EVALUATION OF QUALITY AND SUSTAINABILITY INCENTIVES TO OPTIMIZE THE INDONESIAN TO THE UNITED STATES CRUDE OIL SUPPLY CHAIN

by

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Abstract

EVALUATION OF QUALITY AND SUSTAINABILITY INCENTIVES TO OPTIMIZE

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The New York Times explained that the United States increased its dependence on oil from Saudi Arabia by more than 20 percent last year (Krauss 2012). The United States of Energy Information Administration (U.S. EIA) stated that oil from Saudi Arabia was accounted for 14 percent of the U.S. crude oil and petroleum products in 2012 ("Oil: Explained" 2012). This is problematic due to the fact that 14 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia. What happens to the U.S. economy when Saudi Arabia manipulates demand and possibly stops exporting oil to the U.S.? Governments, crude oil refining companies, and other stakeholders are finding it necessary to invest infrastructure and buy crude oil from other nations including Indonesia.

The objective of this dissertation is to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources. In order to meet the objective, three specific objectives are investigated such as evaluate the supply chain factors that determine supply chain quality of crude oil production; evaluate sampling plans that balances the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia; and evaluate the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. The intellectual merit of this dissertation is a mixed-integer programming (MIP) model that demonstrates the tradeoffs between supply chain quality and supply chain profit for Indonesia that can be expanded to other nations.

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Chapter 1

Introduction

1.1 The United States Dependency on Foreign Oil

The New York Times explained that the United States increased its dependence on oil from Saudi Arabia by more than 20 percent last year (Krauss 2012). However, according to the United States of Energy Information Administration (U.S. EIA), the net imported oil of the U.S. has declined since peaking in 2005 – see Figure 1-1 ("Oil: Explained" 2012). Krauss described that the increase in oil imports from Saudi Arabia began last summer for a number of reasons:

> Saudi Arabia increased oil production and exportation to all countries including the U.S. to keep oil prices stable, because Iran is exporting less oil due to sanctions imposed by the U.S. which gives some fear to make nuclear weapons; several domestic oil refining companies in the U.S. have found it necessary to buy more crude oil from Saudi Arabia to make up for declining production from Mexico and Venezuela; Canadian oil production has been increasing rapidly in recent years, unfortunately, there is not enough pipeline capacity; and there are also echoes from the disastrous British Petroleum (BP) well explosion and spill in 2010, which led to yearlong drilling moratorium in the Gulf Mexico (2012).

1.1.1 Problem Statement

The U.S. EIA stated that the U.S. consumed an estimated 18.8 million barrels per day (MMbd) of petroleum products and produced 10.4 MMbd of crude oil and petroleum products during 2011 ("Oil: Explained" 2012). Therefore, the U.S. net imports of crude oil and petroleum products equaled 8.4 MMbd, making the U.S. dependent on foreign oil – see Figure 1-1 ("Oil: Explained" 2012). The Western hemisphere including North, South, and Central America, the Caribbean, and the U.S. territories; and the Persian Gulf countries such as Iraq, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates, exported 52 percent and 22 percent, respectively of crude oil and petroleum products to the U.S. in 2011 ("Oil: Explained" 2012). Oil from Canada (a Western hemisphere country) and Saudi Arabia (a Persian Gulf country) were accounted for 29 percent and 14 percent, respectively of the U.S. crude oil and petroleum products, which made those countries as the top two foreign oil sources for the U.S. in 2011 – see Figure 1-2 (“Oil: Explained” 2012). This is problematic due to the fact that 14 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia which leaves the U.S. susceptible to Middle Eastern manipulation and homeland security.

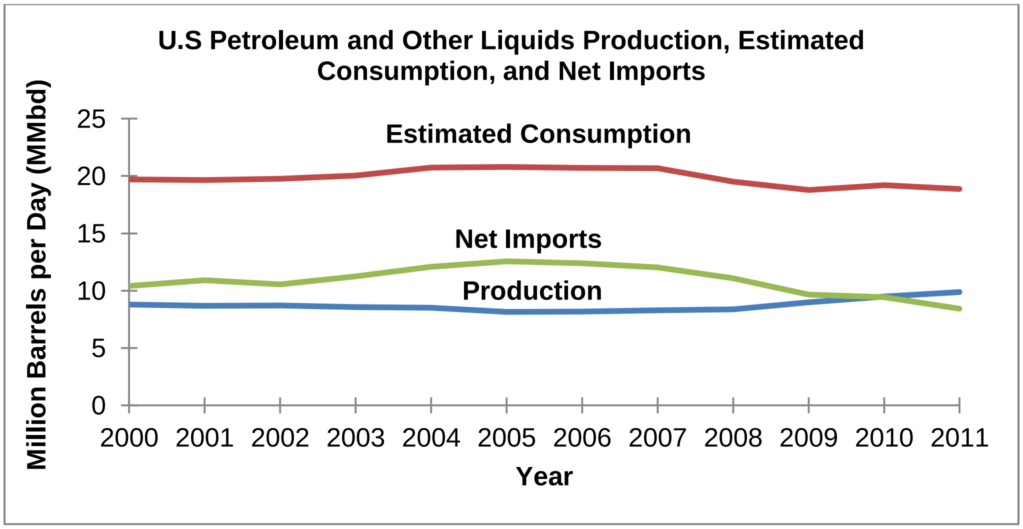

Figure 1-1 U.S. Petroleum and Other Liquids Production, Estimated Consumption, and Net Imports from 2000 – 2011. Preliminary Data: U.S. EIA, October 21, 2012, Web.

1.1.2 Research Significance and Broader Impacts

What happens to the U.S. economy when Saudi Arabia manipulates demand and possibly stops exporting oil to the U.S.? Over the decades, there has been disbelief that the U.S. dependence on foreign oil has presented strategic challenges and has shown effects on the nation’s economy and national security. However, this dependency also helps to shape the U.S. foreign policy and influences international relations. Today, the debate lies in the issues of which foreign oil dependence are more challenging and what steps should be taken by the U.S. government to help ease these issues. The significance of this dissertation is to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that identifies how other nations such as Indonesia can supply some of crude oil imports with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. According to the U.S. EIA, oil from Indonesia was accounted for only 0.24 percent of the U.S. crude oil and petroleum products in 2011 – see Figure 1-2 (“Oil: Explained” 2012). Furthermore, the broader impact is investments into other countries crude oil supply chains can be quantified and optimized, and countries such as Indonesia can be identified as possible candidates for investment for future global crude oil needs.

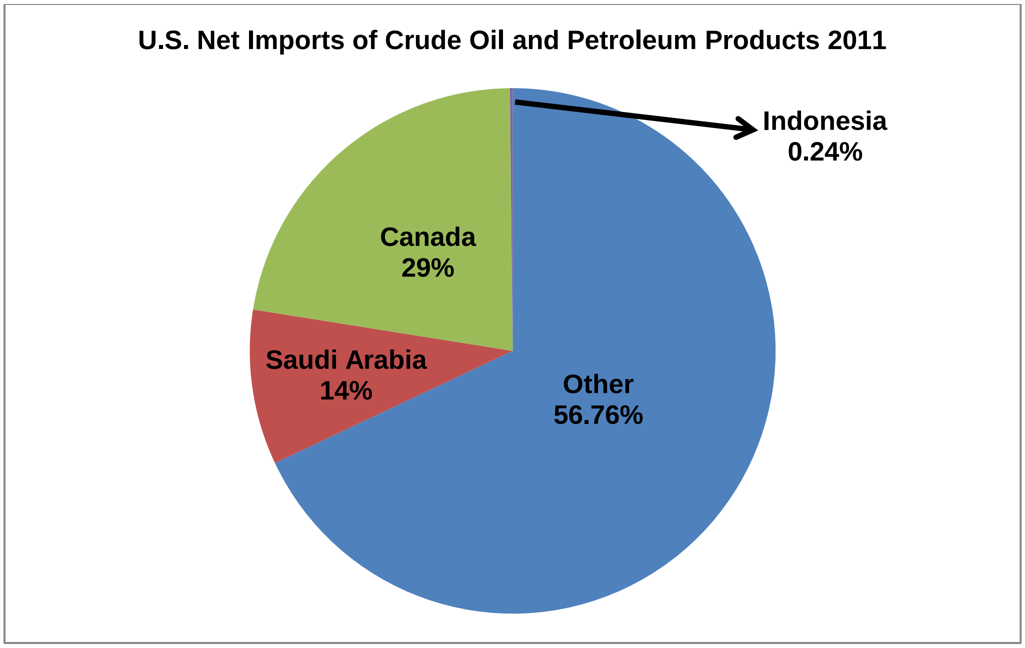

Figure 1-2 U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, and Indonesia in 2011. Preliminary Data: U.S. EIA, October 21, 2012, Web.

1.1.3 Research Question and Hypotheses

The U.S. government, crude oil refining companies, and other stakeholders find that it is necessary to invest infrastructure and to buy crude oil from other nations.

Therefore, this dissertation strives to answer the research question of “When is it economically beneficial to invest in the supply chain quality of crude oil from a given nation?”, hypothesizes that the crude oil supply chain quality will impact the crude oil supply chain costs and the environmental sustainability will have an impact on crude oil supply chain, and suggests that the crude oil supply chains in each of these countries will dictate their ability to provide crude oil.

1.2 Research Purposes

The goal of most companies is to maximize profit and shareholder value. Pirog explained that companies can accomplish this goal through several activities such as organize production so that the company can make profit in the current time frame as well as in the future, make investment decisions to raise the company’s rate of return, and motivate employees to increase productivity, decrease costs, and hence enhance profitability (CRS-5). Those activities assure that the goods or services have high quality and available at the lowest price consistent with demand and supply factors which benefit customers.

1.2.1 Overall Research Objective

In oil industry, resources optimization through managing exploration, production, and development activities will maximize the shareholder value to guarantee a functioning market. Therefore, reserve replacement and the ability to expand production and sales to meet demand are necessary to ensure long term viability of the oil companies. Pirog also stated that the efficiency in all parts of the supply chain leads to cost minimization, improvements in product performance, and environmental integrity (CRS-5).

A majority of governments own their national oil companies, thus, the companies do not follow the maximization of shareholder value. However, they might have to compete with other government's objectives in order to maximize the shareholder value. The amount of a government's influence on its national oil companies varies widely. In the developed nations, the national oil companies such as Statoil of Norway and PETRONAS of Malaysia tend to follow "a commercial oriented strategy" (Pirog CRS-6). In the less developed nations, the national oil companies such as Nigerian National Petroleum Co. of Nigeria, Petroleos de Venezuela of the Bolivarian Republic of Venezuela, and PERTAMINA of Indonesia, often the government objectives supersede commercial objectives. Additionally, the government applies more pressure to those companies to maximize the flow of funds to national treasuries.

With the aim of answering the research question and decreasing the U.S. dependency on foreign oil only from one or two countries, this dissertation has an overall objective to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources and helps PERTAMINA to contribute more funds to the Indonesia's national treasuries as well.

1.2.2 Research Objective and Specific Research Objectives

Unlike other nations, the U.S. does not own a national oil company. Pirog explained that if the U.S. owned a national oil company, it would be established based on a "non-market strategy" policy and would have some potential advantages that other companies do not share such as acting to offset other national oil companies similar to how other nations' national oil companies behave; and the oil company directly responding to and implementing national energy policy (CRS-15). On the other hand, Pirog also argued some potential disadvantages such that if the U.S. had disagreements with a host nation, that country may be more willing to remove the U.S. national oil company versus a privatized international oil company because international politics play a larger role; and international private oil companies are generally more efficient and productive, especially in terms of gaining access to drilling areas (CRS-16).

