“Double” disruptive technologies
Positioning to impact the petrochemical industry

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Agenda

1. What are disruptive technologies?
2. What are they and what makes them interesting?
3. Implication for the industry
In business, “disruptive” relates to a new product, service or idea that radically changes an industry…one that successfully challenges the established incumbent(s)
Ethylene & propylene are the most significant petrochemical chemical feedstocks
165 & 90 MMTPA consumed, respectively

Objective: converting low-cost molecules to high-value molecules
Ethylene & propylene are the most significant petrochemical chemical feedstocks — 165 & 90 MMTPA consumed, respectively.

Objective: converting low-cost molecules to high-value molecules.. and at the lowest capital and operating cost-efficient manner.
Agenda

What are disruptive technologies?

What are they and what makes them interesting?

Implication on the industry
Ethylene (and propylene) Production

by Siluria Technology’s from Direct Oxidative Coupling of Methane
Siluria’s OCM technology produces ethylene and propylene from methane and other NGLs

\[ \text{O}_2 + \text{HCH} \xrightarrow{\text{HCH}} \text{HCH} + \text{H} + \text{H} + \text{H} + \text{H} + \text{H} + \text{2H}_2\text{O} \]

\[ \text{Methanation (CO, CO}_2\text{, and H}_2\text{)} \]

\[ \text{OCM Coupling} \]

\[ \text{Heat Recovery} \]

\[ \text{C}_1\text{ Recycle} \]

\[ \text{CO}_2\text{ Recycle} \]

\[ \text{C}_2\text{ & C}_3\text{ Recycle} \]

\[ \text{Optional: Ethane or Propane} \]

\[ \text{Products Gas} \]

\[ \text{Separation & Purification} \]

\[ \text{Ethylene} \]

\[ \text{Propylene} \]

Sources:
Siluria Technologies
PEP: 2018-06 Siluria OCM Process Evaluation
Siluria’s OCM technology produces ethylene and propylene from methane and other NGLs

Can feed a mix of methane and NGLs feedstock compositions

Methanation (CO, CO₂ and H₂)

OCM Coupling

Heat Recovery

C₁ Recycle

CO₂ Recycle

C₂ & C₃ Recycle

Optional: Ethane or Propane

OCM Reaction Section
methane + O₂ → ethylene + H₂O + heat
ethane + O₂ → ethylene + H₂O + heat

PB Conversion Section
ethane + heat → ethylene + H₂
propane + heat → ethylene + H₂
propane + heat → propylene + H₂

Separation & Purification

Ethylene
Propylene

Sources:
Siluria Technologies
PEP: 2018-06 Siluria OCM Process Evaluation
Siluria’s OCM process (in the Demonstration Stage) is expected to be competitive in “advantaged” configurations…

Siluria’s Technology can be vehicle for upgrading light olefin assets, for example….

<table>
<thead>
<tr>
<th>Asset</th>
<th>Feedstock</th>
<th>Integration Dimension</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Cracker Integration</td>
<td>• Natural gas&lt;br&gt;• Cracking furnace methane containing off-gasses</td>
<td>• Feedstock:&lt;br&gt;❖ Natural gas&lt;br&gt;❖ Methane containing off-gases&lt;br&gt;❖ Cold-end integration</td>
<td>• Additional ethylene production&lt;br&gt;• Lower feedstock costs e.g., off gases&lt;br&gt;• Adds C₁ as feedstock&lt;br&gt;• Reduced GHG intensity&lt;br&gt;• Debottlenecking opportunities</td>
</tr>
<tr>
<td>PDH Integration</td>
<td>• PDH off-gases containing methane/ethane</td>
<td>• Feedstock:&lt;br&gt;❖ Methane/ethane-containing off-gases&lt;br&gt;❖ Cold-end integration</td>
<td>• Additional propylene production&lt;br&gt;• Ethylene for PP plant&lt;br&gt;• Lower overall feedstock costs&lt;br&gt;• PDH increased efficiency (fuel-gas production climbs as PDH catalyst ages)</td>
</tr>
</tbody>
</table>
Crude to Chemicals (Olefins and Aromatics)

ExxonMobil, Saudi Aramco/Sabic JV and Aramco with Chevron Lummus Global (CLG), are companies working on this technology.
Crude to “more” chemicals could be very significant industry “disruptor”

- Reconfiguration in refinery to convert heavy-ends of crude to lighter molecules, “right” for producing petrochemicals
- In order to produce 40-50% of the bbl to chemical feedstocks
- Versus traditional 20-25% for an integrated refinery
- Half of this to light olefins

Source: PEP 29J: Steam Cracking of Crude Oil
Crude-to-olefins is expected to have very significant impact on chemical industry — e.g., for Saudi Aramco/CLG

- Feeds whole (light) barrel to hydrocracker (HK)
- Making distillation more simple than conventional CDU
- HS FCC technology by JV with JX Nippon

Light olefins production is ~40% of crude feed...but 72% for chemical feedstocks

Source: PEP 29J: Steam Cracking of Crude Oil
Crude-to-olefins is expected to have very significant impact on chemical industry — e.g., for Saudi Aramco/CLG

(Reuters 1/8/18)

**Saudi Aramco signs crude-to-chemicals technology agreement**

“… 70 to 80 percent of crude intake will be converted into chemicals, with an eye to beginning commercialization in two years…”

