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Review Paper

Survey of Refinery Processes in India and Other Countries

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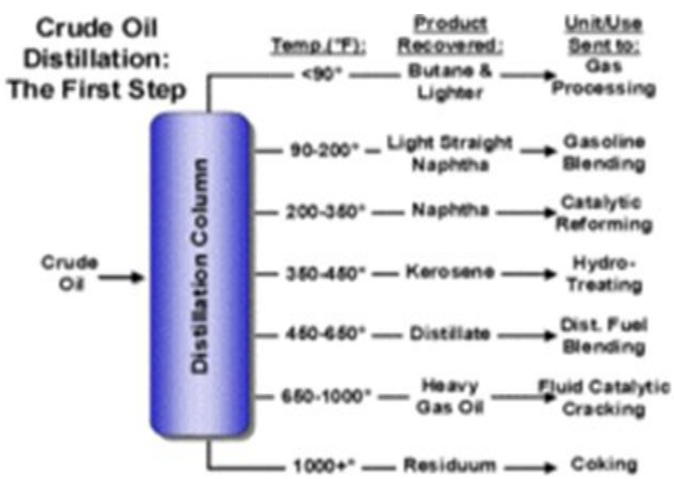
INTRODUCTION

A petroleum refinery is an installation that manufactures finished petroleum products from crude oil, unfinished oils, natural gas liquids, other hydrocarbons, and alcohol. Refined petroleum products include but are not limited to gasolines, kerosene, distillate fuel oils (including No. 2 fuel oil), liquefied petroleum gas, asphalt, lubricating oils, diesel fuels, and residual fuels.

SIMPLE DISTILLATION



Simple crude oil distillation.
Source: Energy Information Administration, U.S. Department of Energy

The core refining process is simple distillation (Figure 1). Because crude oil is made up of a mixture of hydrocarbons, this first and basic refining process is aimed at separating the crude oil into its "fractions," the broad categories of its component hydrocarbons. Crude oil is heated and put into a still—a distillation column—and different products boil off and can be recovered at different temperatures. The lighter products—liquid petroleum gases (LPG), naphtha, and so-called "straight run" gasoline—are recovered at the lowest temperatures. Middle distillates—jet fuel, kerosene, distillates (such as home heating oil and diesel fuel)—come next. Finally, the heaviest products (residuum or residual fuel oil) are recovered, sometimes at temperatures over 1000 degrees F. The simplest refineries stop at this point. Other refineries reprocess the heavier fractions into lighter products to maximize the output of the most desirable products, as shown schematically in Figure 1, and as discussed below.

DOWNSTREAM PROCESSING

Oil refinery in California. Photo: CA Energy Commission

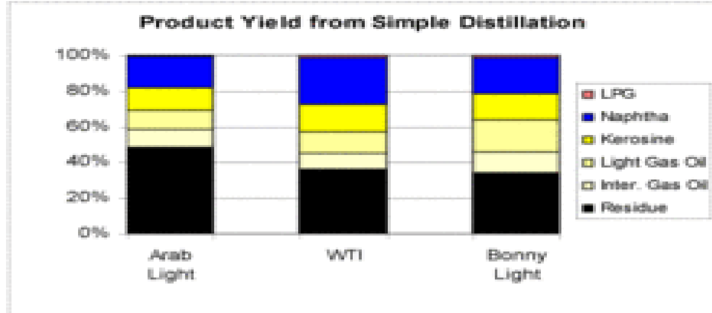
Additional processing follows crude distillation, "downstream" (or closer to the refinery gate and the consumer) of the distillation process. Downstream processing is grouped together in this discussion, but encompasses a variety of highly-complex units designed for very different upgrading processes. Some change the molecular structure of the input with chemical reactions, some in the presence of a catalyst, and some with thermal reactions.

In general, these processes are designed to take heavy, low-valued feedstock—often itself the output from an earlier process—and change it into lighter, higher-valued output. A catalytic cracker, for instance, uses the gasoil (heavy distillate) output from crude distillation as its feedstock and produces additional finished distillates (heating oil and diesel) and gasoline. Sulfur removal is accomplished in a hydrotreater. A reforming unit produces higher-octane components for gasoline from lower-octane feedstock that was recovered in the distillation process. A coker uses the heaviest output of distillation—the residue or residuum—to produce a lighter feedstock for further processing, as well as petroleum coke.

