The use of coke to produce steel has been declining in the United States over the last several years, being directly related to the turbulent situation in the steel industry. Since 1998, the American steel industry has been seriously affected by low-priced steel imports, and this has resulted in the bankruptcies of 35 American steel companies, the elimination of over 50,000 jobs, and steel prices sinking to a historical low in 2001 (The American Steel Industry Current Trade Issues, 2003, Figure 1A and B). Since a Steel Program was initiated two years ago by the federal government, the industry has been showing signs of recovery. It still faces many challenges and obstacles. Imports of steel into the United States continue to grow—a 50 % increase in finished steel in 2004 compared to 2003, and a 14.3 % increase in steel consumption during the same period —documenting our growing reliance on the imported product.

As part of the solution to this problem, coke producers must design a blend that will consistently produce high-quality coke at a relatively low cost. One way to answer this challenge is to include relatively inexpensive carbon materials in blends that do not compromise the quality of the resultant coke. Selected coals of high-volatile bituminous rank could meet these requirements.

**COKING BEHAVIOR OF THE BRAZIL FORMATION COALS**

The Lower Block Coal of the Brazil Formation from Indiana is one example of a coal that has superior coking behavior even though it is of significantly lower rank compared to typical coking coals (Figure 2). With its vitrinite reflectance of 0.5 to 0.6 %, which corresponds to high-volatile bituminous C and B rank, this coal possesses favorable rheological properties, including high fluidity, high fluid range, and high amount of contraction (Valia and Hooper, 1994; Valia and Mastalerz, 2004), properties that are critical during carbonization.

In fact, this unusual coking behavior of selected Indiana coals was noted a long time ago. In the nineteenth century, Indiana coal was widely used to make coke within the state. Coke made from Brazil Formation coals (including the Lower and Upper Block Coal Members) in beehive-style ovens at the Brazil Furnace located near Brazil, Indiana (Alexander, 1876; Warren, 2001). Tests conducted by the Indiana Geological Survey concluded that these “Block” coals produced a “remarkably strong and dense coke” (Cox, 1871; Weeks, 1885). Coke made from these coals was used in Bessemer pig iron production, particularly in Clay County, where Cox (1871, 1879) noted that the lowest of the block coals (namely, the Lower Block coal) made the best coke, particularly owing to minimal sulfur content. Both Alexander (1876) and Cox (1879)
Table 1. Carbonization tests of Indiana coals and comparison with other coals of similar rank (after Valia and Mastalerz, 2004).

<table>
<thead>
<tr>
<th></th>
<th>100% Brazil Fm</th>
<th>100% Danville</th>
<th>100% Illinois #6</th>
<th>100% Illinois #7</th>
<th>100% EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>9.5</td>
<td>11.2</td>
<td>7.42</td>
<td>8.8</td>
<td>6.5</td>
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<tr>
<td>Grind (% -3.35mm)</td>
<td>77.4</td>
<td>85.4</td>
<td>89.2</td>
<td>80</td>
<td>64.7</td>
</tr>
<tr>
<td>Dry oven blk</td>
<td>724</td>
<td>739</td>
<td>776</td>
<td>827</td>
<td>820</td>
</tr>
<tr>
<td>Max. oven wall</td>
<td>2.07</td>
<td>2.96</td>
<td>5.44</td>
<td>6.54</td>
<td>2.55</td>
</tr>
<tr>
<td>Coking time (h)</td>
<td>18.6</td>
<td>20.15</td>
<td>18.62</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Stability</td>
<td>33</td>
<td>33</td>
<td>31</td>
<td>39</td>
<td>nd</td>
</tr>
<tr>
<td>CSR</td>
<td>48</td>
<td>30</td>
<td>27</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>CRI</td>
<td>40</td>
<td>Nd</td>
<td>59</td>
<td>67</td>
<td>nd</td>
</tr>
<tr>
<td>Hardness</td>
<td>54</td>
<td>69</td>
<td>70</td>
<td>72</td>
<td>nd</td>
</tr>
<tr>
<td>Coke size (mm)</td>
<td>53.4</td>
<td>55.1</td>
<td>48.5</td>
<td>56.6</td>
<td>17.02</td>
</tr>
<tr>
<td>Coke yield (%)</td>
<td>67.9</td>
<td>67.0</td>
<td>67.9</td>
<td>65.6</td>
<td>nd</td>
</tr>
<tr>
<td>SHO cont</td>
<td>-10</td>
<td>nd</td>
<td>-2</td>
<td>1.5</td>
<td>nd</td>
</tr>
</tbody>
</table>

EC = coal from Colombia

Table 1. Carbonization tests of Indiana coals and comparison with other coals of similar rank (after Valia and Mastalerz, 2004).

