The Charfuel® Coal Refining Process

By:

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In a fossil fuel energy infrastructure dominated by refined hydrocarbon fuels, coal, in its raw form, cannot meet complex energy needs. The drawbacks associated with use of raw coal include (1) its non-uniform composition which requires changes in boiler design for each particular type of coal; (2) its bulky, solid form which results in transportation and handling problems; and (3) its release of sulfur oxide, nitrogen oxide, and air toxics which are commonly blamed for smog and acid rain. Nevertheless, RAW COAL IS TOO VALUABLE JUST TO BURN.

Despite their differences in appearance, coal and crude oil are quite similar. Both are hydrocarbon-containing fossil fuels. Crude oil, with about 2 hydrogens per carbon, has limited utility as a dirty, sulfur-containing material and must be refined to produce value-added products, such as gasoline, jet fuel, and other fuels and petrochemicals. Thus, gasoline refined from high sulfur crude or from light Arabian crude is still gasoline. Unfortunately, crude oil represents less than 2% of the U.S. known fossil fuel resources.

Raw coal, with a hydrogen-to-carbon ratio of 1:1, contains complex hydrocarbons, sulfur, and nitrogen. High sulfur bituminous coals and high moisture subbituminous coals are very different raw materials and cannot be interchanged as fuels. Coal is our country's most abundant fossil fuel, accounting for over 95% of the U.S. fossil energy reserves. The United States has 43% more energy in its coal reserves than the energy equivalent of all the known oil and gas reserves in the world.

Just as it is unimaginable that crude oil would be used in its raw form, so should it be unthinkable that we would merely burn raw coal.

I. OVERVIEW OF THE CHARFUEL® COAL REFINING PROCESS

The patented Charfuel® coal refining process is analogous to crude oil refining processes in that it employs fluidized hydrocracking to produce char and liquid products from virtually all types of volatile-containing coals, including low rank coal and lignite. It is not gasification or liquefaction which require the addition of expensive oxygen or hydrogen or the use of extreme heat or pressure. It is not the German pyrolysis process that merely "cooks" the coal, producing coke and tar-like liquids. Rather, the Charfuel® coal refining process involves thermal hydrocracking which results in "hydrodisproportionation" (rearrangement of hydrogen within the coal molecule) to produce a slate of co-products, just as is done with crude oil in petroleum refining. See Figure I. In the Charfuel® process, pulverized coal is rapidly heated in a reducing atmosphere in the presence of internally generated process hydrogen. When the coal molecule is hydrocracked, inherent hydrogen is transferred away from certain carbons (yielding char) to other carbons (yielding liquids).
This hydrogen rearrangement allows refinement of various ranks of coals to produce a pipeline transportable, slurry-type, environmentally clean boiler fuel (Charfuel® fluidic fuel) and a slate of value-added traditional fuel and chemical feedstock co-products. Using coal and oxygen as the only feedstocks, the Charfuel® hydrocracking technology economically removes much of the fuel nitrogen, sulfur, and potential air toxics (such as chlorine, mercury, beryllium, etc.) from the coal, resulting in a high heating value, clean burning fuel which can increase power plant efficiency (reduced CO₂) while reducing operating costs. The result is cleaner air and less expensive electricity. The thermally efficient, environmentally benign Charfuel® coal refining process produces no waste products or heavy tars. It does maximize liquid yields by conserving hydrogen inherent in the coal, thus eliminating the need for expensive externally generated hydrogen. This makes the process very economical.

The Charfuel® process is elegant in its simplicity. See Figure II. In the hydrocracker, pulverized demoisturized coal is subjected to a high heat rate, short residence time devolatilization and hydrogenation. A commercially available partial oxidation (POX) unit provides both heat and hydrogen (from the coal) to the hydrocracker. Sulfur and nitrogen, liberated during volatilization, are removed downstream as elemental sulfur and ammonia. The reaction product temperature is reduced by quenching to preserve the liquid product ("process oil") yield by inhibiting the formation of gaseous products which result from hydrocracking at higher temperatures. This quench step conserves valuable inherent hydrogen which would be used up in a hydrocracking reaction. Char is separated from the quenched hydrocracker effluent as a dry, free-flowing solid. The remaining effluent is cooled to condense and recover the liquid products. Naphtha and BTX (benzene, toluene, and xylene) can be separated from the liquid product as valuable co-products. The remaining raw oil can be mildly hydrostabilized, if required, and used as the principal liquid blending component for production of the Charfuel® fluidic fuel. The Charfuel® technology can be applied to waste coals or feedstocks high in pyritic sulfur through appropriate control of process parameters and the inclusion of coal and/or char physical cleaning as necessary.

