Synergy between Refinery – Petrochemicals and Future Configuration for Aromatics

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Presentation Outline

1. Global Business Environment
2. Changing Competitive Landscape
3. Challenges, Drivers & Opportunities
4. Technological Options and Configuration
5. Conclusion
1. Global Business Environment
Weaker product prices in Europe & Singapore caused negative & narrow margins, respectively
European margins had resurgence - more than doubling from late-March’14 due to Gasoline & Gas Oil cracks
Brent Hydroskimming margin returned to positive for the first time since summer 2013
US refiners benefitted from cheaper crude and seasonal change in Gasoline demand
Global Refinery Closures since 2011

- Globally expected Refinery closures: 3.824 million BPD by mid-2015, mainly in Europe & Asia
- European region (N West, Mediterranean and Central & Eastern): 1.63 million BPD (43% of global) for economics
- Asia: string of closures in Japan due to new regulations (National Avg. Cracking-CDU ratio: 13%) and Australia due to labor costs, expensive exchange rate and ageing facilities

Source: Wood Mackenzie, April 2014
Petrochemicals Cyclical Characteristics

- Profitability mainly linked to Supply–Demand → attracts over-investment during high profitability
- Over-supply causes declining margins → influences pricing decisions
- Growth pursued by building assets and M&A → mode during down-cycle
- Consumption behavior pattern gets improved → causes recovery from a trough

Source: IHS, KOGS-Oct. 2013
Commodity Petrochemicals

- Total Market Volume: 350 million TPA
- Total Market Value: $440 billion
- BTX Market Volume: 115 million TPA
- BTX Market Value: $130 billion

**Sources of Aromatics**

- Reformate 29%
- Coke Oven Lt. Oil 3%
- Pyrolysis Gasoline 68%

**138 million T**

- Ethylene
- Propylene
- Butadiene

**90**

**42 million T**

- Benzene
- Toluene
- Xylene

**11**

**44**

Source: IHS - 2013
Petrochemicals Business Environment (2013-2014)

**Demand**:
- Cracker Operating rates: high in USA (95%), stable in SE Asia (88%)
- Self-sufficiency of China increasing, impacted imports from Middle East
- Global Ethylene balance shifting in favor of producers
- Healthy Polymer demand growth in China (PP: 5%, PE: 15%) and India (PP: 3%, PE: 5%)

**Supply**:
- Shale Gas revolution: main driver of profitability in USA for olefins and has reduced pygas supplies
- US Ethylene operating rates: 96% - higher than last 5 years average 87%

**Costs**:
- Ethylene v/s Naphtha economics widened as Gas prices remained soft
- LPG as a popular feed-stock in Western Europe
- Naphtha spreads to BTX wide: oversupply pushing prices down, reforming attractive for Aromatics

**Margins**:
- Sluggish Polymer demand: margin improvement in PE and PP, but PVC (-ve) due to tight FS supply
- High margin for PX – strongly driven by demand from fibers and packaging

*Source: Argus 2013, Reliance Financial Results 2014*
2. Changing Competitive Landscape
Petrochemicals Emerging Supply Chain

- Developed World Matures
  - Lower Demand
  - Higher Imports (finished products)

- Developing World Expands
  - More Capacity
  - Higher Imports (raw materials)

- Middle East Advantage
  - Higher Exports
  - Diverse Capacity

- Renewed Gulf of Mexico
  - Wide Oil & Gas price gap
  - To Emerge as exporter


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Global feedstock slate changing with developments in US & China

- Global feedstock consumption ~ 700 million Tons in 2012-13, growth of 2.2%
- Naphtha to continue as main feedstock, however its share will decline
- Double digit growth in Coal consumption since early 2000s
- Substantial new Coal-based Ammonia and Methanol facilities starting-up in Asia
- Ethane exhibiting strong growth driven by investments in shale in North America

Source: Nexant - Asian Petrochemical Industry Conference-May 2014
Global Benzene: Demand Forecast

★ Benzene demand: 1.12 times World GDP, indicates economic bell-weather with wide applications
★ Benzene production to grow at 3.5% from 43.7 MMTPA (2013) to 50.95 MMTPA by 2017-18

