Introduction

Historically, capital costs of Fischer-Tropsch (FT) coal-to-liquids projects have been high. Rentech Corporation, developer and owner of numerous patents associated with the FT process, has established EPC costs for various plant configurations on the 10,060 bpd example project discussed below from $65,600 to $74,000 per daily barrel of production capacity.

The ‘Simple Recycle’ design has the following characteristics:

- Plant capital costs: $656 million
- Coal input: 6,375 tons per day
- Net Power output: 12 MW
- Total FT liquids production: 10,060 BPD
  - FT diesel: 8,200 BPD
  - FT naphtha: 1,860 BPD

Below is a representative process diagram of a Simple Recycle facility:
Depending on the specific site, it is estimated that up to 70% of capital costs for a coal-to-liquids facility can be incurred on the synthesis gas production portions of the facility. For example, a project with a proposed location in Wyoming and utilizing Powder River Basin coal, has estimated costs for the coal handling and synthesis gas cleanup facilities of $224 million; while the coal gasifier portion of the plant adds another $82 million.

Utilizing Geothermic Fuel Cells (GFCT™) as the source for synthesis gas reduces the costs for the coal handling and gas cleanup portions of the plant by approximately $112 million and eliminates the $82 million for the coal gasifier, resulting in $194 million of cost reductions. (Note: The costs of the GFC balance of plant equipment and gas cleanup/conditioning for use as fuel in fuel cells are part of the net capital costs).

In addition to producing synthesis gas for FT feedstock, GFCs produce a variety of other high value products that dramatically enhance project economics.

Further, GFC in-situ coal gasification addresses a major environmental concern associated with CO₂ emissions of traditional FT projects, as more fully discussed below.

Analysis

With the proprietary Rentech FT process, liquid fuel synthesis occurs in the presence of an iron catalyst at 180° - 280° C and 1 – 30 atmospheres pressure. The relatively low pressures and temperatures involved result in economical costs for these portions of the facility.

At a specific gravity of .756, or 6.3 lbs/gal., a daily requirement of 2.65 million pounds of syn-gas feed stock is needed for a 10,000 bpd plant. GFCs will produce 979 pounds of CO from each ton of coal gasified. Of this amount, nearly 400 pounds will be consumed as fuel in the fuel cells. Part of the balance of 579 pounds can be used to produce FT liquids, depending on hydrogen availability.

Two molecules of H₂ are needed for every molecule of CO in the FT reaction. Accordingly, four hydrogen atoms for every carbon atom are required in the syn-gas supplying the FT process. Further, based on weight, the ratio of carbon monoxide to hydrogen should be 3.5:1. As such, FT liquids are high in hydrogen content and thus produce high quality transportation fuels. It does however mean that the FT process is hydrogen limited.

GFCs will produce 71 pounds of hydrogen from every ton of coal gasified. The available hydrogen can be combined with 248 pounds of the surplus CO to make 319 pounds, or approximately 50 gallons of liquids for every ton of coal gasified. As such, a 10,000 bbl/day FT facility will require 8,400 tons of coal to be gasified by GFCs per day.

Each GFC, assumed heating a hundred aggregate feet of coal depth, will gasify 500 pounds of coal per hour, or six tons of coal per day. Supplying a 10,000 bpd FT plant with syn-gas would require 1,400 GFC heaters. At a heater density of 19 per acre, syn-gas feedstock requirements would entail the continuous processing of approximately 75 acres. Complete processing of a coal seam would require 3 – 4 years, thus requiring the field to expand by approximately 25 acres per year to support one FT facility of this size.
The estimated cost for GFC heater systems is $2,500/kw of electrical output. Designed thermal output of GFC heaters will be 1500 Btu/ft/hr. At 40% electrical efficiency, the result is an electrical capacity of approximately 190 Watts/foot of heater. Thus, a 100-foot GFC heater will have an electrical capacity of 19 kilowatts and an installed cost of $47,500. Therefore, the total cost of the GFC heater system to support a 10,000 bpd coal-to-liquids facility would be approximately $66.5 million.

In addition to the GFC heater system, there is additional cost associated with drilling and casing boreholes. The approximate ratio of GFC heater wells to production wells is 2.35. Therefore, the total boreholes for a 10,000 bpd facility would be 1,995 total holes active at any one time (595 production wells + 1,400 heater wells). Total well costs at an average of 1,000-foot depth per well, will be approximately $99.7 million. The combined cost for the GFCs and installation of the heater system would be approximately $166.2 million.

**Economics Benefits Summary:**

GFCs produce a valuable slate of products in addition to the FT liquids. Each ton of coal processed by a GFC-FT facility will produce:

<table>
<thead>
<tr>
<th>Product</th>
<th>Volume</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFC Power production</td>
<td>157 kWh</td>
<td>$ 8.63</td>
</tr>
<tr>
<td>GFC Pipeline quality gas</td>
<td>4.3 Mcf</td>
<td>$ 25.80</td>
</tr>
<tr>
<td>GFC Oil from coal</td>
<td>10 gal</td>
<td>$ 11.90</td>
</tr>
<tr>
<td>Subtotal GFC</td>
<td></td>
<td>$ 46.33</td>
</tr>
<tr>
<td>FT liquids (*)</td>
<td>50 gal</td>
<td>$ 74.00</td>
</tr>
<tr>
<td>FT Power production</td>
<td>34 kWh</td>
<td>$ 1.79</td>
</tr>
<tr>
<td>Subtotal FT</td>
<td></td>
<td>$ 75.79</td>
</tr>
<tr>
<td><strong>Total Value / ton of coal</strong></td>
<td></td>
<td><strong>$ 122.12</strong></td>
</tr>
</tbody>
</table>

