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Risk Management of Oil Refinery

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Risk Management of Oil Refinery

by

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Abstract

Risk Management of Oil Refinery

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Every business faces risks and the first step in managing risk is making an inventory of the risks that a business faces and getting measure of the exposure to each risk. There are several risks that can affect an oil refinery. Generally recognized risks related to refineries are as follows: crude oil price, crack spread, marketing margin, sales volume, exchange rate, costs, credit and counterparty risk, and hazard risk. In this thesis, among these risk factors, major market price variables, such as crude oil price and crack spread, are regarded as risks or simulation variables; some of the other risks, such as marketing margin, utilization rate, and energy cost, are treated as uncertainties; the others are excluded or fixed. This thesis develops a hypothetical refinery financial model that reasonably approximates real models encountered in practice. To measure the impacts of risk factors on the refinery, three criteria are adopted; present value of net income for ten years, present value of net cash flow, and return on capital employed (ROCE). For sensitivity analysis, five variables are selected: crude oil price, crack spread, marketing margin, utilization rate, and energy cost. In order to measure the risk exposure of an oil refinery, this thesis makes Monte Carlo simulation 10,000 times, by using @RISK software.

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1. INTRODUCTION

For a long time, the benchmark refining margin in Europe has been volatile and low to negative since the downturn began in 2009. As a result, many refiners have reported minimum returns or cash losses, while still having to fund investment. The main reason is that high and volatile oil prices have increased the cost and risk of funding crude oils and products that refiners need to operate. All of this has played out in the context of a tight market in Europe for the dollar-based lending that is critical to this funding. Despite these pressures, refining capacity reductions have been slow to come, with only a handful of sites shutting down permanently, a few sites mothballed and a few seeing reduced operations.

However, restructuring in refining, in a wider sense of revisiting the value chain, is not easy, and demands that a number of different parties revisit their assessment of risk and returns. A key part of this challenge is the fact that understanding between different parties, particularly between refiners and traders, remains poor.

This situation shows that oil refineries are already facing a high risk environment. In order to cope with this risk, several questions should be asked: what are important risk factors, how volatile is each risks, and how strong is the impact of the risk?

In the light of these questions, this thesis aims to analyze risk factors of an oil refinery, and make simulations of its performance in order to measure the impacts of risks. In addition, this thesis develops a financial model of an oil refinery for analysis and simulation. For a better understanding of the refining industry, chapter 2 describes crude oil market including the properties of crude oil, crude benchmarks and pricing, and economic fundamentals. Chapter 3 consists of refining process, refining margin, global product market, and marketing and sales. Chapter 4 builds a financial model of an oil refinery. Chapter 5 analyzes risk factors and makes simulations. Finally, chapter 6 draws conclusions concerning risk management of oil refinery.

2. CRUDE OIL MARKET

2.1 Properties and Qualities

Oil is not a homogenous substance but a mixture of different hydrocarbons with physical and chemical differences related to the number of atoms of carbon and hydrogen in each molecule, and the structure of the molecules, which is the way the atoms of carbon and hydrogen are bonded together. Crudes produced in different locations have qualities dependent upon the proportions of different hydrocarbons and the presence of other substances, which are usually seen as contaminants often requiring complex and expensive processes of removal and disposal. Therefore, each crude oil is different from every other crude oil, although these oils can often be grouped into similar categories of crude oil based on certain properties, such as crude density, sulfur content, and acid content.

Crude	Light	Intermediate	Heavy
Sweet	S < 0.5%, API>31.1	S < 0.5%, 22.3 < API < 31.1	S < 0.5%, API < 22.3
Intermediate	0.5% < S < 2.5%, API > 31.1	0.5% < S < 2.5%, 22.3 < API < 31.1	0.5% < S < 2.5%, API < 22.3
Sour	S > 2.5%, API > 31.1	S > 2.5%, 22.3 < API < 31.1	S > 2.5%, API < 22.3

Table 1: Classification of different crude oils

The two most important qualities of crude oil are viscosity (thickness or density) and sulfur content. Crude oils with lower density are called light crude and usually yield a higher proportion of more valuable final refined products, such as gasoline and other light petroleum products. Their density or weight compared to water is measured by API (American Petroleum Institute) gravity. A crude oil with an API gravity below 10 is heavier than water; if it is above 10, it is lighter than water. Heavy crude oils have a lower share of light hydrocarbons and require more complex refining processes to produce similar proportions of more valuable products. Although sulfur is a naturally occurring element in crude oil, it is an undesirable property. The greater the sulfur content, the more costly the refining process to remove it. Crude oils with high sulfur content are referred as sour crudes, while those with a low sulfur content are known as sweet crudes.

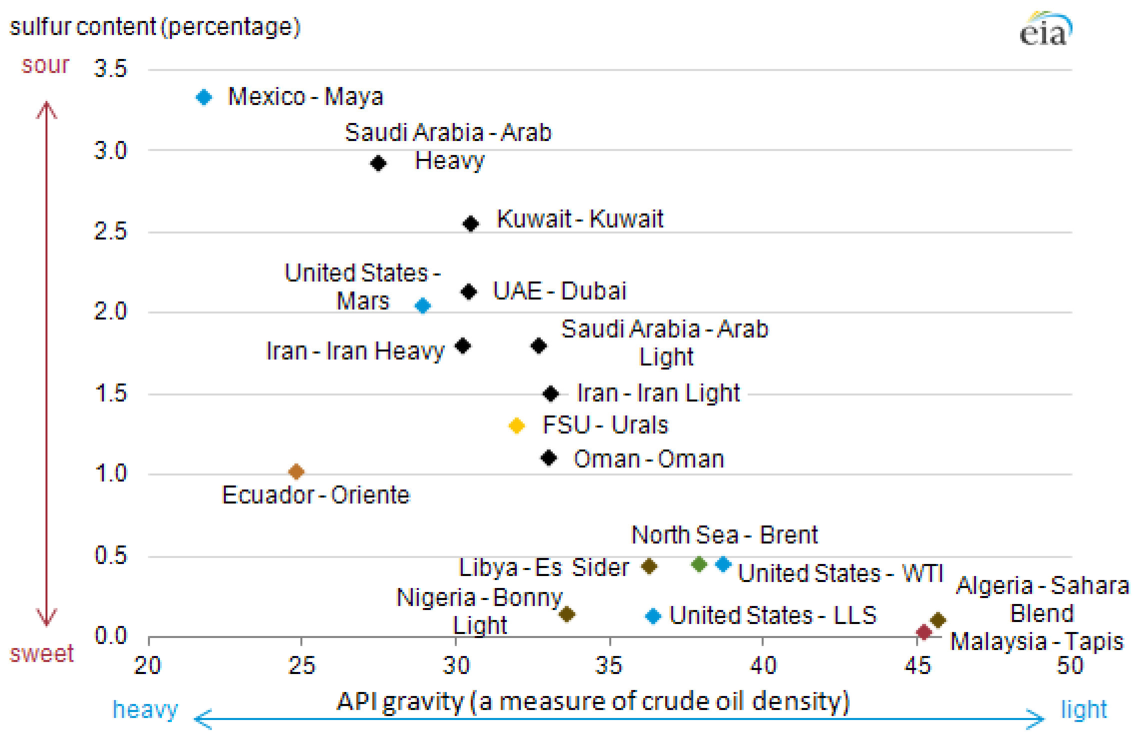

Figure 1: Density & sulfur content of selected crude oils (Crude oils have different quality characteristics, 2012)

2.2 CRUDE OIL PRICE

The properties of any individual crude oil allow it to be valued based upon how it would be processed through different refinery types. The physical components of industry infrastructure such as refineries, pipelines, and tankers are optimized for processing and transporting certain types of crude and products. A typical refinery, for example, is configured to process certain types of crudes and, if a combination of inputs with different qualities has to be used, profits will be reduced. Therefore, the value of any particular crude to one refinery is different to the value of that crude to another refinery. Also the value of any particular crude to a refiner is different with regard to its price.

In general, crude oil prices across the globe vary based upon the demand for a particular crude type, the amount of supply of that type of crude, the ease or difficulty in processing the crude, and the freight cost of moving the crude from supply source to consuming region. Thus a crude oil that more easily produces proportionally higher quantities of desired high value light products such as gasoline and diesel will usually command a higher price than a crude oil that produces more low value heavy products such as fuel oil.

Aside from crude oil quality, international crude oil prices differ from region to region based upon the freight rates needed to deliver crude from one region to another. Although in theory any crude oil can be delivered to any global location, usually crude oils produced in regions that are short of crude oil remain in that region, while crude oils produced in regions that have a surplus of crude oil are exported to other regions with shortages. For example, the Middle East region has a significant crude oil surplus and delivers crude to North America, Europe, India, and Asia. North African crudes are delivered to Mediterranean Europe; West African crudes are sent to Northern Europe and North America.

As a result of this global trade in crude oils, crude oil prices across the globe are linked to each other, with price variations for the same crude in different regions set by freight differentials. Provided adequate logistics exist to deliver the crude to markets, the market is self-adjusting - if a surplus of crude in one region starts to push the price down, the lower price makes the crude more attractive in another region and it will be transported to other regions, tightening the supply in the source region and bringing the price up. Over time, a degree of equilibrium pricing develops between regions for different crudes.

2.3 Crude Benchmarks and Pricing

As there are so many different crude oils, marker or benchmark crudes have been developed to enable easier pricing of different crudes for both sellers and buyers. Well known marker crudes are West Texas Intermediate (U.S.), Dated Brent (North Sea), and Dubai (Middle East). These benchmark crudes developed because they were high liquid crudes, at least originally having high production rates, so they were freely available to multiple buyers and sellers.

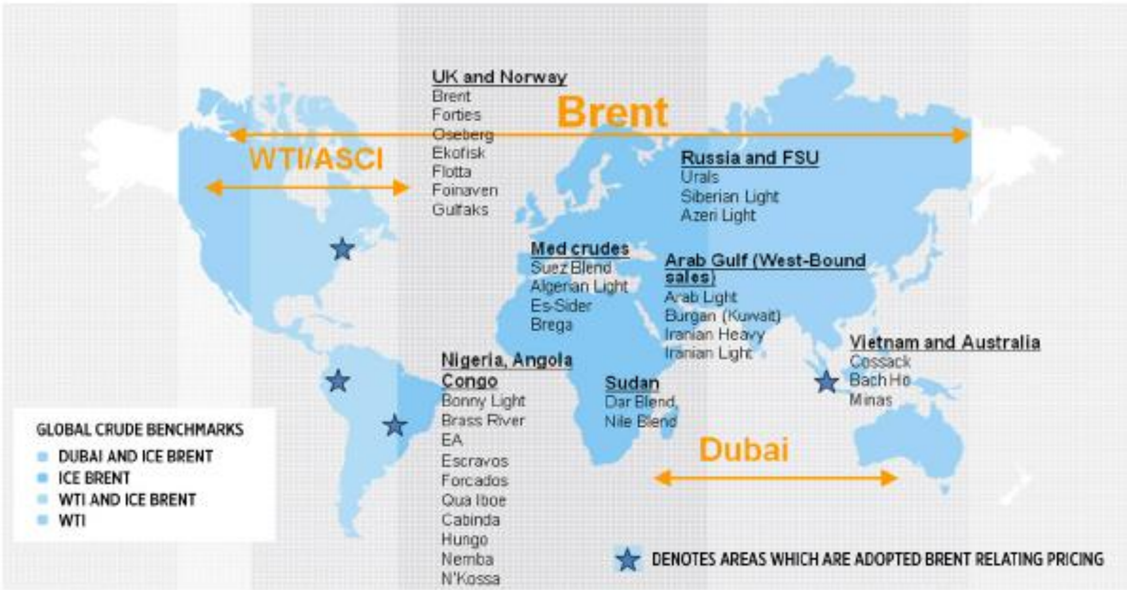

Figure 2: Crude oil pricing worldwide (IntercontinentalExchange(ICE))

Prices of crude are generally quoted for free on board (FOB) at their loading port. Most physical crude oil is priced as a differential to an actively traded futures or forward market. Instead of buyer and seller agreeing on an absolute price for the crude oil cargo, they agree on a floating price, which is generally an average of several days' price around the bill of loading date. Most oil traded in Europe and many West African crudes, for example, are priced against Brent, while almost all crude exported to the U.S., or traded within it, is priced against Nymex futures. In the short-term, the crude oil market is the trendsetter for other energy markets; it is highly sensitive to OPEC rhetoric, to the general economic environment, and to political events or uncertainties.

2.4 Historical Crude Oil Price

To understand the crude oil market, it is important to briefly review the chronology of the oil markets over the years, analyzing the key events that have eventually led to the infrastructure of oil trading we see in the markets today. For the purpose of this study, the timeline will begin in 1970; since that time, some of the most volatile changes have occurred with respect to absolute price trends and with respect to the relationships among the regional crude benchmarks, including WTI.

Over the years, there have been quite a number of significant events that have caused short term volatility in the markets. Figure 3 summarizes the markets from 1970 to the current time in mid-2014, showing many of the most significant events. Some of these events, however, are more important than others, actually changing the course of trade dynamics and/or pricing relationships among grades for the long term. Some of the most prominent events are highlighted in red text on the figure.

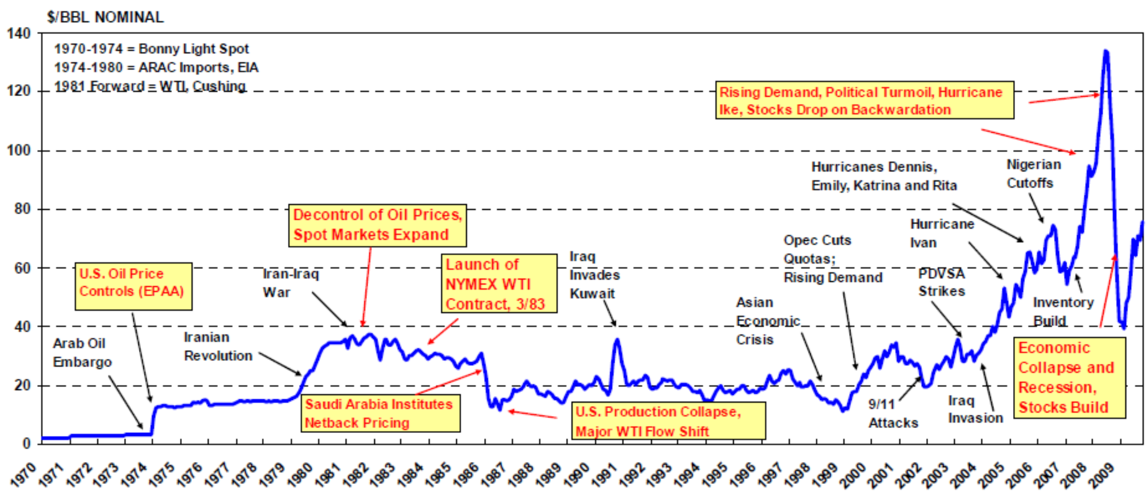

Figure 3: Crude oil price history (U.S. Energy Information Administration(eia), 2014)

Through the 1970s, the markets had extended periods of relative stability. However, there were two major events during that decade that drastically changed the oil market environment, bringing focus to the potential for extreme oscillations in energy trade that had not had such relevance for quite a number of years prior. Though OPEC began raising prices early in the decade, resulting in the U.S. instituting price controls (Emergency Petroleum Allocation Act, EPAA) in 1973, it was the politically-motivated Arab Oil Embargo in mid- to late-1973 that initiated those controls. This had a profound and immediate impact on oil prices. Average prices for oil rose from near $3 per barrel to over $13 per barrel within a few months, ushering in more protective controls by the U.S. The markets would never again see prices as low as those existing during the early 1970s and prior to.

After the major political events aforementioned, oil prices continued to rise, reaching a peak in early 1981 near $37 per barrel in nominal terms, which was a response to the onset of the Iran/Iraq war that was to last from 1980 for almost eight years. That peak, now reflecting actual industry-quoted physical WTI spot prices in the data series, was not to be repeated until late 2004 in nominal dollar terms. In constant 2009 dollar terms, though, that peak was near $78 per barrel, which was not reached again until early 2008.

Following the crude oil market disruptions in 1986, prices of WTI crude oil experienced a period of relative stability through about 2003. This is not to say that there were not periods of extensive volatility on a short term basis during that span, especially late in the millennium during the Asian financial crisis that globally impacted petroleum demand. From a low in 1986 of about $11.5 per barrel for WTI during the bottom of that downturn, prices generally oscillated around the $20 per barrel range for most of this defined period. In fact, OPEC attempted to revive the administered price system again in 1987 due to severe impacts on the markets of their internal competitive price war, but OPEC's attempts were not sustainable and WTI prices fell from their mid-1987 peaks of about $20/bbl to below $15 per barrel through the next year or so.

From 1988 to about mid-1990, prices averaged in the $20 per barrel range, and the markets were relatively quiet. But, in August of 1990, Iraq invaded Kuwait. The natural reaction of the markets at that point was to assume the worst case scenario of major supply disruptions; this resulted in a strong spike in crude oil prices. The initial spike was short-lived, as OPEC quickly worked within the group toward increasing production wherever possible to replace the roughly four million barrels per day of lost supply. The additional supply from Saudi Arabia and Venezuela was largely heavier grades, which, at that time, led to quite significant changes in the premiums for sweet crudes globally.

Beyond this point and into the early part of the next year, the markets were unsettled as negotiations with Iraq were fruitless. On January 16, 1991, the U.S. began its successful air attacks on Iraq and with the announcement of a large release of Strategic Petroleum Reserve (SPR) oil by President George H.W. Bush, prices dropped almost $10 per barrel after having gained about $5 per barrel earlier in the month as the confrontation with Iraq intensified. From this point forward through early 1997, prices, from an overall perspective, were relatively stable, oscillating around the $20 per barrel level. Through this period, there were of course periods of geopolitical turmoil, mostly involving the aftermath of the Iraqi war with the recalcitrant attitude of the Iraqi regime.

