CHAPTER 11

Refining

The downstream process of refining is an essential step in adding value to crude oil and creating different products made from oil and gas. An understanding of how such products are used in hydrocarbon applications is the basis of the supply and demand equation which ultimately defines exits from the Hydrocarbon Highway.

Picky Refineries

Refineries are designed and configured to handle a specific basket of crude, with a distinct preference for sweet and light. Over time, meeting this specific demand becomes difficult as production from original fields serving the refinery declines and new sources and new types of crude must be found to keep the refinery going. Oil companies have several options to keep production steady. They can find crude through the drill-bit, by acquiring competitors or by buying barrels. Only the last two allow some degree of control, but no guarantee of crude blends. Heavy oil from areas such as Canada and Venezuela, for example, cannot be refined at most refineries.

PdVSA (the Venezuelan National Oil Company [NOC]) was able to enter the US refining and distribution market as can be noted by the many 'CITGO—Cities Services' gas stations in the South. The spread of refining options enabled PdVSA to swap and trade crudes so that its own refineries could function more efficiently. This is because its heavy oil could only be refined at a single location. PdVSA's purchase of CITGO basically 'guaranteed' a market for Venezuelan crudes through its swaps and trades.

The bulk of global refineries are found mainly in consuming rather than producing countries which involves the costly transportation of crude or unrefined hydrocarbons[1]. This is a paradox because it would be far more efficient and far less costly to refine products near the source and transport the more valuable refined products to their various markets. It would also provide valuable jobs for producing countries. In addition, positioning refineries in densely populated consumer nations is problematic because of environmental concerns and the 'nimby' (not in my back yard) factor.

Hydrocarbons*, as we have seen in Chapter 3 What's in a Wet barrel?, are made up of different arrangements of volatile hydrogen and carbon compounds held together by weak Van der Waals forces. Variations in the strength and number of intermolecular bonds, along with impurities, determine the viscosity and the melting and boiling points of most hydrocarbon compounds[2]. The stronger these forces and bonds, the heavier or more viscous the oil will be. As viscosity increases, more kinetic energy is needed to overcome the intermolecular forces holding the hydrogen and carbon together. For this reason, heavy oil is also less flammable as the compounds are less volatile, again due to increased intermolecular forces. The reverse also applies and much weaker forces hold together gas. Illustrating this are the two extremes of hydrocarbon scale: methane gas (CH_4) and liquid petrol (about C_5H_{12} to C_7H_{16}) to asphaltene ($C_{80}H_{162+}$)[3].

Homologous Series

In Chapter 3, we also saw that certain hydrocarbon compounds share the same general molecular formula and fo rm part of the homologous series. Alkanes (or paraffins) are saturated hydrocarbons form the basis of most crude oil and natural gas. They have single bonds and are described by the general formula C_nH_{2n+2}. The lightest of the series is CH_4, while the heaviest is asphaltene $C_{80}H_{162}$[4].

Alkanes cover the spectrum of petroleum from methane, ethane, propane, butane (aerosol propellants) and pentane to octane (gasoline), nonane diesel and aviation fuel, hexadecane fuel oil and lubricating oil. Hydrocarbons that contain 35 or more

* For our purposes, we consider hydrocarbons as alkanes, alkenes and arenes.

carbon atoms are generally classed as bitumen, asphalt and tar. By far the most important end use of alkanes is combustion as fuel to provide heat and electric or motive power. In most cases, complete oxidation is not achieved, and varying amounts of incompletely oxidised fragments, carbon monoxide, and elemental carbons are produced[5].

Table: the Molecular Weights and Common Names of Hydrocarbons.

Alkenes

Alkenes are unsaturated hydrocarbons. They have a double carbon bond and are characterised by the formula C_nH_2. The simplest alkene is ethylene and it is often created by the steam cracking of Liquefied Petroleum Gas (LPG), ethane and light naphta (alkynes and acetylenes exist but do not concern us here).

The simplest of the alkenes is ethane (CH_2CH_2). Ethylenes are used extensively as feedstock in many industrial products. They form the basis of plastics (polyethylene, polypropylene, polystyrene and polyvinylchloride or PVC) and industrial alcohol (ethanol). Alkenes themselves can also be produced by the dehydration of alcohol—see the production of ethanol in Chapter 13 Gas and Renewables.

Alkenes are not found in crude oil and are one of the most valuable types of organic molecules in the chemical industry[6].

Cracking heats some of the less used fractions to a high temperature vapour and passing them over a suitable hot catalyst. The main products from cracking alkanes from oil are smaller alkanes (e.g. for petrol or diesel) and alkenes (e.g. for plastics).

