TRABAJO ESPECIAL DE GRADO

ANÁLISIS DE LA DEMANDA Y OFERTA DE LA INDUSTRIA DE REFINACIÓN DE PETRÓLEO EN LOS ESTADOS UNIDOS

Presentado ante la Ilustre
Universidad Central de Venezuela
Por el Br. Gonzalez A. Emmanuelle
Para optar al Título de
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Supply and Demand Analysis of the U.S. Petroleum Refining Industry

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ANÁLISIS DE LA DEMANDA Y OFERTA EN LA INDUSTRIA DE REFINACIÓN DE PETRÓLEO EN LOS ESTADOS UNIDOS

Resumen: El presente trabajo consiste en el análisis de la demanda y oferta de productos refinados en los Estados Unidos de América, haciendo particular énfasis sobre la gasolina en el período comprendido entre 2005 y 2010. Para ello se utilizaron datos estadísticos de la Administración de la Información de Energía (EIA, por sus siglas en inglés), del Departamento de Energía de los Estados Unidos (DOE), y de diversas agencias gubernamentales. El trabajo inicia con la caracterización del sector, incluyendo una descripción de los procesos y productos más importantes de esta industria y la distribución geográfica y configuración de las refinerías existentes. Seguidamente se analizaron las principales características de la oferta de productos refinados en los últimos 10 años, identificando las principales tendencias en capacidad de refinación, empresas operadoras y sus cuotas de mercado, niveles históricos de rentabilidad y crecimiento del sector. Especial interés fue colocado en el análisis del margen de refinación de los últimos 5 años, identificando las principales causas de variabilidad endógena y exógena. Consecutivamente se llevó a cabo un estudio desde el punto de vista de la demanda de gasolina, identificando las regiones de consumo, la elasticidad de la demanda respecto al precio, los principales métodos de transporte y mercadeo. Por último se realizó un análisis del impacto de la creciente producción de etanol; leyes cada vez más estrictas, orientadas a la protección del ambiente, han favorecido el uso del etanol mezclado con gasolina y la disminución efectiva del consumo de combustibles fósiles convencionales como gasolina y diesel.

SUMMARY

Petroleum refining is one of the most important industries in the United States. Its wide variety of products provide for about 37% of the total energy consumed in the country, with a share of almost 90% in ground transportation fuels, comprising public and privately own vehicles (EIA 2011). The principal objective of this thesis is the characterization of the petroleum refining sector in the United States. Special emphasis is made in gasoline since it has the biggest share within the wide variety of petroleum products. The study is focused on the time period from 2005 to 2010.

The first chapter is an introduction to the thesis and an overview of the objectives.

The second chapter serves as a frame of the sector, describing the most common processes and the products involve in crude refining are described. U.S. refineries were classified in order of complexity and analysis was done attempting to explain variations between regions. A brief geographic description of the United States is included.

The third chapter describes the main characteristics of crude and petroleum products supply in the United States. Number and geographic distribution of the refineries, identification of the 10 most important refining companies, market share for each one of them and a concentration index of the sector, growth rate, and future tendencies in supply were considered. Special interest is placed in the historical analysis of the refining margins of the last 5 years, identifying the main endogenous and exogenous causes of variability.

The fourth chapter refers to gasoline demand in the United States; the main factors influencing gasoline demand were discussed. A 5 year analysis was made, identifying middle term trend and seasonality. In this chapter there is also a review of different studies about gasoline elasticity. The most important transportation and marketing methods are described, including current tendencies in transportation. Finally, the influence of ethanol blending in gasoline demand is analyzed.

In the fifth and last chapter conclusions are presented.

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CHAPTER I

INTRODUCTION

Petroleum refining is the physical, thermal and chemical separation of crude oil into its major distillation fractions which are then further processed through a series of separation and conversion steps into finished petroleum products. The primary products of the industry fall into three major categories: fuels (motor gasoline, diesel and distillate fuel oil, liquefied petroleum gas, jet fuel, residual fuel oil, kerosene, and coke); finished nonfuel products (solvents, lubricating oils, greases, petroleum wax, petroleum jelly, asphalt, and coke); and chemical industry feedstocks (naphtha, ethane, propane, butane, ethylene, propylene, benzene, toluene, and xylene). These products comprise and are used as primary input to a vast number of products, including: fertilizers, pesticides, paints, waxes, thinners, solvents, cleaning fluids, detergents, refrigerants, antifreeze, resins, sealants, insulations, latex, rubber compounds, hard plastics, plastic sheeting, plastic foam and synthetic fibers.

Petroleum refining is one of the most important industries in the United States. Its wide variety of products provide for about 37% of the total energy consumed in the country, with a share of almost 90% in ground transportation fuels, comprising public and privately own vehicles. (Bureau of Transportation Statistics, 2003). But its importance seems to be at stake; acknowledgement of the environmental impact caused by crude oil production and refining operations have impulse U.S. governmental agencies to formulate more stringent policies against pollution, many of them enforced by law. Higher crude oil prices, with consequent higher fuel prices, are affecting the way consumers allocate their budget in transportation, investing in higher efficiency vehicles and minimizing fuel consumption in the long term. Altogether, these factors are changing the dynamics of supply and demand, and new alternatives that seemed unlikely are not only been considered, but becoming a reality. A clear example is the development of the ethanol industry and its significant production increase in the last 5 years. In relation to its economic importance, the petroleum industry is comprised of relatively few companies and facilities. This work is a general overview of the modern refining industry, describing the main products in terms of their physical characteristics, processes and units involved in crude oil distillation. A 5 year analysis was done for supply and demand of gasoline (considered the main petroleum product), identifying the main patterns and trends, the biggest companies in the market, pricing, marketing and transportation.

CHAPTER II

GENERAL OVERVIEW

II.1 GEOGRAPHY

The United States of America is a federal constitutional republic divided in fifty states and a federal district. It is located north of the American Continent, bordered by Canada in the north, Mexico in the South, the Atlantic Ocean to the east and the Pacific Ocean to the west. The state of Alaska is in the northwest of the continent, with Canada to the east and Russia to the west across the Bering Strait. The state of Hawaii is an archipelago in the mid-Pacific. The country also possesses several territories in the Caribbean and Pacific.

The United States Census Bureau estimates a total population of 308.7 million of people in 2010. At 9.83 million square kilometers, the United States is the world's third-largest country by size, after Russia and Canada, and by population, after China and India. It is one of the world's most ethnically diverse and multicultural nations, the product of large-scale immigration from many countries. The U.S. economy is the world's largest national economy, with an estimated Gross Domestic Product per capita of $47.200 in 2010 (Central Intelligence Agency, 2011). The major population areas are New York City and northern New Jersey with 18.7 million inhabitants on the east coast; Los Angeles, Long Beach and Santa Ana with 12.9 million on the west coast; and the Chicago area with 9.4 million in the eastern center of the country.

The United States can be divided in 5 regions, called Petroleum Administration for Defense Districts, or PADDs (see Figure II.1). These were created during World War II under the Petroleum Administration for War to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel (or "distillate") fuel. Today, these regions are still used for data collection purposes.
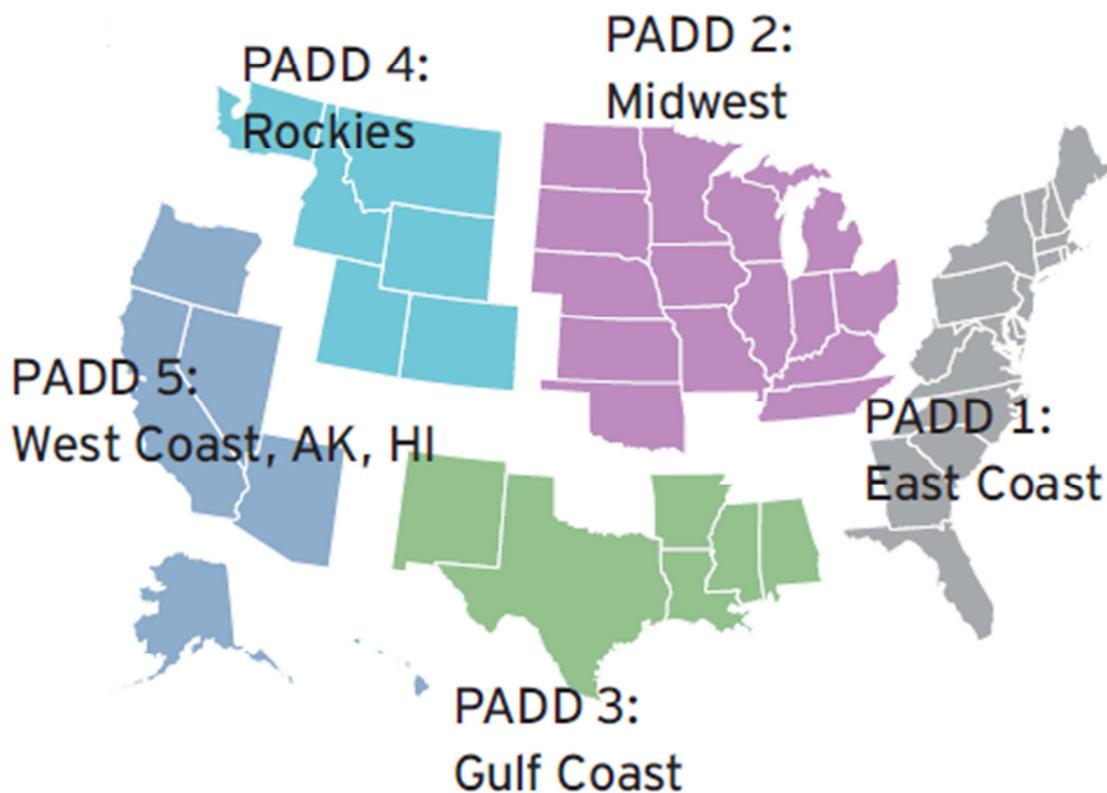
Figure II.1 United States geographic division by Petroleum Administration for Defense Districs (PADDs)

- PADD I (East Coast): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont, Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania, Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia.

- PADD II (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, Oklahoma, Tennessee, and Wisconsin.

- PADD III (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, and New Mexico, and Texas.

- PADD IV (Rocky Mountains): Colorado, Idaho, Montana, Utah, and Wyoming.

- PADD V (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

II.2 U.S. TRANSPORTATION

Personal transportation in the United States is dominated by automobiles, which operate on a network of more than 13 million roads. It is the world's second largest automobile market. In 2002, the United States had the highest rate of per-capita vehicle ownership in the world, with 812 vehicles per 1,000 Americans. (Dargay, Gately, & Sommer, 2007). As shown in figure II.2, the majority of daily trips in 2001 occurred in personal vehicles (87%), whether single occupant (38%) or multiple occupants (49%). The average American adult (accounting for all drivers and nondrivers) spends 55 minutes driving every day, traveling 47Km. (Bureau of Transportation Statistics, 2003)
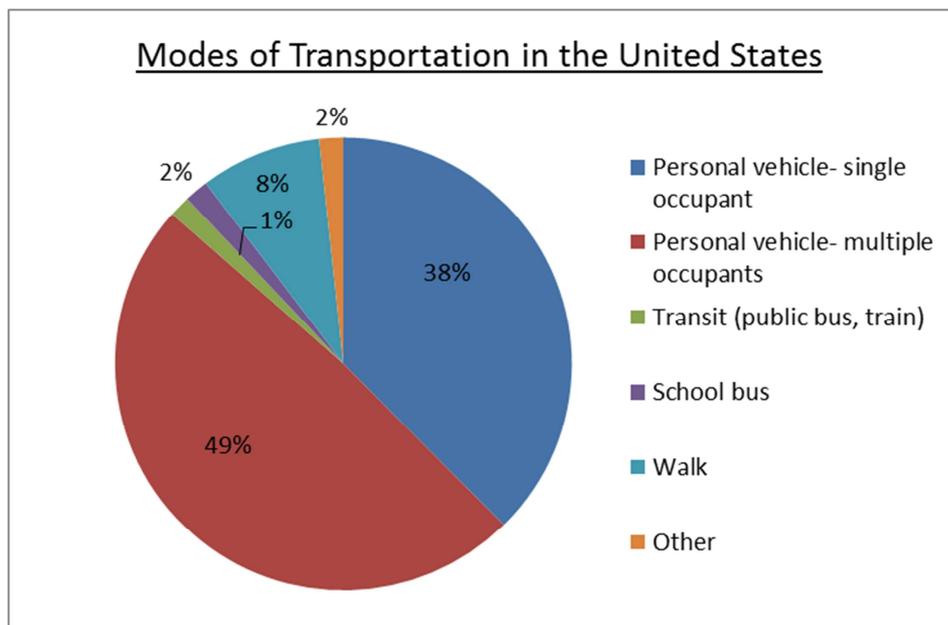
Figure II.2 Distribution of trips by modes of transportation. 2001 National Household Travel Survey

While transport of goods by rail is extensive, relatively few people use rail to travel. Light rail development has increased in recent years but has not reached the levels of countries such as Japan. Bicycle usage is minimal for commuting to work and is more common for recreation.

The civil airline industry is entirely privately owned and has been largely deregulated since 1978, while most major airports are publicly owned. The four largest airlines in the world by passengers carried are American. Of the world's thirty busiest passenger airports, sixteen are in the United States, including the busiest, Hartsfield-Jackson Atlanta International Airport.

II.3 HISTORY OF PETROLEUM REFINING

In 1859, two separate events would start up the petroleum and the auto industries. In that year, "Colonel" Edwin L. Drake drilled the world's first working oil well in Titusville, Pennsylvania, and French engineer J.J. Etienne Lenoir made the world's first dependable internal combustion engine, which was powered by gasoline.

Col. Drake's oil well kicked off the petroleum industry, and Lenoir's work was the precursor for the creation of the modern automobile. That early period from 1860 to 1900 was marked by many technological innovations as auto inventors sought to tap the potential of the internal combustion engine, and petroleum pioneers got better at producing, refining and delivering oil and petroleum products. Oil industry entrepreneurs such as John D. Rockefeller and Henry Flagler discovered new oil fields, drilled deeper oil wells than Col. Drake's first 70-foot well, and made great innovations in both refining and distributing refined products. (Adler, 2008)

The first oil refinery, which used atmospheric distillation to produce kerosene, was constructed in 1862. Naphtha (gasoline) was a byproduct of these early distillation units, and in a few decades, would emerge as their most important product. There were no regulations and new wells were drilled randomly, wildly fluctuating oil supplies and prices. One person saw this chaos and saw through it to the opportunities the new industry offered, if only order could be brought to it. John D. Rockefeller began investing in oil refining in Cleveland in 1863 and within nine years controlled 21 of the 26 refineries in Cleveland. (U.S. Internal Revenue Service, 2008). He saw that he could control the industry by controlling refining. He sought to integrate and control all phases of the business, eliminating wasteful duplication (and competition) in the process. Rockefeller insisted that his products be made to specific standards that the public could depend on, and he proudly named his company the Standard Oil Company. The public preferred reliable products and his empire grew, eventually controlling 90% of oil refining in the United States by 1890. The Sherman Anti-Trust Act and federal litigation eventually broke up Rockefeller's control of the industry. When the Standard Oil Company was broken up in 1911, it was broken into regional companies which remained vertically integrated but which the Rockefellers were forbidden to exercise control of. Those companies began competing with each other and expanding into each other's territories. Today the ones that remain operate virtually worldwide. They no longer monopolize regions, but they are still vertically integrated.

The automobile's rise in the early 19th century bolstered oil demand. While the country only had roughly 8,000 passenger cars at the turn of the century, by 1908, the year that Henry Ford's Model T made its market debut, that figure had swelled to 125,000. Refiners met the skyrocketing demand for motor fuels by advancing beyond the basic

distillation processes that had been in use since the 1860s. In 1913, they developed thermal cracking, which was able to produce more gasoline and diesel from a barrel of oil, and the technique was only the first of many processing innovations that allowed refiners to satisfy market demand.

World War I further established oil's importance. England's oil-powered warships overtook Germany's coal-powered fleet. Tanks and airplanes made their debuts as weapons of war. During the time, aviation fuel was basically naphtha. To keep Allied war vehicles running, major U.S. oil companies teamed up with the Federal Fuel Administration in 1917 to systematize oil production, refining, and shipping. (Adler, 2008).

The country emerged from the war to enjoy a period of economic growth. And much of the prosperity was linked to the rapid road and bridge construction that gave America's automobiles a place to go. From 1920 to 1930, the number of cars owned by Americans jumped from 8.1 to 26.7 million. The Great Depression put a dent on vehicle sales, especially during the early 1930s, but the auto industry was definitely rolling.