There are several examples of unsuccessful deals between national oil companies in which the outcomes failed to meet expectations such as China and Iran as well as China and Saudi Arabia. Unlike with those countries, Indonesia has had a successful history working with the U.S. both domestically and with exporting crude oil. For these reasons, the U.S. would find it beneficial to increase its oil imports from Indonesia. The objective of this dissertation is to evaluate the effectiveness of a mixed-integer programming (MIP) model that demonstrates the tradeoff between crude oil supply chain qualities on profits in Indonesia. In order to meet this objective, three specific objectives are investigated such as evaluating the supply chain factors that determine supply chain quality of crude oil production; evaluating sampling plans that balances the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia; and evaluating the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks.

Chapter 2

Background

2.1 Crude Oil and Petroleum Products

There is a popular misconception that oil comes from dead dinosaurs. Scientists explain that one-celled creatures or tiny sea plants and animals form oil. Those plants and animals died, sank, and settled to the bottom of the ocean floors. Given many thousands of years, sands and sediments bury the organic remains thousands of feet below the surface, which then turned into sedimentary rocks. The earth's heat and pressure, as a result of the rock layers increasing, transformed the ancient organisms into oil and natural gas – see Figure 2-1. Oil reserves cannot be produced because it takes millions of years to form. Therefore, crude oil or petroleum is a nonrenewable energy source.

Petroleum has been used since ancient times, especially by the Egyptians and Chinese to light their homes. In current times, geologists observe rocks types and arrangements within the earth to determine whether or not oil can be found at a specific location. E-Tech International explains that oil exploration and production processes are comprised of five main activities such as geologic survey, exploratory drilling, appraisal, production, and decommissioning (2012). These processes are expensive and often unsuccessful. The National Energy Education Development (NEED) Project showed that only 61 percent of oil exploration and production produced oil in 2010 ("Petroleum" 2012).

Oil exploration and production processes start with geologic surveys. Following the surveys, existing data, such as geological maps and aerial photography are studied to determine favorable locations where hydrocarbons may be present. Next, on site surveys are taken. These comprise of a field geological assessment, and then one of three methods such as magnetic, gravimetric, or seismic site scanning are used to determine the rock strata depths and characteristics.

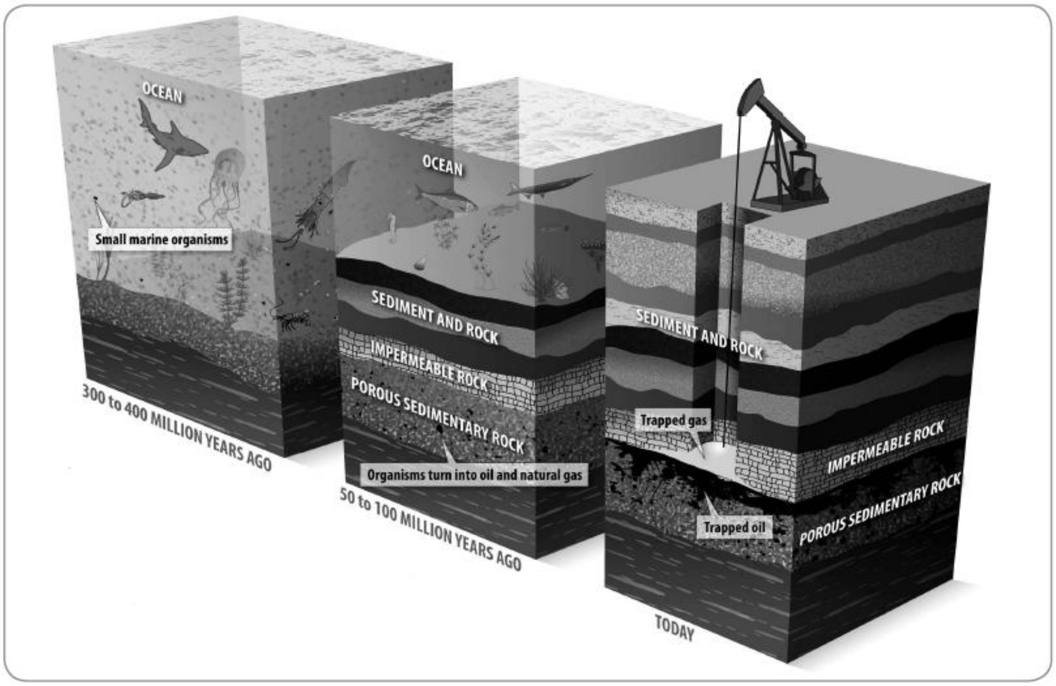

Figure 2-1 Crude Oil and Natural Gas Formations. Source: The Need Project – Petroleum, January 17, 2013. Web.

Exploratory drilling is then used to confirm the presence of oil. Exploratory wells on land begin with clearing the site and constructing a pad to support the drill rig and assembling other facilities such as communication, workforce accommodations, fuel handling and storage, equipment maintenance areas, and waste and disposal handling. Drilling begins with fluid, such as mud, continuously circulated down the drill pipe and back to the surface in order to balance the surface and underground pressure – see Figure 2-2. As boring continues, steel casing is run into the completed sections. If hydrocarbon formation is found, initial well tests are conducted to determine if enough oil exists to make the site commercially viable.

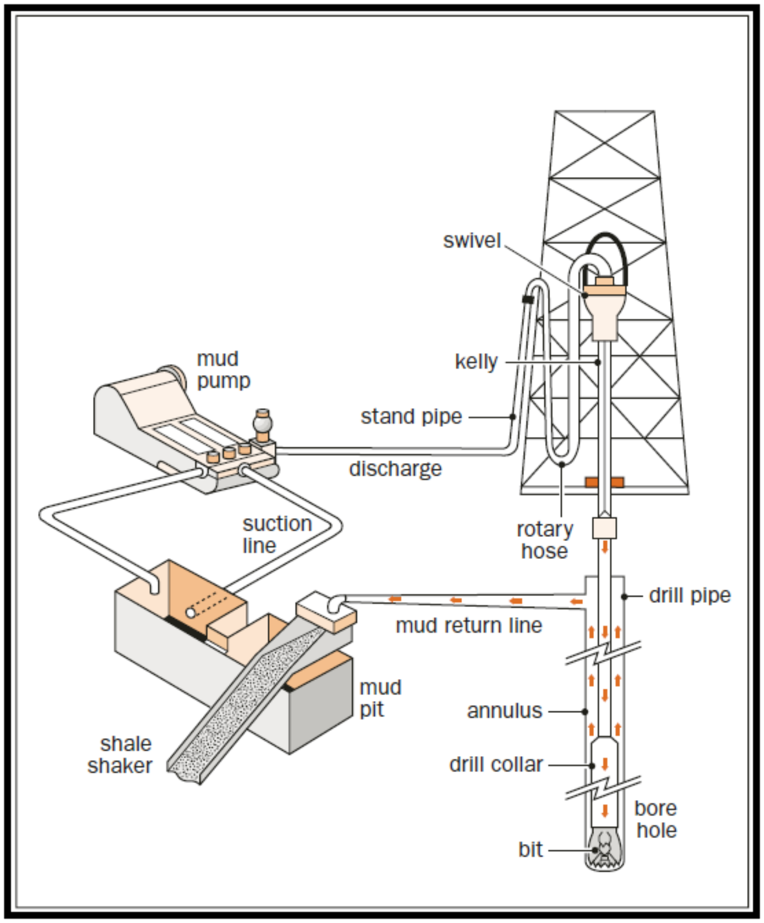

Figure 2-2 Drilling Equipment. Source: E-Tech International: Oil Exploration and Production, January 17, 2013. Web.

The next activity is to drill wells to further appraise the oil reservoir's nature and size. The drilling process is the same as that of exploratory wells, and multiple and/or directional appraisal wells may be drilled. After exploration and appraisal, development or production wells are built. The size of the reserve dictates the number of production wells, which can be over 100 for very large oil fields (E-Tech International 2012). Production wells have lighter weight tubing and control valves and are smaller than exploratory wells. Production consists of routing the oil, either free flowing or pumping, from the wells to a processing facility. Here the oil, gas, and water are separated. The oil is heat treated in order to stabilize it for transport either by tanker truck, ship, or pipeline. The gas is compressed and unwanted components are removed. Offshore exploration and production differ from onshore drilling primarily with regard to drill rig structures. These structures can be one or a combination of steel and concrete platforms, satellite platforms, subsea systems, and floating systems – ships and semi-submersibles. The final step in the process is to decommission the production facility after the oil has been removed from the field reservoir, which typically takes 20 to 40 years (E-Tech International 2012). This step involves removal of facilities, clean-up and site restoration with re-vegetation.

Even though petroleum products have helped people, the products have some tradeoffs. Most air and water pollution is caused by oil refineries where the environment and wildlife can be endangered if there is a spill into rivers or oceans from drilling sites or transporting oil; and groundwater pollution which creates noxious fumes caused by underground storage tank leaks. Oil companies who operate in the U.S. must follow laws and regulations from the United States of Environmental Protection Agency (U.S. EPA) to protect the environment. Most of those companies do a good job obeying the laws by making sure that their drilling sites and transportations are safe for the environment and improving their petroleum products to burn cleaner. However, some companies are negligent and do not follow the U.S. EPA laws and regulations which result in damaging the environment such as the disastrous British Petroleum (BP) drill explosion and oil spill in 2010 which impacted wildlife in the Gulf of Mexico.

After exploration and production processes, crude oil goes to a refinery to be transformed into petroleum products. Refinery is a complex process and it always starts with the initial distillation. In this process, crude oil is heated and broken down into its components. Then, the conversion process transforms lower-valued products into higher-valued products by removing impurities. This conversion process dictates the different types of crude oil, thus, distinguishing the differences in refineries.

West Texas Intermediate (WTI), West Texas Sour (WTS), Arab Heavy, and Bonny Light are some examples of different types of crude oil. There are many characteristics of crude oil, but the most common distinctions relate to its viscosity resulting in light and heavy crude oil. Viscosity in oil industry refers to the amount of impurities contained within the oil. These characteristics determine the amount of required processes to convert the crude oil into saleable petroleum products. Lighter crudes such as gasoline, diesel, and jet fuel require less production processes than heavier crudes. Sulfur is the most common impurity in oil. The more sulfur contained in a crude oil, the more sour it is and the more processing required before it can be sold in the marketplace. Therefore, sour crudes require more processing than sweet crudes.

The U.S. EIA classifies petroleum products into transportation fuels such as gasoline, diesel, and kerosene; fuel oils for heating and electricity generation; asphalt and road oil; and the feedstock which is used to make chemicals, plastics, and synthetic materials ("Petroleum Products" 2012). Americans used about 75 percent of the 6.79 billion barrels of petroleum products in the forms of gasoline, heating oil or diesel fuel, and jet fuel in 2012 – see Figure 2-3 ("Petroleum Products" 2012).

2.2 Today's Crude Oil, Product Markets, and Pricing

The world's most important sources of energy are petroleum, coal, natural gas, nuclear, and renewable energy. The Organization of Petroleum Exporting Countries (OPEC) stated that petroleum contributed to 35 percent of the world's energy source in 2010 – see Figure 2-4 ("World Oil Outlook" 2012). The U.S. EIA stated that Americans utilized petroleum products for about 36 percent (35.3 quadrillion Btu) of the U.S. total energy use (97.5 quadrillion Btu) and 93 percent of transportation relied on those petroleum products in 2011 (“Energy Source” 2012). This shows that the transportation sector is the primary customer of total energy use in the U.S. Transportation moves both products and people from point A to B, thus, it is important to the economy. Industries must have access to get raw materials and distribute products, whilst people must go to work. Therefore, oil is critical to the economic growth and demand for petroleum products from the transportation sector definitely drives the value of oil.

