Out Line

• Introduction
• Oil Refining - Available options & Key Considerations
• Parameters influencing Refinery Configuration – Current and future
• Design Features- FCCU /HCU
• Closing thoughts
Introduction

- Topping Refinery
- Skimming Refinery
- Catalytic Cracking refinery
- Hydro cracking Refinery
- Integrated Refinery
Configuration - Available options

• Primary Processing options
  • Deep cut vacuum

• Secondary Processing options
  • Deep Catalytic Cracking, Petro FCC
  • RFCC
  • Full Conversion Hydrocracker (HCU)
  • Once Thru’ Hydrocracker (OHCU)
  • VGO Hydrotreater
  • Ethylebenzene/Styrene from FCC off gases
Configuration - Available options

- Light ends Processing options (Refinery)
  - Reforming for Gasoline/Aromatic production
  - Isomerisation units
  - Selective Hydrotreatment
  - Steam reforming of Naphtha (H2 Production)
  - Aromatic Complex
  - Alkylation
Configuration - Available options

• Residue Upgrading options
  • Delayed Coking Unit (DCU)
  • Atmospheric Residue Desulphurisation (ARDS)
  • Vacuum residue desulphurisation (VRDS)
  • Resid Hydrocracking
  • Solvent Deasphalting
  • Deep Thermal Cracker
  • Visbreaking
  • Bitumen Blowing
Configuration - Available options

- CPP Type
  - Conventional Liquid based CPP
  - CPP based on Pet coke (CFBC)
  - Residue gasification for Utilities & Hydrogen
Secondary Processing Units

key considerations

Full Conv Hydro cracker/Once thru HCU

• Diesel Maximization as well as Naphtha Maximization mode of operation

FCC

• Maximize LPG/Propylene
• Maximize Ethylene in Off gases
• Maximize aromatics in FCC Naphtha

VGO Hydrotreater

• Set the conversion to maximize the H2 content in the bottoms
Light ends Processing

Key considerations

Aromatic Reformer

• Maximize Aromatics in Reformate

Aromatic Complex

• BTX Extraction.
• Xylene Fractionation.
• Toluene Trans-Alkylation & Disproportionation.
• P-Xylene extraction unit.
• Xylene Isomerization.
Resid upgrading Options
Key considerations

• Maximize feed for secondary processing units
• Upgrade Naphtha in reforming unit
• Anode Grade coke in case of ARDS cases
• Coke for Captive generation of utilities
• Pitch for H2 & utilities
Parameters influencing Refinery Configuration
Configuration - Influencing Factors

**CURRENT**
- Desired product Slate/demand
- Desired Product Quality – Clean Fuels
- Environmental Constraints- Green Globe
- Process heavier and sour feeds
- Zero Fuel Oil export
- Integration with Aromatic Complex / Olefin Complex

**FUTURE**
- Process extra heavy crude oil, tar sands, oil shales
- Integrate Gas/coal processing (GTL/CTL) with refining to produce fuels and petrochemicals.
- Produce clean fuels
- Cleaner options for H2 production
- Capture and sequester CO2 from Hydrogen and power generation facilities
- Co process feed from non fossil sources e.g. biomass
Impact of Product slate/demand on Refinery configuration
**Trends in the Ratio Gasoline to On-road Diesel**

- Dieselization of the markets
- This means more Hydroprocessing and hence more H2 requirements.
- More complex refinery scheme.
- Explore cheaper routes for H2.
Impact of product quality parameters on Refinery Configuration
Product Spec Changes Mean More Complex Refineries

- More and deeper sulfur removal and more aromatics separation or saturation
- Less (no?) MTBE
  - More ethanol
  - More alkylate & clean quality gasoline components
- More hydrogen production and consumption
- More hydrocracking
- More rigid product blend patterns
Results of Greater Complexity and Tighter Product Specs

- Increased likelihood of outages
  - Single unit outage has greater impact on product production
  - Decrease in maximum achievable utilization

- Diminished yields of prime fuels per barrel of crude oil
India adopted Auto Fuel Policy in the year 2003 providing road map for fuel quality and emission norms to control vehicular pollution

- India follows European emission norms for passenger and commercial vehicles
- Bharat Stage III (BS III) equivalent to Euro 3 implemented in 11 major cities in April 2005
- Bharat Stage II (BSII) equivalent to Euro 2 implemented in rest of the country in April 2005
- Stringent emission norms for 2 and 3 wheelers specific to India are in place
- BS II norms implemented in April 2005 in the entire country
## Emission Regulations - Road Map
### Passenger and Commercial Vehicles

<table>
<thead>
<tr>
<th>Standard</th>
<th>Reference</th>
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* National Capital Region (Delhi)
# Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra

For 2 and 3 wheelers, BS III norms expected to be implemented in April 2008, but not later than April 2010

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PETROFED PRESENTATION - Refinery Configuration & Design Aspects
## Motor spirit (regular unleaded) specifications to meet emission norms

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>BS II</th>
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<tr>
<td>VLI (10rvp+7*E70), max Summer/other months</td>
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## Motor spirit (Premium unleaded) specifications to meet emission norms

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<tr>
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<tr>
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<td>Aromatics, max vol%</td>
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<td>35</td>
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<tr>
<td>Olefins, vol%</td>
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<td>18</td>
<td>10</td>
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<tr>
<td>Oxygen content, % wt</td>
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Motor spirit (*Premium unleaded*) specifications to meet emission norms