Oil companies prospered along with automakers. Refiners built more refineries and expanded existing facilities. They also improved thermal-cracking techniques and developed other catalytic processes to produce high-grade products. High-octane gasoline emerged in the 1930s from refiners' tireless efforts, and it would play a role in World War II. Running on high-octane fuel, which optimizes engine performance, Allied planes outmaneuvered German planes using inferior fuels. U.S. oil refineries kept the Allies' fuel supply coming, providing them with as much as 80% of the fuel they used during the war.

Another important development during the war was the building of long-distance pipelines. By that time, crude and product pipelines had overtaken rail tankcars as the main method of transporting liquid hydrocarbons. In 1942 and 1943, engineers built what was then the world's longest crude oil pipeline dubbed "The Big Inch," which spanned 1,254 miles and moved crude from Texas oil fields to East Coast refineries. "The Big Inch" was followed by "The Little Inch," which transported products along a similar route. These two pipelines form part of the Colonial Pipeline system today.

After World War II, the U.S. became a world superpower and created as much wealth between 1950 and 1965 as it did from 1607 (the year that saw the first permanent settlement in Virginia) until 1950. National wealth doubled again from 1965 to 1980. Not only did the hydrocarbon industries benefit from Americans purchasing more than 8 million new cars per year in the 60s, but also started to count on commercial jets as big consumers. Jet fuel demand increased steeply from about 50,000 bpd (barrels per day) in 1950, to 280,000 bpd by 1960, and 970,000 bpd by 1970.

In 1969, an accident on a Union Oil rig produced a large oil slick off the coast of Santa Barbara, California. The government championed the cause of the environment, created the Environmental Protection Agency (EPA) in 1970, and pressured the refining industry and automobile manufacturers to clean up their act. That time period also highlighted another challenge: fuel economy. The United States had to acknowledge its growing dependence on imported oil. Production of petroleum (crude oil and natural gas liquids) in the country's lower 48 states hit its maximum in 1970 at 9.4 million barrels per day. And the disruptive effect of the 1973 embargo of oil imports by the Organization of Petroleum Exporting Countries (OPEC) drilled home that dependence and stressed the need for fuel efficiency.

Once again the fuels and auto industries' priorities overlapped and over the next 30 years, their individual and joint research and development efforts would produce superior engines and cleaner-burning fuels. For example, they raised the average fuel economy of new light-duty vehicles from 13.7 miles per gallon (city driving) in 1975 to 24.2 in 1988. And also claimed another remarkable achievement—the complete phase out of lead from gasoline.

According to the EPA, today's cars release 97% less pollution than they did in 1965. In fact, total U.S. vehicle emissions have decreased by over 30% even though Americans have never done more driving—almost 140% more today than they did in 1970. Refiners are now working on even cleaner-burning fuels to satisfy government mandates that call for the elimination of nearly all remaining emissions from light-duty vehicles.

II.4 REFINERY DESCRIPTION

The typical fuels refinery has as a goal the conversion of as much of the barrel of crude oil into transportation fuels as is economically practical. Although refineries produce many profitable products, the high-volume profitable products are gasoline, diesel and turbine (jet) fuels, and the light heating oils No.1 and No. 2. These transportation fuels have boiling points between 0 and 345°C. Light heating oils are properly transportation fuels but the hydrocarbon components are interchangeable with those of diesel and jet fuels, only the additives are different. Although products such as lubricating oils, refrigeration and transformer oils, and petrochemical feedstocks are profitable, they amount to less than 5% of the total crude oil charged to U.S. refineries. A refiner's choice of crude oil will be influenced by the type of processing units at the refinery.

II.4.1 Feedstocks

The main refinery feedstock is crude oil. Crude oils are complex mixtures containing many different hydrocarbon compounds that vary in appearance and composition from one oil field to another. They range in consistency from water to almost solid, and in color from clear to black. In table II.1, it is possible to see the approximate characteristic of some highly traded crude oils. Crude oils are generally classified as paraffinic, naphthenic, or aromatic, based on the predominant proportion of similar hydrocarbon molecules. Mixed-base crudes have varying amounts of each type of hydrocarbon. Refinery crude base stocks usually consist of mixtures of two or more different crude oils.

Relatively simple crude oil assays are used to classify crude oils as paraffinic, naphthenic, aromatic, or mixed. One assay method (United States Bureau of Mines) is based on distillation, and another method (UOP "K" factor) is based on gravity and boiling points. More comprehensive crude assays determine the value of the crude (i.e., its yield and quality of useful products) and processing parameters. (Stellman, 1998). They usually contain the following data:
- Whole crude salt, gravity, viscosity, sulfur, light-end carbons, and the pour point.
- A True Boiling Point (TBP) curve and a mid-volume plot of gravity, viscosity, sulfur, and the like.
- Light-end carbons analysis up to 8 or 9-carbon atom.
- Properties of fractions (naphthas, kerosenes, diesels, heavy diesels, vacuum gas oils, and resids). The properties required include yield as volume percent, gravity, sulfur, viscosity, octane number, diesel index, flash point, fire point, freeze point, smoke point, and pour point.
- Properties of the lube distillates if the crude is suitable for manufacture of lubes.
- Detailed studies of fractions for various properties and suitability for various end uses.

Crude oils are also defined in terms of API (American Petroleum Institute) gravity. Higher API gravity means a lower crude density. Crude oils with low carbon, high hydrogen, and high API gravity are usually rich in paraffins and tend to yield greater proportions of gasoline and light petroleum products; those with high carbon, low hydrogen, and low API gravities are usually rich in aromatics. The formula to calculate API gravity is:

$$°API = \frac{141.5}{\gamma_o} - 131.5$$

Although there is not an international agreement, crude oil are usually classified as follow:
- <10 °API: Extra-heavy

- 10<°API <20: Heavy
- 20<°API <30: Medium
- 30<°API <40: Light
- >10 °API: Extra-light

Some crude oils contain appreciable quantities of hydrogen sulfide or other reactive sulfur compounds. This is an undesirable property and refiners make heavy investments in order to remove it. Crude oils with high sulfur are referred to as sour crudes while those with low sulfur content are referred to as sweet crudes. Some exceptions to this rule are West Texas crudes, which are always considered sour regardless of their sulfur content, and some Arabian high-sulfur crudes, which are not considered sour because their sulfur compounds are not highly reactive.

Table II.1 Typical Crude Oil Characteristics

Crude	Location	Paraffins (% vol)	Aromatics (% vol)	Naphthenes (% vol)	Sulfur (% wt)	API gravity
Agbami	Africa (Nigeria)	58.8	10.6	30.5	.054	47.2
Brent	Europe (North Sea)	87.5	0	12.5	0.43	38.5
Hamaca	South America (Venezuela)	94.3	0	5.7	1.55	26
WTI	North America (United States)	88.9	0	11.1	0.24	40.8

II.4.2 Configuration

Refineries fall into three broad categories:
(a) Topping plant: It is the configuration with the lowest complexity. Consists only of a distillation unit and sometimes a catalytic reformer to provide octane. Yields from this plant would most closely reflect the natural yields from the crude processed. Typically only condensates or light sweet crude would be processed at this type of facility unless markets for heavy fuel oil (HFO) are readily and economically available. Asphalt plants are topping refineries that run heavy crude oil because they are only interested in producing asphalt.
(b) Cracking refinery: This refinery takes the gas oil portion from the crude distillation unit (a stream heavier than diesel fuel, but lighter than heavy fuel oil) and breaks it down further into gasoline and distillate components using catalysts, high temperature and/or pressure.
(c) Coking refinery: This refinery processes residual fuel, the heaviest material from the crude unit and thermally cracks it into lighter product in a coker or a

hydrocracker. The addition of a fluid catalytic cracking unit (FCCU) or a hydro cracker significantly increases the yield of higher-valued products like gasoline and diesel oil from a barrel of crude, allowing a refinery to process cheaper, heavier crude while producing an equivalent or greater volume of high-valued products.

Figure II.3 below shows that using the same crude input yields a very different range of petroleum products depending on the refinery complexity level. In the case of the cracking and coking refinery, the addition of other blending materials at various stages of production is required but the resulting volumetric output is greater than the volume of the crude oil input. Each refinery is unique due to age, technology and modifications over time, but generalizations are possible. The installation of additional conversion capability increases the yield of clean products and reduces the yield of heavy fuel oil. However, increased conversion capability would generally result in higher energy use and, therefore, higher operating costs. These higher operating and capital costs must be weighed against the lower cost of the heavier crude oil.
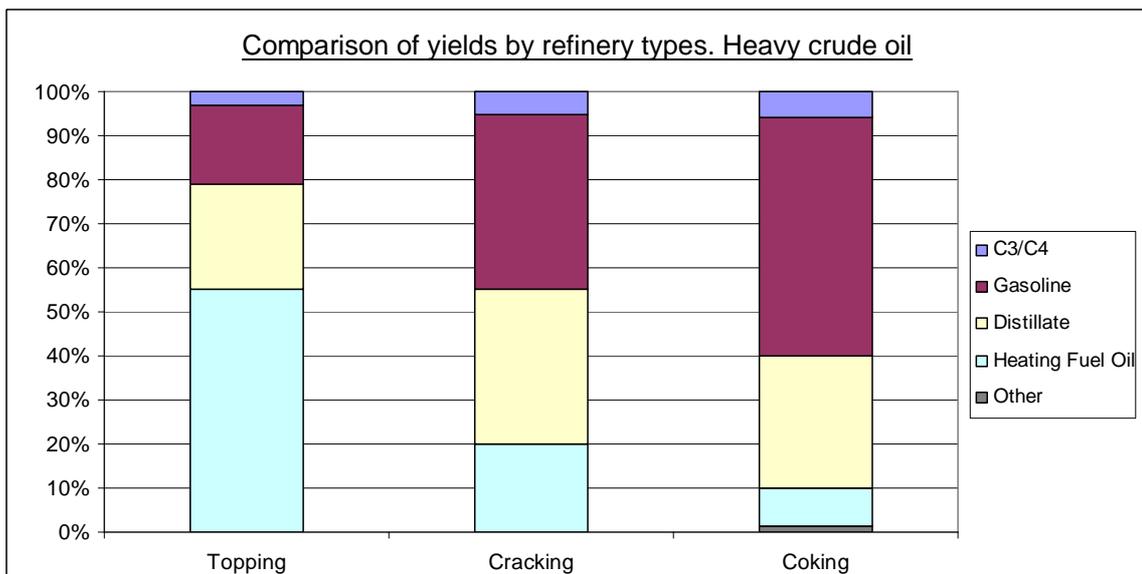
Figure II.3 Comparison of Yields by Refinery Type. Heavy Crude Oil Example

II.4.3 Units and processes

Modern refinery operations are very complex. It is convenient to break down the refinery into a coordinated group of understandable processes. The process flow and products for a refinery of high complexity are shown in figure II.4.
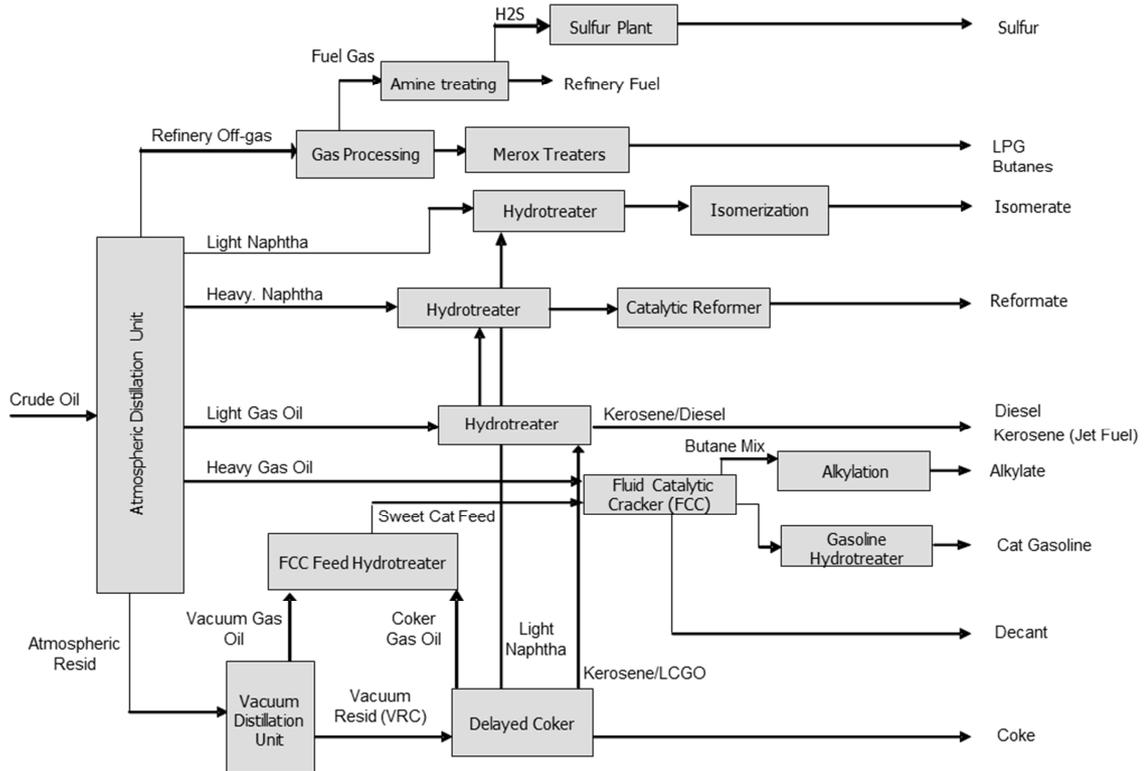
Figure II.4 Refinery processes diagram

Crude oil is heated in a furnace and charged to an atmospheric distillation tower, where it is separated into butanes and lighter wet gas, unstabilized light naphtha, heavy naphtha, kerosene, atmospheric gas oil, and topped (reduced) crude. The topped crude is sent to the vacuum distillation tower and separated into vacuum gas oil stream and vacuum reduced crude bottoms. (Gary & Handwerk, 2001).

The reduced crude bottom (VRC) from the vacuum tower is then thermally cracked in a delayed coker to produce wet gas, coker gasoline, coker gas oil, and coke. Without a coker, this heavy resid would be sold for heavy fuel oil or (if the crude oil is suitable) asphalt. The atmospheric and vacuum crude unit gas oils and coker gas oil are used as feedstocks for the catalytic cracking (FCC) or hydrocracking units (HC). These units crack the heavy molecules into lower molecular weight compounds boiling in the gasoline and distillate fuel ranges. The products from the hydrocracker are saturated. The unsaturated catalytic cracker products are saturated and improved in quality by hydrotreating or reforming.

Hydrotreating is a process used to remove sulphur from finished products. As the requirement to produce ultra-low sulphur products increases, additional hydrotreating capability is being added to refineries. Refineries that currently have large hydrotreating capability are able to process crude oil with higher sulphur content.

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The light naphtha streams from the crude tower, coker and cracking units are sent to an isomerization unit to convert straight-chain paraffins into isomers that have higher octane numbers.

The heavy naphtha streams form the crude tower, coker, and cracking units are fed to the catalytic reformer to improve their octane numbers. The products from the catalytic reformer are blended into regular and premium gasoline for sale.

The wet gas streams from the crude unit, coker, and cracking units are separated in the vapor recovery section (gas plant) into fuel gas, liquefied petroleum gas (LPG), unsaturated hydrocarbons (propylene, butylenes, and pentenes), normal butane, and isobutane. The fuel gas is burned as a fuel in refinery furnaces and the normal butane is blended into gasoline or LPG. The unsaturated hydrocarbons and isobutene are sent to the alkylation unit for processing.

The alkylation unit uses either sulfuric or hydrofluoric acid as catalyst to react olefins with isobutane to form isoparaffins boiling in the gasoline range. The product is called alkylate, and is a high-octane product blended into premium motor gasoline and aviation gasoline.

The middle distillates from the crude unit, coker, and cracking units are blended into diesel and jet fuels and furnace oils.

In some refineries, the heavy vacuum gas oil and reduced crude from paraffinic or naphthenic base crude oils are processed into lubricating oils. After removing the asphaltenes in a propane deasphalting unit, the reduced crude bottoms is processed in a blocked operation with the vacuum gas oils to produce lube oil base stocks.

The vacuum gas oils and deasphalted stocks are first solvent-extracted to remove the aromatic compounds and then dewaxed to improve the pour point. They are then treated with special clays or high-severity hydrotreating to improve their color and stability before blended into lubricant oils.

Each refinery has its own unique processing scheme which is determined by the process equipment available, crude oil characteristics, operating costs, and product demand. The optimum flow pattern for any refinery is dictated by economic considerations and no two refineries are identical in their operations. Table A.1 in appendix summarize and classify the processes in a typical refinery.

