CHAPTER 3

Economics of Oil Refining

Jean-Pierre Favennec

1 Introduction

Refining is a key step in the oil industry, as we do not directly consume crude oil. A petroleum refinery is a set of installations intended to transform crude oil, generally unusable as such, into petroleum products: motor gasoline, jet fuel, diesel fuel, fuel oil, lubricants, liquefied petroleum gases, naphtha, and so on.

The products consumed in largest volumes are motor gasoline, motor diesel, and heavy fuel oil. The products with the fastest growing consumption are jet fuel and diesel fuel (Table 3.1).

1.1 Crude Oil

Crude oil is composed mainly of hydrocarbon molecules formed from carbon and hydrogen atoms. Impurities, particularly sulfur and metals, are also found in oil. Sulfur is found in the products and gives SO_2 by combustion, which is dangerous for the environment. Metals are present in very small quantities (a few parts per million—ppm), but, even in very low concentrations, their presence in petroleum products can be harmful to the processes that use them (especially catalysts).

There are probably more than 400 different crude oils in the world. While the annual production of Arabian Light, a crude oil extracted mainly from the Ghawar field in Saudi Arabia, exceeds 250 million tons per year (Ghawar, from where it is produced, originally contained more than 10 billion tons of crude oil), many crude oils are produced in very small quantities. Only about a hundred crude oils are traded on a significant international scale.

J.-P. Favennec (✉)
WDCOOPERATION, Paris, France
e-mail: jpfavennec@yahoo.fr

M. Hafner, G. Luciani (eds.), *The Palgrave Handbook of International Energy Economics*, https://doi.org/10.1007/978-3-030-86884-0_3

Table 3.1 Global consumption of refined products (million tons)

	1973	*2017*	*2017 vs 1973*
LPG/Naphtha	199	517	260%
Gasoline	559	1112	199%
Jet	114	371	325%
Diesel oil	592	1422	240%
Fuel oil	747	371	50%
Others	196	605	309%
Total	2407	4337	180%

Source: Adapted from International Energy Agency

So many deposits, so many raw materials. Each crude oil is characterized in particular by its density, which is commonly measured in American Petroleum Institute (API) degrees.[1] The current crudes have a density between 0.8 (about 45° API) and 1 (10° API). A light, low-density crude oil will produce relatively high levels of gasoline and diesel fuel and low levels of fuel oil. On the other hand, a heavy crude oil will give a lot of heavy fuel oil.

1.2 The Main Steps of Refining

The refining of petroleum, that is, the transformation of crude oil into finished products, requires several operations that can be grouped as follows:

- the separation of crude oil into different fractions, which are the basis for the manufacturing of finished products
- the improvement of the quality of some cuts
- the transformation of heavy cuts into light cuts
- the final preparation of the finished products by blending

A refinery consists of several distinct parts:

- the process units where oil is separated into fractions or cuts; some cuts undergo additional processing for improvement in order to reach commercial requirements; heavy fractions can be converted into light fractions,
- utilities, that is, all units of production of fuel, electricity, steam, and so on, necessary for refining processes
- storage facilities
- reception and shipping facilities,
- blending facilities.

[1] The formula for API gravity is: (141.5/Specific Gravity)-131.5. Hence water, which has a specific gravity of 1, has an API degree of 10. All crude oil is lighter than water, and the lighter it is, the higher is the API degree.

The area covered by a refinery can reach several tens of hectares, but a large part of this area is covered by storage facilities

2 History and Evolution of Refining

The use of oil goes back to the earliest times. The Mesopotamian king Sargon refers to bitumen in the cuneiform texts that have come down to us. Reference is also made to the bitumen in the Bible, whether it is the caulking of Noah's Ark or the coating of Moses' cradle to allow it to float on the Nile.

Very early on, the Chinese refined crude oil. Many texts mention the use of petroleum-based products as lubricants.

More than one thousand years ago, oil fields were already being exploited in the Baku region (which was the main oil production region at the beginning of the intensive exploitation era, during the Russian Tsar's empire in 1900).