Arenes

Arenes (or aromatics) are also unsaturated hydrocarbons, but they are characterised by a cyclic arrangement of six carbon atoms, the simplest of which is benzene (C_6H_6). Aromatics give rise to various pharmaceutical products, solvents and paints such as paracetamol (C_6H_4) and toluene (C_6H_5-CH_3)[7].

Fractional Distillation

Refineries will distill hydrocarbons into fractions according to their volatility; the most commonly known is petroleum spirit or gasoline. Fuels obtained during the refining process are LPG, naphtha, kerosene, gas-oil and fuel oil. Non-fuel products such as lubricants and asphalt (used in paving roads) can also be obtained during refining. After distillation, however, it is common for refined fractions not to match their commercial demands. Automotive fractions such as petrol and diesel are in great demand so heavier fractions such as heavy naphtha, gas-oil or bitumen are subjected to secondary refining.

Cracking describes the process where heavier fractions are broken down to produce more of the lighter automotive fractions. Catalysts such as zeolite are commonly used to accelerate the cracking process and variations in cracking configurations exist according to the feedstock and final products required[8].

Derivatives such as perfumes and insecticides are also ultimately obtained from crude oil. Naphtha, gasoil, LPG and ethane are used as the raw material or feedstock in many petrochemical processes. There are more than 4000 different petrochemical products, but those which are considered as basic products include ethylene, propylene, butadiene, benzene, ammonia and methanol. The main groups of petrochemical end-products include plastics, synthetic fibers, synthetic rubbers, detergents, chemical fertilisers, solvents, paints, protective coatings and pharmaceuticals.

Less Coke Please

Transportation and industry are the largest consumers of crude oil specifically light distillates. Heavier fuel oils and 'solid coke' are not as desirable as their lighter counterparts. Heavy oils such as bitumen and asphalt are often used in construction, road paving and in electrical power generation where they compete with coal. Heavier crudes or bottoms (residues) may be 'cracked' in order to form lighter crude. This, however, requires more capital investment and more energy to be expended in the refining process. Consequently, this reduces the value of heavier crude. Additionally, Table: The Fractional Distillation of Crude Oil and Gas

impurities such as heavy metals or sulphur will further reduce the value of the crude as it becomes more expensive to refine[9].

The crude blend, with its many different chemicals, must be separated and treated. This blend is distilled into 'fractions' using 'heat and height columns'. Temperatures can reach 350°C in this process. This vaporises the hydrocarbons which subsequently rise to different 'heights' within a vertical column. The hydrocarbons cool down and become liquid again and are separated into fractions.

The solid residue remaining from the refinement of petroleum by the 'cracking' process is also a form of coke. Petroleum coke has many uses besides being a fuel, such as the manufacture of dry cells, electrodes, etc. Gas works that manufacture synthetic gas also produce coke as an end product called 'gas house coke'[10].

Fluid coking is a process by which heavy residual crude is converted into lighter products such as naptha, kerosene, heating oil, and hydrocarbon gases. The 'fluid' term refers to the fact that coke particles are in a continuous system rather than in batches.

Clearly a refinery's configuration will depend on the crude varietals it will process. In turn, this determines its configuration, processes and equipment. The list below gives an overview of standard refinery equipment:

- Desalter unit which washes out salt from the crude oil before it goes into the atmospheric distillation unit
- Atmospheric distiller or fractionating column
- Vacuum distiller which further distills the residual bottoms after atmospheric distillation
- Naphtha hydrotreater
- Alkylation equipment
- Catalytic reformer which contains a catalyst that is used to convert the naphtha-boiling range molecules into higher octane reformates (reformer products)
- Distillate hydrotreater unit which de-sulphurises distillate (diesel) after atmospheric distillation
- Fluid Catalytic Cracking (FCC) Unit which upgrades heavier fractions into lighter, more valuable products
- Hydrocracker unit which upgrades heavier fractions into lighter, more valuable products
- Coking unit which processes asphalt into gasoline and diesel fuel, leaving coke as a residual product
- Steam reforming unit which produces hydrogen for the hydrotreaters or hydrocracker
- Liquefied gas storage units
- Storage tanks for crude oil and finished products, and
- Utility units such as cooling towers for circulating cooling water, boiler plants for steam generation, and wastewater collection and treating systems.

