Refinery/ Petrochemical Integration – An option or a necessity?

Steven Kantorowicz
Refinery Petrochemical Integration (RPI) is the efficient use of resources between the refiner and the petrochemical plant operator to create greater value jointly than the two entities could separately achieve.
KBC founded as independent consulting company

Developed Petrofine simulation software

Created On-site Implementation Services

Developed Reliability, Availability and Maintenance services

Created Petrochemical, Gas Processing and Energy Industry services

Acquired PEL for Oil and Gas market analysis and Linnhoff March to enhance energy services

Petro-SIM™ – Plant-Wide Flowsheet Simulation Software released

Acquire TTS Performance Systems for Human Performance Improvement services & Veritech to extend Energy services

Launched Environmental Practice - acquired a small consultancy business and the Strategy Practice

Acquired Infochem, and integration of additional modelling capabilities into Petro-SIM™

KBC Office Locations

1979

1986

1995

1996

2000

2002

2004

2006

2009

2012
Global Client Base

7 March 2014

PROPRIETARY INFORMATION
Global Perspectives
# Global Energy Perspectives

**Petrochemicals**

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Petrochemical Industry profitability to remain intact ... with hiccups</strong>&lt;br&gt;• The next peak in the cycle is forecast for 2015&lt;br&gt;• PetChem to have higher-than-refining profitability over the cycle</td>
<td></td>
</tr>
<tr>
<td><strong>Petrochemical demand will remain tied to GDP growth; faster than crude</strong>&lt;br&gt;• Troughs in Asia will not be as low as in other regions&lt;br&gt;• Mature regions will remain under import/ margin pressure</td>
<td></td>
</tr>
<tr>
<td><strong>Asian (especially Chinese) Petrochemicals demand and growth drives everything</strong>&lt;br&gt;• Cools periodically due to “seasonality” – weather; holidays;&lt;br&gt;• Chinese growth will ease towards global averages in products where the country has a significant share of global markets</td>
<td></td>
</tr>
<tr>
<td><strong>Capacity rationalization will continue</strong>&lt;br&gt;• No Region is immune – Old, small &amp; inefficient plants</td>
<td></td>
</tr>
<tr>
<td><strong>Geopolitical factors influence investments and hence price levels</strong>&lt;br&gt;• Can be stable … then issues arise essentially overnight!&lt;br&gt;• Who’s next in line for turmoil and production disruption?</td>
<td></td>
</tr>
<tr>
<td><strong>Middle East cost structures will move closer to those of other regions</strong>&lt;br&gt;• The industry so far is absorbing new Middle East additions, while Asian profitability has remained healthy</td>
<td></td>
</tr>
<tr>
<td><strong>Average global olefins feedstock slate will become heavier</strong>&lt;br&gt;• Refinery Petrochemical Integration improves margins&lt;br&gt;• Grassroots crackers &amp; revamps will increase feed flexibility</td>
<td></td>
</tr>
<tr>
<td><strong>Russia is developing large PC complexes with export capability</strong>&lt;br&gt;• Advantaged ethane feed for PE production&lt;br&gt;• Access to Eastern European and Chinese Markets</td>
<td></td>
</tr>
<tr>
<td><strong>Biomass &amp; coal conversion to Petrochems are local opportunities</strong>&lt;br&gt;• Being studied in China and SE Asia where feeds are abundant&lt;br&gt;• Have not yet made significant penetration</td>
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**PROPRIETARY INFORMATION**
### Global Economic Outlook – Weak GDP

#### Selected GDP Growth

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<td>3.0</td>
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<td>3.8</td>
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</table>

- **2013** - Another year of weak economic growth in the US and Europe
Global Petrochemical Profitability

Average Return on Replacement Capital

Profitability is Cyclical in the Petrochemical Business

Average cash margins were at all-time lows
• Now cycling up, are expected to peak in 2015

Refining Challenge – to increase historically low margins

Petrochemical Challenge – to maintain acceptable margins during the downturns

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**KBC Views on RPI**

KBC Conducted a Global Industry RPI Survey

- Hydrocarbon stream transfer is implemented, to some degree, at most refinery-petrochemical complexes
- Shared utilities were implemented to a much lesser extent
- Shared logistics and services were only done at a few locations with common parent company owners on a single site
Effective Implementation of RPI Depends Heavily on Managerial Factors

Common Ownership

- Develop the maximum benefit for the overall organization even though it requires action by separate divisions

Separate Companies

- The managerial challenge is even greater when achieving RPI with no common ownership
  - Conflicting Profit Requirements

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The U.S. and Singapore have the highest degree of RPI

