TRIG™ for Low Rank Coal: A New Perspective on IGCC

Qianlin Zhuang
KBR, Inc., Houston, Texas, USA
KBR at a Glance

Revenue: 2013 - $7.28 Billion
Backlog: $14.41 Billion (As of Dec. 31, 2013)
Headquarters in Houston, Texas
27,000 employees
70+ countries

KBR is a global engineering, construction, and services company supporting the energy, hydrocarbons, government services, minerals, civil infrastructure, power, industrial, and commercial markets
IGCC Development Activities Worldwide

<table>
<thead>
<tr>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool Water IGCC Demo USA</td>
<td>Buggenum IGCC Netherlands</td>
<td>Nakoso IGCC Japan</td>
<td>GreenGen IGCC China</td>
</tr>
<tr>
<td></td>
<td>Wabash River IGCC USA</td>
<td></td>
<td>Duke IGCC 630 MW, USA</td>
</tr>
<tr>
<td></td>
<td>Tampa IGCC USA</td>
<td></td>
<td>KOWEPO IGCC Korea, 2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Southern IGCC Kemper 2015</td>
</tr>
</tbody>
</table>

- IGCC has been anticipated as one of the next generation technologies for electricity generation

- Most IGCC demonstrations use high cost, high quality coal as feedstock
## Coal Still Critical for Many Economies

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal Reserves, MM tonnes*</th>
<th>% World Total*</th>
<th>% LRC*</th>
<th>Reliance of Electricity on Coal 2011**</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>237,295</td>
<td>22.6</td>
<td>54%</td>
<td>43.1%</td>
</tr>
<tr>
<td>Russia</td>
<td>157,010</td>
<td>14.4</td>
<td>69%</td>
<td>15.6%</td>
</tr>
<tr>
<td>China</td>
<td>114,500</td>
<td>12.6</td>
<td>46%</td>
<td>79.0%</td>
</tr>
<tr>
<td>Australia</td>
<td>76,400</td>
<td>8.9</td>
<td>51%</td>
<td>76.5%</td>
</tr>
<tr>
<td>India</td>
<td>60,600</td>
<td>7</td>
<td>7%</td>
<td>67.9%</td>
</tr>
<tr>
<td>Germany</td>
<td>40,699</td>
<td>4.7</td>
<td>100%</td>
<td>44.7%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>33,873</td>
<td>3.9</td>
<td>55%</td>
<td>38.2%</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>33,600</td>
<td>3.9</td>
<td>36%</td>
<td>81.1%</td>
</tr>
<tr>
<td>South Africa</td>
<td>30,156</td>
<td>3.5</td>
<td>0%</td>
<td>92.7%</td>
</tr>
<tr>
<td>Serbia</td>
<td>13,770</td>
<td>1.6</td>
<td>100%</td>
<td>74.6%</td>
</tr>
<tr>
<td>Colombia</td>
<td>6,746</td>
<td>0.8</td>
<td>6%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Canada</td>
<td>6,528</td>
<td>0.8</td>
<td>48%</td>
<td>12.0%</td>
</tr>
<tr>
<td>Poland</td>
<td>5,709</td>
<td>0.7</td>
<td>24%</td>
<td>86.5%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5,529</td>
<td>0.6</td>
<td>73%</td>
<td>44.4%</td>
</tr>
<tr>
<td>Brazil</td>
<td>4,559</td>
<td>0.5</td>
<td>100%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Greece</td>
<td>3,020</td>
<td>0.4</td>
<td>100%</td>
<td>52.3%</td>
</tr>
<tr>
<td>Bosnia and Herzegovina</td>
<td>2,853</td>
<td>0.3</td>
<td>83%</td>
<td>70.7%</td>
</tr>
<tr>
<td>Mongolia</td>
<td>2,520</td>
<td>0.3</td>
<td>54%</td>
<td>95.1%</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>2,366</td>
<td>0.3</td>
<td>100%</td>
<td>54.2%</td>
</tr>
<tr>
<td>Turkey</td>
<td>2,343</td>
<td>0.3</td>
<td>77%</td>
<td>28.9%</td>
</tr>
</tbody>
</table>

- High reliance of power generation on coal
- Large low rank coal reserve
- Effective use of low rank coal still a challenge

Source: * World Energy Council 2011; ** IEA website 2011
TRIG: Transport Integrated Gasification

TRIG is designed as a pressurized, partial dry feed and dry ash discharge technology that operates below ash fusion temperature under transport mode.