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<th>Euro IV</th>
<th>Euro V</th>
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<tr>
<td>@ 100 C V/V</td>
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<td>40-70</td>
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<tr>
<td>@ 150 C V/V</td>
<td>-</td>
<td>75</td>
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<tr>
<td>@ 180 C V/V</td>
<td>90</td>
<td>-</td>
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<td>FBP</td>
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<td>Oxygenates, %V/V, max</td>
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<tr>
<td>Methanol</td>
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<tr>
<td>Ethanol</td>
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<td>Others</td>
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### Typical Properties Of Gasoline pool Constituents

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Reformate</th>
<th>FCC gasoline</th>
<th>Alkylate</th>
<th>Isomerate</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE DEG C</td>
<td>C5-200</td>
<td>C5-220</td>
<td>C5-80</td>
<td>C5-80</td>
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<tr>
<td>RVP</td>
<td>300</td>
<td>400</td>
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<td>700-800</td>
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<td>RON</td>
<td>102-104</td>
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<td>80-90</td>
<td>80-90</td>
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<tr>
<td>MON</td>
<td>90-92</td>
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<td>79-87</td>
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<tr>
<td>OLEF</td>
<td>0</td>
<td>23-32</td>
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<td>0</td>
</tr>
<tr>
<td>C6 A</td>
<td>3-4</td>
<td>1-2</td>
<td>0</td>
<td>0</td>
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<td>AROM</td>
<td>77-80</td>
<td>30-35</td>
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## Impact of changing Gasoline Specifications

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Solution</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane Number increase</td>
<td>Higher reforming severity</td>
<td>Higher aromatics content</td>
</tr>
<tr>
<td></td>
<td>Reforming heart cut FCC gasoline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkylation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light naphtha isomerization</td>
<td></td>
</tr>
<tr>
<td>Reduction in benzene content</td>
<td>Higher IBP of feed to reforming units</td>
<td>Reduces Gasoline volume</td>
</tr>
<tr>
<td></td>
<td>Reformate splitting and light reformate isomerization</td>
<td>High operating costs</td>
</tr>
<tr>
<td></td>
<td>Benzene extraction and alkylation with light olefins</td>
<td></td>
</tr>
</tbody>
</table>
## Impact of changing Gasoline Specifications

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Solution</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in aromatics content</td>
<td>Modify gasoline blend to ensure aromatics content $&lt;35%$</td>
<td>Reduction in reformate and pyrolysis gasoline content of gasoline pool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase in isomerate and alkylate</td>
</tr>
<tr>
<td>Reduction in sulphur content</td>
<td>FCC Feed desulphurization FCC gasoline hydrotreatment</td>
<td>Additional hydrogen required</td>
</tr>
</tbody>
</table>
The Processing Challenge

- Identify processes to
  - Remove contaminants-S, N2
  - Operate selectively for specific objectives
  - Modify HC structures
  - Upgrade heavy fractions to gasoline
  - Optimize processing configurations to meet product quality
  - Provide maximum returns
What do we need to meet Gasoline Specifications

- Streams having high octane numbers
- Low aromatics content
- Low benzene content
- Low olefins content
- Low sulphur content

- A generic technology option is not available

- Feeds, blend component streams and demand will determine the route to be followed
Benzene-sources in Gasoline pool

- Reformer: 81%
- FCC: 17%
- Other: 2%
Benzene reduction strategies

- Remove benzene precursors from reformer feed (Prefractionation)
- Decrease reformer pressure or severity
- Remove benzene from reformate (Post Fractionation)

Benzene extraction
Saturation
Hydroisomerization
Alkylation with light olefins
Reduced reformer pressure

- Increased hydrogen production
- Lower operating temperatures give increased reformate yield
- Less dealkylation – preferential production of xylenes and toluene as compared to benzene
- Increased coke production
Aromatics management

- Blending streams other than reformate and light naphtha required to dilute aromatics in the pool
- Decrease reformer severity
  - Octane loss and reduced hydrogen production
- Production of BTX
Sulphur Management

• FCC Gasoline is the main contributor

• Short term options
  • Low sulphur crude processing
  • FCC Gasoline end pt reduction

• Longer term options
  • FCC feed pre treatment
  • FCC post treatment
  • Combination of the two
FCC Feed pretreatment

- SR VGO with 2.5% S needs to be desulphurized to < 1000 ppm s to get 50 ppm S in FCC gasoline (C5-220 boiling range)

- VGO hydrotreatment gives additional benefits
  - Increased LPG, Propylene and gasoline yields
  - Reduced LCO & CLO yields
  - Additional Diesel from VGO HDT
FCC Feed treatment-limitations

- High capital expenditure
- Does not decrease olefins in FCC Gasoline
- Additional FCC Gasoline processing may be required to meet olefins specs.
FCC Gasoline treatment

- Sulphur removal from FCC Gasoline required on account of tightening specifications

- Lower capital investment and hydrogen consumption give post treatment the edge over feed treatment

- Ultra low sulphur levels may require a combination of both
FCC Gasoline treatment – Technology Licensors

- Prime- G + (Axens)
- CD-Tech
- S Zorb (Philips)
- Octanizing (Exxon-Mobile)
- ISAL (UOP)
Prime-G+ Typical Scheme
10-50 ppm Sulfur Spec

Prime-G+ SHU
Selective Hydrogenation

LCN
C5-65 °C

Ultra Low S LCN to Pool, TAME or Alky Unit

Splitter
(Optional)

Prime-G+
Selective HDS

Ultra-Low Sulfur Gasoline

FRCN

H₂ Make-up

HCN
65 °C +
### FCC Gasoline sulphur removal - Typical (Prime-G+)