Europe has only a moderate amount of RPI

Japan and Korea now showing increased interest in RPI

China, other Asia, and Middle East are increasing the extent of RPI from a low base

New mega projects will be integrated petrochemical refineries
- Example – PETRONAS “RAPID” scheduled to start up in 2017
1. Refinery-derived cracker feeds can be:

<table>
<thead>
<tr>
<th>Standard Feeds</th>
<th>Non-standard Feeds</th>
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<tr>
<td>LVN</td>
<td>• FCC Offgas – ethylene &amp; propylene</td>
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<tr>
<td>HVN</td>
<td>• Alkylation Unit Butane Purge</td>
</tr>
<tr>
<td>FRN</td>
<td>• FCC Ethane and Propane</td>
</tr>
<tr>
<td>AGO</td>
<td>• Reformer LPG</td>
</tr>
<tr>
<td>VGO</td>
<td>• Reformer Fuel Gas</td>
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<tr>
<td>Coker Light Ends</td>
<td>• Hydrocracked Gas Oil (HVGO)</td>
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<td>Hydrocracker Light Ends</td>
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</table>

2. Crackers generate by-product hydrogen
   • Refineries consume hydrogen to remove sulfur and to saturate olefins and aromatics; ideal transfer stream

3. Steam and fuel gas from the cracker are utilized in the Refinery

4. Heavy HC streams are used in a common Co-gen
**Uncomplicated RPI Opportunity**

Recovery of Cracker Hydrogen

Sell to Refinery to Replace Expensive Manufactured $H_2$

Can be implemented by a single company or between separate Cracker/Refinery
KBC Views on RPI

Complicated RPI Opportunity

Transfer of Fluid Catalytic Cracking Unit (FCCU) and Coker Overhead Gases From a Refinery to a Cracker

• For recovery of ethylene and ethane

This upgrade in value over fuel gas can be achieved in all ownership situations
KBC RPI Methodology

Two Phase Program
Tools, Experience, Objectivity
Refinery/Petrochemical Integration (RPI)

Benchmarking and Optimization

- Model plant operations using rigorous simulation
- Implement Best Practices Throughout the Plant Organization
- Identify Opportunities with Quick Payouts
- Constantly Monitor the Implementation Results – Profit Tracker
- Continuous Improvement with Appropriate KPIs

Primary Focus of RPI Study

The less well-integrated producers will be the marginal producers and price setters.

Asian facilities cannot be as competitive as the Middle East but RPI is critical to Margin.

Cost Leader
Gladly takes the price

Cost Laggard
Sets the price
Manage the Molecules

**Full Complement of Rigorous Models**

- **Olefin-SIM™**
  - Rigorous Furnace Model
  - Olefins, iC₄

- **Ethylene Plant**
  - Gas Plant
  - ALK
  - AROM
  - H₂
  - ISOM

- **Unit Light Ends**
- **Light Naphtha**
- **Heavy Naphtha**
- **Kero**
- **Diesel**

- **CDU**
- **VDU**
  - Gasoil
  - Vacuum Residue

- **COKER / VISBREAKER**
- **Coke**
- **RHDS**

- **Coker Model**
- **FCC**
- **Vacuum Residue**

**KBC Petro-SIM™**

Industry-leading Process Simulation Software Suite
RPI Methodology – Phase 1

Data Input

- Clarifications
- Details
  - Business
  - Operations
  - Maintenance
  - Logistics
- Benchmarks

Activity

- Kick-Off Meetings
- Site Visits
- Benchmarking
- Opportunity Generation
- Quick Wins Test Runs

Outcome

- Inception Report
- Base Case Report Petro-SIM Models
- Implement
- Early Benefits
- Recommendations
- Phase 2

Report Generation

Benchmarks

KBC & Owner(s)

Internal Reviews

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RPI Methodology – Phase 2

Typical Scope for Phase 2 Implementation

- Upgrade the combined LP’s to represent ongoing exchange of process streams
- Use LP’s and rigorous process models to estimate detailed economics of opportunities and effect on overall operation
- Conduct rigorous opportunity evaluations where required
- Perform pinch technology studies to evaluate hydrogen and utility integration opportunities
- Evaluate operating and or capital savings by integrating planned or potential strategic project synergies

Agreed Identified Benefit (¢/bbl)

- 20.8 ¢/bbl
- 3.6 ¢/bbl
- 106.6 ¢/bbl

Legend:
- Non Investment
- Minor Investment
- Major Investment

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KBC’s Petro-SIM Refining™

Flow sheet modelling

- Process simulation software suite
- Understanding process impacts
- Confidence that predicted results will match the plant operations
- Estimates potential economic benefits of process and operational changes
- Rigorous models of conventional or step out processes