2004 began with prices in the $35 per barrel range. But by October of that year they had peaked near $55 per barrel. Prices had already reached all-time records that June, as multiple terrorist attacks on Saudi Arabian government facilities exacerbated already anxious markets. OPEC attempted to curtail rises through continuing quota adjustments, to no avail. Demand for petroleum during the year also grew significantly, led by unexpected strength in China, and the tightness in supply and productive capabilities that were starting to appear raised market anxiety further, especially in light of these geopolitical disruptions.

Price trends, however, have been most volatile recently, especially during the time period of 2005 to 2009, achieving never-before-experienced price range movements and record-setting highs before a major collapse in early 2009. From a proportional perspective, the markets had not seen these levels of volatility since the 1986 price crash, and prior to that, the Iranian revolution of 1979 and the Arab Embargo of 1973.

In the early part of 2004, WTI prices hovered in the mid-$30s per barrel, but beyond this point prices began an almost uninterrupted upward track to all-time highs well over $130 per barrel on a monthly average basis in late 2008, with peaks approaching $150 per barrel on a daily basis. This trend was perpetuated by an environment of strong demand early in this period, and was supported by tight productive capacity availability, leaving the markets extremely vulnerable to upsets in a politically-charged, global geopolitical atmosphere. The economic downturn resulted in a rapid price collapse from the $130s per barrel in mid- 2008 to a low of $40 per barrel by January 2009. Actual daily lows were in the mid $30s per barrel for a brief period before some stabilization lead to a return to the $50 per barrel range by mid- year and then back to the $70 per barrel range by the third quarter. At the time of this writing, volatility is expected to continue, particularly in the short- to medium-term given the economic environment and its affect on demand, refinery runs, and trade flows.

2.5 Market Dynamics

The following section presents the economic fundamentals of the crude oil market. It is necessary to understand the whole story of crude oil price within this frame. Ultimately, crude oil prices are determined by two factors: in the long term, by the cost of finding and bringing oil reserves to market and, in the short term, by the supply/demand balance and the actual or perceived tightness of the market in regards to its ability to supply crude and feedstock of different grades to meet product demand (FattouhBassam, 2011).

Under the assumption that production and consumption capacities are considered to be fixed, Figure 4 showed the short-term equilibrium of the oil market. The supply curve stands for total production costs for existing oil fields and displays economic rents due to the relative ease of extraction of crude oil and the proximity to refining centers. Also the vertical shape of the demand curve indicates that the responsiveness of demand to changes in price is inelastic. In the short run, neither supply nor demand is particularly responsive to changes in price, because oil still has no effective substitute as transportation fuel. Moreover, since oil demand usually magnifies economic growth, the vertical curve on Figure 4 is liable to move violently to the left or to the right over the course of a few months.

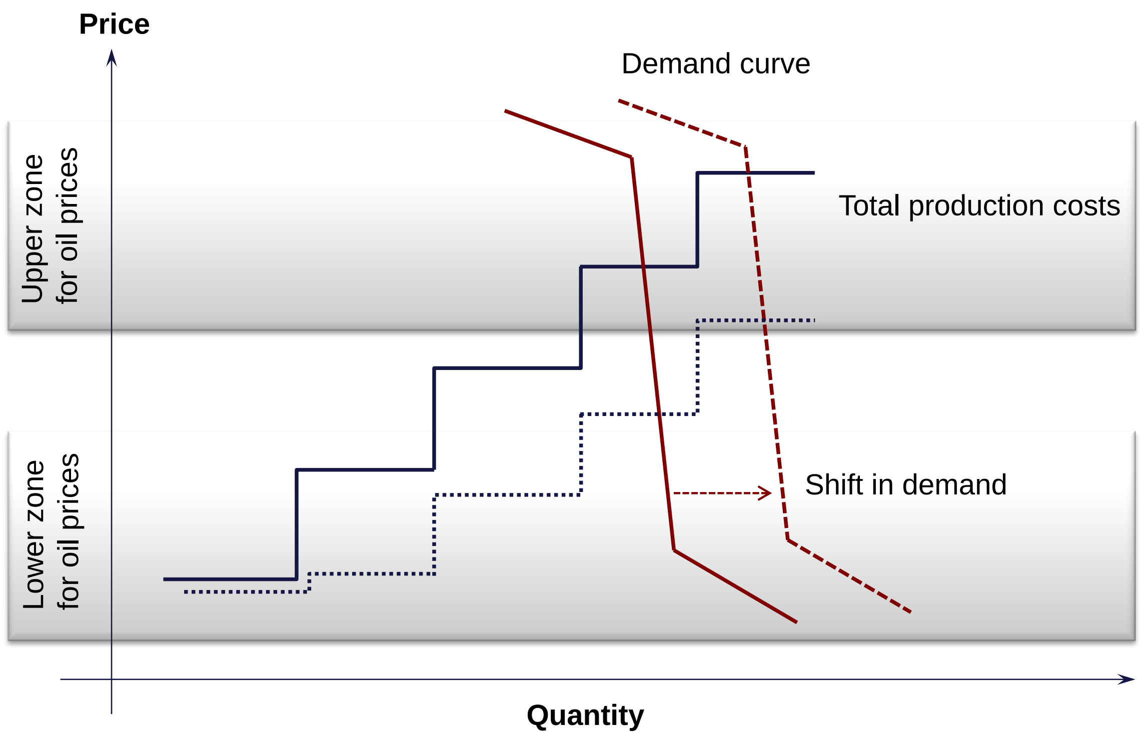

Figure 4: Short-term supply/demand of crude oil market

In a purely competitive market, when production or transportation capacities are close to saturation and demand soars, oil prices would need to reach a fairly high level before return forces would become effective, such as substitution with coal or natural gas in power stations, a marginal increase in production for wells with flexibility in supply volume, or public measures for energy conservation. At its onset, a price hike is self-realizing as it triggers a cautionary demand for stocks, which in turn enhances the original imbalance. Thus, the high price will provoke investments in new production facilities and so cannot be maintained permanently. The required time to build new fields would result in an over-capacity in the upstream sector one to two years later. Conversely, when production exceeds consumption, stocks usually build up and the situation may degenerate into a price war if, in the absence of an agreement between producing countries, any one of them tries to expand its market share at the expense of the others. Since the oil industry is capital-intensive, if the market were completely free, reductions in output should happen only when prices fall below the operating costs of marginal units. When this level is reached, exploration programs are scaled down, wells are ultimately shut down, and the demand side benefits from this substitution favoring oil. As consequence, prices should fluctuate wildly between an upper and a lower zone whose limits are determined by purely economic constraints.

However, the real oil market is not purely competitive. Since the Middle East contains two-thirds of the world's proven reserves and produces approximately a third of total consumption, and the production cost, furthermore, is significantly cheaper and more flexible in this region than almost anywhere else in the world, main producers such as Saudi Arabia, Iran, UAE, Iraq, and Kuwait can operate swing capacities that can be closed well before prices drop below the variable costs of marginal units, and reactivated when demand suddenly peaks. Over the past twenty years, the E&P cost outside of the Middle East has been significantly lowered. Thus, in recent years, OPEC seems not to be able to prop up oil prices but it still has the potential capability to intervene in the market. The resulting situation is summarized in Figure 4.

The dynamic consumption curve relates the rate of increase of worldwide consumption to the long-term oil price: it shifts to the right when economic growth increases; it is bounded upward by the price of substitutes and thus becomes flatter when alternative technologies find their way into the market. The dynamic supply curve (S_2) gives the rate of increase of oil output at a given market price if low-cost producing countries decide to satisfy consumption increments entirely on their own, without any agreement among them. The dynamic supply curve (S_1) is identical to (S_2), except that it assumes that new developments are carried out only by means of price takers' reserves.

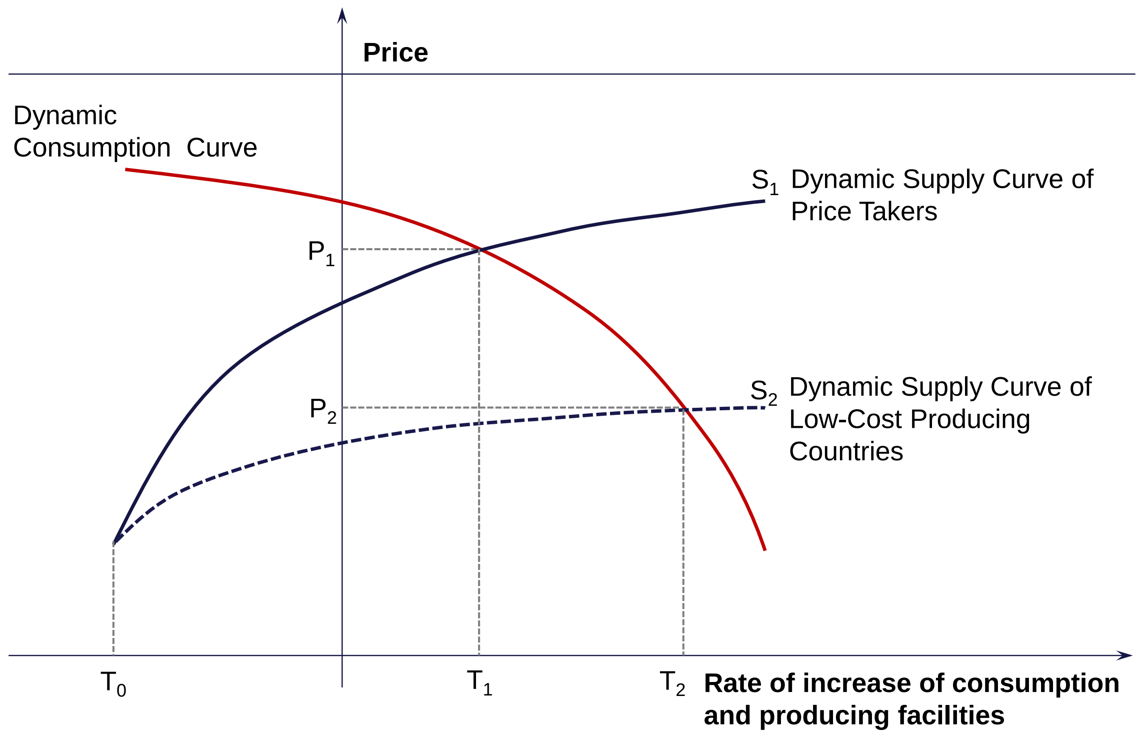

Figure 5: Long-term dynamics of crude oil market

This defines an economic range of prices where low-cost producing countries can attempt to stabilize the market price of oil by varying the development rate of their own reserves. The floor of this range would be reached only if low-cost participants were acting on a purely competitive basis; below this level, an oil shock would be inevitable. On the contrary, if they tried to impose a market price above the ceiling of the range, new developments in the oil industry would only take place in the price takers' reserves and OPEC's market share would steadily decrease.

Thus, from an economic standpoint, there exists an equilibrium range wherein political factors can durably exert their influence on oil prices by political factors, such as stability in the Middle East, security of supply of importing countries, or pace of development of the Gulf States. These secondary factors can themselves contribute to delimiting the variation range of oil prices.

3. REFINING INDUSTRY

Refinery size is measured by crude distillation capacity, which in turn is measured in either barrels per day or tonnes per year. Average size, driven by economies of scale, has been increasing gradually over time. In general, export refineries need to be low cost, and are larger than inland refineries, which supply a specific market and usually have a natural distribution advantage. Typically, a large refinery is over 400 kb/d (20 mtpa); the world's largest refinery complex, Cardon/Judibana in Venezuela, has a capacity of 940kb/d (47 mtpa).

A refinery's configuration is determined largely by its location, i.e, the product demand in its immediate area or its export markets. Petroleum product demands differ significantly: poor countries generally demand heavier fuel oil for electricity generation and ship fuel and have lower environmental standards, meaning that end-products are relatively and loosely specified and easier to manufacture. Over time, rich countries have developed stringent quality standards for light product fuels, resulting in demand that refiners manufacture products with consistently high specifications and low pollution.

Refinery profitability is generally related to multiple markets: supply of crude oil, demand for light products, and demand for heavy products. In general, refining margins rise when oil product demand is strong and supply of oil is relatively abundant, and drop if demand is weak and supply is constrained.

3.1 REFINING PROCESS

Crude oil almost always needs to be processed prior to consumption. The refining process separates crude oil into useable finished products for transportation, residential and commercial heating, power generation, petrochemical production, and asphalt formation. Refining is what gives oil value to end-customers.

Primary refining units fall into three processing categories: separation, conversion, and treatment. The initial stage of a refining run involves the heating and separation of crude oil into its components. Therefore, once the fractionations of crude oil are separated, they are directed to various conversion units to be chemically altered through the introduction of heat, pressure, catalysts, or hydrogen. The output of these conversion units is then subsequently treated or blended.

In order to process crude oil, a refinery needs a crude distillation unit (CDU) which separates the oil into its different components (fractions). The profit from simple distillation in a CDU is generally close to zero, and a refinery derives most of its profitability from the subsequent processing units. By boiling crude oil, in the process that the larger, longer, or heavier hydrocarbon molecules are lower down the distillation column and the lighter, shorter, or smaller molecules are higher up the column, distillation splits the oil into its component fractions.

After crude oil is separated into its fractions, each stream is further converted by changing the size and structure of the molecules through cracking, reforming, and other conversion processes. The converted products are then subjected to various treatment and separation processes to remove undesirable constituents and improve product quality.

Oil refining produces a wide variety of products that are used daily: gasoline for motor vehicles, kerosene, jet fuel, diesel, and heating oil. Petroleum products are also used in the manufacture of rubber, nylon, and plastics.

3.1.1 Petroleum Products

Different types of refineries and different crudes will produce different product yields. The configuration or level of sophistication refers to the extent to which crude oil is processed. The greater the number of processes, the more sophisticated the refinery, and the more value they add to the end-product. The following is the major product categories (in ascending order of molecular weight).

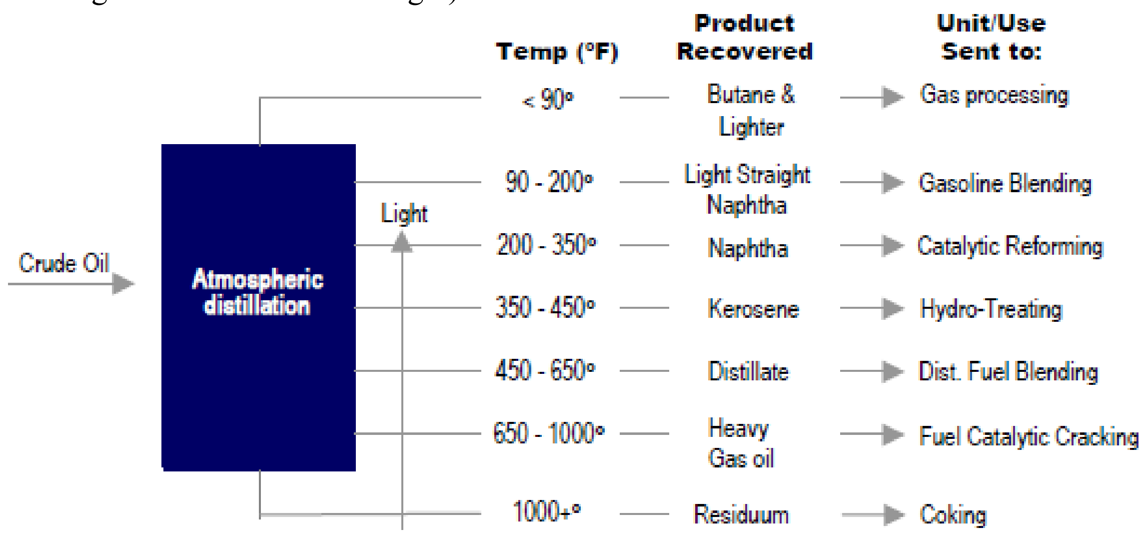

Figure 6: Crude distillation and products (Rigby, et al., 2008)

Liquefied petroleum gas (LPG), petrochemical feedstock, is the output of finished products at the lightest end of the distillation range and can vary greatly, depending on the refinery's sophistication. The gaseous products at the upper end of the distillation curve can be reprocessed into high-quality gasoline components, sold as heating or transportation fuels, upgraded into higher value petrochemical products, or simply burned as a refinery fuel source. Propane and butane are both termed LPG, and can also be produced from reforming and cracking. Once distilled, LPGs are liquefied and sold in bottles for cooking fuel, used for gasoline blending, or used as ethylene steam cracker feedstock to manufacture base chemicals. Heavier products such as naphtha, essentially untreated gasoline, are primary feedstock for the petrochemical industry in Europe and parts of Asia – in the US and Middle East, petrochemical units use natural gas as a feedstock.

Gasoline, the primary transportation fuel of the OECD, is favored in developed nations for its superior combustion and low pollution characteristics. Finished gasoline is composed of straight run gasoline from the distillation column, treated naphtha from reformer, treated cracked gas oil from cat cracker or hydrocracker, alkylate, isomerate, and blending components which are primarily ethers. These gasoline pool constituents are blended together to achieve the desired balance of engine performance and emission reductions. Increasingly stringent European and North American gasoline specifications require a growing degree of sophistication among gasoline-producing refiners.

Kerosene, the original refined product of jet fuel, space heating, and cooking oil, falls within the lightest distillate class, with a boiling range of approximately 160° to 270°C. Kerosene was originally used to replace whale oil as an illuminant, and, over time, its use was adapted for cooking and space heating needs. Today, kerosene is primarily consumed in jet and turbine engines. Kerosene's volatility and pour point fall between that of gasoline and diesel fuel. It is important for jet fuel to maintain very consistent ignition and physical flow characteristics over a broad range of atmospheric conditions. A high flash-point prevents premature explosions in overheated airplane tanks and bullet-compromised tanks in military aircraft, while a low pour point ensures that the jet fuel flows to the engines under subzero temperatures at high altitude. The purity and low smoke requirements of jet fuel necessitate extensive hydrotreating. Primary sources of finished jet fuel are hydrotreated straightrun kerosene and hydrocracked gas oil.

