Alternate technology options for processing refinery residues

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ABB Lummus Global
Gasification Technology Conference
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Refinery product trends

- Need to produce cleaner products
  - Gasoline – Euro 3/Euro 4 specifications
  - Diesel – Euro 3/Euro 4 specifications
  - Refinery fuel – Lower sulfur

- Significant reduction in high sulfur fuel oil demand
  - Reduce HSFO production
  - Substitute LSFO for HSFO

- Limited availability of low sulfur light crudes

Result:
- Investment in refinery residue processing needed
Figure 1 - Base case refinery

Crude Oil → Crude Unit → Vacuum Unit → Stabilizer → Gas Plant

- Lt. Naphtha to Gasoline
- Kerosine
- LT. G.O. to D-HDS (A)

Vacuum Unit

- VIS. → VGO Pretreater

- VBLGO to D-HDS
- VB Resid

Crude Oil → Crude Unit → Stabilizer → Gas Plant

- N-HDS → D-HDS (A)
- K-HDS

Reformer

- Diesel Oil
- To Gasoline Pool
- Kero/Jet

CAT - Cracker Complex

- HDS → C₃’s
- LT. G.O.

Alkylation

- Alkylate
- MTBE
- Methanol

Gas Plant

- H₂ Rich Gas
- H₂ Rich Gas

Gas Plant

- Fuel Oil
- Asphalt
- (A) Euro IV Quality

Figure 1 - Base case refinery

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## Base case unit capacities

*(150,000 bpsd or 20,000 mt/d)*

<table>
<thead>
<tr>
<th>Option</th>
<th>BASE</th>
<th>Arab Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Type</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### UNITS (kBPSD)

- Crude Unit: 150
- Vacuum Unit: 65
- Naphtha HDS: 38
- Distillate HDS: 33
- Cat. Reformer (b): 26
- Cat Cracker (FCCU): 44
- Visbreaker: 20
- VGO HDT: 44
- Gasoline HDT: 30

(a) **Typical Refinery has capacities as shown based on AL design basis**

(b) **Merox Units, as well as Isomerization, MTBE and alkylation Units are also included**
Residue upgrading options

**Factors to consider**

- Existing refinery configuration
  - Capacity
  - Crude slate
  - Degree of residue conversion
  - Degree of VGO hydrotreating (or hydroconversion)
- Current product quality
  - Gasoline
  - Diesel
- Future product specifications
- Future product requirements
  - Outlet for H.S.F.O.
  - Need for power
  - Expansion requirements
Key assumptions

Producing EU clean products in 2005

<table>
<thead>
<tr>
<th>Year</th>
<th>Current</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasoline Specifications</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unleaded Pool (Ron/Mon)</td>
<td>95/85</td>
<td>95/85</td>
</tr>
<tr>
<td>Sulfur Spec, max. ppm</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Aromatics, vol. % max.</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Olefins, wt.% max.</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td><strong>Diesel Specifications</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur, ppm. max.</td>
<td>350</td>
<td>50</td>
</tr>
<tr>
<td>Cetane Index, min.</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>Specific Gravity, max.</td>
<td></td>
<td>0.845</td>
</tr>
<tr>
<td><strong>Fuel Oil Production</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease H.S. Fuel Oil Product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Oil Product, %S max.</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>
## Base refinery operations - 20,000 mt/d

*(Minimal vacuum resid processing)*

<table>
<thead>
<tr>
<th>Option</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Type</td>
<td>AL</td>
</tr>
<tr>
<td>VGO Hydrodesulfurization</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Production (MT/D)

<table>
<thead>
<tr>
<th>Product</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C3 LPG/C3 Mix</td>
<td>570</td>
</tr>
<tr>
<td>Gasoline (95/85)</td>
<td>8340</td>
</tr>
<tr>
<td>Kero/Jet</td>
<td>2060</td>
</tr>
<tr>
<td>LS Diesel</td>
<td>4300</td>
</tr>
<tr>
<td>HSFO</td>
<td>3750</td>
</tr>
</tbody>
</table>

### Product Quality

<table>
<thead>
<tr>
<th>Product Quality</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline (ppm-s)</td>
<td>18</td>
</tr>
<tr>
<td>Diesel (ppm-s)</td>
<td>36</td>
</tr>
<tr>
<td>Diesel Cetane Number</td>
<td>56</td>
</tr>
<tr>
<td>HFO (wt%S)</td>
<td>3.3</td>
</tr>
</tbody>
</table>