<table>
<thead>
<tr>
<th>Pool sulphur, ppm</th>
<th>FCC Naphtha HDS%</th>
<th>FCC N delta octane loss</th>
<th>Hydrogen consumption scf/bbl fccn</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>59</td>
<td>0.3</td>
<td>45</td>
</tr>
<tr>
<td>50</td>
<td>87.6</td>
<td>0.9</td>
<td>90</td>
</tr>
<tr>
<td>30</td>
<td>93.3</td>
<td>1.2</td>
<td>102</td>
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<tr>
<td>10</td>
<td>99.0</td>
<td>2.5</td>
<td>140</td>
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</table>

Estimated investment (ISBL is around $800-1000/bbl)

Source: Axens
Octane compensation options

- Light naphtha isomerization
- Use of oxygenates
- Alkylation
- Reformer revamps
Isomerization

• **Number of Schemes available**
  - Once through
  - Once through with De Isopentanizer
  - Deisohexanizer recycle
  - N-paraffins recycle
  - Total recycle

• **Technology Licensors**
  - Axens
  - CD-Tech
  - UOP
Isomerization (DIH)

C_5C_6 Feed → Isomerization → Off Gas → DIH → iC_5 + nC_5 + DMB’s → Isomerate

Hydrogen → MP’s + nC_6 → DIH → iC_5 + DMB’s + nC_5 + MCP + CH + C_7 → MCP + CH + C_7
Isomerization (DIP & Mole Sieves)

- **C₅C₆ Feed**
- **DIP**
- **Isomerization**
- **Mole Sieves**
- **Off Gas**
- **Hydrogen**

- **iC₅**
- **iC₅ + nC₅ + nC₆**
- **iC₅ + DMB’s + MP’s + MCP + CH + C₇’s**
Isomerization (Mole Sieves & DIH)

Diagram showing the process flow of isomerization using Mole Sieves and DIH, including feed inputs, off-gas, and product outputs.
## Isomerization – performance

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Isomerate RON</th>
<th>ISBL cost $mm</th>
<th>Op cost $/bbl</th>
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</thead>
<tbody>
<tr>
<td>Once through</td>
<td>82.4</td>
<td>6.3</td>
<td>0.9</td>
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<tr>
<td>With deisopropanizer</td>
<td>83.6</td>
<td>8.1</td>
<td>1.4</td>
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<td>Deisohanizer recycle</td>
<td>88.3</td>
<td>14.9</td>
<td>2.6</td>
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<tr>
<td>N paraffins recycle</td>
<td>90.4</td>
<td>14.9</td>
<td>2.2</td>
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<tr>
<td>Total recycle</td>
<td>92.5</td>
<td>17.0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**SOURCE:** IFP
Alkylation

- Converts light olefins to valuable gasoline component
- Alkylates characterized by low RVP, very low sulphur, no olefins or aromatics and good distillation properties
- Iso Butane + Butylene $\rightarrow$ 2,2,4 Tri methyl pentane
Alkylation

• Compared with other olefin upgrading processes - Alkylation provides the greatest yield and octane-volume contribution to the gasoline pool.

• MTBE and ETBE are components with higher absolute octane numbers, however they require the refinery to import either methanol or ethanol and they are made only from the isobutylene component.

• Two types of catalysts are generally employed:
  • Sulfuric acid (H2SO4)
  • Hydroflouric acid (HF)

• Technology Licensors
  • UOP
  • Exxon Mobil
  • STRATCO
Relative contribution to the gasoline pool from various C4 olefin upgrading processes.

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>YIELD Volume Product/ Volume Olefin</th>
<th>RON-VOLUME / Volume of Olefin</th>
<th>MON-VOLUME/ Volume of Olefin</th>
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<tr>
<td>Butene Alkylation</td>
<td>1.7</td>
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<td>MTBE</td>
<td>1.25</td>
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<td>ETBE</td>
<td>1.44</td>
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<td>Dimerisation</td>
<td>0.85</td>
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<td>Cat polymerisation</td>
<td>0.8</td>
<td>78</td>
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</tbody>
</table>

- A comparison with other olefin upgrading processes shows that alkylation provides the greatest yield and octane-volume contribution to the gasoline pool.

- MTBE and ETBE are components with higher absolute octane numbers, however they require the refinery to import either methanol or ethanol and they are made only from the isobutylene component.
# Alkylate Characteristics, Isobutane & Catalyst Usage

<table>
<thead>
<tr>
<th>Feed Type</th>
<th>C3=</th>
<th>C4=</th>
<th>C5=</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield, vol/vol Olefin</td>
<td>1.7 – 2.0</td>
<td>1.75 – 1.8</td>
<td>1.76 – 2.04</td>
</tr>
<tr>
<td>IC4 Required, vol/vol Olefin</td>
<td>1.23 – 1.72</td>
<td>1.13 - 1.18</td>
<td>1.07 -1.39</td>
</tr>
<tr>
<td>Whole Alkylate Properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RON</td>
<td>89-92</td>
<td>94-98</td>
<td>89-92</td>
</tr>
<tr>
<td>MON</td>
<td>88-90</td>
<td>92-95</td>
<td>88-90</td>
</tr>
<tr>
<td>ASTM D86 T50 ºC</td>
<td>93</td>
<td>111</td>
<td>124</td>
</tr>
<tr>
<td>T90 ºC</td>
<td>127</td>
<td>125</td>
<td>153</td>
</tr>
<tr>
<td>End Point ºC</td>
<td>189</td>
<td>202</td>
<td>224</td>
</tr>
<tr>
<td>Acid Usage, kg/m3 alkylate</td>
<td>72-96</td>
<td>36-60</td>
<td>36-72</td>
</tr>
</tbody>
</table>
Reforming

• Technology: CCR will continue to play a major role
  • For new refining & petrochemical complexes
  • For upgrading semi-regenerative units, where the CCR option should be seriously considered.