FB&D evaluated the commercial feasibility of a Charfuel® coal refinery processing 10,000 TPD (MAF) of Powder River Basin coal. FB&D calculated the thermal efficiency of this facility to be about 78.9 percent and attributed this high efficiency to the direct integration of the POX unit and hydrocracker, low oxygen consumption, and direct heat recovery from process streams. See Table I.
<table>
<thead>
<tr>
<th>Energy Input</th>
<th>MMBtu/hr</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal, HHV</td>
<td>10,658.9</td>
<td>97.15%</td>
</tr>
<tr>
<td>(15,547.26 TPD @ 8,227 Btu/lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Power</td>
<td>312.4</td>
<td>2.85%</td>
</tr>
<tr>
<td>(91,529 KW @ 3,413 Btu/KWH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL ENERGY INPUT (HHV)</td>
<td>10,971.3</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

| Energy Output **  |          |                 |
| CHARFUEL Fluidic Fuel | 7,119.4 | 64.89%          |
| Methanol           | 200.2    | 1.82%           |
| BTX                | 583.0    | 5.32%           |
| Naphtha            | 513.4    | 4.68%           |
| Ammonia            | 53.5     | 0.49%           |
| Sulfur             | 18.8     | 0.17%           |
| CO₂ ***            | 164.7    | 1.50%           |

| SUB-TOTAL PRODUCTS AND CO-PRODUCTS | 8,653.0  | 78.87%       |
| CONSUMPTION & LOSSES              | 2,318.3  | 21.13%       |
| TOTAL ENERGY OUTPUT (HHV)         | 10,971.3 | 100.00%      |

**PLANT THERMAL EFFICIENCY 78.87%**
(Product Yield/Energy Input)

* Based upon Ford, Bacon & Davis Feasibility Study

** Does not include MTBE production. MTBE economics are marginal when methanol selling price above $0.50/Gal.

*** CO₂ contains 2.35 Volume % light hydrocarbons desirable in EOR
These high thermal efficiencies compare very favorably with coal conversion processes as shown in Table II. The efficiencies for these processes range from about 49 percent for the indirect conversion of coal-to-methanol-to-gasoline, to about 64 percent for the direct conversion of coal to gasoline. Even the most efficient of these conversion processes is about 17 percent less efficient than a typical Charfuel® coal refining facility. The thermal efficiency of the Charfuel® coal refinery results in improved economics and reduced CO₂ emissions when compared to these direct and indirect coal conversion processes.

**TABLE II**

**COMPARISON OF COAL CONVERSION EFFICIENCIES**

<table>
<thead>
<tr>
<th>Type of Process</th>
<th>Feedstock to Product Conversion Efficiency, % (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal to Gasoline (Direct)</td>
<td>64</td>
</tr>
<tr>
<td>Coal to Methanol (Indirect)</td>
<td>54</td>
</tr>
<tr>
<td>Coal to Gasoline (Indirect-Methanol to Gasoline)</td>
<td>49</td>
</tr>
<tr>
<td>Coal to Diesel (Indirect)</td>
<td>56</td>
</tr>
<tr>
<td>Coal to Gasoline (Indirect)</td>
<td>56</td>
</tr>
</tbody>
</table>

(1) DOE Estimates

The higher efficiency and lower CO₂ emissions of the Charfuel® process are primarily due to conservation of internal hydrogen. Direct and indirect coal conversion processes that produce gasoline, diesel, fuel oil, etc., require large quantities of hydrogen (hydrogen to carbon atomic ratio of over 2:1). Much of the hydrogen required is normally produced via the water-gas shift reaction, i.e., CO + H₂O → H₂ + CO₂. Therefore, producing a large amount of hydrogen also produces a large amount of CO₂, thereby increasing CO₂ emissions.

Economic advantages of the Charfuel® process as compared with coal gasification or other conversion processes include manufacture of multiple products, high yield of lightweight process oil, and lower capital costs. Thermal efficiency of the process and high rates of carbon conversion (up to 60%) make the process extremely economical. Based on a comprehensive financial model developed by Morrison-Knudsen Engineers; Ford, Bacon & Davis; Kidder, Peabody; Arthur Andersen & Co.; and W.R. Grace, projected pre-tax internal rates of return for commercial scale Charfuel® coal refineries are in the range of 20 -
30% when the Charfuel® fluidic fuel is priced at the avoided cost of coal and the remaining co-products are priced to be competitive with petroleum derived products when crude oil is $15/barrel. As compared with the Charfuel® coal refining process, both liquefaction and gasification require extremely high capital costs and the addition of expensive external hydrogen, and/or catalytic reaction systems. Because of their low efficiency, the requirement for hydrogen production, and high operating costs, these coal conversion processes produce excessive amounts of CO₂ and are profitable only when crude oil prices are over $35.00 per barrel.

