Downstream Sector:
Crude Oil Refining

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The Petroleum Industry

The petroleum industry has three key business segments:

1. Crude Oil Exploration & Production (Upstream)
2. Refining
3. Product Distribution & Sales (Downstream)
Oil Refining

We all recall that... Petroleum refining is the process of separating the many compounds present in crude petroleum.

The principle which is used in basic term is that the longer the carbon chain, the higher the temperature at which the compounds will boil, in a process known as DISTILLATION.

An Oil refinery or petroleum refinery is an industrial process plant where crude oil is processed and refined into more useful products.
Petroleum Refining Industry

- Introduction to the Petroleum Refining Industry
  - Early History
  - Characterizing the Petroleum Refining Industry

- Refining Capacity
  - World refining capacity
  - Types of Refinery/Complexity
  - The Nelson Index

- Industrial Process Description
  - Industrial Processes in the Refinery
  - Raw material Inputs and Product outputs

- Upgrading a Refinery
Early History

Records of Early Crude Oil usage

- Prior to the nineteenth century, petroleum was known and utilized in various fashions in Babylon, Egypt, China, Persia, Rome and Azerbaijan.

- The modern history of the petroleum refinery is said to have begun in 1846 when Abraham Gessner of Nova Scotia, Canada discovered how to produce kerosene from coal.

- In 1848, distillation of kerosene from oil by Canadian geologist Dr. Abraham Gesner. Kerosene eventually replaces whale oil as the illuminant of choice and creates a new market for crude oil.

- In 1850, oil from hand-dug pits in California at Los Angeles is distilled to produce lamp oil by General Andreas Pico.

- In 1857, Michael Dietz invents a kerosene lamp that forces whale oil lamps off the market.
Early History

First Oil refinery in the world

- The full fledged refinery was opened in Ploiesti, Romania in 1856-1857.
- It was built by Mehedinteanu brothers with US investments.
- The refinery installations were primitive, all the equipment being build up from iron or raw iron cylindrical vessels, warmed up directly with wood fire.
- It was taken over by Nazi Germany and bombed during World War II.

Change in product demand

- Around 1911, kerosene's output eclipsed for the 1st time by a discarded byproduct – gasoline.
## Implementation of Technology in History

<table>
<thead>
<tr>
<th>Year</th>
<th>Process name</th>
<th>Purpose</th>
<th>By-products, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1862</td>
<td>Atmospheric distillation</td>
<td>Produce kerosene</td>
<td>Naphtha, tar, etc.</td>
</tr>
<tr>
<td>1870</td>
<td>Vacuum distillation</td>
<td>Lubricants (original)</td>
<td>Asphalt, residual coker feedstocks</td>
</tr>
<tr>
<td>1913</td>
<td>Thermal cracking</td>
<td>Increase gasoline</td>
<td>Residual, bunker fuel</td>
</tr>
<tr>
<td>1916</td>
<td>Sweetening</td>
<td>Reduce sulfur &amp; odor</td>
<td>Sulfur</td>
</tr>
<tr>
<td>1930</td>
<td>Thermal reforming</td>
<td>Improve octane number</td>
<td>Residual</td>
</tr>
<tr>
<td>1932</td>
<td>Hydrogenation</td>
<td>Remove sulfur</td>
<td>Sulfur</td>
</tr>
<tr>
<td>1932</td>
<td>Coking</td>
<td>Produce gasoline basestocks</td>
<td>Coke</td>
</tr>
<tr>
<td>1933</td>
<td>Solvent extraction</td>
<td>Improve lubricant viscosity index</td>
<td>Aromatics</td>
</tr>
<tr>
<td>1935</td>
<td>Solvent dewaxing</td>
<td>Improve pour point</td>
<td>Waxes</td>
</tr>
<tr>
<td>1935</td>
<td>Cat. polymerization</td>
<td>Improve gasoline yield &amp; octane number</td>
<td>Petrochemical feedstocks</td>
</tr>
<tr>
<td>1937</td>
<td>Catalytic cracking</td>
<td>Higher octane gasoline</td>
<td>Petrochemical feedstocks</td>
</tr>
<tr>
<td>1939</td>
<td>Visbreaking</td>
<td>Reduce viscosity</td>
<td>Increased distillate,tar</td>
</tr>
<tr>
<td>1940</td>
<td>Alkylation</td>
<td>Increase gasoline octane &amp; yield</td>
<td>High-octane aviation gasoline</td>
</tr>
<tr>
<td>1940</td>
<td>Isomerization</td>
<td>Produce alkylation feedstock</td>
<td>Naphtha</td>
</tr>
<tr>
<td>1942</td>
<td>Fluid catalytic cracking</td>
<td>Increase gasoline yield &amp; octane</td>
<td>Petrochemical feedstocks</td>
</tr>
<tr>
<td>1950</td>
<td>Deasphalting</td>
<td>Increase cracking feedstock</td>
<td>Asphalt</td>
</tr>
<tr>
<td>1952</td>
<td>Catalytic reforming</td>
<td>Convert low-quality naphtha</td>
<td>Aromatics</td>
</tr>
<tr>
<td>1954</td>
<td>Hydrodesulfurization</td>
<td>Remove sulfur</td>
<td>Sulfur</td>
</tr>
<tr>
<td>1956</td>
<td>Inhibitor sweetening</td>
<td>Remove mercaptan</td>
<td>Disulfides</td>
</tr>
<tr>
<td>1957</td>
<td>Catalytic isomerization</td>
<td>Convert to molecules with high octane number</td>
<td>Alkylolation feedstocks</td>
</tr>
<tr>
<td>1960</td>
<td>Hydrocracking</td>
<td>Improve quality and reduce sulfur</td>
<td>Alkylolation feedstocks</td>
</tr>
<tr>
<td>1974</td>
<td>Catalytic dewaxing</td>
<td>Improve pour point</td>
<td>Wax</td>
</tr>
<tr>
<td>1975</td>
<td>Residual hydrocracking</td>
<td>Increase gasoline yield from residual</td>
<td>Heavy residuals</td>
</tr>
</tbody>
</table>
Product Characterization

