Sustainable Catalytic Cracking Technology: Useful for the Energy Transition

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KBR Olefins Technologies

- Propane to Propylene (PDH)
- FCC based — easier to operate and more reliable
- Environmentally friendly catalyst
- Lower CAPEX and OPEX

- Catalystic Olefins Process
- C4-C10 Olefinic, Paraffinic or Mixed Feeds
- Higher Propylene-to-Ethylene Production
- Energy Transition Technology—upgrading Low Value Gasoline Streams

- Steam cracking process
- Furnace flexibility — Ethane to gas oil
- Highest yield in industry
- Lower CAPEX
- Lowest CO₂ footprint

- Ethanol to Ethylene Technology
- Newest addition to Olefins Portfolio
- Production of ‘bio-ethylene’

- Optimized recovery section Design
- Low CAPEX and OPEX
KCOT is a Key to Address Energy Transition, or to Improve Cracker Economics

- Liquid crackers, looking to upgrade C4, C5, non-aromatic gasoline — recycle to K-COT
- Integrated refinery / petrochemical complexes looking to improve overall flexibility and value upgrade
- Refiners with excess naphtha (straight run or cracked) — upgrade to olefins, especially C3
- Upgrade by-products from FT / CTL / MTO / MTP facilities
K-COT TECHNOLOGY OVERVIEW
KCOT: KBR Catalytic Olefins Technology

- KBR Proprietary Modified ZSM-5 catalyst
- KBR’s well-proven Orthoflow™ fast fluidized reactor with 70-year experience
- KBR’s over 100 olefins plant design experience

Proprietary Catalyst...

KBR Orthoflow Reactor

...coupled with the hardware
KBR KCOT is based on over 70 years of innovation and improvements
# The KCOT Advantage

## Ultimate Feed Flexibility

- Ability to process C4-C10 olefinic, paraffinic or mixed streams, such as:
  - Mixed C4s from refineries and conventional steam crackers
  - Amylenes, TAME raffinate and mixed C5s
  - Cracked naphtha from FCCs, steam crackers, cokers and visbreakers
  - Oxygenates, such as methanol and ethanol
  - Other low-value olefinic streams

- No need for feed pre-treatment

## High Value Product

- Ability to convert low-value streams directly into high-value petrochemical feedstock
- High propylene-to-ethylene ratio compared to steam cracking (~1:1 for straight run feed, ~2:1 for olefin-rich feed)
- High aromatics product credit
# KCOT Feedstock Flexibility

<table>
<thead>
<tr>
<th>Feed Type</th>
<th>KCOT P/E Ratio Up to 2.5</th>
<th>Olefins yield up to 60%</th>
<th>SCORE P/E Ratio Up to 0.65</th>
<th>Olefins yield up to 60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
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<tr>
<td>Propane</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Butane</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Straight Run Naphtha</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Steam Cracking olefinic C4’s, C5’s</td>
<td>√</td>
<td></td>
<td></td>
<td>√ (hydrogenated)</td>
</tr>
<tr>
<td>Aromatics Raffinates (C6-C8NA)</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery C4’s</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC/Coker Naphtha</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visbreaker Naphtha</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol, Ethanol</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Other Oxygenates</td>
<td>√</td>
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</tbody>
</table>
Typical Ultimate Yields Performance

P/E Ratio = 1.0 ~2.0
Based on KBR’s 70 years experience in FCC reactor
Large single reactor capacity up to 1200KTA of ethylene and propylene

Based on KBR’s over 100 olefins plant design experience with additional features
- Removal of trace impurities such as oxygen in addition to acetylene
- Unique Quench Oil column design with catalyst recycle scheme
- Simplified C4 – C6NA recycle circuit
- Low CAPEX
Fresh Feeds:
- Ethane
- LPG
- Mixed Refinery C4s
- Straight-run Naphtha
- Cracked Naphtha (FCC, Coker, Visbreaker)
- Raffinate from Aromatics Complex
- Gasoil/HGO/VGO/Unconverted Oil
- By-products from FT/MTO/MTP facilities
- Oxygenates
- Other low value olefinic streams

Optimization based on market conditions

- Highest flexibility on feed side
- Highest flexibility on product side
Typical Steam Cracker

- Naphtha Feed
- Pyrolysis Furnaces
- Oil Quench
- Water Wash
- HP Steam Exch
- Caustic / Drying
- Ethane / Propane Recycle
- Tail gas
- Ethylene
- Propylene
- Butadiene
- C6+ Pygas
- Fuel oil
K-COT / Recycle Converter Configuration

By-products from Refinery / FT / MTO / MTP Oxygenates / Alcohols

Fuel Oil

Naphtha Feed

Pyrolysis Furnaces

HP Steam Exch

Oil Quench

Water Wash

Caustic / Drying

C4 / C5 / C6NA from Ethylene Plant

C3 & Lighter

Converter

O2 Reactor

Deprop/Dehex

BTX-Gasoline

Tail gas

Ethylene

Propylene

Butadiene

C6+ Pygas

Fuel oil

Ethene / Propane Recycle

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Delivering Solutions, Changing the World™
KCOT Integration with Liquid Cracker - Relative Economic Impact

$58/Ethylene ton Average for Entire Period

Simple Payout <3 Years
KCOT Integration with Gas Cracker - Relative Economic Impact

Integrated KCOT solution advantage

- Better capital efficiency
- Increased high-value propylene production (especially with C4 processing)
- Solution flexible to include broader feed mix to adapt to changing market conditions

