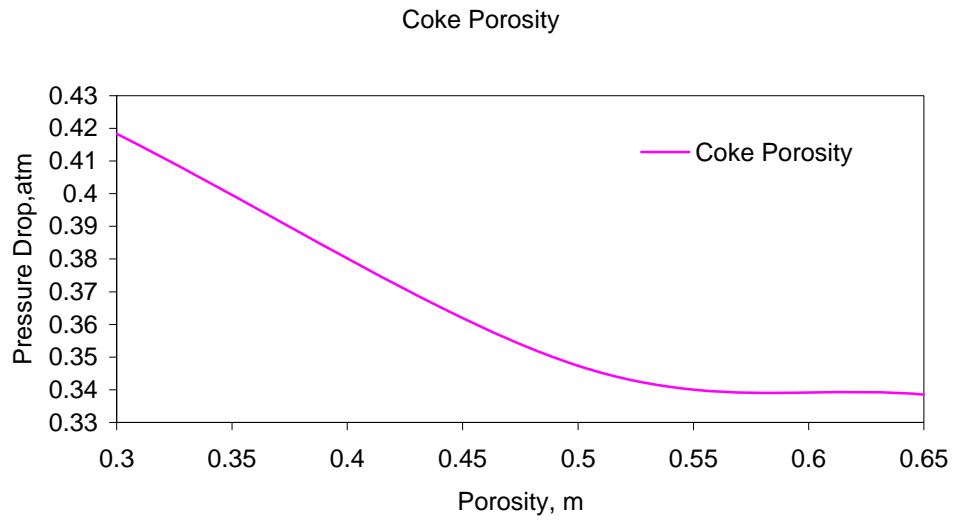


Figure 19: Pressure drop vs Coke Porosity

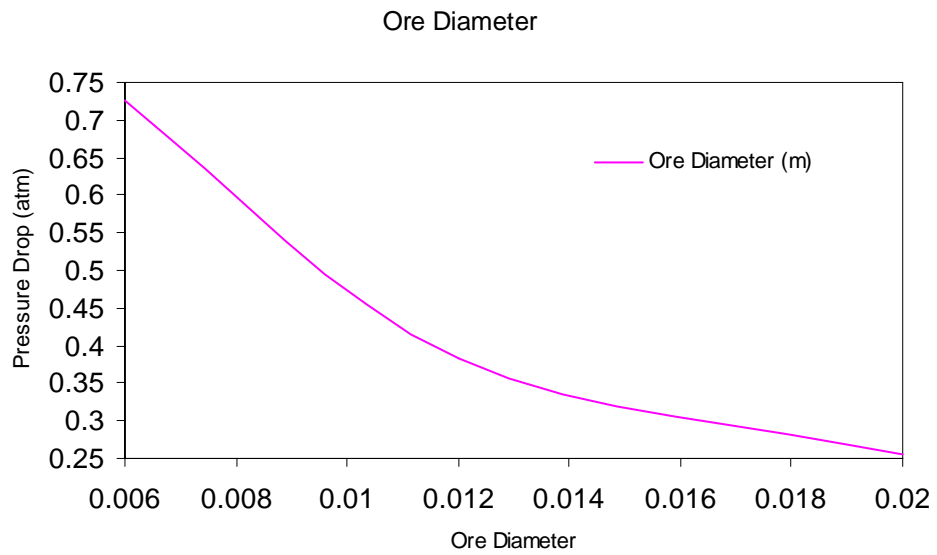


Figure 20: Pressure drop vs Ore Diameter

Ore Porosity

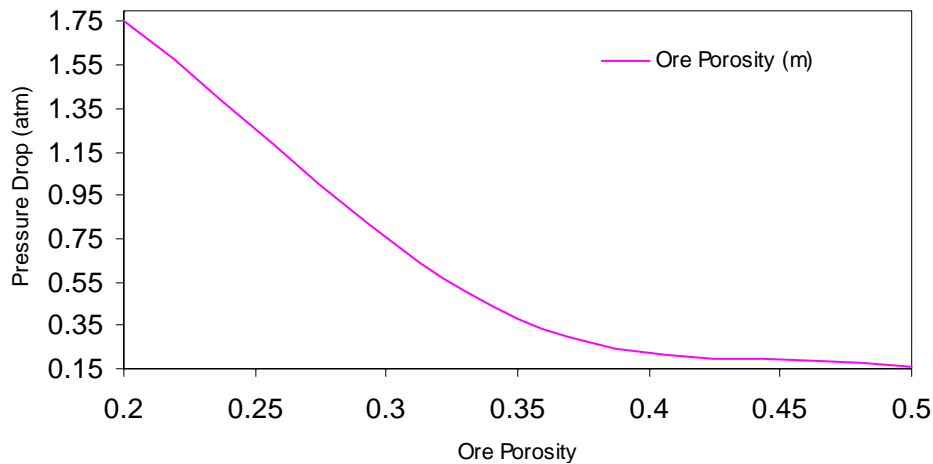


Figure 21: Pressure drop vs Ore Porosity

From this preliminary study, it can be concluded that the pressure drop from the tuyere level to the top of the furnace decreases with increasing the coke and ore diameters and also increasing the coke and ore porosities. This information will be used to assist in increasing the percentage of Indiana coal used for producing coke for use in blast furnaces while maintaining the integrity of the blast furnace wall structure.

This research effort has also considered if it would be conceptually possible to modify the mass balance in the coking process in a way that would allow for a usable level of gas production that could be used to power a combustion turbine for electric production. In discussions with various operational, research, and engineering personnel it has been found that there is a possibility that a portion of the pyrolysis gas could be extracted from the gas stream as it is recirculated to the floor of a non recovery coke oven also referred to as the sole plate. The degree of gasification and influence on operations would need to be considered in a subsequent detailed study. Figure 22 shows the gas recirculation down comers in one non recovery design.¹³

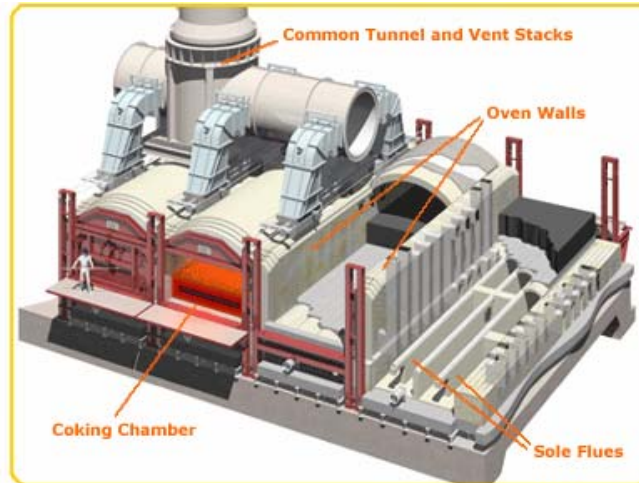


Figure 22: Sole Flue Orientation

Four visits to Argonne National Laboratory were made to discuss various aspects of the proposal. Specifically there was discussion regarding the possibility for partial gasification. Argonne currently uses the Aspen model for much of its coal gasification modeling.¹⁴ Access to the Aspen model licensed to Purdue University is currently being obtained. Efforts to use Aspen for coking operation modeling are being considered. Another process modeling tool, Metsim, was obtained and is currently being used to consider initial design concepts.¹⁵ Metsim is a computer program that can model industrial processes, unit operations, and chemical and metallurgical processes.

The location of the proposed coke production process would take place either near or at an Indiana coal mine or at an existing production facility. The choice of which location would be made based on business issues and also on the availability of transportation capabilities. Transportation of both coal and coke is necessary in this process since the coal used for coke production would be a blend of Indiana and other metallurgical coals. Production of coke at mine mouth would afford a transportation savings because a large portion of coal used by the coking facility would not have to be transported over a long distance. But, coal for blending as well as the finished coke would need to be transported. If sufficient transportation capability exists total transportation cost would be reduced since the mass of the product coke is less than the coal needed to produce it. Thus, a significant cost savings from the reduced weight per mile of material being transported would result if transportation capability was available. This effort is being correlated with research efforts regarding Indiana rail transportation capabilities being conducted by Purdue University North Central. Figure 23 depicts the location of Indiana coal resources.¹⁶ It will be important to consider issues of distance and availability of transportation as part of the commercialization planning process.