Price sensitivity analyses have been performed for Powder River Basin coal in order to assess the impact of price fluctuations on base case economics. Each product price was independently varied ±20% and ±40% from base case prices. The results of the sensitivity analyses are shown on Figure III. The sensitivity analysis indicates that the economic viability of the Charfuel® coal refining process is not particularly sensitive to fluctuations in the prices of the co-products. This is illustrated on the graph by the relatively flat slope of plots for fluctuations in co-product prices.

The short residence time required for coal refining allows a much higher throughput rate in smaller reactor equipment. This, combined with mild operating conditions and high on-line factors, results in very low capital costs. Since the Charfuel® coal refining process requires no external hydrogen and is very thermally efficient, operating costs are minimized.

II. CHARFUEL® FLUIDIC FUEL

A Compliance Boiler Fuel

According to Dr. C. Lowell Miller, Associate Deputy Assistant Secretary of the Office of Clean Coal Technology, DOE data project that if all the operators subject to Phase I compliance decided to scrub, the deposition of wet scrubber sludge would cover the island of Manhattan to a depth of nine feet each year. Echoing Dr. Miller's concerns, Coal Voice¹, in an article entitled "Setting Priorities: Strategies for Environmental Protection", recommended several environmental strategies. Number seven was to emphasize pollution prevention by encouraging action that prevents pollution from being generated in the first place. The conclusion: clean-up the fuel, not the flue gas.

The principal product of the unique Charfuel® coal refining process is a new fuel form, an admixture of the char and a portion of the low viscosity, high Btu, hydrocarbon liquids. See Figure IV. It can be substituted for coal or fuel oil as a boiler fuel and provides a least-cost, multi-option win/win solution for utilities. With a heating value of 13,000

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Btu/lb., virtually no vaporizable metals or chlorine, little fuel nitrogen, reduced thermal NO\textsubscript{x}, and minimal sulfur, the Charfuel\textsuperscript{®} fluidic fuel would allow utilities to keep all their options open. By utilizing the Charfuel\textsuperscript{®} fluidic fuel, either alone or in a co-fired configuration, utilities could not only improve boiler efficiency and achieve emission compliance, avoiding capital and operating costs for scrubbers, but also allocate substantially all of their compliance costs to the cost of fuel. Co-firing Charfuel\textsuperscript{®} fluidic fuel with coal for which the utility has already contracted could allow the utility to select the level of regulated emissions which best suits its business plan and compliance objectives.

The Charfuel\textsuperscript{®} fluidic fuel can be manufactured for a particular boiler's fuel specifications from a wide variety of coal feedstocks by varying process operating parameters. Refined fuels derived from coals having differing characteristics, i.e., eastern coals and western coals, can be "blended" like petroleum fuel oils to produce an economical compliance product.

Combustion of Charfuel\textsuperscript{®} fluidic fuel increases power plant capacity, improves system efficiency and economics, and allows the utilization of a secure, abundant natural resource: U.S. coal. If the utilities targeted for Phase I compliance with the 1990 amendment to the Clean Air Act were to combust Charfuel\textsuperscript{®} slurry (blended 50% from western coal and 50% from eastern coal) rather than unrefined high sulfur bituminous coal, SO\textsubscript{x} emissions could be reduced by 6.75 million tons per year and NO\textsubscript{x} could be reduced by 1.7 million tons per year, without producing any solid or liquid scrubber waste. When a blended Charfuel\textsuperscript{®} product is utilized instead of scrubbers, over a billion dollars a year can be saved. See Figure V. Combusting Charfuel\textsuperscript{®} fluidic fuel is the least cost alternative for meeting SO\textsubscript{2} compliance. See Table III.
## TABLE III
**COMPARATIVE FUEL COSTS**
(SO₂ Compliance Fuels)