### Capex and annual E+P production*

<table>
<thead>
<tr>
<th></th>
<th>Relative ISBL TIC</th>
<th>Relative Ethylene</th>
<th>Relative E+P</th>
<th>Relative TIC/ton E+P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standalone 1800 KTA Ethane Cracker</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Integrated KCOT + C2 Cracker</td>
<td>103</td>
<td>84</td>
<td>119</td>
<td>87</td>
</tr>
<tr>
<td>Int. KCOT + C2 Cracker + C4 Proc.</td>
<td>118</td>
<td>81</td>
<td>131</td>
<td>91</td>
</tr>
</tbody>
</table>

*USGC basis
ENERGY TRANSITION
Market Trends

- Global gasoline demand expected to peak in approximately ten years, then decline thereafter
  - More electric and hybrid vehicles
  - Fleet to become more fuel efficient
  - More renewables (such as ethanol) in fuel pool
- Propylene and ethylene demand continues to grow, and yearly growth is expected to exceed GDP over the coming years
- Many refiners are considering technology to convert fuels into petrochemicals
Refining Trends

Global Refined Products Demand Mix

Reduced gasoline & Naphtha Demand → Outlet for Surplus Naphtha?

Refinery Configuration

- Naphtha HDS
- Refiner
- Gasoline/Naphtha
- Diesel
- Ultra Low Sulfur Diesel Hydro De-sulfurizer
- Crude Distillation
- Crude
- Vacuum
- Coker
- COKE
- Produce polymer grade propylene
- Produce either polymer grade or dilute ethylene
- Propylene
- Mixed Butenes
- Light Naphtha
- Heavy Naphtha
- Kerosene
- LCO
- Fuel Oil
- Coker LN
KCOT Can Simplify Refiners’ Growth to Petrochemicals

- Stand-alone K-COT minimizes investment in downstream units
  - All C4’s and light C5/C6NA gasoline can be recycled without hydrogenation to minimize by-products and enhance light olefins yields
  - Only ethylene and propylene derivatives together with either aromatics or high-octane gasoline
- Stand-alone K-COT can be economic even for small naphtha feed quantities or ethylene/propylene production rates
- KBR is already working on such projects in China
Energy Transition – Maximize Chemicals Production from Crude

- Key technology to address KBR’s solution for Crude to Chemicals to improve capital efficiency
- Key technology to minimize investment in downstream units
  - All C4’s and light C5/C6NA gasoline can be recycled without hydrogenation to minimize by-products and enhance light olefins yields
  - Only ethylene and propylene derivatives together with either aromatics or high-octane gasoline
- Good small scale economics (China)
SUSTAINABILITY – THE PATH TO NET ZERO
A Net-Zero Carbon Future is Built on a Foundation of KBR Innovation

**BLUE/GREEN AMMONIA**
K-GreeN, a fully developed end-to-end green ammonia solution spanning electrolyzer to production
Commercial-scale, proven blue ammonia solutions

**Carbon Capture Storage and Utilization**
Innovative carbon capture and sustainability solutions (e.g., Monolith and LanzaTech projects)
Designed and delivered the world's largest carbon sequestration project

**Hydrogen Expertise**
Extensive hydrogen expertise with NASA range and launch operations
Expertise in designing complex cryogenics and LNG storage facilities

**DECARBONIZATION OF EXISTING ASSETS**
Proprietary software and tools to monitor and optimize output and efficiency and reduce emissions
Design modernization solutions to improve energy efficiency and output

**Circular economy**
Exclusive licensing partner for proprietary, innovative plastics recycling technology, enabling the plastic circular economy
Govt/C-Suite advisory

**Renewable Biofuels**
Developing and designing innovative biofuel solutions for clients spanning start-ups to established players

**Renewables & Renewable Integration**
Automated Tools, to drive efficiency in repetitive designs. EV Charging and Offshore Wind.
Patented floating turbine hulls
Trusted Advisory services
Industry leading Project and Program Management

Delivering a cleaner, greener future with KBR energy transition *expertise* and *proprietary technologies*
# Approaches to Reduce CO₂ Emissions

## Carbon Capture
- End of Pipe Solution
- CAPEX Intensive
- CO2 Disposal Issues

- Easier to implement on K-COT:
  - Only one flue gas point source
  - Equipment synergies

## Energy Efficiency
- Modern Grassroots Facilities Highly Energy Efficient
- Incremental Improvements
- Minor Impact on CO₂ Emissions

Plants are already highly efficient

## Electrification
- E-Drives for all Compressors
- Significant reduction in steam generation demand, CW load
- Electrification of Regenerator

Motor drivers could be applied; KBR has commercial experience with this in KCOT

## Hydrogen as Fuel
- Shift from Fuel Oil use to H2-rich fuel gas
  - Maximize fuel gas (vs. fuel oil)
  - H2-rich fuel gas
  - Pure H2 as fuel (Sourcing Challenges, Fuel Gas Disposition)

KBR has demonstrated “proof of concept” via CFD modeling – seeking commercial demonstration

## Renewable Biofuels
- Alternative feeds
  - Ethanol & Methanol as feed to K-COT
  - Bio-oil as fuel
  - Plastics recycle pyrolysis oil as feed (some by-products may be processed without treatment)
Maximize air preheat
Fuel oil => fuel gas

H₂-rich or import
H₂ as fuel gas
Air preheater
Feed preheater
H₂ to Regenerator

Renewable fuel oil

Sustainable Feeds

Selective Process
Electrification
Electric Motor Drives

CCUS
Single-point capture
KCOT Advantages

- Higher Propylene and Aromatics
  - High propylene and Aromatics product credit from various low-value liquid feed

- Ultimate flexibility
  - Feed and product flexibility for olefins production

- Economy of scale across wide range of capacity
  - Large capacity range – 200 KTA up to 1200 KTA olefins from single reactor
  - Small capacity – economy of size for both PE and PP, simplified recovery

- Based on well proven technologies
  - Catalyst performance
  - Orthoflow reactor
  - Backend separation

Lotte Titan K-COT Reactor