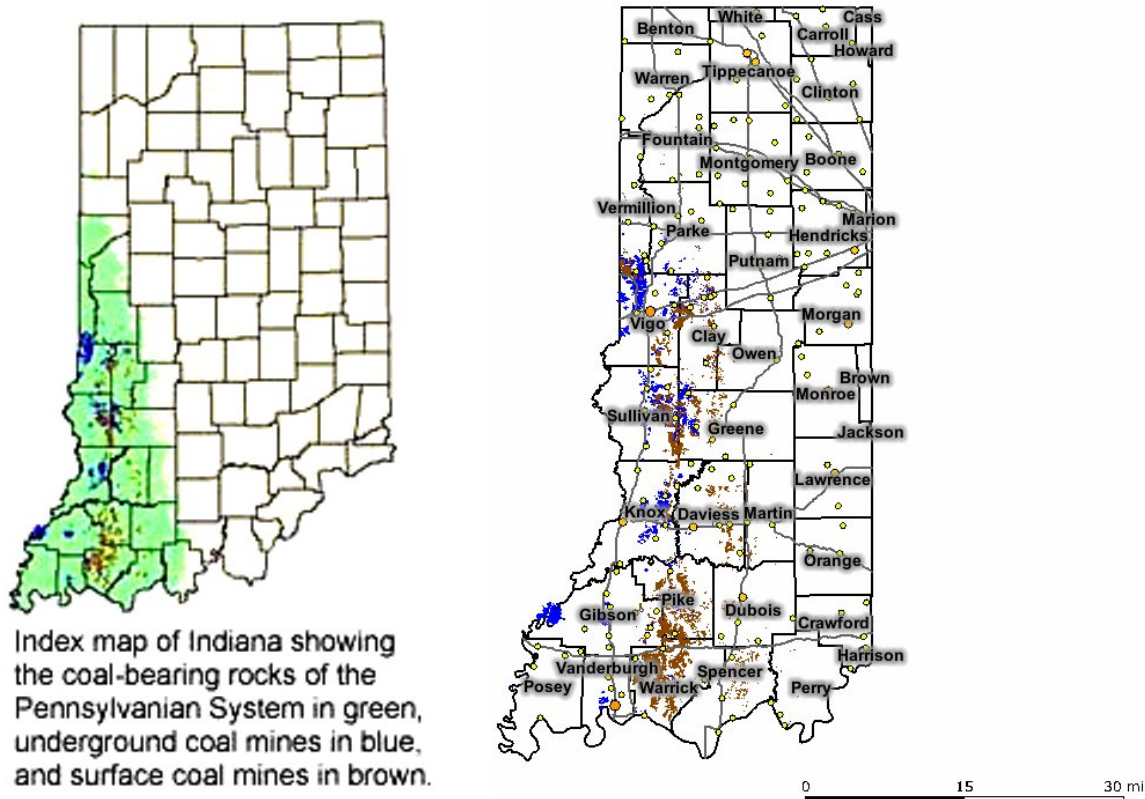


Figure 23: Indiana Coal Locations

Various industry contacts were established to obtain background for the project. Two coal mines were contacted and a coal sample was obtained. Two coal mine operators have indicated an interest in considering the concept for a mine mouth coking facility. Preliminary discussions have considered how such a facility might be developed. Two steel mills were visited and process applications of Indiana coal were discussed. One of the steel mills performed analysis of a sample of Brazil Seam Coal. A coke production facility was visited and issues regarding coking technology were considered.

The coking/coal gasification process would produce metallurgical grade coke using 20-40% Indiana coal and, at the same time, would produce a byproduct gas stream that would be usable in a cogeneration facility for the production of electricity to be sold in the electric market. Initial power flow studies have been investigated to determine the potential value of the generated electricity. Preliminary studies indicate that 100 MW of electricity could be generated from a large coke production facility and that electric grid reliability in either the mine mouth or industrial locations considered would be increased as a result of the additional generation. Alternatives for electric production including heat recovery and potentially partial coal gasification were also evaluated. Results indicate that electric production in conjunction with coke production provides a significant economic benefit. Issues of the ability to produce electric ancillary services as part of the operation are also being considered.

In the proposed process, existing or planned coke production facilities would be used as part of the developmental process thereby reducing the process development risk as compared to construction of a dedicated test facility. The proposed process is based upon a design in which the risk and financing level required for development of an operating facility is reduced by developing the technology in conjunction with an operating or planned coking facility. The value of products, including liquid fuels, would be evaluated in comparison with conventional coke production operation. The amount of such products produced would be determined by optimizing the value of the various product streams. The process would adapt itself to changing market conditions. This would reduce the risk of developing new coal based liquid fuel production capability since the major capital expenditure, the gasifier, is already justified for conventional coke production. This technology can provide a knowledge base in the near term with significantly less cost than a dedicated gasification facility that could then be leveraged for the development of large scale dedicated gasification facilities.

A concept for a process for the sequestration of the carbon dioxide produced by the process was also identified. Preliminary investigations indicate that it may be possible to produce a usable chemical product as part of the carbon dioxide sequestration process by the use of a nano catalysis. A concept for using a nano catalyst to enhance the coke oven gas based Fischer-Tropsch process for the production of liquid transportation fuels is also being considered.

Importance to Indiana Coal Use

The central theme of this effort has been to find ways to increase the use of Indiana coal in coking and other related industrial operations in a way that increases overall value. By finding ways to increase the use of Indiana coal in such processes, imports of coal from sources outside Indiana will be decreased and there will be a potential to open new markets for Indiana coal.

A mine mouth coking/coal gasification facility will have many positive economic and employment effects for Indiana. This facility will be located in Indiana. Typically, a 1.3 million ton per year coke facility employs about 130 people. In addition, it is estimated that 13 new employees would be required in the Indiana mining industry. A new facility of the type considered would provide a significant employment opportunity for Indiana. Such a facility would allow the Indiana Coal Industry to open a new and expanding market. Metallurgical coal contracts increase by 20% to 40% in 2004.¹⁷ In 2002 Indiana imported 8.093 million tons of coking coal. The potential for use of Indiana coal for coke production for use in Indiana is between 2.0 and 3.6 million tons per year. Export potential is estimated to range from 6 to 11 million tons per year.¹⁸ Current coke production at Indiana Harbor facilities is 1.2 million tons per year screened. The proposed facility would be of a comparable size and would result in an estimated cost savings of at least 5 % for delivered coke due to reduced transportation costs and would meet a portion of future demand growth. It would also reduce imports of metallurgical coal by several million tons per year and replace it with coal produced in Indiana. There would also be a potential to export coke to adjacent States including Ohio, Kentucky, and Illinois. The sale of electric power from the cogeneration function would also result in a significant revenue stream to further enhance the benefit of the project.

Indiana's steel industry is a major employer, as well as significant sources of revenue to the State in the form of taxes. This project will help to assure the health of this vital industry, generate new jobs and revenue streams, and advance the technical state of the art by using Indiana coal and simultaneously reducing environmental emissions.

Environmental emissions are often cited as a reason why Indiana coal is not used in the production of coke. The proposed process presents a different option that inverts the classic coke production paradigm. This project has done preliminary work to develop a process in which clean coal technology is used at the mine mouth or at an industrial location to produce coke, rather than transporting coal from sources outside Indiana to non attainment areas for coke production. Gas streams from the coking process will be collected and used for subsequent production of electricity at the site or possibly the production of liquid transportation fuel. This process will result in a net transportation savings, as well as a value stream from cogenerated electricity. Such a facility will provide base load electric generation, but will also have the capability to supply shoulder and peaking power, in addition to, potentially ancillary services.

The U.S. coke industry has two primary product markets (i.e., furnace and foundry coke) that are supplied by two producing sectors—integrated producers and merchant producers.¹⁹ Integrated producers are part of integrated iron and steel mills and only produce furnace coke for captive use in blast furnaces. Therefore, much of the furnace coke is produced and consumed by the same integrated producer and never passes through a market. However, some integrated steel producers have closed their coke batteries over the past decade and purchase their coke supply from merchant producers or foreign sources. A small number of integrated steelmakers produce more furnace coke than they need and sell their surplus to other integrated steelmakers. In 1997, integrated producers accounted for roughly 76 percent of U.S. coke capacity with merchant producers accounting for the remaining 23 percent. These merchant producers sell furnace and foundry coke on the open market to integrated steel producers (i.e., furnace coke) and iron foundries (i.e., foundry coke). Some merchant producers sell both furnace and foundry cokes, while others specialize in only one.

Even though captive consumption currently dominates the U.S. furnace coke market, open market sales of furnace coke are increasing. As production costs increase, U.S. integrated steel producers increase their consumption of furnace coke from merchant coke producers, foreign imports, and other integrated steel producers with coke surpluses.

Merchant coke producers account for a small share of U.S. furnace coke production (about 12 percent in 1997); however, they account for 100 percent of U.S. foundry coke production. The U.S. foundry market appears to be fairly concentrated with two companies in 1997 accounting for almost 68 percent of U.S. production.

Figure 24 depicts the influence of cost factors and linkages in the market.²⁰ In general, captive coke plants supply their excess coke to the furnace coke market with remaining supply from merchant plants and foreign imports. Furnace coke produced at captive coke plants and shipped directly to integrated iron and steel mills owned by their parent companies do not directly enter the market for furnace coke. Environmental compliance costs incurred by captive, or “in-house”, furnace coke batteries indirectly affect the furnace coke market through price and output changes in the steel mill products market.

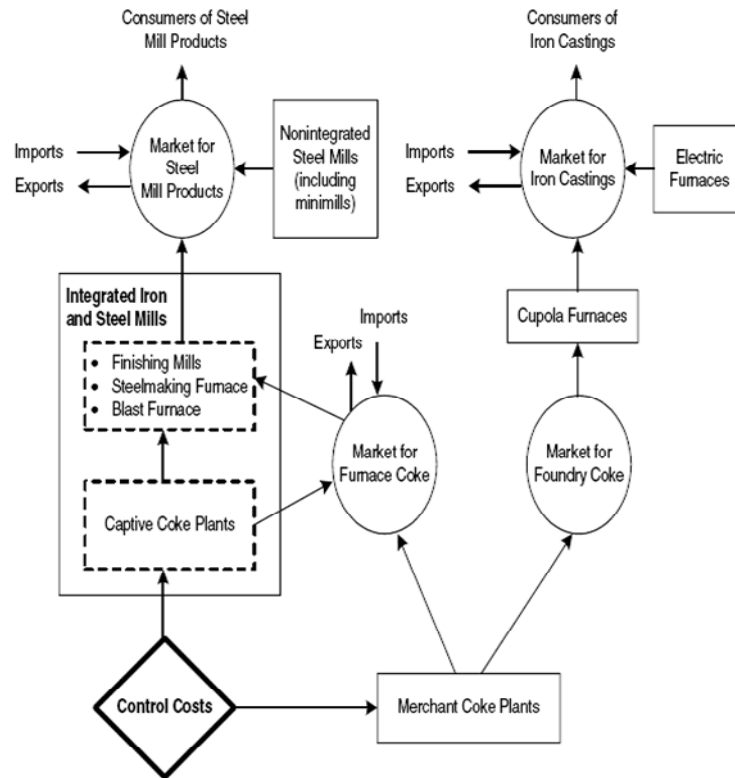


Figure 24: Coke Market Linkages

The research team for this proposal has extensive experience in the coking process, characterization of Indiana coal coking properties, electric generation, engineering, and system analysis. Major products from a facility using the proposed process will be coke, electricity, liquid transportation fuel, and potentially fertilizer and hydrogen. All are crucial to the economic future of Indiana. The locations of Indiana's coal mines provide many unique advantages for coke production.

One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m³ of coke oven gas²¹. From preliminary results it is estimated that from .1 - .25 barrels of liquid transportation fuel could be produced from each ton of coal used in the coking process. Currently Indiana uses approximately 8,000,000 tons of coal per year for the coke production. None of this is Indiana coal. Use of Indiana coal would also provide a financial incentive to the steel industry since Indiana coal is considerably less costly than current metallurgical coal. With a blend of from 20-40% Indiana coal significant coal cost reductions could be realized.