<table>
<thead>
<tr>
<th></th>
<th>Raw Coal Plus FGD</th>
<th>Natural Gas</th>
<th>No. 6 Fluidic Fuel</th>
<th>No. 2 Fluidic Fuel Oil</th>
<th>Charfuel® Fluidic Fuel Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Delivered</td>
<td>$1.29 ¹,²</td>
<td>$2.49 ²</td>
<td>$3.45 ²</td>
<td>$3.84 ²</td>
<td>$1.90</td>
</tr>
<tr>
<td>Fuel Cost, $/MMBtu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Plant Retrofit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costs: ³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Costs,</td>
<td>$0.17</td>
<td>$0.02</td>
<td>$0.05 ⁴</td>
<td>$0.04 ⁴</td>
<td>$0.05 ⁴</td>
</tr>
<tr>
<td>$/MMBtu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating &amp; Mainten-</td>
<td>$0.72</td>
<td>($0.22) ⁵</td>
<td>($0.15) ⁵</td>
<td>($0.19) ⁵</td>
<td>($0.07) ⁵</td>
</tr>
<tr>
<td>ance Cost, $/MMBtu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Fuel Plus Retrofit</td>
<td>$2.18</td>
<td>$2.30</td>
<td>$3.35</td>
<td>$3.69</td>
<td>$1.88</td>
</tr>
<tr>
<td>Cost, $/MMBtu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂ Reduction</td>
<td>90.0</td>
<td>100.0</td>
<td>(0 to 80%)</td>
<td>(74 to 98%)</td>
<td>(80 to 96%)⁷</td>
</tr>
</tbody>
</table>

¹ Coal with 2.5 percent sulfur, HHV of 12,360 Btu/Lb, and SOₓ emission of 3.8 lbs/MMBtu.
² Fuel costs from DOE data.
³ Based on retrofitting pulverized coal-fired boiler with 20 year additional plant life and 274 days/year operation. Net heat rate for power plant before retrofit is 9,493 Btu/KW-Hr.
⁴ Includes 30 days of liquid storage.
⁵ Includes operating and maintenance costs for retrofit equipment and credit for retiring coal storage, handling and grinding, and eliminating or reducing ash handling and disposal costs.
⁶ May require flue gas desulfurization, depending on fuel sulfur content.
⁷ 80% SO₂ reduction utilizing Charfuel® from W. Kentucky No. 9 coal and 96%- reduction utilizing Charfuel® from Powder River Basin coal.
Increased Power Plant Efficiency

In retrofitting to utilize Charfuel® fluidic fuel, electric power generating stations can economically replace current coal storage, conveying, and pulverizing facilities with pumps and storage tanks, possibly maintaining the old coal handling facilities for back-up. These simple replacement facilities to handle Charfuel® fluidic fuel eliminate fugitive dust emissions and coal pile freeze up associated with current coal handling systems. Commercially available corrosion inhibitors (if needed) will ensure safe, long-term operation of the replacement facilities.

The costs at the power facility to store and deliver the new Charfuel® fluidic fuel system to the boiler are much less than the costs to store, crush, pretreat, pulverize, and convey raw coal. In a 500 MW plant, this represents a net savings of approximately 7 MW of power plus a substantial reduction in operating, maintenance, and replacement costs. With proper operation and maintenance of facilities, Charfuel® fluidic fuel is handled more cleanly and safely than coal or dried coal products. The Great Plains Gasification Plant has demonstrated safe, commercial handling of process liquids derived from coal.

The net result of a utility using Charfuel® fluidic fuel is a higher overall efficiency for generating electric power in retrofitted utility plants, i.e., less fuel energy is required to generate a KW-Hr of electricity. Therefore, less CO₂ is produced per net KW-Hr of electric power generated.

Even when the CO₂ generated by the Charfuel® refining facility is added to the combustion CO₂, the total CO₂ produced by combusting Charfuel® fluidic fuel is less than that emitted from a compliance pulverized coal boiler (see Table IV).
### TABLE IV

**CO₂ EMISSIONS BY FUEL TYPE**

(Lbs. of CO₂ Emitted Per KW-Hr) (1)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>CO₂ Emissions Associated With Production Of Fuel (Fuel Source)</th>
<th>CO₂ Emissions Associated With Electric Power Generation (1)</th>
<th>Total CO₂ Emissions (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-Fired Steam Plant:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bituminous Coal w/o Scrubber</td>
<td>0.126 *</td>
<td>1.878 *(2)</td>
<td>2.004</td>
</tr>
<tr>
<td>Bituminous Coal w/Scrubber</td>
<td>0.132 *</td>
<td>1.983 *(3)</td>
<td>2.115</td>
</tr>
<tr>
<td>Sub-Bituminous Coal w/o Scrubber</td>
<td>0.120 **</td>
<td>2.190 **(4)</td>
<td>2.310</td>
</tr>
<tr>
<td>Atmospheric Fluidized Bed Comb.</td>
<td>0.131 *</td>
<td>2.020 **(5)</td>
<td>2.151</td>
</tr>
</tbody>
</table>

Charfuel® Fired Steam Plant

|                                                      | 0.268 **(6)                                                    | 1.79 **(7)                                                | 2.059                  |

(1) Lbs. of CO₂ produced per KW-Hr of electric power placed on power grid.

