The High Stakes Gamble
In the Olefins Industry
Market Risks and Rewards for New Petrochemical Construction

LCA / LCIA Annual Meeting
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Stephen Zinger
Vice President – Chemicals
Wood Mackenzie
Over the last 40 years, Wood Mackenzie has evolved naturally along the energy value chain to capture all the key components affecting global markets.

Our integrated approach allows us to spot trends and forecast future dynamics before anyone else.
The High Stakes Gamble in the Olefins Industry

Agenda

- **Ethylene**
  *Adapting to a Changing Game*
  - Energy volatility brings rewards and risk
  - The gas-based chemical renaissance
  - Gas vs. oil vs. coal based feedstocks

- **Propylene**
  *Witnessing A Market Evolution*
  - Long-term Past: By-product
  - Recent past: Shortage
  - Future: On-purpose technologies
Ethylene

The global ethylene market is dominated by polyethylene demand (for plastic applications) and naphtha (from crude oil) & ethane (from natural gas) supply.

2015 Global Ethylene Market = 145 Million Tons

Source: Wood Mackenzie Long Term Ethylene Service
Ethylene – Energy Volatility Brings Rewards & Risk
The “rollercoaster” of volatility of regional energy valuations has driven investment decisions across the chemical industry.

Key Global Energy Benchmarks

North America Lost Competitiveness to Asia/Middle East

Source: ArgusMedia, NYMEX, SXCoal
Ethylene - Energy Volatility Brings Rewards and Risk

As a result of high natural gas prices and the flight of manufacturing to China, North America shutdown ethylene plants: Equistar Lake Charles, Dow Seadrift, Dow Texas City, ExxonMobil Houston, Eastman Longview, Petromont Varennes, Sunoco Marcus Hook, Equistar Choc Bayou, FHR Odessa

Global Ethylene Capacity Additions

Million tons

- Americas
- Europe + Japan
- Russia and The Caspian
- Middle East + Africa
- China + India
- Rest of World

North America Lost Competitiveness to Asia/Middle East

Source: Wood Mackenzie Long-Term Ethylene Service
Ethylene - The Gas-based Chemical Renaissance
Shale gas has significantly changed US supply, with the Marcellus field becoming the largest gas play in the world for decades to come.

Ethylene - The Gas-based Chemical Renaissance
The “rollercoaster” of volatility of regional energy valuations drives investment decisions across the chemical industry

Emergence of the North America Gas-based & China Coal-based Chemical Industry Advantage

Source: ArgusMedia, NYMEX, SXCoal
Ethylene - The Gas-based Chemical Renaissance
North American now building a $100+ billion gas chemical renaissance

natural gas & natural gas liquids

- 197 new chemical industry projects due to shale gas
  - $125 billion in new capital investment
  - 407 thousand direct & indirect jobs by 2023
  - $274 billion in new economic output
  - $18 billion in new tax revenue by 2023

- ethylene
- propylene
- methanol
- ammonia
- others

Ethylene - The Gas-based Chemical Renaissance

As a result of low natural gas prices (and ethane) relative to high crude oil prices (and naphtha), N. America adding most of the new ethylene capacity in the world.

Global Ethylene Capacity Additions

Source: Wood Mackenzie Long-Term Ethylene Service
Ethylene - The Gas-based Chemical Renaissance

The North America ethylene industry is expanding initially through debottlenecks and then through new world-scale plants.