Distillate fuel oil, also known as gas oil, diesel, or heating oil, have a boiling range of 190° to 340°C. Different grades are used for transportation, residential heating, light industrial and commercial uses, and as a feedstock for secondary processing units and petrochemical plants. Mid-range diesel fuels are primarily differentiated by ignition quality (cetane number) and sulfur content. On-road diesel fuel has a higher cetane number (low self-ignition temperature) and a lower sulfur content than heating oil. Higher cetane grades offer better cold-starting characteristics and reduced smoke emissions. Sulfur reduction is the primary focus of environmental regulation for middle distillates, and has become particularly important in Europe, as sulfur content is effectively being regulated at a level close to zero. Sulfur reduction is primarily achieved through hydrotreating.

Residual fuel oil, also known as fuel oil or bunker fuel and often referred to simply as resid, is the heaviest, most contaminated constituent of crude oil. In fact, it is the only cut that is not vaporized in the distillation column. Resid is the heavy ‘residual’ liquid drained off from the bottom of the distillation tower at the tailend of the distillation process. Residual fuel reigned supreme during the early periods of centralized, pollution-insensitive industrial development. Heavy industrial, utility, and shipping concerns prized resid for its high caloric content, low volatility, and ease of transportation and storage. Unfortunately, the majority of crude oil’s sulfur and heavy metals reside within the residual boiling range. These contaminants, along with resid’s inherently low hydrogen to carbon ratio, conspire to make residual fuel the most polluting of all petroleum products, rendering its combustion undesirable in most developed economies.

3.1.2 Cracking Conversion Processes

Cracking is a conversion process that can employ individually, or in unison, heat, pressure, chemical catalysts, and hydrogen and is used to promote chemical change and reduce the molecular structure of hydrocarbon molecules. The result of cracking is a reduction in the average size of molecules, creating an expansion of the resulting volume -

meaning that the kb/d output of a cracking unit is higher than the kb/d input. The cracking process essentially breaks up heavier high boiling-range feedstock like heavy gas oils and residue into lighter products such as gasoline, liquid petroleum gases (LPGs), and light distillates.

There are three main cracking processes: catalytic cracking, hydrocracking, and thermal cracking (coking). The fluid catalytic cracker (FCC) utilizes heat, pressure and a metallic catalyst to convert heavy straight-run gas oils and vacuum gas oils into gasoline. Cat crackers are used extensively in the gasoline leveraged markets of North America and Western Europe. Cat crackers are also a primary source of olefins (chemical feedstocks). A major problem with cat gasoline is its high sulfur content. Sulfur regulations in Europe and the United States require significant and potentially expensive hydrotreating of either the cat gasoline itself or some of the gas oil streams that are fed into the front end of the unit.

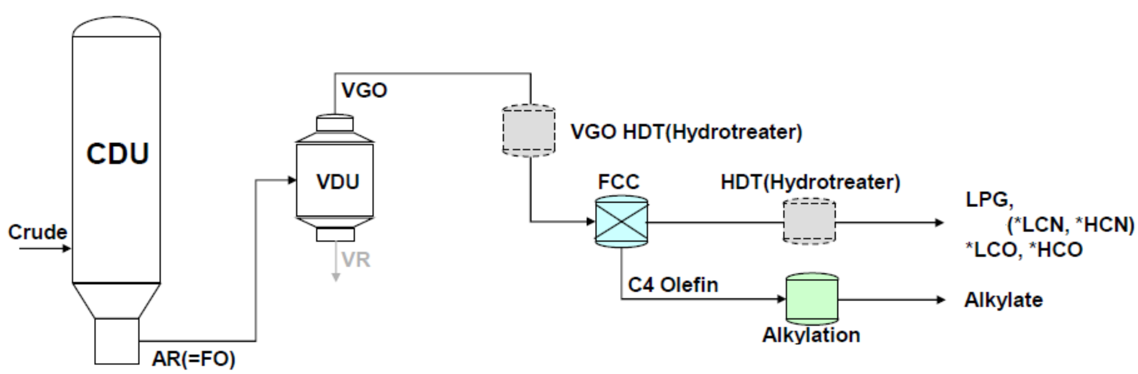

Figure 7: Process diagram of FCC (GS Caltex, 2010)

Catalytic cracking is a hydrogen-deficient operation, generating highly sulfuric and aromatic products. These harmful compounds require further blending and treatment for environmental compliance. The hydrocracker addresses this problem by introducing hydrogen into the cracking process. In addition to producing cleaner final products, hydrocrackers offer greater processing flexibility than do standard FCCs. A hydrocracker can be optimized for gasoline production (yielding 110% of feed, by volume), jet fuel production (70%), or diesel production (85%). This flexibility, of course, comes at a price: the high expense of a stand-alone hydrocracker and its associated hydrogen-generating infrastructure, generally make it the costliest facility in a refinery.

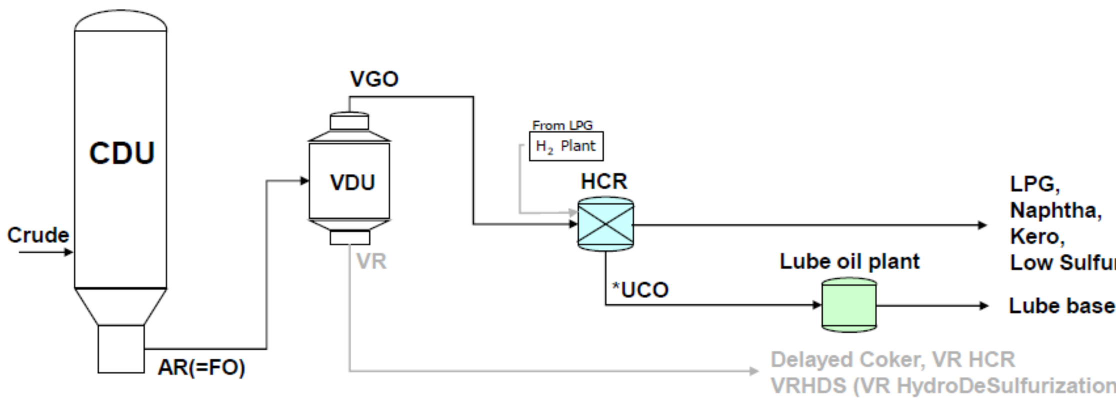

Figure 8: Process diagram of AR hydrocracker (GS Caltex, 2010)

In thermal cracking, hydrocarbons are heated, sometimes under high pressure, resulting in decomposition of heavier hydrocarbons. Thermal cracking may use steam cracking, coking (a severe form of cracking that uses the heaviest output of distillation to produce lighter products and petroleum coke), and visbreaking (a mild form of cracking where hydrocarbons are quenched with cool gasoil to prevent over-cracking, and it is used for reducing viscosity without affecting the boiling point range).

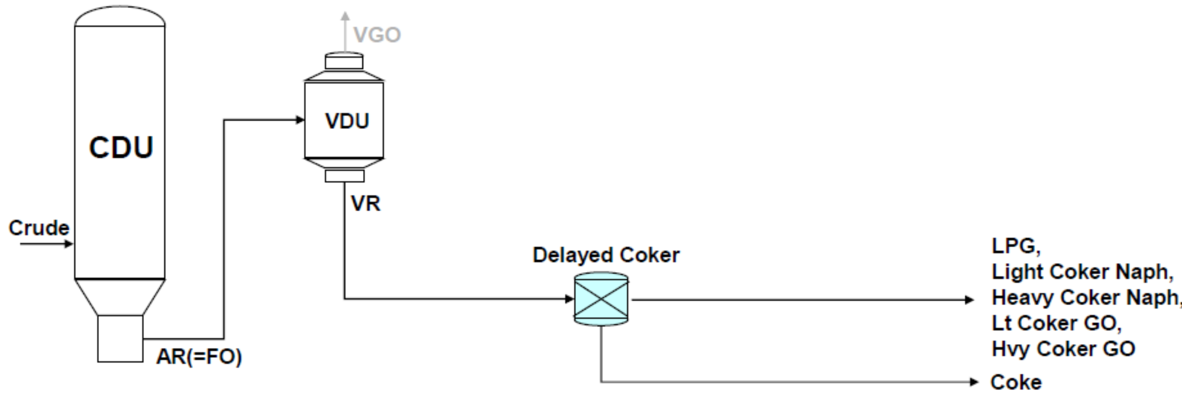

Figure 9: Process diagram of delayed coking (GS Caltex, 2010)

The coking process reduces the yield of low-value heavy products. Coking is the most severe form of thermal cracking, and can eliminate 100% of the residual oil feed. The process employs great heat at a moderate pressure to convert fuel oil into naphtha, gas oils and coke. The process is designed to produce maximum yields of transportation fuels and can be used where there is little or no fuel oil demand. However, the coking process is very expensive, and can increase overall plant operating costs by up to 20% per barrel.

In a comparison between catalytic cracking and hydrocracking, which are most popular, FCC is used to produce gasoline whilst hydrocracking is used to increase distillate yields. In catalytic cracking the heavy distillate (gasoil) undergoes chemical breakdown under controlled heat (450-500°C) and pressure in the presence of a catalyst, a substance which promotes the reaction without itself being chemically changed, such as silica. Fluid catalytic cracking (FCC) uses a catalyst in the form of a very fine powder, which is maintained in an aerated or fluidized state by oil vapors. Feedstock entering the process immediately meets a stream of very hot catalyst and vaporizes. Hydrocracking uses hydrogen as a catalyst.

The main reason that refineries build conversion units is that worldwide crude slate has become heavier, which has caused an increase in the concentration of sulfur and other contaminants. However, sulfur specifications are becoming more stringent. In addition, demand for fuel oil is declining because of environmental issues. In terms of economics, the hydroskimming refinery, which does not have any conversion unit, could not survive because of the increasing cost of light crude relative to heavy crude. In summary, to meet the demand of light products, protect the environment, and survive economically, a refinery has to build conversion units.

3.2 TYPES OF REFINERIES

Refineries are often classified into five categories according to their complexity: Basic or topping, hydroskimming, cracking, coking, and full conversion. Basic or topping refineries simply separate the components of crude oil into various products by distillation. Hydroskimming refineries conduct the basic separation process done by topping facilities but also have naphtha reformers. These reformers generate hydrogen, which can be "skimmed off" for use in desulfurization units, such as hydrotreaters. Cracking refineries have catalytic cracking units, FCC or hydrocracker, in addition to modules, such as an alkylation plant, that can increase the yield of higher value products, such as gasoline or diesel. Coking refineries have the same capabilities as cracking refineries but also have cokers that turn heavy vacuum residue into higher value products. A full-conversion (or complex) refinery is essentially a petrochemical plant coupled with an oil refinery. Such a facility not only has all the capabilities of a coking refinery but also has a steam cracker, which is used to produce ethylene and propylene, the building blocks for producing most plastics.

A typical product yield or a refinery's product slate, the proportion of refined products obtained by refining one barrel of crude, obtained from each type of refinery is shown in the figure below. This yield reflects both the refineries configuration and, because all crude oils differ in their hydrocarbon composition, also the type of crude oil that is processed. The majority of world refinery is cracking refinery, and more complex refineries are increasing in share.

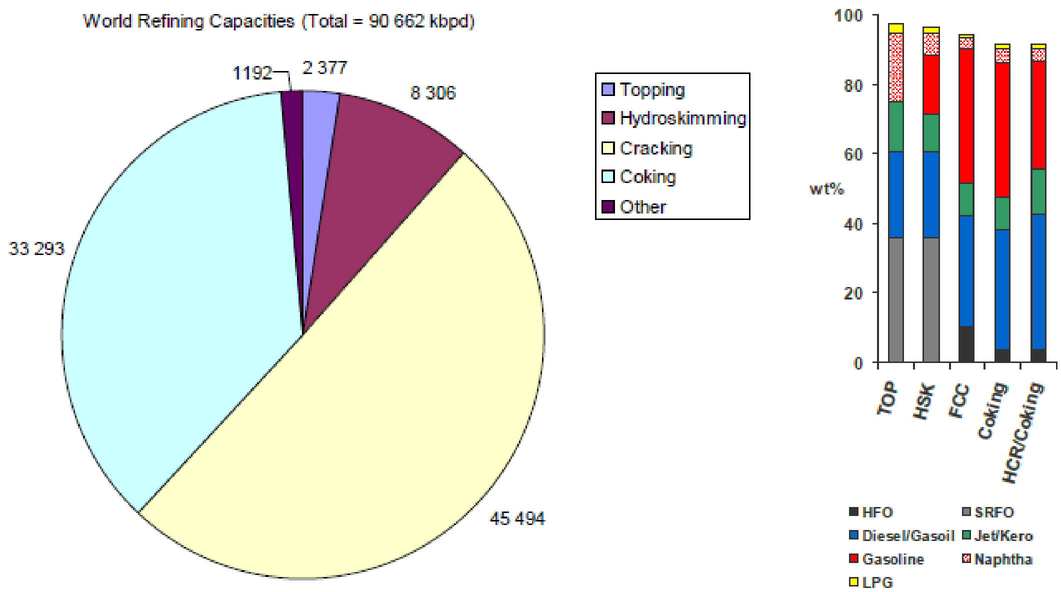

Figure 10: World refining capacities & Yield (KjetilHauge, 2010)

3.3 Refining Margin

To understand refining profitability, several factors need to be considered: Refining is a capital-intensive process, which means that circumstances impacting the availability or allocation of capital to the industry can have a major impact on industry profitability; crude oil is the major variable cost in refining, and this cost is set by world markets; labor, energy, and other operating costs are a small percentage of total costs but receive a lot of attention because they are controllable by refiners; regulatory costs, such as environmental mandates, play a major role in overall refining costs; and most of the products produced by a refinery are commodities or commodity-like.

Oil refining is a capital-intensive business. Planning, designing, obtaining permits to build, and building a new medium-sized refinery is a five to seven year process, and costs $7-10 billion, not counting land acquisition. Cost varies depending on location, which determines land and construction costs, the type of crude to be processed, the range of outputs, the size of the plant, and local environmental regulations. Adding new capacity or complexity to an existing refinery is also expensive.

After the refinery is built, it is expensive to operate. Fixed costs include personnel, maintenance, insurance, administration, and depreciation. Variable costs include crude feedstock, chemicals and additives, catalysts, maintenance, utilities, and purchased energy such as natural gas and electricity. To be economically viable, the refinery must keep operating costs such as energy, labor and maintenance to a minimum. Like most other commodity processors, such as food, lumber and metals, oil refiners are price takers: in setting their individual prices, they adapt to market prices.

Since refineries have little or no influence over the price of their input or their output, they must rely on operational efficiency for their competitive edge. Efficiency is measured by the ratio of output to input, and increases through constant innovation, upgrading, and optimization to produce more output from fewer input - in other words, the refinery's capacity to maximize the difference between the cost of the crude oil and the price received for its refined products (the refinery's gross margin).

Because refining is caught between the volatile market segments of cost and price, it is exposed to significant risks. As Herrman observed, refining is "low return, low growth, capital-intensive, politically sensitive and environmentally uncertain" (HerrmannLucas, DunphyElaine, CopusJonathan, Oil & Gas for Beginners: A guide to the oil & gas industry, 2010). A refinery will close if it cannot sustain its profitability as shown in the figure below. Overall, more than 60 refineries, which stand for 10% of total number of refineries, have closed since 2004, a reflection of the shift to larger, more complex refineries and declining demand.

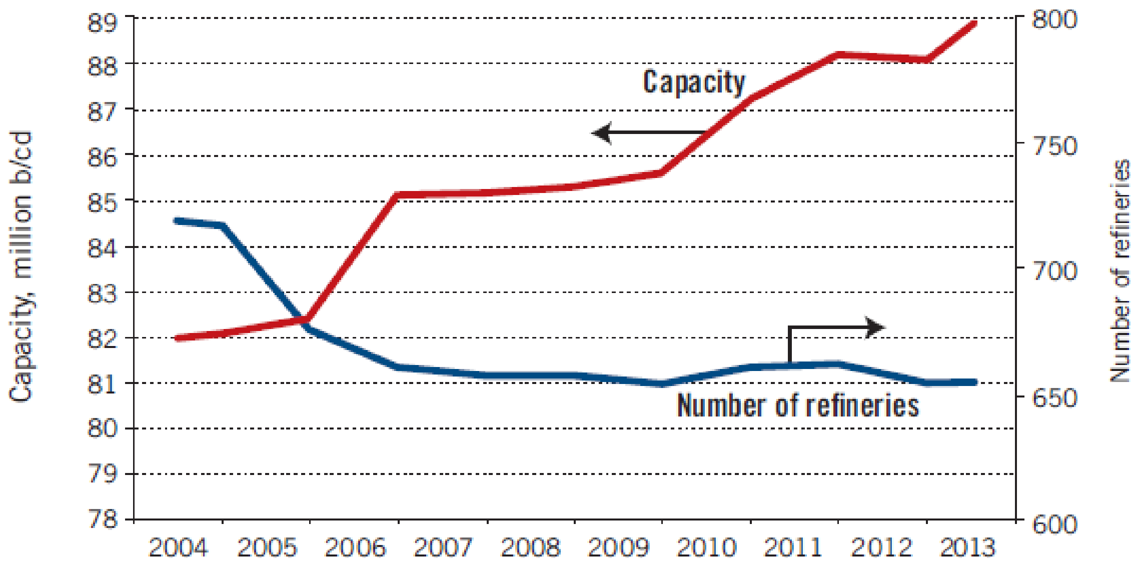

Figure 11: Worldwide refining (Oil & Gas Journal, 2013)

The crack spread is the difference between crude oil prices and wholesale petroleum product prices (mostly gasoline and distillate fuels). Like most manufacturers, a refinery straddles the raw materials it buys and the finished products it sells. In the case of oil refining, both prices can fluctuate independently for short periods due to supply, demand, transportation, and other factors. In 2008, for example, crude oil prices spiked almost 20 percent higher than the price of refined petroleum products. Since then, crude oil prices fell by nearly half, but prices for refined petroleum products are near their 2008 highs. Such short-term volatility puts refiners at considerable risk when the price of one or the other rises or falls, narrowing profit margins and squeezing the crack spread. The crack spread is a good approximation of the margin that a refinery can earn. Crack spreads are negative if the prices of refined products fall below that of crude oil.