*(a) Excludes 100 K-MTA of Bitumen*
Potential refinery options to evaluate

- Define existing refinery configuration
- Identify possible residue upgrading options
- Identify potential crude availability (e.g. in Europe)
  - Mid East blends
  - Russian crudes and feedstocks
  - Low sulfur (North Sea, Africa)
- Impact of crude and product pricing differentials
- Impact of future power pricing
- Impact of financing conditions
## Residue upgrading comparison

**Basis: 150,000 bbl/d crude feed**

<table>
<thead>
<tr>
<th>Option</th>
<th>Configuration</th>
<th>Residue Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Typical Existing Refinery</td>
<td>3.5%S Fuel Oil</td>
</tr>
<tr>
<td>1</td>
<td>LC-Fining&lt;sup&gt;SM&lt;/sup&gt; unit @ 65% Conversion</td>
<td>1.0%S Fuel Oil</td>
</tr>
<tr>
<td>2</td>
<td>Delayed Coker</td>
<td>6%S Fuel Coke</td>
</tr>
<tr>
<td>3</td>
<td>Delayed Coker &amp; POX</td>
<td>200 MW Power &lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>Deasphalting &amp; POX</td>
<td>500 MW Power &lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>Visbreaking/Vac Flash/POX</td>
<td>630 MW Power &lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Uses Arab Light with VGO hydrotreating

<sup>b</sup> Includes hydrogen generation, Net Power Output includes refinery requirements
Residue processing options to consider (part 1)

- Add LC-Fining unit
  - Eliminates production of HSFO
  - Can be used to process wide variety of crudes
  - Offers product slate flexibility

- Add delayed coker complex
  - Complete conversion of vacuum residue
  - Requires coke disposition
  - Requires gas oil hydroconversion treatment

- Add coke based IGCC for power / steam generation
Residue processing options to consider (part 2)

- Increase visbreaker conversion & install IGCC
  - Add vac.flasher or VF with added heater
  - Eliminates production of HFO
  - requires ability to sell excess power
  - IGCC can be built and owned by others

- Add SDA unit & install IGCC unit
  - Eliminates production of HFO
  - requires ability to sell excess power
  - IGCC can be built and owned by others

- Install hydrocracker
  - Suitable for processing thermal and conversion gas oils
  - Offers good crude flexibility
Option 1 - LC-Fining upgrading

Vacuum Unit → VGO HDS → FCCU → D-HDS Unit → DS Gas Oil

Atmos. Resid → Vacuum Unit → VGO HDS → HDS → LCO

Vacuum Resid → LC-Fining 65% Conversion → VGO → HCO (A) → To Naphtha → Distillate

Resid → 1% S Fuel Oil

Asphalt Plant → Asphalt

Natural Fuel Gas → Hydrogen Plant → Hydrogen
Option 2 - Delayed coking

VGO

Vacuum Unit

Atmos. Resid

Vacuum Resid

Delayed Coking

Heavy Naphtha

LCO

LCGO

HCGO

Fuel Coke to Sale

Fuel Coke to Sale

New

Revamped

VGO/HCGO FHC

VGO

VGO HDS

FCCU

FHC

Asphalt Plant

Asphalt

DS Gas Oil

HCO to Refinery Fuel or Sales

LCO/LGO HDT

Hydrogen Plant

Hydrogen

Gas Oil

Hydrogen Fuel Gas

Light Naphtha to FCC

To VGO/HCGO MHC

VGO

VGO

Atmos. Resid

Vacuum Resid

HCGO

New

Revamped

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Option 3 - Delayed coking + IGCC

LVGO → Atmospheric Resid → Vacuum Unit

Vacuum Resid → Delayed Coking

LVGO → HCO → Refinery Fuel or Sales

VGO/HGO FHC → LVGO

VGO HDS → HCGO

Asphalt Plant → Heavy Naphtha

LCO to FCC → LCO/LGO HDT → DS Gas Oil

Gasification & Acid Gas Removal

Hydrogen Recovery

Cogeneration & Power Gen

Coke → Hydrogen

Medium BTU Gas

Steam

Power

H2S to Sulfur Recovery

Fuel Gas

Hydrogen

Asphalt

Coke

Revamped
Option 4 - Deasphalting + IGCC

- VGO
- VGO HDS
- VGO/DAO FHC
- FCCU
- VGO/DAO FHC
- LCO
- HCO to Refinery Fuel or Sales
- D - HDS
- DS Gas Oil
- Refinery Fuel or Sales