Around the year 1000 Arab chemists used the distillation of oil to make different products, like lubricants.

Oil was also widely used as a weapon of war. The famous "Greek fire" spread terror in many naval fleets from the beginning of our era in the Mediterranean area. Arab and Persian chemists, then Chinese chemists, also used highly flammable products in the same way.

However, the modern history of the oil industry is said to have begun with the production of kerosene for illumination. For many years, the use of lamp oil (mostly whale oil) was the best way to illuminate a room, until the whale population decreased rapidly. In 1846, Abraham Gessner of Nova Scotia, Canada, developed a process to produce kerosene from coal. Shortly afterwards, in 1854, Ignacy Łukasiewicz began producing kerosene from hand-dug oil wells in Poland.

In the United States, the indigenous Indians used seepages of oil in different ways, including lighting. Some specialists considered that probably oil could be found in the ground, and the oil industry began in 1859, when Edwin Drake discovered oil near Titusville, Pennsylvania, by digging a 20-meter deep well. Very rapidly, John D. Rockefeller, a young smart accountant, built several refineries to produce mainly kerosene and took monopolistic control of the oil refining and marketing industry in the United States. He created Standard Oil, a company capable of manufacturing kerosene of standard—that is, constant—quality, from different crude oils with different characteristics. The company was an association of several corporations, more or less one per US state. However, in 1911, Standard Oil was taken to court because it was a monopoly, prohibited under the newly approved Sherman Act, and was broken up into 34 companies including Standard Oil of New Jersey, now Exxon, part of Exxon Mobil; Standard Oil of New York, now Mobil, the other part of Exxon Mobil; Standard Oil of California, today's Chevron, and so on. At the beginning of the twentieth century, the introduction of the internal combustion engine and its use in automobiles created the gasoline market, which became the driving force behind the relatively rapid growth of the oil industry. Early oil discoveries, such as those in Ontario and Pennsylvania, were quickly overtaken by large oil "booms" in Oklahoma, Texas, and California.

From a technical point of view, the refining industry really began in 1863 with the construction of the first distillation unit in Boston, USA. Certainly, this unit has nothing to do with the refineries we know today. Still, it made possible to extract from crude oil the kerosene or lamp oil consumed at the time. The development of electricity by Thomas Edison introduced a competitor to kerosene, but the development of electricity consumption was very slow. Shortly afterwards, the appearance of the automobile led to an increase in the consumption of petrol and diesel. Then fuel oil found an outlet in the navy, just before the First World War.

The refining industry was booming, and on the eve of the Second World War, distillation capacity reached 364 MT/y—Million Tons per year—worldwide, two-thirds of which in the United States and only 4% (16 Mt./year) in Europe.

More distillation units, but also more so-called secondary treatment units were built. First of all, thermal reforming was developed to increase the production of gasoline. Then came thermal cracking to reduce the production of heavy fuel oil and increase the production of light products, especially gasoline and diesel. Finally, after Second World War, catalytic reforming was introduced to improve the quality of gasoline. Many other processes developed in parallel, but the refining industry can now be considered a mature industry.

Rockefeller initially focused on crude oil processing and product distribution operations, leaving oil production, which he considered too risky, to other players. But gradually, within the major oil companies, refining has become integrated with oil exploration and production on the one hand, and distribution on the other. Integration provides the company with its sources of crude oil and its outlets, thus promoting the smooth physical operation of the oil chain. Gradually, however, and in particular because of nationalization of the oil fields in several counties in the 1970s (Algeria, Libya, Iraq first, Venezuela, Kuwait, Saudi Arabia some years later), international companies became mainly refining and distribution companies, with crude oil production being largely in the hands of the national companies of producing countries. This trend has been partially reversed: some producing countries opened their oil exploration and production in order to attract the large international oil companies (the Majors), which can bring expertise and financing. Very often this has been carried out through associations (joint ventures) between the national oil company and the foreign companies.