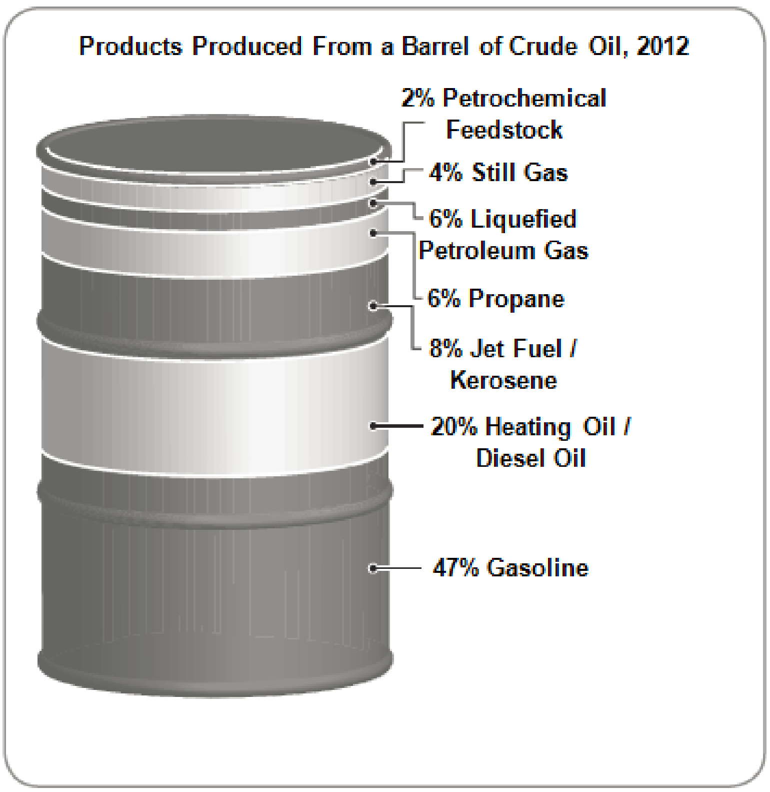

Figure 2-3 Petroleum Products Produced From a Barrel of Crude Oil in 2012. Source: U.S. EIA, January 18, 2013. Web.

Reynolds envisioned that one of the side effects of the U.S. dependency on foreign oil is that only a few Americans could afford transportation due to an increase in oil price that leads to an increase in prices for all products (1). There are many misunderstandings regarding the relationship between crude oil prices and petroleum products such as gasoline prices. One can tell that the change in gasoline prices is related to a change in crude oil prices – see Figure 2-5. The American Petroleum Institute (API) explained three important points on how crude oil prices affect petroleum products prices. First, crude oil and petroleum products are global commodities which supply and demand factors on a global marketplace (see Figure 2-6) determine both crude oil and petroleum products prices. Second, the price paid for petroleum products is determined by crude oil prices. Third, worldwide markets, to a great extent, determine prices taking in account both current and future expected supply and demand conditions ("Today's Crude Oil" 2006).

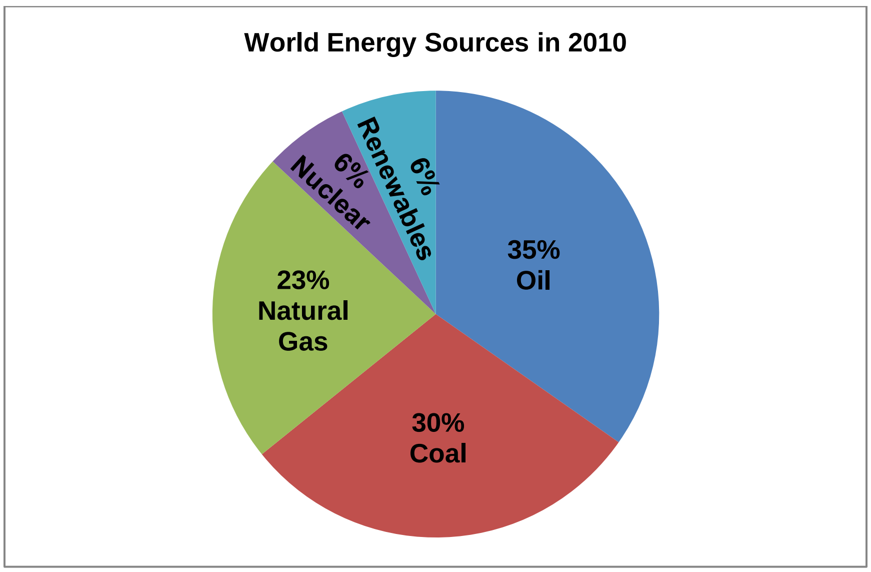

Figure 2-4 World Energy Sources in 2010. Preliminary Data: OPEC World Oil Outlook 2012, January 14, 2013, Web.

In the oil industry, the supply chain occurs within a global marketplace. It is an international chain that links producers, refiners, marketers, brokers, traders, and customers who sell and buy crude oil and petroleum products. Thus, the global oil marketplace facilitates oil movement from where it is produced, to where it is refined into petroleum products, to where those products are ultimately sold to customers ("Today's Crude Oil" 2006).

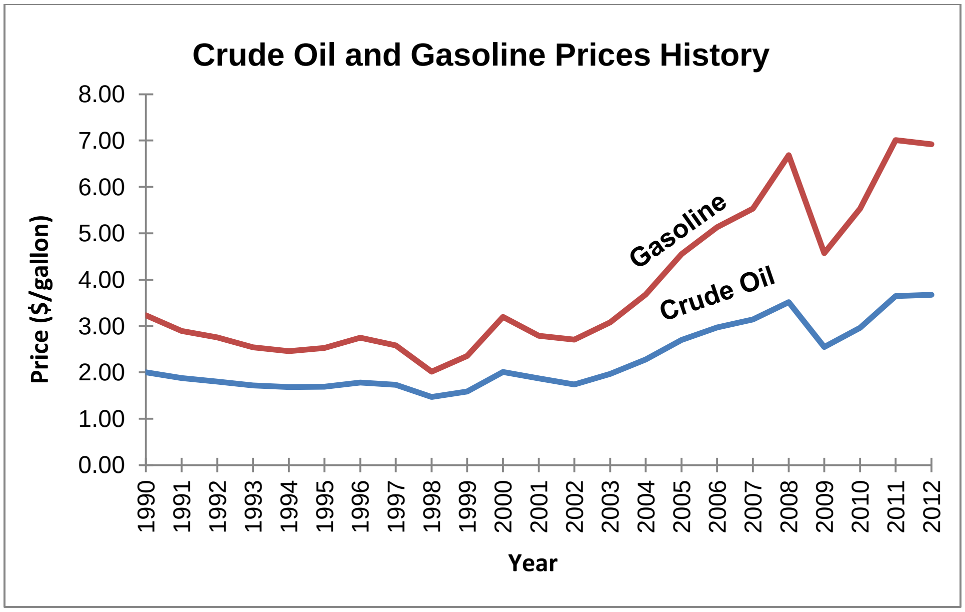

Figure 2-5 Crude Oil and Gasoline Prices History from 1990 – 2012. Preliminary Data: U.S. EIA, February 18, 2013, Web.

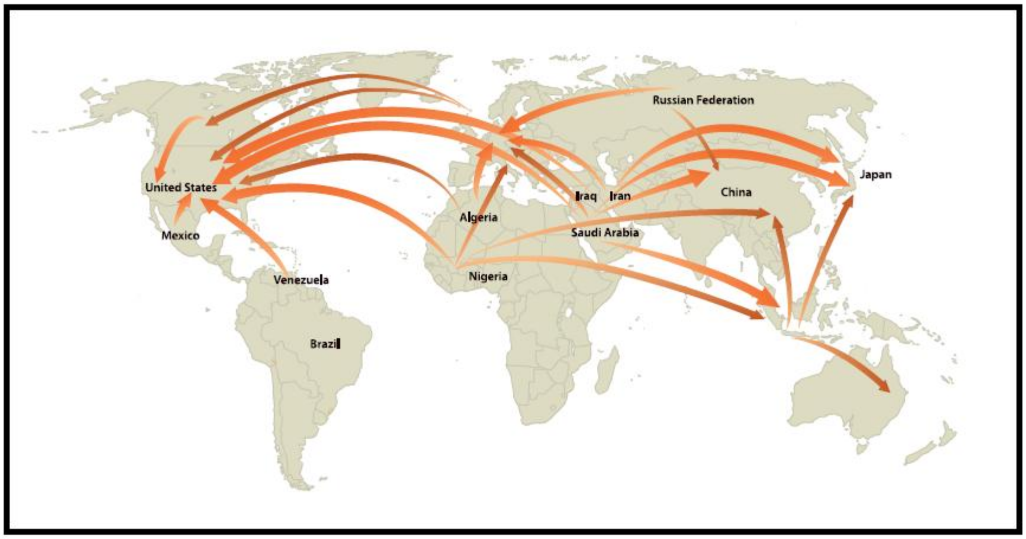

Figure 2-6 Crude Oil Global Marketplace. Source: API, January 20, 2013, Web.

The existing global marketplace reflects both sellers and buyers to the market in order to get the lowest transportation costs from sellers to buyers for each type of crude oil. As a result, trade flows in the global marketplace are the customers' preferences for different qualities of crude oil with the minimum transportation costs. However, this does not make trade flows to evaluate supply and demand or crude oil pricing. As an example, if an oil source cuts off its supply, whether or not that oil flows to the U.S., then competition from buyers for the world's remaining supplies would drive up all crude oil prices because those supplies would find new buyers who would release their existing purchases to the market. Alternatively, if a nation decides to cut off its shipments of crude oil to the U.S. but maintained its production, then long term impact on price would exist.

OPEC stated that the world consumed more than 89.5 million barrels of oil per day (MMbd) ("World Oil Outlook" 2012). Both national and international oil companies around the world supply oil from their respective reserves and produce oil for the world's demand. According to the U.S. EIA, OPEC controls approximately 70 percent of the world's total proven oil reserves and its oil exports represent about 60 percent of the total petroleum traded internationally – see Figure 2-7 ("OPEC Countries" 2012). Most of the largest oil suppliers such as Saudi Arabia, Iran, and Venezuela form OPEC. Its countries produced about 41 percent of the world's oil in 2012 ("World Oil Outlook" 2012).

OPEC consists of 12 countries and has an objective to collect and manage its members' oil supply so that it can be an individual oil producer to influence world oil prices. However, OPEC must limit its oil supply to the marketplace because at certain levels, crude oil prices would harm global economic growth and it is not in the organization's best interest to do so. Moreover, despite its large reserves share and global production, there are some evidences of significant changes in world crude oil prices over the last 25 years which highlight the fact that global supply and demand forces OPEC to limit its ability to influence world crude oil prices.