(2) Bituminous coal with 9,658 Btu/KW-Hr net heat rate*. THIS IS NOT A COMPLIANCE FACILITY.

(3) Bituminous coal and wet limestone scrubber at 10,060 Btu/KW-Hr. Includes CO₂ released from limestone.

(4) Sub-bituminous coal with 8,200 Btu/Lb heating value and 10,200 Btu/KW-Hr net heat rate.

(5) Bituminous coal at 10,000 Btu/KW-Hr net heat rate. Includes CO₂ released from limestone.

(6) Includes CO₂ generated in refining process plus CO₂ generated operating refining facility.

(7) Bituminous coal refined to produce Charfuel® fluidic fuel with 13,830 Btu/lb heating value and 9,390 Btu/KW-Hr net heat rate.

* DOE estimates based on amount of coal required to produce 1 KW-Hr. of net power.
** CFA estimates.
A Pipeline Transportable Fuel

Products from coal hydrocracking are ideally suited for blending to produce a slurry-type, fluidic, boiler fuel. The process maximizes yields of low viscosity liquid products and produces rounded char particles that resemble small ball bearings. With only mild hydrostabilization, the product oil resists oxidation and polymerization. These properties of the oil and char minimize the liquid requirements to blend a pumpable fuel.

The Charfuel® fluidic fuel is more user-friendly than either #6 fuel oil or coal/water slurries. It does not need to be agitated or heated to prevent settling or solidification. Nor does it require bulky and expensive solids-handling equipment. Transportation costs will lower because the fuel can be shipped in the same pipelines used to ship petroleum fuel. Railroads, via tank cars, are available to transport and distribute the co-products as well as the boiler fuel.

As shown in Figure IV, a small quantity of wet methanol and concentrated process water are emulsified with the oil and char to improve the transportation and handling characteristics of the slurry. The dissolved organics and solids in the concentrated process water are natural emulsifying agents that stabilize the three-phase suspension. The emulsified water and methanol also provide a "wall-slip effect" when the slurry is transported by laminar flow in a pipeline, thus giving the fluidic fuel a dynamic viscosity lower than that of light crude oil. The moisture content of the fluidic fuel is less than 5 weight percent. This is less moisture than is contained in subbituminous coal which has been dried using the best available commercial technologies. In addition to enhancing the rheological characteristics of the fuel, the moisture also enhances combustion efficiency.

Actual rheology tests have demonstrated that the Charfuel® product is transportable in laminar flow using existing oil handling facilities (including oil pipelines) at about the same transportation costs as those charged for light crude oil. As shown in Figures V and VI, this represents substantial savings over the transport of coal. Utilization of existing oil pipelines and oil handling systems (which might require minor pump modifications) would eliminate the need to construct new slurry pipelines and create new rights of way. The fluidic fuel, as well as the co-products, can also be transported by rail, barge, truck, or ship.

ARCO Pipeline Company has evaluated the commercial feasibility for pipeline transportation of Charfuel® fluidic fuel. Based on actual rheological measurements, a 24-inch pipeline is estimated to transport 10 MMTPY of Charfuel® fluidic fuel at a cost of about $0.05/MBtu/1000 miles. In comparison with rail transportation costs at $0.020 to $0.025/ton-mile for coal and dried coal products, Charfuel® fluidic fuel is transported 1000 miles by pipeline at a cost of only about $0.0026/ton-mile.

The pumpable nature of Charfuel® fluidic fuel also reduces loading and freight costs for ocean transportation. Oil-type tankers can load and transport Charfuel® fluidic fuel at an estimated cost of $0.30/MBtu for shipment from California to Japan, Taiwan, and
Korea. Loading and shipping Powder River Basin coal for the same ocean transport is estimated to cost $1.00/MMBtu. The combined cost advantage for both land and ocean transport of Charfuel® fluidic fuel from the Powder River Basin to Japan exceeds $2.00/MMBtu. See Figure VI.

The costs at the power facility required to store and deliver the new Charfuel® fluidic fuel system to the boiler are much less than the costs to store, crush, pretreat, pulverize, and convey raw coal. In a 500 MW plant, this represents a net savings of approximately 7 MW of power and a substantial reduction in operating, maintenance, and replacement costs. With proper operation and maintenance of facilities, Charfuel® fluidic fuel is handled more cleanly and safely than coal or dried coal products. The Great Plains Gasification Plant has demonstrated safe, commercial handling of process liquids derived from coal.