(*) Assumes $12/bbl premium for FT liquids over West Texas Intermediate = $62/bbl

Total revenue for a GFC-FT project:

- Daily \(8,400 \text{ tpd} \times \$122.12 = \$1.026 \text{ MM}\)
- Annual \((95\% \text{ Plant factor}) = \$374.5 \text{ MM}\)

Total project cost for a GFC-FT, 10,000 bpd project:

- Original FT costs \$656 \text{ MM}
- Less GFC savings \($194 \text{ MM}\)
- GFC System costs \$166 \text{ MM}
- Adjusted Project costs \$ 628 \text{ MM}\)
BOE Production vs. Capital Cost Analysis

Additional products associated with combining a GFC system with a traditional FT facility will reduce the cost of daily barrel production capacity as follows:

<table>
<thead>
<tr>
<th>Products</th>
<th>Volume/ton</th>
<th>Barrel Oil Equivalents /ton of coal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FT</td>
</tr>
<tr>
<td>GFC Power</td>
<td>157 kWh</td>
<td>–</td>
</tr>
<tr>
<td>GFC Pipeline gas</td>
<td>4.3 Mcf</td>
<td>–</td>
</tr>
<tr>
<td>GFC Oil</td>
<td>10 gal</td>
<td>–</td>
</tr>
<tr>
<td>FT Diesel (85%)</td>
<td>42.5 gal</td>
<td>.9031</td>
</tr>
<tr>
<td>FT Naphtha (15%)</td>
<td>7.5 gal</td>
<td>.1594</td>
</tr>
<tr>
<td>FT Power production</td>
<td>34 kWh</td>
<td>.0193</td>
</tr>
</tbody>
</table>

Total BOEs /ton: 1.0818 2.1259

**Additional Production with GFCs:** 1.0441

**Assumptions:**
- One Barrel Oil = 6 MM Btu
- One Barrel Diesel or Naphtha = 5.355 MM Btu
- One kWh = 3412 Btu
- One cf Pipeline gas = 1,000 Btu

As can be established from the above, combining a GFC system with a traditional FT facility virtually doubles the daily output of energy products on a BOE basis. The effect of this increased production is dramatic on the cost of daily barrel production capacity, reducing the above noted $65,600 per daily barrel production by a factor of 1.9652 (1.0818 + 1.0441/ 1.0818) to $33,400. This cost is comparable to current industry costs for traditional oil and gas production.

**CO₂ Emissions**

One of the most significant criticisms of coal-to-liquids technology is its impact on greenhouse gas emissions. Previously proposed coal-to-liquids projects have been among the worst performers of CO₂ emitted per gallon of liquids produced. Compared with conventional petroleum refineries, coal to liquids plants are estimated to emit twice the carbon dioxide per gallon of hydrocarbon product produced.

Conventional fuels, like petroleum derived gasoline and diesel produce approximately 20 pounds of CO₂ per gallon burned, while a FT process (diesel and naphtha) would produce up to an additional 50 pounds of CO₂ per gallon of produced liquids. For example, in their US Patent 6,976,362, Rentech states that a 5,500 tpd coal to liquids plant will produce 11,300 tons per day of carbon dioxide that is sequestered and another 500 tons per day that is emitted as exhaust. Therefore the ratio of CO₂ to coal in a coal-to-liquids plant can be over 2:1, (i.e. more than two pounds of CO₂ produced for every pound of processed coal). While this level of CO₂ can be compared to simple combustion of a ton of coal, producing 2.86 tons of carbon dioxide, FT liquids still produce the additional 20 pounds of CO₂ per gallon when burned as fuel.

Virtually all of the higher emissions are associated with the coal gasifier. In conventional gasifiers, both surface facilities and in-situ approaches use the coal itself as the source of heat necessary to reach gasification temperatures. In conventional gasification, a small amount of oxidizer is allowed to reach and ignite the coal. Enough heat is released through incomplete
combustion to raise the remaining coal into gasification range. Air is the most common oxidizer; however, pure oxygen may also be used. Pure oxygen raises the Btu value of the gases produced by the process, but is achieved at the cost of building an oxygenation plant. In either case the partial combustion of a part of the coal to produce heat creates an abundance of carbon dioxide. It is this extra CO$_2$ from the gasifier that doubles the carbon output of coal derived liquid fuels.

GFCs can mitigate this problem. With GFCs providing heat for in-situ coal gasification there is no need for partial combustion of the coal. The heat is a byproduct of the electrical production process inside the fuel cells. The inherent thermodynamic efficiency of this process dramatically reduces the amount of carbon dioxide produced. Total CO$_2$ emissions would be reduced from 18,022 tpd for a traditional FT facility (processing 8,400 tpd coal) to 2,880 tpd utilizing GFCs for synthesis gas production, thereby reducing CO$_2$ emissions by 84%!

CO$_2$ emissions can be further reduced by capturing and sequestering carbon dioxide emitted by the fuel cells. Because air and fuel never mix in the fuel cell, the exhaust stream is a mixture of unprocessed fuel, steam, and CO$_2$. The steam and fuel are both recycled to fuel reformers on the surface, leaving an almost pure stream of carbon dioxide that is much easier and less expensive to capture than emissions from a conventional power plant.

**Conclusion**

With decreased capital costs, significantly increased revenues and elimination of excess CO$_2$ emissions, GFCs can remove significant barriers preventing coal-to-liquids conversion from achieving large scale implementation.

One of the potential operating cost savings not discussed in this summary analysis are the coal mining and handling costs. Operating a GFC-FT coal-to-liquids system could potentially reduce or eliminate such mining and coal handling costs.