Technology Developments
From Energy to Chemicals

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We create content with our Chemical Engineers & Chemists….
….and want our customers to be able to use it “all”

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• Process Flow Diagrams
• Heat and Material Balance
• Equipment One-Line Specs

We develop:
• Detailed Capital Investment and Operating Cost Estimates for each product
• Using our Propriety Cost Estimating Software (PEPCOST)
Agenda

- Investment Drivers
- Refinery and Petrochemicals Integration
- COTC projects, Driving Forces & Configurations
- Key Messages/Strategic Implications

ExxonMobil Steam Cracker in Singapore
With an expected US $1 trillion of capital spend (2018-2030), both absolute and relative spending decisions couldn’t be more important.
We think of the significant aspects for deciding where to deploy new capital

- Knowing **where** to deploy capital, and on **what** technology and **feedstock** basis, is a challenging task for chemical (and refining) executives

- High capital investment required to utilize a low cost feedstock has further complicated the investment decision

- Regionally different investment cost dynamics have also added to capital deployment complexity
Feedstock cost has traditionally been the most important and complex long-term decision
Process Technology Developers Responded to advantaged feedstocks
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ExxonMobil Steam Cracker in Singapore
Plateau in refined products demand growth causing many refining companies to evaluate their petrochemical strategy.
Review of refinery integration levels

- **FULL**: Refining + Steam Cracking + PX Complex
- **SINGLE**: Refining + Steam Cracking or Refining + PX Complex
- **REFINING PLUS**: Refining + BTX + Propylene
- **REFINING**: Refining
Crude Oil to Chemicals (COTC) elevates petrochemical production to the refinery scale

- COTC reconfigure a refinery to produce maximum chemicals instead of fuels and thus merge refinery and petrochemical plants into one.
- COTG goes beyond the state-of-art refinery petrochemical integration.
- Due to its large scale, COTC has the potential to be an imminent threat that could have profound strategic implications for the global petrochemical and refinery industries.
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## Crude to Chemical Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Refinery Capacity MMTA</th>
<th>P-Xylene Capacity MMTA</th>
<th>Olefin Capacity MMTA</th>
<th>Investment ($bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hengli Petrochemical</td>
<td>20</td>
<td>4.3</td>
<td>1.5</td>
<td>11.4</td>
</tr>
<tr>
<td>Zhejiang Petroleum and Chemical</td>
<td>40</td>
<td>10.4</td>
<td>2.8</td>
<td>24</td>
</tr>
<tr>
<td>Shenghong Refinery and Integrated Petrochem</td>
<td>16</td>
<td>2.8</td>
<td>1.1</td>
<td>11.0</td>
</tr>
<tr>
<td>Hengyi (Brunei) PMB Refinery-Petrochem</td>
<td>8</td>
<td>1.5</td>
<td>0.5</td>
<td>3.45</td>
</tr>
<tr>
<td>Aramco SABIC JV</td>
<td>20</td>
<td>--</td>
<td>9 (total chemicals)</td>
<td>20</td>
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</tbody>
</table>

Aramco, partnered with Chevron Lummus Global (CLG) CB&I (now McDermott), plans to commercialize its thermal crude to chemicals process that aiming at converting **70-80%** of crude oil to chemicals.
Refineries today produce small amounts of chemicals relative to fuels, but much more is possible with new configurations and new technology.

<table>
<thead>
<tr>
<th>Refinery yield of chemicals and fuel (per barrel of oil) - current configurations versus new projects</th>
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</thead>
<tbody>
<tr>
<td><strong>Global Refining Average</strong></td>
</tr>
<tr>
<td>Naphtha (approx. chemicals)</td>
</tr>
<tr>
<td>8% Other/Fuels</td>
</tr>
</tbody>
</table>

Petro Rabigh in Saudi Arabia provides an example of a recent “fully integrated” refinery/petrochemical plant. The Hengli Refinery-PX project under construction in China is a “Crude to chemicals” configuration. Aramco/SABIC per announcement.
Crude oil to chemical routes

Conventional process

- Crude oil
- Refinery
- Naphtha
- Steam cracker

ExxonMobil

- Light crude
- Steam cracker

Hengli
Zhejiang
Shenghong
Hengyi

- Mixed crudes
- Crude oil to PX complex

Aramco/SABIC

- Light crude
- Crude oil to chemicals complex

Reference*

- PEP 29I
- PEP 29J
- PEP 303
- PEP 29J

* Process Economic Program reports
Driving Forces

Hengli Petrochemical, Zhejiang, Henyi and Shenghong- to back integrate their Polyester-PTA production by configuring refinery to produce maximum PX

Aramco- to monetize its oil assets to produce more chemicals which have higher value and growth rate than transportation fuels
ExxonMobil’s approach to steam cracking crude oil

- Preheat crude oil in cracker furnace convection section
- Partially vaporize heated crude in flash pot outside furnace
- Flash pot overhead vapor (76%) fed to cracker furnace radiant coils
- Dispose of 24% flash pot bottoms liquid (resid) in refinery