• Catalyst: Innovation in CCR catalysts continues
  • New promoters identified
  • Results from new generation catalysts
    ✓ Liquid & H2 yields have been improved
    ✓ Catalyst sensitivity to coke has been reduced
    ✓ Pt inventory decreased

• Technology Licensors
  • Axens
  • UOP
Economics - Reforming Comparison

- Feed PNA (wt %) = 53.5, 30.1, 16.4
- Severity RON = 100

<table>
<thead>
<tr>
<th></th>
<th>Semi-Reg</th>
<th>CCR Medium Pressure</th>
<th>CCR Ultra Low Pressure</th>
<th>CCR Ultra Low Pressure + New catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (barg)</td>
<td>19.0</td>
<td>8.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>H₂ (wt %)</td>
<td>Base (B)</td>
<td>B + 0.85</td>
<td>B + 1.08</td>
<td>B + 1.13</td>
</tr>
<tr>
<td>Fuel Gas + LPG (wt %)</td>
<td>Base (B)</td>
<td>B - 8.8</td>
<td>B - 10.7</td>
<td>B - 11.8</td>
</tr>
<tr>
<td>C₅+ (wt %)</td>
<td>Base (B)</td>
<td>B + 7.9</td>
<td>B + 9.6</td>
<td>B + 10.7</td>
</tr>
<tr>
<td>Product Price - (Feed + OPEX) cost</td>
<td>1.2%</td>
<td>6.8%</td>
<td>7.8%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Feed cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Source: Axens
### Diesel Specifications - Trend

<table>
<thead>
<tr>
<th></th>
<th>BS-II</th>
<th>Euro-III</th>
<th>Euro-IV</th>
<th>WFC (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year of Implementation</strong></td>
<td>2000-2001</td>
<td>2005</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td><strong>Sulfur, ppm</strong></td>
<td>500</td>
<td>350</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td><strong>Cetane Number</strong></td>
<td>48</td>
<td>51</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td><strong>Cetane Index</strong></td>
<td>46</td>
<td>46</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td><strong>Density, kg/cm³</strong></td>
<td>820-860</td>
<td>820-845</td>
<td>820-845</td>
<td></td>
</tr>
<tr>
<td><strong>95% recovery, °C</strong></td>
<td>370</td>
<td>360</td>
<td>360</td>
<td>340</td>
</tr>
<tr>
<td><strong>PAH, wt%</strong></td>
<td>-</td>
<td>11</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td><strong>Flash Point Deg C</strong></td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>60</td>
</tr>
</tbody>
</table>

* Proposed by World Fuel Charter
## Diesel pool streams

### Table 2-4

**Typical Refinery Blending Component Characteristics**

<table>
<thead>
<tr>
<th>Property</th>
<th>SR Diesel</th>
<th>Hydrocracked Diesel</th>
<th>Thermal Distillate</th>
<th>FCC LCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur, wppm</td>
<td>1,000-5,000</td>
<td>10-50</td>
<td>10,000-20,000</td>
<td>1,000-20,000</td>
</tr>
<tr>
<td>Gravity, °API</td>
<td>34</td>
<td>43</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Cetane number</td>
<td>51</td>
<td>58</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Distillation, 95% °C</td>
<td>365</td>
<td>365</td>
<td>350</td>
<td>355</td>
</tr>
<tr>
<td>Aromatics, vol-%</td>
<td>20</td>
<td>10</td>
<td>45</td>
<td>78</td>
</tr>
<tr>
<td>PAHs, vol-%</td>
<td>10</td>
<td>2</td>
<td>25</td>
<td>53</td>
</tr>
</tbody>
</table>
Diesel Blending scheme HCU/DCU

SR Kerosene

SR Diesel

VGO

HCU

DHDS (50 bar)

DCU

Coker diesel

DIESEL
Diesel Blending scheme OHCU/FCC/DCU

SR Kerosene
SR Diesel
VGO

OHCU
LCO
FCC
DCU

DHDT

Diesel
Coker diesel

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Impact of Environmental Constraints on Refinery Configuration
Limitation on SOx Emission

- Flue Gas Desulphurisation for FCC Gases and Boilers
- Replacing Fuel Oil by Gas
- Import Low Sulphur Fuel Oil
- IFO to comprise Low sulphur streams only
Integration between Refinery & Petrochemical Complex
Streams between refinery complex & petrochemical complex.

Refinery Complex
- LGO
- SR Lit. NAP
- HYD Lit. NAP
- DHDT NAP
- SUL EXT REFF
- DHDT DSL
- VGO NAP
- VGO DSL
- HY NAP

Petrochemical Complex
- BUTADIENE HYDROGENATION UNIT
- LPG
- HYDROGEN
- CSS
- TO SUL EXT
- TO XYL. SEP
- LLDPE
- SWING LLDPE / HDPE
- HDPE SLURRY
- HDPE
- MEG
- DEG
- FUEL OIL

Secondary Process
- AROMATIC COMPLEX
- RESID PROCESS

Aromatic Complex
- SR Lit. NAP
- HYD Lit. NAP

Secondary Process
- AROMATIC COMPLEX
- RESID PROCESS

Resid Process
- NAP
Benefits of Integrating Facilities between Refinery & Cracker

Feedstock/Hydrocarbon synergy

✓ Optimizing the traffic between refinery & ECU.
✓ ECU Feed can be low value refinery stream and hence low value refinery stream is upgraded to high value pet chem product.

Logistic synergy

✓ Reduction in storage requirement e.g. cracker feed tanks etc.