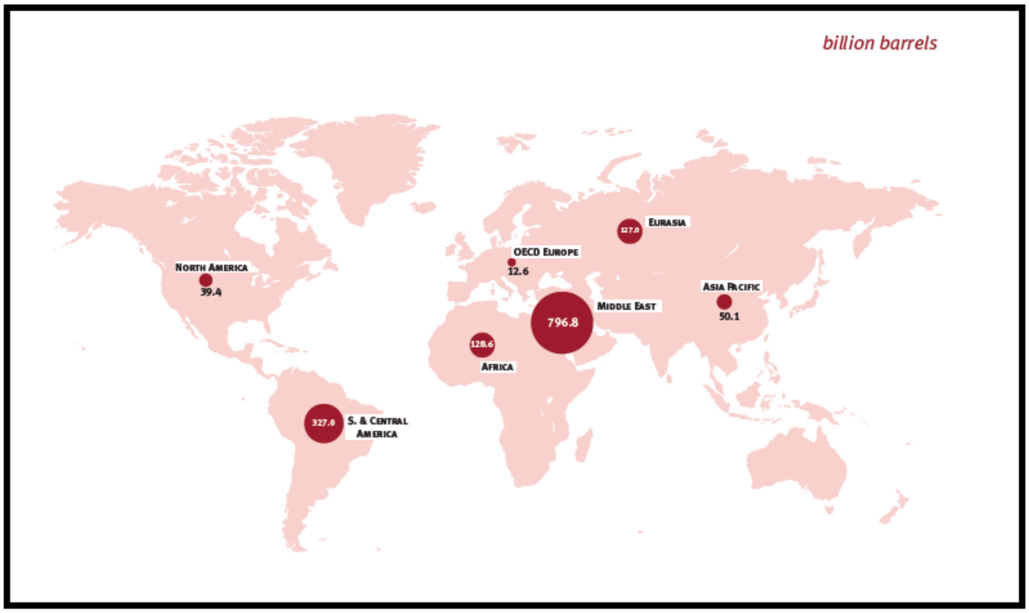

Figure 2-7 Proven Oil Reserves at End 2011. Source: OPEC World Oil Outlook 2012, January 14, 2013, Web.

Aside from OPEC members, there are three types of oil companies who currently supply the world's crude oil demand. This includes international oil companies (IOCs), national oil companies (NOCs), and NOCs with strategic and operational autonomy. IOCs consist of major private companies such as British Petroleum (BP), ExxonMobil, and Royal Dutch Shell which compete individually in the oil global marketplace and primarily seek to maximize the shareholder value by making their decisions based on economic factors. These companies only have small shares of global oil reserves and production to ensure that they act competitively with other private companies and cannot influence world crude oil prices. The characteristic of these major private companies is that they move rapidly to produce the available oil resources and sell their oils in the global marketplace.

Unlike IOCs, NOCs are government agencies, thus, they must follow their governments' programs strategically and/or financially. All OPEC members such as Saudi Aramco of Saudi Arabia and PdVSA of Venezuela, as well as Pemex of Mexico and PERTAMINA of Indonesia are some examples of NOCs. These companies do not develop their reserves at the same pace as IOCs due to diverse situations and objectives of their governments. PERTAMINA, especially, has a wide variety of objectives that are not market-oriented such as to provide fuels domestically for Indonesian customers at lower prices than international market prices, employ citizens, support Indonesia's domestic and foreign policies, participate in generating national long term revenue, and supply other domestic energies.

The last type of oil companies is NOCs with strategic and operational autonomy such as Petrobas of Brazil and Statoil of Norway. These companies operate in ways similar to both IOCs and NOCs. They balance between their own corporate strategies which are primarily commercially driven and to support their country's objectives.

The API explained that the crude oil price increases because demand increases in response to global economic growth. Additionally, the increase in demand is also a result of the world's spare capacity reduction. This reduction is described by a supply that has not fully kept pace with the growing demand because it takes time to bring significant new production in to the market. Politics play roles to the spare capacity reduction; hence, the global marketplace faces uncertainty in the oil supply. There are some examples of supply uncertainty due to geopolitical issues such as the supplies lost due to war in Iraq, civil unrest in Nigeria and Venezuela, and ongoing exports uncertainty from Iran ("Today's Crude Oil" 2006).

The oil global marketplace has been transforming over the last 25 years in its contractual structures of purchasing and selling the crude oil. Formerly, the market structure was based on rigid long term and commercially arranged agreements. Today's market structure is more efficient in that it allows greater flexibility for buyers and sellers to establish commercial relationships and meet their respective needs.

The refining sector of the oil industry has significantly affected the crude oil global marketplace due to the demand growth of petroleum products. Refineries affect the marketplace in terms of the utilization rate of refinery. As the petroleum products demand increases, the demand for conversion capacity increases. The reduction in spare refining capacity has affected the oil global marketplace because refineries are being utilized more for producing petroleum products which are seen as more valuable than the heavier crude oils. The reason refining places a relatively higher value on lighter, sweeter (light sweet) crudes than on heavier, more sour (heavy sour) crudes because light sweet require less production processes for a given volume of higher-valued products. The refined petroleum products have similar global marketplace and international flows as the crude oils.

The prices of petroleum products are a consequence of the world economy's growth regardless of the diminished excess capacity and increased supply uncertainty. This economy's growth increases the petroleum products demand that, in turn, increases the crude oil demand which outpaced the near-term ability to provide more supplies. Subsequently, the crude oil prices increased as a result of tightness in the global oil marketplace. In the production sector, as demand for petroleum products increased, the demand for the refinery capacity to convert crude oil into saleable products increased as well. Additionally, as the utilization rate of the world's refineries increased, demand for light sweet crudes increased relatively to heavy sour crudes. Moreover, these changes in oil global supply and demand increase the prices paid by retailers and, ultimately, by the customers.

2.3 American Oil History

The 20th century has been labeled by many historians as the "American Century" because of the U.S. dominance in the world's political, economic, and military affairs over the last 100 years. The U.S. was a leading producer of oil for the first 70 years of the 20th century, and prior to 1948 was also a net exporter. Also, out of the seven leading international oil companies, five were American owned. As the U.S. oil supply shifted from domestic reserves to overseas, so did the percentage of crude oil imports, with the primary regions being the Middle East and Latin America. The main goal of this international policy was, and still is, to maintain economic and political stability in these regions so that oil prices can be better controlled. This has been accomplished through both direct and indirect involvement, often with unforeseen consequences.

World War I saw the importance of oil on an international level. Prior to this, coal powered most naval and cargo ships. With petroleum fueled engines, ships could travel faster and farther. It was also easier to refuel with oil. Other mechanized weapons were also created or greatly improved upon such as tanks, aircraft, and submarines. With the U.S. help, the disparity in oil production between the Allies, and the Central Powers (mainly Germany), allowed the Allies to better deploy more weapons and transport supplies to the front lines.

On the domestic side, the emergence of inexpensive vehicles for the mass consumer, thanks in most part to the assembly line process used by Henry Ford and General Motors, led to the explosion of the transportation sector. The number of registered cars increased almost seven fold between 1916 and 1920 (Painter 25). The agricultural sector also grew due to mechanized farming equipment and improvements made to pesticides and fertilizers through incorporating petroleum based ingredients.

Companies such as John Deere became a leading manufacturer among the U.S. companies.

The introduction of the automobile created a fundamental shift in American society. Increased personal mobility allowed people to live and work at greater distances. Public transportation became less important. This cycle continued through the rest of the century. In a period of 35 years, energy consumption from oil rose from virtually nothing to 30 percent (Painter 25). Compare that to the rest of the world where it accounted for less than 10 percent of energy consumed (Painter 25). In production terms, the U.S. supplied over two thirds of the world's oil. The U.S. produced so much oil during the 1930's that supply outpaced demand. The major oil fields during this time were located in Southern California, Oklahoma, and East Texas.

It was during this time that the strategic role of oil reserve locations began to take shape. Beginning first with Britain and France held concessions to oil supplies in the Middle East. These countries needed stability in the region in order to maintain access specifically through the Mediterranean Sea and Suez Canal. The U.S. oil companies also gained access to this area along with Venezuela and the Caribbean. In the Western Hemisphere, America was able to use its military, all of which was powered by oil, to protect its interests from foreign intrusion.

On the other side, German and Japanese companies were mostly shut out of the major oil producing regions. This made both countries have to rely on foreign companies to help supply them fuel and petroleum based products. Prior to World War II, coal was Germany's primary source of fossil fuel. In order to regain power in Europe and provide fuel for the military forces, Adolf Hitler increased development of the country's synthetic fuel industry. This required extracting oil from coal but this required massive amounts of energy and manpower. After invading Belgium and France in 1939, Hitler turned east to the Balkan Peninsula, and Romania. Romania contained oil fields that Hitler needed to help power German war industry, but even this was not enough. The next closest regions that had petroleum reserves and made the most logistical sense to invade were North Africa and the Caucus Mountains. In 1940 the Caucuses were part of the Soviet Union. This was one of the factors in Hitler's decision to invade the USSR in 1941.

In the Pacific theatre, Japan also had fossil fuel production, but like Germany it was costly and inefficient. Japan depended on imports from the U.S and the Netherland East Indies (present day Indonesia and New Guinea). When the U.S. ceased exporting oil to Japan in the summer of 1941 the decision was made to capture the East Indies oil fields. At the time, the closest U.S. military presence was bases in the Philippines, located between Japan and New Guinea. On December 8, the day after the attack on Pearl Harbor, Japanese forces invaded, and six months later defeated the Allied forces.

During World War I, gasoline fueled weapons played a role in the fighting; however they were used mainly toward the end of the war and did not have a major influence on the outcome. World War II was the first truly modern war. All important weapons such as ships, tanks, airplanes, and supporting vehicles were powered by oil products, mainly gasoline and diesel fuel. Oil was also used in the manufacturing processes for ammunition and synthetic rubber tires. Throughout all major fighting along the European western front and in the Pacific, almost all of the fuel Western Allies used was supplied by the U.S.

As the war progressed, the territory gained by Germany and Japan which could provide oil, was lost to the Allies. The reduced imports had crippling effect especially on the Japanese war effort. Also during World War II, but outside of the conflict zone, massive oil reserves were discovered in the Middle-East in 1943 by a U.S sponsored survey team. At the time, much of the drilling rights in the area were controlled by private

American companies Standard Oil Company of California (later Socal) and the Texas Company (later Texaco). These two companies denied the request by the U.S. government to buy the rights, and a proposed pipeline running from the Persian Gulf to the Mediterranean also did not materialize. The U.S. government also tried to make agreements with Great Britain that would guarantee that existing concessions continue into the future but this failed because of lack of support from a majority of the industry. The U.S. foreign policy as it effected the petroleum industry continued to be that of limited government intervention, only to the extent that it could secure exportation.

The stated goals of the Cold War were to prevent nuclear war with the Soviet Union and contain the spread of communism. As part of this strategy, the U.S. military established overseas bases that enabled the U.S. to project its power into every region of the world. The forces necessary for this strategy, mainly sea and air power, were used to maintain access to overseas oil reserves. These forces were all dependent on oil and as technology improved weapons became bigger and faster and thus required more fuel to operate.

The significance of oil to U.S. goals led the nation to take an active interest in the security of Middle East nations. One of these nations, Iran, was viewed as a buffer between the Soviet Union and oil reserves in the Persian Gulf to the south. Both Soviet and the U.S. forces occupied Iran during World War II. The U.S. fulfilled its promise to withdraw after the war, but the Soviets remained. The U.S. and Iran worked out a deal that led to Soviet withdrawal and their exclusion from Iranian oil development. Cooperation between Iran's leader Mohammed Reza Shah Pahlavi and the U.S. during the time strengthened the position of the Shah in his struggle with the parliament.

Around the same time of what was taking place in Iran, events occurring in Greece and Turkey were interpreted by some U.S. officials to be part of a Soviet plan to dominate the eastern Mediterranean and the Middle East. Mention of oil was not stated in President Harry S. Truman's 1947 address before Congress pledging resistance to communist expansion, but guarding access to oil was an important part of the Truman Doctrine. The major U.S. oil companies consolidated and joined forces among themselves and British companies. Standard Oil of New Jersey and Socony was the largest agreement of the Saudi Arabian expansion ownership which resulted in a worldwide production management private system. This management facilitated Middle East production and incorporation into the oil global marketplace.