As shown in Figure VIII, the Charfuel® fluidic fuel could be used as a transportation medium: at the destination the oil could be separated from the char, leaving a high concentrated char/oil blend (about 90% solids) for use in existing coal-fired boilers, while the separated hydrocarbon liquid would be available for use as a chemical feedstock, a refinery material, or for turbine peaking.

New installations will be able to burn Charfuel® fluidic fuel in boilers which resemble less expensive, oil-fired units without the need for scrubbers to control emissions, thus greatly reducing the capital and operating requirements of new power generation capacity. There is a significant steam generator cost savings when using a high caloric "clean" fuel (13,000+ Btu/lb) such as the Charfuel® fluidic fuel. These savings result from smaller furnace volume and elimination of capital and operating costs associated with coal pulverizers, flue gas desulfurization systems and NOx conversion systems. The use of peaking turbines (fired using Charfuel® fluidic fuel hydrocarbon liquids) can result in additional savings. Another concept would be to remove the high value oil products from the Charfuel® fluidic fuel and burn the oily char in an on-site fluidized bed boiler. If the oil products are not required for peaking turbines or other stationary combustion, they can be refined or sold "as is" to generate income for the utility, thereby offsetting total fuel cost. In cogeneration applications, the Charfuel® coal refining plant is the process heat generating portion of the cogeneration (see U.S. Patent No. 4,854,937 issued August 8, 1989 to Carbon Fuels Corporation). This configuration is so efficient and economical, it could quite possibly become the prototype for future power generation facilities.

The Charfuel® fluidic fuel, like the BTX, naphtha, and other upgraded co-products, can be utilized as transportation fuel to reduce dependence on foreign oil. The Charfuel® fluidic fuel is a manufactured product and, therefore, the char content can be varied and/or the char can be cleaned to remove inorganic material such as ash. Carbon Fuels Corporation has approached one manufacturer regarding the development of diesel engines which will utilize the Charfuel® fluidic fuel. Unlike coal/water mixtures or powdered coal, the Charfuel® fluidic fuel has a very high Btu content and is comparable to diesel fuel. Ap-
plication as a fuel for off-road vehicles such as mining equipment, agricultural equipment, and the like is particularly important. Another very significant market could include railroad locomotives.

III. COAL REFINERY "VALUE-ADDED" CO-PRODUCTS

In addition to Charfuel® fluidic fuel, the versatile Charfuel® coal refining process produces a number of co-products with established markets. See Table V. Within limits, the process parameters can be adjusted to vary product quantities as demand fluctuates. The co-product slate includes methanol and MTBE (gasoline additives to produce high test, oxygenated motor fuels); BTX (petrochemical feedstock) or benzene (chemical grade); naphtha (component of premium non-leaded fuel and a chemical feedstock); ammonia (fertilizer); and elemental sulfur (chemical feedstock). Industrial grade carbon dioxide can be separated when useful for tertiary oil recovery or other industrial uses. The char product, which usually would be the solid component of the Charfuel® fluidic fuel, could alternatively be utilized to produce formed coke or refined coke for anodes. Coal ash can be recovered for use in cement or other building materials. Even the trace metals in the coal feedstock, which would form air toxics if combusted, can be extracted when economical in light of market demand.

As is set forth in Coal & Synfuels Technology, Volume 10, No. 24, June 19, 1989, the methanol market as an oxygenated fuel is expected to rise substantially. The Clean Fuels Development Coalition estimates that the Clean Air Act Amendments will increase the market for methanol by 100 million to 200 million gallons. The conversion of 1,000,000 cars to alternative fuels would require 500 million to 1 billion gallons of those fuels. The market for MTBE as an oxygenated gasoline additive is also expected to expand exponentially. Thus, the planned market share for these two Charfuel® co-products would have a small impact on total supply of oxygenated fuels.

Figure IX depicts the co-product slates which can be manufactured from Powder River Basin subbituminous coal and from Kentucky high sulfur bituminous coal. Figure X shows that refining coal yields more value-added products than can be derived from crude oil.

