TRIG™: COMMERCIAL STATUS OF COAL GASIFICATION AND NEED FOR LOW RANK COAL TECHNOLOGY

Qianlin Zhuang
KBR Technology, Houston, Texas 77002, USA
KBR at a Glance

- Revenue: 2013 - $7.28 Billion
- Backlog: Dec 31, 2013 - $14.41 Billion
- 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.
KBR/Southern Company Alliance

KBR-Southern Alliance:

- Technology available globally through KBR for all Industrial and Power applications of TRIG™ using low-rank coals
- Collaborative blending of skills and strengths of each company for global customers
- KBR leads all marketing and licensing activities
TRIG - Transport Integrated Gasification

TRIG is a pressurized, partially dried feed, dry ash (non-slagging) discharge and refractory lined gasification that operates at low temperature under transport mode. TRIG is designed to process low quality, low cost, low heating value low rank coal for syngas production.

- Transport operation mode
- Efficient operation
- Tolerant of large coal particle size and moisture level in fed coal
- Large single train capacity up to 5,000 TPD
- Flexibility with air-blown or O₂-blown
- Proprietary dry feeding system without using feed injectors and continuous dry ash discharging system
- Dry syngas cleanup for particulate removal resulting in low water usage
- Good quality syngas

✓ Economical
✓ Reliable
✓ Efficient
✓ Environmentally friendly
✓ Less water usage
## Coal Still Critical for Many Economies

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal Reserves, mm tons*</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>

*Source: * World Energy Council 2011; ** IEA website 2011

- High reliance of power generation on coal
- Large low rank coal reserve
- Effective use of low rank coal remains as a challenge
Commercial Applications of Syngas

Coal Gasification

Syngas $H_2 + CO$

Chemicals

- Methanol
- Ammonia
- Urea
- Ammonia nitrate/sulfate
- Formaldehyde
- MTBE
- Acetic acid
- Amine
- DME
- Olefins
- Oxochemicals: Butanol, Ethylhexanol

- Hydrotreating
- Hydrocracking
- Hydrodesulfurization
- Hydrodenitrogenation

Fuels

- Coal to SNG
- Gas Industry

Electricity (IGCC)

- Iron Industry

Refineries

- Coal to Liquid (Direct or indirect liquefaction)
Coal Gasification Technologies in Marketplace

- Licensor: KBR, Siemens, Qinghua, MHI, Shell, Choren
- Feed: Slurry, Dry, Syngas Cooler
- Discharge: Formed coal, Slagging, Agglomerating
- Reactor Type: Fluidized, Moving, Fixed Bed, Down-Flow

Ash Fusion Temp (AFT), Operating Range:
- Slagging
- Agglomerating
- Non-slagging

T1, T2, T3, T4

Fixed/Moving Bed Transport

Entrained Bed

Coal Gasification Technologies in Marketplace

©2013 KBR, Inc. All Rights Reserved | 8
TRIG™, developed for low rank coal, is operated as a non-slagging technology at a well managed moderate temperature range that minimizes formation of hydrocarbons such as tars and oils.

**Non-Slagging TRIG Gasification Technology**

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

**TRIG** has these general characteristics:

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

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

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

High price/quality coal

Slagging Gasification based IGCC’s play field

Standard Classification of Coals by Rank per ASTM D388

- HHV, kcal/kg
- FC, wt%
Low Rank Coal TRIG 800 MW IGCC
- China Cost Study

- Develop an advanced Low Rank Coal TRIG™ IGCC product with low emissions and low water usage,
- Develop China cost estimate of +/- 30% accuracy,
- Total power plant approach by working with experienced engineering companies.

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

Inner Mongolia Low Rank Coal

<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>Element</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>wt.%</td>
<td>39.71</td>
<td>48.20</td>
</tr>
<tr>
<td>H</td>
<td>wt.%</td>
<td>2.59</td>
<td>3.14</td>
</tr>
<tr>
<td>N</td>
<td>wt.%</td>
<td>0.62</td>
<td>0.75</td>
</tr>
<tr>
<td>S</td>
<td>wt.%</td>
<td>1.00</td>
<td>1.21</td>
</tr>
<tr>
<td>O</td>
<td>wt.%</td>
<td>10.79</td>
<td>13.08</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 800 MW IGCC
- Plot Plan

Coal Storage
Coal Drying
TRIG™ Gasification
N2 Plant
Sulfur Block
Water Treatment
Gas Turbine
Switch Yard
Steam Turbine
Purification
Cooling Tower
Low Rank Coal TRIG 800 MW IGCC
- Division of Work

©2013 KBR, Inc. All Rights Reserved | 13
Low Rank Coal TRIG™ IGCC
- Performance Summary

✓ LRC TRIG™ IGCC is efficient using low rank coal

<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>409</td>
</tr>
<tr>
<td>Combined Cycle Output, Gross</td>
<td>MW</td>
<td>999</td>
</tr>
<tr>
<td>Aux. Power Consumption</td>
<td>MW</td>
<td>157</td>
</tr>
<tr>
<td>Power Output, Net</td>
<td>MW</td>
<td>842</td>
</tr>
<tr>
<td>Net Heat Rate Of IGCC</td>
<td>kJ/kWh</td>
<td>8,360</td>
</tr>
<tr>
<td>Net Efficiency Of IGCC</td>
<td>%</td>
<td>43.1</td>
</tr>
</tbody>
</table>