High-Volatile Bituminous Coals, (cont.)

emphasized the importance of using the Block coals for local smelting over the importation of coke from other states for economic reasons. After that period, however, Indiana coal was not used for coking.

Ispat Inland (previously Inland Steel) renewed interest in the coking properties of the Brazil Formation coals from Indiana, and their carbonization oven tests (Table 1) demonstrated a significantly better quality of coke could be obtained from Indiana’s Brazil Formation coals than from the Danville Coal in Indiana or the Herrin and Danville coals from Illinois, and coal of a similar rank from Colombia. In particular, the carbon strength after reaction (CSR), a critical parameter for coking, is significantly higher for Indiana coals constituting 25% of the blend, coke has excellent stability and CSR, and that with a proper blend design, Indiana coal could be successfully incorporated in amounts up to 45% of the coal blend.

REASONS FOR SUPERIOR COKING BEHAVIOR OF “NON-COKING” COALS

High-volatile bituminous coals, like those from the Brazil Formation in Indiana, traditionally have been considered “non-coking” and their favorable behavior upon carbonization is unusual. Valia and Hooper (1994) suggested that the presence of liptinite macerals, and exsudatinite in particular, contributes to higher fluidity, which is related to the higher hydrogen content of these macerals. Recent studies by our research team compared the Lower Block coking coal to the non-coking Danville coal, and demonstrated that, at a very similar rank, the Lower Block

Note: I = Commercial results; II, III, IV = Pilot oven results; Ind = Brazil Formation coals; EHV = Eastern high volatile coal; EMV = Eastern medium volatile coal.

Table 2. Commercial and pilot-scale carbonization of Indiana coals blended with high volatile and medium volatile bituminous coals (data from Valia and Hooper, 1994).

Figure 3. Comparison of petrographic composition of the Lower Block and Danville coals. The Lower Block Coal has significantly less vitrinite and more liptinite and inertinite than the Danville Coal.
coal has greater carbon contents (and lower O/C ratios) and a higher organic sulfur content that correlated with a plastic range (Walker et al., 2001). Another very distinct difference exists in petrographic composition, with the Lower Block containing more liptinite and inertinite and lower vitrinite contents than the Danville coal (Figure 3). Further studies indicate that the individual maceral chemistries combined with the maceral composition are the primary controls on coking properties (Walker and Mastalerz, 2004). Lower Block liptinite macerals contribute a considerable amount of long-chain, unbranched aliphatics (as detected by infrared spectroscopy) to the overall composition of the coal, likely leading to a higher cracking temperature during coking. An increased cracking temperature may help to maintain coherency and strength in the coking process, assisting plasticity. In addition, contributions of tar and oily by-products from the breakdown of such liptinites would also contribute to prolonged plasticity of the coal during carbonization.

IMPLICATIONS

There are two important implications of documenting coals with favorable coking behavior that traditionally, because of their lower rank, would be considered non-coking:

1) They can successfully replace coking coals that are significantly higher-priced and in low supply, without jeopardizing coke quality. This, in turn, would be beneficial to the steel industry.

2) The criteria of classifying coking coals may need to be revised so that the applicability for coking blends not be determined based solely on criteria derived for high-rank coking coals. According to the existing criteria, the Lower Block coal is not considered useful for coking. This has been one reason why this coal has not found its way into industrial coke ovens. Other lower rank coals that are similar in properties to the Lower Block might also be overlooked, and their potential unrecognized.

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Mountaintop Mining, Energy and Sustainable Development

J. Steven Gardner
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In recent decades, large surface mines in Appalachia, particularly Mountaintop Mining (MTM) operations, have been characterized by environmental activists as so destructive that they force people from their land and homes, destroy the land and water forever and cause major flooding. This image has been conveyed to the public across the country, resulting in politicians, churches, environmental groups and others condemning and asking for an abolition of the practice. There is another side to this story.

Mountaintop mining has been a method utilized in Central Appalachia for around 40 years. Coal companies operating in the Appalachian region have been vilified as “Robber Barons” taking the wealth and leaving a legacy of poverty and environmental damage. Barbara Freese noted in her book, “Coal, a Human History,” the U.S. and Great Britain owe their rapid industrial growth and economic base to their respective coal industries. The U.S. still relies on coal for its economic base, of which the Appalachian coalfields are an important component.

