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

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Introduction

Although coke is an absolutely essential part of iron making and foundry processes, currently there is a shortfall of 5.50 million tons of coke per year in the United States. The current shortfall of this critical raw material is being filled by imports, mainly from China and, to a lesser extent, from Japan. The result of the shortfall internationally has been that recent coke prices have risen sharply. 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 with considerable volatility.

The significant shortfall of needed coke has placed an enormous strain on Indiana's steel industries. A resolution and/or mitigation of this formidable problem through the use of Indiana coal in a mine mouth, 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. 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.

Expansion of the capability to produce coke is being planned by Indiana's steel industry and at present essentially all of the coal used in the coking process is imported from outside Indiana. This proposal addresses a new concept for producing coke that would use Indiana coal as the main feed stock.

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] Most of this coking coal comes from West Virginia and Virginia.

Recently it has been reported that a subsidiary of the Russian steel giant, OAO Severstal plans to invest $140M to rebuild aging coke ovens at the Wheeling-Pittsburgh Steel Corporation's Follansbee site.[3] After the renovation, Severstal plans to retain 50% of the coke output for their use. Such an investment by an international steel producer is an indication of the crucial nature of coke for the steel industry. The proposed research provides a path for Indiana coal to be an active participant in this highly profitable expanding market. The approach will involve not the rebuilding of an aged technology, but the development and utilization of a cutting-edge technology that will be especially relevant for the future of the industry.

This proposal seeks to conduct research that will lead to the development of a mine mouth coking/coal gasification concept that will use Indiana coal. Initially, a feasibility and conceptual study will be conducted to determine major issues and technology for the proposed coking concept. Additional funding will be pursued as part of the initial proposal to conduct a detailed study that will be targeted at developing a plan for actual construction of a coking facility in Indiana within 5 years. Federal and other funding sources; will be pursued to leverage the funding from this proposal. It is anticipated that additional funding sources could include Department of Energy, Environmental Protection Agency, Steel Industry, Coal Industry, Electric Utilities, Independent Power Producers, and coal agencies of neighboring States.

Key Considerations and Current Research Results

1. The coal used for the 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.

   Indiana coal when converted to coke has less strength than coke produced from conventional metallurgical coal. This decreased strength results in a smaller particle size of 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 use of coke produced from Indiana coal in various industrial processes is under way. One effort is preliminarily considered concepts for how current Computational Fluid Dynamic Research efforts for blast furnace hearth modeling could be extended to increase the use of coke produced from Indiana coal in the steel making process. Computational fluid dynamics (CFD) simulation has become a cost-effective tool that can provide detailed information on flow properties and that can be used to conduct extensive computer experiments for design and optimization of flow systems. 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. A formal CFD coke research effort could significantly extend this use.

Research efforts regarding blast furnace Computational Fluid Dynamics (CFD) at Purdue University Calumet, currently funded by the 21st Century Fund at $1.29 million, will be leveraged to provide additional support for this proposal. Preliminary concepts for the inclusion of CFD technology in mine mouth coking processes, as well as the use of the produced coke in blast furnace operations, will be considered. Due to the physical characteristics of Indiana coal[4], 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. The use of CFD analysis will assist in maximizing the applicability and value of coke generated from Indiana coal.

Detailed CFD studies could be done in a follow on concept design study. It is anticipated that such a detailed study would develop a computational fluid dynamics (CFD) model to analyze and predict thermal, chemical, and physical phenomena for optimizing the coke/cogeneration process. The CFD simulations can be used to (1) provide fundamental insights of the process (2) investigate the impact of key operation and design parameters on process performance and (3) scale-up and optimize the process.

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

	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 I. Examples of Coke Quality

Currently one steel manufacturer has agreed to test coal samples at their laboratory as a means of initially assessing the suitability of Indiana coal for coking and other production purposes. A sample of Brazil seam coal is being obtained from an Indiana coal mine for this testing. This testing will consist of determining ash, sulfur, moisture, volatile materials, and a histogram.

It is anticipated that it may be possible to obtain exploratory analyses of Indiana Coal samples at little or no cost as part of this research. Currently preliminary discussions have been held to investigate this possibility. Should such testing become available the tests will be selected from the menu depicted in Table II.