On the other hand, some OPEC countries now play a key role in refining. The countries of the Persian Arab Gulf and Venezuela have developed significant capacities, which are largely export-oriented. For strategic reasons, some of them (Saudi Arabia and Venezuela) have also taken control of important capacities abroad (especially in the United States).

3 Refining Capacities Around the World

Refining capacity, measured by atmospheric distillation capacity, increased from just over 1 billion tons per year in 1950 to over 4 billion tons per year in 1980. It declined to less than 3.60 billion tons in 1985, following the second oil crisis. After the fall in oil prices in 1986, capacity increased again and is currently of the order of 5 billion tons per year, or 100 million barrels per day.

- *Asia* (from Pakistan to Japan, and including Australia and New Zealand) is now the world's largest refining area, with a distillation capacity of 1.7 billion tons per year. Japan and China have the largest facilities, but South Korea and India also have a significant tool. Capacity has increased very rapidly in recent years due to the very strong growth in demand, especially in China and India.
- *North America* (the United States, Canada, and Mexico) also has a very large refining base, representing more than 20% of the world's capacity. The United States has more than 80% of the capacity in this region. It should be noted that the number of US refineries has fallen from 320 to 135 in 40 years, while total capacity increased. Small refineries in the middle of the United States have been closed for lack of crude oil at the time, while large refineries developed on the coast.
- *Western Europe and Turkey*, with 17% of the world's capacity, remains a major refining area, despite the very sharp capacity reductions in the early 1980s. The number of refineries has decreased from 160 to about 100, with a 30% reduction in total capacity. Capacity in Eastern Europe is around 13% of global total. Most (80%) of this capacity is located in the former USSR, but these figures should not be misleading: facilities in this region are generally old, unsophisticated, and currently much underutilized.
- *Central and South America* is well equipped with refineries, with Brazil and Venezuela having the largest capacities. Large-scale refineries are located in the Caribbean and Venezuela: they are often export-oriented and the United States is a privileged market for refineries in this subregion. However, it should be stressed that at the time of writing US sanctions on Venezuela are impacting the refining industry there.
- *The Middle East* is also an important refining center with several large refineries for export, particularly to Asia. The largest exporters are Kuwait, Saudi Arabia, and Abu Dhabi. The strong growth in demand, driven by economic growth and rather low product prices, requires a rapid increase in capacity. In addition, large new refineries have recently been built in Saudi Arabia, for example, SATORP, a 20 million tons very sophisticated refinery built by Total and Aramco. Sinopec and Aramco are building a similar refinery.
- Finally, *Africa* has only limited capacity. Four countries (Algeria, Egypt, Nigeria, and South Africa) represent more than 60% of the continent's

capacity. Apart from Algeria, Libya, and Egypt, which export finished products to Europe and the United States, refineries in this area are mainly used to supply local markets. In many sub-Saharan countries, there are small refineries (of about 1 to 3 million tons) to supply local markets of the same size. The profitability of these refineries is precarious, but they give autonomy in terms of products, which can be precious, to the countries where they are located.

However, many of these refineries have closed more or less recently (Mauritania, Sierra Leone, Liberia, Togo on the West Coast; Mombasa, Dar Es Salaam, and Maputo on the East Coast). These refineries are finding it increasingly difficult to compete with products that arrive in large quantities from large refineries built in the Persian Gulf or in India.

In total, there are currently approximately 700 refineries worldwide with a total processing capacity of approximately 100 million barrels per day. The average capacity of a refinery is therefore around 150,000 b/d or nearly 8 Mt./year.

The Jamnagar refinery is the largest oil refinery in the world since 2008, with a processing capacity of 1.24 million barrels per day (more than 60 million tons per year, almost equivalent to the capacity of a major European country!). Located in Gujarat, India, it is owned by Reliance Industries.

Among other very large facilities, we find the Paraguana refinery in Venezuela, which is the result of the merger of the Amuay and Cardon refineries (pipe connections have been established between the two refineries). Its capacity totals 980,000 barrels per day. There are also the South Korean refineries in Ulsan (two refineries) and Yeosu, whose combined size exceeds 2 million barrels per day. Other very large refineries are found in Saudi Arabia and the United States.