Source: IHS Aromatics Update-June 2012
Benzene: Global Trade (42 MMTPA)

Source: Argus Singapore, May 2013

By 2015-16
In K Tons

S. America 3%
Middle East 9%
Europe 21%
N. America 23%
Asia Pacific 44%

China 21%
USA 16%
Others 31%
Germany 9%
S Korea 13%
Japan 10%

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World Mixed Xylenes Demand by End Use

Source: IHS-June 2012

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Global Paraxylene: Demand Forecast

- New PX capacity required ~ 35 MMTPA (more than 50% of current capacity)
- Next 10 years: pX demand ~6.5% avg. – would drive need for more Naphtha
- China: 22 Million Tons demand growth at ~ 7% – would drive global pX demand

Source: UOP, KOGS-2013
Paraxylene : Net Trade 2012-2016

- Capacity additions to exceed demand growth after 2014
- Asia: major investments ($1 billion+) with new or re-vamped refineries - inevitably taking longer completion
- Asia: Constraints on feed-stocks encouraging JV’s for MX thus avoiding heavy investment in Reforming
- Mid. East: SATORP JV in 2013 first in 4 years, four investments from 2016: Saudi & Qatar: 4 MMTPA
Benzene and Xylenes account for more than a half of Toluene consumption.

Demand for Toluene growing due higher consumption in Benzene, MX & PX

Lower demand for Toluene Di-isocyanate (TDI) production, whereas demand from solvents was moderate

Toluene demand anticipated to grow in Africa, the Indian subcontinent and Northeast Asia - the largest Toluene consumer and is expected to keep its leading position.

Source: Argus-2013
3. Challenges, Drivers & Opportunities
ECONOMIC:
- In a single global market; manufacturers must be highly competitive to survive
- Cyclic market and high-priced feed-stocks
- High energy costs
- Price forecasting of feed-stocks & products: assess full value of exchange of streams, Capex & Opex
- Effective Resource management

POLICY DECISIONS:
- Government-Business cooperation strengthening
- Stringent environmental norms and Fuels quality spec.: Benzene in Gasoline → adjust Reformer or extract for Petrochemicals
- Bio-ethanol blends in Gasoline in Europe can create surplus Naphtha

TECHNOLOGICAL:
- Increasing reliance on Refineries for Propylene and Aromatics
- Limited flexibility in product reprocessing and by-products utilization
- Disposal of high sulfur residues makes gasification attractive for potential chemical use

Source: Global Polyethylene IHS PEMEX PE June 2012

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Strategic Drivers to Maximize Margins

★ Adopting latest Technology for Conversion units

<table>
<thead>
<tr>
<th>Stream</th>
<th>Old Configuration</th>
<th>New Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGO</td>
<td>FCC</td>
<td>Hydrocracker</td>
</tr>
<tr>
<td>Hy. Naphtha</td>
<td>Reformer for Gasoline</td>
<td>Reformer for BTX</td>
</tr>
<tr>
<td>Lt. Naphtha</td>
<td>Petrochemicals</td>
<td>Isomorate (Gasoline)</td>
</tr>
</tbody>
</table>

★ Potential Petrochemical Integration:

<table>
<thead>
<tr>
<th>Source</th>
<th>Petrochemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Gas</td>
<td>C2</td>
</tr>
<tr>
<td>LPG</td>
<td>C3</td>
</tr>
<tr>
<td>Methanol</td>
<td>Ethylene &amp; Propylene</td>
</tr>
<tr>
<td>Toluene &amp; Xylene</td>
<td>Benzene by Hydro-dealkylation</td>
</tr>
<tr>
<td>Toluene</td>
<td>p-Xylene by Methylation</td>
</tr>
<tr>
<td>Heavy Crudes, Residues, Coal Tar</td>
<td><strong>Hydrogen addition:</strong> Two-stage conversions (2014-2016): Hydro-treating &amp; Hydrocracking to low-sulfur Naphtha, ULSD, FCC feed-stocks, high-value Petrochemicals</td>
</tr>
</tbody>
</table>

Source: Foster Wheeler, ERTC - Nov. 2012
Drivers for Refinery-Petrochemicals multi-unit complex

Product prices relative to Naphtha

FCC technology has developed to produce higher volumes of Olefins and Aromatics

Source: Foster Wheeler - Feb. 2014
Benzene: Sources

- Benzene primarily produced as a by-product while producing Gasoline, Ethylene and PX, supply driven by demand for these products.
- Cat. Reforming accounts for ~55% of Benzene production, incl. associated Toluene conversion.
- Steam Cracking and associated Toluene conversion accounts for >40% of Benzene production.