**Steam System Modelling**

- Site Source Sink Profiles
- ProSteam Utility Model
- Power, Steam & Fuel
- Utility Infrastructure
- Scope for Savings

**Pinch Analysis**

- Heating Target
- Cooling Target
- Utility Pinch
- Process Pinch

KBC’s ProSteam™ & SuperTarget™
Integrate New Unit into Exiting Site

- Enhance Energy Efficiency
- Manage Environmental Impacts
- Maintain Key Integrations such as Hydrogen
- Build Rigorous Simulation of Existing Complex

Hydrogen System Management
- H₂-Pinch identifies means of optimizing H₂ supply
- Reactor modelling predicts the impact of changes on processes

Refinery Modelling
- Refinery modelling provides the overall economic perspective

H₂ Process Technology
- H₂ process technology may be required to meet targets

Integration of Gas Plant, Refinery, Aromatics Plant and Olefins Plant

Power Balance

- LPS
- Heat Exchangers
- Steam Demand
- Steam/Feedwater
- Total Demand

Cost Calculation

- Feed (Dry)
- Utilities
- Total
- Annual Cost (KMY)

7 March 2014
## Technical Evaluation - Overview

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Technology</strong></td>
<td>• Measure of quality of unit process design &amp; incorporated technology</td>
</tr>
<tr>
<td><strong>Licensor Experience</strong></td>
<td>• Measure of technology/ licensor commercial experience for similar size &amp; application</td>
</tr>
<tr>
<td><strong>Licensor Package</strong></td>
<td>• Measure of quality of licensor package; guarantees and liabilities; engineering and license fees</td>
</tr>
<tr>
<td><strong>Global Technical Assistance</strong></td>
<td>• Ability of licensor to provide technical assistance during start-up/normal operations</td>
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<tr>
<td><strong>Design Complexity &amp; Construction Schedule</strong></td>
<td>• Assessment of investment costs and schedule implications; long-lead equipment</td>
</tr>
<tr>
<td><strong>Operations and Maintenance</strong></td>
<td>• Comparison of criteria affecting the operability of the plant such as Shut-downs, Reactor Conditions, Design Complexity</td>
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</table>

7 March 2014
### Economics Evaluation - Overview

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
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<tbody>
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<td>Utility Consumption</td>
<td>• Quantitative comparison of utilities consumptions from guarantee figures</td>
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<tr>
<td>Yield Performance</td>
<td>• Quantitative measure of guaranteed feed consumption and product/by-product production</td>
</tr>
<tr>
<td>Catalyst Performance</td>
<td>• Quantitative measure of initial cost of catalyst + inert materials + annual catalyst costs</td>
</tr>
<tr>
<td>Chemicals and Solvents</td>
<td>• Comparison of annual cost for Chemicals and Solvents from guaranteed Licensor figures</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>• Quantitative comparison of Capital Cost based on KBC estimates and validated by Licensor figures</td>
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</tbody>
</table>
Examples