The developing postwar petroleum order had its first trial with the Palestine issue. Truman's decisions to support the United Nations plan to create a Jewish state of Israel in May 1948 went against the advice of some in the administration. Some feared that U.S. support for the creation of a new nation out of Palestine could undermine relations with the Arab world and lead to loss of access to Middle East oil at a time when the West needed it for European and Japanese reconstruction. Most private oil companies managed to keep distance from government policy because the official relations between the Arab and the U.S. suffered due to U.S. support for Israel.

Middle East oil was crucial to the success of rebuilding postwar Western Europe, as it faced a coal shortage owing to wartime overproduction and destruction. At the same time, Soviet expansion into Eastern Europe left the USSR in control of most of Europe's known oil reserves. The rebuilding, known as the Marshall Plan, used oil mostly from U.S. holding company reserves in the Middle East, thus providing these companies with international markets. However, dependence on this oil increased European vulnerability to supply disruptions.

In 1951 Iran nationalized the Anglo-Iranian Oil Company (AIOC), at the time owned by the British. This event highlighted all elements of the emerging government's oil foreign policy such as maintaining security in petroleum rich areas, opposition to nationalization, and cooperation with major oil companies. Britain feared that if nationalization were successful, all of its overseas investments would be in jeopardy. The U.S. also feared that Iranian nationalism could threaten its concessions in the Middle East and other areas. The U.S. and the British attempted to negotiate a diplomatic settlement with Iran to prevent nationalizing AIOC but it failed. The U.S. also attempted to convince the Shah to remove the prime minister, who was in favor of nationalization, but this also was unsuccessful. This event caused Britain and America to boycott Iran oil exports, which severely decreased government revenues. Two years later in 1953 the U.S. and Britain organized a coup that removed the prime minister, Mohammed Mossadeq, and allowed the Shah to become a royal dictator. Private oil companies, most of which were U.S. firms, then set up a consortium to run the Iranian oil industry.

The year of 1956 saw the nationalization of the Suez Canal Company by Egypt. The Canal was an important route that oil tankers used to transport oil from the Middle East to Western Europe. Two thirds of this oil passed through this point. This also was a concern to Israel which imported oil from the Persian Gulf. When this happened, British, French, and Israeli forces attacked Egypt. In response to this, the Egyptians sunk their own ships in the canal thus closing it off, Saudi Arabia stopped exporting oil to Britain and France, and Syria shut down pipelines to the Mediterranean Sea. The U.S. condemned this action by its allies and refused to supply them oil to make up for imports that they had lost. Also President Dwight Eisenhower threatened to cut off economic aid to Israel until the nations withdrew from Egypt. Seven months later British and French forces pulled out, the canal was cleared and shipping resumed. Israel also withdrew its forces after the U.S. gave its assurance to free access to sea routes adjacent to Egypt and that United Nations forces would be stationed between the two countries.

President Eisenhower believed that, as a result of the Suez conflict, a power vacuum had formed in the Middle East due to the exiting of Great Britain and France. Eisenhower feared that this had allowed Egyptian leader Gamal Abdel Nasser to spread his Arab policies and form alliances with Jordan and Syria, and had opened the Middle East to Soviet influence. Eisenhower wanted the U.S. to fill this vacuum before the Soviets could step in. Because Eisenhower feared that radical nationalism would combine with international communism in the region and threaten Western interests, he was willing to commit to sending U.S. troops to the Middle East under certain circumstances. This policy, labeled the Eisenhower Doctrine, also sought to bolster Arab regimes that were more conservative and willing to support Western interests especially when it came to oil production.

The next crisis came in July 1958 when a portion of the Iraqi army overthrew the pro-Western monarchy. Many felt this action would increase nationalism and anti-Western feelings in the surrounding countries. However, the rivalry between Egypt and Iraq that had long existed continued to remain in place. This revolution may have even reduced the danger to U.S. and European interests in the region. Around the same time, a political and economic union between Egypt and Syria ended, oil production in North Africa increased and the Soviet Union built a pipeline which connected to central and then Western Europe. All these events made Europe not have to depend on oil from the Persian Gulf.

One of the most important events, which continue to influence world oil markets, took place in 1960. Saudi Arabia, Kuwait, Iran, Iraq, and Venezuela formed the Organization of Petroleum Exporting Countries (OPEC) in September of that year. Initially OPEC did not have a strong market influence, because countries in the Middle East wanted to protect their own interests through securing the revenues from oil.

Following the Suez settlement, the Israeli port of Eilat at the head of the Gulf of Aqaba emerged as the main conduit for oil entering Israel from Iran. By the early 1960s, 85 percent of Israel's oil needs were being met by Iran (Painter 32). The withdrawal of United Nations forces from Egypt in May 1967, threatened Israel's access to oil. Rather than risk Arab retaliation against U.S. oil interests if it intervened to reopen the gulf, and confident that Israeli forces would prevail, the U.S. stood aside and let Israel deal with the issue on its own. After Israel launched a preemptive strike against Egypt on June 6, now known as The Six-Day War, the main Arab oil producers cut off shipments to the U.S., Great Britain, and West Germany. The fighting also closed the Suez Canal, and Syria again disrupted shipments through the pipelines connecting the Persian Gulf to the Mediterranean. The increased oil production in the U.S., Venezuela, and Iran could now bypass the canal with supertankers by going south around Africa, made up for the shortfall. The Arab embargo began to break down after a month, and by September, exports from the Arab states were back to pre-crisis levels.

Returning back to domestic concerns, in 1956 under the Eisenhower Administration, the Interstate Highway System was created. Initial legislation approved 41,000 miles of uninterrupted multilane roads stretching across the entire country (Painter 32). This project encapsulated the American feeling of independence with a person now being able to drive anywhere. Ironically, this made the U.S. more dependent on foreign oil to satisfy its transportation needs. Between 1945 and 1970, vehicle registrations increased from 25 million to almost 100 million and per capita gasoline consumption nearly doubled (Painter 33). Western European countries were also dependent on oil to meet their transportation needs. Automobile use skyrocketed and by 1972 oil accounted for nearly 60 percent of energy consumption (Painter 33). Around 80 percent of Western European oil imports came from the Middle East and North Africa (Painter 33).

During the 1970s a combination of political turmoil and shifts in the global economy threatened U.S. imports of overseas oil. With nationalization of petroleum companies, countries now had more control of production and greater influence on the global oil market. OPEC became one of the main drivers of setting prices. While consumption soared during the decade, U.S. domestic production peaked in 1970 at 18.7 percent of world production, forcing the U.S. to import increasing amounts of oil to meet its needs (Painter 33). Imports rose from 23 percent of U.S. oil supply in 1970 to 36 percent in 1973 (Painter 33). The Middle East's share of world oil production rose from 7 percent in 1950 to 40 percent in 1973 as the low cost of producing Middle East oil concentrated investment and production in the region (Painter 33).

At the same time, war and revolution in the Middle East and the changing dynamics of the Cold War raised questions about the ability of the U.S. to retain access of oil in the Middle East. In early 1968 the British government informed the U.S. that they planned to withdraw their military forces from positions east of Suez Canal by the end of 1971, forcing the U.S. to turn to Iran to take over as guardian of the Gulf. The Shah was eager to accept, hoping to restore the power and prestige of his country. The U.S. also looked to Saudi Arabia to take over the U.S. role of maintaining spare production capacity that could be used to help moderate prices.

The U.S. hoped to avoid oil supply disruptions by allowing prices to rise slowly, and gradually ceding ownership of oil concessions and facilities. Higher oil prices could stimulate increased investment and production, especially in such high-cost areas as Alaska and the North Sea, making the West less dependent on Middle East oil. Higher prices could also encourage conservation, efficiency in oil use, and increased utilization of alternative sources of energy.

In 1973 fighting took place again between Israel and Arab countries, and again like the Suez Crisis and Six-Day War, oil exports to the U.S. were halted. The countries now involved were OPEC's Arab members and Bahrain, Egypt, and Syria. In Iran throughout the 1960's and into the 1970's higher oil prices led to an increase in oil revenues. This spurred military spending, inflation, and massive rural–urban migration, and increased inequalities in wealth and income. The weapons systems the Shah bought also brought thousands of Western technicians and military advisers into Iran, which increased conservative fears of destructive Western influence and swelled the ranks of the Shah's opponents. In 1978 declining oil earnings and decreases in real oil prices caused domestic economic problems, sparking widespread demonstrations. By the time the U.S. government realized what was happening, it was too late to save the Shah, who fled Iran in January 1979. The turmoil surrounding the Iranian Revolution disrupted oil supplies and markets, and led to a doubling of oil prices.

The oil crises of the 1970s evoked images of a weakened U.S., especially since those crises coincided with the U.S. withdrawal from Vietnam, the Watergate crisis, and a wave of revolutions in the Third World. High oil prices intensified the economic problems faced by the U.S. and other Western countries such as inflation and stagnation that increased unemployment. In addition, the crisis paralleled the decline of U.S. manufacturing as a result of increased competition from Western Europe and Japan.

In contrast to the West, the Soviet Union benefited from high oil prices. As newly discovered fields in western Siberia entered production, the Soviets overtook America as the world's leading oil producer in 1974. Although most Soviet oil exports went to communist states in Eastern Europe, Cuba, and Vietnam, hard-currency earnings from oil exports to Western Europe and Japan rose sharply and by 1976 were responsible for half of the Soviet Union's earnings. The revenue from higher prices allowed the Soviets to import large amounts of Western grain and machinery, giving the illusion of continued growth to a system that was already in serious trouble.

After a problematic decade, the beginning of the 1980's saw the U.S. reassert its influence through a strategy that included permitting higher prices to encourage more efficient use of oil, such as manufacturing more fuel efficient automobiles, replacing oil used for electricity generation with other fuels like natural gas and nuclear plants, and reducing imports from OPEC producers by increasing domestic production. Despite losing their concessions, the oil companies managed to retain an important role in the world oil economy and still remained among the largest corporations in the world.

The U.S. also assumed a direct role in assuring Western access to Middle East oil. Shortly thereafter, the U.S. established a rapid deployment task force dedicated to this mission. Although Carter made the announcement in the wake of the Soviet invasion of Afghanistan, his administration had been considering this move for years. In 1983 the task force became the U.S. Central Command (CENTCOM), a regional command combining each branch of the military include Navy, Air Force, Army, and Marines, with responsibility for the defense of U.S. interests in the Middle East, North Africa, and Central Asia.

Between 1979 and 1985 decreases in oil consumption in the noncommunist world and increases in oil production outside of OPEC resulted in a drop of 10.2 million barrels per day in demand for OPEC oil (Painter 36). Despite the disruption caused by the Iran-Iraq War, from 1980 to 1988, these changes in supply and demand began to affect oil prices. After initially trying to support prices by reducing output, the Saudi leadership decided in the fall of 1985 to regain their position in world markets by increasing production. Rather than selling oil at a fixed price, the price would be based on what refined products sold for in the marketplace minus a fixed cost for the refiner. The new system put a premium on quantity rather than price and led to a collapse of world oil prices in 1986. Saudi oil production, which had fallen to 3,175,000 barrels per day in 1985, increased to 4,784,200 in 1986 and 6,412,500 in 1990 (Painter 36). Oil revenues dropped from $26 billion in 1985 to $18 billion in 1986, but began increasing in 1987 and reached $40 billion in 1990 (Painter 36).

Soviet hard currency earnings plummeted because of this price collapse and undermined the reform plans of the new government of Mikhail Gorbachev, who had taken power in March 1985. Gorbachev hoped to use oil earnings to finance a modernization of Soviet industry and to improve living standards. Known as perestroika or restructuring, this movement was meant to ease the transition from a command economy to a market driven one and to create a more democratic society. Instead, declining oil prices played an important role in the collapse of the Soviet economy. Some people claim that the U.S., under the Reagan administration, engineered the oil price collapse to help bring about the fall of communism in Europe and win the Cold War. However Gorbachev and the generation of Soviet leaders that emerged in the 1980s had already concluded that continued conflict with the West threatened their goal of overcoming the devastating legacy of the past 50 years that began under Stalin. Thus, rather than killing communism, which was already in decline, the collapse of oil prices prohibited the possibility of social democracy in the Soviet Union.