- There are specifications for over 2000 individual refinery products.
- They can be classified in 2 different ways:
  - By form
    - Solids: coke, asphalt, briquettes
    - Liquids: gasoline, kerosene, diesel
    - Gases: natural gas, butane
  - By usage
    - Fuels: gasoline, gasoil, diesel
    - Finished Non-fuels: solvents, lubricating oils, greases, wax
    - Industrial feedstock: ethylene, propylene, benzene.
Characterizing the Petroleum Refining Industry

- Industry Size and Geographic Distribution

<table>
<thead>
<tr>
<th>Name of Refinery</th>
<th>Location</th>
<th>Barrels per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamnagar Refinery (Reliance Industries)</td>
<td>Jamnagar, India</td>
<td>1,240,000</td>
</tr>
<tr>
<td>SK Energy Co., Ltd. Ulsan Refinery (SK Energy)</td>
<td>Ulsan, South Korea</td>
<td>1,120,000</td>
</tr>
<tr>
<td>Paraguana Refinery Complex (PDVSA)</td>
<td>Paraguana, Falcon, Venezuela</td>
<td>940,000</td>
</tr>
<tr>
<td>GS Caltex Yeosu Refinery (GS Caltex)</td>
<td>Yeosu, South Korea</td>
<td>730,000</td>
</tr>
<tr>
<td>S-OIL Onsan Refinery (S-OIL)</td>
<td>Ulsan, South Korea</td>
<td>669,000</td>
</tr>
<tr>
<td>ExxonMobil</td>
<td>Singapore</td>
<td>605,000</td>
</tr>
<tr>
<td>Port Arthur Refinery (Motiva Enterprises)</td>
<td>Port Arthur, Texas, USA</td>
<td>600,250</td>
</tr>
<tr>
<td>Baytown Refinery (ExxonMobil)</td>
<td>Baytown, TX, USA</td>
<td>560,500</td>
</tr>
<tr>
<td>Ras Tanura Refinery (Saudi Aramco)</td>
<td>Saudi Arabia</td>
<td>550,000</td>
</tr>
<tr>
<td>Garyville Refinery (Marathon Petroleum)</td>
<td>Garyville, LA, USA</td>
<td>522,000</td>
</tr>
<tr>
<td>Baton Rouge Refinery (ExxonMobil)</td>
<td>Baton Rouge, LA, USA</td>
<td>502,500</td>
</tr>
</tbody>
</table>
Economic trends

The key reason behind the lackluster performance of oil and gas companies, including the likes of Exxon Mobil, BP Plc. and Chevron last year, was thinner refining margins. Almost 80% of the year-on-year decline in Exxon’s 2013 full-year operating earnings (earnings adjusted for divestment gains in 2012) can be attributed to thinner downstream margins. This was primarily due to industry overcapacity amid sluggish demand and higher crude oil prices. - Forbes Trefis Team.