This proposal leverages experience from current coking facilities in Indiana. Additional research is required to extend these technologies for use in the proposed coking process, but the technical risk will be less than for a completely new experimental concept. Such an approach is made possible by the use of proven technology in the new coking paradigm of this research effort. This approach significantly increases the probability that an actual productive facility could be operational within a 5 year time frame.

The proposed coke production technology will provide many advantages over current production methods. These advantages will also be attractive both within and outside the United States. Due to current market shortages and the price volatility of coke internationally, there is an opportunity to market Indiana coal in a new way in the form of coke to a variety of new markets both within and outside Indiana.

Relevance to Previous Studies

Coal is an abundant energy resource that has been characterized by a variety of different groups. The availability of this resource provides many opportunities to displace other energy sources such as oil that have high price volatility and supply concerns. The following information from the Energy Information Administration characterizes the availability of coal resources²².

Total recoverable reserves of coal around the world are estimated at 1,083 billion tons — enough to last approximately 210 years at current consumption levels. Although coal deposits are widely distributed, 60 percent of the world's recoverable reserves are located in three countries: the United States (25 percent), FSU (23 percent), and China (12 percent). Another four countries—Australia, India, Germany, and South Africa—account for an additional 29 percent. In 2001, these seven countries accounted for 80 percent of total world coal production. Recoverable coal reserves and consumption are depicted in Figures 25 and 26 respectively.

World Recoverable Coal Reserves

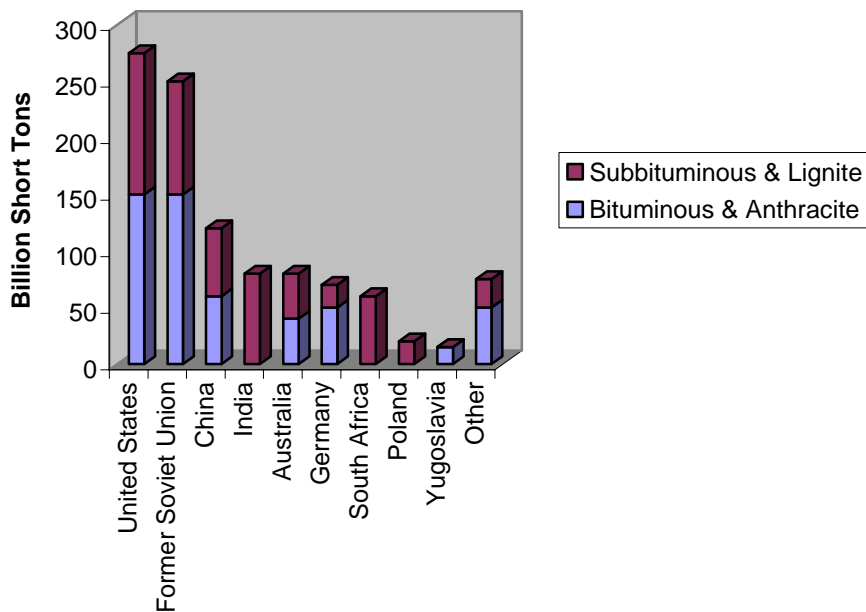


Figure 25: World Recoverable Coal Reserves

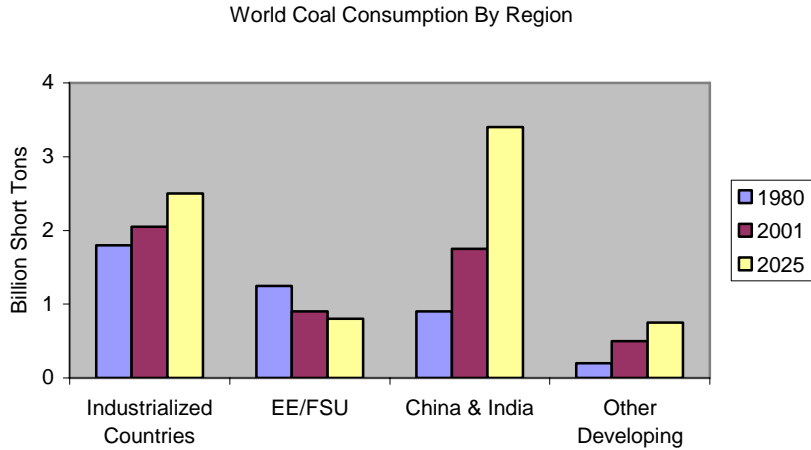


Figure 26: World Coal Consumption by Region, 1980, 2001, and 2025

As can be seen from the previous two figures, coal is an abundant resource and its use is anticipated to expand in the future. This expanding usage provides an opportunity to increase the use of Indiana coal for coking and other purposes. Figure 27 depicts World Coal Trade for 1985, 2002, and 2025²³ and also indicates specifically an increase in coke consumption.

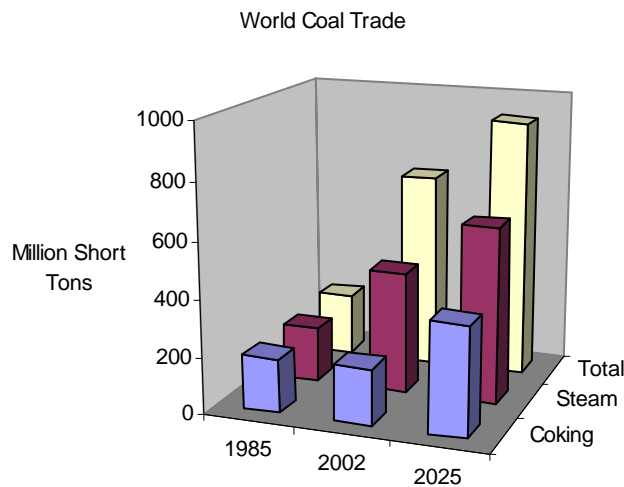


Figure 27: World Coal Trade, 1985, 2002, and 2025

Figure 28 depicts the relative amounts of U.S. coal imports and exports projected to 2025.²⁴ This figure indicates that there will be an increasing trend to import more coal relative to coal produced domestically. As the fraction of imported coal increases there

will be additional pressure placed on coking coal supplies. The proposed technology to use Indiana coal to produce coke could supplement the coal supply for coking purposes and enhance the future market for Indiana coal.

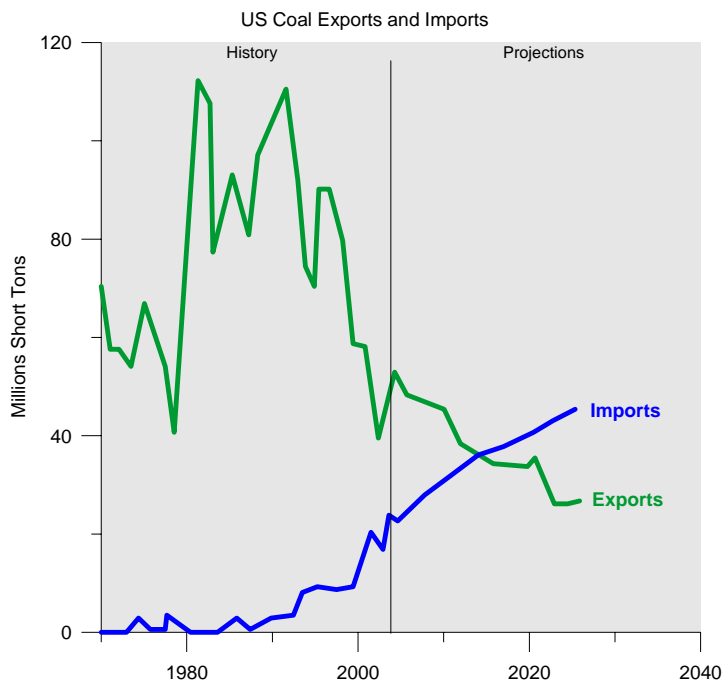


Figure 28: U.S. coal exports and imports, 1970-2025

In the early 1900s Indiana coal was used for coke production.²⁵ Technology and requirements have changed since this time, but it is now appropriate to again start using Indiana coal for coke production. To accomplish this it will be necessary to develop methods that alleviate issues with using Indiana coal for coke production and simultaneously add value to the process. This proposal presents an approach that is targeted at meeting these requirements.

The particular mix of high- and low-volatile coals used and the length of time the coal is heated (i.e., coking time) determine the type of coke produced: (1) furnace coke, which is used in blast furnaces as part of the traditional steelmaking process, or (2) foundry coke, which is used in the cupolas of foundries in making gray, ductile, or malleable iron castings.²⁶ Furnace coke is produced by heating a coal mix of 10 to 30 percent low-volatile coal for 16 to 18 hours at temperatures of 2,200°F. Most blast furnace operators use coke sized between 0.75 inches and 3 inches. Foundry coke is also produced by heating a mix of 50 percent or more low-volatile coal for 27 to 30 hours at temperatures of 1,800°F. Coke size requirements in foundry cupolas are a function of the cupola diameter (usually based on a 10:1 ratio of cupola diameter to coke size) with foundry coke ranging in size from 4 inches to 9 inches.²⁷ The longer coking times and lower temperatures required for foundry coke results in a longer life of these batteries.