On the other hand, there also are small refineries adapted to small and isolated markets. Inland countries (Mali, Niger, Chad, Uganda, Rwanda, and so on) are very difficult to supply with finished products from the African coast, which can be more than a thousand kilometers away. In Chad and Niger, which have domestic oil resources, two similar 20,000 barrel per day refineries were built by Chinese companies just after 2010.

4 Refining Structure and Evolution of Demand by Product

As we have seen, the strong growth in the consumption of oil (and therefore petroleum products) dates back to the 1950s and 1960s. At that time, the switch from coal to liquid fuels led to an impressive increase in demand for heavy fuel oil and heating oil. Until the early 1970s, a simple refinery (composed of Distillation + Catalytic Reforming + Desulfurization Units), which processed a medium crude oil of the Arabian Light type, was perfectly adapted to demand, producing 40 to 50% heavy fuel oil, used in the industry and for electricity production, in line with the demand.

The 1973 and 1979 oil shocks, by increasing the price of oil tenfold, led to a sharp drop in demand for heavy fuel oil, replaced by coal, gas, or nuclear power. On the other hand, demand for gasoline, diesel oil, and jet fuel, for which there were no substitutes, continued to grow. To cope with this change in the structure of demand, it was necessary to build many conversion units, which are capable of transforming heavy distillation fractions into lighter fractions, petrol or diesel components. Most of the units built were of the FCC type (fluid catalytic cracking) because they have the dual advantage of very high fuel efficiency and a "moderate" investment cost compared to that of alternative solutions, such as a hydrocracker. The conversion rate, measured by the ratio of the weighted sum of a refinery's conversion capacity to its distillation capacity, increased in all regions of the world. The development of conversion has been significant in Western Europe, where the conversion rate of around 5% in 1975 increased to more than 50%. In 1977, Western Europe had 143 refineries, but only one-third of them had FCCs. Ninety percent of the remaining 100 refineries are now equipped with FCCs (or equivalent process units).

Similar trends have been observed in other regions of the world. The latest refineries built in Asia and recent extensions in the Middle East include many cracking units.

4.1 Recent Developments

Refineries must constantly adapt to major changes, for example, switch to unleaded petrol around 1990; general reduction in the sulfur content of fuels; and reduction in sulfur dioxide emissions from ships, which requires the installation of scrubbers or switching to LNG.

Thus, we have witnessed the construction of units capable of supplying gasoline components with increased octane number (regenerative catalytic reforming, isomerization, alkylation, etc.) to meet the demand for unleaded petrol and remodeling—rather than new construction—of desulfurization units to cope with the mandated reduction in the sulfur content of products, and in particular diesel fuel.

The decrease in heavy fuel oil production—which is imperative given market trends—is being achieved through improvements to existing FCC-type units capable of handling "heavier" loads and recent or future projects in deep conversion units, and remains a major challenge for refiners. The construction of very expensive deep conversion units (residue hydrocracking, coking with coke gasification) requires a considerable spread between the prices of diesel oil and that of heavy fuel oil. The changes to the FCCs also allow heavier loads to be handled. The transformation of residues into electricity via gasification is also an interesting option.

The refining industry in the United States is characterized by a particularly high conversion rate. Traditionally, the American refining industry has had to face very strong demand for motor gasoline. US demand for gasoline is in the order of 400 million tons per year, or about 45% of total US demand for petroleum products and 40% of total world demand for gasoline. The size of the car fleet, the high unit consumption of cars in the United States, and the fact that part of the commercial vehicle fleet is equipped with gasoline engines explain the strong demand for this product. On the other hand, abundant gas and coal resources have reduced the market for heating and heavy fuel oil. As a result, American refineries—or at least the largest ones—are equipped not only with FCC units but also with cokers. Eighty percent of cokers in the world are located in the United States. The average gasoline yield of US refineries exceeds 55%.