- The major reasons for this are
  - Industry Overcapacity
  - Increased focus on ULSF (ultra-low sulfur fuel)
  - Increased constraint by environmental laws on wastes.
Refining Capacity

- World Refining Capacity

Refining capacity is rising in Asia, falling in North America and Western Europe

Refining capacity (% by region)

Sources: BP Statistical Yearbook; A.T. Kearney analysis
Refining Capacity

Different types of refineries

Every refinery has different units/sizes

- Determined by crude run and products produced
- Far East and European refineries run light crude to produce more diesel.
- East Coast refineries in the US make home heating oil, like diesel.
- Rocky Mountain refineries in the US have limited crude access.
- West Coast refineries in the US run relatively heavy crude to make gasoline and are the most complex in the world.
- Specialty plants produce asphalt, solvents or petrochemicals.
A Topping Refinery is the simplest kind of oil refinery. It only splits the crude oil in its main components. A large portion of SR fuel oil.
A Hydroskimming Refinery is a little more advanced. It has a naphtha reformer (REF) and can produce gasoline, but maintain a high SR fuel oil production.
Refining Capacity

Types of Refinery/Complexity

Catalytic cracking (FCC) refinery

- A FCC Refinery
  - is a medium upgraded refinery
  - can convert SR fuel oil to gasoline and diesel in the FCC unit.
  - There is still some fuel oil production.
A Coker Refinery is the most advanced oil refinery. It upgrades most of the fuel oil to lighter products.
Refining Capacity

- Types of Refinery/Complexity

- Majority Cracking refineries
- Increasing share of more complex refineries
- Topping refineries - small share

Source: PIRA
Refining Capacity

The Nelson Index

A refinery's level of complexity is often based on how much secondary conversion capacity it has. The Nelson Complexity Index is one measure of refinery complexity. This index was developed in the 1960s by W.L. Nelson.

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Unit Size (kbd)</th>
<th>Nelson Factor</th>
<th>Nelson Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDU</td>
<td>100</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>VDU</td>
<td>60</td>
<td>2</td>
<td>1.2</td>
</tr>
<tr>
<td>FCC</td>
<td>50</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Hydrocracker</td>
<td>30</td>
<td>6</td>
<td>1.8</td>
</tr>
<tr>
<td>Delayed Coker</td>
<td>20</td>
<td>6</td>
<td>1.2</td>
</tr>
<tr>
<td>Cat Reformer</td>
<td>30</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Alkylation</td>
<td>10</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Lubes</td>
<td>1</td>
<td>60</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Total: 11.3

*Nelson Refinery Capacity method. From OGJ Dec 20 1999*

Refinery Nelson Complexity = Sum of (Unit capacity/ CDU capacity x Nelson Factor) for all units on refinery.
Refining Capacity

- The Nelson Index
Refining Capacity

The Nelson Index

U.S. Refinery Nelson Complexity by Company

Source: 2003 World Refining
Industrial Process Description

- Industrial Processes in the Refinery
  - The processes are divided into units.
    - Separation Process
      - Desalting units
      - Distillation units
      - Light ends unit
      - Deasphalter and dewaxer units
    - Conversion Units
      - Catalytic & Thermal Cracker
      - Catalytic Reformer
      - Visbreaker and hydrocracker
      - Alkylater
      - Delayed Coker
    - Finishing units
      - Blending
      - Hydrotreater
Industrial Process Description

Industrial Processes in a Modern Refinery
A Hydroskimming Refinery is a little more advanced. It has a naphtha reformer (REF) and can produce gasoline, but maintain a high SR fuel oil production.
Separation Process

- Distillation Units: Desalting Unit

  - Crude oil introduced to refinery processing contains many undesirable impurities, such as sand, inorganic salts, drilling mud, polymer, corrosion byproduct, etc. The salt content in the crude oil varies depending on source of the crude oil. When a mixture from many crude oil sources is processed in refinery, the salt content can vary greatly.
Separation Process

- Distillation Units: Atmospheric Distillation Unit
  - Process Objective:
    To distill and separate valuable distillates (naphtha, kerosene, diesel) and atmospheric gas oil (AGO) from the crude feedstock.
  - Primary Process Technique:
    Complex distillation
  - Process steps:
    - Preheat the crude feed utilizing recovered heat from the product streams
    - Desalt and dehydrate the crude using electrostatic enhanced liquid/liquid separation (Desalter)
    - Heat the crude to the desired temperature using fired heaters
    - Flash the crude in the atmospheric distillation column
    - Utilize pump around cooling loops to create internal liquid reflux
    - Product draws are on the top, sides, and bottom
Separation Process

- Distillation Units: Atmospheric Distillation Process Schematic
Conversion Process: Catalytic Reforming

- **Process Objective:** To convert low-octane naphtha into a high octane reformate for gasoline blending and/or to provide aromatics (benzene, toluene, and xylene) for petrochemical plants. Reforming also produces high purity hydrogen for hydrotreating processes.