As depicted in Figure 29, furnace coke accounts for the majority of coke produced in the United States.²⁸ In 2000, furnace coke production was roughly 17.7 million short tons, or 85 percent of total U.S. coke production, while foundry coke production was only 1.3 million short tons. Integrated iron and steel producers that use furnace coke in their blast furnaces may either produce this coke on-site (i.e., captive coke producers) or purchase it on the market from merchant coke producers.²⁹

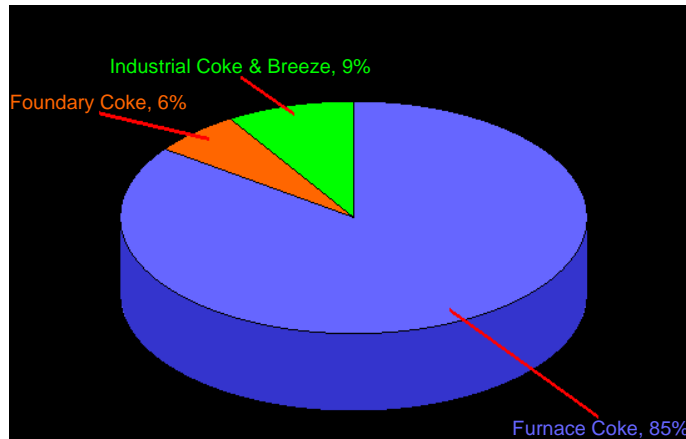


Figure 29: U. S. Coke Production by Type, 2000

Furnace coke also accounts for the majority of domestic coke usage.³⁰ Figure 30 depicts the world distribution of coals suitable for coke production.³¹ Figure 31 depicts world coke production capacity minus consumption. The dotted line in this figure is a minimum level taking into account scheduled and forced outages.³² It can be observed that the supply of coke is anticipated to increase slightly in the future above the base level in 2004, but will level off at a relatively low value. This will result in a situation of elevated price and need for additional supply. Coke produced from Indiana coal could serve to meet a portion of this demand.

Estimated World Recoverable Coking Coal

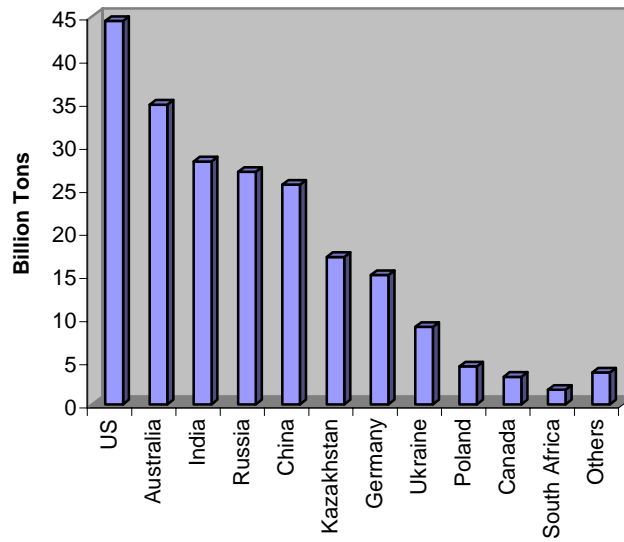


Figure 30: Estimated World Recoverable Coking Coal

World Coke Balance
(Capacity - Consumption)

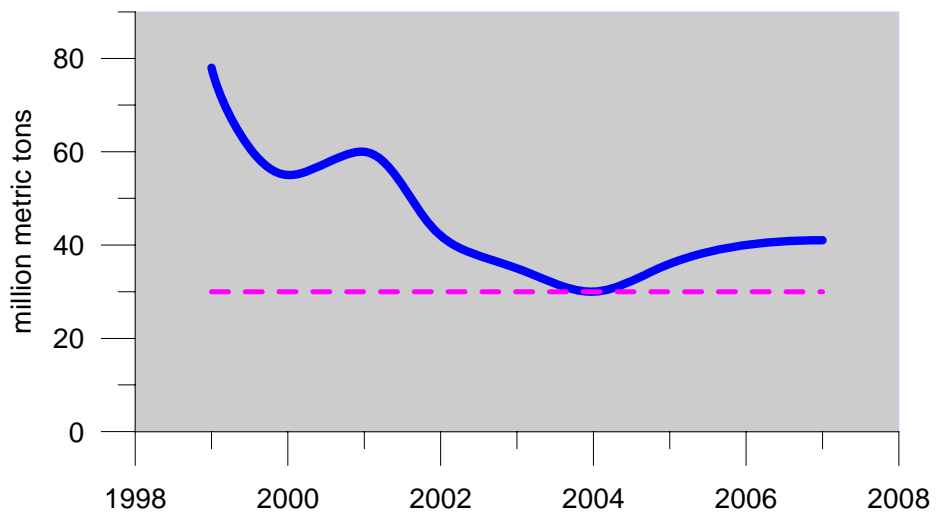


Figure 31: World Coke Balance (Capacity – Consumption)

Due to a variety of circumstances including the tightening of emissions regulations, the number of coke ovens is decreasing as can be seen in Figure 32.³³ This indicates that there is clearly a need for new environmentally friendly coking production capability. The proposed research would support the development of such capability using Indiana coal.

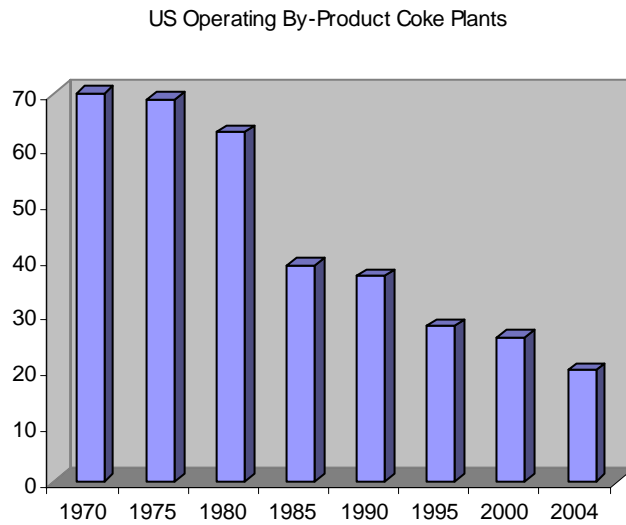


Figure 32: US Operating By-Product Coke Plants

In addition to decreasing numbers, a significant portion of the existing capacity is reaching end of life. Figure 33 depicts coke battery age at Mittal Steel.³⁴ This also supports the observation that there is need for new environmentally friendly coking production capability. As units reach the end of life, maintenance costs and outages increase dramatically.

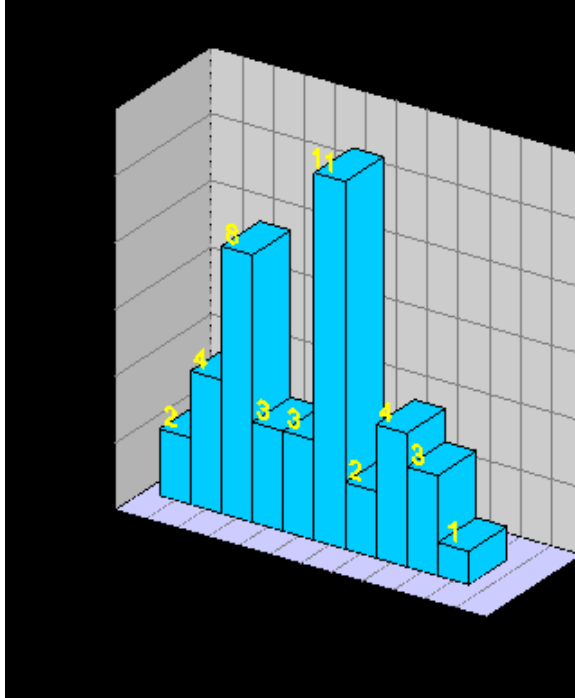


Figure 33: Battery Age – Mittal Steel

Figure 34 depicts the global production of coke³⁵ and Figure 35 depicts the global consumption of coke products. From this figure it is clear there is a need for new coke production capacity.³⁶ In general domestic supplies of coke are decreasing while international demand is increasing.³⁷ The estimated 2.2 billion tons of metallurgical reserves in the U.S. at an assumed consumption rate of 50 million tons per year would result in 40 years worth of recoverable reserves from currently operating mines. Using Indiana coal in the coking process described in this effort could improve economics and extend these reserves.

Competition from China also will increase pressure on domestic coke production facilities. China presently has capacity to produce 208.73 million metric tons of coke per year.³⁸ Of this 173.73 million metric tons is from slot ovens and the remainder from bee hive ovens. In 2004 China produced 193.7 million metric tons of coke and 50 million metric tons was exported.³⁹ Currently 180 coke ovens are being constructed in China with a combined production capacity of 60 million tons.

The price volatility experienced recently in China is a result of supply and export policies. In 2001 the cost of coke was \$80/ton FOB to a Chinese port. In 2040 it was \$410/ton. Currently it is \$200/ton.⁴⁰ In 2002 Chinese government decreased the number of coke export licenses to meet growing demand.⁴¹ It is anticipated that prices could stabilize at the \$200/ton level.⁴² This would provide a clear incentive for the construction of additional coke production capacity.