CRUDE OIL QUALITY

The physical characteristics of crude oils differ. Crude oil with a similar mix of physical and chemical characteristics, usually produced from a given reservoir, field, or sometimes even a region, constitutes a crude oil "stream." Most simply, crude oils are classified by their density and sulfur content. A common unit of measurement is API gravity—the American Petroleum Institute's measure of specific gravity of crude oil or condensate in degrees. It is an arbitrary scale expressing the gravity or density of liquid petroleum products.

Less dense (or "lighter") crudes generally have a higher share of light hydrocarbons—higher value products—that can be recovered with simple distillation. The denser ("heavier") crude oils produce a greater share of lower-valued products with simple distillation and require additional processing to produce the desired range of products. Some crude oils also have a higher sulfur content, an undesirable characteristic with respect to both processing and product quality. For pricing purposes, crude oils of similar quality are often compared to a single representative crude oil, a "benchmark," of the quality class.



Typical product yield from simple crude oil distillation. Source: Energy Information Administration, U.S. Department of Energy

The quality of the crude oil dictates the level of processing and re-processing necessary to achieve the optimal mix of product output. Hence, price and price differentials between crude oils also reflect the relative ease of refining. A premium crude oil like West Texas Intermediate (WTI), the U.S. benchmark, has a relatively high natural yield of desirable naphtha and straight-run gasoline (see Figure 2). Another premium crude oil, Nigeria's Bonny Light, has a high natural yield of middle distillates. By contrast, almost half of the simple distillation yield from Saudi Arabia's Arabian Light, the historical benchmark crude, is a heavy residue ("residuum") that must be reprocessed or sold at a discount to crude oil. Even West Texas Intermediate and Bonny Light have a yield of about one-third residuum after the simple distillation process.

OTHER REFINERY INPUTS

In addition to crude oil that runs through a simple distillation, a variety of other specialized inputs, usually to downstream units, enhance the refiner's capability to make the desired mix of products. Among these products might be unfinished (partly refined) oil, or imported residual fuel oil used as input to a vacuum distillation unit. The supply pattern for "reformulated gasoline" or RFG, the mandated low-pollution product first required in 1995, includes an important share of blending components that are classified as refinery inputs. These blending components include oxygenates but consist mainly of products that could be classified as finished gasoline in other jurisdictions or products that require little additional blending to be classified as finished gasoline. While they are counted as "refinery inputs," they are brought to saleable specifications in terminals and blending facilities, not in conventional refineries.

MAJOR REFINERY OUTPUTS

The most important refinery product is motor gasoline, a blend of hydrocarbons with boiling ranges from ambient temperatures to about 400° F. The important qualities for gasoline are octane number (antiknock), volatility (starting and vapor lock), and vapor pressure (environmental control). Additives are often used to enhance performance and provide protection against oxidation and rust formation.

Kerosene is a refined middle-distillate petroleum product that finds considerable use as a jet fuel and around the world in cooking and space heating. When used as a jet fuel, some of the critical qualities are freeze point, flash point, and smoke point. Commercial jet fuel has a boiling range of about 375°-525° F, and military jet fuel 130°-550° F. Kerosene, with less-critical specifications, is used for lighting, heating, solvents, and blending into diesel fuel.

Liquified petroleum gas (LPG) consists principally of propane and butane and is produced for use as fuel and is an intermediate material in the manufacture of petrochemicals. The important specifications for proper performance include vapor pressure and control of contaminants.

Distillate fuels such as diesel fuels and domestic heating oils have boiling ranges of about 400°-700° F. The desirable qualities required for distillate fuels include controlled flash and pour points, clean burning, no deposit formation in storage tanks, and a proper diesel fuel cetane rating for good starting and combustion.

Residual fuels are heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. Many marine vessels, power plants, commercial buildings and industrial facilities use residual fuels or combinations of residual and distillate fuels for heating and processing. The two most critical specifications of residual fuels are viscosity and low sulfur content for environmental control.

A variety of solvents, whose boiling points and hydrocarbon composition are closely controlled, are produced in refineries. These include benzene, toluene, and xylene.