A major determinant of a crack spread is the ratio of how much crude oil is processed into different refined petroleum product, because each type of crude more easily yields a different product, and each product has a different value. Some crude inherently produces more diesel or gasoline due to its composition. These ratios and product combinations vary by region. The most common ratio in the US is three barrels of crude to produce two barrels of gasoline and one barrel of middle distillates (or 3:2:1). In Europe, which includes the Atlantic Basin covering Eastern Canadian refineries, a 6:3:2:1 ratio is the most common: six barrels of crude produce three barrels of gasoline, two barrels of distillates, and one barrel of residual fuel. Whilst, for a long time, crack spreads greater than $4 per barrel are considered as strongly profitable, current view is that it should be greater than $9 per barrel to be profitable.

3.3.1 Determination of Refining Profitability

Whilst all refineries focus on converting crude oil into oil products, the profitability of one refinery relative to another can vary markedly. As illustrated below, refinery configuration, or complexity, has a major role in determining the refining margin. Other important factors include the type of crude oil processed, location, crude delivery method and overall efficiency.

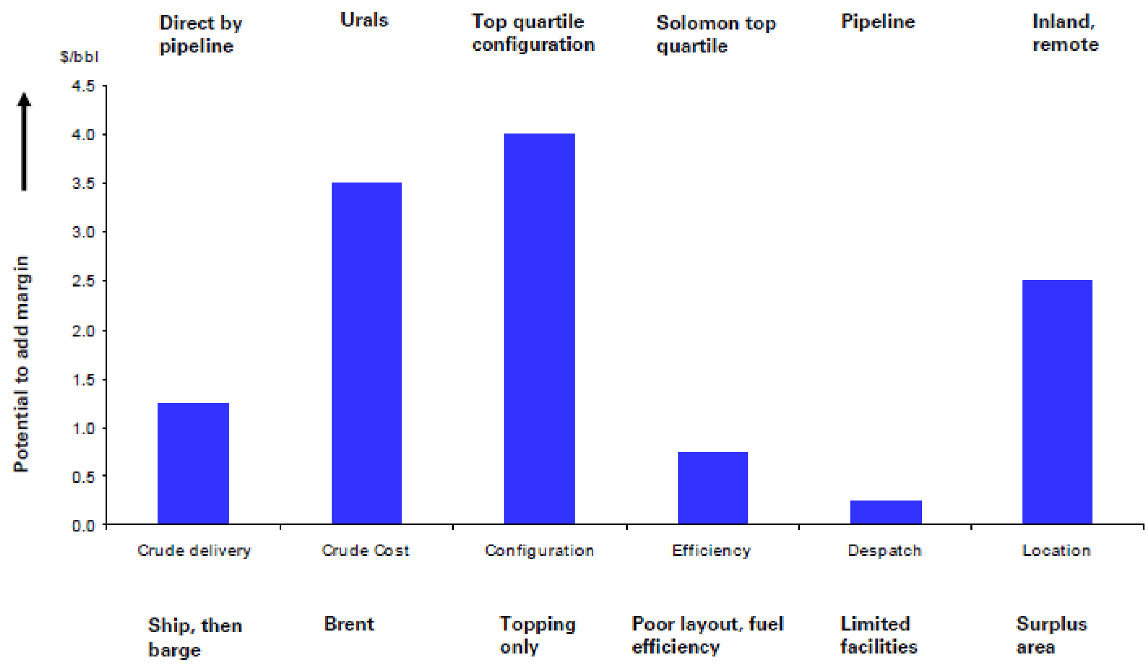

Figure 12: Major factors impact on a refiner's net margin (Herrmann, Dunphy, & Copus, Oil & Gas for Beginners: A guide to the oil & gas industry, 2010)

3.3.1.1 Type of Crude

Worldwide, there are more than 150 different types of crude oil. The basic choice of which crude to refine is between lighter and heavier grades. Crude oil markets have long compensated for the differences in quality between light and heavy crude oils by paying a premium for lighter grades. However, this light-heavy spread does not fully compensate for the lower cost of refining lighter crude. Since the cost of crude oil is a refinery's largest input cost, processing cheaper heavy crude into higher-value lighter products usually improves profit margins.

Cost is not the only reason to choose a particular grade of crude oil. Each grade of crude yields a different array of refined products, each of which has a different price that also varies by region. A "netback" value expresses the worth of each type of crude in terms of the value of the products it makes. Demand from refineries also affects the price differential for different grades of crude. If the crack spread is low, refineries are reluctant to invest in upgrades to process heavier crudes. This dampens demand for heavy crude, and keeps the price difference between light and heavy crude high. However, if more refineries upgrade to process heavy crude, increasing demand for these oils constricts the light-heavy price spread. Recent growth in heavy oil refining capacity has outstripped available heavy oil feedstock, shrinking the light-heavy price differential. Other factors behind the current and longer term outlook for a narrow price differential between light and heavy crudes are the post-2008 recession drop in oil demand and the rapid growth of light sweet crude supply in North America.

Paradoxically, even as the supply of heavy crude has increased, the demand profile for refined petroleum products has shifted to a greater proportion of lighter, higher quality products from heavy fuel oil, bunker, and marine fuels, to diesel and gasoline. This has resulted in the so-called “quality gap” caused by the growing availability of heavier crudes and older refineries’ inabilities to convert them into lighter products.

Therefore, every refinery faces a range of choices, which also could be risk and uncertainty to refinery. In the short term, they must constantly juggle their choices of crude inputs and refined outputs. In the longer term, they have to decide whether to invest in changing their configuration or shutting down.

3.3.1.2 Refinery Size, Configuration and Complexity

Economies of scale are an important factor in refinery profitability - refinery size does matter. Larger facilities are more efficient, better able to withstand cyclical swings in business activity, and able to distribute fixed costs over a larger number of barrels like those from new regulatory requirements.

Refinery complexity also matters, especially since the trend is to have heavier, more sour crudes and lighter products. There are several measures of complexity for refineries. The most publicly used is the Nelson Complexity Index (NCI) developed in the 1960s by Wilbur Nelson in a series of articles for *the Oil and Gas Journal*. The NCI is a pure cost-based index. It provides a relative measure of refinery construction costs based upon the distillation and upgrading capacity a refinery has. The index assigns a complexity factor to each major piece of refinery equipment based on its complexity and compared with simple crude distillation, which is assigned a complexity factor of 1.0. The complexity of each piece of refinery equipment is then calculated by multiplying its complexity factor by its throughput ratio as a percentage of crude distillation capacity. The total sum of the complexity values assigned to each piece of equipment, including crude distillation, determines a refinery's NCI number. The higher the NCI number of a refinery, the more complex and costly it is to build and operate.

The increased demand for lighter petroleum products made from heavier crude oil requires more complex refineries. The complexity of a refinery refers to its ability to process crude oil into value-added products. A simple refinery, also known as a topping refinery, is essentially limited to distilling crude oil; for example, making the raw material for gasoline and heavy fuel oil. A hydroskimming refinery is also quite simple, with an NCI of about 2, and is mostly limited to processing light, sweet crude into gasoline for motorists. By contrast, a complex refinery has expensive secondary upgrading units such as catalytic crackers, hydrocrackers, and fluid cokers. These refineries are configured to have a high capacity to crack and coke crude 'bottoms' into high-value products and to remove sulfur to meet vehicle exhaust system limitations and environmental requirements. Therefore, complex refineries rank higher on the NCI.

Nearly all new refinery capacities built in the world since 2003 are made up of more complex operations. For example, the Jamnagar refinery belonging to India-based Reliance Industries Limited is now one of the most complex refineries in the world with an NCI of 14. According to author Robert Maples and *Oil and Gas Journal*, US refineries rank highest in complexity index, averaging 9.5, compared to 8.2 for Canada and 6.5 for Europe. The increased flexibility of complex refineries enables them to quickly adapt to constant changes in market conditions for both input and output. This reduces risk and boosts profits. With the closure of older, simpler refineries, complex refineries now represent the vast majority of the world's refining capacity. Since 2003, therefore, the most complex refineries have generated the highest profit margins. However, the addition of more complexity comes at a cost and with some significant business risks. It also entails higher operating costs from additional inputs and greater energy use.

3.3.1.3 Production Mix

A refinery's ability to adjust its product slate to meet changes in demand has a huge impact on its profitability. Typically, the most profitable products are gasoline, diesel, jet fuel, and lubricating oils. However, a refinery's flexibility to adjust to market demand is constrained by the types of crude oil available and its own configuration and complexity. Different regional markets have different demand profiles, and these shift over time due to changes in demographics, economic circumstances, regulatory policies, and consumer preferences. In addition, seasonal shifts in demand are common, such as increased demand for gasoline during the summer driving season and for heating oil in winter.

Even so, local refineries often cannot economically meet demand in a given region for a certain refined product; they must import from other regions or countries. For example, European demand has gradually shifted from gasoline to diesel due to the large-scale conversion of domestic vehicles. As a result, European refineries have a surplus of gasoline and a shortage of diesel. They have responded by exporting gasoline to the U.S. and importing diesel from the U.S. Transportation costs will help determine whether matching production to demand in this way can be profitable in the long term.

3.3.1.4 Logistics and Transportation

Refineries receive crude oil via pipelines, ships, and rail cars. Pipeline and marine tankers are the lowest cost and therefore the preferred mode of transporting crude oil to the refinery. There is more flexibility in transporting crude oil than refined petroleum as the latter cannot be exposed to contaminants. Pipelines, ships, and rails are the preferred modes to transport products from refineries to terminals located near major markets, where the fuels are then trucked to retail outlets.

A refinery's location directly affects the cost of bringing crude oil to the facility and then getting the refined product to market. Distance and mode of transportation for crude oil and refined products are the determining factors for cost. Coastal plant will often have low crude supply costs and will be able to access export markets cheaply. However, inland refiners may be closer to areas of high demand and may be specifically configured to relatively isolated markets.

3.3.1.5 Operational Efficiency

Maximizing capacity utilization is highly dependent on planning and scheduling. Refinery scheduling is one of the most complex operational tasks, involving a multitude of steps, in all of manufacturing. The goal is optimization of crude oil input and refined product output. In order to optimize the combination of input and output, refiners face a daily challenge of which crude to use, which refinery units to use and under what conditions, and what mix of products to refine. In addition, they must make these decisions while taking scheduled maintenance and inventory levels into account.

The first optimization technique applied in practice to the solution of large-scale problems was linear programming (LP). In the past, refineries would use a number of complimentary models to optimize different segments of their operations; crude acquisition and transportation, refining, product blending and product distribution. Nowadays, a typical LP program for a refinery may have as many as 3,500 decision variables and 1,500 constraints. The field is dominated in the U.S. by a number of firms that developed sophisticated optimization program customized for refinery use. RPMS (Honeywell's Refinery and Petrochemical Modeling System), PIMS (Aspen Technology), GRTMPS (Haverly Systems), and PETRO (Chevron) are the most popular ones.

3.4 Global Product Market

Similarly to the global crude market, long term global prices for refined products of the same quality do not vary by more than the freight differential between regions. If the price of a particular product rises in one region, which would be due to a supply constraint such as an unscheduled refinery shut-down, then it very quickly becomes worthwhile to ship products from other regions to the higher priced region. This has the ultimate impact of increasing the price in the supplying region, and reducing the price in the receiving region, until the equilibrium is re-established again. In addition, prices of refined products of similar quality also will not vary substantially more than the freight differential between regions, as refiners and blenders in the regions are capable of purchasing product in one region and blending it into a similar product in another region.

There are a number of structural flows of refined products across the globe, e.g. gasoline flows from Europe to North America. Therefore, structurally, the price for bulk gasoline in North America (U.S. East Coast) is higher than the gasoline price in Europe (Amsterdam Rotterdam Antwerp, ARA). Diesel flows from Russia, North America, and India to Europe. Therefore, European diesel prices are higher than in all other supplying regions. Jet fuel flows from the Middle East and Asia to Europe and so European jet prices are also among the highest across the globe. Fuel oil flows from Russia and Europe to the Far East. Therefore, European fuel oil prices are among the lowest in the world.

When there is a short term disruption to normal product supply in a region, prices for the product can spike upwards as local demand temporarily exceeds supply. The price spike encourages producers in other regions to increase production with subject to their own maximum capacity constraints and export product to the region with the shortage. This in turn results in an increase of the in-demand product price in all regions. However, owing to the time it takes to produce the additional product, schedule the export cargo, and then deliver over long distances, the local restriction in supply can remain in a region for a number of weeks before equilibrium is re-established.

The differences in refined product demand in different regions impact the price of crude and refined products in different regions, which in turn impacts refinery gross margins in the different regions.

3.5 Marketing & Sales

In developed nations, motor fuels such as gasoline and diesel are by far the most visible and politicized elements of the global oil industry. Local gas stations and their highly visible price displays are unable to be avoided by motorists, making motor fuels unique among consumer products in that customers are always aware when prices are rising and falling.

The daily movements of fuel prices are debated and discussed by politicians, pundits, and everyone who drives a car. Other refined products are much less visible and are sold primarily into B2B or industrial markets. Although motor fuels eventually end up as consumer products, refiners may sell motor fuel to industrial and wholesale markets or they may sell to company-owned or company-franchised retail sites.

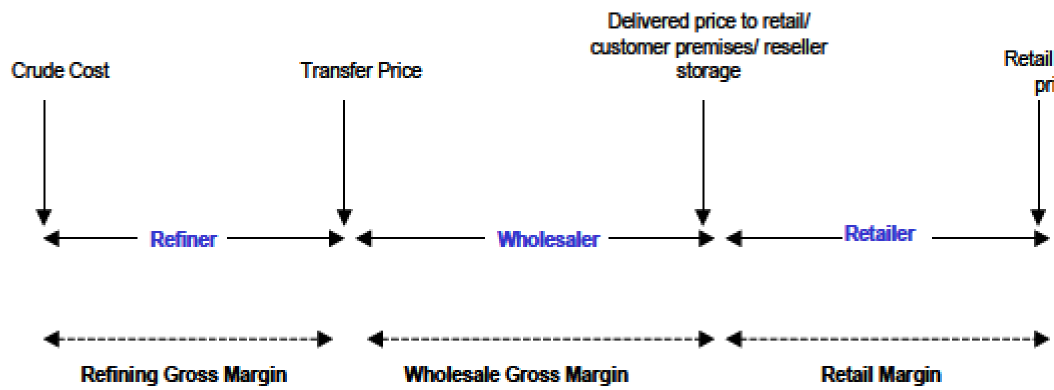

Figure 13: Total marketing margin = wholesaler margin + retailer margin (Herrmann, Dunphy, & Copus, Oil & Gas for Beginners: A guide to the oil & gas industry, 2010)

Refining companies use a variety of methods to sell their motor fuels. Refiners may own and operate their own retail outlets. They may sell their product to a dealer who operates a branded franchise. Product may be sold to a jobber that operates its own retail outlets. Refiners may sell to large retailers, such as Costco in the U.S. or Carrefour in Europe. Finally, refiners may occasionally sell their fuel into spot markets. As in the figure above, total marketing margin could be divided by wholesale gross margin and retail margin. At the wholesale level, they typically supply to retail service stations, industrial and commercial customers, oil distributors and other oil companies. Retail sales typically occur through either own branded service stations or through a franchise network. Thus, refiners have a variety of ways to sell their product and often find themselves competing in a retail channel with the same companies to which they supply fuel on a wholesale basis.