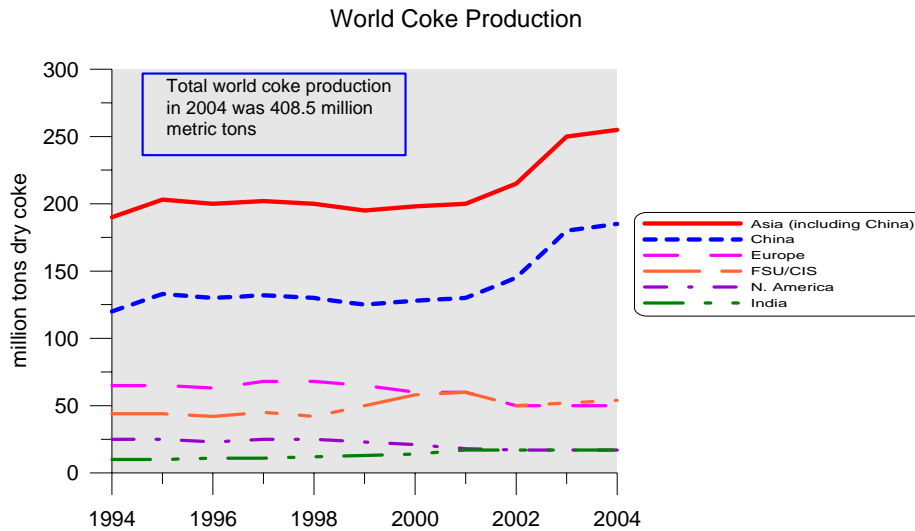


Figure 34: World coke production

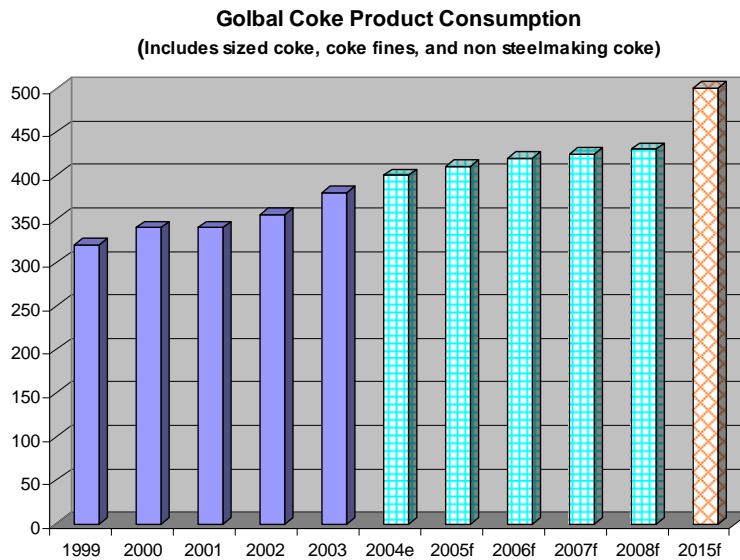


Figure 35: Global Coke Consumption

Producing combustible gases from solid fuels has been done since ancient times. Pyrolysis is a process in which feed material is heated with little air present. Synthesis gas is produced with partial oxidation of the feed material.⁴³ The coke oven was developed for the metals industry in order to provide a substitute for charcoal during the second half of the eighteenth century. Towards the end of the eighteenth century gas

was produced from coal by pyrolysis on a larger scale. In 1812 the London Gas, Light, and Coke Company commercialized gas production. The most important gas produced at this time was Town Gas. Town Gas can be produced by pyrolysis (producing gas with a heating value of 20,000- 23,000 kJ/m³) or by the water gas process (coke is converted into a mixture of equal parts of hydrogen and carbon monoxide with a heating value of approximately 12,000 kJ/m³).⁴⁴ Converting part or all of the carbon monoxide into hydrogen produces synthesis gas. This can then be used in Fischer-Tropsch processes for the synthesis of hydrocarbons or acetic acid anhydride. In this context, blast furnaces can be considered to be large gasifiers of coke.⁴⁵

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.⁴⁶ One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m³ of coke oven gas.⁴⁷

This hydrogen content is typically too high for use directly in Fischer-Tropsch processes. Methods to reduce this to the range of 2-4 to 1 hydrogen to carbon monoxide ratio, possibly by combining with syngas streams, will be considered. Other processes for removing various constituents from the gas stream including oil, sulfur, and naphthalene will also be considered.⁴⁸ It is also possible to adjust this ratio by blending various coals as was shown previously in Figures 6 and 7. Currently, an optimization scheme is under development that maximize both coke properties and pyrolysis gas composition.

Policy, Scientific and Technical Barriers

In the early 1900s Indiana coal was used for producing coke. As natural gas decreased in price and increased in availability along with decreasing energy costs in general, Indiana coal was used much less for industrial purposes. This also was the result of economics and environmental concerns and to some degree expediency in ramping up steel production levels.

Today, there have been considerable advances in coke oven, emissions control, catalysis, and other related technologies that provide an opportunity to gain operational and economic benefits by using Indiana coal in heavy industrial applications such as the production of coke for blast furnaces. This use will require reconsideration of blending and other process operational functions, but the benefit can be significant. Using tools such as multiple optimized blending strategies, it is possible to develop methods to significantly increase the level of Indiana coal that could be used to produce coke for blast furnace and other operations.

Issues regarding transportation of coke from central to south western Indiana will need to be considered further. It will be necessary to assure that transportation bottlenecks do not negate the benefits. Locating a coking facility at mine mouth will tend to reduce net transportation costs. Issues regarding local emissions requirement will need to be addressed further. Another option will be to utilize existing coke production facilities or new facilities at existing locations.

One byproduct of the proposed technology is electricity. It will be necessary to consider associated electric system issues in optimizing the value of generated. Issues regarding integration of the unit into a local control area will need to be addressed as well as any concerns with ancillary electric system services.

Since this technology has the potential to increase sales of Indiana coal as well as creating jobs, there may be possibilities to gain economic development incentives. There is also the possibility that coke markets can be established outside Indiana. Relationships at a state level will need to be arranged for such opportunities.

Further research and development is needed to develop the technology for the production of liquid transportation fuels through Fischer-Tropsch processes using pyrolysis gas. Research regarding coke oven gas composition, catalysis, processes to use the gas in Fischer-Tropsch processes, and system optimization will be required to assure the feasibility of the concept. Efforts to consider a demonstration at either a coal mine or an existing coke facility will need to be intensified in the future.

Conclusion

This study has shown that Indiana coal can become an important resource for the production of coke for the steel and other industries both inside and outside Indiana. As was noted in the study, currently there is a shortfall of 5.50 million tons of coke per year in the United States. This research effort has shown that Indiana coal can become one way to reduce current and future coke supply issues as well as reducing price by as much as 10%.

The significant shortfall of needed coke has placed an enormous strain on Indiana's steel and foundry industries. The need for additional coke production capacity is evident given plans for coke plant expansion being considered by Indiana's steel industry and others. The results of this study indicates that coke supply and high price volatility issues can be mitigated through the use of Indiana coal in a mine mouth or local, environmentally friendly, high efficiency multi purpose coke, liquid transportation fuel, fertilizer, and hydrogen production facility. Such a facility would also increase coke supply and production, while, at the same time, reducing the cost for Indiana's steel and foundry industry. In addition, such a high efficiency coking facility would produce electricity for sale to the wholesale electric market, thereby reducing costs and environmental emissions and, at the same time, enhancing electric system reliability. This project started in March 2006 and was completed in September 2007.

The following are major results from this study:

1. A mixture of Indiana Brazil Seam or potentially other Indiana coals, as previously identified by the Indiana Geological Survey, could be blended with other coals to meet metallurgical coke quality and emissions requirements.
2. There is interest in the coal and steel industry to consider establishing a coke production process at an Indiana coal mine or steel facility. Moreover, there may be an opportunity to consider the value of some emissions credits, due to the "clean coal technology" as well as the different geographic location.
3. The total transportation cost could be reduced, since the mass of the product coke is less than the coal needed to produce it and also because coke is less dense than coal. Thus, a significant cost savings from the reduced weight per mile of material being transported would result. Issues regarding the availability of transportation need to be considered before a final recommendation on location can be made.
4. Results indicate that it is highly likely that a coking/coal gasification process can be developed that would produce metallurgical grade coke using 20%+ Indiana coal and, at the same time, would produce a byproduct gas stream that would be usable in a cogeneration facility for the production of electricity to be sold in the electric market. By using a new blending approach that optimizes coke properties and pyrolysis gas composition it is possible to increase the percentage of coke

produced from Indiana coal blended with coke from other coals in blast furnace operations.

5. Preliminary results indicate that it is possible to utilize the pyrolysis gas generated from a coke oven feed with a blend of Indiana and other coal to produce electricity, liquid transportation fuels by means of a Fischer-Tropsch process, fertilizer, and hydrogen. It may be possible to enhance this process with nano catalysis technology. There are also indications that it may be possible to isolate carbon dioxide from the process and use it to produce a marketable chemical product with nano catalysis technology.

Indiana's steel and foundry industries are major employers, as well as significant sources of revenue to the State in the form of taxes. This technology will help to assure the health of these vital industries, generate new jobs and revenue streams through the use of Indiana coal at a facility to be located in Indiana, and advance the technical state of the art by using Indiana coal and simultaneously reducing environmental emissions.

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Appendix

Resumes

Robert A. Kramer, Ph.D.

Director, Energy Efficiency and Reliability Center
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Robert A. Kramer is currently a Professor in the Electric and Computer Engineering Department at Purdue University Calumet and Director of the Energy Efficiency and Reliability Center at Purdue University Calumet. In this role he is involved in the development of research programs in energy utilization and efficiency, electric power, reliability, electric transmission, renewable energy sources including hydrogen production from biomass, coal gasification for the production of liquid transportation fuels and fertilizer, energy optimization, and combined heat and power systems. He teaches various courses in Engineering and Physics.

Prior to coming to Purdue University Calumet he was the Chief Scientist for NiSource Energy Technologies and most recently was responsible for technical developments of new energy technologies including Combined Heat and Power Systems. He was at NiSource from 1973 until January 2004 and held the positions of Nuclear Fuel Engineer, Manager Applied Research, Manager Strategic Planning, Manager Technical Support, Director of Electric Engineering and Applied Research, Director of Electric Operations, Director of Electric Services, Vice President, and Chief Scientist. During this time, he also taught a variety of courses in Physics and Engineering at Purdue University Calumet and Indiana University Northwest.

Dr. Kramer has conducted a variety of energy and energy efficiency research and development projects and programs. These projects range from enhancing reliability of bulk electric transmission systems to high efficiency local generation sources utilizing Combined Heat and Power that generate electricity locally and use byproduct heat to achieve over 72% net system efficiency. Energy sources such as microturbines, reciprocating engines, fuel cells, solar, coal, and biomass are considered in this work. Current research efforts include: advanced control schemes utilizing neural networks and fuzzy logic in a feed forward configuration for industrial as well as commercial and building applications: wireless communications and control: production of liquid transportation fuels, fertilizer, coke, and bulk hydrogen from coal: biological production of hydrogen, control of large industrial loads to improve electric transmission system reliability: combined heat and power: and production of hydrogen from an aluminum-water process.

He has worked closely with various local and national industries in an effort to develop new concepts for process and energy modeling and optimization. He has also worked with the North American Electric Reliability Council on the development of

concepts and procedures for the monitoring and improvement of the reliability of the national electric transmission system. He has served as the principal investigator for three Department of Energy research contracts with a total value of over \$6,500,000 as well as being one of the co founders of the Center for Advanced Control of Electric Power Systems funded by the National Science Foundation and the Electric Power Research Institute. He currently serves as the principal investigator for research grants totaling approximately \$2.5M. He has also received a guest appointment to the Laboratory of Renewable Resource Engineering at Purdue University Lafayette, Indiana and is a member of the Executive Board of the Energy Center at Purdue University Lafayette.