II.4.4 Turnaround (Maintenance)

According to the American Petroleum Institute (2008), a turnaround is a planned, periodic shut down (total or partial) of a refinery process unit or plant to perform maintenance, overhaul and repair operations and to inspect, test and replace process materials and equipment. Some key facts are:

(d) Turnarounds allow for necessary maintenance and upkeep of operating units and are needed to maintain safe and efficient operations.

(e) Turnarounds are scheduled at least 1-2 years in advance and do not necessarily focus on the same operating units.

(f) In assessing whether to delay a turnaround, a refiner has to include the opportunity cost of a possible unplanned shutdown resulting from the decision to delay the turnaround.

(g) Depending on the process unit and the amount of maintenance needed, the length of the turnaround can vary from 1 week to 4 weeks or more.

(h) A major turnaround usually will involve the crude unit or the catalytic cracking unit and will result in a more significant decrease in the utilization rate than a minor turnaround that may involve units such as the alkylation unit, isomerization unit or sulfur plant.

(i) Not every unit is impacted during every turnaround. For example, the industry average is about 4 years between turnarounds catalytic cracking units.

(j) A turnaround is not necessary to enable a refinery to shift from gasoline mode to distillate mode. However, if a turnaround is planned, it is possible to take steps, such as catalyst upgrades, that could improve the distillate yields.

(k) In general, the less often units are started up and taken down, the better (safer) it is since refinery incidents are more likely to occur during these occasions.

Planned turnarounds exhibit a seasonal pattern: they occur most frequently in the first quarter and in the fall. These times are when total U.S. petroleum product and crude oil demands are at their lowest points seasonally. Within those periods, other factors affect turnaround and shutdown timing, such as availability of labor, given the very large swings in skilled workers needed for turnarounds. Holidays and hunting season are avoided for this reason. Since adequate skilled workers are not available to handle simultaneous large turnarounds, contract and engineering firms cannot schedule such activities at the same time. Various sources of information are available to assist in avoiding clashing projects. The contractor and engineering firms themselves are important players. Large turnarounds require enough outside contracting that plans become known even when companies do not announce them. Private information sources like Industrial Information Resources publish information on such plans, and the trade press picks up public announcements as well as information on shutdowns that must be provided to organizations such as the Texas Commission on Environmental

Quality, which requires filings on operational changes that may result in potential changes in emissions.

Weather conditions affect turnarounds. Refineries in northern areas will push their turnarounds later into the spring than southern refineries, avoiding bitter winter weather, since snow and ice make turnarounds difficult. On the Gulf Coast, January frequently sees high winds, which prevent the use of large cranes needed for major turnarounds, even though the demand profile is favorable at that time.

II.5 REFINERY PRODUCTS.

Refineries generate a wide range of products including: propane, butane, petrochemical feedstock, gasolines (naphtha specialties, aviation gasoline, motor gasoline), distillates (jet fuels, diesel, stove oil, kerosene, furnace oil), heavy fuel oil, lubricating oils, waxes, asphalt and still gas. But in general, the products which dictate refinery design are relatively few in number, and the basic refinery processes are based on the large-quantity products such as gasoline, diesel, jet fuel, and home heating oils. Storage and waste disposal are expensive, and it is necessary to sell or use all of the items produced from crude oil even if some of the materials, such as high-sulfur heavy fuel oil and fuel-grade coke, must be sold at prices less than the cost of fuel oil. Economic balances are required to determine whether certain crude oil fractions should be sold as is (i.e. straight-run) or further processed to produce products having greater value. Usually the lowest value of a hydrocarbon product is its heating value of fuel oil equivalent (FOE). This value is always established by location, demand, availability, combustion characteristics, sulfur content, and prices of competing fuels.

II.5.1 Gasoline

Gary & Handwerk (2001) define gasoline as a complex mixture of hydrocarbons, having typical boiling ranges from 38 to 205°C. Components are blended to promote high antiknock quality, ease of starting, quick warm-up, low tendency to vapor lock, and low engine deposits. The most common components used in blending motor gasoline are light straight-run gasoline or isomerate, catalytic reformate, catalytically cracked gasoline, hydrocracked gasoline, polymer gasoline, alkylate, n-butane, and such additives as MTBE (methyl tertiary butyl ether), ETBE (ethyl tertiary butyl ether), TAME (tertiary amyl methyl ether) and ethanol. Other additives can be added, for example, antioxidants and metal deactivators.

Light straight-run gasoline (LSR) consists of the C5-88°C fraction of the naphtha cuts form the atmospheric crude still. C5-88°C fraction means that pentanes are included in the mix but 4-carbon atom range and lower boiling compounds are excluded, and the

True Boiling Point (TBP) is approximately 88°C. Some refiners cut at slightly different TBP end point, in any case, this the fraction that cannot be significantly upgraded in octane by catalytic reforming. As a result, it is processed separately from the heavier straight-run gasoline fractions and requires only caustic washing, light hydrotreating, or, if higher octanes are needed, isomerization to produce a gasoline blending stock. For maximum octane with no lead addition, some refiners have installed isomerization units to process the LSR fraction and achieve Pump Octane Number (PON) improvements of 13 to 20 octane numbers over that of the LSR.

Catalytic reformate is the 5+-carbon atom gasoline product of the catalytic reformer. Heavy straight-run (HSR) and coker gasolines are used as feed to the catalytic reformer, and when the octane needs require, FCC and hydrocracked gasolines of the same boiling range may also be processed by this unit to increase octane levels. The processing conditions of the catalytic reformer are controlled to give the desired product antiknock properties in the range of 90 to 104 Research Octane Number (RON), approximately 85 to 98 PON.

The FCC and HC gasolines are generally used directly as gasoline blending stocks, but in some cases are separated into light and heavy fractions with the heavy fractions upgraded by catalytic reforming before being blended into motor gasoline. This has been true since motor gasoline is unleaded and the clear gasoline pool octane is now several octane numbers higher than when lead was permitted. It is usual for the heavy hydrocrackate to be sent to the reformer for octane improvement.

The reformer increases the octane by converting low-octane paraffins to high-octane aromatics. Some aromatics have high rates of reaction with ozone to form visual pollutants in the air and some are claimed to be potentially carcinogenic by the United States Environmental Protection Agency (EPA). Restrictions on aromatic contents of motor fuels have impacted and continue to impact refinery processing, as more severe restrictions are applied. This will restrict the severity of catalytic reforming and will require refiners to use other ways to increase octane numbers of the gasoline pool by incorporating more oxygenates in the blend.

Polymer gasoline is manufactured by polymerizing olefinic hydrocarbons to produce higher molecular weight olefins in the gasoline boiling range.

Alkylate gasoline is the product of the reaction of isobutante with propylene, butylene, or pentylene to produce branched-chain hydrocarbons in the gasoline boiling range. Alkylation of a given quantity of olefins produces twice the volume of high octane motor fuel as can be produced by polymerization. In addition, the blending octane (PON) of alkylate is higher and the sensitivity (RON-MON) is significantly lower than that of polymer gasoline.

Normal butane is blended into gasoline to give the desired vapor pressure. The vapor pressure (expressed as the Reid Vapor Pressure RVP) of gasoline is compromise between high RVP to improve economics and engine starting characteristics and a low RVP to prevent vapor lock and reduce evaporation losses. The Environmental Protection Agency (EPA) also regulates the maximum RVP permitted each quarter of the year, in order to reduce toxic evaporation losses and reduce the impact on the environment. As such, it changes with the season of the year and varies between 7.2 psi on summer and 13.5 psi on winter. Butane has a high blending octane number and is a very desirable component of gasoline; refiners put as much in their gasolines as vapor pressure limitations permit. Isobutane can be used for this purpose but it is not as desirable because its higher vapor pressure permits a lesser amount to be incorporated into gasoline than n-butane.

II.5.2 Kerosene

The most important use of kerosene is as aviation turbine fuel. This product has the most stringent specifications, which must be met to ensure the safety standards of the various categories of aircraft. The most important specifications are the flash and freeze points of this fuel. Because the Reid Vapor Pressure of kerosine-type fuels is very low, volatility is controlled by flash point limits and vapor pressure does not appear in the specifications for these grades. In turn, the maximum boiling range and therefore the availability for these fuels is limited by flash point and freezing point. (Gary & Handwerk, 2001 and Montemayor, 2008)

Because of the extreme operating requirements of aviation gasoline, the volatility range has to allow for fuel evaporation, i.e., engine starting, at very low temperatures, but at the same time protect against vapor lock at elevated fuel system temperatures as well as help prevent carburetor icing at low temperatures. Additional limitations can be placed on the fuel by high altitude conditions where very low ambient pressures in unpressurized aircraft tankage could lead to high evaporation losses. (Montemayor, 2008).

Basic civil jet fuels are:

1. Jet A, a kerosene-type fuel having a maximum freeze point of -400°C. Jet A-type fuel is used by mainly domestic airlines of various countries, where a higher freeze point imposes no operating limitations.
2. Jet A-I, a kerosene-type fuel identical with Jet A but with a maximum freeze point of -47°C. This type of fuel is used by most international airlines. Jet A and Jet A-I generally have a flash point of 38°C.

3. Jet B is a wide-cut gasoline-type fuel with a maximum freeze point of -50 to -58°C. The fuel is of a wider cut, comprising heavy naphtha and kerosene, and is meant mainly for military aircraft.

A limited number of additives are permitted in aviation turbine fuels. The type and concentration of all additives are closely controlled by appropriate fuel specifications. The following aviation turbine fuel additives are in current use:

- Antioxidants. Its use is mandatory in fuels produced by a hydrotreating process, to prevent formation of hydrogen peroxide, which can cause rapid deterioration of nitrile rubber fuel system components.
- Static dissipators, also known as antistatic additives or electrical conductivity improvers. Its use is mandatory to increase the electrical conductivity of the fuel, which in turn promotes a rapid relaxation of any static charge build-up during the movement of fuel.
- Fuel system icing inhibitor (FSII). The main purpose of FSII is to prevent fuel system blockage by ice formation from water precipitated from fuels in flight. Because of the biocidal nature of this additive, it is very effective in reducing microbiological contamination problems in aircraft tanks and ground fuel handling facilities. As most commercial aircrafts are provided with fuel filter heaters, they have no requirement for the anti-icing properties of this additive. FSII is therefore not usually permitted in civil specifications, its use is confined mainly to military fuels.
- Corrosion inhibitor/lubricity improver. Its use is optional to protect storage tanks and pipelines from corrosion and improve the lubricating properties of the fuel.

II.5.3 Diesel

Diesel grades have an ASTM end point of 650-7000F. Diesel fuel is a blend of light and heavy distillates and has an ASTM boiling range of approximately 350-6750°F. (Parkash, 2003). Marine diesels are a little heavier, having an ASTM boiling end point approximately 775°F. The most important specifications of diesel fuels are ignition quality (expressed as cetane number or cetane index), sulfur content, percent aromatics, and pour or cloud point. Cetane number is related to the burning quality of the fuel in an engine. The permissible sulfur content of diesel is being lowered worldwide due to the environmental pollution concerns resulting from combustion of this fuel. Aromatics are pollutants and content in diesel fuels is regulated by the Environmental Protection Agency. Pour point or cloud point of diesel is related to the storage and handling properties of diesel and depends on the climatic conditions in which the fuel is being used.

II.5.4 Heating oil

Heating oil is very similar to diesel fuel, and both are classified as distillates. It consists of a mixture of petroleum-derived hydrocarbons in the 14- to 20-carbon atom range. It is used as a fuel for furnaces or boilers in buildings.

Heating oil is known in the United States as No. 2 heating oil. In the U.S., it must conform to ASTM standard D396. Diesel and kerosene, while often confused as being similar or identical, must conform to their own respective ASTM standards. Heating oil is widely used in parts of the United States and Canada where natural gas is not available and propane is priced higher, although increasingly severe environmental restrictions on fuel emissions have caused some users of heating oils to convert to natural gas and Liquefied Petroleum Gas (LPG). Expansion of air and truck travel has increased diesel and jet fuel demands.

II.5.5 Liquefied Petroleum Gas

The gases obtained from crude oil distillation are ethane, propane, and n-butane isobutene. These products cannot be produced directly from the crude distillation and require high-pressure distillation of overhead gases from the crude column. Propane and butane particularly are recovered and sold as LPG, while methane and ethane are generally used as refinery fuel.

II.5.6 Naphtha

C5-200°C ASTM cut is generally termed naphtha. There are many grades and boiling ranges of naphtha. Many refineries produce 200°C end-point naphtha as an overhead distillate from the crude column, then fractionate it as required in separate facilities. Naphtha is used as feedstock for petrochemicals either by thermal cracking to olefins or by reforming and extraction of aromatics. Also some naphtha is used in the manufacture of gasoline by a catalytic reforming process.

II.5.7 Vacuum Gas Oil

Vacuum gas oil is the distillate boiling between 700 and 10000F. This is not a saleable product and is used as feed to secondary processing units, such as fluid catalytic cracking units, and hydrocrackers, for conversion to light and middle distillates.

II.5.8 Residual Fuel Oil

Hydrocarbon material boiling above 540°C is not distillable and consists mostly of resins and asphaltenes. This is blended with cutter stock, usually kerosene and diesel, to meet the viscosity and sulfur specifications of various fuel oil grades.

II.5.9 Product Slates

Refinery configuration is influenced by the product demand in each region. In the U.S., the demand for gasoline is much larger than distillate demand and, therefore, refiners configure their installations to maximize gasoline production. Gasoline sales account for nearly 50% of demand while distillate sales account for less than 30% of product demand. In several Western European countries, most notably Germany and France, policies exist that encourage the use of diesel engines creating a much stronger distillate component. Gasoline accounts for less than 20% of petroleum product sales in Europe.

U.S. refineries are configured to process a large percentage of heavy, high sulphur crude and to produce large quantities of gasoline, and low amounts of heavy fuel oil. U.S. refiners have invested in more complex refinery configurations, which allow them to use cheaper feedstock and have a higher processing capability.

The relationship between gasoline and distillate sales can also create challenges for refiners. A refinery has a limited range of flexibility in setting the gasoline to distillate production ratio. Beyond a certain point, distillate production can only be increased by also increasing gasoline production. For this reason, Europe is a major gasoline exporter, primarily to the U.S.

CHAPTER III

SUPPLY ANALYSIS

The United States has an approximate refining capacity of 17.8 million barrels of crude oil a day. The number of refineries has declined by 10% since 2000, and no new refineries have been built since the late 1970s. Nonetheless, atmospheric distillation capacity has been growing steadily as shown in figure III.1. Moreover, refineries are more complex than they were in the past, reflected by the overall increase not only in atmospheric distillation capacity, but vacuum distillation, hydrocracking and delayed coking capacities.
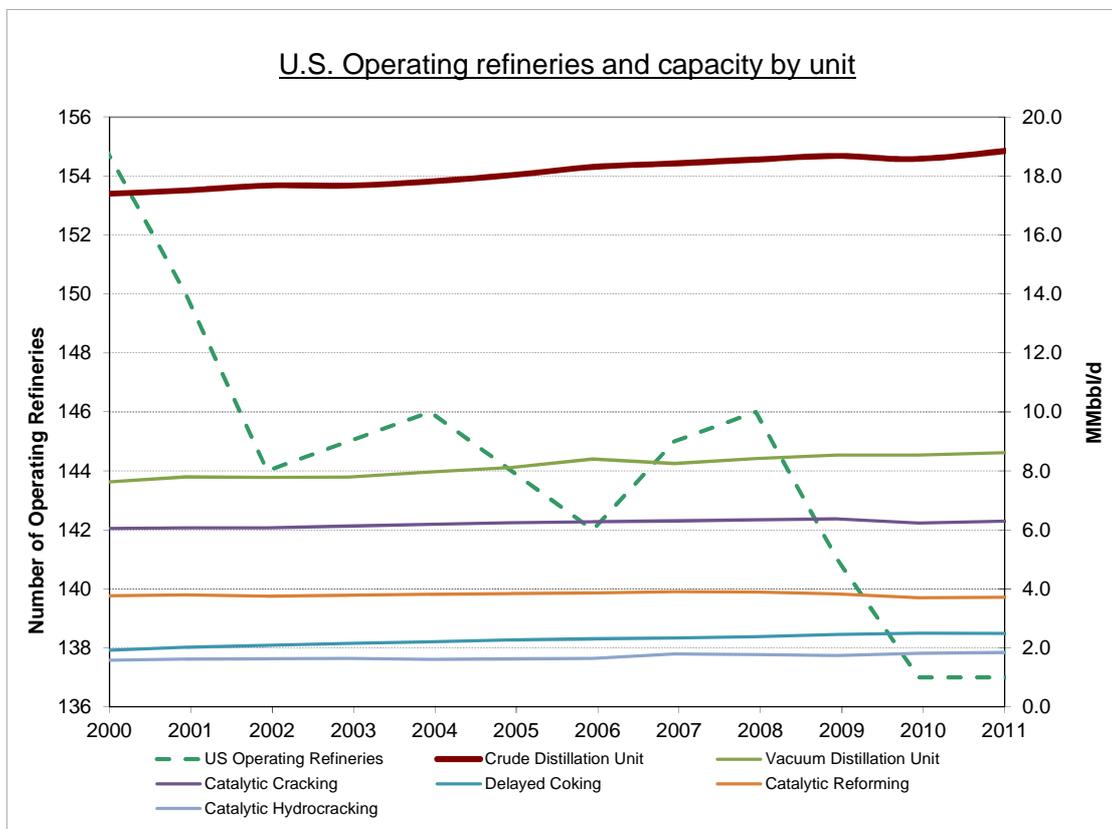
Figure III.1 Number of operating refineries in the United States and total capacity by unit.