*Industry Implementation of RPI*
<table>
<thead>
<tr>
<th>RPI Activity</th>
<th>Type of Implementation</th>
</tr>
</thead>
</table>
| **Feedstock Flexibility**                       | Cracking NGLs Through Naphtha  
Cracking NGLs Through Gas Oil  
Crack Conditioned Crude Oil                                                                 |
| **BTX Raffinate Optimisation**                  | Crack or Blend in Gasoline                                                                                                                               |
| **Crude and Cracker Feedstock Selection &**     | Optimise with a Single Linear Programming Model for Refinery & PetChem  
Consider Refinery & Cracker in Optimisation but Run in Separate Models                                                                  |
| **Optimisation of Operating Parameters**         | Select Catalyst & Operating Conditions for Increased Olefins Production  
Run Deep Catalytic Cracking                                                                                                                      |
| **FCC Propylene Optimisation –**                |                                                                                                                                                    |
| production and recovery                         |                                                                                                                                                       |
| **Condensate Optimisation**                     | Crack Condensate in Furnaces (as-is or after treating)                                                                                               |
| **Hydrocracker Unconverted Oil Optimisation**   |                                                                                                                                                    |
| **Use LCO as Primary Fractionator's Quench Oil**| Use LCO in Primary Fractionators                                                                                                                       |
| **Recover Light Gases from Coker Overheads**    | Recover Coker Dry Gases and Separate the Olefins; Crack the Paraffins                                                                               |
| **Recover Light Gases from FCC Overheads**      | Recover FCC Dry Gases and Separate the Olefins; Crack the Paraffins                                                                               |
| **Recover Light Gases from Fuel Gas**           | Recover Paraffins from Fuel Gas Systems; use as Cracker Feeds                                                                                         |
| **C₄ Optimisation/ Recovery**                   | Produce C₄ Products such as Alkylate; Butadiene; MTBE; Propylene                                                                                       |
| **Aromatics Optimisation**                      |                                                                                                                                                    |
| **Cutpoint Optimisation**                       | Consider Petrochemicals when Optimising Reformer Cutpoint                                                                                            |
| **Hydrogen Optimisation**                       | Maximize Hydrogen Recovery in Cracker for Use in Refinery                                                                                             |
| **Share C₃ Splitter – Maximize Propylene Recovery** | Aggregate all Mixed C₃ Streams and Process in One C₃ Splitter                                                                                     |
| **C₅ Optimisation – Cracking versus Gasoline**  | Consider Recovery of C₅ Molecules such as Isoprene; DCPC; Piperylenes                                                                             |
| **Pyrolysis Gas Oil Optimisation**              | Recover Aromatics from Pyrolysis Gasoline; Recycle Crack C₆-C₈ NA                                                                                   |
| **Pyrolysis Tar Optimisation**                  | Optimise PyTar to Cutter Stock, Carbon Black Feed or Needle Coke Feed                                                                                 |
| **Plan Operations with Neighbors**              | Develop Operating Plans with Separately Owned Neighbors                                                                                               |
| **BTX Heavies Optimisation**                    | Optimise C₉+ Molecules to Blending or to Fuel                                                                                                          |
| **Integrate Waste Handling/ Effluent Treating** | Ensure Full Compliance to All Regulations                                                                                                             |
| **Site-Wide Utility Complex; No Reliance on Grid** | Maximum Utilization of All Heavy HC Streams                                                                                                           |
| **Optimum Use of Storage and Logistics**        | Convert Under-utilized Tanks to Other Uses                                                                                                             |
## Feedstock Diversification

### Indifference Values
- Used extensively by PetChem producers
- “What can I afford to pay?”
- Requires detailed knowledge of yield and operating cost effects
- Provides the maximum premium or minimum discount required against a reference feed

### Parity Pricing
- Used by refiners to determine values for intermediate streams
- “What is this stream currently worth to me?”
- Requires knowledge of marginal blending mechanisms
- Invalidated by changes to constraining product quality

### Netback Values
- Used by refiners & PC producers to evaluate process unit economics
- “What is the value of this stream if it’s processed in this unit?”
- Provides a basis for deciding between alternative stream dispositions.
- Should naphtha be sent to the reformer or to the steam cracker?
Example: Feedstock Diversification

Current Situation

Assuming
- Naphtha price ↑
- Ethylene (derivative) price ↓
- Benzene (derivative) price ↑

Naphtha (Import)

Naphtha Cracker

Ethylene
Propylene
Butene
Benzene
Toluene
Xylene

Refinery Plant
Example: Feedstock Diversification

Before Integration

Conventional way to reduce ethylene production was to reduce throughput

As a result, overall production was reduced (big loss including downstream)
Ethylene production was decreased without decreasing production by feedstock diversification and operation optimization.

Loss was minimized as reduced ethylene was compensated by others.
Cracker Yields For Various Feedstocks

Cracker feeds are:
- Ethane LPG, or “dry gas”
- Liquids – NGLs, Naphtha, Raffinate
- Heavy Liquids – Heavy Naphtha, Diesel, Gas Oil, Condensate

Many Crackers use 10 or more different feeds depending on seasonal pricing and availability

C₄ and C₅ yields vary significantly depending on feed and cracking severity
- Butadiene 40-50% of C₄’s
- Isoprene 14-18% of C₅’s

<table>
<thead>
<tr>
<th>Yields, wt%</th>
<th>Ethane</th>
<th>Propane</th>
<th>FR Naphtha</th>
<th>Light AGO</th>
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<td>Hydrogen</td>
<td>3.93</td>
<td>1.56</td>
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<td>34.55</td>
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Change in feed and operating severity impacts supply volumes to the downstream units
## Cracker Yields For Various Feedstocks