Utilities synergy

✓ shared sparing and back up philosophy

Levels of synergy

✓ Maximum synergy can be realized if refinery & pet chemical complex be designed with oil-chemical synergy in mind
### Phasing options

**Economic & Strategic Options**

<table>
<thead>
<tr>
<th></th>
<th>cracker first</th>
<th>refinery first</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>strengths</strong></td>
<td>1. The most profitable part first.</td>
<td>1. World class sizing of all process units</td>
</tr>
<tr>
<td></td>
<td>2. Secure outlet for naphtha/diesel from other sources.</td>
<td>2. Platform for addition of world class sizing of ethylene cracker</td>
</tr>
<tr>
<td></td>
<td>3. Freedom to select the optimal sizing of the refinery at a later date.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Will deter others from investing in crackers in the country</td>
<td></td>
</tr>
</tbody>
</table>
### Phasing options

**Economic & Strategic Options**

<table>
<thead>
<tr>
<th></th>
<th>cracker first</th>
<th>refinery first</th>
</tr>
</thead>
</table>
| Weakness   | 1. Feedstock supply comes under threat if domestic naphtha would no longer be available.  
             2. Heavy naphtha or condensate is required to fully load the aromatics complex.  
             3. Strongly dependent upon early export opportunities for chemical products. The demand is there, but the channels of trade and the access to the market need to be developed early. | 1. Strongly dependent on export opportunities for oil products in the years before the cracker will start to take feedstock from the refinery.  
             2. Economics in the early years are depressed. |

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Observations & Conclusions

Economic drivers: The main margin generating sections of the refinery & Pet chem complex are:
- ECU & downstream units
- Propylene/LPG, plus diluted ethylene for SM production
- Aromatic complex for PX & benzene.

Integrated cases have higher IRR compared to Standalone configurations. This shows the economic benefit of integrating Cracker with Refinery and Aromatic complex.

Phasing of investments is definitely an option to be considered by Client.
Refinery Configuration for heavy/opportunity Crude processing
Opportunity crude processing

Where is the heavy oil?

According to the American Petroleum Institute, the largest known extra-heavy oil accumulation is Venezuela’s Orinoco heavy oil belt (Fig. 4). The reserve boasts 90% of the world’s extra-heavy oil when measured on an inplace basis.

The Canadian province of Alberta contains 81% of the world’s known recoverable bitumen. These two countries’ reserves account for approximately 3.6 trillion bbl of heavy oil and bitumen in place.
## Unconventional Canadian and Syncrude Crude Quality

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
<th>Bitumen</th>
<th>SCO</th>
<th>DilBit</th>
<th>SynBit</th>
<th>CokerBit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Method</td>
<td></td>
<td>SAGD</td>
<td>Same</td>
<td>SAGD</td>
<td>SAGD</td>
<td>SAGD</td>
</tr>
<tr>
<td>% Diluent in Blend</td>
<td>v%</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>w%</td>
<td></td>
<td></td>
<td>21.5</td>
<td>43.0</td>
<td>60.2</td>
</tr>
<tr>
<td>API</td>
<td></td>
<td>9.0</td>
<td>31.8</td>
<td>22.1</td>
<td>46.9</td>
<td>26.8</td>
</tr>
<tr>
<td>Elemental Analysis, Dry</td>
<td>w%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>84.1</td>
<td>88.9</td>
<td>84.5</td>
<td>86.2</td>
<td>86.0</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>10.0</td>
<td>10.5</td>
<td>10.9</td>
<td>10.2</td>
<td>10.3</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>4.6</td>
<td>0.5</td>
<td>3.6</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>0.4</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Metals</td>
<td>wppm</td>
<td>60</td>
<td>0</td>
<td>47</td>
<td>34</td>
<td>24</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>170</td>
<td>0</td>
<td>134</td>
<td>97</td>
<td>68</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>300</td>
<td>0</td>
<td>236</td>
<td>171</td>
<td>120</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>0.8</td>
<td>0.0</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Oxygen</td>
<td>w%</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>TAN +/- high</td>
<td></td>
<td>++</td>
<td>n/a</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

- BITUMEN: Athabasca tar sands oil
- SYNCRUDE (or SCO): a low sulfur zero bottoms product
- DILBIT: Bitumen diluted with condensate
- SYNBIT: Syncrude used as the bitumen diluent
- COKERBIT: Coker distillates as the bitumen diluent

---

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## Venezuela Unconventional Crude Quality

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
<th>Orinoco</th>
<th>SCO</th>
<th>Naphtha Refinerd to field as Diluent</th>
<th>Feed to Upgrader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen Production % Diluent in Blend</td>
<td>w%</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>API</td>
<td></td>
<td>8.5</td>
<td>32.2</td>
<td>59.7</td>
<td>20.8</td>
</tr>
<tr>
<td>SG</td>
<td></td>
<td>1.010</td>
<td>0.864</td>
<td>0.740</td>
<td>0.929</td>
</tr>
<tr>
<td>Elemental Analysis, Dry C</td>
<td>w%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>9.0</td>
<td>12.5</td>
<td>14.0</td>
<td>10.5</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>3.8</td>
<td>0.1</td>
<td>0.01</td>
<td>2.7</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>0.6</td>
<td>0.03</td>
<td>0.0002</td>
<td>0.4</td>
</tr>
<tr>
<td>Metals</td>
<td>wppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>89</td>
<td>0</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>414</td>
<td>0</td>
<td></td>
<td>290</td>
</tr>
<tr>
<td>Oxygen</td>
<td>w%</td>
<td>0.5</td>
<td>0.0</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td>w%</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Unconventional Crude Quality Concerns

- Due to the quality difference of the unconventional crudes, making each one requires different treatment options.

- A summary of the major quality concerns and their significance is discussed.