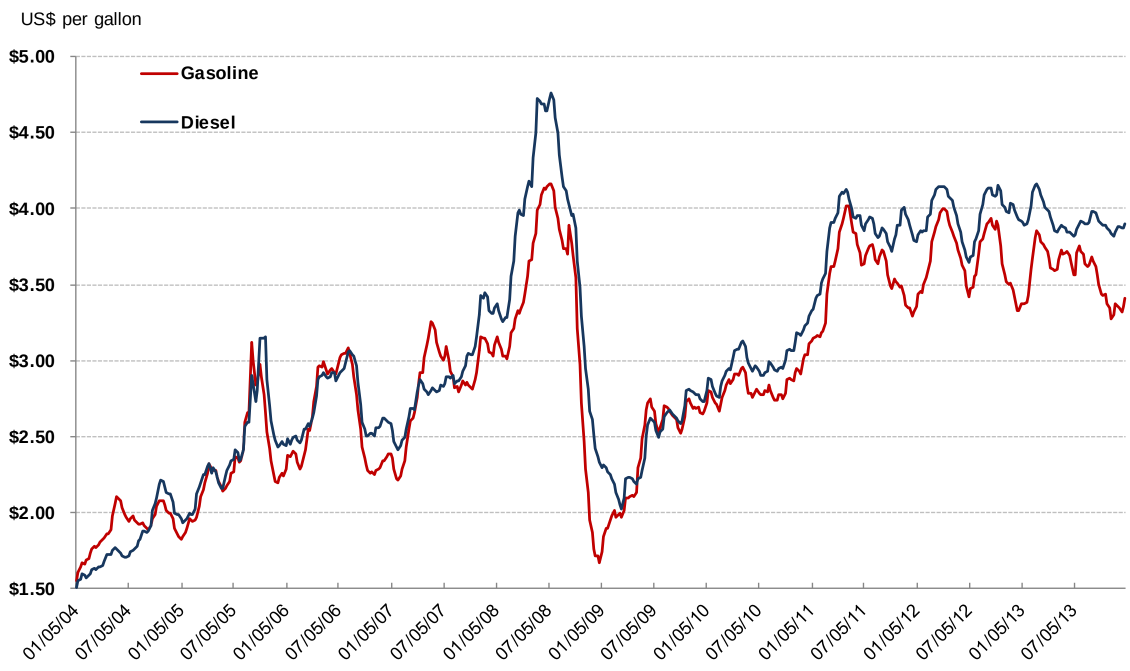

Figure 14: U.S. gasoline and diesel prices, weekly Jan. 2004 - Dec. 2013 (U.S. Energy Information Administration(eia), 2014)

Like crude oil, motor fuels prices are volatile and unpredictable. Figure 14 shows U.S. gasoline and diesel prices over a ten-year period. Prices for gasoline ranged from less than $2.00 per gallon to more than $4.00. Prices for diesel have the same trends as gasoline, but the highest prices for diesel were quite a bit higher than the highest gasoline prices. In the U.S. the main components of the retail price of gasoline are crude oil, federal and state taxes, refinery costs, and margins, distribution, marketing, and retail dealer costs and profits. The percentage of gasoline price in distribution, marketing, and retail dealer costs and profits is lower now than in the previous decade, which is consistent with the decision by the IOCs to divest company-owned stations. Profit margins have been falling for several decades as a result of competition from hypermarkets, increased credit card transaction fees, and the limited ability to capture brand value.

Product	Gasoline		Diesel	
Period	2004-2013	Dec. 2013	2004-2013	Dec. 2013
Retail Price ($/gallon)	$2.85	$3.28	$3.08	$3.88
Crude Oil	61.5%	68.1%	57.1%	57.4%
Refining Costs & Profits	12.8%	9.3%	14.8%	17.6%
Distribution & Marketing	10.0%	9.9%	11.2%	12.4%
Federal & State Taxes	15.6%	12.8%	16.9%	12.6%

Table 2: Price components of gasoline & diesel in the U.S. (U.S. Energy Information Administration(eia), 2014)

4. FINANCIAL MODEL OF OIL REFINERY

This section develops a financial model of an oil refinery in order to analyze and simulate risk factors. There are several risks that can affect an oil refinery. Generally recognized risks related to refineries are as follows:

Crude oil price (flat price or timing risk)

This results from the time lag between crude purchases and product sales. Generally, an oil refinery is required to purchase crude feedstock approximately one to two months in advance of processing, whereas the domestic supply or export of finished products takes place after the crude feedstock is discharged and processed. This timing difference can lead to differences between the cost of its crude feedstock and the revenue from the proceeds of product sales, due to the fluctuation in prices during the time period.

Crack spread (margin risk)

Month to month changes of crack spreads, even when the pricing of both crude purchases and product sales fall into the same month, can affect the profitability of an oil refinery.

Marketing margin (product price premium)

Major factors affecting marketing margin are the availability of price arbitrage for refined products between different geographical markets, the changes in the mandatory product specifications used by governmental authorities for refined products, or pricing and other actions taken by competitors that impact the market.

Sales volumes

The pace of the execution of renewable fuel legislation, such as the U.S Renewable Fuel Standard, national regulations, and the EU Renewable Energy Directive, can affect demand of refined products

Exchange rate

Trading in commodities and refined products mainly takes place in US dollars, but domestic sales take place in local currency, which exposes oil refineries (except US oil refineries) to exchange rate volatility.

Costs

Extra costs to an oil refinery can result from changes in the cost and availability of logistics services for feedstock and refined products, changes in environmental and other regulations that could require an oil refinery to make substantial investments without necessarily increasing the capacity or operational efficiency of its refinery, and pricing and other actions taken by competitors that impact the market.

Hazard risk

Hazard risk is defined as the risk of financial losses arising from events leading to the damage of physical or intellectual assets, business interruption, personnel injuries, or environmental, product, or other liabilities. Risks in the area of marine transportation may, if realized, have a major cost effect.

Credit and counterparty risk

Credit and counterparty risk arises from sales, hedging, and trading transactions, as well as cash investments. Risk is linked to the potential failure of counterparties to meet their contractual payment obligations, and depends on the creditworthiness of counterparties and the size of the exposure concerned.

In this thesis, among these risk factors, major market price variables, such as crude oil price and crack spread, are regarded as risks or simulation variables; some of the other risks, such as marketing margin, utilization rate, and energy cost, are treated as uncertainties; the others are excluded or fixed.

4.1 MODEL STRUCTURE

To measure the impacts of risk factors on the refinery, three criteria are adopted; present value of net income for ten years, present value of net cash flow, and return on capital employed (ROCE). Many reports of the refining sector just analyze the impact on income statement, such as operating income or net income. As the crude oil price is over $100 per barrel, a refinery could suffer from the cost of inventory, which could not be seen easily in an income statement, but could be seen in a cash flow statement. Thus, it is also necessary to focus on net cash flow. In addition, in order to make comparisons with other industries or investments, it is necessary to include the measure of return, such as ROCE. After the 2000s, ROCE has been widely used to measure the performance of a company. As shown in Figure 15 below, refinery performance could be broken down in terms of ROCE. Therefore, the refinery financial model in this section follows this structure in principle.

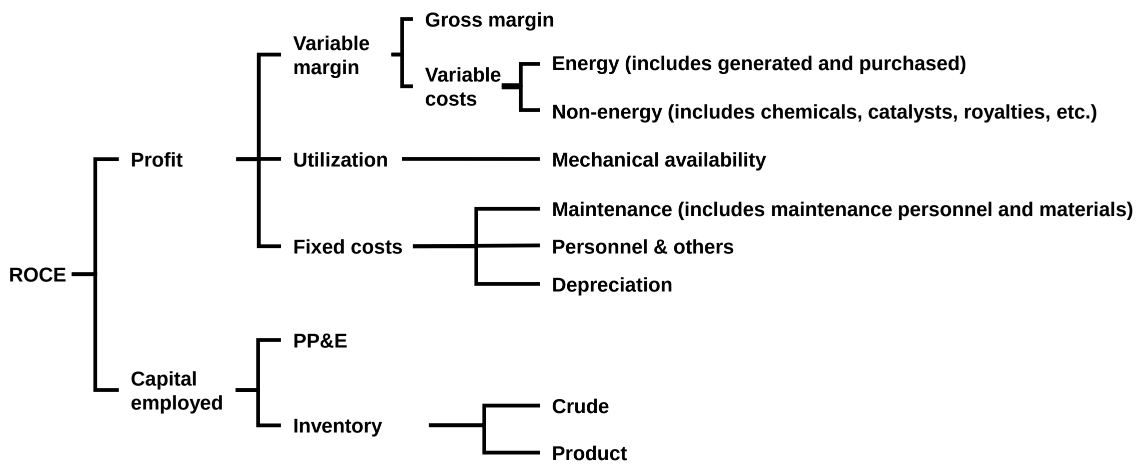

Figure 15: Refinery performance breakdown

4.2 MAJOR ASSUMPTIONS

The objective in this chapter is to develop a hypothetical refinery financial model that reasonably approximates real models encountered in practice. The following table shows major assumptions of the refinery, such as CDU capacity, initial investments, utilization rate, refinery type, and production yield.

Total CDU Capacity	**800**	MBPCD
Initial Investment - PP&E	**17,630**	Million USD
Utilization rate	**95.0%**	
Crude Oil Throughput	**760**	MBPCD
Refinery Type	**HCR/Coking**	
Nelson Complexity	**10.3**	
Sour Crude Oil Throughput ratio	**50.0%**	
Production Yield	**94.0%**	
Gasoline	36.0%	
Naphtha	5.0%	
Jet Fuel	12.0%	
Diesel	38.0%	
Fuel Oil	3.0%	
Production/Sales Volume	**714**	MBPCD

Major Unit	MBPCD
CDU	**800**
VDU	**433**
FCC	**283**
HC	**85**
Coker	**163**
Reformer	**144**
Alkylation	**46**
Upgrading Ratio	**66%**

- **Start-up: Jan. 1, 2004**

Table 3: Refinery assumption summary

As shown in Figure 10, since the majority of the world's refineries are cracking refineries, and more complex refineries are increasing in share, a refinery with hydrocrackers and coking units is assumed. Thus, almost of the production consists of high value products such as gasoline, jet fuel, and diesel. In addition, thanks to a high upgrading ratio, this refinery can input sour crude oil at 50%.

According to *Solomon Associates*, the world average capacities of refineries are 187 mbpcd and average capacities of the best four refineries are 355 mbpcd. For a more realistic and competitive refinery, a refinery with CDU of 800 mbpcd is assumed, which means that this refining company has three refineries with CDUs of 300 mbpcd, 300 mbpcd, and 200 mbpcd respectively.

Initial investments stem from the decision of refinery type and capacity. As shown in Figure 16 below, upgrading facilities is much more expensive than a CDU, even if the capacity is relatively small.

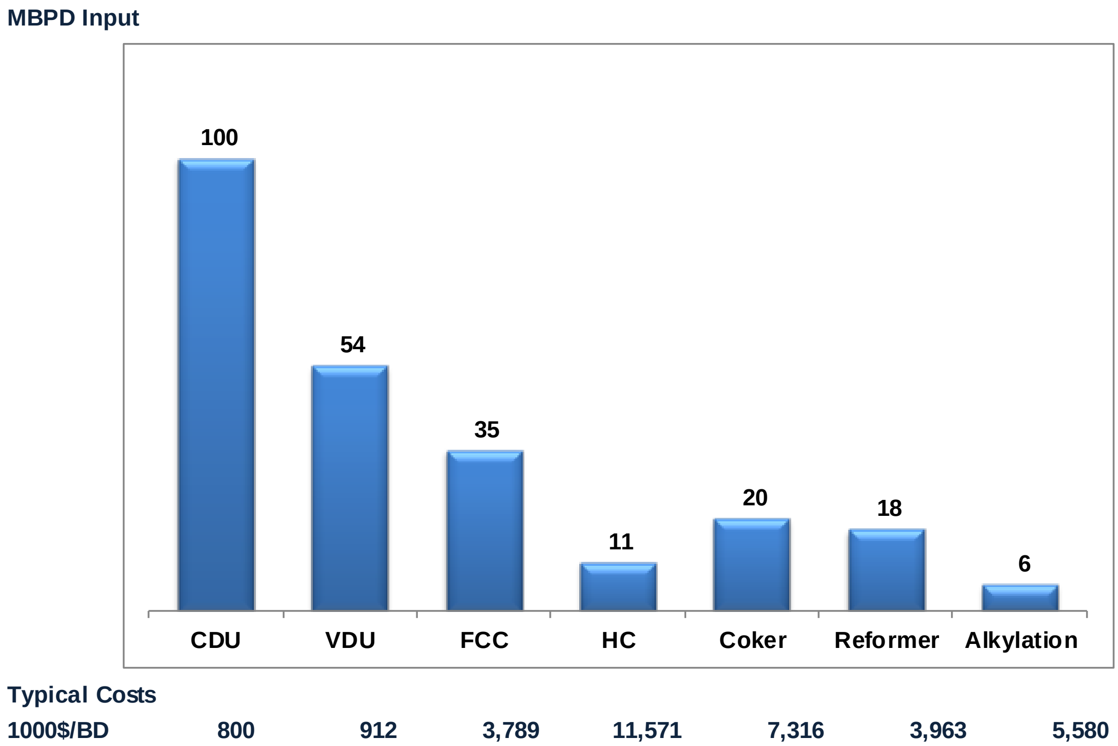

Figure 16: Typical refinery unit size & costs (Gary, Handwerk, & Kaiser, 2007)

Aside from these major units, it is necessary to include H2 unit, utility and steam facilities, and storage costs to calculate total investment cost. In addition, the higher the Nelson Complex Index (NCI) is, the more expensive the initial investment cost. The NCI of this refinery is 10.3, which is slightly over the average of U.S refineries and remarkably over the world average as of December 2013. Detailed information about investment costs as of 2004 (one year after this refinery is assumed to be built), are as follows:

UNIT NAME	BPCD	M$, 2004	Power, (MkWh/d)	Cooling water (gpm)	Process steam (Mlb/h)	Fuel (Mlb/h)	MMBtu/h	Nelson Complexity
Desalter	100,000	5,500	10	277	87			
CDU	100,000	80,000	50	417		25.0	292	1.0
VDU	54,147	49,400	11	2,336		21.0	92	1.3
Coker	20,366	149,000	25	990		24.0	119	7.5
Middle distillate HT	32,053	71,800	192	11,130		13.4	267	2.5
FCC HT	36,144	78,000	217	12,550		15.0	301	2.5
FCC unit	35,421	134,200	213	12,300		(44.3)		6.0
HC unit	10,621	122,900	138	3,319		33.2	89	8.0
Naphtha HT	18,040	27,800						2.5
Reformer	18,040	71,500	90	7,520		27.1	300	5.0
Isomerization	5,828	29,000	6	3,237		49.0		3.0
Alkylation	5,735	32,000	15	10,577		1.9	178	10.0
Polymerization	3,170	3,000		417	147	3.1	3	10.0
H_2 unit, MMscfd	42	53,300	32	5,660			396	1.0
Satd, gas plant, MMscfd	13	27,300	13	14,697			408	
Amine treater, gpm	652	9,100	9	1,630	6		39	
Claus sulfur, LT/d	117	13,500				(31.7)		0.2
SCOT unit, LT/d		13,500						
Subtotal		***970,800***	***1,021***	***87,057***	***240***	***136.7***	***2,484***	***10.3***
Cooling water system		19,500	63	13,135	5,016			
Steam system		33,300			34	34.2	205	
Subtotal		***1,023,600***	***1,084***	***100,192***	***5,290***	***170.9***	***2,689***	
Storage		460,000						
Subtotal		***1,483,600***	***1,084***	***100,192***	***5,290***	***170.9***	***2,689***	
Offsite (15%)		222,540						
Subtotal		***1,706,140***						
Location, Special costs, & Contingency (43.		742,512						
TOTAL		***2,448,652***						

Capital Cost		
Total Capacity	800	MBPCD
Economies of Scale	10%	
Total Capital Cost	**$ 17,630**	**MM$**
Year of Life	20	years
Depreciation method	Straight-line method	
Depreciation Cost	**$ 882**	**MM$/yr**

	Nelson Complexity
U.S.	**10.9**
World	**6.9**
(as of Dec. 2013)	

Table 4: Capital costs & Nelson Complexity Index

In addition, all products that are produced by the refinery are assumed to be sold. Thus, a production of 714 mbpcd, resulting from a crude throughput of 760 mpbcd and a production yield of 94%, will be sold in the market.

4.3 Cost Assumptions

Refinery operating costs are highly dependent on a number of key parameters, including size and complexity of the refinery, utilization rate, local wage expectations for refinery workers, employment, and environmental regulations. Different countries or regions thus have a wide variation in operating expenditures (Opex), which have a direct impact on refinery net cash margins. Operating costs vary with refinery throughput, as some cost components are fixed (such as labor and insurance) while others vary with throughput (such as catalyst and chemical consumption). Thus low throughputs on an economic or maintenance basis can lead to higher per-barrel Opex. A further difficulty with refinery operating cost information is that it is not necessarily reported on a common basis, possibly including or excluding energy costs, financing costs, maintenance costs, depreciation, etc. According to EIA, indicative refining operating costs per barrel in the U.S, Europe, and Asia are $3.3, $4.0, and $3.0 respectively. These costs exclude energy costs, and depreciation and amortization, which will vary widely with refinery configuration, age and local accounting or tax requirements. The following table describes overall cost assumptions in the financial model of the refinery. Due to a limitation of information, these assumptions are mainly based on data from Marathon Petroleum Corporation and Valero Energy.

Costing Method	**Monthly Average**	
Cost		
Energy Cost	**1.4**	$/bbl
Non-energy Cost	**0.5**	$/bbl
TA & Major Maintenance	**1.0**	$/bbl
Other manufacturing	**1.0**	$/bbl
Districution & Marketing Cost	**3.1**	$/bbl
Customer Excise Tax		
Gasoline	**17.9**	$/bbl
Diesel	**21.2**	$/bbl
Interest Rate		
Baa Corporate Bond Yield	**6.4%**	
Corporate Income Tax rate	**35.0%**	

Table 5: Cost assumptions

As shown in Figure 17, the major operation costs are crude oil costs, but that is a risk factor, so it could not be included in assumptions. In addition, when the crude oil price is volatile, the total cost of goods sold (COGS) depends on the costing method. Thus, a monthly average method is assumed, because it can easily and reasonably reflect changes in crude oil prices on a financial statement and also can exclude LIFO liquidation effects.