### North America Ethylene Capacity

- **Existing Capacity**
- **Firm Projects**
- **Likely Projects**
- **Hypothetical Projects**

**Debottlenecks of Existing Capacity**

- BASF/Total (TX), CP Chem (TX), Dow (TX/LA), Eastman (TX), Equistar (TX), INEOS (TX), Westlake (LA), Williams (LA)

**Firm/Likely Projects Underway (Before 2020)**

- Braskem Idesa Mexico (end-2015)
- Oxy/Mexichem Texas (2017)
- Chevron Phillips Texas (2017)
- ExxonMobil Texas (2017)
- Dow Texas (2017)
- Formosa Texas (2018)
- Sasol Louisiana (2018)
- Shintech Louisiana (2019)

**Other Projects Under Study (before FID)**

- Aither (WV – Cancelled), Appalachian Resins (OH – Cancelled), Axiall/Lotte (LA), Badlands NGL (ND), Braskem (WV), CP Chem2(TX), Formosa2 (TX/LA), Hanwha (Cancelled), Indorama (LA), NOVA (CAN), PTT/Marubeni (OH), Sabic (TBD), Shell (PA), Total (TX), Williams (LA), Others

Source: Wood Mackenzie Long Term Ethylene Service (1H 2015)
Ethylene - The Gas-based Chemical Renaissance

Significant growth in ethylene derivative exports will occur in 2017 to 2018 since domestic demand will not keep up with new supply.

**North America Ethylene Equivalent Exports**

<table>
<thead>
<tr>
<th>Year</th>
<th>Polyethylene</th>
<th>Vinils</th>
<th>Ethylene Glycol</th>
<th>Styrene</th>
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<tbody>
<tr>
<td>2005</td>
<td>-16</td>
<td>-14</td>
<td>-12</td>
<td>-10</td>
</tr>
<tr>
<td>2010</td>
<td>-8</td>
<td>-6</td>
<td>-4</td>
<td>-2</td>
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<tr>
<td>2015</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>2020</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
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<tr>
<td>2025</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

**Global Trade of Ethylene Equivalents**

<table>
<thead>
<tr>
<th>Year</th>
<th>Rest of World</th>
<th>China + India</th>
<th>Middle East</th>
<th>Europe</th>
<th>Russia and The Caspian</th>
<th>Latin America</th>
<th>Latin America</th>
<th>United States + Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>-16</td>
<td>-14</td>
<td>-12</td>
<td>-10</td>
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<td>60</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

*Source: Wood Mackenzie Long Term Ethylene Service (1H 2015)*
**Ethylene - The Gas-based Chemical Renaissance**

Like shale gas, US tight oil supplies are grown tremendously from Eagle Ford / Bakken / Permian basins, and this is now impacting global oil prices.
Ethylene - Gas vs. Oil vs. Coal based feedstocks

Since August 2014, global crude oil prices fell because of US tight oil supplies, weaker global demand growth and new OPEC policy to protect market share instead of price.

Source: ArgusMedia, NYMEX, SXCoal
Ethylene - Gas vs. Oil vs. Coal based feedstocks

A flatter global production cost curve still keeps North America ethylene competitive at $50/bbl crude; however, investment returns/paybacks will be lower than expected.

Source: Wood Mackenzie

Sep 2014 Ethylene Costs (Brent=$98/bbl; Henry Hub=$3.90)

Aug 2015 Ethylene Costs (Brent=$47/bbl; Henry Hub=$2.80)
Ethylene - Gas vs. Oil vs. Coal based feedstocks

Naphtha crackers’ competitiveness with ethane is a function of the relative value of crude oil and natural gas; China coal competitiveness if related to crude oil vs. coal.

Crude (Naphtha) to Natural Gas (Ethane) Correlation

$100 Crude Oil => $12 Natural Gas

Crude Oil ($/bbl) vs. Natural Gas ($/MMBTUs)

Ethylene Cash Production Costs ($/ton)

- Asia Naphtha
- US Ethane

Crude (Naphtha) to Coal (CTO) Correlation

$100 Crude Oil => $110 Coal

Crude Oil ($/bbl) vs. Coal ($/ton)

Ethylene Cash Production Costs ($/ton)

- Asia Naphtha
- China Coal

Source: Wood Mackenzie Long Term Ethylene Service
Ethylene - Gas vs. Oil vs. Coal based feedstocks

Naphtha crackers’ competitiveness with ethane is a function of the relative value of crude oil and natural gas; China coal competitiveness if related to crude oil vs. coal