- Designed for low rank coal
- 5,000 TPD single train capacity
- Flexible design with air-/O₂-blowed
- Proprietary dry feeding system and continuous dry ash discharging system
- Dry syngas cleanup for particulate removal
- Good quality syngas

✓ Economical
✓ Reliable
✓ Efficient
✓ Environmentally friendly
✓ Less water usage
Gasification Technologies in Marketplace

Players
- GE/Texaco
- Siemens
- Qinghua
- MHI
- Choren
- KBR
- CoP
- ECUST
- Lurgi’s
- Shell
- HT-L
- BGL
- SES
- NWRI
- PWR
- Sedin

Feed
- Slurry
- Dry
- Formed coal
- Slagging

Discharge
- Quench
- Single FI
- Multi FI
- Non-slagging
- Agglomerating

Reactor Type
- Fluidized
- Moving
- Fixed Bed
- One Stage
- Transport
- Down-Flow
- Up-Flow

Transport
- Ash Fusion Temp (AFT)

Operating Range
- T1
- T2
- T3
- T4

Types
- Slagging
- Agglomerating
- Fluidized Bed
- Fixed/Moving Bed

Players
- PWR
- ECUST
- SES

Gasification Technologies in Marketplace
**Non-Slagging TRIG Gasification Technology**

**TRIG Attributes:**
- Good Syngas Quality (+)
- High Energy Efficiency (+)
- High Single-Train Capacity (+)
- Suitable for Low-Rank Low-Cost Coals (+)

Developed for low rank coal, TRIG operates at a well managed moderate temperature range below T1 that minimizes formation of hydrocarbons such as tars and oils.

TRIG maintains positive aspects of slagging gasification technologies while avoiding negatives of other non-slagging technologies.
TRIG for Utilizing Low Rank Coal

Low cost/low quality and hard to transport low rank coal, ideal for TRIG

High price/high quality coal

Slagging Gasification based IGCC’s play field

Standard Classification of Coals by Rank per ASTM D388
850MW TRIG IGCC Cost Study

Objective:
Low Rank Coal TRIG IGCC meets 43% net efficiency and cost less than 10,000 RMB/kw.
Cost estimate at +/- 30% accuracy

Plant Design Considerations

- Mine-mouth plant base-load plant, 7,500hrs annual
- Dedicated coal drying process
- Air blown gasification
  - 5 ppm/SOx, 25 ppm/NOx without SCR;
  - Mercury (Hg) removal included;
  - CO₂ capture not required
- Two gasifiers to load two 9F class GT
- Light distillate for start-up

Collaborative Effort

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>As Rcv’d</th>
<th>As Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>Kcal/kg</td>
<td>3,424</td>
<td>4,157</td>
</tr>
<tr>
<td>Moisture</td>
<td>wt.%</td>
<td>34.1</td>
<td>20.0</td>
</tr>
<tr>
<td>Ash</td>
<td>wt.%</td>
<td>11.22</td>
<td>13.61</td>
</tr>
<tr>
<td>Volatile</td>
<td>wt.%</td>
<td>23.77</td>
<td>28.86</td>
</tr>
<tr>
<td>Fixed C.</td>
<td>wt.%</td>
<td>30.93</td>
<td>37.55</td>
</tr>
</tbody>
</table>
Low Rank Coal TRIG 850 MW IGCC Plot Plan

- Coal Storage
- Gas Turbine
- Coal Drying
- Water Treatment
- Steam Turbine
- Purification
- Switch Yard
- Cooling Tower
- N₂ Plant
- Sulfur Block
- TRIG Gasification
- Water Treatment
- Steam Turbine
- Switch Yard
- Cooling Tower
- N₂ Plant
- Sulfur Block
- TRIG Gasification
## Low Rank Coal TRIG 850 MW IGCC Performance Summary

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Consumption Rate, as received with 34% Moisture</td>
<td>TPD</td>
<td>11,740</td>
</tr>
<tr>
<td>Coal Consumption Rate, as fed with 20% Moisture</td>
<td>TPD</td>
<td>9,670</td>
</tr>
<tr>
<td>Power Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GT Output/unit</td>
<td>MW</td>
<td>295</td>
</tr>
<tr>
<td>ST Output</td>
<td>MW</td>
<td>424</td>
</tr>
<tr>
<td>Combined Cycle Output, Gross</td>
<td>MW</td>
<td>1,014</td>
</tr>
<tr>
<td>Aux. Power Consumption</td>
<td>MW</td>
<td>166</td>
</tr>
<tr>
<td>Power Output, Net</td>
<td>MW</td>
<td>848</td>
</tr>
<tr>
<td>Net Heat Rate Of IGCC</td>
<td>kJ/kWh</td>
<td>8,250</td>
</tr>
<tr>
<td>Net Efficiency Of IGCC</td>
<td>%</td>
<td>43.7</td>
</tr>
</tbody>
</table>

Note: Gas turbine performance is estimated based on vendor spec.