5 Refining Investment Costs

The investment cost of a completely new refinery depends on its size, complexity, and location. It is generally estimated that a 160,000 b/d (8 million tons per year) refinery, equipped with catalytic cracking, visbreaking, and gasoline units and built in Europe, would currently cost more than $6 billion. This cost can be significantly increased in the event of extremely stringent emission regulations, in terms of both the refinery's environment and the product quality.

A simple refinery (atmospheric distillation and catalytic reforming, plus distillate hydrodesulfurization) of a smaller size (100,000 b/d or 5 million tons per year) would cost half of this amount, or $3 billion. But the construction of such small refineries, which are no more profitable because they produce too much heavy fuel oil, is no longer on the agenda. Conversely, the investment required for a very large refinery, equipped with a deep conversion unit in order to reduce the production of heavy fuel oil to very small quantities, would cost more than $10 billion.

The analysis of investment costs shows the very high proportion of "offsites" (production of utilities, storage, receiving and shipping facilities), which can represent more than half of the cost for simple refineries. All other things being equal, the degree of autonomy of the refinery in electricity (whether or not it is purchased externally), the size of the tank farm, the size of the reception and shipping facilities are, among many others, important parameters in the total amount of the investment.

Two characteristics are essential in determining the investment cost:

- *Size*: The volume of a vessel (which determines its production capacity) is a function of the cube of the radius, while the surface (which determines its cost) is a function of the square of the radius. As the size of the vessel increases, its production capacity therefore increases faster than its cost. There are therefore significant economies of scale in a refinery. These savings are limited by the maximum size of some units. Thus, an atmospheric distillation unit will usually not exceed a dozen million tons per year of capacity. A larger refinery will therefore have at least two atmospheric distillation columns.

- *Location*: The cost of transporting the equipment and the cost of assembly are significant elements of the construction cost. A refinery located at a site far from the manufacturing plants for the main components (columns, reactors, etc.) will therefore be more expensive than the same refinery located near suppliers (North America, Europe, and Southeast Asia). The scarcity of local labor, forcing the movement of specialized teams, also has a significant impact on investment. Finally, particular climatic conditions can also have an impact on the price of the equipment.

6 Refining Costs

For ease of analysis, a distinction is made between variable costs (proportional to the quantities of crude processed), fixed costs (independent of the quantity of crude oil processed: personnel, maintenance, overheads) and capital costs (or depreciation).

6.1 Variable Refining Costs

These are proportional to the quantities of crude oil processed: they are mainly related to chemicals and catalysts.

Chemicals: A large number of chemicals are used in refining processes, but the costs involved remain limited. For a long time, the main focus was on lead additives (tetra-ethyl lead) to improve the octane number of gasoline. The gradual disappearance of these additives led to a reduction of the total cost for "chemicals". However, the increasing use of other additives (cetane improvers, additives improving cold resistance for diesel fuel, "pour depressants", etc.) slightly increases costs.

Catalysts: Most refineries—with the exception of refineries which have just a single distillation column—include catalytic process units: reforming, cracking, isomerization, alkylation, hydrodesulfurization, catalytic cracking, hydrocracking, and so on. The catalysts used are very diverse. The reforming process uses noble metal catalysts, whose cost exceeds several hundred dollars per kilo. However, these catalysts are regenerated (continuously in recent units, periodically in older units): at the end of the use cycle, the noble metals are recovered and reused.

For catalytic cracking, catalyst losses are continuously compensated by an injection of new catalyst. The cost of the catalyst is limited.

In total, the cost of chemicals and catalysts, per barrel of crude oil processed, is in the order of one dollar.

6.2 Fixed Costs

These costs include personnel, maintenance, insurance, local taxes, overheads, and so on, which are almost independent of the quantity of crude processed. Indeed, whether the refinery operates at 60% or 100% of its nominal capacity, personnel costs, for example, are the same.