Crude (Naphtha) to Natural Gas (Ethane) Correlation

$3 Natural Gas => $30 Crude Oil

Crude (Naphtha) to Coal (CTO) Correlation

$40 Coal => $50 Crude Oil

Source: Wood Mackenzie Long Term Ethylene Service
Ethylene - Energy Volatility Brings Rewards and Risk

Natural gas and crude oil prices returned to similar levels in 2015, but are expected to diverge again based on longer-term fundamentals that keep natural gas prices low and drive crude oil prices to respond to higher costs of production than tight oil.

Source: Wood Mackenzie Macro Oil Service (1H 2015) & N. America Gas Service (1H 2015)
The High Stakes Gamble in the Olefins Industry

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- **Ethylene**
  *Adapting to a Changing Game*
  » Energy volatility brings rewards and risk
  » The gas-based chemical renaissance
  » Gas vs. oil vs. coal based feedstocks

- **Propylene**
  *Witnessing A Market Evolution*
  » Long-term Past: By-product
  » Recent past: Shortage
  » Future: On-purpose technologies
What is Propylene? The World’s second largest basic chemical building block, consumed to make plastics, synthetic materials, and fuels

Source: Wood Mackenzie Chemical Market Service
Propylene – Witnessing a Market Evolution
Phase 1 = Propylene is a by-product

Before 2010

<table>
<thead>
<tr>
<th>Era</th>
<th>Long-Term Past</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Characteristics</td>
<td>By-product Supply</td>
</tr>
<tr>
<td></td>
<td>Rapid Demand Growth</td>
</tr>
<tr>
<td>Pricing Dynamics</td>
<td>Naphtha Cracking &amp;</td>
</tr>
<tr>
<td></td>
<td>Refinery Economics</td>
</tr>
</tbody>
</table>

Source: Wood Mackenzie Long Term Propylene Service
Propylene – Long-term Past: By-product

Historically, most propylene produced from naphtha crackers as a by-product of ethylene or refinery FCC units as a by-product of gasoline. At this time, propylene prices correlated well with naphtha and gasoline prices.

2005 Global Propylene Production

- Steam Cracker: 62.3%
- Refinery Splitter: 33.8%
- PDH: 2.6%
- Others: 1.3%

2005 Global Propylene Market = 64 Million Tons

2000-2009 Naphtha-to-Propylene Correlation

Source: Wood Mackenzie

Source: ArgusMedia, PetroChem Wire, Wood Mackenzie
Propylene – Witnessing a Market Evolution
Phase 2 = Propylene in shortage; High prices cause demand destruction

Before 2010

2010-2015

<table>
<thead>
<tr>
<th>Era</th>
<th>Long-Term Past</th>
<th>Recent Past</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Characteristics</td>
<td>By-product Supply</td>
<td>US Cracker Yield Loss</td>
</tr>
<tr>
<td></td>
<td>Rapid Demand Growth</td>
<td>China Rapid Growth</td>
</tr>
<tr>
<td>Pricing Dynamics</td>
<td>Naphtha Cracking &amp; Refinery Economics</td>
<td>Derivative Demand Destruction</td>
</tr>
</tbody>
</table>

Source: Wood Mackenzie Long Term Propylene Service
Propylene - Recent past: Shortage

Shale (ethane cracking) caused the US propylene shortage in 2010-2014

**US Ethane Cracking Increases**

Million Tons, US Ethylene Production

**US Propylene Supply Gap**

Million Tons, US Steam Cracker Propylene

Propylene Gap 3.5 M tons/yr

Source: AFPM, Wood Mackenzie

www.woodmac.com
Propylene - Recent past: Shortage

In past five years, propylene’s historical price relationship to naphtha has broken, as volatile prices rose to levels of demand destruction; On-purpose propylene growth so far mostly limited to metathesis (tied to crackers or FCC units).