<table>
<thead>
<tr>
<th>Property</th>
<th>Comment</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Typically the gravity approaches water are near requiring a diluent to separate water from hydrocarbon</td>
<td>Water/Oil Separation</td>
</tr>
<tr>
<td>S</td>
<td>High sulfur levels requiring H2 for removal producing H2S</td>
<td>Corrosion</td>
</tr>
<tr>
<td>N</td>
<td>High nitrogen levels requiring H2 for removal producing NH3</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Metals Ni/V/Fe</td>
<td>High catalyst replacement</td>
<td>Catalyst deactivation</td>
</tr>
<tr>
<td>Metals Na/Ca/As/Ti</td>
<td>Alkaline metals, special guard bed catalysts for removal</td>
<td>Corrosion/Catalyst deactivation</td>
</tr>
<tr>
<td>Asphaltenes</td>
<td>Potential for fouling requiring S/D to clear</td>
<td>Fouling</td>
</tr>
<tr>
<td>Naphthenic Acids</td>
<td>High levels causing corrosion</td>
<td>Corrosion/fouling</td>
</tr>
<tr>
<td>Chlorides</td>
<td>Typically associated with Alkaline metal</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Too high to pump. requires diluents</td>
<td>High transportation costs</td>
</tr>
</tbody>
</table>
Technology Types for Unconventional Crude Upgrading

• Given the quality of Unconventional Crude upgradations are required to convert this material into something typical refineries can process.

• Most upgrades receive the crude with diluents that must be removed. The upgradation process includes primary fractionation to remove the diluents is a conventional crude fractionation system.

• Using a diluent with these materials may cause some incompatibly unless the diluent is aromatic.

• Incompatibility between crude and diluent may cause fouling and sedimentation.

• Aromatic diluents are depleting in volume and replacements are being sought through processing of the bitumen. The majority of the crude (or bitumen) is produced at 975°F+, and it requires further upgrades.
Carbon Rejection

- Carbon rejection are processes that increase the product hydrogen content by removing carbon from the feed.

- Examples of these processes are Coking and Fluid Catalytic Cracking, of which only coking is appropriate for this service.

- Delayed and Fluid Coking was used in the first upgrading operations. The products are high in sulfur and olefins requiring hydrotreating to produce low sulfur syncrude.

- Recent trends are to consider using coker products as diluent to produce a blend suitable for pumping in the pipeline, but are requiring special handling at the refinery.

- The coordination between upgrading technology and refining process is one of the key factors in successful business.
**Technology Types for Unconventional Crude Upgrading**

**H2 Addition**

- Primary H2 addition had been accomplished by the ebullated bed processes.

- The ability to add catalyst allows these units to continue to process high containment levels. The use of these units is a technology challenge and requires special knowledge to successfully operate.

- The products have a volume swell and are lower in sulfur and nitrogen. Additional treating is still needed to produce finished fuels.

- A significant quantity of hydrogen is required per barrel of feed
Residue Hydrocracking
CLG’s LC-Fining – Process scheme
Onstream Catalyst Replacement (OCR).

CLG’s OCR technology is commercially demonstrated as a safe and simple method to continuously add fresh catalyst and selectively withdraw spent catalyst from an operating high pressure residuum hydroprocessing reactor, while maintaining the reliability of the proven Fixed bed hydroprocessing system.
Axens Ebullated-Bed Technologies

- H-Oil\(_{RC}\) characteristics
  - Residue Hydrocracking
  - Vacuum residue feedstock
  - 40 - 80% VR conversion
  - Unconverted residue application
    - Low sulfur (up to S< 1%) and stable fuel oil
    - Feed for coker, SDA or gasification units
  - On-line Addition / Withdrawal of catalyst
    - Availability > 96%
    - 2 to 4 years cycle length

- H-Oil\(_{DC}\), Heavy DAO feedstock
- H-Coal\(_{TS}\), Direct Coal Liquefaction
Solvent deasphalting

- **SDA** is a well-proven process which separates vacuum residues into a low metal/carbon deasphalted oil and a heavy pitch containing most of the contaminants especially metals.

- SDA is a subject of much interest from refiners because it allows to recover a substantial quantity of incremental light feedstock notably for lubricants oil base production from vacuum residue, which means that the yield of the refinery can be increased.

- Moreover, the pitch could be gasified to meet a zero fuel oil production.
Gasification

- Which consists in conversion by partial oxidation of the feed, liquid or solid, into a synthesis gas in which the major components are H2 and CO.

- Gasification is a clean flexible technology already improved on coke or heavy crude.

- Gasification is now receiving a global interest because of the integrated gasification combined cycle (IGCC)

- Major concern will be in the future on the important CO2 emissions of such processes.

- Capital costs of integrated gasification combined cycle has fallen. However, the oxygen production phase is still costly and many researches are going to improve air separation and integration of this part with the partial oxidation in a singlestep reactor.
Technology Types for Unconventional Crude Upgrading

Secondary Systems

- The products for delayed coking, fluid coking or H2 addition require further hydrotreating to produce a low sulfur syncrude.

- The hydrotreating equipment is mostly fixed bed in design. The use of guard bed reactors and graded catalyst is needed for activity maintenance and long catalyst life.

Fixed Bed Hydrotreating

- The work horse of the Upgrader is the fixed bed hydrotreating unit.

- These units process all of the oil leaving the upgrader and remove sulfur, nitrogen, metals and other impurities replacing them with hydrogen.

- The hydrotreater operation is severe requiring higher temperatures and pressures with shorter run lengths than similar refinery processes.
Technology Types for Unconventional Crude Upgrading

H2 Production

- The hydrogen production for the majority of the existing or planned upgraders is via Steam Methane Reforming (SMR).
- Declining NG production and projected shortfall made the consideration of gasification a trend.
- The quantity of bitumen needed to be gasified for H2 production is about 10-12% of the feed bitumen to the Upgrader.
- Gasification technology has been proven, but it is more expensive and complex to operate than SMR.