Refining Efficiencies

Certain analysts and companies use product produced per barrel indices and refining efficiencies as Key Performance Indicators (KPIs) of refineries. With so many variables, however, it is hard to make like-for-like comparisons. In addition, some companies may be acting as equity transfer advisors, and therefore, would have a vested interest in transacting a refining asset. Refining and marketing can offer margins; for example, in the US you can acquire stock in downstream companies (Enron was a bad example, but Premcor and Valero are good examples) that make healthy profits. This US fondness for investing in specialised parts of the oil and gas chain is catching on elsewhere. Several existing Russian and Eastern European refineries are being groomed for private equity deals (and perhaps even Initial Purchase Offerings [IPO]) which shows the confidence some people now have in refining margins)[11] .

Those profits, however, have not stacked up sufficiently to motivate investment in new refineries. Undoubtedly, one of the key contributors to heightened and more sensitive oil prices is the lack of refining capacity. Not a single new oil refinery has been built in America since 1976 with existing plants working close to capacity. This is largely due to onerous government restrictions and permitting requirements as well as the aforementioned 'nimby' factor. As seen in 2005, hurricanes can shut down refineries causing prices to sky-rocket. As long as there is a continuing shortage of refining capacity, prices will continue to act this way. Refining is a continuous process, and should not be shut down once it has begun; however, even the most efficient plants must shut down for maintenance or for a product change periodically. By coincidence, if two or more refineries go offline at once for maintenance or a 'turnaround' it can cause a localised shortage that precipitates a price spike. Refineries try to mitigate periodic supply shortages by overproducing into storage facilities that can serve as a supply buffer during short offline periods (see Chapter 12 Paper Barrels and Markets)[12].

Supply Side Discussion

Today's bottlenecks of minimal spare capacity are not caused by a peak in production or because of a lack of reserves; we have seen that there are plenty of opportunities (see Chapter 2 Reserves, Peak Oil and Medieval Maps). The problem lies with refining capacity and inventories. We have noted that most current global refining capacity is geared toward sweet and light. That refining profile is not well suited to handling the increasing volumes of sour and heavy crude coming onto the market[13].

Building new refineries to handle sour and heavy crudes seems obvious enough given the characteristics of tough-to-produce reserves. So why aren't oil companies queuing up to build new refineries?

Part of the hesitancy is explained by the bull market of the past few years where the highest average utilization is 86%. Surely, however utilisation (and profitability) for new build refineries would be even higher given their up-to-date configuration for sour and heavy? Even though the answer is probably yes, the explanation for the reluctance in building new refineries lies with market uncertainties of future demand rather than profitability, social 'nimby' attitudes against refineries and the tendency for refineries to be built in large consuming countries.

If a refinery project begins today, it takes between five to seven years before it is operational. At that time, there is no idea of where the market will be. Industry does not look favourably on idle capacity and private companies are loathe to idling[14].

This is because shareholders want healthy returns yet refining margins are notoriously difficult to get right for new builds, which do not make huge profits, and still there is the real risk of idling.

Spare refining capacity, however, is precisely what the market needs to insulate it from knee-jerk reactions and maintain stable prices. That responsibility has fallen in the main part to Saudi Arabia, which has for years sought to provide a soft landing mechanism by maintaining excess production capacity, the so called supply cushion[15].

Ultimately, this is in the exporters' best interests because a prolonged period of depressed prices not only means a loss of windfall profits but giving oil away on the cheap. It can mean having the value of your most valuable resource mercilessly halved or cut even further. To illustrate, take Saudi Aramco, for example. Saudi Arabia's reserves are calculated at a high value of 18.48 trillion USD at an oil price of US$70 (x 264 billion), 13.20 trillion USD at an oil price US$50 and 6.60 trillion USD at US$25. A sobering exercise, no doubt but it is also worth mentioning that exporting countries are highly dependent on cashflow from oil revenues to keep their economies afloat[16].

That means NOCs must also keep a cash cushion when low prices swing back. Otherwise, exporters will simply have to pump higher volumes at lower prices to make up for lost revenues, if at all. That is a definite no-no in today's climate of resource sovereignty and maximising wealth.

A loss in short-term earnings and a wipe-out of the value of a finite set of reserves is not something exporters would be keen to see happen. That is why the Saudi Arabians are often called 'the voice of reason'. They want to keep markets and prices stable. They keep an eye on US inventories and check production forecasts accordingly. For exporters, an ideal rate of global economic growth is approximately one to two percent. In short, a stable scenario is one where economies grow at a manageable rate and sustain energy demand at moderate levels. Any shortfall in petroleum supply can be picked up by E&P technology gains, frontiers and growing renewables which are attractive at that price range. Lower prices and investment is pulled back.

There is a 'paper' spanner in the works, which we discuss in the next chapter.