Steam Cracking: Choice of feedstocks for Benzene

Typical Benzene yield from Steam Cracking: (depending on feed-stock, severity, pressures, etc.)

- Naphtha: 4.5-6.5 wt%
- Gas Oil: 4.5-6.5 wt%
- LPG: 2.5-3.0 wt%
- Ethane: 0.6-1.0 wt%

Source: IHS Aromatics Update-June 2012, Argus –May 2013
Paraxylene : New Capacity Development 2012-2030

Basis: Feed : Naphtha 1.3 MMTPA
Prodn.: PX : 600 KT, OX : 100 KT, BZ : 295 KTPA

- C8’s now have to be created as existing MX pools have dried up: requiring high Capex
- Emergence of US Shale Oil & Gas not as positive for US Aromatics due to impact on Naphtha composition and Reforming economics
- JV’s being established between Japanese MX aligning with new PX capacity in South Korea, avoiding large Capex and timing delays to plug short-term gap

Steam Cracker Feed Options

Yields for Steam Cracker Feeds v/s FCC and CCR

- Ethylene
  - C2
  - C3
  - nC4
  - iC4
  - LN
  - AGO
  - FCC
  - CCR

- Propylene
- Butenes
- BTX

- VM: Variable Margin (Revenue – feedstocks & utilities)
- COP: Crude Oil Price at 100 $/bbl, equivalent to LNG ~ 13 $/MMBTU


LNG cost impact on world-scale Olefins Cracker Margins

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4. Technological Options
Typical Value Addition by Integration

- Total Natural Resources: US $1.5 Billion/year
- Total Petrochemicals Products: US $8.6 Billion/year

### Refineries
- Cracker #1
  - Ethane 1,100 KTPA
    - US $80 Million
  - Propane 1,200 KTPA
    - US $360 Million
- Cracker #2
  - Crude to Naphtha 20 MMTPA
    - (equiv. 400 MBPD)
      - US $800 Million
  - Raffinate & Naphtha 4.5 MMTPA
    - US $350 Million
- Secondary Feeds
  - US $225 Million

### Aromatics
- US $575 Million

### Ethylene Derivatives
- Ethylene 2,600 KTPA
  - US $1000 Million
- Cracker #1
  - US $1.1 Billion

### Propylene Derivatives
- Propylene 965 KTPA
  - US $385 Million
- Cracker #1
  - US $1.1 Billion

### C4 Derivatives
- Mixed C4s 450 KTPA
  - US $75 Million
- Cracker #2
  - US $1.1 Billion

### Aromatics Derivatives
- Aromatics 1500 KTPA
  - US $450 Million
- Cracker #2
  - US $1.1 Billion

### Secondary Products
- US $225 Million

### Product Derivative
- Value in MM $
- Investment in US $ Billion

### Gross Margin Value-added Ratio:
- (Products / Feed) = 8.6 / 1.5 = 5.7 times benefits

### Full Integration Total Investments:
- US $11.6 Billion

### Refinery-Petrochemicals value addition:
- 1.9 times benefits

### RPI Investments:
- US $2.8 Billion

Source: Flour Corp. case study - 2007

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Refinery – Cracker – Aromatics: Degree of Integration

- Analysis based on 300,000 BPD Refinery capacity
- Refinery + Cracker + Aromatics integration would enable petrochemicals harvest upto 36% from the medium sour crude feeds
- High degree of cracking can increase the fuel & loss component
- Petrochemicals-FCC units would remain a minority of the total FCC units – given the size of Aromatics v/s Gasoline market