Combined System

- The use of H2 addition combined with coking of the bottom produces a bottomless syncrude. Using SDA ahead of an ebullated bed unit produces a syncrude low in sulfur,
- Coking followed by hydrotreating also produces a bottomless syncrude.
Technology Types for Unconventional Crude Upgrading

Upgradation Product Options

• The upgrader can provide a variety of products from LPG to Clean VGO. Products such as LPG and ULSD are typically products for local consumption.

• The different syncrudes and syn-bits combinations can be produced to meet refinery requirements.

Technology and Upgraded Products

• The selection of different technologies changes the investment and operating cost structures of the venture. Each of these decisions has different associated risks requiring evaluation.
Technology Types for Unconventional Crude Upgrading

Technology Risk

- Proven technology in the refining of crude oil does not necessarily operate as well in the upgrading environment. The complexity of the upgrading train and the susceptibility to contaminate or foul determines unit run length and maintenance costs for cleaning. The trade-off between product quality and risk sets future profitability.

Business Risk

- The risk factors associated with upgrading are the same as any large capital intensive project.
- Additional recent risks are falling **conventional crude prices** manpower shortages, rising construction material costs, and a tightening capital market.
- The government’s stance on Kyoto and environmental regulations further complicates the business horizon.

Environmental Risk

- Historically, the typical upgrader has been constructed and operated in remote locations. Emissions regulations have been slow to take these facilities into account, but no more.
- Regulations from CO2 capture and control, as well as other initiatives, will increase the operational and investment costs of the upgraders.
- CO2 emissions are 4 to 6 and even 10 times higher than in the conventional one, depending on projects.
Integration of CO2 capture, H2 & power generation facilities
Carbon Capture and Sequestration

Trends in CO2 capture and storage

• Carbon capture and storage (CCS) is a promising technology for carbon abatement, even though it has not yet been applied to large-scale power generation.

• Widespread deployment of CCS depends on developments in legal and regulatory frameworks, financing mechanisms, international co-operation, technological advances and public awareness.

• Recommendations on how to accelerate the deployment of CCS were developed in 2007 under a joint International Energy Agency-Carbon Sequestration Leadership Forum (IEA-CSLF) initiative, involving wide consultation with interested parties.

• These recommendations include launching 20 full-scale CCS projects by 2010 and making CCS eligible for funds from the Clean Development Mechanism (IEA-CSLF, 2007)
Technologies for CO2 Capture

• Pre-combustion Technology

  • In precombustion CO2 capture, CO2 is removed from synthesis gas from gasification unit. The technologies used are autothermal reforming, gasification, acid gas removal, combined cycle power generation

• Post – combustion Technology

  • The technologies for CO2 capture from post combustion exhaust streams are proprietary or licensed as is much of pre-combustion CO2 capture.
  • The technologies for large scale capture of CO2 are
    • Chemical solvent scrubbing
    • Physical solvent scrubbing
Pre-combustion capture scheme

Fossil Fuel → Gasifier/Reformer → CO2 capture → Power and Heat

Air → Air separation Unit → O2 → CO2 for Dispatch

CO2 for Dispatch → H20, N2, O2

Source: Carbon capture Project
Post-combustion capture scheme

Fossil Fuel → Power and Heat → CO2, N2, O2 → Chemical absorption

N2, O2 → CO2 for Dispatch

Source: Carbon capture Project
## Technologies for CO2 Capture

<table>
<thead>
<tr>
<th>Post Combustion and Pre combustion advantages disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Post combustion: Applicable to the majority of existing coal-fired power plants</td>
</tr>
<tr>
<td>Retrofit technology option: Applicable beyond power</td>
</tr>
<tr>
<td>Applicable beyond power</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Fuel gas has low concentration of CO2 and at very low pressure requiring large equipment and high circulation volume required for high capture level</td>
</tr>
</tbody>
</table>
Impact on Refinery Configuration for co-processing feed from non-fossil fuels
**Alternate Fuels – BioFuels**

• What are Biofuels?
  
  • The term Biofuels covers a wide range of liquid or gaseous fuels produced from biomass. These include biodiesel, bio-ethanol and other components that can be blended into transportation fuels pool

• Drivers to biofuels
  
  • The move to biofuels is driven by two main concerns:
    • Reduced greenhouse gas (GHG) emissions, particularly those from transport
    • Efforts by governments to reduce national dependence on imported oil to improve the security of supply for transportation fuels
## Bio diesel specifications – IS 15607: 2005

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>0.86 – 0.9</td>
</tr>
<tr>
<td>Flash point (pmcc) deg C</td>
<td>120</td>
</tr>
<tr>
<td>Cetane no. min</td>
<td>51</td>
</tr>
<tr>
<td>Viscosity, cst, 40 C</td>
<td>2.5 - 6</td>
</tr>
<tr>
<td>Neutralization number, mg koH/g</td>
<td>0.92</td>
</tr>
<tr>
<td>Total glycerin, percent</td>
<td></td>
</tr>
<tr>
<td>Free Glycerin</td>
<td></td>
</tr>
<tr>
<td>Sulfur content, mg/kg</td>
<td>50</td>
</tr>
<tr>
<td>Sulfated ash, percent</td>
<td>0.02</td>
</tr>
<tr>
<td>Esters, % mass min</td>
<td>96.5</td>
</tr>
<tr>
<td>Water, mg/kg, mass</td>
<td>500</td>
</tr>
<tr>
<td>Carbon residue wt% (Ramsbottom)</td>
<td>0.05</td>
</tr>
<tr>
<td>Total contamination, mg/kg, mass</td>
<td>24</td>
</tr>
</tbody>
</table>
Incorporating Bio-ethanol into gasoline pool

- Incorporating Bio-ethanol in Gasoline pool
  - The properties of ethanol make it much more difficult to incorporate into gasoline pool than bio diesel in to diesel pool.
  - Properties of ethanol such as high Rvp & RON have impact on refinery configurations.
  - Adding ethanol reduces pressure on RON and aromatics but increases pressure on RVP.