The recovery and sale of acid rain precursors, i.e., sulfur and nitrogen, and of greenhouse gases (carbon dioxide) along with the production of naphtha, BTX, and methanol co-products, improve the economics for producing the low-sulfur, low-nitrogen, high Btu, pipeline transportable Charfuel® fluidic fuel. Thus, the Charfuel® process has the potential of allowing coal-derived products to reach both traditional and non-traditional domestic energy markets in an environmentally responsible manner and to reduce dependence on foreign oil. Moreover, exporting the clean-burning Charfuel® fluidic fuel opens new foreign markets for U.S. coal while reducing the trade deficit.
## CO-PRODUCT MARKETS AND PRICES

<table>
<thead>
<tr>
<th>Year</th>
<th>INDEX</th>
<th>QUADS (c)</th>
<th>MARKET</th>
<th>PROD.</th>
<th>TOTAL</th>
<th>PROD.</th>
<th>TOTAL</th>
<th>PROD.</th>
<th>TOTAL</th>
<th>PROD.</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1.00</td>
<td>15.3</td>
<td>0</td>
<td>---</td>
<td>16,940 (d)</td>
<td>---</td>
<td>3,670 (d)</td>
<td>---</td>
<td>30,450 (d)</td>
<td>---</td>
<td>11,650 (d)</td>
</tr>
<tr>
<td>2000</td>
<td>1.57</td>
<td>22.6</td>
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<td>.22</td>
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<td>1.76</td>
<td>27.6</td>
<td>5</td>
<td>1.09</td>
<td>29,010</td>
<td>100</td>
<td>.34</td>
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<td>1,620</td>
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(a) Price for boiler fuel pegged at avoided cost of coal; other co-product prices for 1990 from Chemical Marketing Reporter.
(b) Chemical grade Benzene varied from $1.30 to $2.00/gal in 1990
    Chemical grade Toluene varied from $0.76 to $1.65/gal in 1990
    Chemical grade Xylene varied from $0.78 to $1.35/gal in 1990
(c) Output for 10,000 TPD (MCF) Coal Feed = 0.060 Trillion Btu = 0.060 quads (quadrillion Btu)
(e) 1990 Amendments to Clean Air Act will require about 3,500,000 tons additional methanol by 2000.
IV. NATIONAL AND REGIONAL BENEFITS

Fundamental problems facing the U.S. include (1) environmental pollution, (2) energy security, (3) balance of trade deficit, (4) regional economic depression, and (5) remaining competitive in an increasingly global economy. The Charfuel® coal refining technology provides answers to each of these problems, whether the feedstock is high sulfur eastern coal, western subbituminous coal or great plains or southern lignite.

Environmental Pollution

Since about 85% of the sulfur and 65% of the fuel nitrogen are removed from the raw coal during the refining process, combustion of the uniform Charfuel® fluidic fuel produces very limited amounts of the pollutants which cause acid rain. This new fuel form can be fired in existing power plants in compliance with current environmental laws without the need for scrubbers or other flue gas clean-up apparatus. Further, by avoiding FGD, no scrubber sludge is produced. An additional advantage is that eliminating the need for pollution control equipment increases power plant efficiency, thus reducing production of "greenhouse gases". The Charfuel® process also reduces volatile toxics such as mercury, lead, cadmium, sodium, beryllium, and chlorine in the fuel. These materials are rendered benign or removed during the process so that they are not emitted from the power plant stack.

Energy Security

Because the Charfuel® fluidic fuel is a manufactured product, it is applicable to boilers in all regions and can utilize a wide variety of domestic coal feedstocks. Petroleum substitutes refined from U.S. coal will supplement domestic crude oil reserves, thus reducing the need for imported oil. By relying on U.S. resources to meet our energy requirements, we can enhance our national security.

Balance of Trade Deficit

Charfuel® fluidic fuel can be transported easily and inexpensively in crude oil pipelines to coastal ports, loaded aboard oil tankers, and exported to such markets as Japan, Korea, Taiwan, and Europe, helping our negative balance of trade. The high quality Charfuel® fluidic fuel and its liquid co-products derived from U.S. coal are expected to be highly competitive in overseas markets, particularly those in the Pacific Rim. At present, U.S. coal exports are declining. This trend can easily be reversed by lowering the transportation costs, upgrading export products, and making available a stable resource base (U.S. coal).
Regional Economic Depression

In the Charfuel® process, approximately 2 tons of coal yield about 1 ton equivalent of boiler fuel and about 1 ton equivalent of value-added co-products which are salable to non-traditional coal markets. This results in double the demand for raw coal. Thus, there is an economy of mining because of large scale operations. Since the Charfuel® coal refinery can utilize a wide range of feedstocks, there is no need to "hi-grade" or to waste material in order to meet contract requirements. Mine mouth plants can be located in all coal producing states, not only increasing mining jobs, but also employing operators for the refinery and creating new jobs for support and spin-off industries.