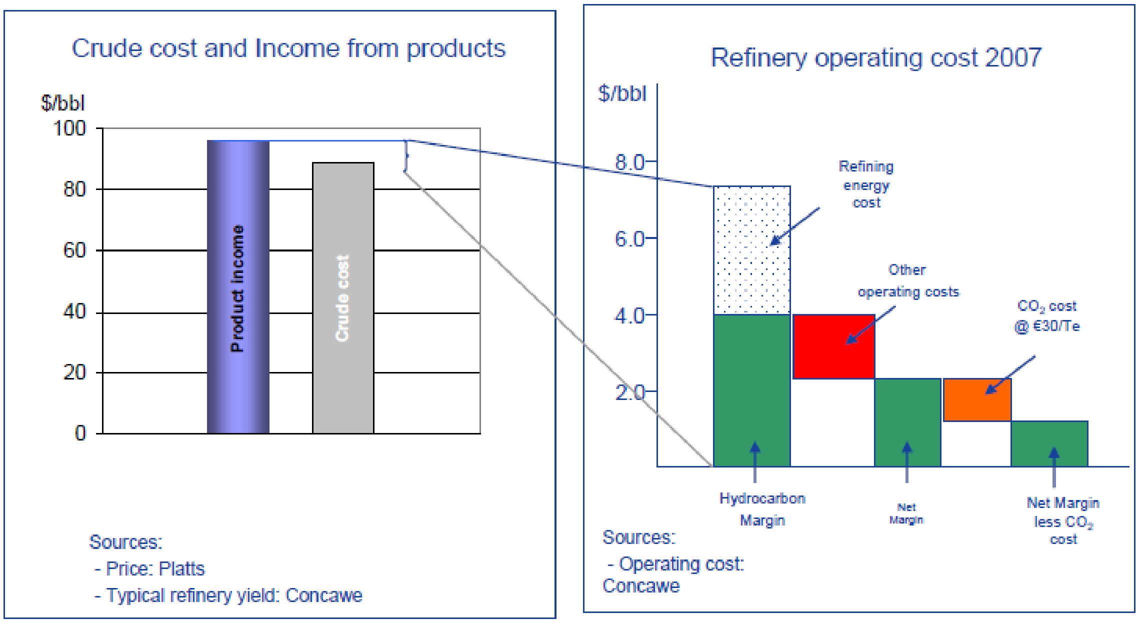

Figure 17: Energy costs (Beddoes, 2010)

The biggest cost of refinery operation is energy related expenses, which stands for 60% of operation cost as shown in the above figure. Crude refining consists of many processes, that require a certain amount of energy in order to achieve the production of dedicated products. The wide range of this use depends on the level of conversion and the complexity of the refinery. The simpler the refinery is, the lower the specific energy consumption. Conversely, the higher the crude conversion is, the higher the energy consumption.

According to *Solomon Associates*, refinery energy costs in the U.S. fell by 26% due to shale gas whilst those in Europe increased by a factor of 3.8 over the same period.

Korea/Singapore energy costs increased over the 2010-2012 period, probably due to higher fuel oil prices after the 2011 Tokyo earthquake and tsunami that struck Japan.

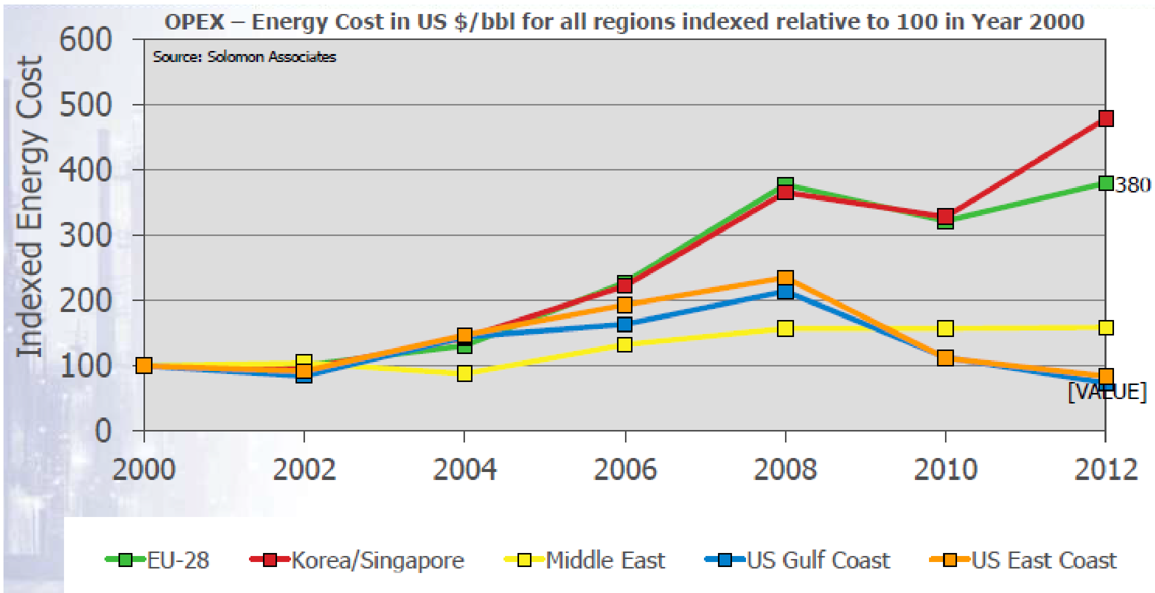

Figure 18: Indexed energy cost (Beddoes, 2010)

Non-energy cost includes chemicals, catalysts, and royalties, which are relatively small and also vary by country or region. Customer excise tax is a federal and state tax on gasoline and diesel. December 2013 level is assumed to be maintained (See Table 2).

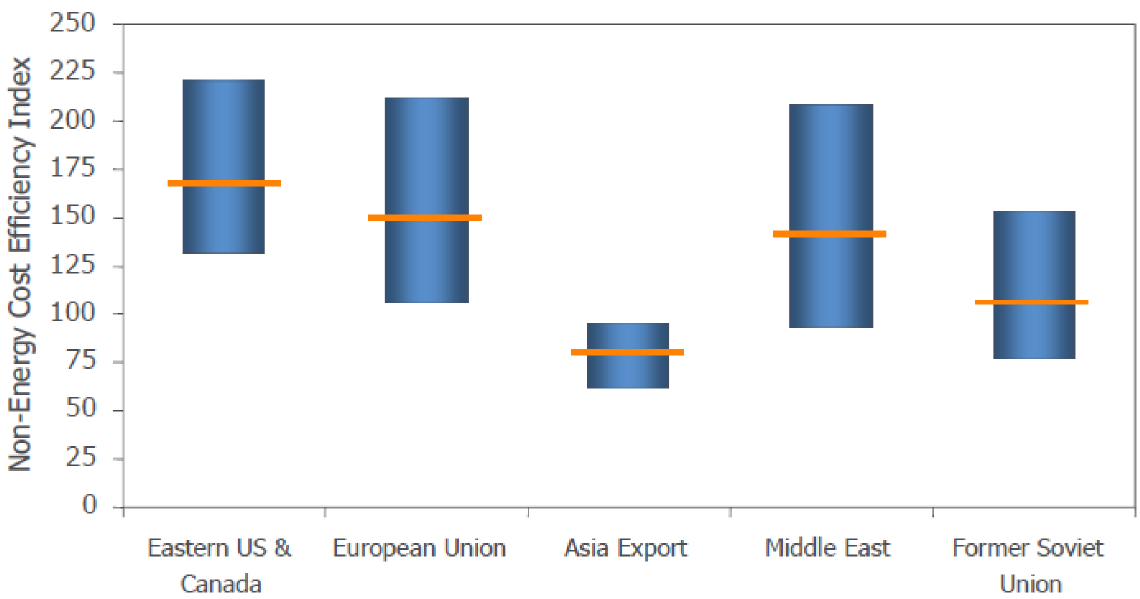

Figure 19: Solomon non-energy cost efficiency Index (Beddoes, 2010)

4.4 Business Assumptions

The final assumptions are related to business operation. Generally, every refinery has to maintain a certain level of inventory to meet customer demand and operation, which is assumed to be 30 days (10 days for crude oil and 20 days for product). Crude oil sellers usually give credit to the refinery, which is assumed to be 30 days. Also the time it takes to get cash from sales is assumed to be 30 days.

Trade Receivables	**30** days
Suppliers' Credit	**30** days
Inventory	
Crude Oil	**10** days
Product	**20** days
Dividend Policy	
Net D/(D+E) > 50%	**0.0%**
Net D/(D+E) <= 50%	**20.0%**
Net D/(D+E) <= 30%	**40.0%**

Table 6: Business assumptions

4.5 Model Validation

To check the validation of the refinery's financial model with these above assumptions, it is best to use historical data and compare it with the actual performance of refineries. The Industry Data Book by Deutsche Bank is used as the reference of the actual performance. Figure 20 shows that the net income of the refining and marketing (R&M) sector was changed mainly due to changes in crack spreads. Also, the ROCE of 2003- 2008 period was over 10%; the ROCE after 2009 was under 10%.

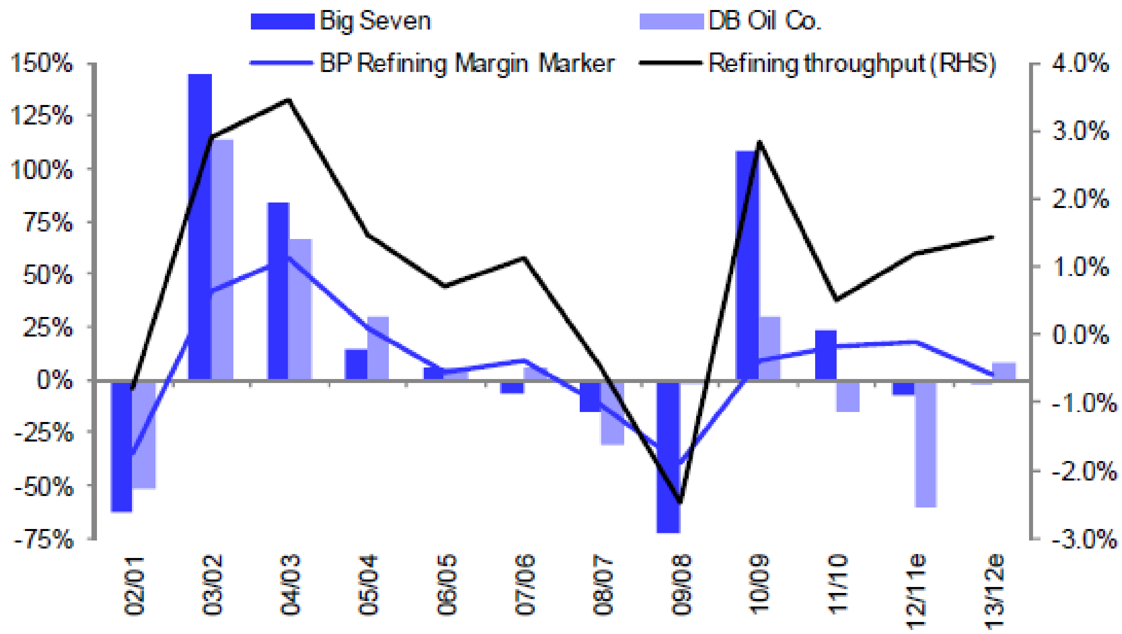

Figure 20: Year-on-year growth in R&M NI vs. key drivers (Herrmann & Bloomfield, Global Integrated Oil - Industry Data Book, 2012)

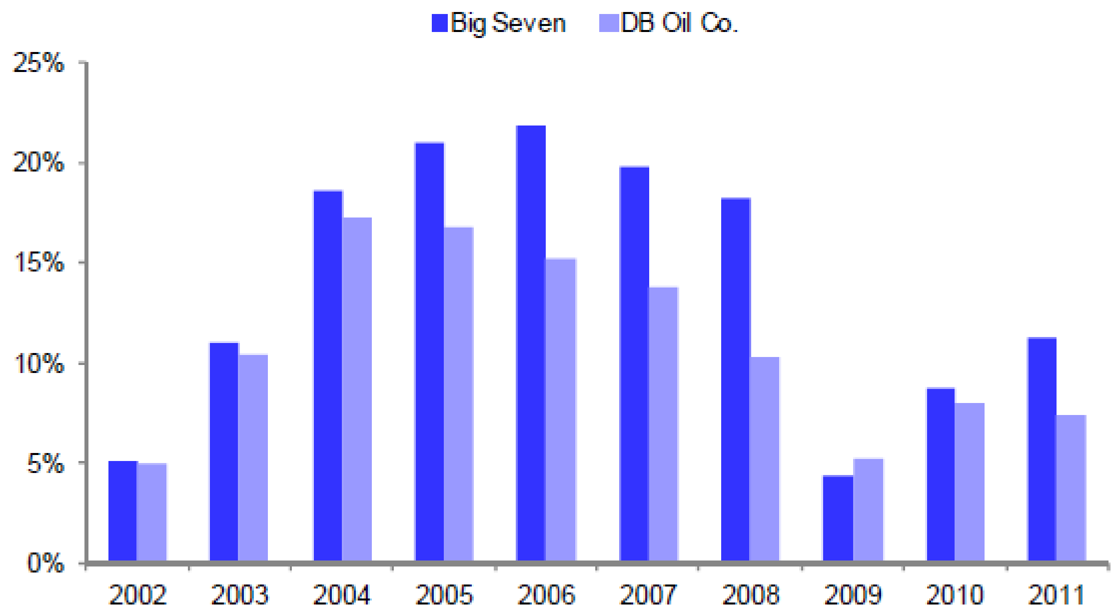

Figure 21: Sector average ROCE in R&M division 2002-2011 (Herrmann & Bloomfield, Global Integrated Oil - Industry Data Book, 2012)

The financial statements resulting from the model with the historical crude oil price and crack spreads are as follows:

INCOME STATEMENT	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Crude Oil Price - WTI	**$ 41.5**	**$ 56.6**	**$ 66.0**	**$ 72.2**	**$ 100.1**	**$ 61.9**	**$ 79.4**	**$ 95.0**	**$ 94.1**	**$ 97.9**
Brent less Dubai	**$ 4.7**	**$ 5.2**	**$ 3.6**	**$ 3.9**	**$ 3.7**	**$ -0.0**	**$ 1.4**	**$ 5.1**	**$ 2.6**	**$ 3.1**
USGC Coking Margin	**$ 12.6**	**$ 19.0**	**$ 17.1**	**$ 17.3**	**$ 16.5**	**$ 4.3**	**$ 8.9**	**$ 9.1**	**$ 9.0**	**$ 7.3**
Sales Revenue	**20,249**	**25,716**	**28,581**	**30,705**	**37,948**	**26,028**	**31,115**	**39,643**	**40,629**	**39,239**
Variable Costs	-14,630	-19,296	-22,962	-24,617	-33,993	-23,086	-27,090	-34,773	-36,085	-34,374
Contribution Margin	**5,619**	**6,420**	**5,619**	**6,088**	**3,956**	**2,941**	**4,025**	**4,870**	**4,545**	**4,865**
Opex	-2,185	-2,179	-2,179	-2,179	-2,185	-2,179	-2,179	-2,179	-2,185	-2,179
Depreciation & Amortization	-882	-837	-800	-768	-741	-719	-701	-687	-676	-670
Operating Income	**2,553**	**3,404**	**2,640**	**3,142**	**1,030**	**44**	**1,146**	**2,004**	**1,684**	**2,017**
Net Interest	-959	-846	-790	-674	-703	-651	-494	-441	-356	-322
Other Income	-	0	0	0	0	0	0	0	0	0
Income Before Tax	**1,594**	**2,558**	**1,850**	**2,468**	**328**	**-607**	**652**	**1,564**	**1,327**	**1,694**
Income Tax	-558	-895	-648	-864	-115	213	-228	-547	-464	-593
Net Income	**1,036**	**1,663**	**1,203**	**1,604**	**213**	**-395**	**424**	**1,016**	**863**	**1,101**
ROCE	**9.2%**	**12.0%**	**9.5%**	**11.5%**	**3.8%**	**0.2%**	**4.5%**	**7.7%**	**6.4%**	**7.7%**
Interest Coverage	**2.7**	**4.0**	**3.3**	**4.7**	**1.5**	**0.1**	**2.3**	**4.5**	**4.7**	**6.3**

Table 7: Income statement of refinery's financial model with historical data

CASH FLOW STATEMENT	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Net Income	**1,036**	**1,663**	**1,203**	**1,604**	**213**	**- 395**	**424**	**1,016**	**863**	**1,101**
Depreciation	882	837	800	768	741	719	701	687	676	670
Operating Cash	**1,917**	**2,500**	**2,002**	**2,372**	**954**	**324**	**1,124**	**1,703**	**1,539**	**1,771**
Working Capital Change	**-1,320**	**-495**	**-254**	**-188**	**-584**	**911**	**-358**	**-708**	**-113**	**99**
Trade Receivables	-1,660	-454	-235	-175	-587	971	-418	-701	-72	105
Inventory	-904	-396	-280	-192	-642	791	-351	-654	-54	102
Suppliers' Credit	914	355	262	179	645	-851	411	646	13	-108
Others	331	-	-	-	-	-	-	-	-	-
Cash from Operations	**597**	**2,005**	**1,748**	**2,184**	**370**	**1,235**	**766**	**995**	**1,426**	**1,870**
Capital Investment	-0	-84	-160	-230	-296	-359	-420	-481	-541	-603
Free Cash	**597**	**1,921**	**1,588**	**1,954**	**73**	**876**	**346**	**514**	**885**	**1,268**
Dividend Payment	-	-	-	-	-	-	79	-85	-203	-173
Net Cash	**597**	**1,921**	**1,588**	**1,954**	**73**	**876**	**425**	**429**	**682**	**1,095**
Funding	-126	-1,886	-1,562	-1,936	-8	-961	-386	-365	-680	-1,106
Increase(Decrease) in Cash	**471**	**35**	**27**	**18**	**65**	**- 85**	**39**	**65**	**1**	**- 11**
Cash Opening	-	471	507	533	551	616	531	570	635	636
Cash Closing	471	507	533	551	616	531	570	635	636	625
RCF/Net Debt	**13.5%**	**20.3%**	**18.7%**	**27.0%**	**10.9%**	**4.1%**	**16.2%**	**22.9%**	**20.9%**	**30.2%**

Table 8: Cash flow statement of refinery's financial model with historical data

Overall trends of year-on-year change in net income are similar to actual data. However, the movement of ROCE looks very different from actual data. Compared to the data from Deutsche Bank, the ROCE of this model is too low. There are two main reasons. First, this refinery was built at the end of 2003, so its assets were relatively big, meaning that the accumulation of depreciations was small. On the contrary, most of the companies from actual data were old enough to reduce their assets, especially Property, Plant, and Equipment (PP&E). The second reason for the model's relatively low ROCE is that, in a rising price environment, LIFO stock accounting, which is adopted by many of oil and gas companies, is much more helpful to their net income.