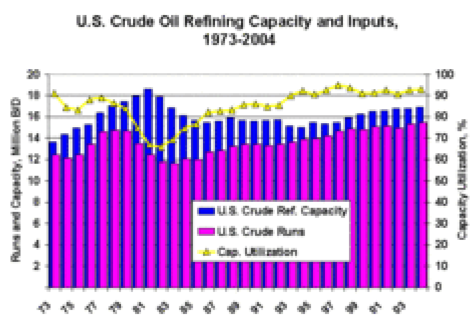
Petrochemicals are products derived from crude oil refining, such as ethylene, propylene, butylene, and isobutylene, which are primarily intended for use as chemical feedstocks in the production of plastics, synthetic fibers, synthetic rubbers, and other products.

Lubricants are produced in special refining processes. Additives such as demulsifiers, antioxidants, and viscosity improvers are blended into the base stocks to provide the characteristics required for motor oils, industrial greases, lubricants, and cutting oils. The most critical quality for lubricating-oil base stock is a high viscosity index, which provides for greater consistency under varying temperatures.

Coke is a residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. It is almost pure carbon with a variety of uses from electrodes to charcoal briquets.

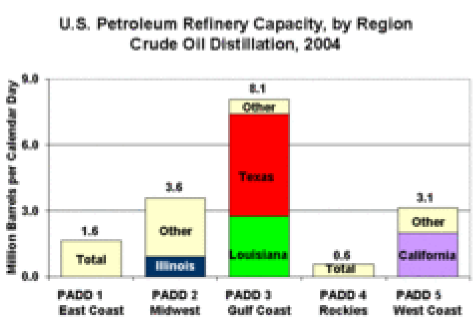
Asphalt is dark brown-to-black cement-like material obtained by petroleum processing and containing bitumens as the predominant component. It used primarily for road construction and roofing materials, and thus must be inert to most chemicals and weather conditions.

REFINING CAPACITY



U.S. Refining Capacity, Crude Runs, and Utilization Rate, 1973-2004. Source: Energy Information Administration, U.S. Department of Energy

U.S. refining capacity, as measured by daily processing capacity of crude oil distillation units alone, has appeared relatively stable in recent years, at about 16 million barrels per day of operable capacity (Figure 3). While the level is a reduction from the capacity of twenty years ago, the first refineries that were shut down as demand fell in the early 1980's were those that had little downstream processing capability. Limited to simple distillation, these small facilities were only economically viable while receiving subsidies under the Federal price control system that ended in 1981. Some additional refineries were shut down in the late 1980's and during the 1990's, always, of course, those at the least profitable end of a company's asset portfolio. At the same time, refiners improved the efficiency of the crude oil distillation units that remained in service by "debottlenecking" to improve the flow and to match capacity among different units and by turning more and more to computer control of the processing. Furthermore, following government mandates for environmentally more benign products as well as commercial economics, refiners enhanced their upgrading (downstream processing) capacity. As a result, the capacity of the downstream units ceased to be the constraining factor on the amount of crude oil processed (or "run") through the crude oil distillation system. Thus crude oil inputs to refineries ("runs") have continued to rise, and along with them—given the stability of crude oil distillation capacity—capacity "utilization" rose throughout much of the 1990's (Figure 3). Utilization—the share of capacity filled with crude oil—reached truly record levels in the last half of the decade, nominally exceeding 100 percent for brief periods.



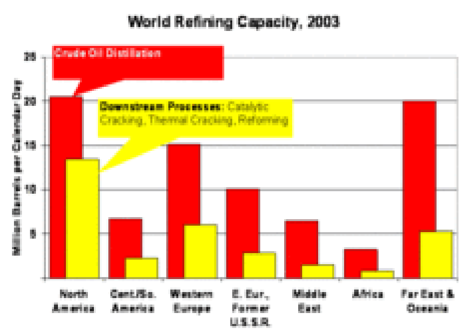
Source: Energy Information Administration, U.S. Department of Energy

As with most aspects of the U.S. oil industry, the Gulf Coast is by far the leader in refinery capacity, with more than twice the crude oil distillation capacity as any other United States region (Figure 4). (The difference is even greater for downstream processing capacity, because the Gulf Coast has the highest concentration of sophisticated facilities in the world.) As discussed in the section on Trade, the Gulf Coast is the nation's leading supplier in refined products as in crude oil. It ships refined product to both the East Coast (supplying more than half of that region's needs for light products like gasoline, heating oil, diesel, and jet fuel) and to the Midwest (supplying more than 20 percent of the region's light product consumption.)