Vacuum Unit
- Atmos. Resid
- Vacuum Resid
- Vacuum Resid
- Deasphalting ~50% Lift
- Pitch
- Gasification & Acid Gas Removal
- Medium BTU Gas
- H2S to Sulfur Recovery
- Asphalt Plant
- Asphalt
- Hydrogen Recovery
- Hydrogen
- Fuel Gas
- Cogeneration & Power Gen
- Steam
- Power

New
Revamped

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Option 5 - Visbreaking/vacuum flasher + IGCC

- **Vacuum Unit**: Atoms Resid and Resid
  - VGO to VGO HDS

- **Visbreaking with Vacuum Flasher Added**: VB VGO and VGO
  - VBGO
  - Tar to Gasification & Acid Gas Removal

- **Gasification & Acid Gas Removal**: Medium BTU Gas
  - H2S to Sulfur Recovery
  - Asphalt to Asphalt Plant

- **Hydrogen Recovery**: Fuel Gas
  - Hydrogen

- **Cogeneration & Power Gen**: Steam to Power
  - Power

- **FCCU**: LCO
  - D - HDS
  - HCO to Refinery Fuel or Sales
  - DS Gas Oil
Residue processing options

*(Coker effluent processing)*

- **Naphtha**
  - Inject into FCCU riser
  - Process in naphtha HDS (>50 bar)

- **Light gas oil**
  - Needs hydrotreating (~75 bar) to saturate aromatics

- **Heavy gas oil**
  - Needs to hydrotreat (>75 bar) or hydrocrack

- **Coke**
  - Sale
  - Power generation via IGCC
Residue processing options

(Visbreaking/vacuum flash effluent processing)

- Naphtha
  - Inject into FCCU riser
  - Process in naphtha HDS (>50 bar)

- Light gas oil
  - Needs hydrotreating (~75 bar) to saturate aromatics

- Heavy gas oil
  - Needs to hydrotreat (>75 bar) or hydrocrack

- Tar
  - Power generation
Material balance comparison (20,000 mt/d)

### MATERIAL BALANCE COMPARISON

<table>
<thead>
<tr>
<th>Option</th>
<th>Base</th>
<th>LCFINER (65%)</th>
<th>Delayed Coker</th>
<th>Coker + IGCC</th>
<th>SDA + IGCC</th>
<th>VB with Flasher &amp; IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESCRIPTION</td>
<td>Base</td>
<td>LCFINER</td>
<td>Delayed Coker</td>
<td>Coker + IGCC</td>
<td>SDA + IGCC</td>
<td>VB with Flasher &amp; IGCC</td>
</tr>
<tr>
<td>Crude Split</td>
<td>100/0</td>
<td>0/100</td>
<td>0/100</td>
<td>0/100</td>
<td>0/100</td>
<td>0/100</td>
</tr>
<tr>
<td>Long Resid Import (25,000 b/d)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

#### Production MT/D

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
<th>Option 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3 LPG</td>
<td>143</td>
<td>174</td>
<td>201</td>
<td>201</td>
<td>185</td>
</tr>
<tr>
<td>Propane/Propylene Mix</td>
<td>426</td>
<td>476</td>
<td>394</td>
<td>394</td>
<td>450</td>
</tr>
<tr>
<td>95/85 Gasoline</td>
<td>8,343</td>
<td>8,542</td>
<td>8,683</td>
<td>8,683</td>
<td>8,453</td>
</tr>
<tr>
<td>Kero/Jet</td>
<td>2,061</td>
<td>1,711</td>
<td>1,466</td>
<td>1,466</td>
<td>1,567</td>
</tr>
<tr>
<td>LS Diesel</td>
<td>4,295</td>
<td>4,405</td>
<td>9,260</td>
<td>9,292</td>
<td>8,298</td>
</tr>
<tr>
<td>#2 Heating Oil</td>
<td>0</td>
<td>711</td>
<td>393</td>
<td>435</td>
<td>394</td>
</tr>
<tr>
<td>3.5% S Fuel Oil</td>
<td>3,751</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.0% S Fuel Oil</td>
<td>0</td>
<td>3,473</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt Plant Feed</td>
<td>290</td>
<td>290</td>
<td>290</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>coke</td>
<td>0</td>
<td>0</td>
<td>2,345</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>sulfur</td>
<td>214</td>
<td>520</td>
<td>521</td>
<td>678</td>
<td>674</td>
</tr>
<tr>
<td>Total liquid/Solid Product</td>
<td>19,522</td>
<td>20,302</td>
<td>23,553</td>
<td>21,439</td>
<td>20,310</td>
</tr>
</tbody>
</table>