He has participated in a variety of industry committees including the Coordination Review Committee (CRC) for the East Central Area Reliability Council (ECAR), the Research Advisory Committee (RAC) for the Electric Power Research Institute (EPRI), the Basic Science Committee of the Gas Research Institute, and the Control Criteria Task Force, Performance Sub committee, and other committees of the North American Electric Reliability Council. He is a former president of the Calumet Engineering Education Association.

He is a Senior Member of The Institute of Electrical and Electronics Engineers (IEEE) and The Association of Energy Engineers (AEE). He is also a member of the American Physical Society (APS), American Nuclear Society (ANS), American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), the Association of Iron and Steel Engineers (AISE), the American Institute of Aeronautics and Astronautics (AIAA), and the Sigma Pi Sigma physics honorary.

Dr. Kramer received a Ph.D. (1985) and M.S. (1979) in Nuclear Engineering from Purdue University, West Lafayette, Indiana, and B.S. (1971) and M.S. (1973) degrees in Physics, also from Purdue University, West Lafayette.

Dr. Kramer has published numerous papers regarding energy system design and efficiency, energy markets, electric system operation, reliability, and Combined Heat and Power. He also holds three patents. A listing of his publications and patents follows;

Publications

Kramer, R., "Optimization of the Energy Efficiency of a Parking Garage," accepted for publication in *Energy Engineering*, 2007.

Bowen, B., Irwin, M., Sparrow F., Mastalerz, M., Zuwei, Y., Kramer, R., "Clean Coal Initiatives in Indiana", *International Journal of Energy Sector Management*, 2007.

Kramer, R., "Using Energy Audits to Enhance Experiential Energy Education", *Energy Engineering*, 2007.

Kramer, R., "System Integration of Distributed Generation for Complete Building Systems, Final Report", National Renewable Energy Laboratory Report to be published in 2006.

Kramer, R., "Mine Mouth Coking/Coal Gasification Energy Optimization Study", *Proceedings of American Institute of Aeronautics and Astronautics 3rd International Energy Conversion Engineering Conference*, August 2005.

Kramer, R. "CHP System Dynamic Optimization in Conjunction with Renewable Resources", Proceedings of American Institute of Aeronautics and Astronautics 2nd International Energy Conversion Engineering Conference, August 2004.

Kramer, R., "System Integration of Distributed Generation for Complete Building Systems, report 2", National Renewable Energy Laboratory Report NREL/SR-560-35054, 2003.

Kramer, R., "System Integration of Distributed Generation for Complete Building Systems , report 1", National Renewable Energy Laboratory Report NREL/SR-560-34966, 2003.

Chang-Chien, L., Ong, C., Kramer, R., "Field Test and Refinements of an ACE Model", Institute of Electrical and Electronics Engineers Transactions on Power Systems, Vol 18, No. 2, May 2003.

Chang-Chien, L., Ong, C., Kramer, R., "Estimation of β For Adaptive Frequency Bias Setting in Load Frequency Control", Institute of Electrical and Electronics Engineers Transactions on Power Systems, Vol 18, No. 2, May 2003.

Kramer, R., Shoureshi, R., Thomas, H., "Intelligent Control for Optimal Hybrid Power System in Commercial Buildings", Second International Symposium on Distributed Generation Conference Proceedings, Stockholm, Sweden, October 2002.

Hoonchareon N., Ong C., Kramer R., "Feasibility of Decomposing Ace to Identify the Impact of Selected Loads on CPS1 and CPS2", Institute of Electrical and Electronics Engineers Transactions on Power Systems, Vol 17, No. 3, Aug 2002, pp 752-756.

Hoonchareon N., Ong C., Kramer R., "Implementation of an ACE Decomposition Method", Institute of Electrical and Electronics Engineers Transactions on Power Systems, Vol 17, No. 3, Aug 2002, pp757-761.

Hoffner B., Shoureshi R., Kramer R., "Feedforward Neural Fuzzy Control of Electric Power Sysdtems Containing Highly Varying Loads", in American Control Conference Proceedings, December, 2002.

Siriariyaporn V., Gotham D., Kramer R., Sparrow F., "Measuring the Cost of Providing the Regulation Ancillary Service with Highly Varying Loads", North American Power Symposium, ASU, May 2002.

Hoffner B., Shoureshi R., Kramer R., "Development of an Intelligent Automatic Generation Control System for Electric Power Plants", in International Mechanical Engineering Congress & Exposition Proceedings, 2002.

Shoureshi R., Hoffner B., Kramer R., "Neural-Based Generation Control for Highly Varying and Uncertain Loads", Power Tech Conference, Institute of Electrical and Electronics Engineers, Porto, Portugal, 2001.

Shoureshi R., Li H., Kramer R., Klaiman H., "Intelligent Control for Electrical Power Generation Systems", in Proceedings of the ASME Dynamic Systems and Control Division, DSC-Vol. 61, 1997.

Gaul S., McGill M., Kramer R., Compressed Air Energy Storage Offers Flexibility For Low Cost Providers of Electricity, in "Power-Gen 95 Proceedings", Anaheim , CA, December 1995.

Kramer R., "In the Midst of Change", Transmission and Distribution (magazine), January 1994.

Heydt G., Karipides D., Shoureshi R., Wheeler M., Kramer R., Stears M., "Active and Reactive Power Flow for Multi-area Systems on Automatic Generation Control in the Presence of Rapidly Changing Loads", Journal of Electric Machines and Power Systems, 1994.

Stears M., Heydt G., McGranaghan M., Wagenblast G., Kramer R., Samotyj M., "Characterizing Highly Varying Loads Associated With the Steel Industry", in 1993 Electric Power Research Institute Power Quality Conference proceedings, San Diego, California, November 1993.

Douglas L., Green T., Kramer R., "New Approaches to the AGC Non-conforming Load Problem, in IEEE-PICA'93 Conference Proceedings, Phoenix Arizona, May 1993.

Kramer R., "Maintaining Power Quality and Reliability in a Changing Environment", in VI Latin IVERO American Conference on Operations Research proceedings, Mexico City, Mexico, October 1992.

Kramer R., "Changes in the Electric Utility Industry will Provide Increased Engineering Challenges as Well as Benefits", Transmission and Distribution (magazine), January 1992

Kramer R., "Analytic and Operational Consideration of Electric System Reliability", in Iron and Steel Exposition proceedings, Pittsburgh, Pennsylvania, September 1991.

Kramer R., "Electric System Reliability in a Changing Utility Environment", in American Power Conference proceedings, Chicago Illinois, April 1991.

Kramer R., "Maintaining Industrial Power Quality in a Changing Utility Environment", in 1991 Annual Reliability and Maintainability Symposium proceedings, Orlando, Florida, January 1991.

Kramer R., Jacobs R., "Weathering-Steel H-Frames Support New 345-KV Line, Transmission and Distribution (magazine), June 1990.

Kramer R., "Consideration of Heavy Industrial Load in Regard to Electric System Reliability", in American Power Conference proceedings, Chicago, IL, April 1990.

Kramer R., "Improving Transmission Line Reliability", in T&D World Expo 90 proceedings, Indianapolis, IN, March 1990.

Kramer R., Adams T., "Power-Quality Program Detects Substation Problems", in T&D World Expo 90 proceedings, Indianapolis, IN, March 1990.

Kramer R., Adams T., "Evaluation of Substation Physical State by use of Harmonic and Transient Monitoring Equipment", in American Power Conference proceedings, Chicago, Illinois, April 1989.

Kramer R., Vance R., "Automated Construction Budget With Cost Benefit Prioritization", in American Power Conference proceedings, Chicago, Illinois, April 1989.

Kramer R., "Time Dependent Behavior of Distribution Systems Containing Repairable Components", in Second International Symposium on Probabilistic Methods Applied to Electric Power Systems proceedings, Oakland California, September 1988.

Kramer R., "Consideration of Time Dependent Failure Rates in the Analysis of Electric Distribution and Liquefied Natural Gas Storage Systems", in 14th Inter-RAM Conference for the Electric Power Industry, Toronto Canada, May 1987.

Kramer R., "Application of Probabilistic Risk Assessment to the Analysis of Gas System Reliability", in 1986 International Gas Research Conference proceedings, Toronto, Canada, September 1986.

Kramer R., "Application of Probabilistic Risk Assessment Techniques to Electric Power Systems", in International Symposium on Probabilistic Methods Applied to Electric Power Systems proceedings, Toronto, Canada, June 1986.

Kramer R. and Gailar O., "Influence of Generating System Reliability on Power Plant Operations Decisions", in 12th Inter-RAM Conference for the Electric Power Industry proceedings, Baltimore, Maryland, April 1985.

Kramer R. and Gailar O., Sensitivity of Alternative Nuclear Fuel Cycles to Plant Operating Conditions, in "Electric Power Utility Research Conference Proceedings", Midwest Energy Research Consortium, Chicago, Illinois, 1984.

Kramer R. and Gailar O., "Application of Computer Graphics to Safeguards and Security Analysis", Journal of the Institute of Nuclear Materials Management, Fall 1981.

Kramer R. and Gailar O., "Isotopic Inventory Prediction Employing A Monte Carlo Dancoff Factor", Journal of the Institute of Nuclear Materials Management, Fall 1980.

Kramer R. and Gailar O., "Improved Isotopic Inventory Prediction Methods", Journal of the Institute of Nuclear Materials Management, Spring 1979.

Kramer R. and Gailar O., "A Modification of the LEOPARD Computer Program in Order to Improve Isotopic Inventory Prediction Accuracy", Journal of the Institute of Nuclear Materials Management, Fall 1978.

Patents

US Patent No. 6,757,591 B2, Energy Management System and Methods for the Optimization of Distributed Generation, 6/29/2004.