By the end of the century, 40 percent of global energy use originated from oil, including over 90 percent of transportation energy use (Painter 36). The U.S. military shrank after the end of the Cold War, but it still maintained a large force of ground vehicles, aircraft, and warships and remained the largest single user of petroleum products in the country. These forces also ensured that military operations would continue to be an oil-intensive activity.

The U.S. continued its embrace of patterns of socioeconomic organization premised on high levels of oil consumption. Maintaining access to foreign oil, especially to the vast reserves in the Persian Gulf, remained a top priority of U.S. foreign policy. Even though the U.S. obtained, a relatively small portion of its oil needs from the Persian Gulf, this region still played a crucial role in the world oil economy, and the global nature of world markets meant that shortfalls anywhere would be reflected in higher prices in other parts of the world.

Preserving access to the Persian Gulf was a key objective of the U.S. reaction to Iraq's invasion of Kuwait in August 1990. Iraq's take-over of Kuwait gave Saddam Hussein control of about 20 percent of the world petroleum reserves (Painter 37). If Iraq also seized Saudi Arabia's oil fields, it would control almost half of world reserves. Even if Iraqi forces stopped at Kuwait, they would still control enormous resources and gain leverage over the other Persian Gulf states. In response, the U.S. assembled an international military coalition to force Iraq out of Kuwait and after the war instituted economic sanctions to contain Iraq.

In order to reduce the leverage of Middle East producers, the U.S. promoted oil development in areas outside the region. This strategy included efforts to increase domestic oil production, develop a Western Hemisphere oil partnership with Canada, Mexico, and Venezuela, increase production in West African countries like Nigeria, and promote the rapid development of Caspian Sea and Central Asian oil. Relatively successful individually, these efforts failed as a whole to displace Persian Gulf oil from its dominant place in the world oil economy.

The last 100 years shows that the strategic and economic benefits of controlling world oil significantly shaped U.S. foreign policy. Social and economic patterns that fostered high levels of oil use reinforced U.S. determination to maintain access to foreign oil, especially after domestic production failed to keep pace with the nation's growing appetite for oil. The alternative of reducing consumption was rarely seriously considered due to well-organized political and economic interests. The oil industry is one of the most powerful sectors of the U.S. economy. Thus, it operates in a political climate that favors private interests and places significant limits to public policy.

The history of domestic oil in the U.S. begins when North America was still European Colonies and largely unexplored. Along the west coast, in what today is Southern California, oil slicks were observed on the ocean in the 1500s. In the 1800's, oil had been used by the settlers as a light source for medicine and in the form of grease for lubricating wagons and tools. Oil lamps fueled by rock oil extracted from shale were observed by John Austin, who was a New York merchant. This created the rock oil industry in the U.S. in which it roared and whale oil increased in price. Oil prices collapsed due to an increase in production and refining. This cycle became a characteristic of the industry.

Also in the 1850's, oil was discovered near Titusville, Pennsylvania, floating on the surface of ponds and streams. At first it was unknown what properties the liquid possessed, so a sample was taken to Yale University where chemist Dr. Benjamin Silliman analyzed it. One thing he discovered is when slowly burned, the oil produced light. After this discovery, the land was purchased by George Bissell, James Townsend, and several friends and they started the first oil corporation in America. They named it the Pennsylvania Rock Oil Company of Connecticut (later the Seneca Oil Company). To find more, Bissell hired a salt driller, Edwin Drake, to locate underground deposits.

Titusville and other towns in Pennsylvania exploded. John D. Rockefeller, who was an entrepreneur, learned of the discovery. The same year that oil was discovered under Pennsylvania, Rockefeller and a partner sold their commission firm in Cleveland and built a small oil refinery. In 1866, an export office was opened by Rockefeller in New York as soon as he bought out his partner. Many other oil companies created by discoveries in Pennsylvania quickly sold out to Rockefeller as he bought out the competition. By 1870 Standard Oil refined the majority of petroleum in the state and Rockefeller became a leading figure in the U.S. industry.

Early on, Standard's drive for gaining business and revenue were through using pipelines. A pipeline constructed by Sam Syckel connected oil wells in Pithole, Pennsylvania to the closest railroad where it was pumped into tanker cars. Rockefeller saw this and began buying pipelines. To provide an efficient oil transportation, the company started to own most of the lines. When oil prices fell, the ensuing anxiety began the Standard Oil alliance in 1871. Within twelve years the company was somewhat united, from supplying the raw material through production and distribution and ranked as one of the world's largest corporations. Hermann Frasch II, an industrial chemist, developed the process of removing sulfur found in oil, since sulfur made distilling kerosene problematic. Soon after this, Standard employed scientists both to improve the extracted oil and for researching other uses. Rail and rivers linked cities to oil fields. Oil exports from the east coast became so important that companies located refineries in those cities. A trade balance which paid the U.S. bonds' interests was provided by exported petroleum products to Europe by the mid 1860's.

The Civil War interrupted the flow of kerosene and other petroleum products to the Western U.S. This increased pressures to find a better method of oil utilization found in such states as California. However, Rockefeller was not interested in the West Coast oil industry until the 1890’s. In that decade the number of oil wells and companies grew from none in 1891 to over 2,500 by 1897 (Wall, et al 1988). Seven other oil companies had been established in California before Standard entered in 1900. The company purchased the Pacific Coast Oil Company shortly after 1900. The Standard Oil Trust, as the parent company, was established by Rockefeller in 1882 so that he could control the out-of-state taxation threat on the company’s properties and production operations. The Standard Oil Trust began controlling the sub-companies through financial means, similar to a holding company. Not wanting to be bought out, companies in Pennsylvania joined to create an important rival, the Pure Oil Company, Ltd. This unease endured for more than 50 years.

On January 10, 1901 one of the largest and most important oil strikes in U.S. history occurred on an area named Spindletop, close to Beaumont, Texas. Soon after, oil wells drilled there were producing 100,000 barrels per day and more than fifteen hundred oil companies had been chartered (Wall, et al 1988). Standard Oil took over all of oil companies such as the Gulf Oil Corporation, the Magnolia Petroleum Company, and the Texas Company. As Standard Oil got bigger, it encountered opposition from its competitors as well as a large part of the American public. Standard continued to fight its competition when it gained special railroad and shipping rates. It also persuaded law makers in Washington D.C. through tactics that were unethical, though common during the time. The company's control of labor was just as bad.

A Supreme Court ruling in 1911 stated that the Standard Oil Trust was operating illegally to monopolize and control production, and it sentenced the trust to break-up into 34 companies, even though its share of the industry was decreasing (Wall, et al 1988). The process of separating the companies was difficult. The concerns of moving toward vertical integration of their businesses included some marketed changes in the way the companies behaved. The court verdict guaranteed that though the oil industry had large companies, they at least competed with one another.

To refine crude oil into kerosene requires a distillation process, a by-product of which is a light weight volatile liquid. Prior to the 20th century, this was seen by refiners as a useless by-product. When the internal combustion was invented, it was discovered this engine could run on this by-product, now called gasoline. As the U.S. oil discoveries grew, the demand for gasoline used in automobiles and airplanes continued to increase in the early 1900s. As a result, refiners sought better ways to produce and improve gasoline. With the outbreak of World War I in Europe, the U.S. began shipping fuel to the Allies. The American Petroleum Institute (API) was formed at the war's end by oil executives in 1919. This entity would become a major force in the industry. Before World War I, the U.S. owned few foreign oil fields although the industry had advertised a lot overseas.

A major domestic oil shortage was judged by many producers from exploration and they believed that it would soon occur. American companies were pressured to seek oil abroad by the Secretary of Commerce Herbert Hoover and the Secretary of State Charles Evans Hughes. These firms searched for oil everywhere through the next decade while they continued exporting. On October 5, 1930 the largest oil reserve ever found in America up to that time was discovered in East Texas near Tyler. The strike was made by Columbus Marion Joiner. From surveys, he became convinced that a basin like structure in the area contained oil. The 140,000 acre field, holding 5 billion barrels, was purchased from Joiner by oil entrepreneur H.L. Hunt and later sold to oil companies at a profit of $100 million (Wall, et al 1988).

The largest domestic reserve is probably that on Alaska’s North Slope discovered in 1967. The numerous oil strikes made many people aware of a condition exclusive to the U.S. People owning land had rights termed the common law “right of capture” to all natural materials underground, including oil (Wall, et al 1988). Companies negotiated with each landowner for drilling rights. Right of Capture would continue for years, against the efforts of oil professionals such as Cities Service Oil Company that was owned by Henry L. Doherty. He wanted to start unitizing oil fields. However, this common law caused early oil fields exhaustion and an energy source waste.

2.4 Indonesian Oil History

Historically, Indonesia was a key player and one of the oldest oil producers in the world. Hunter stated that Indonesia contributed about 24,000,000 metric tons per annum or 1.6 percent of total world oil production in the 1960s (59). Ancients had used Sumatra’s crude oil to light torches and fuel seal boats. The Dutch formed the Royal Dutch Company in 1890 and controlled oil reserves in Sumatra. This company grew substantially and its production rose throughout 1890s. In the other islands of Indonesia, Borneo, the British formed British Shell Transport and Trading. The two companies then merged to form the Royal Dutch Shell in 1907 and operated almost all oil production in the East Indies. During the same year, the Indonesian government propagated a mining law to manage the country’s oil industry, which lasted only until 1960.

Indonesia’s oil production achieved more than 4 percent of the world’s production in 1911 and continued to rise throughout 1930s (Hertzmark 5). The most historical time in the industry was when the engineers of the Balikpapan refinery purposely torched the facility during World War II. The war impacted production which weakened the oil industry such that, the Japanese left its oil developments because of the Hiroshima bombing and the Dutch began to limit production in Kalimantan and Tarakan reserves. However, soon before the war, Standard Oil of California and Texaco of Texas joined to form Caltex Petroleum Corporation and based its oil production in the Duri and Minas reserves in

Riau, Sumatra. These reserves did not operate until the 1950s and were the backbones of Indonesia's oil products.

After World War II, many international and national oil companies re-established the industry. Sadly, the Indonesian politics and policies obstructed the progress. The Royal Dutch oil reserves in Northern Sumatra were taken by the Republic's army in 1957. President Soekarno's mandated all international oil companies to be under his administration's supervision. The government formed three national-owned upstream oil companies such as PERMINA (the National Oil Mining Company) which handled North Borneo reserves, PERTAMIN (the Indonesian Oil Mining Company), and PERMIGAN (the State Oil Company). Additionally, the parliament also ratified the Oil and Mining law, which stated that the state and its oil company were the only agencies that authorized to conduct and engage the oil mining.

In 1965, Soeharto's regime, known as the New Order, ousted Sukarno's administration. At the beginning of the New Order, the country's oil industry showed significant changes. The government strengthened its control over the industry which merged PERTAMIN and PERMINA into PERTAMINA and dispersed PERMIGAN. In 1971, the parliament promulgated a law which set out PERTAMINA's duties as a national oil company. Its responsibilities included managing licenses and contracts with international oil companies, marketing the crude oil and gas products, and supplying refined products to the domestic market. Figure 2-8 shows PERTAMINA's upstream and downstream activities.