MTM began as an efficient, low-cost mining method. To those not familiar with the practice, it essentially applies area mining to a mountaintop, removing all overburden above coal seams, resulting in full recovery of the resource with the excess or swelled spoil material – (rock and dirt) being deposited in engineered fills in hollows (known as hollow fills or valley fills, analogous to highway fills). The reclaimed area can be a gently rolling to flat plateau. The practice was even refined and encouraged by federal research efforts and regulatory agencies in the 1970’s. In the early days of MTM, the means justified the end. Over time landowners realized the mining method could be a value-added process creating a valuable resource i.e., useable land, in a region short of land that could be developed. To them, the end now justified the means.

Many have compared Central Appalachia to other Appalachian regions that have thrived and pointed to the coal industry as the villain holding back development potential. They point to areas and cities such as Asheville, North Carolina. Topography between regions in Appalachia differs. While mountains are prevalent in Central Appalachia, the valleys are so narrow that potential for development is limited. True, there may be some blame to be shared by the coal industry and larger landowners, but there is enough blame to be spread around to all parties. Failed government social engineering programs from the 1960’s have left an area with many residents who are dependent upon government subsidies. Drug use has become prolific and a drug culture still exists.

Analyzing the root causes of these problems is material for many debates beyond our capacity as engineers and scientists. However, it is clear that blaming the coal industry and large landowners is a smokescreen for other problems. Success stories in the Appalachian region are generally in areas where good infrastructure and roads make the areas attractive for development. Only in recent years has the Central Appalachian region opened up with new highways crisscrossing the region making the travel to the region as easy as other parts of the country. The derivative benefit of these new highways and the new opportunity of developable land have changed the potential economic climate. Reclaimed mountaintop areas also open up tourism possibilities in the region, with land that can now be developed into golf courses, mountaintop retreats, fish and wildlife areas, and now large vast acres that can be open for the outdoor enthusiasts; including ATV users, horseback riders, etc.

Critics of MTM have also used the argument that only so much land can be developed and no MTM should be allowed unless there is designated use approved and financed upfront. Representative post mining land uses that are examples of both planned and unplanned value-added development include airports, residential, commercial, and industrial sites, golf courses, schools, hospitals, prisons, as well as agricultural and recreational areas. The benefits of these projects will continue for generations. Now that the potential has been realized, other areas can be mountaintop mined and held in reserve for future uses with greater planning from the outset of the mining project.

Critics also worry that MTM will level Appalachia and destroy the environment. According to the EPA Environmental Impact Statement of Mountain Top Mining, in a 12 million acre study area including 59,000 miles of streams, only 6.8% of the acreage has been or could be affected by mountain top mining. 1.200 miles of headwater streams, or only about 2%, have been or will be directly impacted by MTM.
Sustainable development has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Today’s progressive mining industry is taking care of the needs of the present and creating opportunities for future generations. This is clearly evident by the preponderance of the developments taking place in the Appalachian region that are creating jobs, living spaces, and recreation for this and future generations. Informal surveys of land transfers in Eastern Kentucky have shown the reclaimed MTM land is some of the most valuable land in the region. There are now thousands of people living, working and enjoying activities on reclaimed MTM sites in Central Appalachia. This truly is one of the best examples of sustainable development, not only in the United States, but the world.

MTM is just one source of coal for energy and raw materials. It is a finite resource. Will we find an alternative to coal? Yes. It will be engineers and scientists who discover new revolutionary sources, probably within our lifetime. We will always need to mine natural resources for raw materials to make the products we use every day. Many feel there is nothing good about coal or people associated with mining coal. However, coal is an industry that everyone’s lifestyle depends on. Now Mountaintop Mining is creating opportunities for an entire region after the finite resource of coal is gone. That is Sustainable Development.

Mr. Gardner is President/CEO of Engineering Consulting Services, Inc. headquartered in Lexington, Kentucky and Chairman/CEO of Specialty Coal Processing, Inc. located in Whitley County, Kentucky. He holds graduate and undergraduate degrees from the University of Kentucky in Mining Engineering and Agricultural Engineering Departments, respectively, plus a graduate level Environmental Systems Certificate. He is a licensed Professional Engineer in KY, VA, WV, and TN, and a Licensed Professional Surveyor in WV. In his career he has worked as an engineer and manager in mining operations and consulting engineering, as well as having served on a mine rescue team. He was recently appointed to the Kentucky State Board of Licensure for Professional Engineers and Land Surveyors. His consulting practice focuses on natural resources, mining and quarry operations, sensitive land use issues, environmental, health and safety, and industrial heritage projects.