US Patent No. 4,646,940, Method and Apparatus for Accurately Measuring Volume of Gas Flow as a Result of Differential Pressure, 3/3/1987

US Patent No. 4,914,275, Regasifier, 4/3/1990

Libbie S. W. Pelter
Assistant Professor, Chemistry
Purdue University Calumet

Education:

Ph.D. Organic Chemistry, University of California at Berkeley
Research Advisor: Dr. K. Peter C. Vollhardt.

Recent Appointments:

2005-Summer University of Nebraska-Lincoln

Research Assistant Professor of Chemistry, Department of Chemistry

- Collaboration with Professor James Takacs

2003-Present Purdue University Calumet

Assistant Professor of Chemistry, Department of Chemistry and Physics.

- Director, Undergraduate Research Program (8/03-5/05)

2001-2003 Purdue University Calumet

Professional Development Specialist, School of Engineering, Mathematics and Sciences

- Assistant Dean (1/03-7/03)
- Coordinator, Undergraduate Research Program
- 0.25 FTE Department of Chemistry

1999–August 2000 Center for Nanoscale Science and Technology Rice University

Research Scientist/Postdoctoral Fellow

- Research Director: Dr. James M. Tour
- Preparative combinatorial routes to thousands of precise conjugated oligomers

Research Interests:

Development and evaluation of transition metal catalysts useful in carbon-carbon bond forming reactions with improved TON and TOF. Solid-phase organic synthesis and metal mediated carbon-carbon bond forming reactions for the synthesis of conjugated oligomers. These highly conjugated organic molecules are of interest in molecular electronic applications and the construction of nanoarchitectures. Organic synthesis using microwave heating.

Selected Publications and Presentations:

Takacs, J. M.;* Venkataraman, S.; Andrews, R. N., "N-Heterocyclic Carbene–Palladium Catalysts for the Bisdiene Cyclization-Trapping reaction with Sulfonamides under Thermal and Microwave Conditions," *J. Organomet. Chem.*, accepted 31 August 2005 (available on line)

Michael W. Pelter, Libbie S. W. Pelter, Dusanka Colovic, Regina Strug, "The Microscale Synthesis of 1-Bromo-3-chloro-5-iodobenzene: An Improved Deamination of 2-Chloro-4-bromo-6-iodoaniline," *J. Chem. Ed.*, **2004**, 81, 111.

J. M. Takacs and L. Pelter, "Formation of C-C Bonds by Electrocyclic Reactions", in Houben-Weyl Stereoselective Synthesis E 21; G. Helmchen, F. W. Hoffman, J. Mulzer and E. Schaumann, ed.; Georg Thieme Verlag: New York, 1995; Vol. E 21 d; pp. 3833-49.

Libbie S. W. Pelter*, Brian Heiberger, Solomon Brown, and Michael W. Pelter*, "Synthesis and coupling of halogenated benzene compounds useful in the construction of nanoelectronic components", Presented at the 230th ACS National Meeting, Washington, D.C., Aug.-Sept. 2005.

Kenneth R. Berg (Dr. Libbie Pelter), "Suzuki Couplings for the Synthesis of Nanoscale structures with Applications in Molecular Electronics" NCUR 2004: 18th National Conference on Undergraduate Research, Indianapolis, IN, April 15-17, 2004.

Regina J. Strug, Ken R. Berg, Amy S. Gorcowski, Stacy L. Snyder, and Solomon E. Brown (Dr. Libbie Pelter, Dr. Michael Pelter), "Combinatorial Approach to Organic Synthesis of Nanoelectronic Components" NCUR 2004: 18th National Conference on Undergraduate Research, Indianapolis, IN, April 15-17, 2004.

M.W. Pelter*, L.S.W. Pelter*, R. Strug, K. Berg, A. Gorcowski, "Combinatorial Screening of Reagents and Catalysts in Homogeneous Metal Mediated Cross-Coupling Reactions" National Organic Symposium, American Chemical Society, Bloomington, IN, June, 2003.

HARVEY ABRAMOWITZ

Purdue University Calumet

(219)989-2473 Ph

Areas of Research Interest

- Cryogenic treatment of tool steels
- Application of new experimental techniques to fatigue testing
- Treatment of metal bearing wastes for metal recovery
- Development of nonpolluting processes for metal production

Professional Experience

Academic Appointments

2003-present	Professor , Department of Mechanical Engineering, Purdue University Calumet. Responsible for all courses in Materials Science and Metallurgy. Also teach Introduction to Engineering Design and a course in Solid Waste Management.
1993-2003	Associate Professor , Department of Engineering. Developed a post baccalaureate program in Iron and Steel Metallurgy. In 1999, a group of 10 engineers from Hadeed Steel Company, Saudi Arabia were the first to complete the program.
2000-2002	Visiting Professor , Department of Materials Science – Steel Research Center, Northwestern University. Participated in freshman and upper level design courses. Learned techniques in the computer design of alloys.
1991	Summer Fellow , Faculty Research Participation Program, Chemical Technology Division, Argonne National Laboratories, Lemont, IL. Theoretical work on thermodynamic analysis of new treatment method for disposing of the metal wastes from the Integral Fast Reactor.
1988-1993	Assistant Professor , Department of Engineering, Purdue University Calumet
1987-1988	Visiting Assistant Professor , Department of Engineering, Purdue University Calumet
1987	Adjunct Associate Professor , Department of Metallurgy, University of Missouri, Rolla, MO. Developed and taught course entitled "Metallurgical Plant Design and Economics."
1986	Visiting Scholar , Department of Metallurgy, University of Missouri, Rolla, MO. Developed research projects for the recovery of the metal content from waste materials.
1979-1980	Research Assistant , Department of Mineral Engineering, Columbia University, New York, NY. Laboratory instruction of extractive metal lurgy. Designed and built equipment for use in pyrometallurgical experiments.

Engineering Appointments

- 1985-Present **President**, A₂Z Consultants, Inc., Chicago, IL.
Consultant mainly in the application of mineral processing and extractive metallurgy to treatment of metal bearing wastes (both hazardous and nonhazardous) for metal recovery.
- 1980-1985 **Research Engineer**, Inland Steel Company, East Chicago, IN. Member of iron-bearing materials and refractories group of the raw materials and primary processing division, responsible for recovery of iron from iron-bearing waste oxides with particular emphasis on treatment of materials containing zinc.

Education

- EngScD(1983) Columbia University, New York, NY
Extractive Metallurgy and Mineral Engineering
- MS (1975) Extractive Metallurgy and Mineral Engineering
- BS (1972) Materials Science

Professional Honors:

- Association for Iron and Steel Technology
Foundation Grant Professor 2004-present
- Iron and Steel Society Foundation Grant Professor, 2002-2004.
- Frances Rhodes Prize – Columbia University, 1972.

Professional Memberships and Offices:

- Iron and Steel Society (ISS)
- Education Committee/University Relations Committee 1990-present
 - Co-Chairman 1991-1995
 - Chairman Jerry Silver Award Committee 1992-1996
 - Research in Progress Session Chair 1988,1991,2001
 - Continuing Education Committee 1996-present
- ASM, International
- Calumet Chapter
 - Chairman 1992-1993,2001-2002
 - Vice Chairman 1991-1992,2000-2001
 - Chairman Education Committee 1988-1991
 - Board of Directors 1988-present
- Institute of Briquetting and Agglomeration (IBA)
- Board of Directors 1987-present
 - Jerry Rice Award Committee 1993-present
 - Award for best paper at IBA Conference
- The Materials Society (TMS)
- American Society for Engineering Education (ASEE)
- Campus Representative 1994-1995
- Sigma Xi
- American Foundry Society (AFS)

Publications

Abramowitz, H., Bennett III, R.E., Bennett, J.H., Hendrickson, R.J., Koulourides, C.,

Kucharski, W., and Tredway, B.W., "Load Testing of Temporary Structural Platforms," Proceedings of ASEE Annual Conference, Montreal, Canada, June 2002.

Abramowitz, H., Bennett III, R.E., Bennett, J.H., Hendrickson, R.J., Koultourides, C., Kucharski, W., and Tredway, B.W., "Load Testing of Temporary Structural Platforms," National Educators' Workshop New:Update 2001 Standard Experiments in Engineering, Materials Science, and Technology, University of Maryland, College Park, MD, June, 2002, pp.413-434.

Bennett III, R.E, Abramowitz, H., Bennett, J.H., Hendrickson, R.J., Koultourides, C., Kucharski, W., and Tredway, B.W., "The Static and Dynamic Loading on Scaffolding Planks," Eighth International Conference on Composites, Tenerife, Spain, August 2001, pp. 75-76.

Abramowitz,H. "Mechanical Properties of Sheet Steels Used in Stamping and Drawing," National Educators' Workshop New:Update 99 Standard Experiments in Engineering, Materials Science, and Technology, Dearborn and Auburn Hills, MI, October 2000, pp.391-421.

Abramowitz,H. "Use of Piezoelectric Crystals for Voice Recognition," National Educators' Workshop New:Update 98 Standard Experiments in Engineering, Materials Science, and Technology, Brookhaven National Laboratory, NY, October, 1999, pp.379-392.

Kin,Y., Abramowitz,H., Hentea,T., Higley,J., and Richards,J., "Laboratory Measurement of J-Integral," National Educators' Workshop New:Update 98 Standard Experiments in Engineering, Materials Science, and Technology, Brookhaven National Laboratory, NY, October, 1999.

Kin,Y., Abramowitz,H., Hentea,T. and Xu,Y., "Life Estimate Based on Fatigue Crack Propagation," National Educators' Workshop New:Update 97 Standard Experiments in Engineering, Materials Science, and Technology, November, 1997, Seattle, WA, pp.369-380.

Kin,Y., Hentea,T., Abramowitz,H., and Xu,Y., "Theoretical and Experimental Investigation of Fatigue Crack Propagation in Laminates for Aircraft Canopies," Fourth International Conference on Composites Engineering, July, 1997, Hawaii, pp.537-538.

Bennett III,R., Abramowitz,H., Wright,J. and Boynak,D., "Pull-out Depth of Composite Reinforcing Bars in Concrete," Fourth International Conference on Composites Engineering, July, 1997, Hawaii, p.176.