PERTAMINA introduced a contract form, known as the Production Sharing Contracts (PSCs), to be in charge of the international oil companies' activities such as training, technology transfer, and domestic supply. PSCs stated the concept of split profit of oil production between the international oil companies and the Indonesia government, which was represented by PERTAMINA. These contracts explained that the government assumed to own all exploration and production structures and equipment used within Indonesia. Most PSCs stated that Indonesia governments received 85 percent of oil produced once the international oil companies recovered costs, thus, the country's oil contract terms were considered as one of the toughest oil contracts in the world (Hertzmark 9). PERTAMINA had widely varied its profit oil shares as a method to attract new international oil companies for many years.

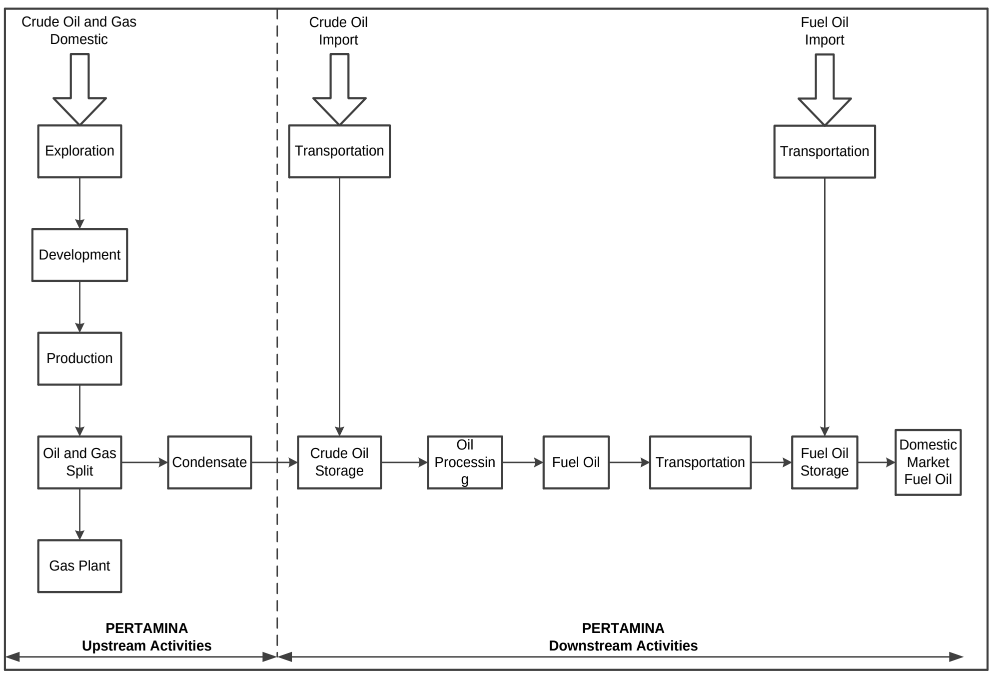

Figure 2-8 PERTAMINA Upstream and Downstream Activities. Source: DitJen MIGAS, January 13, 2013. Web.

The oil exploration activities diminished and led to declining production due to several reasons such as the Indonesian's government demand of a larger oil production share, oil prices declining globally, and most upstream activities slowing due to the discoveries of only smaller reserves in Indonesia. Unfortunately, the PSCs structure did not provide PERTAMINA operational experience handling the downfalls. Moreover, the PSCs retarded domestic oil development. It penalized production from smaller domestic reserves, treated them the same way as the larger reserves, and created a larger regulation for domestic oil sector without the domestic-based investment related development. Thus, this did not make PERTAMINA the best role model for domestic oil developments to benefit the national oil cash flow. Under Soeharto's administration, initially PERTAMINA was given some independence, but eventually Soeharto and his chosen bureaucrats controlled the company. This led to corruption because they let out oil contracts. The legislature and judiciary no longer had a role to determine PERTAMINA's policies. As a result, energy bureaucracy weakened due to lack of administrative and professional experience in PERTAMINA.

In 1973 to 1974, PERTAMINA had its golden years and experienced a cash flow boom. The sudden injection into the national cash flow and the oil embargo created a political problem for the Indonesia government and PERTAMINA. Consequently, Soeharto was forced by people to invest large sums in other domestic industries such as steel, cement, mechanicals, and fertilizer to reduce the role of international private companies. The Krakatau steel works, the Dumai oil refinery, and Asahan aluminum smelter took advantages of the investments. Sadly, the cash flow boom did not last long due to increasing corruption in PERTAMINA's officials. The situation was exacerbated in that PERTAMINA could not pay its loans to Western Banks. By mid-year of 1976, the PERTMINA's total amount of debt reached an estimated $10 billion (Hertzmark 12). Hertzmark stated that Indonesia produced an estimated 1.64 million barrels per day in 1977 and by 1982; its production went down to an estimated 1.26 million barrels per day (12). In 1990, Indonesia was in a need to diversify its economy due to the falling price of crude oil. The country started to focus on the natural gas sectors. Mobil Company discovered the Arun gas fields in Aceh, Sumatra. The company and PERTAMINA decided to export the natural gas because domestically Indonesia did not have any feasible market for natural gas and also Aceh had little infrastructure and skills. PERTAMINA was able to rebuild financially from the natural gas earnings thereafter.

Throughout the 1980’s and 1990’s, Indonesian refined oil products rose rapidly due to strong economic growth as well as under priced for domestic fuels. Thus, the government appointed PERTAMINA to organize new refineries such as in Cilacap and Balongan, Java. Indonesia was expected to be a net oil exporter by the late 1990s. The expectation never materialized because of several reasons such as clashing trend lines in the domestic demand which showed a decline in production and an increase in consumption; and a financial crisis that hit the country for several years. Indonesia became a net oil importer in 2005 and refined products total consumption increased so that it was greater than domestic crude production. Afterwards, Indonesia has been relying on imported crude oils for its domestic refineries. The government then began to encourage the Middle East investors to establish new refineries along the sea lanes to Northeast Asia (Hertzmark 15). Additionally, the government had purchased an Independent Power Producer (IPP), a take or pay basis plan to supply domestic market. As a result, the plan generated more costs, arbitrations, and investment shortages that continue to this day.

Similar to many oil exporter countries, Indonesia tried to spread its oil revenues such as crude oil sale profits, PSCs cost revenues, and subsidies or oil benefits through refined products throughout the country. Sadly, those revenues never reached to the Indonesian Central Bank because they were overseen by PERTAMINA staff engaged in corruption and misallocation. The approval process of PSCs profitability for oil production costs strengthened PERTAMINA’s bureaucratic power which created another form of corruption. Another leakage from PERTAMINA's revenues generated from its upstream activities include exploration and production processes. PERTAMINA operated those processes with very high finding, development, and production costs. PERTAMINA's upstream costs were at least 150 percent higher than any other PSC operations (Hertzmark 16). With such a steep production costs, PERTAMINA was never able to establish its upstream position and overseas diversification. Moreover, the company had never learned to operate in a competitive environment, which requires to control costs and to provide essential skills to its upstream operations outside Indonesia such as sales and procurement in Japan, the U.S., and Australia.

In 1997, a financial crisis hit Indonesia and several other Asian countries. The crisis highlighted Indonesia's economy downfalls including a weak banking system and an overextended international lending. This led the Soeharto administration to ask for a help from the International Monetary Fund (IMF). The most controversial agreement between Soeharto and the IMF was it demanded to reform the government commodity subsidies which leveled domestic fuel prices to international ones. By the next fiscal year, 1998 to 1999, the fuel subsidies' value reached almost one quarter of the government's budget (Hertzmark 18). This level was revisited a number of times until the current president, Susilo Bambang Yudhono, terminated the subsidy program in 2005. The Asian financial crisis ousted the Soeharto administration. This caused PERTAMINA's future to be in jeopardy because if the IMF Special Audit showed that PERTAMINA was not a net national asset, then its prerogatives and roles needed to be curbed which made a significant change in the oil industry.

In 2001, the new Indonesia government passed a new oil law and relieved PERTAMINA from its role as the government's representative in the upstream oil business. The government formed BP MIGAS and its duties include taking over the contracting and licensing functions from PERTAMINA. Moreover, the relationship between the government's representative and the PSCs was changed. Where before, PERTAMINA had taken physical possession of PSC crude and then sold, swapped, or refined the oil as it saw fit, now the crude was priced at the PSCs boundary areas and BP MIGAS would contract out sales of the crude as appropriate. Additionally, the government's share of the profit oil went directly to the Central Bank without passing through PERTAMINA.

However, BP MIGAS was not without problems nor were they free from corruption entirely, but at least the corruption level was lower than when PERTAMINA operated the upstream activities. BP MIGAS faced many problems such as when it was slow to recognize some reality changes in both the world oil markets as well as Indonesia's hydrocarbon resources which resulted in the new production investment levels to fall; domestic refined products prices did not achieve the international market levels; and other Indonesia's refineries that did not belong to PERTAMINA, which were accounted for more than 85 percent of capacity, remained uncertain (Hertzmark 21). In November 2012, the Indonesia's government dissolved BP MIGAS as an upstream oil regulatory body. The Energy and Mineral Resources Ministry took over BP MIGAS' responsibilities until a new oil law is drafted to serve as the legal foundation for the supervisory body.

Indonesia has reestablished good relationships with its neighbor countries over the years. Its relations with China have been reinstated for several decades, as the two nations have had a history of broken diplomatic and economic ties. Additionally, the Timor independence movement stressed Indonesia relations with Australia. However, this tension was ended several years ago. Unlike Malaysia, the Indonesia's government has never considered using the oil resources to shape its foreign policy which leaves the country free of international problems.

2.5 Supply Chain Management (SCM) in the Oil Industry

Chopra and Meindl define a supply chain as “all parties involved, directly and indirectly, in fulfilling a customer request” (2007). This definition implies that the objective of a supply chain is then to maximize customer service. A customer, by definition, is an output’s user of a process. For a company that focuses on customer service, a customer’s customer is also very important. Thus, this company will link the upstream suppliers to the downstream distributors in its supply chain. The goal of a business is to make money or profit. In order to maximize profit, a company must minimize costs. Chima stated that all benefits and costs must be weighed on each decision that a company makes along its supply chain (27).

Over the years, there has been an apprehension that oil industry has a very scarce resources challenge. Studies have shown that oil resources are not the constraints in oil supply chain. Moreover, oil companies will still be able to sustain their current production levels for more than 50 years. However, in reality, Chima explained that the challenge lies on putting oil reserves into production and delivering final products to customers at the lowest cost possible for most oil companies (28). Therefore, oil companies must have a solid supply chain model to maximize profits.

The oil industry involvement in global supply chain includes domestic and international transportation, order visibility among suppliers and customers, import or export facilitation, and information technology. Thus, this industry requires a solid model to implement its supply chain. Chima described that an oil supply chain consists of exploration, production, refining, marketing, and consumer – see Figure 2-9 (28). The link represents oil flow through the supply chain. This oil supply chain exists whenever the oil companies' suppliers keep their systems continuously resupplied. There are many activities involved within each sector of the supply chain.

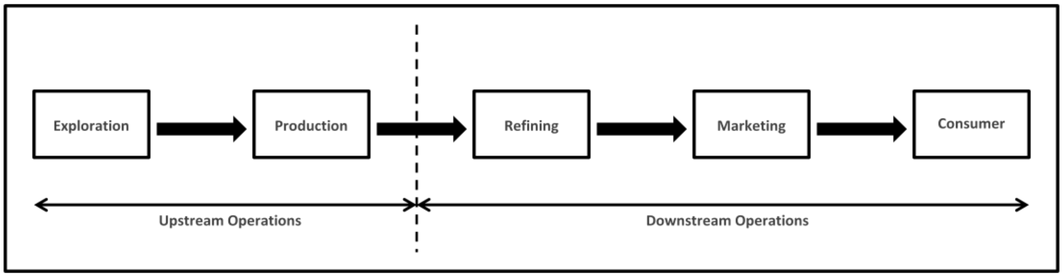

Figure 2-9 Supply Chain Model in the Oil Industry

A typical supply chain model in oil industry comprises of two main activities such as upstream and downstream operations. Upstream operations deal with exploration and production of the industry, whilst downstream operations deal with refining and processing of crude oil products, marketing, and distribution of crude oil products to customers. An oil company may fully integrate which has both upstream and downstream operations, or may concentrate on a particular sector such as exploration and production as well as refining and marketing.