Source: Jacobs Consultancy – Nov. 2009 & Grass-root project in SE Asia

All figures in Thou. Tons per annum

<table>
<thead>
<tr>
<th>Feeds</th>
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<tbody>
<tr>
<td>Oman Export Blend</td>
<td>13,724</td>
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<tr>
<td>Natural Gas</td>
<td>425</td>
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<tr>
<td>Methanol</td>
<td>148</td>
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<tr>
<td>Total Feed</td>
<td>14,296</td>
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<table>
<thead>
<tr>
<th>Products</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Fuel Products</td>
<td></td>
</tr>
<tr>
<td>Naphtha</td>
<td>213</td>
</tr>
<tr>
<td>MTBE</td>
<td>410</td>
</tr>
<tr>
<td>Diesel</td>
<td>5,078</td>
</tr>
<tr>
<td>LSFO</td>
<td>58</td>
</tr>
<tr>
<td>Carbon Black Feedstock</td>
<td>1,187</td>
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<tr>
<td>Sulphur</td>
<td>113</td>
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<table>
<thead>
<tr>
<th>Petrochemical Products</th>
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<tbody>
<tr>
<td>Paraxylene</td>
<td>1,895</td>
</tr>
<tr>
<td>Benzene</td>
<td>583</td>
</tr>
<tr>
<td>Ethylene</td>
<td>1,163</td>
</tr>
<tr>
<td>Propylene</td>
<td>1,283</td>
</tr>
</tbody>
</table>

| Total Products             | 11,982     |
| - of which fuels           | 7,059      |
| - of which petrochemicals  | 4,923      |
| Fuel and Loss              | 2,314      |

Petrochemicals as % Crude 36%

S E Asia Project example

- $7.5/bbl Petrochemicals Advantage (Naphtha & Aromatics complex: Benzene & PX)
- $4/bbl Import Tax Advantage
- $3/bbl Configuration (RFCC-2 modes, Isom, PRU)
- $0.4/bbl Freight Advantage

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Refinery with Hydro-cracker + FCC + Aromatics

Refinery feed-rate: 400,000 bbl/d
Aromatics production:
- Paraxylene: 700 KT/yr.
- Benzene: 140 KT/yr.

Source: Axens-2012
Refinery with Steam Cracker + Aromatics

Existing refinery

Heavy Naphtha

Aromatic Complex

(ParamaX)

Benzene
Paraxylene

C\textsubscript{2}, LPG, Raffinate

Steam Cracker

Propylene
Ethylene

Light Naphtha

Gasoline
Kero
Diesel
Residue

Refinery feed-rate:
400,000 bbl/d

Aromatics production:
Paraxylene: 1,400 KT/yr.
Benzene: 650 KT/yr.

Source: Axens-2012
**Types of Aromatics : feed-stock based**

<table>
<thead>
<tr>
<th>Components, wt%</th>
<th>Pygas</th>
<th>Reformate</th>
<th>Light Reformate</th>
<th>Coke Oven Lt. Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>30</td>
<td>3</td>
<td>24</td>
<td>65</td>
</tr>
<tr>
<td>Toluene</td>
<td>20</td>
<td>13</td>
<td>46</td>
<td>18</td>
</tr>
<tr>
<td>Xylenes</td>
<td>4</td>
<td>18</td>
<td>&lt; 0.5</td>
<td>6</td>
</tr>
<tr>
<td>Ethyl-Benzene</td>
<td>3</td>
<td>5</td>
<td>&lt; 0.5</td>
<td>2</td>
</tr>
<tr>
<td>C₉⁺ Aromatics</td>
<td>3</td>
<td>16</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total Aromatics</strong></td>
<td><strong>60</strong></td>
<td><strong>55</strong></td>
<td><strong>70</strong></td>
<td><strong>98</strong></td>
</tr>
<tr>
<td>Naphthenes</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Olefins</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Paraffins</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sulfur</td>
<td>~1000 ppm</td>
<td>&lt; 1 ppm</td>
<td>Low</td>
<td>~1 %</td>
</tr>
</tbody>
</table>

- Toluene extraction will increase for converting to Benzene and Xylenes via dis-proportionation