| Power Import, MW (a)     | 37,724   | 49,973   | 50,004   | -195,335 | -498,367 | -633,637  |
**Investment costs $MM - Basis: N.W. Europe 2001**

*(Includes 30% allowance for offsites)*

<table>
<thead>
<tr>
<th>Option</th>
<th>Configuration</th>
<th>Delta Investment $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Base Refinery with Visbreaker</td>
<td>Existing Facility</td>
</tr>
<tr>
<td>1</td>
<td>LC Finer @ 65% Conversion</td>
<td>361</td>
</tr>
<tr>
<td>2 a</td>
<td>Delayed Coker</td>
<td>456</td>
</tr>
<tr>
<td>3 a</td>
<td>Delayed Coker with IGCC</td>
<td>743</td>
</tr>
<tr>
<td>4 a</td>
<td>Solvent Deasphalting &amp; Gasification (IGCC)</td>
<td>865</td>
</tr>
<tr>
<td>5</td>
<td>Visbreaking with Vac. Flasher and Gasification (IGCC)</td>
<td>759</td>
</tr>
</tbody>
</table>

Note: a) Includes processing of 25,000 bpsd of long residue
# Prices used in study

## 5 Year Average 1995 - 1999 @ Rotterdam

<table>
<thead>
<tr>
<th>FEEDS</th>
<th>$ / MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabian Light</td>
<td>$ 125.42</td>
</tr>
<tr>
<td>Arabian Heavy</td>
<td>$ 112.00</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>$ 125.00</td>
</tr>
<tr>
<td>n-Butane</td>
<td>$ 265.20</td>
</tr>
<tr>
<td>MTBE</td>
<td>$ 271.50</td>
</tr>
<tr>
<td>Methanol</td>
<td>$ 160.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>$ / MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3 LPG</td>
<td>$ 167.00</td>
</tr>
<tr>
<td>Propane/Propylene Mix</td>
<td>$ 260.00</td>
</tr>
<tr>
<td>C4 LPG</td>
<td>$ 160.00</td>
</tr>
<tr>
<td>95/85 Regular Unleaded</td>
<td>$ 184.67</td>
</tr>
<tr>
<td>Jet / Kerosene</td>
<td>$ 180.51</td>
</tr>
<tr>
<td>L.S. Diesel</td>
<td>$ 165.88</td>
</tr>
<tr>
<td>Gas Oil ( No. 2 Fuel Oil )</td>
<td>$ 160.64</td>
</tr>
<tr>
<td>L.S. Fuel Oil ( 1 - 1.4 % )</td>
<td>$ 99.50</td>
</tr>
<tr>
<td>H.S. Fuel Oil ( 3.5 % max. )</td>
<td>$ 90.60</td>
</tr>
<tr>
<td>H.S. Fuel Coke</td>
<td>$ 10.00</td>
</tr>
<tr>
<td>Carbon Black Feed</td>
<td>$ 104.50</td>
</tr>
<tr>
<td>Bitumen Feed</td>
<td>$ 88.00</td>
</tr>
<tr>
<td>Sulfur</td>
<td>$ 65.00</td>
</tr>
</tbody>
</table>

**Power**

35$ - 50$ / MW-Hr
# Cash flow calculations

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Project life</td>
<td>20 years</td>
</tr>
<tr>
<td>Depreciation</td>
<td>10 years (straight line)</td>
</tr>
<tr>
<td>Interest (a)</td>
<td>7% per year</td>
</tr>
<tr>
<td>Debt/equity</td>
<td>75/25</td>
</tr>
<tr>
<td>Loan payback</td>
<td>7 years + 3 years grace period</td>
</tr>
<tr>
<td>Tax rate</td>
<td>35%</td>
</tr>
<tr>
<td>Salvage value</td>
<td>10% of original cost</td>
</tr>
<tr>
<td>Product/crude pricing</td>
<td>5 year average (1995-1999)(b)</td>
</tr>
</tbody>
</table>