Therefore, considering the simplicity of the financial model and the complexity of the actual performance of refineries, this section's developed financial model could be realistic enough to analyze and simulate the risk factors of an oil refinery.

5. RISK ANALYSIS AND SIMULATIONS

The objective of this chapter is to analyze risk factors using sensitivity analysis and to make Monte Carlo simulations using major risk factors such as crude oil price and crack spread.

5.1 Risk Analysis

For sensitivity analysis, five variables are selected: crude oil price, crack spread, marketing margin, utilization rate, and energy cost. This sensitivity analysis adopts the following criteria: present value of net income, present value of net cash flow, and average ROCE for ten years. Also, the upper, medium, and lower bounds of each variable are chosen as “Strong Case”, “Base Case”, and “Weak Case” respectively. To avoid global financial crisis in the sensitivity analysis, crude oil price data is based on the period from 2009-2013. Crack spread data is based on the time period of 1995-2013. The other variables are based on the past ten years. In addition, the discount rate for present value is assumed to be 10%.

@ 10% discount rate	Case			PV of Net Income - 10yrs			PV of Net Cash - 10yrs			ROCE - 10yrs average		
($ in million, $/bbl)	Weak	Base	Strong	Weak	Base	Strong	Weak	Base	Strong	Weak	Base	Strong
Crude Oil Price	$ 110.0	$ 97.9	$ 80.0	6,004	6,599	7,480	4,542	5,292	6,401	6.1%	6.8%	7.8%
				-595		*881*	*-750*		*1,109*	*-0.7%*		*1.0%*
Crack Spread	$ 4.6	$ 10.8	$ 12.3	-1,131	6,599	8,499	-1,007	5,292	6,840	0.2%	6.8%	8.4%
Gasoline	$ 1.5	$ 7.3	$ 13.5	*-7,731*		*1,899*	*-6,299*		*1,548*	*-6.6%*		*1.6%*
Naphtha	$ 1.2	$ 3.2	$ 2.3									
Jet Fuel	$ 8.9	$ 15.4	$ 15.7									
Diesel	$ 8.9	$ 17.3	$ 15.2									
Fuel Oil	$ -16.0	$ -14.3	$ -10.4									
Marketing Margin	$ 3.0	$ 5.0	$ 7.0	4,108	6,599	8,779	3,221	5,292	7,104	4.6%	6.8%	8.6%
				-2,491		*2,180*	*-2,071*		*1,812*	*-2.1%*		*1.8%*
Utilization Rate	90%	95%	97%	6,033	6,599	6,826	4,842	5,292	5,472	6.3%	6.8%	6.9%
- Sales Volume (MBPCD)	677	714	729	*-566*		*227*	*-450*		*180*	*-0.5%*		*0.2%*
Energy Costs	$ 3.0	$ 1.5	$ 1.0	4,715	6,599	7,228	3,725	5,292	5,814	5.2%	6.8%	7.3%
				-1,885		*628*	*-1,567*		*522*	*-1.6%*		*0.5%*
PV of Net Income - 10yrs	-6,382	6,599	11,429									
PV of Net Cash - 10yrs	-6,169	5,292	9,359									
ROCE - 10yrs average	-4.3%	6.8%	11.1%									

Table 9: Sensitivity table of oil refinery

If crude oil price goes up, net income also goes up in the short-term, which is mainly due to the flat price effect. However, a higher crude oil price increases the cost of production, which is due to a production yield of 94%. If the crude oil price is $80 per barrel, a 6% yield loss accounts for $80, but this would account for $120 in a higher oil price case. In addition, according to a higher crude oil price, working capital increases, which can make net cash flow even worse. Furthermore, the ROCE will exponentially deteriorate by higher capital employed such as inventory due to the higher crude oil price.

Impacts of the other variables are much more intuitive. Since annual production and sales volume is 277,400 Mbbl, impacts of crack spread on earnings would be the sales volume multiplied by the crack spread difference. The impacts of the marketing margin would be the sales volume multiplied by the marketing margin difference. The impacts of the utilization rate are realized through the sales volume change. Also, the impacts of energy cost would be the production volume multiplied by the energy cost difference.

5.2 MEAN REVERSION OF CRUDE OIL PRICE

WTI prices as a major risk factor are assumed to follow a simple type of mean-reverting process. In the sub-section, mean reversion process will be introduced and then actual calculation results will be described.

5.2.1 Introduction to Mean Reversion

Most commodity prices and some interest rates follow a mean reverting process: if the price is above the long run mean, supply increases and demand declines, bringing the price down; if the price is below the long run mean, supply decreases and demand increases, raising the price. The simple standard discrete time model of a mean reverting process is

$$X_{t+1} = X_t + \kappa\left(\mu - X_t\right) + \varepsilon_{t+1}, \qquad (1)$$

where X_t is the current value of the process at date t, μ is the long run mean value of the process, κ is the speed of adjustment coefficient, and ε_{t+1} is the value of a random shock that is independent of X_t. The amount (μ - X_t) is the correction toward the long run mean. The random shocks $\cdots\varepsilon_t$, ε_{t+1} $\cdots$ are independent, normally distributed, mean zero, constant variance (square of the standard deviation).

There are three parameters that need to be estimated, the long run mean μ, the speed of adjustment κ, and the standard deviation of the random shock σ. Subtracting X_t from both sides of (1) we get

$$X_{t+1} - X_t = \kappa\mu - \kappa X_t + \varepsilon_{t+1}. \quad (2)$$

This is just like a regression with dependent variable X_{t+1} - X_t and independent variable X_t with intercept = $\kappa\mu$ and slope = -κ. So regression of the price changes X_{t+1} - X_t on the price level X_t will produce estimates of the intercept and slope coefficients. If the estimated slope coefficient $-\hat{\kappa}$ is positive, there is no mean reversion and it is needed to change the specification. If the slope coefficient $-\hat{\kappa}$ is negative, then $-\hat{\kappa}$ is positive indicating the presence of mean reversion. The statistical significance of this coefficient can be tested by looking at its t-statistic. The rule of thumb is that if the absolute value of this t-statistic is greater than 2, then it is statistically significant. For a large enough sample size, if the absolute value exceeds 1.645, then the statistic is significant.

Finally, if the estimate of $\hat{\kappa}$ is statistically significantly positive and if the intercept coefficient is statistically significant, the long run mean could be estimated by solving $\hat{\mu}$ = intercept/$\hat{\kappa}$, and the standard deviation would be estimated as $\hat{\sigma}$ = standard error of the regression. To do this, it is necessary to know a starting value for the price level X. Typically the starting value of the price level is some latest historical observation.

5.2.2 Mean Reversion of WTI price

Future WTI prices are assumed to follow a simple type of mean-reverting process. To avoid an inflation effect on the price and on the financial performance of the refinery, historical prices are converted to real values as of January 2014. Also, in order to exclude the impact of global crisis in 2008 (designated by a red circle in the figure below) from simulation process, WTI prices after 2009 are used. However, WTI prices will be generated by a mean reversion method, which reflects the short-term supply shock such as crises in Libya in 2011 and in Syria in 2013.

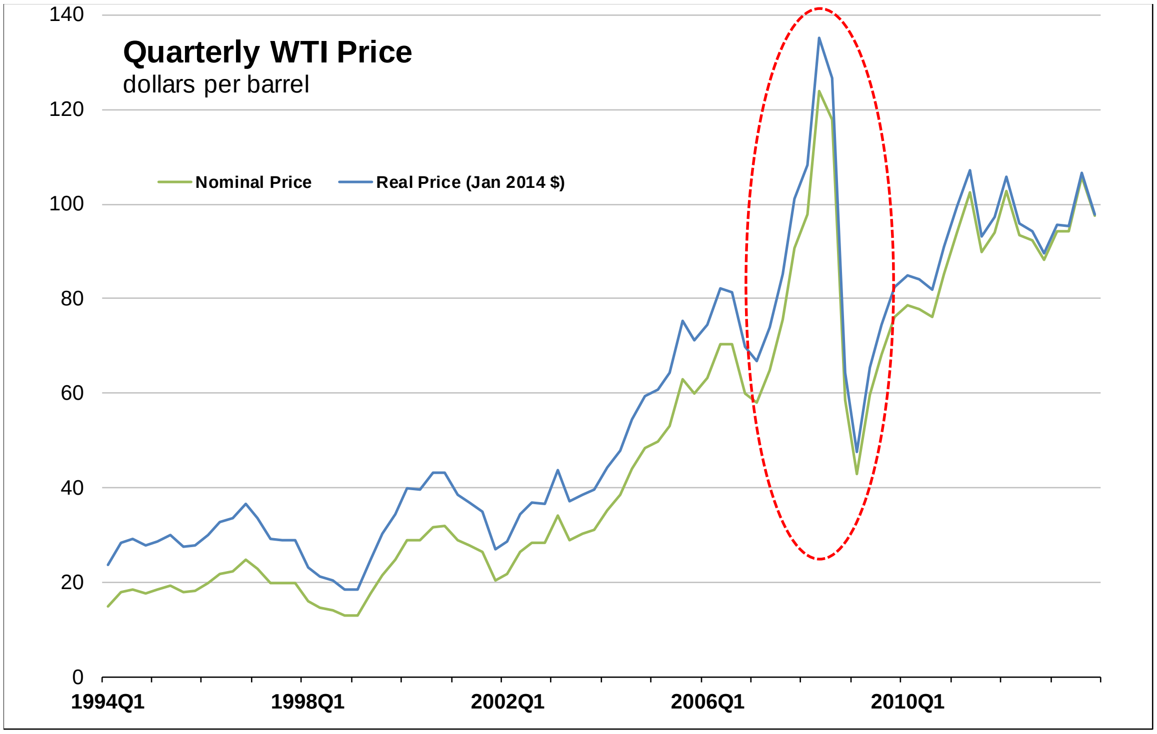

Figure 22: Quarterly WTI price - Nominal vs. Real (U.S. Energy Information Administration(eia), 2014)

If Xt is the average WTI price in $/bbl in year t, then:

$$X_{t+1} = X_t + \kappa\left(\mu - X_t\right) + \varepsilon_{t+1} \quad ,$$

where

κ is the mean reversion rate (speed of reversion to the mean reversion level)

μ is the mean reversion level or long run equilibrium price

σ is the standard deviation of the random shock

ε_{t+1} is a normally distributed random variable

Regression of the price changes X_{t+1} - X_t on the price level X_t based on the quarterly WTI price from 2009 to 2013 leads to the following table:

REGRESSION SUMMARY OUTPUT	

Regression Statistics	
Multiple R	0.8163
R Square	0.6664
Adjusted R^2	0.6479
Standard Error	8.5775
Observations	20

REGRESSION FORMULA

$$X_{t+1} = X_t + \kappa\left(\mu - X_t\right) + \varepsilon_{t+1}$$

ANOVA

	df	SS	MS	F	Significance F
Regression	1	2,645.46	2,645.46	35.96	0.00
Residual	18	1,324.32	73.57		
Total	19	3,969.78			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	22.0341	11.4091	1.9313	0.0694	-1.9357	46.0038	-1.9357	46.0038
Price t	0.7681	0.1281	5.9964	0.0000	0.4990	1.0373	0.4990	1.0373

κ	0.2319
μ	95.0272

X_{t+1} =	22.0341	+	0.7681 X_t	+ ε_{t+1}

Table 10: Regression summary for mean reversion

As shown in table above, the value of $-\hat{\kappa}$ is 0.2319, indicating the presence of mean reversion, and the absolute value of $\hat{\kappa}$'s t-statistic is 5.9964, which means that it is statistically significant.

5.3 Selection of Crack Spread Set

Unlike future crude oil price generating, crack spread generation is much more complicated and delicate. Each product price is affected by the product's supply and demand, and one product price can also affect another product price. If gasoline price increases, refineries want to produce more gasoline. Given that process, fuel oil production will also increase, because of the refining process's characteristic, which results in the decrease of fuel oil price. Thus, this thesis determined the selection process from historical crack spread sets. The basic pool of selection is constituted by annual crack spreads from 1995 to 2013. To place an emphasis on the recent price set, quarterly crack spreads from 2010 to 2013 are included in the pool. Thus, random selection is conducted from a crack spread pool with a total of 35 price sets. Since the crude oil price differential is linked with the crack spread, the selected crack spread set determines the crude oil price differential.

No.	Time	WTI less LLS	Brent less Dubai	Crack Spread	Gasoline	Naphtha	Jet Fuel	Diesel	Fuel Oil
1	1995	$ -0.18	$ 0.93	**$ 2.09**	$ 2.80	$ 1.15	$ 2.17	$ 1.83	$ 2.27
2	1996	$ -0.19	$ 2.11	**$ 2.56**	$ 2.69	$ 1.11	$ 3.18	$ 2.85	$ 2.54
3	1997	$ -0.11	$ 0.97	**$ 2.80**	$ 3.88	$ 1.99	$ 2.77	$ 2.31	$ 3.21
4	1998	$ 0.21	$ 0.47	**$ 2.53**	$ 3.19	$ 1.37	$ 2.76	$ 2.38	$ 2.68
5	1999	$ 0.22	$ 0.80	**$ 1.88**	$ 2.80	$ 1.08	$ 1.81	$ 1.42	$ 2.05
6	2000	$ -0.01	$ 2.39	**$ 4.23**	$ 4.70	$ 2.93	$ 5.22	$ 4.30	$ 4.33
7	2001	$ 0.04	$ 1.68	**$ 4.04**	$ 5.05	$ 2.57	$ 4.39	$ 3.79	$ 4.37
8	2002	$ -0.13	$ 1.22	**$ 2.78**	$ 4.04	$ 2.27	$ 2.56	$ 2.13	$ 3.14
9	2003	$ -0.10	$ 2.05	**$ 3.54**	$ 5.43	$ 3.14	$ 3.41	$ 3.23	$ -7.16
10	2004	$ -0.05	$ 4.67	**$ 5.36**	$ 7.66	$ 4.86	$ 6.79	$ 5.38	$ -16.76
11	2005	$ -0.45	$ 5.23	**$ 10.37**	$ 10.29	$ 6.04	$ 14.93	$ 13.65	$ -20.51
12	2006	$ -1.44	$ 3.64	**$ 10.67**	$ 9.94	$ 3.68	$ 13.30	$ 15.71	$ -21.90
13	2007	$ -3.06	$ 3.94	**$ 10.85**	$ 10.90	$ 6.03	$ 14.04	$ 14.75	$ -22.17
14	2008	$ -2.73	$ 3.67	**$ 10.13**	$ 2.26	$ -2.03	$ 21.71	$ 20.30	$ -29.86
15	2009	$ -2.55	$ -0.01	**$ 4.36**	$ 5.07	$ 1.21	$ 5.46	$ 5.45	$ -8.52
16	2010	$ -3.35	$ 1.37	**$ 5.09**	$ 4.21	$ 1.81	$ 7.49	$ 7.83	$ -13.11
17	2011	$ -17.31	$ 5.08	**$ 7.44**	$ 4.39	$ 0.09	$ 13.56	$ 12.43	$ -16.55
18	2012	$ -17.57	$ 2.59	**$ 11.21**	$ 8.53	$ 4.77	$ 16.59	$ 16.53	$ -12.35
19	2013	$ -9.44	$ 3.14	**$ 10.78**	$ 7.29	$ 3.17	$ 15.40	$ 17.32	$ -14.30
20	1Q 2010	$ -1.20	$ 0.41	**$ 5.23**	$ 5.98	$ 3.58	$ 6.36	$ 6.35	$ -9.50
21	2Q 2010	$ -4.39	$ 0.18	**$ 5.61**	$ 5.83	$ 2.35	$ 7.04	$ 7.78	$ -13.63
22	3Q 2010	$ -3.60	$ 2.96	**$ 4.84**	$ 3.38	$ 0.11	$ 7.55	$ 8.16	$ -12.95
23	4Q 2010	$ -4.18	$ 2.17	**$ 4.60**	$ 1.54	$ 1.24	$ 8.94	$ 8.94	$ -16.03
24	1Q 2011	$ -13.17	$ 4.48	**$ 6.01**	$ 1.79	$ 0.72	$ 13.05	$ 11.47	$ -19.65
25	2Q 2011	$ -16.11	$ 6.64	**$ 8.67**	$ 9.78	$ 1.44	$ 12.97	$ 10.85	$ -20.04
26	3Q 2011	$ -22.90	$ 6.35	**$ 9.35**	$ 7.62	$ 1.28	$ 14.58	$ 13.72	$ -14.07
27	4Q 2011	$ -16.76	$ 2.85	**$ 5.52**	$ -2.01	$ -3.26	$ 13.48	$ 13.58	$ -12.55
28	1Q 2012	$ -16.61	$ 2.34	**$ 8.71**	$ 6.17	$ 2.35	$ 14.18	$ 13.21	$ -11.73
29	2Q 2012	$ -15.03	$ 1.84	**$ 12.30**	$ 13.48	$ 2.30	$ 15.74	$ 15.16	$ -10.43
30	3Q 2012	$ -17.29	$ 3.29	**$ 15.07**	$ 14.67	$ 6.55	$ 19.83	$ 19.60	$ -12.07
31	4Q 2012	$ -21.34	$ 2.53	**$ 8.52**	$ -0.68	$ 8.02	$ 16.51	$ 17.99	$ -15.17
32	1Q 2013	$ -19.63	$ 4.36	**$ 9.97**	$ 5.38	$ 11.94	$ 16.04	$ 15.83	$ -16.78
33	2Q 2013	$ -10.51	$ 1.67	**$ 10.78**	$ 11.81	$ -6.55	$ 11.57	$ 15.47	$ -13.76
34	3Q 2013	$ -4.09	$ 4.06	**$ 10.48**	$ 8.53	$ -1.04	$ 13.72	$ 16.65	$ -16.89
35	4Q 2013	$ -3.55	$ 2.46	**$ 11.90**	$ 3.43	$ 8.35	$ 20.28	$ 21.33	$ -9.76

Table 11: Crack spread pool

5.4 CORRELATION BETWEEN CRUDE OIL PRICE AND CRACK SPREAD

The notion that if crude oil price increases, then the net income of oil refinery also increase was accepted as a common sense axiom about refining sector until 2008. Because crude oil is the biggest cost of an oil refinery, at a glance, this notion appears to be nonsense. However, the background behind this thought is that crude oil price and crack spread have a positive correlation. In addition, because the conversion margin, such as gasoline price minus fuel oil price or diesel price minus fuel oil price, increases in higher oil price period, USGC Heavy Sour Coking margin reached a level of $25 per barrel.