III.1 GEOGRAPHIC DISTRIBUTION

Refining capacity is asymmetrically distributed throughout the United States, as we can see in the figure III.2. Nearly half of U.S. refinery distillation capacity is located in the Gulf Coast region or Petroleum Administration for Defense District 3 (PADD 3). Most expansions of refinery distillation capacity have taken place at the larger refineries and

most of these large refineries are located in PADD 3. In 2011, U.S. refinery distillation capacity outside of PADD 3 was 10.1% on the East Coast (PADD 1), 21% in the Midwest (PADD 2), 3.6% in the Rocky Mountains region (PADD 4), and 17.2% on the West Coast (PADD 5).

East Coast (PADD 1): Refineries range from very small to quite large, with the region's capacity largely dominated by the two large independent refiners, Sunoco and Valero, and by the integrated company, ConocoPhillips. The refineries in this area are under strong competitive pressure, and some of them are at risk of closure due to its exposure to product imports from Europe. The plants most at risk of closure are the smaller and less efficient or sophisticated refineries, but other refineries could also face pressure, regardless of size and financial support of the underlying companies. East Coast refineries contribute only about 30% percent of local demand. Therefore, it is dependent on supply from distant sources, the Gulf Coast and imports.

Midwest (PADD 2): The Midwest is the biggest PADD in terms of population. Demand in this region exceeds maximum refining capacity, therefore is a net importer of refined products. About 20% of the products supply in this market arrived through the Explorer pipeline from the Gulf Coast. The region has some small refineries competing against larger and more complex plants, but the plants operated by the large integrated companies dominate the region. In the past years, crude oil imported in this area has been traditionally heavy, and therefore cheaper than lighter crudes; topping refineries, which can only optimally process lighter and generally more expensive crudes, had to be closed or upgraded to remain competitive in this market.

Gulf Coast (PADD 3): The Gulf Coast accounts for 48.1 % of the total crude distillation capacity in the United States (Atmospheric Distillation Unit and Vacuum Distillation Unit), with 83 refineries in the area. The region is dominated by a number of very large, high complexity level plants. Most expansions of refinery distillation capacity have taken place at the larger refineries and most of these large refineries are located in PADD 3. It ships refined products to both the East Coast, supplying more than half of that region's needs for light products like gasoline, heating oil, diesel, and jet fuel, and to the Midwest, supplying more than 20% of the region's light product consumption. Colonial Pipeline (1,500 miles) and Plantation Pipe Line (1,100 miles) are long distance pipelines that move petroleum products from the Gulf Coast to the East Coast. Explorer Pipeline (1,400 miles) and TEPPCO, LP (1,100 miles) are long distance examples from the Gulf Coast to the Midwest.

Rocky Mountain (PADD 4): It is the smallest market with 18 refineries. It is a self-sufficient area. Most of the crude supply in this area is imported from Canada. Typical crudes imported are: Western Canadian Select (WCS), Light Sour Blend (LSB), and

synthetic crudes. Although small, refineries have been upgraded to process these medium-heavy crudes, and topping refineries are inexistent.

West Coast, Hawaii and Alaska (PADD 5): This PADD has been traditionally balanced in demand and supply. It is not a refining center like the East and Gulf Coast regions. A diverse mix of refineries operates in the region; this region has proportionally more topping refineries than the other regions.
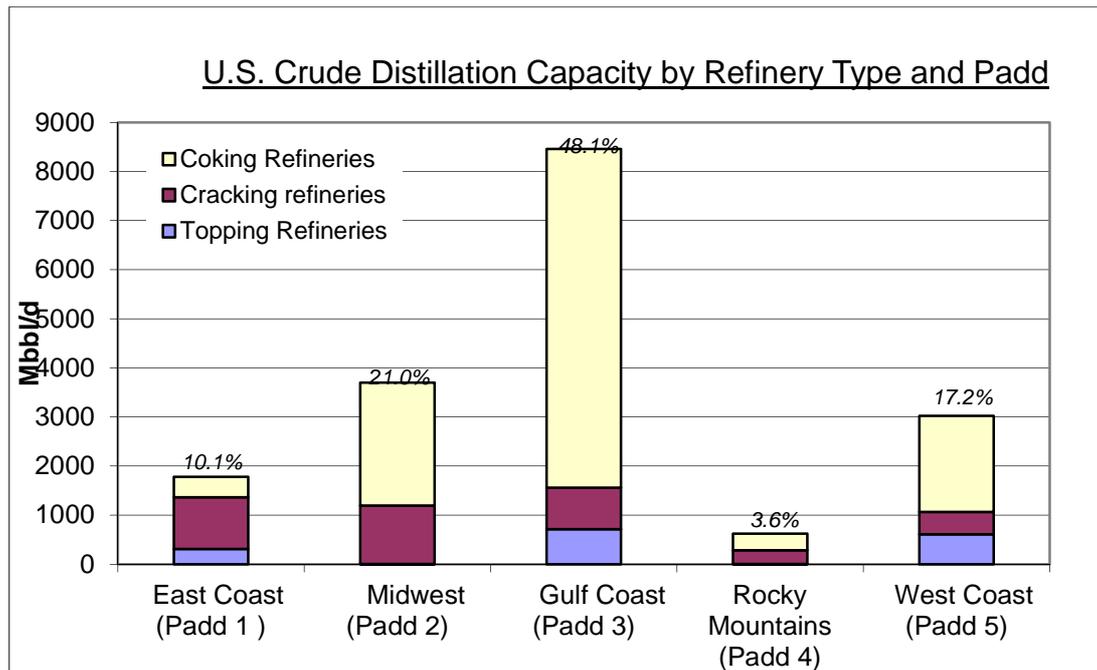
Figure III.2 U.S. Crude Distillation Capacity by Refinery Type and PADD

The configuration of U.S. refineries have changed during the past years; declining production of domestic crudes like West Texas Intermediate (current benchmark crude for the United), and increasing average crude oil price have constrain refinery margins. In the Gulf Coast particularly, refineries were initially built to exploit local sources of crude oil supply, abundant in the state of Texas. Later, declining production constrained refinery operators to invest in expensive equipment and upgrades, with 10-15 years of payback, to accommodate processing of heavy sour crudes. These crudes are typically priced at a discount respect to lighter sweeter crudes. These refineries are more sensitive to light-heavy crude oil price spreads, since higher conversion capability results in higher energy use, and therefore, higher operating costs.

III.2 COMPANIES

The US refining system includes facilities owned and operated by:
  (a) Publicly traded integrated oil and gas companies

(b) Publicly traded independent refining companies (i.e., refining companies that do not have any exploration and production or "upstream" operations)

(c) Privately owned (non-traded) independent refining companies

(d) Subsidiaries of foreign national oil companies (NOCs)

(e) Joint ventures of foreign NOCs and US refining companies

Table III.1 Top 10 Refining Companies in the United States

Company	Classification	Number of Refineries	Refining Capacity (Mbbl/d)	Gasoline Production Capacity (Mbbl/d)	Market Share/ Crude distillation capacity	Market Share/ Gasoline production capacity
ExxonMobil	(a)	7	2050.0	1076.3	11.7%	12.0%
ConocoPhillips	(a)	11	1779.7	925.6	10.1%	10.3%
Valero Energy Corp.	(b)	11	1695.9	850.1	9.6%	9.5%
BP PLC	(a)	6	1492.0	781.4	8.5%	8.7%
Marathon Oil Corp.	(a)	6	1122.0	573.3	6.4%	6.4%
Chevron	(a)	6	946.0	492.8	5.4%	5.5%
Flint Hills Resources	(c)	3	813.9	398.6	4.6%	4.4%
Royal Dutch Shell PLC	(a)	5	771.3	385.7	4.4%	4.3%
CITGO Petroleum Corp.	(d)	3	745.9	391.6	4.2%	4.4%
Sunoco Inc.	(b)	2	505.0	258.6	2.9%	2.9%
Subtotal		**60**	**11921.7**	**6133.9**	**67.8%**	**68.5%**
Other		77	5669.0	2824.6	32.2%	31.5%
Total		**137**	**17590.8**	**8958.5**	**100.0%**	**100.0%**

In table III.1 it is possible to observe that combined capacity of less than half of the refineries, holds about 67.8% of total crude distillation capacity. Large and complex refineries dominate the market, and most of them are owned by only 10 companies. Market share based on gasoline production capacity does not differ much than the market share calculated with total crude capacity; refinery structure (large and complex) is relatively uniform among the top 10 companies, and gasoline yield estimations between companies does not differ more than 0.5%.

Market share* is calculated with two methods:

1. Dividing crude oil distillation capacity by total U.S. crude oil distillation capacity
2. Dividing gasoline production capacity by the total gasoline production capacity of the United States.

To estimate gasoline production capacity, refineries in the United States were classified according to their complexity level, and for each classification it was assumed a light/heavy crude oil ratio as follows:

(a) Topping Plants: 75/25 light/heavy oil ratio
(b) Cracking Refineries: 60/40
(c) Coking Refineries: 25/75

The light/heavy crude oil ratio is determined by refinery economics; as the refinery becomes more complex, it can process heavy sour crudes, which are typically cheaper than light crudes. Light and heavy crudes have different product yields, and depending on the type of the refinery those yields can change. Due to the nature of light crudes, quality and composition can oscillate; the same happens for heavy crudes.

As a measure of the market concentration, the Herfindahl-Hirschman Index (HHI) was calculated. The HHI takes into account the relative size and distribution of the firms in a market and approaches zero when a market consists of a large number of firms of relatively equal size. The HHI increases both as the number of firms in the market decreases and as the disparity in size between those firms increases. It is calculated by squaring the market share of each firm competing in the market and then summing the resulting numbers.

$$HHI = \sum_{i=1}^{N} Si^2 = 0.0584$$

Where *Si* is the market share of each firm.

The United States Federal anti-trust authorities such as the Department of Justice and the Federal Trade Commission use the Herfindahl index as a tool to determine whether a proposed merger is likely to raise antitrust. Herfindahl indexes between 0.1500 and 0.2500 are considered moderately concentrated and indexes above 0.2500 to be concentrated. As the market concentration increases, competition and efficiency decrease and the chances of collusion and monopoly increase. Considering that the Herfindahl for the petroleum refining industry in 2011 is 0.0584, this market is not considered especially concentrated. Despite the Herfindahl index is low, it cannot be said that the market is homogeneus, since large and complex refineries dominate the market and these are owned by a few companies.

III.3 MARGINS

Refining margins are complex because they involve a multi-product process. Given a particular quality crude oil, a specific refinery produces many different products simultaneously from that crude oil. The revenues are a function of both the prices of

different products and the refinery yields for those products. They are very volatile, correlated to crude oil prices (upstream) and gasoline and diesel prices (downstream). Yield varies with refinery configuration, operating decisions, and crude oil being used. Crude oil and product prices vary according to their respective markets. Operating and maintenance costs vary mainly with refinery configuration, labor costs, and the price of the energy internally required to operate the refinery.

Crude cost is the single most important determinant for the profitability of an oil company. With crude costs accounting for around 80% of the refinery expenditures, processing cheaper crudes can have a very positive impact on refinery margins. For refineries that have freedom in crude choice, the selection of an optimum crude package is of vital importance. This requires intense teamwork between the traders and the supply/ manufacturing economist and typically linear-program (LP) models of individual refineries are routinely used to determine the relative use values among crudes.

Gasoline is an important determinant of refiners' margin level in any given year. An entire year's financial success can be made or broken with a larger than normal variation in gasoline prices alone. Similarly, crude oil represents about three quarters of refining costs. Small swings in the price of crude oil, unless quickly passed through to the prices of petroleum products, can produce large changes in cash margins and therefore in refiners' profits.

It is a common practice in the refining industry to estimate gross margins through the so-called 6-3-2-1 or 3-2-1 cracks. In the case of 3-2-1, it is assumed that 2 barrels of crude oil yield 1 barrel of gasoline and 1 barrel of residual fuel oil (or 1 barrel of crude oil yield 66,6% of gasoline and 33,3% of residual fuel oil). Gross margin can be estimated as:

Gross Margin = (2* Gasoline price per barrel + 1*Residual fuel oil price per barrel – 3*crude oil price per barrel)/3

Prices used for this calculation must have been settled at the same delivery point; otherwise transportation costs have to be considered. This formula does not consider any refining costs other than the price of crude oil.

In the case of 6-3-2-1 charts, it is assumed that 6 barrels of crude oil yield 3 barrels of gasoline, 2 barrels of distillate fuels and 1 barrel of residual fuel oil. The formula for this case is:

Gross Margin = (3* Gasoline price per barrel + 2*distillate fuels price per barrel + 1*Residual fuel oil price per barrel – 6*crude oil price per barrel)/6
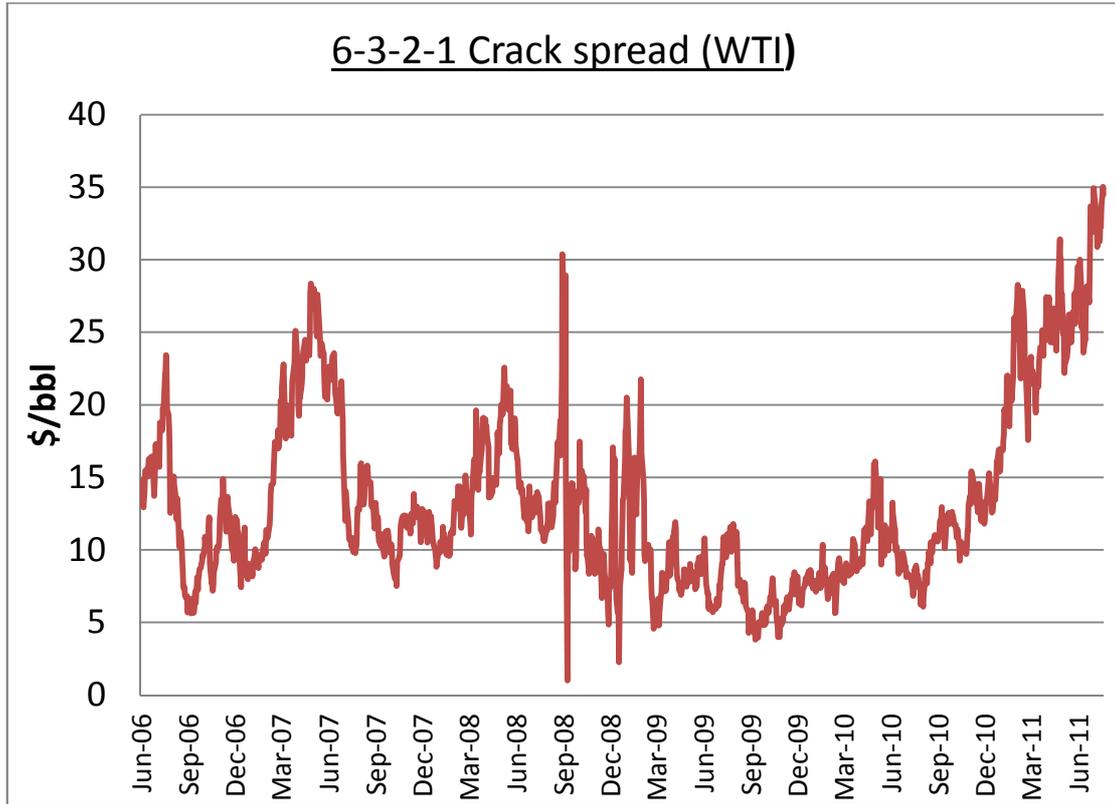
Figure III.3. 6-3-2-1 West Texas Intermediate (WTI) crack spread.