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. Rehological Properties
a. Gieseler Plastometry (fluid characteristics)
b. Arnu Dilatatio (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 II: Possible Coal Tests

Various industry contacts were established to obtain background for the project. Two coal mines were contacted and coal samples have been requested. One mine has 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 discussions regarding the application of Indiana coal for their processes are underway. A coke production facility was visited and discussions regarding potential technology are ongoing. Contact is being established with the research department of the coke producer. Tours and discussions of coking and associated electric generation facilities are ongoing.

Two 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. Should additional funding become available it may be possible to arrange for scoping studies to be conducted using the Aspen model. As an intermediate step, a copy of the Metsim model has been obtained and will be used for initial process modeling.

At present there are two main methods of producing coke in the United States. The first is 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 carcinogenic compounds. There is also a major concern with the tar that is left after processing. This material is also carcinogenic and is generally stored on site currently and thus presents a significant future disposal concern. The complexity of the chemical processing introduces added cost and process operational details that have not made this option acceptable in the past for coking and simultaneous power production.

The second coke producing process is a non recovery process in which air is introduced at the top of the coke oven and combusts the volatiles prior to the time that they form carcinogenic materials. 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.

The current research is considering if it would be conceptually possible to modify the mass balance in the non recovery process in a way that would allow for a usable level of hydrogen production that could be used to power a combustion turbine for electric production. Contacts with the research department of a coke oven designer have been established and discussions are starting regarding this concept. The degree of gasification and influence on operations would need to be considered in a subsequent detailed study.

Modeling efforts, using the previously described Metsim model, are being initiated to consider alternatives for electric production including heat recovery and potentially partial coal gasification. This aspect will be considered in more detail in the remainder of the current effort.

Efforts regarding a new process for the sequestration of the carbon dioxide produced by the process are also under way. Preliminary results indicate that it may be possible to produce a usable chemical product as part of the carbon dioxide sequestration process.

2. The coke production process would take place near or at an Indiana coal mine and, hence, 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. At times transportation costs have approached the cost of the coal itself. The total transportation cost would 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. 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. Preliminary discussions regarding

transportation have occurred, but more detailed discussion is awaiting more detail as to possible facility site locations.

3. A coking/coal gasification process would be used that would produce metallurgical grade coke using a significant percentage of 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. Issues of the ability to produce electric ancillary services as part of the operation are also being considered.

4. With a mine mouth operation, blending and storage of coal feed streams would be done on site and would thus allow for scheduling the production of electricity to correlate with times of high market value. Further discussions of this topic are awaiting more information on possible site locations.

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 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.

Relevance of Proposal

This proposal is consistent with and directly supports the CCTR Research Topics for 2004-2005.

1. **Advantages and Disadvantages of Using Indiana Coals with Clean Coal Technologies**

   Environmental emissions are often cited as a reason why Indiana coal is not used in the production of coke. This proposal presents a different option that inverts the classic coke production paradigm. We propose to develop a process in which clean coal technology is used at the mine mouth to produce coke, rather than transporting coal 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. This process will result in a net transportation savings, as well as a value stream from cogenerated electricity. The locations of Indiana's coal mines provide many unique advantages for coke production relative to expanded production at current facilities. Special consideration will be given to assure that the proposed process is optimized for the use of Illinois basin coals from Indiana. 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. A key aim of the research will be to facilitate the development of a physical production facility within 5 years.

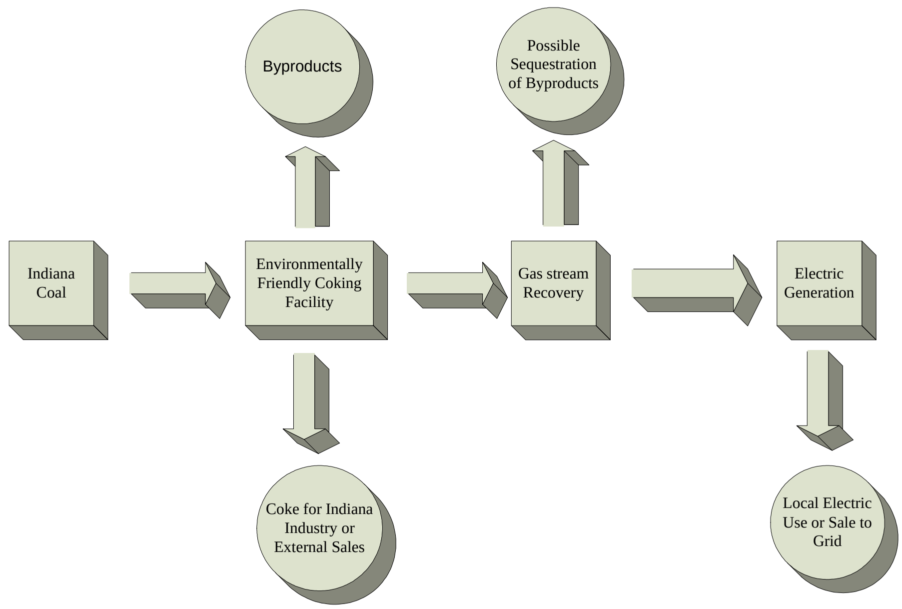
2. **Factors That Affect The Design and Implementation of Clean Coal Technologies in Indiana**