”… thermal crude-to-chemicals technology - would cut capital costs by 30 percent compared to conventional refining…”

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**Light olefins production is ~40% of crude feed… but 72% for chemical feedstocks**

<table>
<thead>
<tr>
<th>Product</th>
<th>MM MT/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene</td>
<td>4.7</td>
</tr>
<tr>
<td>Propylene</td>
<td>3.0</td>
</tr>
<tr>
<td>Mixed C₄</td>
<td>2.6</td>
</tr>
<tr>
<td>Pygas</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14.3</strong></td>
</tr>
</tbody>
</table>

Source: PEP 29J: Steam Cracking of Crude Oil
Aramco/CLG is expected to produce 14,300 KTPA (we are going to need a “bigger” boat slide)

Light Olefins portion: 7,700 KTPA

Source: PEP 29J: Steam Cracking of Crude Oil
Direct Syngas to Light Olefins

OX-ZEO process, developed by DICP, and process developed by SARI*
have potential to be commercially viable

*both under Chinese Academy of Sciences
Based on an oxide of Zn/Cr metals with modified zeolite catalyst, “direct” syngas process yields high light olefins without need for a methanol intermediate.

### Ox-Zeo Process

| C₂-C₄ olefins from syngas conversion, wt %: | 82 | 87 |
| Ethylene/propylene ratio | 1.5 | 1.0 |
| H₂/CO molar ratio (gasifier) | 0.6:1 | 2:1 |
| Carbon eff% from coal | 45 | 36 |

Source: PEP 299: Direct Syngas to Light Olefins
Integrated Coal-to-Liquids (CTL) – Naphtha via advanced Fisher-Tropsch synthesis

Integrated Coal - Calcium Carbide – Acetylene – Ethylene
Several CTL developers in China claim to have superior slurry Fischer-Tropsch (F-T) catalyst & reactor technology

- Synfuel China, has Medium-Temperature Slurry-Bed Fischer-Tropsch Process (MTSFTP) technology with an iron–based catalyst
- Claimed be to “significantly” more active and selective than conventional F-T synthesis

Source: PEP 305: CTL Enhanced Production of Naphtha and Light Olefins
There are CTL plants totalling 4 MM TPA of naphtha from coal being commercialized and planned in China

<table>
<thead>
<tr>
<th>Company</th>
<th>Shenhua Ningmei’s</th>
<th>Lu’an</th>
<th>Shaanxi Energy</th>
<th>Yitai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Fuels, MM TPA</td>
<td>4 (55 Bn RMB/$7.9 Bn)</td>
<td>1</td>
<td>4</td>
<td>1 at Yili &amp; 2 at Ordos</td>
</tr>
<tr>
<td>Stage of Development</td>
<td>Commercial Dec 2018</td>
<td>Commercial Dec 2017</td>
<td>Feasibility</td>
<td>Approved, Op Pilot (160KTPA)</td>
</tr>
<tr>
<td>Coal Feed, MM TPA</td>
<td>20.4</td>
<td>5?</td>
<td>20 ?</td>
<td></td>
</tr>
<tr>
<td>Naphtha, MM TPA</td>
<td>1.08</td>
<td>0.25</td>
<td>1.0</td>
<td>0.25 &amp; 0.75</td>
</tr>
<tr>
<td>LPG, MM TPA</td>
<td>0.34</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel, KTPA</td>
<td>2.73</td>
<td>0.71</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: PEP 305: CTL Enhanced Production of Naphtha and Light Olefins
Agenda

What are disruptive technologies?

What are they and what makes them interesting?

Implication for the industry
And finally...

Double Disruption

Lowest feedstock cost

Lowest investment capital intensity

Most competitive

China investment location factor ~0.53 USGC, due to:
- Efficient construction methods
- High construction productivity
- Low skilled labor cost
- Extensive domestic equipment manufacturing capabilities

?? Market drivers are expected to close this advantage over time

Source: PEP 204C: Location Factors
Crude oil to chemicals …target to drive chemical feedstock capacity and value add to crude oil, especially in Middle East

Impact footprint: Crude oil cracking

Source: IHS Markit

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Crude oil cracking …but also could have a significant import impact, if built in petrochemical -deficit regions

Impact footprint: Crude oil cracking

Source: IHS Markit
Ox-Zeo Direct conversion of to olefins….could have industry impact in China by making coal-based technology more sustainable

Impact Footprint: Ox Zeo DCIP (Direct conversion) of coal-based synthesis gas to olefins

- Indigenous Feedstock
- Portfolio Enhancement
- Import Replacement
- Incremental Capacity
- Volume
- Environmental (by substitution)

Source: IHS Markit

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Siluria’s OCM to ethylene…positioned to impact at company level

Impact footprint: Siluria’s OCM to ethylene

- Indigenous Feedstock
- Portfolio Enhancement
- Incremental Capacity
- Import Replacement
- Volume
- Environmental (by substitution)

Source: IHS Markit

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Really finally…the bar is moving up for capital and operating resources to achieve a competitive & sustainable advantage by:

- Securing feedstock advantage
- Converting lowest cost molecules to high value products
- Leveraging technology developments – especially revolutionary ones
- Integrating physically, upstream and downstream
- Decreasing **Capital Intensity**: through scale, simplicity and location