KBR Olefins Technology – Technology options to meet uncertain market conditions

4th Petrochem Conclave
Delhi, 12th February 2015

Sourabh Mukherjee
Agenda

- World Olefins market trends

- Olefins technology combinations targeting improved flexibility and economics
Olefins Market
Change

We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten. Don't let yourself be lulled into inaction.

- Bill Gates
Underestimating 10 Year Change = **UNCERTAINTY**

### 2004 View USA Petrochemicals
- High Cost of Ethylene: USA vs Asia: 150%
- Feedstock Disadvantaged & Least Competitive in the World
- Gas/Oil Price Ratio: 109%
- Bad Place to Invest
- Rapidly Declining Exports; Expected to Import
- Europe is 2\textsuperscript{nd} Most Competitive

### Early 2014 View USA Petrochemicals
- Low Cost of Ethylene: USA vs Asia: 70%
- Cheap & Abundant Feedstock & 2\textsuperscript{nd} Most Competitive in the World
- Gas/Oil Price Ratio: 29%
- $120 Billion Invested in Chemicals (IHS Estimate 2014)
- Rapidly Growing Export
- Europe is Least Competitive
Underestimating Sudden Change = **UNCERTAINTY**

<table>
<thead>
<tr>
<th>2014 View USA Petrochemicals</th>
<th>Late 2014 View Petrochemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Low Cost of Ethylene:</td>
<td>- Crude prices drop from $100/bbl range to $50/bbl range – within <strong>four-six month</strong> span</td>
</tr>
<tr>
<td>USA vs Asia: 70%</td>
<td>- Consequential reduction in naphtha price means the cost of Ethylene from liquid becomes more competitive (almost on par with ethane)</td>
</tr>
<tr>
<td>- Cheap &amp; Abundant Feedstock &amp; 2\textsuperscript{nd} Most Competitive in the World</td>
<td>- Investment plans for ethane crackers being reconsidered</td>
</tr>
<tr>
<td>- Gas/Oil Price Ratio: 29%</td>
<td>- Europe and Asia competitiveness improves</td>
</tr>
<tr>
<td>- $120 Billion Invested in Chemicals (IHS Estimate 2014)</td>
<td></td>
</tr>
<tr>
<td>- Rapidly Growing Export</td>
<td></td>
</tr>
<tr>
<td>- Europe is Least Competitive</td>
<td></td>
</tr>
</tbody>
</table>
Uncertainty in the market cannot be avoided

To overcome market uncertainty producers need to

– Produce the right products from their assets

&

– Be flexible towards feed
Producing the right products from an Ethylene Complex
Ethylene Complex

Steam Cracker

Hydrocarbon Feed

Utilities

Waste

Ethylene

Co-Products

- Hydrogen
- Methane
- Propylene
- C4's
- PFO
- Etc..

Operations & Maintenance

Traditional focus

Potential to drive Technology Selection

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### Ethylene Complex Economics (Ethane)

#### Ethane Feed
- **Cost:** $380/MT

#### Utilities
- **Cost:** $98/MT Ethylene

#### Operations & Maintenance
- **Cost:** $53/MT Ethylene

#### Depreciation + ROC
- **Cost:** $250/MT Ethylene

<table>
<thead>
<tr>
<th>Cost</th>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane Feed</td>
<td>Ethylene</td>
</tr>
<tr>
<td>380</td>
<td>1000</td>
</tr>
<tr>
<td>Utilities</td>
<td>Co-Products</td>
</tr>
<tr>
<td>$98/MT Ethylene</td>
<td>Note 1</td>
</tr>
<tr>
<td>Operations &amp; Maintenance</td>
<td></td>
</tr>
<tr>
<td>$53/MT Ethylene</td>
<td>Note 1: Dependent upon co-product recovery</td>
</tr>
<tr>
<td>Depreciation + ROC</td>
<td>$250</td>
</tr>
</tbody>
</table>

