Direct Oil and Gas to Ethylene
- The Search for the Holy Grail -

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Dr. Richard Charlesworth
Managing Director, Middle East

Richard.charlesworth@ihsmarkit.com
Acknowledgment

King Arthur:

Go and tell your master that we have been charged by God with a sacred quest.

If he can provide us food and shelter for the night he can join us on the quest for the Holy Grail.

French Soldier:

Well, I'll ask him, but I don't think he'd be very keen. He's already got one you see!
Agenda

• Ethylene market trends
• Why are direct routes relevant?
• Who are using direct routes?
• What are the difficulties?
• Are direct routes competitive?
• Conclusions
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• Ethylene market trends
• Why are direct routes relevant?
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The market for ethylene is expected to grow at above GDP levels driven by polyethylene

Demand = 146.5 million metric tons

Uses of Ethylene 2016

- HDPE 29%
- LLDPE 19%
- LDPE 14%
- Ethylene Oxide 15%
- Vinlys 9%
- Styrenics 6%
- Alpha Olefins 3%
- VAM 1%
- Other 4%
- Styrenics 6%
- Other 4%
- VAM 1%
- Alpha Olefins 3%
- Ethylene Oxide 15%
- Vinlys 9%
The global feedstock mix has become lighter but is still dominated by naphtha cracking.

Sources of Ethylene, 2016

- Ethane: 36%
- Propane: 9%
- Butane: 6%
- Naphtha: 43%
- Gasoil: 3%
- MTO: 1%
- CTO: 1%
- Other: 1%

Production = 146.4 million metric tons
However, world ethylene supply growth is expected to be dominated by North American ethane.
Nevertheless liquids cracking is needed to fill the C3/4/6 supply gap
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Since 2010, the Gas-to-Crude ratio favours N. America gas investments and therefore direct methane-to-olefins
In the Middle East, feedstock availability drives petrochemical industry evolution, not the market

- **C1/C2 based feedstock Projects**
- **Mixed feedstock C1/C2/C3/C4/Light Naphtha based Projects**
- **Refinery/Petchem Integrated Naphtha Based (non-discounted) projects**
- **Projects with Specialty/Differentiated Products**

**Key Objectives:**
Monetize Gas, Diversify Local Economies, Downstream Industry and Job Creation
Energy at the extremes has catalyzed a “New Era” in light olefins production

- Light olefins supply based on refinery & naphtha cracker integrated sites in past.
- Ethane crackers emerged where ethane was advantaged.
- Propylene was a byproduct of refining and heavy or flexible steam cracking.
- Light olefins can now be made on purpose via a variety of technologies beyond refining and steam cracking: PDH, CTO/P, MTO/P, Metathesis, GTO/P, OCM(methane).
- A high crude oil prices in the long term will enable more on-purpose, leaving C4= & higher hydrocarbons with future supply issues
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Why hasn’t crude oil been steam cracked in the past?

- Residual content of crude oil will quickly coke up in furnace radiant tubes.
- Crude consists of many fractions, there is no one “optimal set of conditions”
- Optimum steam-cracking temperature changes with feedstock composition (800–850°C, higher temperatures for lighter feed).
- Optimum dilution steam to oil ratio also changes with feedstock composition (0.3–0.5, higher ratio for heavier feed).
Why would anyone want to steam crack whole crude oil rather than refined oil products?

- By-passing refinery saves US$5–10/barrel processing costs and saves 5–14 days processing time in refinery.

*B,S&W: Bottoms, solids, and water
Three companies have announced crude oil steam-cracking programs

- ExxonMobil has been reported to be cracking crude oil at its Singapore complex since January 2014.
- Saudi Aramco announced an operational demo plant.
- SABIC suggested a “Crude Oil to Chemicals” project for Yanbu (KSA).
- Aramco and SABIC announced a JV in 2016.
ExxonMobil’s approach to steam cracking crude oil

- Preheat crude oil (Tapis Light) 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) which is not suitable for steam cracking in refinery.
ARAMCO’s approach has significantly different yield than conventional cracking

- ARAMCO crude oil-to-ethylene process integrates hydrocracking, FCC and steam cracking processes.
- ARAMCO proprietary high-severity FCC makes 20% propylene + FCC naphtha.
- FCC naphtha is not suitable for steam-cracker feed unless hydrogenated.
- CAPEX is 40% higher than conventional steam cracking due to Hydrocracker/FCC.
- Feed rate 80,000 barrels per day of Dubai crude to make 935 thousand tons per year of ethylene (0.93 stream factor)
Siluria has a demonstration OCM plant

- Oxidative coupling of methane (OCM) into ethylene truly is a Holy Grail
- Methane is a cheaper and more plentiful raw material than ethane
- There would be the considerable energy savings over ethane steam cracking because methane conversion would be exothermic
- Siluria has taken OCM further than any of its predecessors
  - Lower reaction temperatures
  - Substantially higher pressures
  - Catalyst lifetimes measurable in years rather than months
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Design basis for ExxonMobil economic evaluation

- 1.0 million tons per year ethylene production from Tapis Light 43 °API crude oil
- AACE Class-3 process design
- PFDs, stream-by-stream MatBal, equipment list with duty specs, itemized and fully loaded CAPEX estimate (+/- 25%).
- Yields simulated using commercial cracking simulation software
- Singapore project site location
- IHS PEP report #29J (by Mike Arne).
Yield comparison with naphtha steam cracking shows some differences