2010 Global Propylene Production

2010 Global Propylene Market = 77 Million Tons

- Steam Cracker 56.6%
- Refinery Splitter 35.4%
- PDH 3.2%
- Others 4.8%
- MTO/P 0.1%

2010-2014 Naphtha-to-Propylene Correlation

\[ y = 0.1771x + 1232.2 \]
\[ R^2 = 0.07 \]

$/Ton, US PG Propylene Price vs. $/Ton, US Naphtha Price

Source: ArgusMedia, PetroChem Wire, Wood Mackenzie
Propylene – Witnessing a Market Evolution
Phase 3 = On-purpose propylene defines future market dynamics

<table>
<thead>
<tr>
<th>Era</th>
<th>Long-Term Past</th>
<th>Recent Past</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Characteristics</td>
<td>By-product Supply</td>
<td>US Cracker Yield Loss</td>
<td>On-purpose Capacity</td>
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<tr>
<td></td>
<td>Rapid Demand Growth</td>
<td>China Rapid Growth</td>
<td>Balances Demand</td>
</tr>
<tr>
<td>Pricing Dynamics</td>
<td>Naphtha Cracking &amp;</td>
<td>Derivative Demand</td>
<td>Costs &amp; Returns for</td>
</tr>
<tr>
<td></td>
<td>Refinery Economics</td>
<td>Destruction</td>
<td>On-purpose Supply</td>
</tr>
</tbody>
</table>

Source: Wood Mackenzie Long Term Propylene Service
Propylene - Future: Global On-purpose technologies

The age of on-purpose supply is imminent, with the most rapid growth occurring in 2015 to 2017 in PDH (Propane Dehydrogenation) and MTO (Methanol-to-Olefins)

Source: Wood Mackenzie Long Term Propylene Service
Propylene - Future: China On-purpose technologies

With the world’s second largest reserves of coal, China is investing heavily in Coal-to-Methanol-to-Olefins (23 by end of 2015); About 40% based on purchased methanol. There will be too much excess capacity in 2016 to 2018.

- **Existing MTO/P Capacity**

<table>
<thead>
<tr>
<th>China</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenhua Baotou 1</td>
<td>Ningxia Baofeng</td>
</tr>
<tr>
<td>Shenhua Ningxia 1</td>
<td>Shandong Shenda</td>
</tr>
<tr>
<td>Datang Duolun</td>
<td>Pucheng Clean Energy</td>
</tr>
<tr>
<td>Sinopec Zhongyuan</td>
<td>Shandong Huabin</td>
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<tr>
<td>Ningbo Heyuan</td>
<td>Shandong Ruichang</td>
</tr>
<tr>
<td>Wison Nanjing</td>
<td>Shandong Lushenfa</td>
</tr>
<tr>
<td>Shaanxi Yanchang Yulin</td>
<td>Zhejiang Xingxing</td>
</tr>
<tr>
<td>Shandong Luqing</td>
<td>Shandong Yangmei Hengtong</td>
</tr>
<tr>
<td>Shandong Yuhuang</td>
<td>Shandong Daze (Oct 15)</td>
</tr>
<tr>
<td>China Coal Shaanxi Yulin</td>
<td>Inner Mongolia Mengda (Nov15)</td>
</tr>
<tr>
<td>Shenhua Ningxia 2</td>
<td>Shenhua Yulin (Nov15)</td>
</tr>
<tr>
<td></td>
<td>Fund Changzhou (Nov15)</td>
</tr>
</tbody>
</table>

- **Firm & Likely MTO/P Underway (by 2020)**
  - ~25 Projects

- **Speculatively Announced MTO/P Projects**
  - Multiple

Source: Wood Mackenzie Long Term Propylene Service
Propylene - Future: North America On-purpose technologies

With some existing metathesis by Lyondell and BASF/Total, N. America has and will invest mostly in PDH with some interest in MTP; Export oriented investments will be facilities limited to Americas demand growth.

