On-purpose Olefins through CATOFIN® -CATADIENE® Technologies

Global Propylene & Derivatives Summit

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Agenda

- Cracker Feedstock Trends
- Commercial Routes to Propylene
- CATOFIN/CATADIENE Technology
- CATOFIN PDH Technology
- CATADIENE Technology
- Conclusions
Diverging Oil and Gas Prices...

US Oil & Gas Price History

Source: EIA

A World of Solutions
Ethane 27%
Naphtha 55%
Propane 7%
Butane 4%
Gas Oil 5%
Others 2%

2005

Ethane 35%
Naphtha 45%
Propane 9%
Butane 5%
Gas Oil 3%
Other 3%

2015

Ethane 33%
Naphtha 50%
Propane 8%
Butane 4%
Gas Oil 3%
Others 2%

2010

...are Lightening Global Cracker Feedstocks

A World of Solutions
Feedstock Determines Product Slate
Global utilization moving towards peak in 2015-2016

- Asia leading the way in capacity additions
Cracker co-product capacity growth relatively flat

Refinery FCC units represent the other conventional source of propylene

– Flat gasoline demand growth a constraint there
Co-product Pricing Strengthening

Average annual prices provided by Global Data

Ethylene, Propylene, Butadiene Prices (2000 = 100)
Propylene Growth Regions and Usage Patterns

Announced Propane Dehydrogenation Production Capacity of Propylene

Propylene End Markets

Propylene – PDH is necessary to fill propylene demand gap globally; China will import large volumes of propane from the US to make propylene

Source: Wood Mackenzie

A World of Solutions
Commercial Routes to Propylene

Traditional Technologies
- Steam Cracker
- FCC
- MTO
- Propane Dehydrogenation (PDH)
- Olefins Conversion Technology (OCT)

New Technologies
- Propylene
20% of the global propylene market by 2016

Charts provided with permission of IHS Chemical
Favorable Feed/Product Pricing Differential

Propane/Propylene Differential USGC

Source: ICIS

Information provided from ICIS Pricing, a member of the Reed Elsevier plc group
Propylene Selectivity Comparison

“By-product” Technologies

“On-purpose” Technologies

% Propylene Yield

Ethane Naphtha FCC MTO PDH OCT

By-product
On-purpose

0 25 50 75 100

Yield

A World of Solutions
What is CATOFIN /CATADIENE Technology?

- Proven technology platform licensed by CB&I for single-stage, fixed bed dehydrogenation of paraffins
- CATOFIN for propane and isobutane dehydrogenation
  - Propane to Propylene (C₃ CATOFIN)
  - Isobutane to Isobutylene (iC₄ CATOFIN)
- CATADIENE for n-butane dehydrogenation
  - n-Butane to Butadiene and Butylenes
- Catalyst supplied by Clariant
CATOFIN technology is a high selectivity process for propylene production

- propane $\Rightarrow$ propylene + hydrogen
- $< 1.15$ ton propane required per ton propylene

- Fixed bed reactor system
- Largest single train capacities (up to 850 kta)
- Highest reliability ($> 97\%$)
- 14 CATOFIN units licensed to date
  - Several operating units are integrated with polypropylene
  - Total propylene capacity: $> 7000$ kta
CATOFIN Process Flowsheet

- Charge Heater
- Reactor on Purge
- Reactor on Stream
- Reactor on Reheat
- Waste Heat Boiler (WHB)
- Air
- Air Heater
- Propylene Product
- Byproduct Recovery/Fuel gas
- Low Temp. Section
- Flash Drum
- Product Compressor
- Cooler
- Steam
- Fresh Propane
- Propane Recycle
Flowsheet Options for CATOFIN Plant

- **Low CAPEX design**
  - Optimal for areas of the world where low-cost energy is available
  - Heat-pumped product splitter
  - Common waste heat boiler for hot exhaust streams

- **Low OPEX design**
  - Patented “Low-energy Scheme”
  - Optimization of energy use around product compressor and reboilers
  - Optimization of air heating
  - Best application for high energy cost regions
Continuous CATOFIN Improvements

- Latest CATOFIN catalyst “breakthrough” in commercial operation
- 2 – 3% increase in olefin selectivity
- 5 – 10% energy savings
- Up to $30 million profit boost over conventional catalyst units

Improves return on investment
What About Butadiene?

- New butadiene extraction opportunities limited due to tightening raw C₄ supply from liquids crackers
  - Few liquids crackers remain without BD extraction from crude C₄s
  - Butadiene a key profit driver for Asian crackers
- Recent pricing exceeded $US 4,000 per ton
  - Supply limitations continue to be forecasted on back of strong demand for synthetic rubbers

![Asian Ethylene, Propylene, Butadiene Prices (US$/t)](chart)

*Average annual prices provided by Global Data*
Butadiene/Butane Pricing

![Graph showing price trends for Butane mix, BD USGC, and BD NE Asia from 10/10/06 to 8/14/13.](Image)

Information provided from ICIS Pricing, a member of the Reed Elsevier plc group.
Commercial Routes to Butadiene

Steam Cracker

Butylene Oxidative Dehydrogenation

Butane Dehydrogenation

“By-product” Technologies

Butadiene

“On-purpose” Technologies
CATADIENE one-step dehydrogenation of butane to butadiene

n-Butane + Heat → n-Butenes + Butadiene + Hydrogen

Butene recovery for OCT or Alkylation feed

n-Butene / n-Butane Recycle

Butadiene Extraction

n-Butane

CATADIENE

Butadiene

n-Butene

n-Butenes

n-Butane

Extraction

CATADIENE – On-purpose BD Technology

- Only on-purpose technology available for production of 1,3 butadiene and/or n-butenes by dehydrogenation of n-butane.
- First CATADIENE dehydrogenation unit started up in 1944 to meet demand for synthetic rubber during World War II.
- 19 more units built in 1950s to 1980s.
- Most plants discontinued in 1970s/1980s due to abundance of butadiene as co-product from naphtha crackers.
- Three plants remain in operation in Russia.

<table>
<thead>
<tr>
<th>Decade</th>
<th>Units Built</th>
<th>Olefins Capacity KMTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1960</td>
<td>9</td>
<td>600</td>
</tr>
<tr>
<td>1960s</td>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>1970s</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>1980s</td>
<td>1</td>
<td>180</td>
</tr>
<tr>
<td>After 1990</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Units currently operating</td>
<td>3</td>
<td>270</td>
</tr>
</tbody>
</table>

New grassroots on-purpose butadiene project under design.
Conclusions

- Proven higher selectivity of the process with the implementation of HGM
- Large design capacities are possible to take advantage of the economy of scale
- CATOFIN technology improved flowsheets meet local utility constraints at various locations around the world
- CATOFIN productivity and profitability maximized with latest improvements
- CATADIENE proven technology for on-purpose butadiene production
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