   This proposal leverages experience from current coking facilities in Indiana. Research will be required to extend these technologies for use in a mine mouth coking facility, but the technical risk will be less than for a completely experimental concept. The major products from the facility will be coke and electricity. Both are crucial to the economic future of Indiana. This 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. Such an approach is made possible by the use of proven technology in the new coking paradigm of this proposal. This approach significantly increases the probability that an actual productive facility could operational within a 5 year time frame.

3. **Key Issues That Encourage or Inhibit the Increased Use of Indiana Coal at Existing Facilities**

   Mine mouth coke production with cogeneration 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.

A diagram of the proposed process is depicted in the following figure;



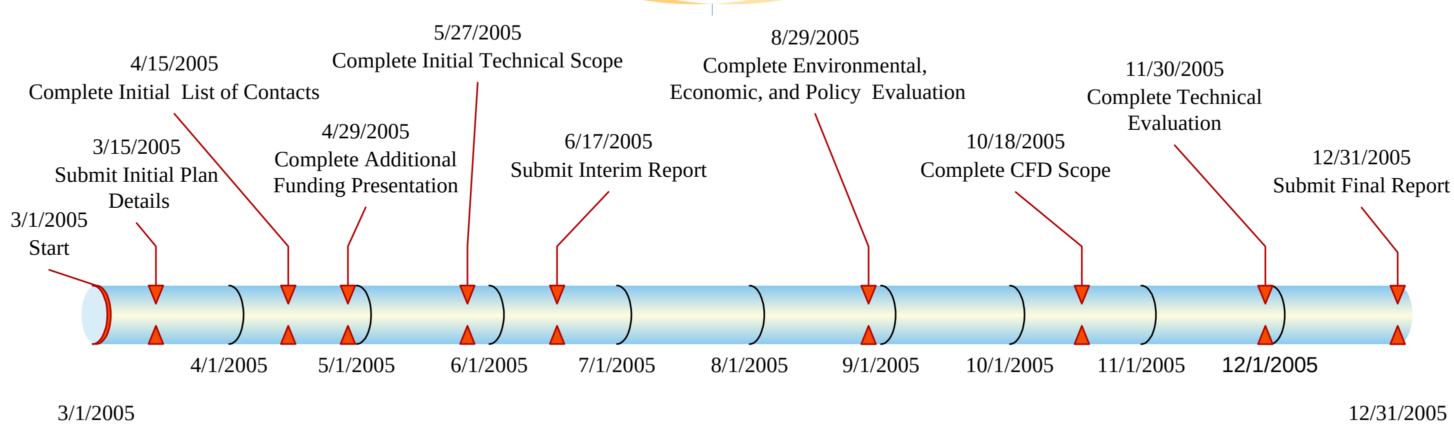
A mine mouth coking/coal gasification facility will have many positive economic and employment effects for Indiana. This facility will be located in Indiana. Typically, a 1.3 million ton per year coke facility employs about 130 people. In addition, it is estimated that 13 new employees would be required 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 increases by 20% to 40% in 2004.[5] 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.[6] 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.