Table III.2 summarizes the most important factors influencing cracks, thus influencing refinery margins as well. They have been classified in recurrent and casual. Recurrent factors are those that repeat from time to time. For example, summer increase in gasoline demand occurs once a year. Casual factors are unpredictable events that may strengthen or weaken oil cracks.

Table III.2 Typical factors influencing crack spreads

	Issue	Typically Affects	Crack Spread Effect
Recurrent	Refinery Maintenance	Decline in product production	Crack strength
	Summer seasonality	Increase in gasoline demand	Crack strength
	Winter seasonality	Increase in distillate demand	Crack weakness
	Slow/fast economic growth	Increase/ decline refined products demand	Crack strength/ weak
	Expiration of trading month	Cash market	Crack fluctuates due to closing of positions

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	Environmental regulations	Tightening of product supply	Crack strength
	Strong/weak Sustained Product demand	High/low refinery utilization	Crack strength/weak
	Currency exchange rate	Crude oil strength/weak	Crack strength/weak
Casual	Geopolitical issues	Crude oil supply	Crack weakens initially: higher crude oil prices Crack strengthens later; as refineries respond to tighter crude oil supply and reduce product outputs
	Natural disasters	Crude oil and/or products supply	Crude oil and/or products price will rise. Depending of the nature of the disaster, crack strengthens or weakens.

Between 2006 and 2011 several casual events affected profoundly the crack curve. In figure III.3 it can be seen the high volatility of the spread, ranging from 1 to 35 dollars per barrel. The liquidity crisis of September 2008 became a severe crisis that affected not only the United States but all countries. A series of bank and insurance company failures triggered a financial crisis that effectively halted global credit markets and required government intervention. These failures caused a crisis of confidence that made banks reluctant to lend money amongst themselves.

The financial crisis affected negatively in refinery margins, and the following period from 2009 to mid-2010 was especially difficult for refinery operators. Average crack was 5$, barely covering operating costs. 9 refineries were closed permanently during this period, with a combined capacity of about 300 thousand barrels a day (see figure III.1)

In 2011, signs of economic recovery began to appear. The price of gasoline soared in late 2010 and early 2011, driven by market optimism about global growth and turmoil in the Middle East. In the other hand, WTI prices did not increase as much as other crudes with similar characteristics did; for example, the difference between Brent and WTI ranged 5-15$ in early 2011. This combination caused refinery margins to increase steeply, reaching 35$ in June 2011.

Refining margins exhibit several typical variations:

Seasonal: Margins peak frequently in the second or third quarters and hit their low points during the winter (fourth or first quarters). U.S. refining margins are highest in the spring and summer months (second and third quarters) because they are heavily influenced by gasoline markets. The gasoline market is highly seasonal, with price spreads (spot gasoline minus crude oil prices) generally peaking in late spring or early summer as the industry prepares to meet peak driving demand, which usually occurs around June (see figure IV.1 chapter IV). This tendency is shown in figure III.3; before September 2008, there were 3 peaks in gasoline crack spread around June-August. 2008 was a turbulent year with a huge volatility; therefore this seasonality cannot be observed as easily as in previous years. In 2010 it regains its normal behavior, peaking around June. The spring margin increase is a primary determinant of a refiner's performance for an entire year. Distillate has a counter-cyclical demand and price pattern from gasoline. The distillate price rise in the fall tends to moderate the margin's seasonal pattern, but it does not counterbalance the gasoline market's strong seasonal influence on refining margins. Distillate's smaller influence is a result of its small volume relative to gasoline. Refining margins are generally lowest during the winter quarters (fourth and first quarters) when gasoline demand and prices have fallen and inventories are building. The weather's impact on distillate prices tends to determine if the first quarter or the fourth quarter is the lowest margin quarter.

Long-term: Several long-term factors can affect margins. Such factors include crude market tightness which sometimes influences product market tightness for extended periods, the light-heavy crude oil and product supply demand balance, and refining capacity utilization.

III.4 U.S. CRUDE OIL SUPPLY

The United States is a net importer of oil with 9.3 million of barrels a day in January 2011. Domestic production accounts for 5.5 million barrels a day, about 37% of total crude oil demand. Texas contains 77% of PADD 3's proven oil reserves, approximately 4.6 billion barrels. Total PADD 3 reserves equal 5.9 billion barrels, 31% of total US reserves. However, reserves are declining by approximately -3.4% a year (Energy Information Administration, 2010).

Due to the complexity and geographic extension of the U.S. market, PADDs have different crude suppliers. As observe in figure III.4, crude oil imported and processed in PADD 1, 2 and 3 is originated from many countries all around the globe, including members of the Organization of Petroleum Countries (OPEC) as well as other important crude oil suppliers like Canada and Mexico.

PADD 3 has maintained high levels of crude output, however both the United States and PADD 3 crude oil production is falling. The Gulf Coast remains an important crude producing region, but naturally as domestic production falls, dependence on foreign crude imports continue to rise.

Most of the crude oil imported in PADD 2 and PADD 4 comes from Canada. Enbridge Inc. pipelines transport Canadian oil as well as oil produced from the Bakken shale, in North Dakota, principally to the Midwest (PADD 2). In recent years, Canada has increased the production of crude oil, resulting in an oversupply to the Midwest area and the increase on inventories in Cushing, Oklahoma. There is limited capacity for Gulf Coast refiners to access this crude, since the traditional direction of flow was from PADD 3 to PADD 1 and 2. This situation has created a disconnection between WTI and international crude oil prices, since higher inventory levels usually lead to lower prices. Refiners are beginning to consider other crudes as benchmark; in the Gulf Coast for example, the locally produced and consumed Light Louisiana Sweet (LLS) reflects more accurately the current market price. This is also incentivizing pipeline operators to invest in pipeline capacity expansion that could bring crude oil from northern PADD. Several projects are currently considered, but until July 2011 none have been approved due to the lack of shipper's commitment to make it commercially viable. Magellan Midstream Partners LP owns a pipeline that transport crude from the Gulf Coast to Cushing, and is planning to reverse the flow and invest in capacity expansions. This 18-inch pipeline would have an initial capacity of 135 thousand barrels of crude oil a day, and the project is expected to finish in 2013.

(a) Padd 1

Legend for (a): Canada, Angola, Nigeria, Lybia, Saudi Arabia, Other

(b) Padd 2

Legend for (b): Canada, Saudi Arabia, Algeria, Other

(c) Padd3

Legend for (c): Canada, Venezuela, Saudi Arabia, Nigeria, Mexico, Other

(d) Padd 4

Legend for (d): Canada

(e) Padd5

Legend for (e): Canada, Irak, Saudi Arabia, Ecuador, Brazil, Russia, Other
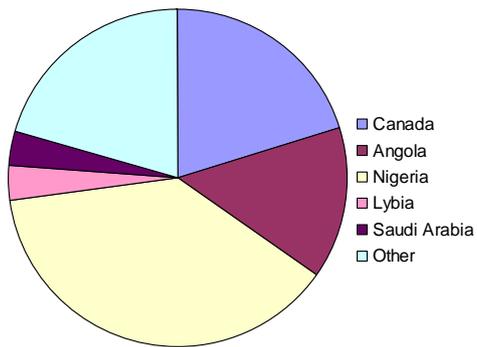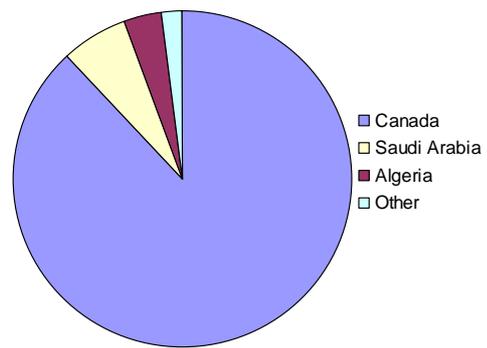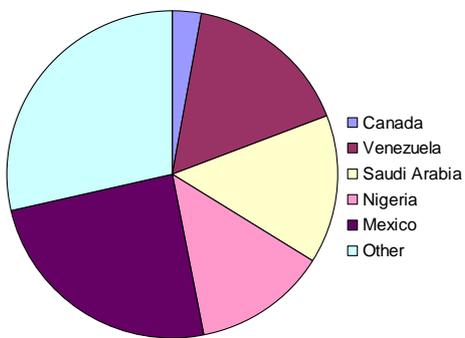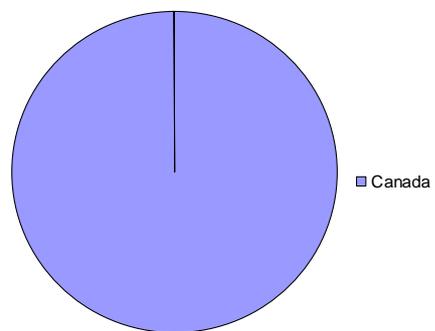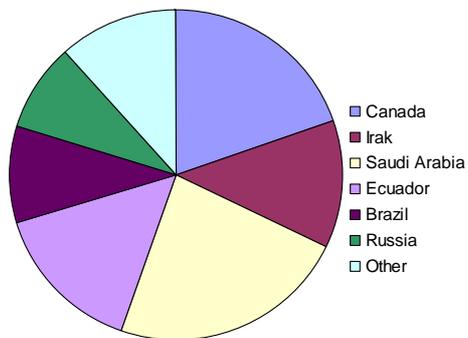
Figure III.4 Crude oil imported and processed by U.S. PADDs

III.4.1 Crude oil Pricing System

Crude oil can be commercialized through the physical (cash) market or through bilateral long-term contracts. Contracts are rarely settled with an immediate delivery date because of transportation logistics; instead, delivery is settled 45 to 60 days ahead in the future, so even for spot transactions there is an important element of forwardness.

Long-term contracts are agreed between two parties for usually a period of 1 or 2 years; among many things, these contracts specify the quantity of crude oil to be delivered, the schedule, and the method that should be used in calculating the price of an oil shipment.

Since the quality and composition of crude oil is not homogenous, prices are settled at a premium or discount with a reference crude or *benchmark*. The formula is straightforward:

$$P_C = P_B \pm D$$

Where Pc is the price of the crude, PB is the benchmark crude price and D is the value of the price differential. This formula may apply for every type of contract: spot, forward or bilateral long-term.

The differential D takes into account the relative quality of the crude, but also reflects the movements in the Gross Product Worth (GPW) obtained from refining the reference crude B and the crude C. GPW varies according to the relative supply and demands of the different types of crudes, which in turn depend of the relative price of petroleum products.

The differential to a benchmark may be settled independently by the oil-producing country. In setting the differential, an oil-exporting country will not only consider the differential between its crude and the reference crude, but has also to consider how its closest competitors are pricing their crude in relation to the reference crude. This implies that the timing of setting the differential matters, especially in a weak market. Oil-exporting countries that announce their differentials first are at the competitive disadvantage of being undercut by their closest competitors. This can induce them to delay announcement of the differential or, in the case of multiple transactions, compensate the buyers by adjusting the differential downward in the next rounds. Competition between various exporters implies that crude oils of similar quality and destined for the same region tend to trade at very narrow differentials. (Bassam, 2011).

The differential D is not set only by oil-producing countries; it can be assessed by Oil Price Reporting Agencies (PRAs). These agencies are an important component of the oil industry. Prices assessed by these agencies underlie the basis of long-term contracts, spot market transactions, futures markets contracts and derivatives instruments. Some PRAs

affirm that through their methodological structure for reporting physical transactions, they act as a mirror to the trade and provide transparency on what would otherwise be a collection of bilateral deals.

Platts and Argus are two worldwide recognized companies that provide specialized information on energy markets, covering crude and petroleum products, natural gas and liquefied natural gas, electricity, coal, emissions, biomass and biofuels and transportation. With different methodologies, using detailed knowledge of the energy industry and a network of knowledgeable contacts, these companies gather information about commodity transactions all over the world to publish news, research, commentary, market data and analysis, and daily price assessments widely used as benchmarks in both physical and futures markets.

PRAs use a wide variety of methods to identify the oil price which may include the volume weighted average system, low and high deals done, and market-on-close (MOC). Platts, prior to January 2001, produced its assessment from an arithmetic weighted average of deals done during this period. Platts stopped using this system and replaced it with the Market on Close methodology (MOC). Platts' MOC system seeks to reflect transactable values prevailing at the respective market close on a normal working day. Platts derives these values by tracking market evolution during the respective assessment *window* and by making *assessments* that reflect the value at which a deal could or did take place at the close of the market. The window is the period of the day established by Platts where representative, openly negotiated transactions are considered; the evolution of the bid-offer spread during the window is also very important for the assessments. (Platts, 2011)

Argus uses a variety of methodological approaches to identify market prices. The assessed crude prices are based on prices from the open spot market whenever possible. Usually Argus identifies prices through a process of intelligent interpretation based on bids, offers, and transactional information. Argus attempt to reduce the possibility of price report manipulation, or unintended distortion, by applying intelligent interpretation to the weighting of information it receives. In some markets, Argus will produce trade weighted averages when the industry requests them and there is enough market liquidity to justify them. (Argus, 2011)

Both the volume-weighted average method and the MOC have been criticized at some point. While the volume-weighted average method allows the inclusion of a large number of deals and hence is more representative, it may result in an index that is out of step and not reflective of the actual market price prevailing at the close of the day. This would especially be the case on days with high volatility. Weighted averages may also be distorted by the pattern of trading liquidity over the day. A key weakness in all trade-weighted average assessments is that they will lag the market price. They will reflect a

price that was, rather than the price that is. The main criticism of the MOC methodology is that the window often lacks sufficient liquidity and may be dominated by few players which may hamper the price discovery process.

Since PRAs pursue different methodologies in their price assessments, they not always produce the same price for the same benchmark. Even if price quotations are based on a mechanical methodology of deals done, two price reporting services could publish different prices for the same crude because their price identification process and the deals they include in the assessment could be different. For example, one PRA might use a volume weighted average of transactions between 9.00am and 5.00pm while another PRA might use last trade or open bid/offer at specified period of time.

Benchmarks

Since the switch to market-related pricing in the 1980s, crude oil pricing has been focused around three key benchmark grades: Dubai for oil moving from the Middle East into Asia; North Sea Brent crude oil for a wide variety of crude oils from Europe or bound for Europe; and West Texas Intermediate (WTI), for deliveries into and within the Americas. Another important American benchmark is the Argus Sour Crude Index; unlike WTI, all crudes in this index are waterbone and hence they are not subject to the same logistical and storage problems.

WTI: West Texas Intermediate (WTI) is a blend of crude oil produced in the fields of Texas, New Mexico, Oklahoma and Kansas. It is a pipeline crude and deliveries are made at the end of the pipeline system in Cushing, Oklahoma. It is the main benchmark used for pricing oil imports into the United States, the world's largest oil consumer. More crude oil is priced-off the Brent complex, but the Light Sweet Crude Oil Futures Contract, which is based on WTI, is one of the most actively traded commodity futures contract.

While WTI is the most widely known U.S. crude stream, other crude streams exist alongside WTI. One such is the Light Louisiana Sweet (LLS) crude which has become the local benchmark for sweet crude in the US Gulf Coast. Other important streams include the US-Gulf Coast Sour and Medium crudes such as Mars and Poseidon (produced offshore Louisiana) and Southern Green Canyon (produced offshore Texas). On the basis of transactions in these three crude streams, Argus derives ASCI. Platts publishes a similar index known as Americas Crude Marker which incorporates the value of the four sour grades: Mars, Poseidon, SGC and Thunder Horse (produced offshore Louisiana).

As in the case of Brent, the WTI market is also characterized by a large number of independent producers who sell their crude oil to large number of gatherers. However, unlike Brent which is waterborne crude, WTI is pipeline crude and thus is subject to problems of logistical and storage bottlenecks. Brent is exportable which makes it more flexible and more responsive to trading conditions in the Western Hemisphere. (Bassam, 2011)

Brent: The North Sea crude market is one the most important oil markets in the world. For many years, the main North Sea crude price was the price of Brent Blend. This was the main price benchmark against which other crudes were valued. In addition to trading physical cargoes, and having other physical grades price against it, the Brent market developed a forward market and also a series of derivative markets, such as short-term contract for differences and long-term swaps. The Brent market is also the underlying market to London-based Intercontinental Exchange's Ice Brent futures contract. In 1980, the production of Brent started to decline, making it less reflective of the market status and therefore it became an unreliable benchmark. To overcome this problem, other crude streams have been added over the years, widening of the definition of this benchmark; Ninian was comingled to Brent in 1990; In 2002, Oseberg and Forties were added, creating a new benchmark known as Brent-Forties-Oseberg (BFO); Finally, in 2007, a new grade, Ekofisk, was added to the complex which led to the creation of the current benchmark known as BFOE, though it is still commonly referred to as Brent or North Sea.