Implementation of this technology is within steam cracker; increase in petrochemical production is significant but incremental
Saudi ARAMCO’s approach to steam cracking crude oil

• ARAMCO feeds Arabian Light crude oil to resid hydrocracker (HK)
• Lightest 85% of HK product conventionally steam cracked
• Heaviest 15% of HK product fed to proprietary high-severity fluid cat cracker (FCC), making cracked naphtha + propylene
• FCC technology developed as joint venture with Nippon JX.
• Aramco announced work with Chevron Lummus Global (CLG) to develop hydrocracking technology (70-80% per barrel of oil to chemicals)

Reference: PEP 29J
Hengli’s Refinery-PX complex configuration

Crude Oil
20 MMTPA

60% Saudi Heavy
30% Saudi Medium
10% Marlim

Avg. API= 27.62
S= 2.26%

Key technologies supplied by Axens

Atmospheric and Vacuum Distillation
2 x 10 Mta

Light Hydrocarbon Recovery 4.5Mta

Kerosene Hydrotreating 2.0 Mta

Diesel Hydrocracking 6.0 Mta (2 Units)

Resid Ebullated Bed Hydrocracking 6.0 Mta(2 H-Oil)

Solvent De-asphalting (Solvahl)

C3/C4

Naphtha Hydrogenation

Heavy naphtha

Gasoil Hydrocracking 7.5 Mta (2 x HyK)

Continuous Reforming 9.6 Mta (3X 3.2 Mta Aromizing™)

PP, MTBE

Isomerate

PX

Benzene

Lube oil

Residue gasification
Hengli’s Refinery-PX complex product yields

Coal gasification → Hydrogen → Methanol (for MTBE)

Hengli Refinery – PX Complex

*Total Chemicals = 8.4 Mta (42% Conversion)*

Yields in Mta
- PX 4.34
- Benzene 0.97
- Naphtha 1.63
- PP 0.44
- Lube 0.54
- Acetic Acid 0.35
- Heavy Aromatics 0.13
- LPG 0.65
- Gasoline 4.61
- Kerosene 3.74
- Diesel 4.61
- Sulfur 0.52

Source: PEP based on company announcements

12 Mta Saudi heavy
6 Mta Saudi medium
2 Mta Marlim

Avg. API= 27.62
S= 2.26%

Mta= million tons per year

Residue gasification → Hydrogen, Heat
Global PX production capacity ranking

World PX plant capacity rank

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<th>Capacity (KTA)</th>
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<td>Hengli</td>
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China PX Capacity vs. Demand

China PX Imports in 2017

Total PX Imports= 14,437 Kta in 2017

- South Korea: 6,586 Kta
- Japan: 2,231 Kta
- Taiwan: 2,570 Kta
- India: 1,572 Kta
- Singapore: 804 Kta
- Others: 674 Kta

China PX Imports in 2017:

South Korea 6,586
Japan 2,231
Taiwan 2,570
India 1,572
Singapore 804
Others 674
We expect the PX projects to be very competitive on the global cash cost curve
Aramco + Chevron Lummus Global yields

Total chemical products about 14.3 Mta (72% yield)

Yields in Mta
- Ethylene 4.71
- Propylene 3.08
- C4 Fraction 2.54
- Pyrolysis Gasoline 4.00
- Gasoline (Aromatics Rich) 1.15
- Hydrogen (95%) 0.26
- Fuel Oil 1.24
- Light Cycle Oil 0.32
- Methane 2.1 (used as fuel in steam cracker)
- Sulfur 0.6

Source: PEP 29J Conceptional design based on Aramco patents
We expect the Aramco projects to be competitive on the global cash cost curve

2027 World Cost Curve: Ethylene

(Cost Basis = Plant Gate, Product Basis = Ethylene, Operating Rate Basis = IHS Baseline)

Source: IHS Markit
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Key Messages on COTC evolution

- COTC considered “ultimate” integration; aiming to produce maximum chemicals instead of fuels
- COTC projects have been started in China and Saudi Arabia
  - Three PX focused expected to start operation in 2019-21
  - Each represent substantive S/D disruption
- COTC requires very high capital investment cost, but produces huge amount of chemicals
  - Capital intensity creates entry barriers, restricting members of the ‘club’ to majors and super majors
  - Makes most sense for China with low CAPEX and large markets
  - Attractive to Middle East producers to better monetize oil assets and national strategic support
  - Diverse product slate opens many value chains and presents ‘Verbund’ opportunities
Strategic implications and uncertainties

• The market can handle only small numbers of these complexes
  > What is the potential impact from delays/entry
  > Risk from plastics de-selection and acceleration of EV
• National/country strategies impact investment decisions
  > Does this change the reinvestment hurdles?
• Industry structure. Supermajor scale unprecedented
  > Not have technological, operational and market knowledge.
• Integrated refining cost structures increasingly complex
  > Will there be operational flexibility to react to intermediate intra-value chain market dislocations?
  > How to capture value in operational optionality and diversification