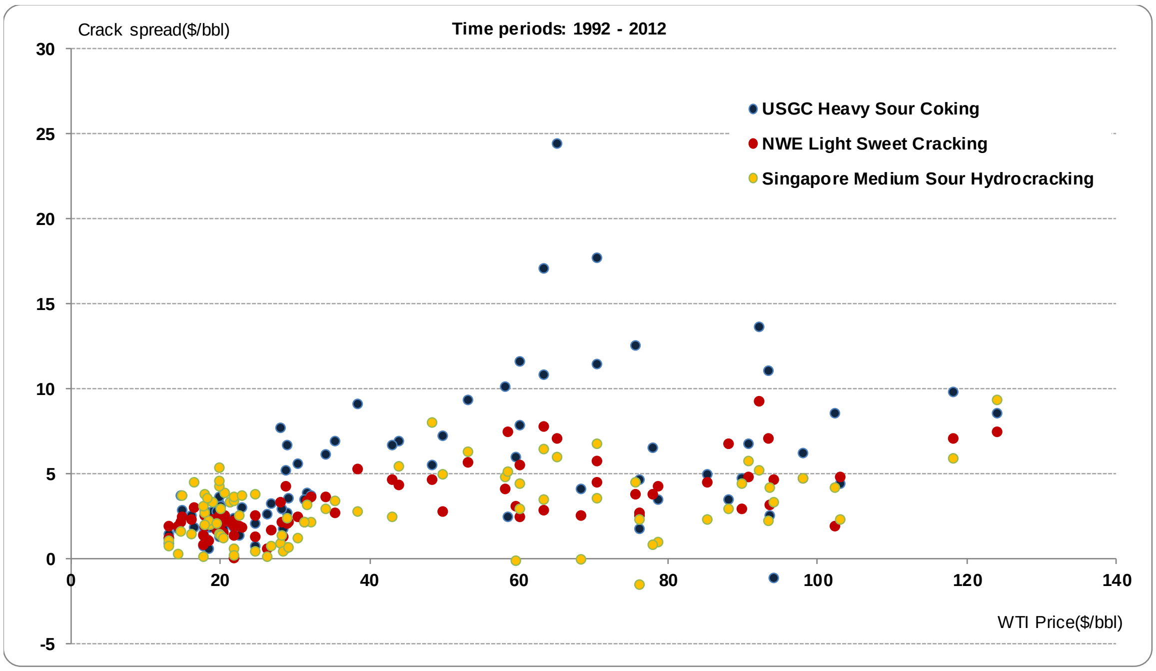

Figure 23: Correlation between crude oil price and crack spread 1992-2012 (BP, 2013)

As shown in the figure above, USGC Heavy Sour Coking (blue dots) is apparently correlated with the WTI price at a level under $80. But, at a level over $80, this relationship is unclear or disappeared. Separation of the time period can make this view clear. In the following figure, time periods are separated before and after 2008.

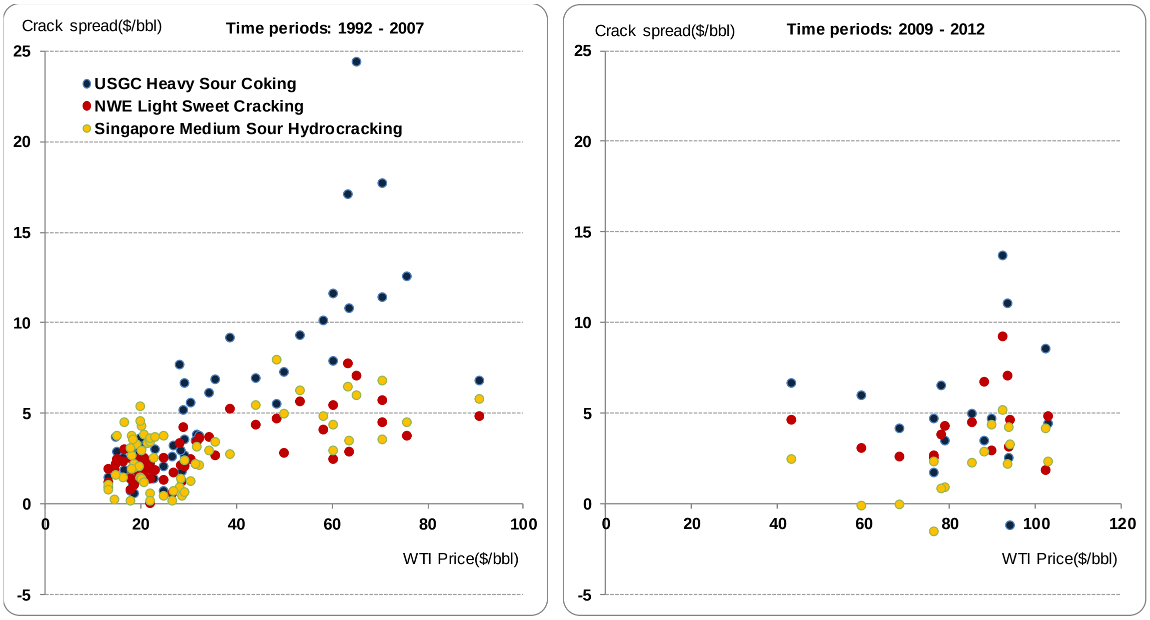

Figure 24: Correlation between crude oil price and crack spread 1992-2007 vs. 2009-2012 (BP, 2013)

The different relationships between crude oil price and crack spread depend on the factors that push up prices. From 1992 to 2007, the demand of refined product was increasing due to the stable growth of the global economy and crude supply and refining capacities were not enough to meet the demand, so the strong demand pulled the refined product price and crude oil price together. However, after the crisis in 2008, global demand of refined product shrunk due to the staggering economy, so crack spread decreased even when crude oil price increased. Therefore, this thesis does not assume that crude oil price is related with the crack spread.

5.5 Monte Carlo Simulation

In order to measure the risk exposure of an oil refinery, this thesis makes Monte Carlo simulation 10,000 times, by using @RISK software, with the assumptions of base case in the previous section. Output variables are present value of net income (PV of NI), present value of net cash flow (PV of NC), and average ROCE for future ten years.

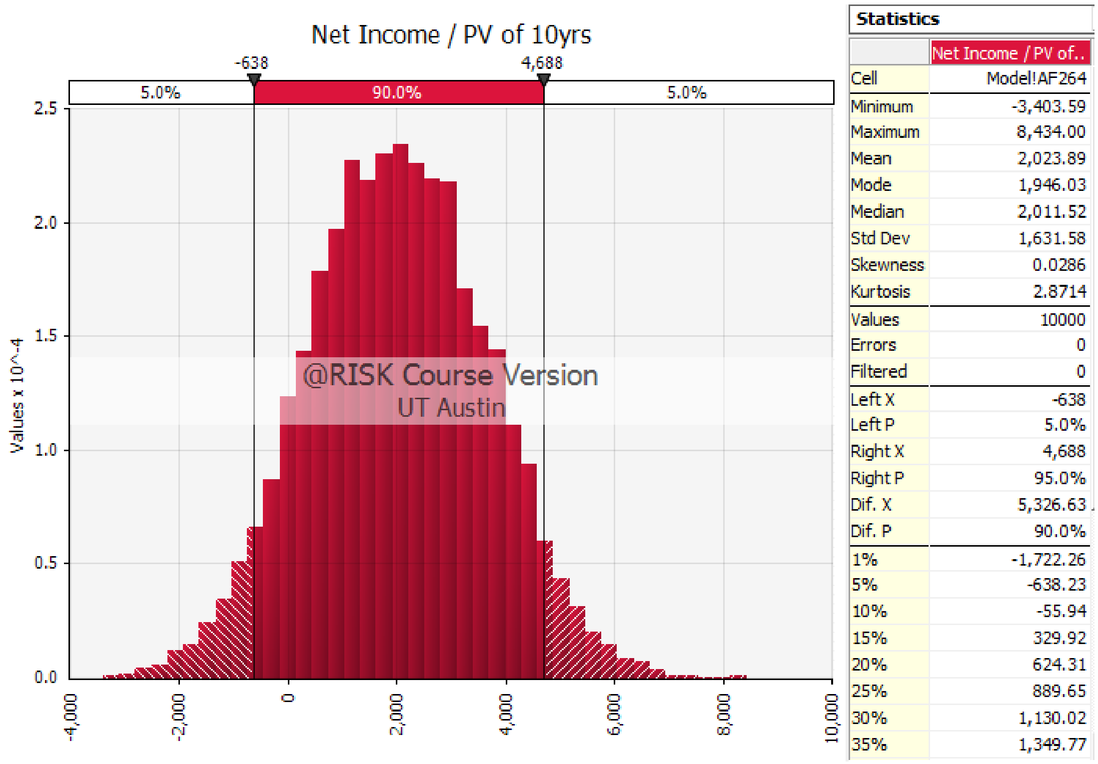

Figure 25: Simulation output - PV of NI

The simulation result of PV of NI is that its mean value is about 2 billion dollars and standard deviation is about 1.6 billion dollars. The mean value is not a bad one, but the standard deviation matters. With this standard deviation, accumulation of net income for ten years could be negative in the 90% of confidence interval. Because net income includes many of non-cash items, negative net income of small probability would not be a big deal, if net cash flow would not be negative.

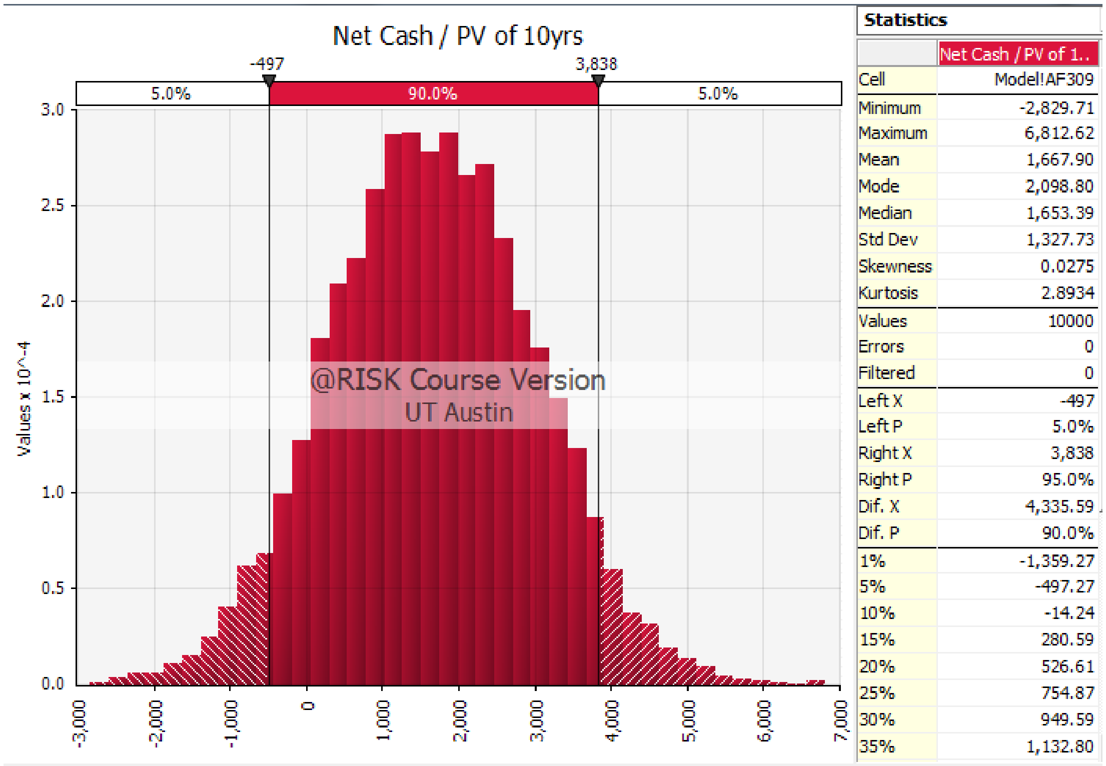

Figure 26: Simulation output - PV of NC

However, the simulation results show that cumulative net cash flow would be negative with similar probability, which means that this oil refinery could not repay for its debt with its operation and business, but have to borrow from bond market or equity market for future ten years.

In addition, refining sector does not look good to investors. Money flows into the investment opportunities with high return. As shown in the figure below, the mean of average ROCE for future ten year is about 3.0% and 5.0% at best. Compared with 10% guideline of ROCE by Chevron, it is too low and unattractive to investors. The fact that, in recent five years, major oil companies, such as Chevron and Exxon, continuously divest their downstream assets supports this interpretation.

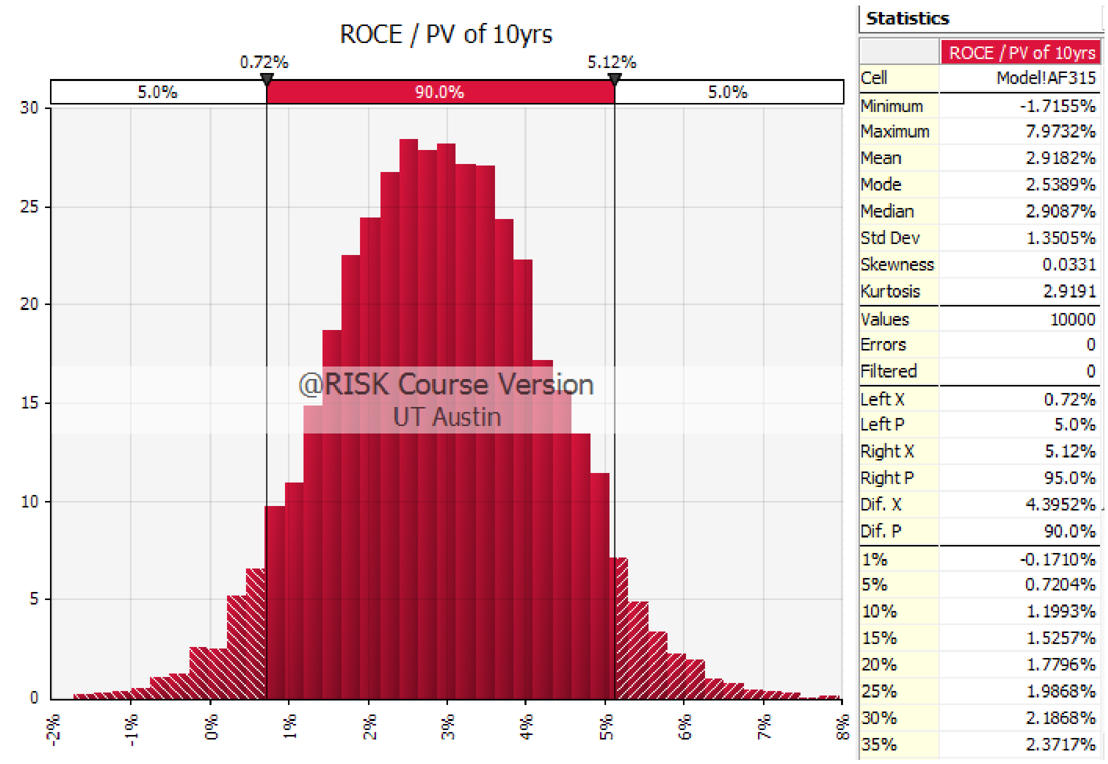

Figure 27: Simulation output - average ROCE

In consequences, if they do not prepare a countermeasure, oil refineries should be exposed to volatile risks. In this analysis, reduction of demand due to high crude oil price and development of renewable energy is not included, but it is probable story in near future. Therefore, oil refineries have to consider how to cope with the situation, which would be the next study topic.

6. CONCLUSION

The refining industry has long sought to improve profit margins through operating efficiencies and price risk management. In recent years, capital constraints, regulatory changes, and new refinery construction around the world have resulted in additional cost pressure and great competition. Furthermore, market volatility has increased.

This study examined the volatility of an oil refinery in terms of net income, net cash flow, and ROCE by using a Monte Carlo simulation. This thesis analyzed the risk factors of an oil refinery, and made simulations of its performance in order to measure the impacts of risks. In addition, this thesis developed a financial model of an oil refinery for analysis and simulation.

The simulation results show that cumulative net income and cumulative net cash flow for ten years would be negative with the 90% of confidence level, which means that this oil refinery could not repay for its debt with its operation and business and would have to borrow from a bond market or an equity market for the future ten years. Moreover, the mean of the average ROCE for the future decade is about 3.0%; 5.0% at best. Therefore, it would not be easy for the refinery to borrow money from financial markets with this unattractive ROCE.

Even though, in order to cope with this situation, refiners are seeking a range of solutions, such as process and efficiency improvements, reduction in working capital, and investment in energy efficiency and fuel quality, these efforts could not give returns enough. However, the emergence of more creative financial structures offers an innovative and compelling alternative that should help many refiners to capture higher, more stable returns. Therefore, trading players and banks should be expected to play an important role in defining the vision of the future competitive refining market.

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