### Yield Patterns, % of Ethylene Production*

<table>
<thead>
<tr>
<th>Typical*</th>
<th>Ethane</th>
<th>Propane</th>
<th>Butane</th>
<th>Naphtha</th>
<th>AGO</th>
<th>VGO</th>
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<td>Feedstock Required; ton/ ton C&lt;sub&gt;2&lt;/sub&gt;-</td>
<td>1.2</td>
<td>2.4</td>
<td>2.5</td>
<td>3.1</td>
<td>3.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Propylene</td>
<td>3</td>
<td>50</td>
<td>40</td>
<td>50</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>Butadiene</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>15</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Other C&lt;sub&gt;4&lt;/sub&gt; Olefins</td>
<td>1</td>
<td>3</td>
<td>17</td>
<td>25</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Pyrolysis Gasoline</td>
<td>2</td>
<td>15</td>
<td>18</td>
<td>75</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>Benzene</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>15</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Toluene</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>10</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>C&lt;sub&gt;5&lt;/sub&gt; Monomers</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>-</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>70</td>
<td>125</td>
</tr>
<tr>
<td>Other (mainly H&lt;sub&gt;2&lt;/sub&gt; + CH&lt;sub&gt;4&lt;/sub&gt;)</td>
<td>17</td>
<td>65</td>
<td>62</td>
<td>45</td>
<td>50</td>
<td>45</td>
</tr>
</tbody>
</table>

* Project-specific Requires Rigorous Refining and Cracker Yield Models
Example: Feedstock Diversification

Feedstock blend ratio and operation conditions will be optimized in order to decrease ethylene yield with maximizing benzene yield.

Before diversification

Light Naphtha 90%
Condensate 10%

Study of diversification

Kerosene X %
Gas oil Y %
Light Naphtha 90–(X+Y) %
Condensate 10%

Current product balance

Major olefins
Major aromatics
Others

After diversification

Major olefins
Major aromatics
Others

Feedstock blend ratio and operation conditions will be optimized in order to decrease ethylene yield with maximizing benzene yield.
Example

Refinery Modifications to Integrate with an Adjacent Cracker
Example Refinery Modifications to Integrate with an Adjacent Cracker

Over-riding Objective: Provide Advantaged Feedstocks to the Cracker

- **Sour Water Stripper Revamp**: Increase capacity to accommodate flows from the Cracker.
- **New Deep Vacuum Unit**: Provide additional feedstock for the cracker.
- **New Sulphur Recovery Unit**: To process the additional sour gas produced.
- **Extensive ISBL and OSBL tie-ins**: To enable stream transfers, utility optimizations, etc.
# Example Refinery Modifications to Integrate with an Adjacent Cracker

<table>
<thead>
<tr>
<th>Modification</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Modify Hydrocracker to Maximise Unconverted Bottoms Production** | - A cracker feedstock with high C₂- yield  
  - An outlet for the heavy fuel produced in the cracker is required – can be a cogen |
| **Revamp the Gas Oil Hydrotreater – Decrease Sulphur Content of Waxy Distillate Streams** | - Meet processing requirements of the downstream units operating in maximum olefins production mode |
| **Upgrade (or add) Amine Treating Unit and Regeneration Facilities** | - Reduce product H₂S levels – required as a result of using the heavier cracker feeds |
| **Modify Condensate Splitter System**       | - Allows the flexibility to utilize other liquid feeds in the Cracker when pricing dictates |
Conclusions

- Keys to Successful Project Development
- Systems Required for RPI Success
- Is RPI a Option or a Necessity?
Keys to Successful Project Development

Conduct Preliminary Economic Screening

- Current Market Size
- Raw Material Costs
- Product Prices
- SWOT & Barriers
- Opportunity Ranking

Identify viable integration options and technologies

Embrace Capital Project Excellence (CapX) and Operational Excellence (OpX) throughout the project

Methodology - keep up with the latest licensor and vendor offerings

Tools – undertake rigorous simulations of the configurations being studied

Experience – familiarity based on diverse industry experience

Project Evaluation & Execution

- Process Licensor Technology Comparisons
- Ranking Based on Detailed Methodology – Technical and Commercial Considerations
- Implementation Issues – Planning; FEED; PMC Services; Construction During Operation

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The following systems are critical to the success of the effort:

- Formation of a joint short-range feedstock optimization team responsible for feedstock acquisition and optimum disposition of streams suitable for sending to the steam crackers.

- Creating positions of “feedstock facilitation” in both the refinery and the petrochemical complex.

- Interchange of refinery and petrochemical personnel enables the interests of refining and petrochemicals to be effectively brought to bear on RPI activities.

- Build integrated process & economic models to optimize the profitability of the combined operations.

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Is RPI an Option or a Necessity?

RPI is Being Implemented in Essentially all Grassroots Complexes Worldwide

Simple RPI Activities are not Enough to Compete Against Highly Integrated Sites

Effective RPI Implementation Requires Strong Managerial Support

Rigorous RPI Study & Implementation Requires Methodology, Tools and Expertise

→ YES - RPI is a necessity to be competitive
Thank You

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