**Note 1:** Dependent upon co-product recovery
Example 1: US Gulf Coast Cracker

Grassroots Cracker
Location: US Gulf Coast
Feedstock: Ethane (US Shale Gas)
Products:
- 1000 KTA Ethylene
- C3+ Stream (Sell)
- Fuel Oil
- Fuel Gas

Overall Material Balance

<table>
<thead>
<tr>
<th>Feed/Product</th>
<th>77% Yield (KTA)</th>
<th>80% Yield (KTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>1287</td>
<td>1250</td>
</tr>
<tr>
<td>Ethylene</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Fuel Gas</td>
<td>180</td>
<td>163</td>
</tr>
<tr>
<td>Mix C3+</td>
<td>102</td>
<td>85</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>5</td>
<td>2</td>
</tr>
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</table>
Example 1: US Gulf Coast Economics

<table>
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<tr>
<td>Ethylene</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Fuel Gas</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Mix C3+</td>
<td>103</td>
<td>87</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>1,131</strong></td>
<td><strong>1,111.4</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>77% Yield</th>
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<tbody>
<tr>
<td>Ethane Feed</td>
<td>489</td>
<td>475</td>
</tr>
<tr>
<td>Utilities</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Depreciation + ROC</td>
<td>250</td>
<td>250</td>
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<tr>
<td><strong>Sub-Total</strong></td>
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<td>876</td>
</tr>
<tr>
<td><strong>Total Margin</strong></td>
<td>241</td>
<td>235.4</td>
</tr>
</tbody>
</table>

Lower selectivity = ~$5.6 MM USD/yr Advantage
Example 2: CIS Region Cracker

Grassroots Cracker
Location: CIS Region
Feedstock: Ethane (Gas Plant)
Products:
- 1000 KTA Ethylene
- C3+ Stream (Fuel)
- Fuel Oil
- Fuel Gas

Overall Material Balance

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**Example 2: CIS Region Economics**

### Revenue ($MM USD)

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</tr>
<tr>
<td>Fuel Oil</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>1,051</strong></td>
<td><strong>1,043.4</strong></td>
</tr>
</tbody>
</table>

### Cost ($MM USD)

<table>
<thead>
<tr>
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### Margin ($MM USD)

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<tbody>
<tr>
<td>Revenue</td>
<td>1,051</td>
<td>1,043.3</td>
</tr>
<tr>
<td>Cost</td>
<td>890</td>
<td>876</td>
</tr>
<tr>
<td><strong>Total Margin</strong></td>
<td><strong>161</strong></td>
<td><strong>167.3</strong></td>
</tr>
</tbody>
</table>

Higher selectivity = ~$6.3 MM USD/yr Advantage
Example 3: CIS Region Cracker (Fixed Feed)

Grassroots Cracker
Location: CIS Region
Feedstock:
- 1200 KTA Ethane (Gas Plant)
Products:
- Ethylene
- C3+ Stream (Use for Fuel)
- Fuel Oil
- Fuel Gas

Overall Material Balance

<table>
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<th>80% Yield (KTA)</th>
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<tbody>
<tr>
<td>Ethane</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Ethylene</td>
<td>932</td>
<td>960</td>
</tr>
<tr>
<td>Fuel Gas</td>
<td>168</td>
<td>156</td>
</tr>
<tr>
<td>Mix C3+</td>
<td>95</td>
<td>82</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
### Example 3: CIS Region Economics (Fixed FEED)

<table>
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<tr>
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<td>23</td>
</tr>
<tr>
<td>Mix C3+</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>979</strong></td>
<td><strong>1,001.3</strong></td>
</tr>
</tbody>
</table>

### Cost ($MM USD)

<table>
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<th>77% Yield</th>
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</tr>
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<tbody>
<tr>
<td>Ethane Feed</td>
<td>456</td>
<td>456</td>
</tr>
<tr>
<td>Utilities</td>
<td>91</td>
<td>91</td>
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<tr>
<td>O&amp;M</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Depreciation + ROC</td>
<td>233</td>
<td>233</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>829</strong></td>
<td><strong>829</strong></td>
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### Margin ($MM USD)

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<tr>
<td>Cost</td>
<td>829</td>
<td>829</td>
</tr>
<tr>
<td><strong>Total Margin</strong></td>
<td><strong>150</strong></td>
<td><strong>172.3</strong></td>
</tr>
</tbody>
</table>

Higher selectivity = ~$22.3 MM USD/yr Advantage
How can Technology Impact Selectivity?