- Typical impact on gasoline pool adding because of 5% ethanol is given below.
  - **FCC based configuration:**
    - Adding ethanol directionally reduces amount of Isomerate
    - Reformate quantity & RON may be lowered.
      - This will result in lower thru puts of Reformer(less H2) or opportunity for more gasoline.
    - Some Heavy naphtha can be blended.
Incorporating Bio-ethanol into gasoline pool

- Bio-ethanol is added outside refinery gate (near petrol bunks?) due to logistic problems of transporting ethanol-added gasoline.
- This means refiners will be producing gasoline that meets the specifications once ethanol is added.
- The impact of this is case-specific but directionally

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
<th>Target with out ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rvp</td>
<td>9.85</td>
<td>9.64</td>
</tr>
<tr>
<td>RON</td>
<td>95</td>
<td>93.2</td>
</tr>
<tr>
<td>Aromatics</td>
<td>35</td>
<td>37</td>
</tr>
<tr>
<td>Benzene</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Olefins</td>
<td>18</td>
<td>20</td>
</tr>
</tbody>
</table>
Incorporating Bio-ethanol into gasoline pool

• This increases the total volume of conventional gasoline in the gasoline pool because of high RON of Ethanol.

• reduced reformate RON results in higher reformate yield and hence more gasoline.

• This moves the bending pool in the opposite direction of which the market trend is following which is Dieselization
The Integration of Biofuels Inside the Refinery Gate: Implementation, Logistics and Strategies

- Since biofuels are being largely mandated, it is important for the refining and catalyst industries to respond with innovative and economically workable solutions.

- The industry is already underway with its plans to address these issues, with a representative response as follows:

  - UOP LLC, a Honeywell company, and Eni S.p.A announced that Eni will build a production facility using EcofiningTM technology to produce diesel fuel from vegetable oils.

  - The facility, to be located in Livorno, Italy, will process 6,500 bpd of vegetable oils to supply European refineries with a high-cetane "green" diesel fuel.
The Integration of Biofuels Inside the Refinery Gate: Implementation, Logistics and Strategies

- Bio fuels producing significant amount of bio mass.
- Bio mass can be used to generate steam, power in CFBC or gasification.
- Gasification of bio mass produces bio Hydrogen.
- Another option for bio hydrogen is to use glycerine which is a byproduct in Bio diesel production. This requires discussions with catalyst vendors to suggest usage of glycerin for H2 production. Preliminary results are encouraging.
- Linking gasification to FT process can produce Synthetic Crude.
**Issues with bio fuels**

**First generation biofuels**
Bio diesel from vegetable oil & ethanol from sugar, starch or corn

The feed is limited in supply and costly and one may ask the question if it makes sense to downgrade these scarce and high value edible materials to transportation fuels.

**Second generation biofuels**
This makes use of abundantly available cellulosic biomass waste.

Cellulosic ethanol can be produced via enzymatic conversion once the solid cellulose is separated from lignin and opened up and made more accessible to the enzymes.

Several on going projects to develop pre-treatment process in this area. Unfortunately the separation of ethanol from water remains a costly factor. High rvp of ethanol limits the amount.
Issues with bio fuels

Second generation biofuels
New technologies under development

- Convert to solid biomass into a gas and produce synthetic gas (CO+H2) which can be converted into liquid via FT process. This is often called BTL (Biomass to liquid)
  - Although this can work it requires several complex process steps and is expensive in investment and energy.

- More simple and robust approach is to convert the solid biomass into a liquid by direct liquefaction. Several thermal and thermo-catalytic processes are under development.
  - Drawback is quality of bio crude produced is rather poor and extensive hydrotretreatment is required before blended into transportation fuels

- An interesting new approach in this respect in Catalytic pyrolysis of biomass. Catalytic technology is used to achieve the liquefaction of the solid biomass under milder conditions and at a lower cost. This is similar to FCC and hence may be easy to commercialize.

- Source: Paper by Mr. Paul O’connors of BIOeCON
Design Features- FCCU /HCU
**Hydrocracker Unit - Design aspects**

- Single Stage Once Through

[Diagram showing the flow of products from Fresh Feed to Reaction Section, then to Distillation Section, with outputs of C4, Naphtha, Kerosene, Diesel, and Unconverted Bottoms.]
Hydrocracker Unit- Design aspects

- Single Stage Recycle
Hydrocracker Unit- Design aspects

• Two Stage
FCC Unit - Design aspects

- Single Stage Regenerator
FCC Unit- Design aspects

- Two Stage Regenerator
FCC Unit - Design aspects

- PRT on flue gases

Flue gases from Regenerator

Orifice Chamber

PRT

Third Stage Separator

Flue gases to CO-Boiler
Closing Thoughts
Closing Thoughts

• Challenging Choices for Refiners
  • Type of crude oils
  • Fuel quality specifications
  • Bottoms processing choices

• Crystal Ball Reading
  • Bottoms processing will continue – possibly reduced rate
  • Complexity will increase
  • Refinery configurations to be adjusted to favour diesel or gain flexibility
  • Energy portfolio to be extended to include Biofuels into the configuration
  • Integrating refineries?
Thank you

The pillars of our strength.