- **Primary Process Technique:**
  - Reforming reactions occur in chloride promoted fixed catalyst beds; or continuous catalyst regeneration (CCR) beds where the catalyst is transferred from one stage to another, through a catalyst regenerator and back again.

- **Process steps**
  - Naphtha feed and recycle hydrogen are mixed, heated and sent through successive reactor beds
  - Each pass requires heat input to drive the reactions
  - Final pass effluent is separated with the hydrogen being recycled or purged for hydrotreating
  - Reformate product can be further processed to separate aromatic components or be used for gasoline blending
Catalytic Reforming Process
Treatment: Hydrotreating

- **Process Objective:** To remove contaminants (sulfur, nitrogen, metals) and saturate olefins and aromatics to produce a clean product for further processing or finished product.

- **Primary Process Technique:**
  - Hydrogenation occurs in a fixed catalyst bed to improve H/C ratios and to remove sulfur, nitrogen, and metals.

- **Process steps**
  - Feed is preheated using the reactor effluent
  - Hydrogen is combined with the feed and heated to the desired hydrotreating temperature using a fired heater
  - Feed and hydrogen pass downward in a hydrogenation reactor packed with various types of catalyst depending upon reactions desired
  - Reactor effluent is cooled and enter the high pressure separator which separates the liquid hydrocarbon from the hydrogen/hydrogen sulfide/ammonia gas
  - Acid gases are absorbed from the hydrogen in the amine absorber
  - Hydrogen, minus purges, is recycled with make-up hydrogen
Treatment: Hydrotreating
Why Upgrade An Oil Refinery?

- Oil refining releases carbon dioxide into the atmosphere
- **Response to changing market demands for certain products**
- Government regulations
- Clean Air Act Amendments of 1990 (CAAA90)
- Changing consumer demand for better and different products
- Decrease the number of non-hydrocarbons, impurities, and other constituents
- Potential physical, mechanical, chemical, and health hazards are recognized in air
Trends in Refinery Upgrades / Revamps

• Environmental
  – Benzene Reduction – EPA MSAT II mandate
  – Air Quality Projects
  -SOx and NOx in FCC and Fired Heater flue gas
  – Carbon capture
  – EPA Tier III for further sulfur reduction in gasoline
• Reduce product sulfur content
  – Grassroots Hydrotreating units
  – Revamp existing units with more catalyst volume
  – Sulfur Recovery Unit (SRU) capacity
  – Hydrogen generation capacity or buy it over the fence
• Crude quality and capacity upgrades
  – Grassroots conversion units – cokers / hydrocrackers
  – Metallurgical upgrades
  – Pump upgrades for higher viscosity / rate
  – Desalter upgrades
  – Efficiency upgrades
Separation Process

Distillation Units: Deasphalting Unit

Solvent deasphalting is a refinery process for extracting asphaltenes and resins from heavy vacuum gas oil, atmospheric residue or vacuum residue to produce valuable, deasphalted oil that otherwise cannot be recovered from the residue by conventional distillation. The process consists of contacting the feedstock with a solvent in a countercurrent extractor at temperatures and pressures to precipitate the asphaltene and resin fractions that are not soluble in the solvent.
Separation Process

- **Distillation Units:** Vacuum Distillation Unit.

**Process Objective:**
To recover valuable gas oils from reduced crude via vacuum distillation.

**Primary Process Technique:**
Reduce the hydrocarbon partial pressure via vacuum and stripping steam.

**Process steps:**
1. Heat the crude to the desired temperature using fired heaters
2. Flash the crude in the vacuum distillation column
3. Utilize pump around cooling loops to create internal liquid reflux
4. Product draws are on the top, sides, and bottom
Conclusion

- The Oil Refinery is a capital intensive high risk business.
- They are run based on market demands.
- The need to have upgradable refineries is a new R&D opportunity.
- Environmental and waste control is a big deal.
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