(a) Base rate + premium and swap fees  
(b) Rotterdam location
Study - 1A: IRR vs power tariff (1995-1999 Prices)

Debt/equity @ 75/25

- LC-Fining
- Coker
- Coker/IGCC
- SDA/IGCC
- Vis./VF/IGCC

<table>
<thead>
<tr>
<th>Power Tariff ( $/MWH )</th>
<th>IRR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$35</td>
<td>10</td>
</tr>
<tr>
<td>$40</td>
<td>15</td>
</tr>
<tr>
<td>$45</td>
<td>20</td>
</tr>
<tr>
<td>$50</td>
<td>25</td>
</tr>
<tr>
<td>$55</td>
<td>30</td>
</tr>
</tbody>
</table>
## Prices used in study

### 2.5 Year Average 1999 - 2001 @ Rotterdam

#### FEEDS

<table>
<thead>
<tr>
<th>Feed</th>
<th>Price / MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabian Light</td>
<td>$165.40</td>
</tr>
<tr>
<td>Arabian Heavy</td>
<td>$151.60</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>$151.00</td>
</tr>
<tr>
<td>n-Butane</td>
<td>$265.20</td>
</tr>
<tr>
<td>MTBE</td>
<td>$381.00</td>
</tr>
<tr>
<td>Methanol</td>
<td>$160.00</td>
</tr>
</tbody>
</table>

#### PRODUCTS

<table>
<thead>
<tr>
<th>Product</th>
<th>Price / MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3 LPG</td>
<td>$240.00</td>
</tr>
<tr>
<td>Propane/Propylene Mix</td>
<td>$380.00</td>
</tr>
<tr>
<td>C4 LPG</td>
<td>$233.00</td>
</tr>
<tr>
<td>95/85 Regular Unleaded</td>
<td>$275.00</td>
</tr>
<tr>
<td>Jet / Kerosene</td>
<td>$272.50</td>
</tr>
<tr>
<td>L.S. Diesel</td>
<td>$255.00</td>
</tr>
<tr>
<td>Gas Oil ( No. 2 Fuel Oil )</td>
<td>$234.00</td>
</tr>
<tr>
<td>L.S. Fuel Oil ( 1 - 1.4 % )</td>
<td>$138.60</td>
</tr>
<tr>
<td>H.S. Fuel Oil ( 3.5 % max. )</td>
<td>$126.00</td>
</tr>
<tr>
<td>H.S. Fuel Coke</td>
<td>$10.00</td>
</tr>
<tr>
<td>Carbon Black Feed</td>
<td>$143.60</td>
</tr>
<tr>
<td>Bitumen Feed</td>
<td>$123.40</td>
</tr>
<tr>
<td>Sulfur</td>
<td>$65.00</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td><strong>$35 - 50 / MW-Hr</strong></td>
</tr>
</tbody>
</table>
Study - 1b: IRR vs power tariff (1999-2001 Prices)

Debt/equity @ 75/25

- LC Fining
- Coking
- Coker/IGCC
- SDA/IGCC
- Vis./VF/IGCC

Power Tariff ( $/MWH )

IRR (%)
Study - 1c: IRR vs power tariff (Coke price sensitivity)

Debt/equity @ 75/25

IRR (%) vs Power Tariff ($/MWH)

- Coke (10/mt)
- Coke (20/mt)
- Coke (30/mt)
- Coker/IGCC

Power Tariff ($/MWH):
- $35
- $40
- $45
- $50
- $55

IRR (%):
- 14
- 16
- 18
- 20
- 22
- 24
- 26
General conclusions

- Elimination of H.S. F.O. will require significant refinery investment.
- Thermal upgrading processes will require addition of VGO Hydroconversion
- With addition of residue conversion processes refiners should examine viability of long residue import
General conclusions (part 2)

- IGCC options competitive with non IGCC options.
- IGCC options more competitive when refinery gross margins are low. (1995-1999 price basis)
- Power co-production, provides a more stable clean product revenue stream.
- If refineries have existing hydrocracker units, thermal processing options with power generation will have improved rates of return
- IGCC projects allow refiners to explore added financing options with potential investors in the IGCC unit or residue conversion facilities