ASCI: The Argus Sour Crude Index (ASCI) price creates a single daily volume-weighted average of aggregate deals done for the component crude grades as if they were one grade of crude. It provides a daily benchmark price for medium sour crude at the US Gulf of Mexico trading hub. The components are Mars, Poseidon and Southern Green Canyon. Should aggregate trade in the component crude grades not achieve the established volume minimum (1000 barrels in an individual grade, combined volume must reach 6000 barrels), the price published will default to a proportional assessment (Argus, 2011).

III.4.2 Crude oil transportation

The United States of America counts with an intricate crude oil pipeline system. Figure A.2 in the appendix shows the main lines that connects each PADD. The U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) is responsible for regulating and ensuring the safe and secure movement of hazardous materials to industry and consumers by all modes of transportation, including pipelines. This administration issues the HMR (Hazardous Material Regulations), which apply to the transportation of hazardous materials in interstate, intrastate and foreign commerce by aircraft, railcar, vessel, and motor vehicle. PHMSA also has issued procedural regulations, including provisions on registration and public sector training and planning grants.

Enbridge operates, in Canada and the United States, the world's longest crude oil and liquids pipeline system, which comprises approximately 8,500 miles of pipeline, delivering more than 2 million barrels per day of crude oil and liquids primarily from reserves in western Canada to refining centers in the Midwest (PADD 2) and Ontario, Canada.

Crude transported in the Enbridge pipeline is typically heavy (approximately 25°API or less). Western Canadian Select (WCS), Western Canadian Blend (WCB), Lloyd Kerrobert (LLK) and Lloyd Blend (LLB) are the most common, but there are at least 19 types of heavy crudes. In smaller proportions, medium crudes (25°-35°API) are transported through this system. They could have been produced naturally from the fields in the area, like the Husky Sour Blend (HSB), Light Sour Blend (LSB) and Sour Heavy Edmonton (SHE) or they can be synthetic crudes like Syncrude (SYN) Husky Synthetic Blend (HSB) and Premium Albian Synthetic (PAS). Synthetic crudes are the output from a bitumen/extra heavy oil upgrader facility used in connection with oil sand production; they have typically 30°API and low sulfur concentration (<0.5% by weight). Naturally produced light crudes of 35°API or more are very rare, since oil fields produce mainly heavy and medium crude oils. The Alberta Condensate (ABT) is one example.

The system is connected to Cushing, Oklahoma. Cushing is a major hub in oil supply connecting the Gulf Coast suppliers with northern consumers, since it holds about 11.1% of the total U.S. crude inventory (January 2011). Cushing is established as the price settlement point for West Texas Intermediate (WTI) on the New York Mercantile Exchange.

CHAPTER IV

DEMAND ANALYSIS

Refineries produce many profitable products; however, the high-volume profitable products are gasoline, diesel and turbine (jet) fuels, and the light heating oils No.1 and No. 2. In this chapter, analysis will be concentrated on gasoline, since it is one the main products for the U.S. refining industry and accounts for more than 50% of the total volume.

Over the short term, as prices rise or fall, gasoline demand is relatively inelastic. People only make small changes in their consumption of gasoline when there are large changes in the price, and this pattern helps balance the supply and demand of gasoline. Over the long term, however, sustained price changes affect profoundly the demand curve. Consumers look for alternatives to gasoline, and there are more incentives for the automotive industry to develop new technologies to reduce consumption (more efficient engines), or even replace gasoline use (i.e. electric engines, ethanol).

The East Coast and the Midwest account for more than a half of total U.S. population, therefore most of the U.S. gasoline consumption is found in these regions. In the other hand, population density in the Rocky Mountains is less than 50 people per square mile, with total 10.9 million inhabitants as observed in table IV.1; logically, demand in this region is very small compared to the other PADDs.

Table IV.1 Population distribution by PADDs (U.S. Census Bureau 2009)

	East Coast	Midwest	Gulf Coast	Rocky Mountains	West Coast
Inhabitants per Sq. mile	171	118	70	21	48
Total Inhabitants (millions)	81.1	114.5	41.8	10.9	58.7
% U.S. Population	26.4%	37.3%	13.6%	3.6%	19.1%

IV.1 GASOLINE SEASONALITY AND TREND

The demand for gasoline is highly seasonal. As observed in figure IV.3, it reaches its higher values in summer months (July, August), while decreases in winter months, especially in January and February.

PADD 2 is the region with the biggest demand for gasoline, accounting for about 37% of U.S. It is followed by the East Coast, with 27%, and the West Coast with 18% approximately. The Gulf Coast stands as fourth in gasoline consumption, with about 12% of the total; refining capacity in this PADD triples local demand. The Midwest is the smallest market with a share of 6% of total demand.

A linear trend was estimated with the least squares method, after eliminating the seasonality factor with a symmetric moving average. It can be seen that demand has remain very stable in the 5-year period. In fact it has remained stable for at least 10 years. Several factors have influenced this trend; crude oil is a geopolitical asset of great importance, and the U.S. Government's interest is to reduce dependency of external suppliers. Its policies have been oriented with this objective. The increase in crude oil prices over the decade has stimulated the development of new transportation technologies and the use of alternative energy sources. In addition, tighter fuel efficiency standards have the objective of reducing the environmental impact of transportation fuel use, and to reduce total consumption stimulating the use of alternatives and cleaner energy sources. It is expected therefore that consumption of motor gasoline remain stable or decrease in the following years, while the increase in demand for transportation fuels will be met by an increase in production of ultra-low sulfur diesel and biofuels such as ethanol and biodiesel.
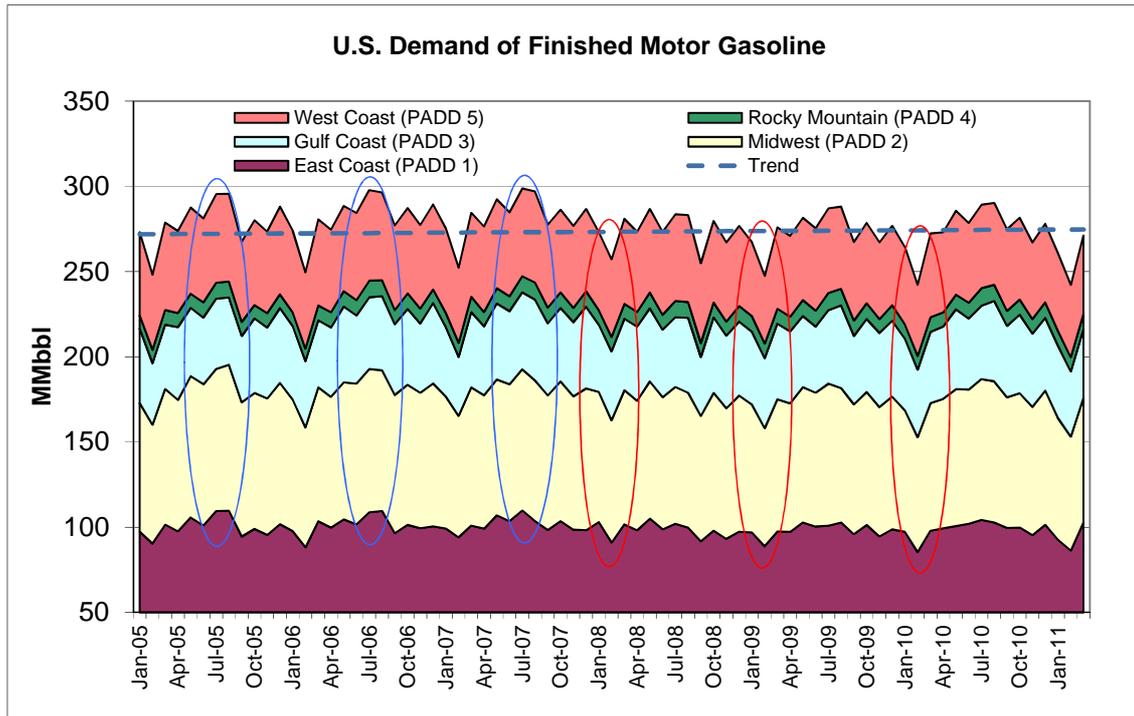
Figure IV.1 U.S. Demand of Finished Motor Gasoline

IV.2 PRICING

The main factor underlying gasoline prices is the price of crude oil. It is not difficult to demonstrate strong positive correlation, since crude oil is basically the only feedstock for this product. But the price of gasoline is not solely determined by the supply and demand of crude, several other important factors come into play as well. Distribution and Marketing comprehends approximately 10% of total price. Taxes, depending on the region, can add substantially to the retail price of gasoline. Over time, inflation also results in higher gas prices. In the past 10-years, taxes on gasoline have reduced from 30% of the total price to about 10% in 2011. Since the price of crude oil has increased dramatically during the same period, the U.S. Government reduced taxes to minimize the negative impact of long-term high crude prices. These can be observed in figure IV.2. Fuel prices, especially gasoline, affect every sector of the economy; due to its characteristic inelasticity, consumers tend to diminish expenses in other areas. In other words, gasoline demand decrease slightly while other sectors demand like electronics, automotive, food, among others, get reduced significantly.
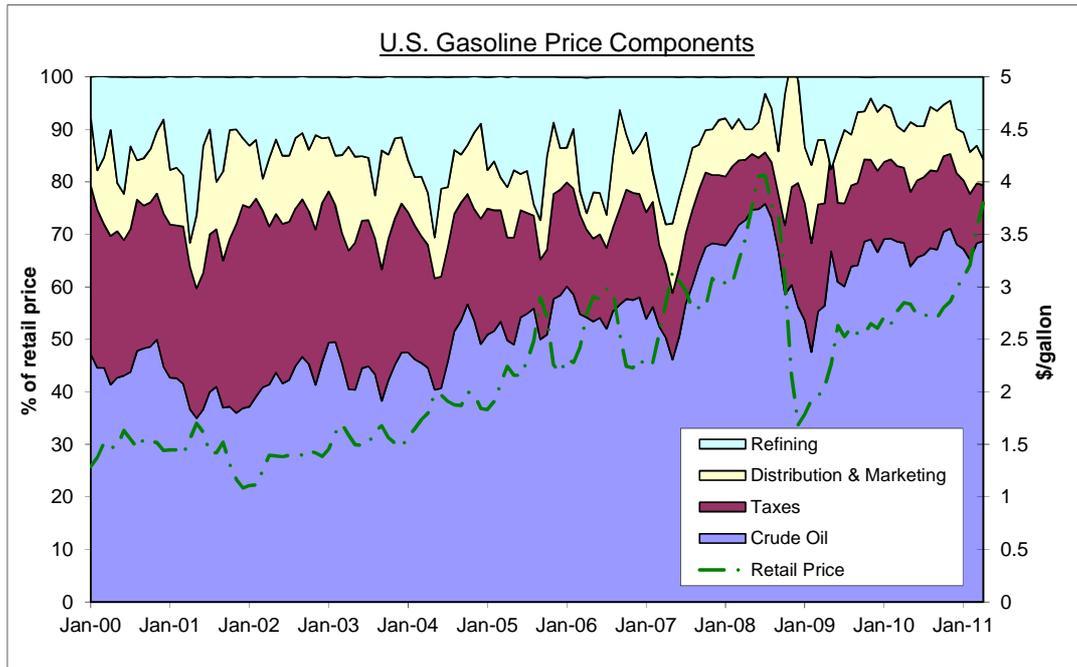
Figure IV.2 U.S. Gasoline Price Components

IV.3 GASOLINE ELASTICITY

Many studies have been made to estimate gasoline elasticity in the United States. In 1993, Dahl developed conducted a survey of Energy Demand Elasticities, which covered several studies on components of the Demand for Gasoline and demand elasticities for transportation. According to Dahl, the most popular way to break gasoline demand into a structural model is to consider Vehicle Miles Travelled (VMT) and the efficiency of the stock of vehicles, measured as Miles per Gallon (MPG). In this breakdown, gasoline demand is equal to VMT/MPG. VMT and MPG might be modeled as a direct function of gasoline prices. Alternatively, vehicle miles may be modeled as a function of cost per mile.

Table IV.2 summarized the results of some of the most important studies done on elasticity estimations before 2000. The mean value for short run price elasticity is -0.30, considerably lower than long run elasticity of -0.82.

Table IV.2 Gasoline elasticity studies

	Price elasticity		Income elasticity	
	Short run	Long run	short	Long run
Taylor (1977)	-0.1 to -0.5	-0.25 to -1.0	-	-
Bohi & Zimmerman (1984)	0 to -0.77	0 to -1.59	-0.18 to 1.20	-0.34 to 1.35
Dahl (1986)	-0.29	-1.02	0.47	1.38
Dahl & Sterner (1991)	-0.26	-0.86	0.48	1.21
Goodwin (1992)	-0.27	-0.71 to -0.84	-	-

39

Elasticity estimates may be different depending on the empirical model specification and the method. Using state or regional level data does not produce significantly different elasticity estimates than those using national level data. (Espey, 1998). Gasoline demand is affected by distance driven, the number of vehicles being driven, and the fuel efficiency of those vehicles. Models that include some measure of vehicle ownership and fuel efficiency capture the 'shortest' short-run elasticities by effectively measuring the influence of price and income changes on driving only. Models that omit one or both of these variables would measure changes in consumption through driving as well as through changes in vehicle ownership and or fuel efficiency (all implicitly), hence measuring an intermediate or long-run elasticity, depending on other features of the model and data. Models that include some measure of vehicle ownership and or vehicle characteristics such as fuel efficiency produce less price-elastic estimates for the short-run.

In a more recent study, Hughes, Knittel & Sperling (2007) estimated price and income elasticities of gasoline demand in a 5-year period, 2001 to 2006, and compare it with the elasticity in 1975-1980. The estimated short-run income elasticities range from 0.21 to 0.75 and it is not significantly different between the two periods. According to their estimates, short-run price elasticity range between -0.21 and -0.34 for the period from 1975 to 1980, showing consistency with the results found in previous studies. For the period from 2001 to 2006 instead, estimates of price elasticity range from -0.034 to -0.077, evidence of a dramatic decrease in price elasticity.

Morris (2007) made a similar study, estimating price and income elasticity of gasoline demand for two periods: 1977 to 1989, and 1994 to 2006. He estimated short-run elasticity in -0.05 to -0.08 and -0.02 to -0.04. Although their estimates were much lower than those of Hughes Hughes, Knittel & Sperling, again there is evidence of a decrease in elasticity between the two periods.