Staff: The number of people working in a refinery varies greatly. It is at least about 200 to 250 people for a simple refinery. It can be much higher for a complex refinery, equipped with several atmospheric distillation units and cracking. For example, a large refinery (with two atmospheric distillations, two reformers, one catalytic cracker, one hydrocracker, one visbreaking unit, but also hydrodesulfurization units and an oil chain) directly employs more than 1000 people. The staff numbers therefore depend very little on size, but mainly on complexity. Personnel costs range from about \$15 million/year for a simple refinery to \$40 million/year for a refinery equipped with deep conversion. As a reminder, it should be noted that some refineries, particularly in the former Soviet Union countries, had a very large number of employees, several times higher than the number of employees in a Western European refinery. This is due to both the multiplication of small units in the same refinery and the existence of highly developed ancillary services (some factories even had spare parts manufacturing workshops, health services, and agricultural production cooperatives).

Maintenance: Maintenance is more or less proportional to the initial investment cost. A rule of thumb considers that the annual maintenance cost represents approximately 1 or 2% of the initial investment, that is, between about \$50 million/year (simple refinery) and \$100 million/year (deep conversion refinery). In Western refineries, most of the maintenance services, which are not considered part of the core business, are now outsourced.

General costs: These cover taxes, insurance, miscellaneous operating costs, overheads.

Total fixed costs are in the order of \$2 to \$3 per barrel processed (if the refinery operates at or close to capacity).

6.3 Recovery of Capital Costs

Capital, whether it is the cost of initial capital investment for a new refinery or the cost of new units in an existing refinery, must be recovered as depreciation. For a 160,000 barrel per day refinery equipped with conventional conversion, the initial investment, as we have seen, is about \$6 billion. If this unit is new, the incidence of capital depreciation (which can be interpreted as the sum of interest and repayments assuming the money needed to build the refinery is fully borrowed) will be in the range of \$8 to \$9 per barrel of crude processed (again, if the refinery operates at or close to capacity).

6.4 Total Refining Cost

In total, the costs and charges (excluding utilities) for a new conventional conversion refinery operating at full capacity would amount to just over \$10 per barrel. But the majority of refineries in operation is largely amortized and therefore operates with lower refining costs, in the order of \$3 to \$5 per barrel of crude oil processed.

6.5 Factors That Influence Refining Costs and Profitability

As we have seen, fixed costs (personnel, maintenance, and overheads) and capital costs represent the bulk of the total cost of processing crude oil. This has a very significant impact on the economics of refining.

(a) *Operating Rate*

This is the most important parameter. It is essential for a refinery to operate at a rate close to the maximum. This is of course true not only for atmospheric distillation but also for other units. A running rate of 66% translates, compared to full capacity operation, into a 50% increase in fixed costs per ton of crude oil processed.

This reasoning can be tempered by the fact that the full capacity operation of all refineries in an area where distillation capacities exceed overall product demand can result (and generally results) in a collapse of prices and therefore margins. This is why some refiners in such circumstances sometimes decide to decrease the quantity of crude oil processed. These measures are generally of short duration because a strengthening of margins immediately translates into a return to full capacity.

(b) *Size*

For a given utilization rate, the refining cost per ton of crude decreases as the size of the refinery increases. Indeed:

- Personnel and overhead costs are almost independent of the size of the refinery.
- Maintenance costs and capital charges increase less quickly than size.

For this reason, refineries with a size of less than about 5 million tons of distillation per year are no longer built, except in very special cases. Only geographical reasons (proximity to crude oil, e.g., in the United States; proximity to isolated markets, e.g., in Africa) can justify the existence of small refineries.

(c) *Complexity*

The degree of complexity of a refinery naturally increases the cost of processing a ton of crude oil. This is mainly due to higher cost of capital and maintenance. Two important remarks, however:

- a complex refinery will generate a higher margin than a simple refinery, all other things being equal (size, location, market, etc.) due to higher yields of light products

- a complex refinery will effectively generate a higher margin than a simple refinery if the crude oil is adapted to the processing in the conversion units. In other words, it will have to deal with heavier loads allowing it to fully utilize its crackers.