Residence Time Effect on Ethylene Yields

- More Ethylene
- More Co-Products

Relative Percent Yield Improvement vs. Residence Time (sec)

- NAPHTHA
- GAS OIL
- BUTANE
- PROPANE
- ETHANE

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How does KBR Address Residence Time?

Furnace Coil Portfolio

Relative Percent Yield Improvement

Residence Time (sec)

- GAS OIL
- NAPHTHA
- BUTANE
- PROPANE
- ETHANE

SC-1

SC-2

SC-4
KBR Furnace Portfolio & Experience

SC-1
Single Pass Straight Tube
(~ 0.08 - 0.12 sec)

SC-2
Two-Pass “U-Coil”
(~ 0.20 - 0.25 sec)

SC-4
Serpentine-Type E.g., “W-Coil”
(~ 0.35-1.0 sec)

# of Furnaces
209  49  207
### KBR & Competitors

<table>
<thead>
<tr>
<th>Coil Type</th>
<th>Residence Time (sec)</th>
<th>KBR</th>
<th>Competitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>W type</td>
<td>0.4</td>
<td>SC-4</td>
<td>Yes</td>
</tr>
<tr>
<td>U Type</td>
<td>0.2</td>
<td>SC-2</td>
<td>Yes</td>
</tr>
<tr>
<td>One pass</td>
<td>0.1</td>
<td>SC-1</td>
<td>No</td>
</tr>
</tbody>
</table>

KBR has BROADEST Technology Portfolio
Steam Cracking Around the World

The Heavier the Hydrocarbon Feed, the more complicated the economics

North America:
Shale Gas

Middle East:
Ethane
Refinery Integration
Liquids

Russia/CIS:
Ethane
Refinery Integration
Naphtha

Asia:
Naphtha
Heavy Liquids

KBR Collaborates with client to determine best configuration
Flexibility towards feed
SCORE Feed Flexibility

Multi-Feed (Hybrid) Cracking

SCORE Furnaces

- Large Capacity
- Single Cabin Firebox
- 8 individually flow controlled passes
- Number of Feeds only limited by inlet piping arrangement
- Each Feed can be cracked at optimum conditions:
  - Temperature
  - S:HC Ratio

Flexibility of 8 mini furnaces within a single firebox
Hybrid Cracking Example

------ Naphtha & HCR ------
101-B

1 2
3 4
5 6
7 8

Naphtha
HCR

------ Naphtha, LPG/C3R & Ethane ------
103-B

1 2
3 4
5 6
7 8

Ethane
LPG/C3R

------ Naphtha, LPG/C3R & Ethane ------
104-B

1 2
3 4
5 6
7 8

LPG/C3R

------ Off Line ------
106-B

1 2
3 4
5 6
7 8

Off Line
## KBR Olefins Technology Offering – Adding further feed flexibility

<table>
<thead>
<tr>
<th>What</th>
<th>Feeds</th>
<th>Features</th>
</tr>
</thead>
</table>
| SCORE (Steam Cracking) | Ethane thru Gas Oil  | • Residence time ~0.08 – 1.0 sec  
• Low CAPEX  
• Superior Performance  
• Offered via Agreement with ExxonMobil |
| K-COT™ (Catalytic Olefins) | Olefinic C4-C10      | • P/E ratio ~ 2/1  
• Gasoline by-product >50% aromatics  
• Recycle C4-C6 NA to extinction without additional treating |
|                       | Paraffinic naphtha, light distillates | • P/E ratio ~ 1/1  
• Recycle C4s/C5s without additional treating |
|                       | Non-traditional      | • High olefin yields from methanol, ethanol and other oxygenates and MTO/MTP and FT by-products |
K-COT™ Overview