IV.4 STOCKS

In figure IV.3 it is shown the gasoline inventory levels in the United States. On average, there were 215 million barrels in the first semester of 2011, roughly the same average as the last 3 years. Considering gasoline demand of approximately 290 million barrels a month, inventories at this level could supply for 22 days the entire United States. Petroleum inventory plays the role of smoothing operations on both the supply side and demand side and of hedging against price changes. More specifically, inventory levels are determined in the short run by factors such as expected seasonality and general trends in production and demand as well as unexpected supply or demand shifts, and price changes caused by these shifts. There may also be other factors such as interest rates and

changes in the cost of physical storage that may be important in the long run. Inventory levels lower/higher than normal influence the price of gasoline. Refinery operators rely not only in internal production, but in the spot market to satisfy their costumers; a decrease in inventories is perceived as insufficient gasoline supply and will consequently drive prices and refinery utilizations rates up.
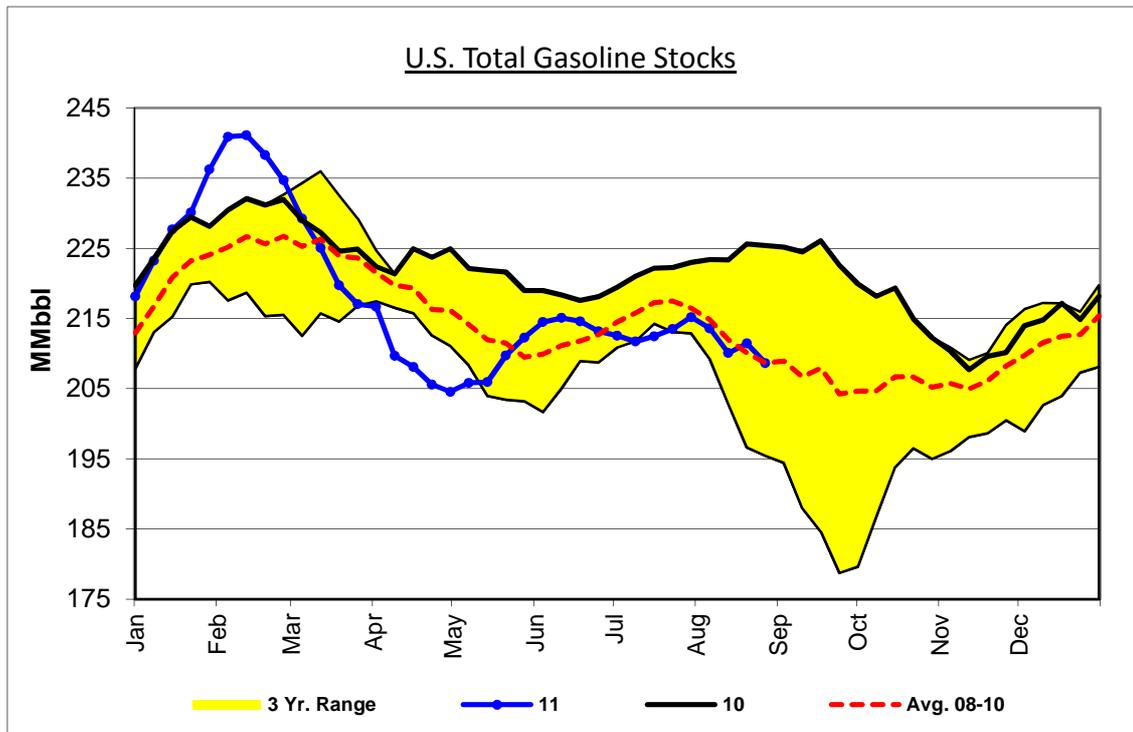
Figure IV.3 U.S. Gasoline stocks from 2008 to 2011

IV.5 TRANSPORTATION AND MARKETING

Plant operators have to keep the products they produce moving smoothly out to retail markets. The available storage capacity is very small compared to the enormous volume of petroleum products moving through the U.S. system. This smoothly running enterprise again depends on well developed markets for traders to easily dispose of their surpluses in petroleum component and buy promptly when needed. As with crude oil, there is no particular attempt made by refiners to move the gasoline they produce through their own service stations only. Instead, a Gulf Coast refiner would typically deliver its surplus gasoline to other marketers in the immediate area in trade for similar volumes received from other refiners on the East Coast, West Coast, or other PADDs. This saves the cost of physically moving the products around the country. Figure IV.4 shows the physical structure of gasoline transportation. Bulk volumes are transported in pipelines, barges and railroad to terminals. Trucks are the last piece in the puzzle, connecting terminals with retail outlets.
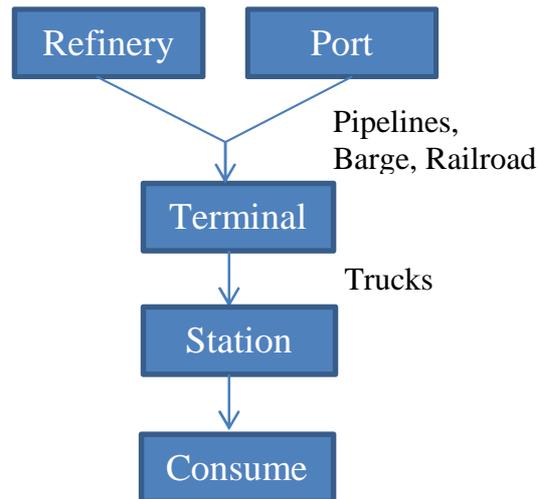
Figure IV.4 Physical Structure of Gasoline Transportation

IV.5.1 Pipelines

Pipelines are by far the most important form of bulk transport of crude oil in the United States. Pipeline share in transportation of crude oil is approximately 80%, with the remaining 20% assigned almost entirely to water carriers, since transportation in railroads and trucks combined is less than 1%. (Association of Oil Pipe Lines, 2011)

Pipelines are the core of the U.S. petroleum transportation system too; they are the key to meeting petroleum demand. As shown in figure IV.5, in 2008, oil pipelines transport roughly 486 billion ton-miles, in other words about 60 % of the petroleum shipped in the United States. Other important forms of bulk transport include tankers and barges, especially in transportation from Alaska to the contiguous United States. These forms of transport have declined in recent years, from 36% of ton-miles in 1990 to 27% of ton-miles in 2008. The overall significant decline in shipments between 1990 and 2001 is at least partly attributed to declines in residual fuel oil shipped by water transportation (FTC, 2004). Trucks and railroads (motor carriers) accounted for the remaining 12% of bulk transport of gasoline to storage terminals in 2008.
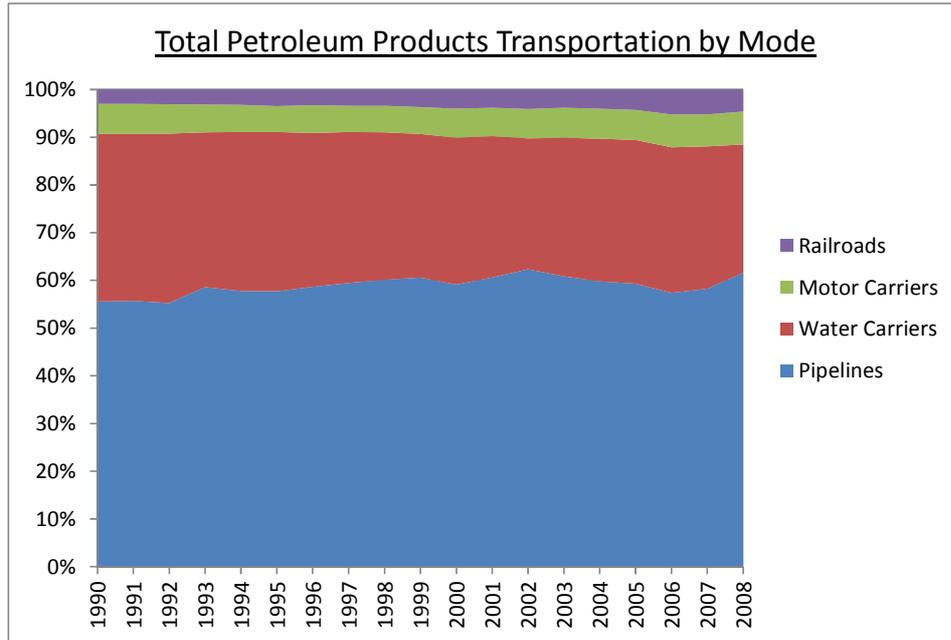
Figure IV.5. Total Petroleum Products transportation by Mode

The Gulf Coast is the PADD with the biggest refining capacity in the United States which exceeds local demand (see chapter III); petroleum products shipped from the Gulf Coast to the East Coast and the Midwest, for its final consumption, constitute an important share in total petroleum products transportation.

Petroleum shippers select transportation modes on the basis of cost and logistics. Once constructed, economics favor pipelines compared to the other methods (barges, trucks or railroads). Pipelines are (in average) the cheapest transportation alternative, followed by barges and trucks. The logistics of transporting bulk volumes also favor pipelines. For example, a shipment from the Gulf Coast (Houston) to the East Coast (New York) is approximately 1600 miles long. On average, a truck can hold 200 barrels and travel 500 miles per day. In order to replace a medium size pipeline, with 150.000 barrels/day of capacity, it would take a fleet of 750 trucks unloading every 2 minutes. Colonial pipeline cover this route and delivers on average 2.4 million barrels of petroleum products a day including intermediate terminals. Consequently, despite the fact that trucks are available, trucking is limited to short distances where other alternatives are unavailable, principally from small producing areas to storage points and between terminals and retail outlets. Trucks are a faster alternative though; following the same example, a truck would a little more than 3 days to arrive to New York, while shipping through the pipeline would take 14 days, considering an average speed of 120 miles per day.

Railroad tank cars costs are less expensive than trucks (in terms of barrel per mile), but they are not as widely available as pipelines, and they still cost more than pipeline and waterborne alternatives. Returning to the Houston-New York pipeline example, it would take a train of 75 tank cars (each tank capacity is assumed to be 2000 barrels) to replace it, without considering the installation of the rails required.

Waterborne transportation can be priced competitively with pipelines, but their use is limited by geography. The Mississippi and Illinois rivers are extensively used for this purpose, since they connect the Gulf Coast with the Midwest, allowing waterborne transportation directly to the Chicago area. Ships can travel along the Gulf and the East Coast, but these movements are subject to economic competition with the Colonial pipeline.

In terms of logistics, another advantage of waterborne shipments is that there are fewer limitations to transport non-fungible products. These could be unfinished products, in example gasoline with lower/higher RVP than required for the season; an unfinished product used as feedstock in a refinery unit, for example heavy gas oil & vacuum gas oil to feed the hydrocracking unit; or gasoline components like alkylate or reformate used for blending a variety of gasoline grades. An operator could be constrain to sell these products due to economics or technical problems in a processing unit(s).

Pipeline Operations

To move crude oil through the pipelines, electric, diesel or gas fueled pumps are sited at the originating station and at 30 to 100 mile intervals along the length of the pipeline, depending on physical characteristics of the crude transported, like density and viscosity, topography and capacity requirements. Oil moves at a speed of 60 to 160 miles per day.

Product Flow

It is possible to ship different grades of the same product through a pipeline, or even different products like gasoline and diesel. Product batches are injected in sequence; batch minimum volume is dictated by the pipe size and the transportation speed, as well as the logistic needs of the shippers.

Most of the pipelines operate in fungible mode. The same product from different shippers can be mix together and sent as one batch, if they meet pre-established specifications. This gives access to shippers with smaller volumes whose products meets pipeline's specifications to transport their goods through the pipeline. Specifications are settled by pipeline operators, based on quality standards and environmental regulations. For example, the Explorer pipeline publish on an annual basis the monthly schedule of the maximum permitted Reid Vapor Pressure (RVP) for every gasoline grade; typically

in summer months, RVP for regular gasoline cannot exceed 7.8 psig, in winter cannot exceed 13.5 psig, with transitional months in February/March and September/October. Products that have to be kept separate or do not meet the specifications must meet the minimum batch volume or sent by other transportation methods. A typical sequence of petroleum product batches is shown in figure IV.6.
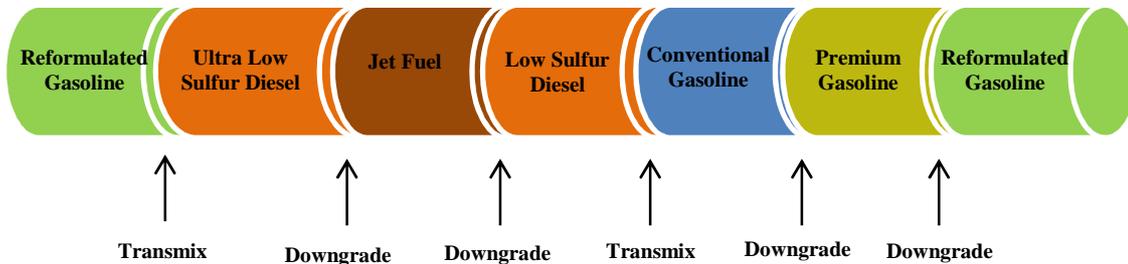
Figure IV.6 Typical sequence of petroleum products batches through a pipeline.

There are no physical separations between the batches; therefore, a certain volume of each product mixes with the following and the prior product in the line. If the products are similar, such as different grades of gasoline, the mixed volume (downgraded) is added to the lower value product. If they are very different, such as diesel and gasoline, the mixed volume (transmix) must be store separately and reprocessed. Complexity rises with the number of different grades for every product; for example, the Explorer pipeline publishes over 17 different grades of fungible gasolines.

Logistics Hubs

Hubs are characterized by their significant storage capacity, their interconnections among many pipelines and often among other modes of transportation, including railroad cars, barges and trucks. These hubs greatly increase flexibility, as they allow movements between different systems and provide alternatives for shippers, very important aspects for an efficient market.

New York Harbor is a logistic hub for refined petroleum products: products from the Gulf Coast (having arrived by pipeline) and abroad (having arrived by tanker) are traded along with supplies from area refineries; it acts as a central distribution center for the region, and many of the petroleum products delivered to the Harbor are redistributed to smaller ports where they supply local demand. In particular, the Hudson River, which meets the Atlantic Ocean in New York Harbor, provides a major inland water route for petroleum product barges supplying eastern New York and parts of western New England. On the other side of the State, western New York product markets are primarily supplied from Canada at the Port of Buffalo, and via the Buckeye and Sunoco pipeline systems from Pennsylvania and the Midwest. It has a storage capacity of over 75 million

barrels, making it the largest petroleum product hub in the Northeast (U.S. Energy Information Administration, 2009).

Cushing, Oklahoma, is a major hub in oil and product supply connecting the Gulf Coast suppliers with northern consumers, since it holds about 11.1% of the total U.S. crude inventory (January 2011). Cushing is established as the price settlement point for West Texas Intermediate (WTI) on the New York Mercantile Exchange. Production of West Texas Intermediate and other domestic crude oils comes together with supplies imported through the Gulf Coast and is re-distributed northward to Chicago area refineries and, decreasingly, south to the Gulf Coast refineries. Other large transportation hubs in the United States include Chicago, Patoka, Los Angeles, and the Texas-Louisiana Gulf Coast.

IV.5.2 Waterborne: Oil Tankers and Barges

Waterborne transportation is the second most used method to ship oil and petroleum products. Oil tankers can be classified according to their capacity in Dead Weight Ton (DWT) and their ability to cross key geographic channels, like the Panama Canal and the Suez Canal. (Asariotis, Benamara, & Hoffman, 2011). Channel's dimension limits the size of vessels that can cross it. Therefore, two ships with the same DWT can have different length, beam, draft, and one of them may not be able to traverse the channel.

- Handy/ Handymax: These are small vessels with less than 50.000 DWT, suited for small ports with length and draft restrictions or lacking infrastructure.

- Panamax: Ocean-going cargo vessel of the maximum size possible to pass through the locks of the Panama Canal. These vessels are typically of 50.000 to 79.999 DWT, with moulded breadth (maximum beam excluding external plating) less than 32.31 meters.

- Aframax: Ocean-going crude oil tanker vessels of standard size between 80.000 and 124.999 DWT. They combine a large carrying capacity with flexibility and lower overheads than those of VLCCs or Suezmax vessels. They are often deployed for trading within and between the following regions: North-West Europe, the Caribbean, the East Coast of North America, the Mediterranean, Indonesia and East Asia.

- Suezmax: Ocean-going cargo vessel of the maximum size possible to pass through the locks of the Suez Canal in Egypt, usually with capacities that range 125.000 to 199.999 DWT. However, because of many modifications to the locks and dredging works in the canal itself, currently allows for vessels of up to

240.000 DWT. Suezmax vessels play an important role in trade from West Africa to North-West Europe, and to the Caribbean/East Coast of North America, as well as across the Mediterranean.

- Very Large Crude Carrier (VLCC): Ocean-going crude oil tanker of 200.000 to 349.999 DWT. These vessels have greater flexibility than ULCCs due to their smaller size and are used extensively in the Mediterranean, West Africa and the North Sea. These vessels can sometimes be ballasted through the Suez Canal.

- Ultra Large Crude Carrier (ULCC): Ocean-going crude oil tanker of 350.000 DWT or more. These are the largest vessels in the world and are used for carrying crude oil on long haul routes from the Arabian Gulf to Europe, America and the Far East, via the Cape of Good Hope. These vessels require custom built terminals for loading and discharge.

Handymax and Panamax vessels are often used to carry refined petroleum products, and referred as "clean" tankers. These tankers are specialized cargo-carrying vessels which can carry – for example – naphtha, clean condensate, jet fuel, kerosene, gasoline, gas oil, diesel, cycle oil and fuel oil. Unlike "dirty" tankers, which primarily transport crude oil and unfinished products from its origin to the location of the refinery, clean tankers handles the processed cargo that leaves the refinery destined for its point of consumption. These vessels are typically used in short distances, and it is very unlikely to see movements through PADDs, since longer distances increases freight costs and shippers prefer to transport petroleum products through pipelines. In the Midwest (PADD 2), local demand exceeds refining capacity, in contrast with the Gulf Coast (PADD 3), where local demand for finished products is lower than available capacity; therefore, excess production from Gulf Coast is transported through vessels or the Colonial Pipeline System to PADD 1; through the Explorer Pipeline system for consumption in PADD 2; or exported to Central and South America using Handymax or Panamax vessels.

"Dirty" tankers are larger vessels (Aframax, Suezmax, and so forth) since there are economies of scale in long distance travels, a very common situation due to the asymmetrical distribution of crude oil reserves in the world and within the United States. But transportation of crude oil in large vessels is limited only to imports and exports; the number of vessel available is very small since the Jones Act limits the carriage of goods between United States ports to U.S. built and flagged vessels, travels between U.S. are short, and the owners cannot compete with lower transportation costs offered by crude oil pipeline operators and their extensive network.