A total of some 750 full-time employees would be required to operate both a 10,000 TPD Charfuel® refinery and the coal mine(s) dedicated for supply of 4 million tons per year of coal feedstock. An estimated additional 1,100 jobs would be created in the local area to provide support for the permanent 750 new jobs created for the Charfuel® refinery and coal mines. Moreover, spin-off industries for utilizing or marketing the slate of co-products will add to the employment base. Locally, these new jobs result in higher property values, increased tax revenues and enhanced community services. At a state level, increased mining and industrial infrastructure contribute increased mineral royalties, income taxes, and corporate taxes, thereby providing funding for additional economic development programs.

U.S. Position in a World Market

To remain competitive, domestic manufacturers must control costs, improve productivity and offer innovations in products and services not found elsewhere. Maintaining a secure, least cost electric power supply is one essential element of this strategy. Reducing dependence on foreign oil is another. Unless electricity costs to critical industries are minimized and fuel supplies are secure, the whole U.S. economy is threatened. Utilization of Charfuel® fluidic fuel is less expensive and more environmentally responsible than burning coal and it improves the production efficiency of the power plant. Thus, this new fuel form creates a "domino" effect: less expensive electricity, less expensive manufactured goods, less importation of foreign goods and energy, and, ultimately, a better quality of life throughout the nation.
CHARFUEL® REFINING PROCESS
VS. OIL REFINING PROCESS
(HYDRODISPROPORTIONATION)

OIL

H = 2.0 ATOMS
C = 1.0 ATOM

OIL REFINERY

LIQUID PRODUCTS
H = 2.2 ATOMS
C = 1.0 ATOM

COKE (SOLIDS)
H = ~ 0.0 ATOMS
C = 1.0 ATOM

96% LIQUIDS & GASES
4% COKE

H = 1.0 ATOM
C = 1.0 ATOM

CHARFUEL® PROCESS

LIQUID PRODUCTS
H = 2.0 ATOMS*
C = 1.0 ATOM

CHAR (SOLIDS)
H = ~ 0.0 ATOMS
C = 1.0 ATOM

55% LIQUIDS & GASES
45% CHAR

* 10 PERCENT OF HYDROGEN COMES FROM
CONVERSION OF WATER IN THE COAL
CHARFUEL® PRODUCTION FACILITY
SENSITIVITY ANALYSIS
POWDER RIVER BASIN COAL
prepared May, 1991

BASE CASE PARAMETERS:

- INVESTMENT $596,000,000*
- COAL PRICE $7.00/TON
- CHARFUEL® $1.90/MMBTU
- METHANOL $0.60/GAL.
- BTX $1.65/GAL.
- NAPHTHA $0.88/GAL.
- CO2 $1.25/MCF

(a) Process area capital, general facilities, engineering, home office
and 20% project contingency allowance.

FIGURE III
Production Of Charfuel® Fluidic Fuel

Coal

Charfuel Process

Wet Methanol

Process Oil

Char

5-15%

25-35%

50-80%

FIGURE IV
COST OF REDUCING 5,000,000 TONS SO2
(Phase 1 of Clean Air Act)

WET SCRUBBER VS. CHARFUEL® FLUIDIC FUEL

FIGURE V
EXPORT TRANSPORTATION ECONOMICS

CHARFUEL® FLUIDIC FUEL

LOADING & OCEAN TRANSPORTATION
$0.30/MMBTU

STANDARD OIL PIPELINE TRANSPORTATION
$0.10/MMBTU

TANKER

CHARFUEL® PROCESS

$0.40/MMBTU TOTAL TRANSPORTATION COST

COAL

LOADING & OCEAN TRANSPORTATION
$1.00/MMBTU

RAIL TRANSPORTATION
$1.87/MMBTU *

FREIGHT

$2.87/MMBTU TOTAL TRANSPORTATION COST

* @ .02/TON - MILE
A Value-Added Process

**Powder River Basin Coal**

- **MTBE**: $1.85
- **CO2**: $3.57
- **Methanol**: $2.86
- **Sulfur**: $0.26
- **BTX**: $7.99
- **Naphtha**: $7.30
- **Ammonia**: $9.34
- **Charfuel Fluidic Fuel**: $21.98

Total Co-product Value: $46.24

**Kentucky #9 Coal**

- **Methanol**: $7.75
- **Sulfur**: $1.25
- **BTX**: $1.32

Total Co-product Value: $24.00

**FIGURE IX**

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Comparative Economics Of Refining Processes

Arabian Light Crude

$15.00/BBL
($2.00/MMBTU)

Oil Refining

$1.00/BBL
($0.13/MMBTU)

$23.20 Value-Added Products
($4.00/MMBTU)

Powder River Basin Coal

Coal

Chartuel' Process

Coal

Chartuel' Process

FIGURE X

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