(d) *Location*

A refinery whose investment cost was increased by the distance from equipment suppliers, the scarcity of labor and extreme climatic conditions will of course have a higher operating cost per ton of crude oil.

(e) *Synergy with Petrochemicals*

The juxtaposition of refining with other activities, in particular, production of petrochemicals, is a very important asset, not only for the direct provision of charges for the steam cracker (the main process unit to make olefins which are the basis for the manufacturing of plastics, synthetic fibers, and synthetic rubber), but also because of the potential for common support services (maintenance, laboratory, general services, shipments, etc.) for all the site's activities.

7 Costs and Margins

The refining (gross) margin is the difference between the value of products (excluding taxes and distribution costs) leaving the refinery and the cost of crude oil entering the refinery. The net margin is equal to the gross margin less variable costs. The refining margin depends on many parameters and in particular on the refining scheme. We will thus speak of a TRCV margin for a refinery equipped with Topping, Reforming, Cracking (catalytic) and Visbreaking. Refining margins also depend on the region in which the refinery is located. A good geographical location translates into increased product value and therefore a better margin. In the United States, for example, refining margins in the interior of the continent are higher than those on the coast.

As previously discussed, total, refining costs for a newly built conventional refinery with 160,000 barrels per day of capacity and standard conversion units would be about $10 per barrel of crude processed, taking into account capital costs (interest and loan repayments). But most refineries, at least in North America and Europe, were built more than 20 years ago and are now depreciated. Their operating costs are in the order of $3 per barrel.

While production costs are relatively stable, margins are highly variable. They will depend on the market situation. Refining margins were very low until around 2000. They have improved over the past few years due to rationalization of capacity, which has involved many closures. Current margins, without generally allowing full cost coverage, make it possible to cover the limited cash costs and depreciation of recent investments. Indeed, most of the refineries in operation were built before the first oil crisis. In most Western countries, the most recent refineries date back to the 1970s. The initial installations are therefore largely amortized. Of course, new investments are constantly being made in refineries. But the economic depreciation associated with these new investments is only a small fraction of that that would result from the construction of a new refinery.

7.1 Margins by Region

Margins in the United States vary widely from one region to another. Around the Gulf of Mexico, the refining margins of the large, sophisticated refineries built to maximize gasoline production are fair. Margins in this area, which is very open to imports, are affected by product arrivals, particularly from Europe and Latin America. On the other hand, margins are much higher in the Midwest and even more so in California due to a better supply-demand balance on the one hand, and higher product prices on the other. Higher quality standards for products are reflected in prices. We should stress that the price of crude oil in the center of the United States is referred to the quotation of WTI (West Texas Intermediate crude) in Cushing, Oklahoma. Cushing is a place supplied with crude oil from many different origins (including synthetic crude from Canada) and equipped with large storage facilities. The price of WTI, which is a reference for other US crude oils, is normally low compared to Brent because of the large inflow of crude and limited pipeline facilities to transfer the crude. This is the main reason for better margins in the United States.

Refining margins in Asia were relatively high before the Asian crisis of 1997. Margins in this region were then more favorable than elsewhere due to continued growth in demand and the protection of certain markets. Margins collapsed in mid-1997 due to the region's economic problems, which slowed demand growth just while very large capacities were built. They rebounded in 2000, but remain relatively low if calculated on the basis of spot prices. However, we should remember that product prices are controlled by the government in many countries, allowing some profitability of the industry.

In Europe, the margins of a complex reference refinery located in Rotterdam were in the order of \$1 to \$2 per barrel in the 1990s, before recovering in 2000. Rapid variations in crude oil prices can also lead to very significant variations in the level of the margin.

7.2 Future Margins and Costs

Margins published by oil companies or trade journals are typical margins for fictitious refineries. This is called a margin indicator. In Europe, margin indicators generally correspond to the case of a refinery located in Rotterdam and operating in a highly competitive environment. These "Rotterdam calculated" margins do not cover the full costs of a new refinery.