Freight costs are calculated with the following formula:

$$Freight\ cost = \frac{MT * FR * ML}{100}$$

Where:

MT= Vessel's capacity (in Metric Tons)

FR= Flat Rate from origin to destination port (in $/Metric Ton)

ML= Market level (%)

Flat Rates are determined by Worldscale, a unified system of establishing payment of freight rate for a given oil tanker's cargo. Once a year, a set of base voyage costs (including bunkers, port costs, etc. for both laden and return ballast legs) is published for a theoretical standard vessel plying its trade between each of the world's main loading and discharging ports. Worldscale is produced by Worldscale Association (NYC) Inc. for the Americas and by Worldscale Association (London) Ltd. for the rest of the world.

It is common to express market levels in terms of a direct percentage of the flat rates instead of a plus or minus percentage. This method is known as "Points of Scale" and thus Worldscale 100 (WS100) means 100 points of 100 per cent of the published rate.

Several companies offer shipping brokerage services. One of the most important is RS Platou, an international ship- and offshore broking company established in 1936. This company serves the shipping and offshore industry worldwide by providing services within chartering, sale and purchase and contracting of ships and offshore units. It provides investment banking services and project financing with a core focus on the shipping and offshore industries.

Regulations

Maritime commerce in U.S. waters and between U.S. ports is regulated by the Merchant Marine Act of 1920. Section 27, also known as the Jones Act, deals with cabotage and requires that all goods transported by water between U.S. ports be carried in U.S.-flag ships, constructed in the United States, owned by U.S. citizens, and crewed by U.S. citizens and U.S. permanent residents.

The cabotage provisions restrict the carriage of goods or passengers between United States ports to U.S. built and flagged vessels. At least 75 % of the crewmembers must be U.S. citizens. Moreover, the steel of foreign repair work on the hull and superstructure of a U.S.-flagged vessel is limited to 10 % by weight. This restriction largely prevents American ship-owners from refurbishing their ships at overseas shipyards. In addition, amendments to the Jones Act, known as the Cargo Preference Act, provide permanent

legislation for the transportation of waterborne cargoes in U.S.-flag vessels. (U.S. Law, 1936)

IV.5.3 Motor Carriers

Trucks offer the greatest flexibility, since they can arrive to practically any location over land and the number of trucks is virtually limitless. However, each truck can transport a maximum volume and transportation costs increases dramatically to the number of trucks and distance. Trucks are the best option in short distances and small volumes. Although the share of petroleum product transportation is small compared with the share of pipeline and waterborne transportation, they play an important role transporting finished products from ports and terminals to retail outlets. Ethanol-blended gasoline cannot be transported by pipeline because ethanol is corrosive highly affinity with water. It is blended at the terminals or directly at retail outlets, transported by truck in any case.

IV.5.4 Downstream Marketing Arrangements for Refined Petroleum Products

Once the refined petroleum products leave the refinery, they reach consumers through one or more marketing channels. This final step in the supply of refined petroleum products includes two components: wholesale distribution (from product terminals to retail outlets) and retail distribution (to final consumers). Truck transportation is the most common delivery method of gasoline to retail outlets. There are four primary gasoline marketing channels for wholesale distribution. Three of these constitute direct distribution of product:

- Refiner-operated retail outlet: Refiners directly distribute gasoline to their own retail outlets.
- Lessee dealer: Retail outlets are owned by the wholesale distributor but leased to a gasoline dealer.
- Independent retailer: Retail outlets are owned and operated by independent dealers.
- Jobber: Distributors purchase directly from refiners and then sell products to retail outlets. This is an indirect product distribution.

IV.6 ETHANOL BLENDING

Concern over the effects of hydrocarbon fuels usage on the environment has caused changes in environmental regulations which impact gasoline and diesel fuel compositions. The main restrictions on diesel fuels limit sulfur and total aromatics

contents, and gasoline restrictions include not only sulfur and total aromatics contents but also specific compound limits (benzene), maximum Reid Vapor Pressure, and minimum oxygen contents for areas with carbon monoxide problems. This has led to the concept of reformulated gasoline. A reformulated gasoline specification is designed to produce a fuel for spark ignition engines which is at least as clean burning as high methanol content fuels. The areas where reformulated gasoline use is mandatory are shown in figure IV.7. These areas include the majority of the most populated cities of the United States, like Chicago, Houston, Los Angeles, New York and Washington, which typically have higher pollution levels in the air; it is also mandatory in the whole state of California, while is optional elsewhere. In total, it includes 17 states, the District of Columbia and some protected environments.

Figure IV.7 Reformulated Gasoline areas in the United States.

Blending ethanol in gasoline dramatically reduces carbon monoxide emissions. According to the National Research Council, carbon monoxide emissions are responsible for as much as 20% of smog formation. Ethanol contains 35% oxygen. Adding oxygen to fuel results in more complete fuel combustion, reducing harmful emissions. These reductions offset the slight increase of evaporative emissions due to the higher volatility of ethanol-blended fuel. In reformulated areas however, gasoline blended with ethanol must meet the same evaporative emission standard (Reid Vapor Pressure) as gasoline without ethanol.

Ethanol can be produced from any feedstock that contains plentiful natural sugars or starch that can be readily converted to sugar. Feedstocks include sugar cane (Brazil),

sugar beets (Europe), and corn (United States). Ethanol is produced by fermenting sugars. Corn grain is processed to remove the sugar in wet and dry mills (by crushing, soaking, and/or chemical treatment), the sugar is fermented, and the resulting mix is distilled and purified to obtain anhydrous ethanol. (U.S. Energy Information Administration (EIA), 2007)

Most fuel ethanol in the United States is used in gasoline blends, where it accounts for as much as 10 % of each gallon of fuel. In higher blends, ethanol can make up as much as 85% of each gallon of fuel by volume. The increased use of ethanol as a transportation fuel over the past years has raised the issue of fuel volume versus energy content. Ethanol contains less energy per gallon than conventional gasoline. A gallon of ethanol has only two-thirds the energy of a gallon of conventional gasoline, and the number of miles traveled by a given vehicle per gallon of fuel is directly proportional to the energy contained in the fuel.

All gasoline vehicles in use in the United States today can accept gasoline blended with up to 10 % ethanol. Flexible Fuel Vehicles (VVFs) are cars and trucks that can use any level of ethanol up to 85 percent. They're built with special fuel system components designed to be compatible with higher ethanol concentrations. (Renewable Fuels Association, 2011).

Ethanol fuel mixtures have "E" numbers which describe the percentage of ethanol fuel in the mixture by volume. For example, E85 is 85% ethanol and 15% gasoline. Under current U.S. policy, ethanol is permitted to be blended with gasoline in mixtures up to 10% ethanol (E10), by volume, or 85% ethanol (E85). In the past, blends with ethanol content above 10 % but less than 85 % were not permitted, except for use in Flexible Fuel Vehicles. In 2010 and 2011, the U.S. Environmental Protection Agency (EPA) granted two partial waivers that allow but do not require the introduction into commerce of gasoline that contains greater than 10 % (E10) in volume of ethanol and up to 15 % in volume of ethanol (E15) for use in model year 2001 and newer light-duty motor vehicles. These decisions were based on test results provided by the U.S. Department of Energy (DOE) and other information regarding the potential effect of E15 on vehicle emissions.

Figure IV.8 shows the production of ethanol in the United States. It averaged 0.9 million barrels in the first semester of 2011, well above the previous 3 years. There is an upward trend in production. Ethanol use in the United States is regulated by federal law and intermediate gasoline blends with more than 10% and less than 85% ethanol are prohibited (except for the 2 partial waivers mentioned before), so ethanol consumption has reached its ceiling. Most of the retail stations sell E10 blends, so production levels are higher than demand and the excess volume is destined for exportation.
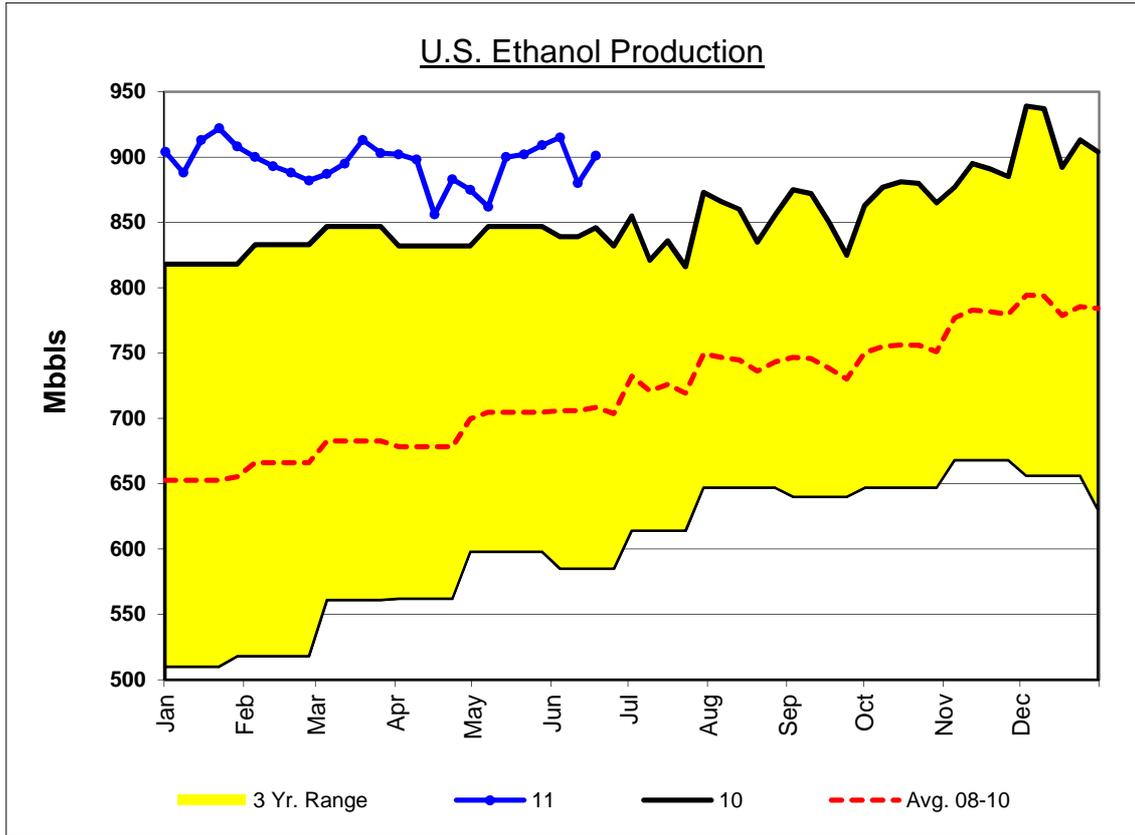
Figure IV.8 U.S. Ethanol production

CHAPTER V

CONCLUSIONS

Consumption of crude oil and petroleum products has trended upward since its discovery in 1859, along with their prices. In 1978, consumption was approximately 7.4 million barrels per day. In 1981, following a recessionary period along with increasing gasoline prices, consumption was 6.5 million barrels per day. It was not until 1993 that consumption surpassed the levels in 1978. Since then, consumption has steadily increased. In the 21st century, the United States is the single largest consumer of oil products. Taking into account seasonality effects, demand for gasoline in the United States has increased slightly in the last 10 years, averaging 9.6 million barrels per day in 2010.

Modern refinery operations are very complex; they involve many processes and yield a wide variety of products. In the United States, gasoline production accounts for about 50% of total volume produced; it is therefore the main product and it is an important determinant of refiners' margin level in any given year. Crude oil price is an important factor influencing margins too; since it is practically the only feedstock for the refining industry, small price variations can produce large changes in margins.

Supply and demand is strongly asymmetrical throughout the United States. The Gulf Coast refining capacity exceeds by far local demand and the refining capacity in other PADDs. The Rocky Mountains and the West Coast are balanced. The East Coast and the Midwest have lower capacity than demand and they rely on product imports from the Gulf Coast. The East Coast is under strong competitive pressure, caused by petroleum products imports from Europe. This competitive pressure may result in refinery shutdowns and therefore lost in capacity.

Gasoline demand is very inelastic in the short term. There is strong evidence of a dramatic decrease in the last decade. Since elasticity is very close to zero, it means that regardless of the percent change in price, the percent change in quantity is negligible. For refinery operators this creates an opportunity to profit. Also, the participants on the financial side of the oil market may profit. Natural hedgers, such as banks, trading companies, and oil companies themselves are involved in the financial aspects, such as futures.

The number of refineries in the United States has decreased in the past years, in contrast with the increasing refining capacity. Refining capacity increase is due to large investments in upgrades and the expansion of existent refineries. It is a very tight market; high competition and very stringent environmental regulations leave very few

opportunities for new operators to enter the market, in fact leading to the closure of some refineries. These regulations increase operating costs, since refinery owners must invest heavily in new technologies and upgrades to meet the mandates and make their products within narrow specification, otherwise they cannot sell it to final consumer and they are constrain to reprocess it.

Bulk transport of crude oil and petroleum product is done by pipelines. Pipelines dominate the entire transportation market in the United States with 60% in 2008, and its share in transportation continue to rise as new projects regarding the construction and expansion of existent pipelines are currently developed. Most of the crude oil imported from Canada is transported by this method. Despite the small share of waterborne and truck methods, these are very important because they give more flexibility to the system and allow the transportation of non-fungible or unfinished products. Trucks transport products from terminal and ports to retail outlets. Ethanol-blended gasoline can only be transported in this manner; it is too corrosive for transportation in pipelines and subject to contamination for its affinity with water.

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APPENDIX

Table A.1 Overview of Petroleum Refining Processes

Process name	Action	Method	Purpose	Feedstock(s)	Product(s)
Fractionation Processes					
Atmospheric distillation	Separation	Thermal	Separate fractions	Desalted crude oil	Gas, gas oil, distillate, residual
Vacuum distillation	Separation	Thermal	Separate w/o cracking	Atmospheric tower residual	Gas oil, lube stock, residual
Conversion Processes-Decomposition					
Catalytic cracking	Alteration	Catalytic	Upgrade gasoline	Gas oil, coke distillate	Gasoline, petrochemical feedstock
Coking	Polymerize	Thermal	Convert vacuum residuals	Gas oil, coke distillate	Gasoline, petrochemical feedstock
Hydro-cracking	Hydrogenate	Catalytic	Convert to lighter HC's	Gas oil, cracked oil, residual	Lighter, higher-quality products
*Hydrogen steam reforming	Decompose	Thermal/ catalytic	Produce hydrogen	Desulfurized gas, O2, steam	Hydrogen, CO, CO2
*Steam cracking	Decompose	Thermal	Crack large molecules	Atm tower hvy fuel/ distillate	Cracked naphtha, coke, residual
Visbreaking	Decompose	Thermal	reduce viscosity	Atmospheric tower residual	Distillate, tar
Conversion Processes- Unification					
Alkylation	Combining	Catalytic	Unite olefins & isoparaffins	Tower isobutane/ cracker olefin	Iso-octane (alkylate)
Grease compounding	Combining	Thermal	Combine soaps & oils	Lube oil, fatty acid, alky metal	Lubricating grease
Polymerizing	Polymerize	Catalytic	Unite 2 or more olefins	Cracker olefins	High-octane naphtha, petrochemical stocks
Conversion Processes- Alteration or Rearrangement					

Catalytic reforming	Alteration/ dehydration	Catalytic	Upgrade low-octane naphtha	Coker/ hydro-cracker naphtha	High oct. Reformate/ aromatic
Isomerization	Rearrange	Catalytic	Convert straight chain to branch	Butane, pentane, hexane	Isobutane/ pentane/ hexane
Treatment Processes					
*Amine treating	Treatment	Absorption	Remove acidic contaminants	Sour gas, HCs w/CO2 & H2S	Acid free gases & liquid HCs
Desalting	Dehydration	Absorption	Remove contaminants	Crude oil	Desalted crude oil
Drying & sweetening	Treatment	Abspt/ therm	Remove H2O & sulfur cmpds	Liq Hcs, LPG, alky feedstk	Sweet & dry hydrocarbons
*Furfural extraction	Solvent extr.	Absorption	Upgrade mid distillate & lubes	Cycle oils & lube feed-stocks	High quality diesel & lube oil
Hydrodesulfurization	Treatment	Catalytic	Remove sulfur, contaminants	High-sulfur residual/ gas oil	Desulfurized olefins
Hydrotreating	Hydrogenation	Catalytic	Remove impurities, saturate HC's	Residuals, cracked HC's	Cracker feed, distillate, lube
Solvent deasphalting	Treatment	Absorption	Remove asphalt	Vac. tower residual, propane	Heavy lube oil, asphalt
Solvent extraction	Solvent extr.	Abspt/ precip.	Separate unsat. oils	Gas oil, reformate, distillate	High-octane gasoline

Figure A.1 Main crude oil pipelines and refinery capacities in the United States