Note: Gas turbine performance is estimated based on vendor spec.
Low Rank Coal TRIG 800 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 842 MW</th>
<th>Ultra Supercritical, 1,000 MW (2)</th>
<th>NGCC, 9FA Base (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td></td>
<td>Lignite</td>
<td>Lignite</td>
<td>NG</td>
</tr>
<tr>
<td>Heating Value as received, LHV</td>
<td>kcal/kg</td>
<td>3,424</td>
<td>3,886</td>
<td></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>43.1</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 800 MW IGCC
- Emissions Regulation for New Unit

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

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Unit</th>
<th>TRIG™ IGCC</th>
<th>Current Limits 9 Special Areas/Rest China</th>
<th>2004 Limits New Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>mg/m³</td>
<td>2.95¹</td>
<td>50/200</td>
<td>400</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/m³</td>
<td>47</td>
<td>100/200</td>
<td>450</td>
</tr>
<tr>
<td>Mercury</td>
<td>mg/m³</td>
<td>0.001²</td>
<td>0.03</td>
<td>n/a</td>
</tr>
<tr>
<td>Particulate Matter (PM)</td>
<td>mg/m³</td>
<td>0.025³</td>
<td>20/30</td>
<td>50</td>
</tr>
</tbody>
</table>

1. SO₂ emission at HRSG stack, the total plant SO₂ averaged at 17.13 mg/Nm³ (dry basis).
2. 85% Hg removal assuming Hg content in coal at 0.13 mg/g (dry basis).
3. PM from baghouse vent streams excluded.

China has made a significant progress on emissions reduction;
Conventional technology faces challenges for further reduction.
Low Rank Coal TRIG 800 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.

### Makeup Rate. ton/hr

<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
Improvement by Optimization
- Low Rank Coal TRIG 800 MW IGCC

Optimization of
AGR and
SRU/TGTU
What Differentiates TRIG from Others?

- IGCC and PC

Utilize large reserves of low rank coal resources available in China

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>As Rcv’d</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>Kcal/kg</td>
<td>3,424</td>
</tr>
<tr>
<td>Moisture</td>
<td>wt.%</td>
<td>34.1</td>
</tr>
<tr>
<td>Ash</td>
<td>wt.%</td>
<td>11.22</td>
</tr>
<tr>
<td>Volatile</td>
<td>wt.%</td>
<td>23.77</td>
</tr>
<tr>
<td>Fixed C.</td>
<td>wt.%</td>
<td>30.93</td>
</tr>
</tbody>
</table>

Most Advanced 43.5+% (LHV)

Small plot plan

Significant decrease in capex to below RMB 9k/kw vs. previous IGCCs at 12+k level

LRC TRIG™ IGCC

1,000 MW
2 gasifiers
2x9F GT/ST
Air blown gasification
Low SOx, NOx, PM
Hg Removal
Dedicated Drying
No Carbon Capture
Complete scope
Leverage local capability & practice
Quote for major equip

Less Water Consumption

Superior Environmental Performance vs PC

**Pollutant** | **Unit** | **TRIG™ IGCC**
--- | --- | ---
SO₂ | mg/m³ | <18
NOx | mg/m³ | 47
Mercury | mg/m³ | 0.001
Particulate Matter (PM) | mg/m³ | 0.025
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)**
  - **2,720,000** - Carbon dioxide used for EOR
  - **122,000** - Sulfuric acid
  - **18,000** - 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

~112 km transmission
  ✓ Station energized

~96 km CO₂ pipeline (for EOR)
  ✓ 100% Complete

~8 km natural gas pipeline
  ✓ 100% Complete

~125 km² mine site.
  ✓ Placed in Service in June 2013

~48 km treated effluent line
  ✓ 100% Complete
### Key Startup Milestones Completed

<table>
<thead>
<tr>
<th>Key Milestones</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Admin/Control Building - DCS Control System Functional</td>
<td>21-Sep-12</td>
</tr>
<tr>
<td>✓ Start Filling Treated Effluent Reservoir</td>
<td>15-Oct-12</td>
</tr>
<tr>
<td>✓ Station Service Energized</td>
<td>8-Nov-12</td>
</tr>
<tr>
<td>✓ Water Treatment Plant Commissioning Completion</td>
<td>30-Mar-13</td>
</tr>
<tr>
<td>✓ Cooling Tower Completion</td>
<td>10-Apr-13</td>
</tr>
<tr>
<td>✓ Fire Auxiliary Boiler</td>
<td>5-Aug-13</td>
</tr>
<tr>
<td>✓ First Fire Combustion Turbine – A</td>
<td>28-Aug-13</td>
</tr>
<tr>
<td>✓ First Fire Combustion Turbine – B</td>
<td>4-Sep-13</td>
</tr>
<tr>
<td>✓ Steam Turbine – Sync To Grid</td>
<td>5-Oct-13</td>
</tr>
<tr>
<td>• First Gasifier Heatup</td>
<td></td>
</tr>
<tr>
<td>• Reliable Syngas To Combustion Turbine A</td>
<td></td>
</tr>
<tr>
<td>• Reliable Syngas To Combustion Turbine B</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

✔ TRIG IGCC is an efficient, cost effective clean coal technology 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 will correspond well to future policy for CCS implementation, technologically and economically
Thank You!

For more information...

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