A number of factors improve the economic situation of refining:

- Very significant productivity progress has been made in terms of costs: a few years ago, a large French company announced that it would lower its refining "break-even point" by around $1 per ton of crude oil processed per year. This trend continues: improvement in operating rates, efforts on the various items, reduction of inventories, and strict selection of investments are among the elements that explain this improvement;
- The generally published margins only take into account major products (gasoline, jet fuel, diesel, fuel oil). The so-called specialties products (lubricants, bitumen, LPG, or even petrochemical products) are not taken into account. However, these products often generate positive results that contribute to improved refining margins;
- The prices at which some refineries can actually sell their products are often higher than those taken into account in the calculation of margin indicators, because of a possibly more favorable geographical situation: a refinery located in Europe inland in an importing area will sell its products at a much higher price than Rotterdam, the difference reflecting transport costs;
- In a number of countries, refiners offset low refining margins with their presence in the distribution sector
- In order to better cope with competition and poor market conditions, restructuring is taking place in cooperation between operators.

Capacity restructuring in the face of a market that is likely to continue to grow for a few years suggests a good situation for global refining.

8 Oil Demand for Tomorrow

In a base scenario, the International Energy Agency (IEA) forecasts that oil demand—100 Million b/d in 2018—could exceed 110 Mb/d (5.5 Gtoe) in 2030, with most of the increase in demand coming from emerging countries, which will account for more than 60% of world consumption in 2030 compared to slightly more than 50% today. The share of motor fuels in oil consumption will continue to rise to more than 60%. Of course, in this baseline scenario, global carbon dioxide emissions will increase in contradiction with the Paris agreements of 2015.

However, the IEA proposes a second scenario, reflecting the impact of proactive energy policies and measures by governments and leading to a modest demand reduction of 10% in 2030 compared to the baseline scenario. In the latter scenario, oil consumption is therefore reduced to 99 Mb/d and the share of biofuels in total fuels increases from 4 to 7%, which seems unambitious but can be explained, at least in Europe, by the difficulties encountered in harmonizing the actions of the 27 Member States.

The increase in oil-related carbon dioxide emissions will greatly increase pressure on governments to limit demand growth, but the implementation of measures with a significant impact will require real political will.

Oil will increasingly be used for fuels and petrochemical bases, to the detriment of uses for heating and power generation.

The development of oil substitutes: agro fuels, synthetic fuels obtained by the Coal to Liquids (CTL), and Gas to Liquids (GTL) processes will be limited because they are expensive in energy and the improvements of the catalysts make it possible to manufacture products of excellent quality in refineries. The only GTL units recently built were in Qatar but no new units are planned.

9 The Future of Refining

The steady increase in the consumption of petroleum products requires increased refining capacity. Given the disappearance of refineries, often of small size, because unprofitable, the construction of new capacities is inevitable. These capacities will be built mainly in Asia, to cope with growing demand, and in the Middle East, where the availability of crude oil is a major factor. The refineries to be built will have to take into account the constant decrease in the demand for heavy products, because of price and the need to reduce pollution. The shift of ships to use of low sulfur fuels, which became mandatory in 2020, illustrates this perspective. New refineries will also face increasingly stringent specifications for light products.

Refineries will benefit from a favorable factor, rarely anticipated by forecasters. While in the 70s and 80s it seemed inevitable that the oils to be discovered would be increasingly heavy and sulfurous, this trend never materialized. For example, the crude oils found in Saudi Arabia after the discoveries of the large deposits around the Second World War were lighter than the oils of the first discoveries. Of course, the massive production of shale oil, called Light Tight Oil because their density (API degree between 40 and 45) is very low, goes in the same direction. The development of refining will no doubt be limited by the uncertain future of demand for petroleum products. Why build a refinery today if demand is to decline in 20 or 30 years?

The economic situation of refining is however better today than it was 30 years ago. The recurring weakness of margins—and profits—in the 1980s led to restructurings that paid off. We can therefore expect a slow but certain evolution toward refineries on average larger and more sophisticated, with a fair profitability.

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