*Source: ThyssenKrupp UHDE & Axens*
<table>
<thead>
<tr>
<th>Main source</th>
<th>Process Steps</th>
<th>Main Products</th>
<th>By-products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrolysis Gasoline</td>
<td>Selective Hydrogenation</td>
<td>--</td>
<td>C5+ to Gasoline</td>
</tr>
<tr>
<td></td>
<td>Full Hydrogenation</td>
<td>--</td>
<td>Off-gas to Cracker</td>
</tr>
<tr>
<td></td>
<td>Extractive Distillation</td>
<td>Benzene &amp; Toluene</td>
<td>Non-Aromatics to Cracker</td>
</tr>
<tr>
<td></td>
<td>Hydro De-alkylation</td>
<td>Benzene</td>
<td>C9+ to Gasoline and Hy. Aromatics</td>
</tr>
<tr>
<td>Reformate</td>
<td>C7+ Extractive Distillation</td>
<td>Benzene &amp; Toluene</td>
<td>Non-Aromatics to Gasoline</td>
</tr>
<tr>
<td></td>
<td>Toluene Disproportionation</td>
<td>Benzene</td>
<td>Light Ends</td>
</tr>
<tr>
<td></td>
<td>C8+ &amp; Xylenes → Adsorption</td>
<td>p-Xylene</td>
<td>--</td>
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<tr>
<td></td>
<td>Xylene Isomerization</td>
<td>p and o-Xylene</td>
<td>C9+ to Gasoline</td>
</tr>
<tr>
<td></td>
<td>Toluene &amp; C9+ Aromatics →</td>
<td>Max. p-Xylene</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Trans-alkylation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke Oven Light Oil</td>
<td>Selective Hydrogenation</td>
<td>--</td>
<td>Off gas &amp; Tar</td>
</tr>
<tr>
<td></td>
<td>Extractive Distillation</td>
<td>Benzene &amp; Toluene</td>
<td>Non-Aromatics to Gasoline</td>
</tr>
<tr>
<td></td>
<td>C8+ column</td>
<td>Xylenes</td>
<td>--</td>
</tr>
</tbody>
</table>

*Source: ThyssenKrupp UHDE & Axens*
### Technologies: Commercial Attractiveness

<table>
<thead>
<tr>
<th>Technology</th>
<th>Attractiveness</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aromatization of Light Olefins and Paraffins</td>
<td>- Operating options: Fixed Bed and Catalyst circulation</td>
<td>Feed from: C2 in FCC dry gas, Refinery LPG, C5+ from Light Naphtha</td>
</tr>
<tr>
<td>Feed-stock options:</td>
<td>- Flexible schemes: Aromatics, LPG as feed for Ethylene or Gasoline oriented</td>
<td>Products:</td>
</tr>
<tr>
<td>- C4+ Olefins</td>
<td>- More Aromatics from non-traditional feed-stocks</td>
<td>- Dry Gas</td>
</tr>
<tr>
<td>- FCC C6-C8 non-Aromatic cut</td>
<td>- Better than recycling FCC Naphtha to Refomer</td>
<td>- LPG</td>
</tr>
<tr>
<td>- C5-C12 Pygas streams</td>
<td>- Steam cracker heavy Olefins</td>
<td>- Aromatics</td>
</tr>
<tr>
<td>- Steam cracker heavy Olefins</td>
<td></td>
<td>Economics requires low Coal prices – high metals correlation</td>
</tr>
</tbody>
</table>

Benzene capacity from Coal has grown by six times, whereas Coke Oven Light Oil contributes only 4-5% of global Benzene supply

5. Conclusion
Investment options come with wide range of Capex and Risks:

🌟 Opportunities for enhancing value-addition from cheaper advantageous feed-stocks:

1. Operational flexibility to swing production from BTX intermediates to Gasoline blends → as per market demand
2. Unlock value from non-traditional feeds: by-product streams of Naphtha Cracker & FCC
3. Upgrade heavy Naphtha and Condensates to Aromatics

🌟 Aromatics Molecule Management, mainly in view of:

1. Shifting towards lighter feed-stocks in Crackers will produce less Benzene
2. Increased Ethanol blending to reduce need for Aromatic octane boosters in Gasoline
3. Decrease in US Gasoline demand would lower need for Reformate
Thank You
Happy to take Questions