There are seasonal patterns in refinery input. In the United States, refinery runs mirror the overall demand for products—lower in the colder months and higher in the warmer months. In addition, as they move out of the gasoline season in the early autumn and then into the next gasoline season in the late winter, refiners routinely perform maintenance. The duration and depth of the cutback in refining activity during each maintenance season is affected by a variety of factors, including the relative strength of the market for refined products. Therefore, when stocks are high and demand slack, the refinery maintenance season is likely to be longer and deeper. Refinery activity will also respond to the market's need (and hence relative prices) for product, with changes in the level of crude oil throughput as well as emphasis on one product over another.

WORLD REFINING CAPACITY

Broadly speaking, refining developed in consuming areas, because it was cheaper to move crude oil than to move product. Furthermore, the proximity to consuming markets made it easier to respond to weather-induced spikes in demand or to gauge seasonal shifts. Thus, while the Mideast is the largest producing region, the bulk of refining takes place in the United States, Europe or Asia (Figure 5).



Source: Energy Information Administration, U.S. Department of Energy

There have historically been a few exceptions—concentrations of refining capacity that were not proximate to consuming markets. A refining center in the Caribbean, for instance, supplied heavy fuel oil to the U.S. East Coast where it was used for power, heat, and electric generation.

As the demand for this heavy fuel oil, or residual fuel oil, waned, so did those dedicated refineries. While the Caribbean refineries, as well as refineries in the Middle East and in Singapore, were built for product export, they are the exception. As such, most refineries meet their "local" demand first, with exports providing a temporary flow for balancing supply and demand.

The largest concentration of refining capacity is in North America (in fact, the United States), accounting for about one-quarter of the crude oil distillation capacity worldwide, as shown in the graph in Figure 5, and as discussed more fully below. Asia and Europe follow as refining centers. As also shown in the graph, North America (again, the United States) has by far the largest concentration of downstream capacity—the processing units necessary to maximize output of gasoline. The gasoline emphasis of course mirrors the demand barrel and hence refinery output in the different regions, since no other global region uses as much of its oil in the form of gasoline as North America does.

In addition to gravity and sulfur content, the type of hydrocarbon molecules and other natural characteristics may affect the cost of processing or restrict a crude oil's suitability for specific uses. The presence of heavy metals, contaminants for the processing and for the finished product, is one example. The molecular structure of a crude oil also dictates whether a crude stream can be used for the manufacture of specialty products, such as lubricating oils or of petrochemical feedstocks.

Refiners therefore strive to run the optimal mix (or "slate") of crudes through their refineries, depending on the refinery's equipment, the desired output mix, and the relative price of available crudes. In recent years, refiners have confronted two opposite forces—consumers' and government mandates that increasingly required light products of higher quality (the most difficult to produce) and crude oil supply that was increasingly heavier, with higher sulfur content (the most difficult to refine).

Global strategic petroleum reserves ("GSPR") refer to crude oil inventories (or stockpiles) held by the government of a particular country, as well as private industry, for the purpose of providing economic and national security during an energy crisis. According to the United States Energy Information Administration, approximately 4.1 billion barrels (650,000,000 m^3) of oil are held in strategic reserves, of which 1.4 billion is government-controlled. The remainder is held by private industry. At the moment the US Strategic Petroleum Reserve is one of the largest strategic reserves, with much of the remainder held by the other 26 members of the International Energy Agency.[1] Other non-IEA countries have begun creating their own strategic petroleum reserves, with China being the largest of these new reserves. Since current consumption levels are neighboring 0.1 billion barrels (16,000,000 m^3) per day, in the case of a dramatic worldwide drop in oil field output as suggested by some peak oil analysts, the strategic petroleum reserves are unlikely to last for more than a few months.

INTERNATIONAL ENERGY AGENCY RESERVES

According to a March 2001 agreement, all 28 members of the International Energy Agency must have a strategic petroleum reserve equal to 90 days of prior year's net oil imports for their respective country. Only net-exporter members of the IEA are exempt from the reserve requirement. The exempt countries are Canada, Denmark, Norway, and the United Kingdom. However, Denmark and the UK have both recently created strategic reserves due to their requirements as European Union members.

FORWARD COMMERCIAL STORAGE AGREEMENTS

To allow oil-exporting countries increased flexibility in their production quotas, there has been an increased movement towards forward commercial storage agreements. These agreements allow petroleum to be stored at an oil-importing country, however the reserves are technically under the control of the oil-exporting country. Oil importing countries benefit from the close access to the commercial reserves, while reducing the costs of access. Emergency oil sharing agreements

In addition to maintaining a domestic stockpile of petroleum, several countries also have agreements to share their stockpiles in the event of an emergency.