- ExxonMobil’s process produces a little more ethylene, and a lot more fuel oil.
- Wide-range naphtha produces more propylene, C4 fraction, and pygas.
ExxonMobil approach has advantages versus naphtha steam cracking

- Assuming a Brent Oil price of $50/bbl, the high level parameters are:

<table>
<thead>
<tr>
<th></th>
<th>ExxonMobil</th>
<th>Wide Range Naphtha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex ($US billions)</td>
<td>1.973</td>
<td>1.926</td>
</tr>
<tr>
<td>Feedstock Consumption (mt/mt)</td>
<td>4.444</td>
<td>3.557</td>
</tr>
<tr>
<td>C2Footnote1</td>
<td>388</td>
<td>429</td>
</tr>
<tr>
<td>Feedstock Price ($US/mt)</td>
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<td></td>
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</tbody>
</table>

Footnotes:
1. C2Footnote1 = $789 FOB S’pore

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Strategic implications for considering ExxonMobil’s process

- Makes economic sense where the naphtha price is significantly greater than the price of whole crude oil
- Makes economic sense when selecting a light crude oil with low resid content
- Likely to replace conventional naphtha steam cracking where lower-cost NGL feedstocks (ethane, propane) are not available
- Disposition and value of flash pot bottoms are an important economic consideration
Design basis for Aramco economic evaluation

- 935 KTPA tons per year ethylene production from Dubai crude oil.
- AACE Class-3 process design.
- PFDs, stream-by-stream MatBal, equipment list with duty specs, itemized and fully loaded CAPEX estimate (+/- 25%).
- Yields simulated using commercial cracking simulation software.
- Kingdom Saudi Arabia (KSA) project site location
- IHS PEP report #29J by Mike Arne.
Yield comparison with naphtha steam cracking is significantly different

- ARAMCO process produces 13% more pygas + fuel oil.
- Traditional naphtha steam cracking produces 3% more ethylene + propylene.
- ARAMCO produces much more hydrogen
Aramco approach has advantages versus naphtha steam cracking

- Assuming a Brent Oil price of $50/bbl, the high level parameters are:

<table>
<thead>
<tr>
<th></th>
<th>ARAMCO</th>
<th>Wide Range Naphtha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex ($US billions)</td>
<td>3.062</td>
<td>2.177</td>
</tr>
<tr>
<td>Feedstock Consumption (mt/mt C2&lt;sup&gt;+&lt;/sup&gt;)</td>
<td>4.248</td>
<td>3.487</td>
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<tr>
<td>Feedstock Price ($US/mt)</td>
<td>331</td>
<td>429</td>
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Strategic implications for considering ARAMCO’s process

- Production cost is higher than ExxonMobil’s process at Singapore, but slightly below conventional naphtha steam cracking.
- ROI for US$1 billion of additional CAPEX in hydrocracker + high-severity FCC is questionable.
- It is probably a better idea to place HK bottoms into an existing FCC, given its low flow rate (12,000 barrels per day).
- Economic viability in KSA depends upon availability and price of historically much-lower-cost NGL feedstock.
Design basis for Siluria economic evaluation

- 1 MMTPA tons per year ethylene production from Natural gas.
- AACE Class-3 process design.
- PFDs, stream-by-stream MatBal, equipment list with duty specs, itemized and fully loaded CAPEX estimate (+/- 25%).
- Yields simulated using commercial cracking simulation software.
- USGC project site location
- IHS PEP report 2014-07 by Sumod Kalakkunnath.
Siluria comparison with ethane steam cracking is slightly different

• xxx
Strategic implications for considering Siluria’s process

- CAPEX, omitting the air separation unit (ASU), is similar to an ethane cracker so is competitive in a low gas price environment.
- Oxygen can be supplied via third party provider however it makes more economic sense to have ASU co-located.
- With co-located ASU, production costs are similar to ethane cracking at equivalent capacity.
The global ethylene cost curve flattens as crude declines.

**World Cost Curve: Ethylene**

Brent Crude
- 2014 = 99.4 $/bbl
- 2015 = 52.3 $/bbl

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The three technologies are competitive on the global production cash cost curve

<table>
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<tr>
<th>World Cost Curve: Ethylene</th>
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<tr>
<td>Brent Crude</td>
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<tr>
<td>2015 = 52.3 $/bbl</td>
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<tr>
<td>Aramco Crude</td>
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<td>Saudi</td>
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<td>Exxon Crude</td>
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<td>Singapore</td>
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<tr>
<td>Naphtha</td>
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<td>Singapore</td>
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<td>Siluria OCM</td>
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<td>USGC</td>
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Cumulative Production - Million Metric Tons

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• Direct routes through crude oil cracking and oxidative coupling of methane to ethylene offer a holy grail to certain regions

• Both ExxonMobil and ARAMCO costs are below naphtha cracking

• ARAMCO’s depreciation cost (representing CAPEX) is significantly higher than ExxonMobil or naphtha steam cracking

• Naphtha crackers still required for ethylene and co-products which will drive ethylene prices
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