- **North America Propylene Production**

  **Million Tons Propylene**

  **% On-Purpose**

  18

  35%

  

- **Existing PDH Capacity**

<table>
<thead>
<tr>
<th>US</th>
<th>Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHR Petrologistics TX</td>
<td>PEMEX (Shutdown)</td>
</tr>
<tr>
<td>Dow Texas TX (Nov)</td>
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</tbody>
</table>

- **Firm and Likely PDH Underway (by 2020)**

<table>
<thead>
<tr>
<th>US</th>
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<tbody>
<tr>
<td>Enterprise TX (2016)</td>
</tr>
<tr>
<td>Formosa TX (2018)</td>
</tr>
</tbody>
</table>

- **Speculatively Announced PDH/MTP Projects**

<table>
<thead>
<tr>
<th>US</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascend 1&amp;2 TX</td>
<td>Williams 1 CAN</td>
</tr>
<tr>
<td>Dow 2 TX</td>
<td>Williams 2 CAN</td>
</tr>
<tr>
<td>Enterprise 2 TX (Cancelled)</td>
<td></td>
</tr>
<tr>
<td>FHR Petrologistics 2 TX</td>
<td></td>
</tr>
<tr>
<td>Rextac TX (Cancelled)</td>
<td></td>
</tr>
<tr>
<td>Sunoco Logistics PA</td>
<td></td>
</tr>
<tr>
<td>BASF TX (MTP)*</td>
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</tbody>
</table>

**Source:** Wood Mackenzie Long Term Propylene Service
The High Stakes Gamble in the Olefins Industry
Ethylene Summary & Conclusions

- Since 2010, North America’s shale has caused an abundance of natural gas and natural gas liquids
- Structural advantage for gas based chemical industry and beginning of a $100+ billion investment renaissance, most of which is in the ethylene industry
- Now, North America’s oil from shale contributing to global oil price declines & threatening North America’s gas chemical renaissance
- Chemical plants under construction will continue, but new plans will likely delay decisions and look for more risk mitigation strategies
- If crude oil prices return higher, then the North American gas based chemical investment renaissance will continue mostly as planned
- If crude oil price stay at low or lower levels, then North America gas based chemical investment renaissance will slow considerably
The High Stakes Gamble in the Olefins Industry
Propylene - Summary & Conclusions

- Before 2010, most propylene was produced as a by-product of ethylene (steam crackers) or gasoline (refineries).

- North America’s shale gas chemical renaissance recently caused a shortage of propylene when steam crackers maximized ethane cracking.

- Now, new on-purpose propylene technologies are under construction to solve the propylene shortage problem.

- PDH (propane dehydrogenation) is the dominant on-purpose technology of choice in North America, but PDH and MTO/P (Methanol-to-Olefins/Propylene) are both important in China.

- Longer-term these on-purpose technologies will be the balancing mechanism for demand growth, and propylene prices will be much more impacted by PDH economics.
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Steve Zinger joined Wood Mackenzie in 2012 to develop a global chemical research team to compliment Wood Mackenzie’s existing capabilities in energy, metals, and mining. In 2013, he coordinated the launch of a comprehensive package of chemical research analyses, including the “Short-term Ethylene & Propylene Market Service” and the “Long-term Ethylene & Propylene Market Service”.

Steve currently contributes to research, multi-client, and private consulting studies using his expertise in the markets for ethylene, propylene, and butadiene. He regularly provides executive presentations about the outlook for the chemical industry for his customers’ private meetings as well as for key chemical industry events.

Steve has 25 years of international experience in the chemical industry. Previous to Wood Mackenzie, he worked for a boutique chemical consulting firm, in various roles including Managing Director of Asia (Singapore) and Global Olefins Business Director (USA). Steve also worked for Shell Oil Company (USA) as a process engineer and planning manager within several olefin plants and refineries.

Steve has a chemical engineering degree from Virginia Tech (USA) and a masters degree in business administration from Tulane University (USA).