LRC TRIG IGCC is efficient using low rank coal
Low Rank Coal TRIG 850 MW IGCC

Comparison with Advanced USC in China

- China has made a big stride in building USC using good quality coal
- USC Deployment using low rank coal is underway
- LRC TRIG IGCC is advanced and competitive

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>LRC TRIG IGCC 850 MW</th>
<th>Ultra Supercritical, 1,000 MW (2)</th>
<th>NGCC, 9FA Base (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Heating Value as received, LHV</td>
<td>kcal/kg</td>
<td>3,424</td>
<td>3,886</td>
<td>NG</td>
</tr>
<tr>
<td>Moisture, as received</td>
<td>%wt</td>
<td>34.1</td>
<td>31.3</td>
<td>n/a</td>
</tr>
<tr>
<td>Coal as fed</td>
<td>%wt</td>
<td>20</td>
<td>23</td>
<td>n/a</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>%</td>
<td>43.7</td>
<td>42.9</td>
<td>55.9</td>
</tr>
</tbody>
</table>

Note: 1 - in operation; 2 - in early development phase
## Low Rank Coal TRIG 850 MW IGCC
### Emissions Regulation for New Unit

- Conventional technology faces significant challenges for additional reduction
- IGCC is able to make another big step

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**Pollutant** | **Unit** | **TRIG IGCC** | **Current Limits** | **2004 Limits**
--- | --- | --- | --- | ---
SO\(_2\) | mg/m\(^3\) | 17.1\(^1\) | 50/200 | 400
NO\(_x\) | mg/m\(^3\) | 47 | 100/200 | 450
Mercury | mg/m\(^3\) | 0.001\(^2\) | 0.03 | n/a
Particulate Matter (PM) | mg/m\(^3\) | 0.025\(^3\) | 20/30 | 50

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1. Average total plant SO\(_2\) emission (dry basis). SO\(_2\) emission at HRSG stack is 2.95 mg/m\(^3\).
2. 85% Hg removal assuming Hg content in coal at 0.13 mg/g (dry basis).
3. PM from baghouse vent streams excluded.

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China has made significant progress on emissions regulations.
Low Rank Coal TRIG 850 MW IGCC
Water Usage Comparison

- Process Design minimizes water blow-down.
- Majority of water makeup stems from cooling tower water loss.
- TRIG IGCC has minimum water usage relative to other similar IGCCs

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFW</td>
<td>100</td>
<td>77</td>
</tr>
<tr>
<td>Cooling Tower</td>
<td>1,139</td>
<td>665</td>
</tr>
<tr>
<td>Drying</td>
<td>(89)</td>
<td>(89)</td>
</tr>
<tr>
<td>Others</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>1,185</td>
<td>660</td>
</tr>
</tbody>
</table>

Comparison with Other IGCCs

Source: DOE NETL Study 2011
## Economic Analysis Assumptions

<table>
<thead>
<tr>
<th>Major Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Period</td>
<td>Month</td>
<td>36</td>
</tr>
<tr>
<td>Annual Operating Hour</td>
<td>Hour</td>
<td>7,500</td>
</tr>
<tr>
<td>Plant Staffing</td>
<td>Person</td>
<td>317</td>
</tr>
<tr>
<td>Equity/Loan</td>
<td></td>
<td>20/80</td>
</tr>
<tr>
<td>Loan Interest Rate</td>
<td>%</td>
<td>6.55</td>
</tr>
<tr>
<td>Depreciation Period</td>
<td>Year</td>
<td>15</td>
</tr>
<tr>
<td>Standard Coal Price (Inc’l taxes)</td>
<td>RMB/ton</td>
<td>300</td>
</tr>
<tr>
<td>Water</td>
<td>RMB/ton</td>
<td>1</td>
</tr>
<tr>
<td>O&amp;M Base of Capital Investment</td>
<td>%</td>
<td>4</td>
</tr>
</tbody>
</table>