In mid-2007 Japan announced a program to share its strategic reserve with other countries in its region. Negotiations are currently underway with New Zealand on an emergency oil-sharing program whereby Japan would make available for purchase its strategic reserves. In an emergency New Zealand would pay the market price plus negotiated option fees for the amount of oil previously held for them by Japan.

South Korea and Japan have also agreed to share their oil reserves in case of an emergency.

India has begun the development of a strategic crude oil reserve sized at 37,400,000 barrels (5,950,000 m^3), enough for two weeks of consumption. Petroleum stocks have been transferred from the Indian Oil Corporation (Indian Oil) to the Oil Industry Development Board (OIDB). The OIDB then created the Indian Strategic Petroleum Reserves Ltd (ISPRL) to serve as the controlling government agency for the strategic reserve.

This total amounts to approximately 34 days of net import cover, according to 2006 estimates of demand. KNOC has plans to expand the country's strategic storage capacity from 116,000,000 barrels (18,400,000 m^3) to 146,000,000 barrels (23,200,000 m^3) by 2009, and to fill the emergency reserves to 141,000,000 barrels (22,400,000 m^3) by 2010.

India is the sixth largest consumer of oil. There is a huge demand-supply gap in oil and gas in India. The country imports more than 70% of its crude oil requirement. In 2005, oil and gas accounted for 38% of primary energy consumption in India, followed by coal at 55%. Oil and gas industry is broadly classified into Upstream and Downstream segments and comprises 18 refineries, with total refining capacity of 132.47mmtpa as of April 1, 2006.

Consumption of crude oil was estimated at 130.11mmt, whereas consumption for natural gas was estimated to be 31.02bcm in the same year. The production and consumption of petroleum products was estimated at 119.75mmtpa and 111.92mmt respectively. Recently, India has emerged as net exporter of petroleum products.

OG Analysis new research service- "The Future of India Oil and Gas Industry to 2020" provides a comprehensive overview of the India oil and gas sector, covering the entire value chain of the industry. It analyzes and forecasts each of the oil and gas segments in India including upstream sector, pipeline, refinery, LNG and storage sectors. The report also gives detailed analysis of investment opportunities in each sector, highlighting the growth potential and feasibility of projects. It also identifies the key challenges, drivers and restraints in the country's oil and gas industry and the impact of these metrics on the industry.
The report gives outlook of India production and consumption of crude oil, petroleum products, natural gas and coal to 2020. It also provides detailed information including operators, owners, location, capacity and production for each of the oil and gas assets. Company wise and asset wise forecasts along with competitive structure is provided for each segment. Profiles of three major oil and gas companies and updates the major deals and events in the industry.

INDIAN OIL & GAS INDUSTRY: AN INDUSTRY ANALYSIS

The report - "Indian Oil & Gas Industry: An Industry Analysis" - provides an objective analysis on the Oil & Gas sector in India along with detailed information on the exploration, production and other processes. Annual consumption figures and future growth projections are also included in this report. It gives a detailed overview of the opportunities, challenges and critical success factors for the growth of the industry.

KEY FINDINGS

India, in 2004-2005, met 75 %of its crude oil demand through imports. The domestic production of crude oil has been in the range of 30-34 Million Metric Tons from 2001-2005. About 60 % of its crude import is from Middle East.
The consumption of natural gas grew at a CAGR of 2.7 % in the period 1999-2005, supported by rise in availability through domestic and imported sources of gas.

Oil comprises 36 % of India's primary energy consumption in 2005, and is expected to grow both in absolute and percentage terms driven by overall economic growth. Growth in demand is expected to catapult the overall demand to 196 Million Metric Tons in 2011-2012 and 250 Million Metric Tons in 2024-25.

Demand for oil is expected to grow from 119 Million Tons Oil Equivalent (MTOE), from 2004, to 250 MTOE, during 2025, at an annual growth of 3.6%. During the same period domestic production from existing developed reserves is expected to grow at approximately 2.5 %.

Natural gas comprises 9 % of India's primary energy consumption at present and it will be 14% of energy mix by 2010. Demand for natural gas is also likely to increase at an annual growth rate of 7.3%.

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