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

Status Report
12/6/2006

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

- **Robert Kramer** (Ph.D.) is Director of the Purdue University Calumet Energy Efficiency and Reliability Center. Dr. Kramer serves as the Principal Investigator. His areas of expertise include energy research, electric system design and operation, engineering, physics, Combined Heat and Power systems, environmental engineering, and project management. He has over 30 years of industrial experience in the energy field, most recently as the Chief Scientist for NiSource. He also teaches various courses in Physics and Engineering.

- **Libbie Pelter** (Ph.D.), Assistant Professor, Department of Chemistry and Physics, Purdue University Calumet. Dr. Pelter has a background in surface chemistry and catalysis from the petroleum industry. Her current interests include development of nano catalysis and surface chemistry.

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

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

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

- **Anita Katti** (Ph.D.), Assistant Professor, Department of Chemistry and Physics, Purdue University Calumet. Dr. Katti has a background in chemical engineering from the pharmaceutical industry.
Initial Scoping Study Completed

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

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

Heat Recovery And Steam Generation

Electric Generation

Non Recovery Coke Plant

Coke

Gas Turbine

Electric Generation

Fischer-Tropsch Processing

Liquid Transportation Fuel

Gas Separation

Fertilizer & Bulk Hydrogen

Pyrolysis Gas

Indiana Coal

Other Coal
Coal Blending Is Key to Using Indiana Coal For Coke Production

Table VII: Analytical data for selected Indiana-Illinois coals

<table>
<thead>
<tr>
<th>Petrography</th>
<th>Coal A</th>
<th>Coal B</th>
<th>Coal C</th>
<th>Coal D</th>
<th>Coal E</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Inerts(%)</td>
<td>18.91</td>
<td>23.38</td>
<td>22.22</td>
<td>10.82</td>
<td>10.22</td>
</tr>
<tr>
<td>O. Inerts(%)</td>
<td>15.03</td>
<td>18.63</td>
<td>19.29</td>
<td>6.21</td>
<td>6.62</td>
</tr>
<tr>
<td>Exinite (%)</td>
<td>12.80</td>
<td>8.0</td>
<td>11.40</td>
<td>4.20</td>
<td>4.20</td>
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<tr>
<td>Reflectance (%)</td>
<td>0.56</td>
<td>0.55</td>
<td>0.53</td>
<td>0.56</td>
<td>0.65</td>
</tr>
<tr>
<td>Inert Index</td>
<td>0.64</td>
<td>1.11</td>
<td>0.96</td>
<td>0.43</td>
<td>0.37</td>
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<tr>
<td>Rank Index</td>
<td>2.54</td>
<td>2.43</td>
<td>2.57</td>
<td>2.45</td>
<td>2.52</td>
</tr>
<tr>
<td>P. Stability</td>
<td>12(33)</td>
<td>4</td>
<td>11(25)</td>
<td>19(33)</td>
<td>25(31)</td>
</tr>
<tr>
<td>USSCBI</td>
<td>0.84</td>
<td>1.09</td>
<td>0.97</td>
<td>0.44</td>
<td>0.30</td>
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<td>USSSI</td>
<td>2.57</td>
<td>2.49</td>
<td>2.82</td>
<td>2.46</td>
<td>2.54</td>
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<tr>
<td>USP. Stab.</td>
<td>21</td>
<td>17</td>
<td>24</td>
<td>5.22</td>
<td>4.49</td>
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<tr>
<td>Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>V.M.(%,db)</td>
<td>37.5</td>
<td>36.3</td>
<td>37.0</td>
<td>36.50</td>
<td>35.80</td>
</tr>
<tr>
<td>F.C.(%,db)</td>
<td>55.6</td>
<td>54.9</td>
<td>50.0</td>
<td>55.40</td>
<td>58.40</td>
</tr>
<tr>
<td>Ash(%,db)</td>
<td>7.0</td>
<td>8.8</td>
<td>5.0</td>
<td>6.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Sulfur(%,db)</td>
<td>0.82</td>
<td>0.75</td>
<td>0.86</td>
<td>0.86</td>
<td>1.04</td>
</tr>
<tr>
<td>FSI</td>
<td>1.5</td>
<td>1.0</td>
<td>4.0</td>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td>Alkali Index</td>
<td>0.78</td>
<td>0.85</td>
<td>0.92</td>
<td>1.53</td>
<td>1.33</td>
</tr>
<tr>
<td>Phosphorus(%)</td>
<td>0.043</td>
<td>0.037</td>
<td>0.005</td>
<td>0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>Rheology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.Range(Deg.C)</td>
<td>64</td>
<td>52</td>
<td>54</td>
<td>53</td>
<td>41</td>
</tr>
<tr>
<td>M.F.(dpm)</td>
<td>48</td>
<td>30</td>
<td>24</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>P. CSR</td>
<td>50(48)</td>
<td>43</td>
<td>42(48)</td>
<td>35(30)</td>
<td>29(27)</td>
</tr>
</tbody>
</table>

Blend of 23% Indiana coal - 37% Eastern High Volatile (EHV) coal - 40% Eastern Medium Volatile (EMV) coal

Zones of a blast furnace

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

Source: Modern Blast Furnace Ironmaking, Verlag Stahleisen GmbH, 2004
Preliminary CFD Results

Pressure

Streamlines

Velocity Vectors
Coke Oven
Initial Test Setup
Initial Pyrolysis Test
Post Initial Test
New Pyrolysis Design
Coke Oven Gas

- In a recovery coke oven, typically the coke oven gas has a composition of 58% hydrogen, 26% methane, 5.5% nitrogen, 2.25% acetylene, 2% carbon dioxide, 6% carbon monoxide, and .25% oxygen.
- One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m³ of coke oven gas.

Source:
Slow Pyrolysis Gas Composition vs Temperature

Source: Coal Conversion Technology, Wen, C., Lee, E.
Current GC for Gas Analysis
GC for Next Testing Stage
Next Phase Issue

• There is an opportunity to significantly accelerate the testing program and the development of test capability for the production of liquid transportation fuels

• This will also facilitate blending tests leading to increased usage of Indiana Coal
CSL Non Recovery Coke Simulator
CSL non recovery pilot oven

- Existing Gas port
- Proposed gas port site in down comer
- Proposed Gas port sites in the sole flue
Slow Pyrolysis Gas Production Rate

\[
\frac{dV}{dt} = \frac{K_0 V_0}{m'} 10^{-\left(\frac{E}{RT} - \frac{K_0 RT^2}{mE} e^{\left(\frac{E}{RT}\right)}\right)}
\]

(1975 data)

\[m' = \text{heating rate} = \frac{dT}{dt}\]

\[V = \text{volume of any particular gas released at time } t \text{ (not total volatiles)}\]

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

\[E = \text{activation energy } \text{kJ/mol}\]

\[R = \text{gas constant, kJ/mol} \text{ °K}\]

\[m = \text{order of reaction}\]

<table>
<thead>
<tr>
<th>Gas</th>
<th>(K_0)</th>
<th>(E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{H}_2)</td>
<td>20</td>
<td>22.3</td>
</tr>
<tr>
<td>(\text{CH}_4)</td>
<td>1.67x10^{-5}</td>
<td>31.0</td>
</tr>
<tr>
<td>(\text{CO}_2)</td>
<td>550</td>
<td>19.5</td>
</tr>
<tr>
<td>(\text{CO})</td>
<td>55</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Source: Coal Conversion Technology, Wen, C., Lee, E.
Phase 2 Issues

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

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