Abramowitz,H., Hentea,T., Kin,Y., and Xu,Y., "Fatigue Investigation of Polycarbonate Used for Aircraft Canopies," Proceedings of the Fourth International Colloquium on Aging of Materials and Methods for the Assessment of Lifetimes of Engineering Plant, Cape Town, South Africa, April, 1997, pp.309-317.

Abramowitz, H., Hamling, J.W., and Landreth, R.R., "Inland Fixation Process," Proceedings of the National Research & Development Conference on the Control of Hazardous Materials, sponsored by the Hazardous Materials Control Research Institute, Feb. 20-22, 1991, Anaheim, CA, pp.439-442.

Chen, Y., Ricketts, J., Hevezi, J., and Abramowitz, H., "Expert System for Blast Furnace Operation," Proceedings of the 3rd International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems, Industrial and Engineering Applications/Artificial Intelligence Engineering-90, July 15-18, 1990, Charleston, SC, 8 pps.

Abramowitz, H. and Balajee, S.R., "Recycling of Zinc-Bearing Steelmaking Dust Through Micro-Pelletizing and Pot-Grate Sintering," Proceedings of the 20th Biennial Conference, Vol. 20, Institute of Briquetting and Agglomeration, Orlando, FL, September, 1987, pp.65-80.

Abramowitz, H., Gaffney, L. J. and Ziegert, W. L., "Taphole Mix Properties and Performance for the First Year of Operation on Inland's No. 7 Blast Furnace," Ironmaking Proceedings, Vol. 42, Iron and Steel Society of the American Institute of Mining, Materials, and Petroleum Engineers, 1983, pp.681-694.

Abramowitz, H. and Rao, Y. K., "Direct Reduction of Zinc Sulphide by Carbon and Lime," Transactions/Section C, Institution of Mining and Metallurgy, Sept. 1978, Vol. 87, pp. C180-188.

Abramowitz, H., Insinga, R. and Rao, Y. K., " Kinetics of Sulfur Dioxide with Carbon," Carbon, 1976, Vol. 14, pp.84-86.

CHENN QIAN ZHOU

PURDUE UNIVERSITY CALUMET

Chenn Zhou received her B.S. and M.S. in Power Engineering from the Najing University of Aerospace and Aeronautics. In 1991, She was awarded a Ph.D. in Mechanical Engineering from Carnegie Mellon University. She had three years of industrial experience before joining the PUC faculty in 1994. She is currently Professor of Mechanical Engineering and the Graduate Coordinator in the Department of Engineering.

Professor Zhou teaches undergraduate and graduate courses in the areas of CFD, combustion, air pollution control, fluid dynamics, and heat transfer. Her main research areas include multiphase reacting flow modeling, energy utilization as well as pollutant formation and control. She has collaborated with many experts from academia, research organizations, and industry and conducted a number of funded research projects. Since 1995, she has participated in several projects at Argonne National Lab. Her specialization in Computational Fluid Dynamics (CFD) has enabled her to help regional and national corporations for enhancing their economic standing in manufacturing. She has conducted a number of projects funded by federal and state government agencies and companies. In 2003, Dr. Zhou received a \$1.29 million grant from the Indiana 21st Century Research and Technology Fund for developing a CFD modeling system for steel blast furnaces. She has published over 100 technical papers and received several awards including University Outstanding Teacher and Researcher in 1999 and Outstanding Northwest Indiana Researcher, Northwest Indiana Chapter of Sigma Xi in 2001. Recently, she was elected a Fellow of The American Society of Mechanical Engineers (ASME) International.

Selected Publications

- Chang, S.L. and C.Q. Zhou, "Combustion and Thermodynamics", Article Number NRGY 00087 in *Encyclopedia of Energy*, Elsevier, Volume 1. 2004
- Vernengo, S., R. Milanovic, C.Q. Zhou, P. Chaubal and D. Huang, "Computations of

- Liquid Flow and Heat Transfer in the Hearth of a Blast Furnace”, *IMECE2003-55504*, Proceedings of 2003 ASME International Mechanical Engineering Congress and Exposition, Washington, D.C., November 15-21, 2003
- Chang, S.L. and C.Q. Zhou, "Simulation of FCC Riser Multiphase Heat Transfer and Cracking Reactions", *Computational Mechanics*, 31, 519-532, 2003
 - Chang, S.L., B. Golchert, C.Q. Zhou, and M. Petrick, “An Investigation of the effects of Firing Patterns on Heat Transfer and NO_x Formation in A Glass Furnace,” Proceedings of the 35th National Heat Transfer Conference, NHTC2001-20235, Anaheim, Cal. (June 10-12, 2001).
 - Chang, S.L., C.Q. Zhou, S.A. Lottes, and M. Petrick, “Numerical Evaluation of Advanced Multi-stage FCC Units,” HTD-Vol.367:69-78, International Mechanical Engineering Congress and Exposition, Orlando, FL (November 5-10, 2000).
 - Chang, S.L., S.A. Lottes, and C.Q. Zhou, Computational Fluid Dynamics Applications, *Energy 2000: State of the Art*, Edited by P. Catania, Balaban Publishers, L’Aquila, Italy, pp.299-324 (2000).
 - Su, K. and C.Q. Zhou, "Numerical Study of Spray Parametric Effects on Gas Turbine Combustion Performance", HTD-Vol. 364, Proceedings of the ASME Heat Transfer Division 2:345-354, International Mechanical Engineering Congress and Exposition, Nashville, TN, November, 1999
 - Zhou, C.Q., L.G. Neal, R. Bolli, J. Haslbeck, and A. Chang, "Control of NO_x Emissions by NO_x Recycle Approach", *The 26th Symposium (International) on Combustion*, Vol. 2, pp2091-2098, Combustion Institute, 1996
 - Zhou, Q. S.C. Yao, T. Russell and J. Boyle, "Flue Gas NO_x Reduction Using Ammonia Radical Injections", *Journal of Air Waste & Management Association*, Vol.42, No.9, pp.1193-1197, Sept., 1992.
 - Zhou, Q. and S.C. Yao, "Group Modeling of Impacting Spray Dynamics", *International Journal of Heat and Mass Transfer*, Vol. 35, No.1, pp.121-129, January, 1992

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EDUCATION:

Ph.D. Geology, Boston University, Boston, Massachusetts, 1976

M.A. Geology, Bryn Mawr College, Bryn Mawr, Pennsylvania, 1972

M.Sc. (Tech.) Applied Geology, Nagpur University, Nagpur, India, 1968

EXPERIENCE:

Current: Consultant to steel mills, coal companies and coke plants in USA., China, India, and various other countries around the world.

September 1979-June 2002: Staff Scientist, Ispat Inland Inc. (earlier Inland Steel Company), R & D Laboratories, East Chicago, IN, USA.

August 1978-May 1979: Assistant Professor, Geology Dept., Oberlin College, Oberlin, Ohio.

January 1978-May 1978: Visiting Assistant Professor, Geology Dept., Case Western Reserve University, Cleveland, Ohio.

May 1976—November 1977: Post Doctoral Fellow, Boston University, Boston, Massachusetts.

EXPERTISE:

Blend designs for non-recovery and slot oven cokemaking; Research on carbonization behavior of coal in non-recovery and slot oven cokemaking; Prediction of coke quality for non-recovery and slot oven cokemaking; Extensive knowledge of Chinese nonrecovery and slot oven plants; Modification of Chinese beehive cokes for blast furnace usability; Use of reverts in cokemaking, ironmaking, and steelmaking; Research in understanding coke behavior in blast furnace through tuyere coke sampling; Coal behavior in blast furnace pulverized coal injection; Coal selection for PCI.

AWARDS AND HONORS:

Iron and Steel Society's Joseph Becker Award, 1999, ("Distinguished Contributions in the Field of Coal Carbonization and Coal Technology").

American Iron and Steel Institute President Medal, 1989, ("Outstanding Paper Published in 1988-1989").

Eminent Visitor Program – sponsored by CCSD/CSIRO, Australia, Feb. 10, 2003- Feb. 21, 2003.

Key Note Lecture, 2001, 3rd Ironmaking Conference, Instituto Argentino De Siderurgio, Buenos Aires.

Organized a special three part session entitled "Use of Coal in the Steel Industry" at the 11 th Annual Pittsburgh Coal Conference, Pittsburgh, PA, September 12-16, 1994; followed by a special two part session on "Coal Use in Steel Industry" for the 13th Annual Pittsburgh Coal Conference, Pittsburgh, PA, September 3-7, 1996.

Sigma Xi – The Scientific Research Society of North America (National Research Honor Society) Grant Award, 1975.

Gold Medal, 1966, Nagpur University, Nagpur, India.

American Men and Women of Science.

TECHNICAL COMMITTEES:

Program Committee Member, Ironmaking Division, Iron and Steel Society, 1995-present.

Joseph Becker Award Committee Chairman, Iron and Steel Society, 2001-present.

American Iron and Steel Institute Technical Committee on Coke Oven Practice Member, 1995-2001.

American Iron and Steel Institute Tall Oven Task Group Member, 1988-1990.

McMaster University, Coordinating Committee Member, Cokemaking Course, 1999.

McMaster University, Coordinating Committee Member, Cokemaking Course, 1997.

American Iron and Steel Institute Direct Steelmaking Process Consultant, Coal Selection, 1989.

TECHNICAL SESSIONS CHAIRED:

- 19)Valia, H. and Best, M., Cokemaking, ISSTech 2003, ISS Conference, Indianapolis, IN, April 28, 2003.
- 18)Valia, H. and Best, M., Special Session on Coal, ISS Ironmaking Conference, Nashville, TN, March 11, 2002.
- 17)Valia, H. and Williams, H., Coal Market & The Steel Industry, ISS Ironmaking, Conference Baltimore, MD, March 27, 2001.
- 16)Valia, H. and Ellis, C., Coal & Coke Research, ISS Ironmaking Conference, Pittsburgh, PA, March 27, 2001.
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- 14)Valia, H., Intensive Course on Cokemaking, McMaster University, Hamilton, Canada, May 11, 1999, AM Session.
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- 2003 – Cokemaking Course, McMaster University
- 1999 - Coke Production, Blast Furnace Ironmaking, McMaster University
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