Major Tasks, Issues, and Timeline

The work of this proposal will be managed, consistent with the Timeline and Milestones and Task schedule depicted in the following chart and also consistent with the budget. Tasks will be as follows;

1. Develop initial plan details and submit to CCTR for approval – A detailed work plan for the project will be developed during the first two weeks and this will be submitted to CCTR for approval. This plan will assist in establishing a clear understanding of work activities, schedule, and reporting requirement details for all parties to the project.
2. Establish interface with industry contacts – Contacts with industrial, governmental, regulatory, technical, and other appropriate sources will be formalized. Communication and information exchange procedures will be established to provide assistance in assuring the success of the project.
3. Prepare Presentation for expanded project and additional funding – Consistent with the requirements of the RFP, a presentation will be prepared that will recommend additional funding and expansion of the project. The Principal Investigator will be available to make presentations regarding the project to various groups at the request of the CCTR.
4. Prepare Initial Technical Scoping Study – A report will be prepared that will describe the initial technical issues determined as part of the technical development of the project scope.
5. Prepare interim report – An interim report will be prepared that will describe results and progress made and specifically address items “a” through “g,” listed under the Goals of the RFP.
6. Prepare environmental, economic, and policy evaluation scoping report – A scoping report of the issues regarding the environmental, economic, and policy aspects of the project will be prepared. This report will serve as the basis for more detailed consideration of these issues in the final report.
7. Evaluate Computational Fluid Dynamics aspects – An appraisal of the potential to use CFD techniques as part of a subsequent expansion of the project will be prepared. This will facilitate the interface of this project with ongoing research efforts regarding blast furnace operation and optimization.
8. Technical Evaluation – An initial evaluation of the technology that could be used for an operating facility will be conducted.
9. Prepare final report – A detailed final report will be prepared and presented within 30 days of the completion of the project. This report will address the issues and requirements listed in the RFP as well as the milestones described as part of this proposal.

Timeline
Major Milestones



Task Schedule

ID	Task Name	Start	Finish	Duration	2005 Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Develop Initial Plan Details and Submit to CCTR for Approval	3/1/2005	3/15/2005	11d										
2	Establish Interface With Industry Contacts	3/1/2005	4/15/2005	34d										
3	Prepare Presentation for Expanded Project and Additional Funding	3/15/2005	4/29/2005	34d										
4	Prepare Initial Technical Scoping Study	3/15/2005	5/27/2005	54d										
5	Prepare Interim Report	5/2/2005	6/17/2005	35d										
6	Prepare Environmental, Economic, and Policy Evaluation Scoping Report	4/15/2005	8/29/2005	97d										
7	Evaluate CFD Aspects	6/16/2005	10/18/2005	89d										
8	Technical Evaluation	4/18/2005	11/30/2005	163d										
9	Prepare Final Report	9/15/2005	12/30/2005	77d										

Resources

Project personnel include:

Robert Kramer (Ph.D.) is Director of the PUC Energy Efficiency and Reliability Center. Dr. Kramer will serve as the Principal Investigator, coordinate the efforts, and maintain the overall program for this proposal. His areas of expertise include energy research, electric system design and operation, engineering, physics, Combined Heat and Power system design and operation, environmental engineering, and project management. Currently his research interests include the simultaneous optimization of Combined Heat and Power Systems and Renewable energy systems as well as electric system reliability and quality. He has over 30 years of industrial experience in the energy field, most recently as the Chief Scientist for NiSource. He has previously served as principal investigator for three Department of Energy research contracts with budgets totaling over $6.5M. He currently teaches various courses in Physics and Engineering.

Chenn Zhou (Ph.D.), Professor of Mechanical Engineering Purdue University Calumet. Dr. Zhou is an expert in computational fluid dynamics. She is the principal investigator for a $1.29M 21st Century Grant to develop Computational Fluid Dynamic techniques for use in blast furnace operations. She has modeled various industrial systems and has considered energy and process optimization as part of the modeling effort. Recently, she was elected a Fellow of the American Society of Mechanical Engineers.

Harvey Abramowitz (Ph.D.), Professor**,** Department of Mechanical Engineering, Purdue University Calumet. Dr. Abramowitz has had extensive experience in metallurgy and steel making processes in general. He has worked in the steel industry and is familiar with steel and iron quality and production issues. He has also worked on process costing and economics.

Hardarshan Valia (Ph.D.), President, Coal Science, Inc. Dr. Valia will serve as a team member and consultant to the project. He has extensive experience in the steel industry and specifically in the utilization of coal and the coking process. He also has experience with various production and economic aspects of both the coal and steel industry.

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