- Model uses China standard one for utility sector
- Routines for power project development followed
- Price guideline referenced
- Local prices used for utilities

*Note: RMB stands for Chinese Renminbi; 1 USD = 6.2 RMB*
### Findings: Economic Analysis

- LRC TRIG IGCC meets project approval criteria in China
- Increased emissions compliance cost will make LRC TRIG IGCC an ideal clean coal technology
- Support of government policy will encourage its wide adoption

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Unit</th>
<th>Total IRR 8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGCC Net Output</td>
<td>MW</td>
<td>1,014</td>
</tr>
<tr>
<td>Static Investment</td>
<td>MM RMB</td>
<td>7,251.1</td>
</tr>
<tr>
<td>Loan Interest during construction</td>
<td>MM RMB</td>
<td>350.3</td>
</tr>
<tr>
<td>Liquidity</td>
<td>MM RMB</td>
<td>90.6</td>
</tr>
<tr>
<td>Cost of Electricity w/o Tax</td>
<td>RMB/MWh</td>
<td>265.6</td>
</tr>
<tr>
<td>Cost of Electricity with Tax</td>
<td>RMB/MWh</td>
<td>310.3</td>
</tr>
<tr>
<td>IRR after Taxes</td>
<td>%</td>
<td>8.18</td>
</tr>
<tr>
<td>Pay Back Period</td>
<td>Year</td>
<td>12</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>MM RMB</td>
<td>494.8</td>
</tr>
<tr>
<td>Project Internal Rate Of Return On Equity</td>
<td>%</td>
<td>13.03</td>
</tr>
<tr>
<td>Internal Rate Of Return Of Investment</td>
<td>%</td>
<td>8.0</td>
</tr>
<tr>
<td>Net Rate Of Return on Equity</td>
<td>%</td>
<td>12.2</td>
</tr>
</tbody>
</table>
COE Sensitivity

- Annual operating hours has the most impact to COE increase
- CAPEX has the most impact to COE reduction
Kemper County TRIG IGCC Overview

- 2x1 Integrated Gasification Combined Cycle (IGCC)
  - 2 Transport Gasifiers
  - 2 Siemens SGT6 - 5000F CTs
  - 1 Toshiba Steam Turbine
  - 582 MW peak and 524 MW on syngas
  - Heat Rate: 12,810 kJ/kWh
  - 32.1% LHV Efficiency w/ CO2 control and >40% moisture coal
  - UOP’s Selexol Process for H2S and CO2 removal
  - Haldor Topsøe’s Wet Sulfuric Acid for H2SO4 production.
  - 65% CO2 capture (~360 kg/MWh emission rate)
  - Mine Mouth Lignite

- Owner & Operator: Mississippi Power

- By-Products (metric tonnes per year)
  - 3,500,000 - Carbon dioxide used for EOR
  - 150,000 - Sulfuric acid
  - 19,000 - Ammonia

### Kemper Lignite Composition

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV kcal/kg</td>
<td>2572</td>
<td>2317 – 2854</td>
</tr>
<tr>
<td>Moisture %</td>
<td>45.5</td>
<td>42 – 50</td>
</tr>
<tr>
<td>Ash %</td>
<td>12</td>
<td>8.6 – 17</td>
</tr>
<tr>
<td>Sulfur %</td>
<td>1</td>
<td>0.35 – 1.7</td>
</tr>
</tbody>
</table>
Kemper County IGCC Infrastructure

Additional Scope

- **112 km** transmission
- ~**96 km** CO₂ pipeline (for EOR)
- ~**8 km** natural gas pipeline
- ~**125 km²** mine site.
- ~**48 km** treated effluent line
Project Current Status

Construction
◆ Essentially complete except for heat tracing & insulation. Support for startup and operations now through COD

Startup
◆ Gasifier first-fire is expected in the 4th quarter.

Operations
◆ Plant staff at 173, planning for 220 by COD. Operation and Maintenance training in progress. Team participation in startup and commissioning

Combined Cycle
◆ CC in service Aug. 9, 2014

Mine
◆ Mine staffing at 120, estimated 220 at full operations. ~890,000 tons of lignite mined
Conclusion

- TRIG IGCC, as an efficient and cost effective clean coal technology, presents a solution to unlock the value of low rank coals
- Its superior environmental performance and low water usage address an increasing need for many regions or countries
- Its design flexibility for CO2 Capture corresponds well to future policy for CCS implementation, technologically and economically
For more information

- Visit coal.kbr.com or email coal@kbr.com