- Catalytic cracking of light *olefinic* and/or *paraffinic* feeds
- High propylene yields, with ethylene and aromatic-rich gasoline byproducts
  - Typical P/E ratio = 2:1 for olefin-rich feed
  - Typical P/E ratio = 1:1 for straight run naphtha
- Use of custom formulation of ZSM-5 catalysts
- Utilizes fluidized reactors (FCC)
  - Over 60 years of KBR experience in FCC
- Product separation similar to ethylene plants with trace impurity removal to produce polymer grade products
  - Over 60 years of KBR experience in Ethylene
Typical Refinery and Steam Cracker

- Crude Oil
- CDU
- FCC
- Isom
- Hydrotreaters
- De-asphalting
- Coker
- Others
- Naphtha
- LPG
- Catalytic Olefins
- Gasoline
- Distillate
- Jet / Kero
- Fuel Oil
- Recovery
- Ethylene
- Propylene
- Butadiene
- PyGas
Typical Refinery and Steam Cracker

- **CDU**: Crude Oil Deasphalting
- **Coker**: Coke
- **Hydrotreaters**: Hydroprocessing
- **FCC**: Fluid Catalytic Cracking
- **Isom**: Isomerization
- **Others**: Additional units

**Products**
- **Gasoline**
- **Distillate**
- **Jet / Kero**
- **Fuel Oil**
- **Ethylene**
- **Propylene**
- **Butadiene**
- **PyGas**

**Non-traditional: Oxygenates (MeOH, EthOH)**

**MTO/MTP by-products**

**FT by-products**
K-COT™ for Steam Cracker Retrofit

Typical liquid crackers produce several low-value C4+ streams (about 20% of the fresh feed)
Recycle with K-COT™

- K-COT allows recycle of mixed, low value streams without the need for pre-treatment.

- Based on historical prices, K-COT provides better margin than either traditional option.
Naphtha Cracker: Recycle vs. Sell

Based on historical worldwide price data

<table>
<thead>
<tr>
<th></th>
<th>C4 Raff 1</th>
<th>C5’s</th>
<th>C6NA</th>
<th>All</th>
<th>C4 Raff 1</th>
<th>C5’s</th>
<th>C6NA</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Since Jan 06</td>
<td>-9</td>
<td>10</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>69</td>
</tr>
<tr>
<td>Since Jan 08</td>
<td>-10</td>
<td>9</td>
<td>-1</td>
<td>-2</td>
<td>18</td>
<td>26</td>
<td>19</td>
<td>63</td>
</tr>
<tr>
<td>Since Jan 11</td>
<td>-14</td>
<td>9</td>
<td>0</td>
<td>-4</td>
<td>18</td>
<td>26</td>
<td>20</td>
<td>65</td>
</tr>
</tbody>
</table>
Combined Olefins Process

Fresh Feeds → K-COT™ → Pyrolysis → Recovery

Recycles

Tail gas → Ethylene → Propylene → Raw C4s → BTX-gasoline → Fuel oil
Technology Flexibility

- Technology flexibility has become a necessity
  - Feeds/products
- SCORE olefins technology range of furnace options and superior feed flexibility
- K-COT™ technology provides feed/product flexibility, especially for non-traditional feeds for olefins
- Combination allows operators to respond to an increasingly dynamic market

Sasol Catalytic Olefins Unit, Secunda, South Africa
2006 Startup
Conclusions

- Impossible to predict feed/product prices
- Selectivity is important and should be a key decision criteria in investment decisions
- “Duplicate” / “Conventional” grassroots designs might miss economic opportunity
- Ability to be feed flexible keeps you on track in an uncertain market place.
- Latest technology offerings provide unprecedented opportunities to integrate and beat market uncertainties.
Thank you for your kind attention!

Questions?