As explained earlier, oil exploration and production processes are comprised of five main activities such as geologic survey, exploratory drilling, appraisal, production, and decommissioning (E-Tech International 2012). Refining simply is a process that transforms crude oil into petroleum products such as gasoline, kerosene, engine oil, diesel, and jet fuel. However, the oil refinery production process is one of the most complex processes because it involves many different processes with various connections in the supply chain. Marketing includes distribution and retail sale which involves movement of those refined products from refineries to end customers.

Most oil companies need to plan all significant operations in advance and manage their costs throughout the entire supply chain to enhance the profit margin. In the oil industry, the exploration and production sectors produce the same petroleum products for all competing companies, due to a narrow product differentiation. As a result, oil companies cannot introduce an exciting new product to distinguish themselves from one another. However, the companies must have the ability to adapt a solid supply chain model that can economically locate and produce oil efficiently to set apart themselves from their competitors.

Chapter 3

Methodology

3.1 Literature Review

In the oil industry, all levels of decisions such as strategic, tactical, and operational arise in its supply chain. Due to the scope of this dissertation, some literature reviews are provided in the following manner: decision levels in oil exploration and production, refinery, and distribution using pipeline transportation processes; oil supply chain quality; multi-objective optimization oil supply chain; and environmental sustainability oil supply chain.

3.1.1 Exploration and Production Processes

Exploration development is a complex and an expensive process in the oil industry. Thus, most oil companies are facing some problems in their exploration processes such as long planning horizons, a large number of choices of platforms, wells, and reserves, and pipeline interconnection infrastructure. The main challenges in resolving those problems lie in the complexity of the optimization model that is usually characterized by uncertainty and the large dimensionality of those problems due to large time horizon.

Van den Heever and Grossman (2000) presented a mixed-integer non-linear programming (NLP) model for offshore oil fields infrastructure planning. Their model incorporated non-linear reservoir behavior into the formulation. Goel and Grossman (2004) considered a stochastic programming model to find an optimal investment and operational planning of oil field developments under uncertainty, where the shape of the scenario tree associated with the described problem depended on the investment decisions. Carvalho and Pinto (2006) proposed an optimization model that determined the existence of a given set of platforms and their potential connection with wells and the timing of extraction and production rates for offshore oil fields. Tarhan, et al. (2009) proposed a multistage stochastic programming model that captured the economic objectives and non-linear reservoir behavior and optimized the investment and operating decisions over the entire planning horizon. They considered uncertainties such as in the initial maximum oil flow rate, the recoverable oil volume, and the reservoir's water breakthrough time.

3.1.2 Refinery Processes

In oil supply chain, intermediate or final product streams and distributions centers interconnect crude oil suppliers and refineries. Thus, a solid planning of multistage supply and distribution is very important in oil refinery supply chain design. Most common issues on designing this multistage supply chain include operation details consideration at different stages and interconnectivity integration between stages and the appropriate logistics.

Julka, et al. (2002) proposed an agent based framework for supply chain Decision Support Systems (DSSs) which served as a central DSS through all studied refinery processes and enabled to integrate decisions with respect to the overall refinery businesses. They also demonstrated the DSSs' applications through a prototype system for crude oil procurement. Rejowski and Pinto (2003) proposed a general framework for modeling petroleum supply chains. They considered chain nodes as the elementary group entities that were connected by intermediate streams. Then, the supply chain topology was built by connecting those nodes representing refineries, terminals, and pipeline networks. Persson and Gothe-Lundgren (2005) suggested an optimization model that integrated shipment planning and scheduling processes at the refineries. The model concerned with the simultaneous planning of how to route a fleet of ships and the planning of which products to transport in these ships.

Nishi, et al. (2008) proposed a distributed optimization framework of supply chain planning using an augmented Lagrangian decomposition and coordination approach for multiple oil companies. MirHassani (2008) showed a capacitated network that dealt with a multi-product scheduling and a multi-depot system receiving of a number of petroleum products from different refineries and distributed them among several depots and market areas under demand uncertainty. This network analyzed long term transportation of oil by pipelines, trucks, railways, and ships so that it could reduce the distribution cost. Pitty, et al. (2008) presented a dynamic model of an integrated refinery supply chain which considered various crude oil and intra-refinery supply chain activities and transportation such as procurement planning, scheduling, and operations management. This dynamic model considered stochastic variations in transportation, oil fields, prices, and operational problems.

Al-Qahtani and Elkamel (2008) designed and analyzed multistage integration and coordination strategies within a petroleum refineries network using different crude combination alternatives. They extended their study to petrochemical system and modeled both the refinery and the system as a mixed-integer problem which had objectives of minimizing the annualized cost over a given time horizon among the refineries and maximizing the petrochemical network value added. Carneiro, et al. (2010) analyzed oil supply chain strategic planning. They developed a two-stage stochastic model with fixed resource and risk management incorporation to optimize the chain. The model took a scenario based approach and addressed three uncertainty resources.

Although significant progress has been made in the supply chain design and planning for petroleum refining industry, the production plan of an industrial supply chain is in general created first and a compatible schedule is then identified accordingly. Because the detailed scheduling constraints are often ignored in the planning model, there is no guarantee that an operable schedule can be obtained with this hierarchical approach. To address this issue, it is necessary to propose an efficient formulation to coordinate various planning and scheduling decisions for optimizing the supply chain performance. Solving this kind of model can yield the proper procurement scheme for crude oils, the schedules for producing various petrochemical products, and the corresponding logistics. The appropriate sources or suppliers of raw materials, the economic order quantities, the best purchasing intervals, and also the transportation schedules can be identified accordingly. Finally, it is worth mentioning that most of the oil industry companies still operate their planning, central engineering, upstream operations, refining, and supply and transportation groups as complete separate entities. Therefore, systematic methods for efficiently managing the petroleum supply chain as one entity must be explored.

3.1.3 Pipeline Transportation Processes

The pipeline network plays a key role in the petroleum business. These operational systems provide connections between ports and/or oil fields and refineries or upstream, as well as between these and consumer markets or downstream. Transportation is among the basic challenges in a refinery supply chain with the dimensionality of the problem and the specificities of each individual implementation to be the main issues.

The system discussed by Rejowski and Pinto (2002), was composed of a petroleum refinery, a multiproduct pipeline connected to several depots, and the corresponding consumer markets that received large amounts of gasoline, diesel, and aviation fuel. A Multiple Integer Linear Programming (MILP) optimization model that was based on a convex-hull formulation was proposed for the scheduling system. In their later work, Rejowski and Pinto (2002) divided the pipeline into segments that connected two consecutive depots and packs that contained one product and composed the segments. Recently, Rejowski and Pinto (2002) proposed a MILP formulation based on a continuous time representation for the scheduling of multi-product pipeline systems that must supply multiple consumer markets. The proposed continuous time representation was compared with the previously developed discrete time representation of Rejowski and Pinto (2002) in terms of solution quality and computational performance.

Cafaro and Cerda (2009) studied the scheduling of a multi-product pipeline system receiving a number of liquid products from single refinery source to distribute them among several depots. The problem of scheduling a transmission pipeline carrying several petroleum products from a single oil refinery to a unique distribution center over a monthly horizon was studied in their later work. They further introduced a continuous formulation for the scheduling of multiple source pipelines operating on the fungible or segregated mode. MirHassani and Ghobanalizadeh (2008) presented an integer programming approach to oil derivative transportation scheduling. The system reported was composed of an oil refinery, one multi branch multiproduct pipeline connected to several depots and also local consumer markets which received large amounts of refinery products. Herran et al. (2010) also proposed a discrete mathematical approach to solve short term operational planning of multi pipeline systems for refined products. Jetlund and Karimi (2004) developed an optimization model to obtain the maximum profit scheduling of a fleet of multi parcel tankers engaged in shipping bulk liquid chemicals.

Comilier et al. (2008) studied the Petrol Station Replenishment Problem with Time Windows (PSRPTW) which aimed to optimize the delivery of several petroleum products to a set of petrol stations using a limited heterogeneous fleet of tank or trucks. They described two heuristics based on arc pre-selection and on route pre-selection. Extensive computational tests on randomly generated instances confirmed the efficiency of the proposed heuristics. Abraham and Rao (2009) studied the existing practices of production planning, scheduling and prevailing constraints in the six plants of a lube oil section in a petroleum refinery. On the basis of the data collected from these plants, some generative and evaluative models were developed. The generative models developed were flow network optimization model and binary integer linear programming model. The evaluative model developed was simulation.

3.1.4 Oil Supply Chain Quality

Many organizations emphasize quality as a means to stay competitive in the marketplace over the long run. They view having a reputation of high quality as representing future market share for new customers and maintaining market share for existing customers over their lifetime. Further, improving quality can provide long term financial savings such as scrap and rework reduction. In order for a supply chain to remain profitable, quality from suppliers must be considered on the decision making process. Competing strategies of increasing profit as opposed to increasing quality will require many tradeoffs. This dissertation is to model the tradeoffs and to identify situations that a decision maker can use to optimize the benefits of both.

The quality of the manufacturing process determines the quality of a finished product. In the supply chain it is not always possible to control the manufacturing process for incoming materials, especially for outside suppliers. In this instance, quality can only be measured by the percentage of defective goods received from the suppliers. In order to more effectively manage the supply chain, companies must choose suppliers that will produce quality materials without a substantial price tag.

Supply Chain Management (SCM) is responsible for the optimization of the flow of products between the various levels of the supply chain and for minimizing the total cost of these operations. This term SCM is a unification of a series of concepts about integrated business planning that are joined together by advanced information technology (IT) (Shapiro 2007). Despite the IT advances, many companies have not completely taken advantage of computing power to make cost effective decisions. Competition between companies, more demanding customers, and reduced profit margins make the success of a company more challenging. In this context, SCM became a very important practice for companies that not only want to stay in business but also have their results optimized and meet the customers' expectations.

Responsiveness in the supply chain has gained importance and it is a trend that will dictate future decisions regarding supply chain design. It can be seen that SCM plays and will continue to play an active role in successful companies' routines. Literature about supply chain design is extensive and diverse. The common issue addressed in similar literature is to optimize the supply chain while the customers' demand is satisfied at some level. While existing supply chain decision levels have been divided in strategic, tactical, and operational levels (Anthony 1965), the focus of this dissertation was to address strategic and tactical aspects of the supply chain. The main difference between these levels is that strategic decisions are concerned with the supply chain topology, such as which nodes are going to be utilized, represented by binary variables. Tactical decisions usually assume that the supply chain topology is already given and its main purpose is to optimize production rates, utilization, vendor selection, and resource allocation. Several works have been published about the optimization of supply chains. A very useful literature review and critique was presented by Meixell and Gargeya (2005).

3.1.5 Optimization Oil Supply Chain

Most of existing literature is focused on the optimization of only one objective function, usually cost or profit; and other important factors such as quality are left outside the analysis. There are many techniques for multi-objective optimization such as the ε-constrained method, sequential optimization, weighted methods, and distance-based methods (Szidarovszky, et al. 1986). Gullien, et al. (2005) utilized the ε-constrained method in order to optimize profit, demand satisfaction, and financial risk cost of a three echelon supply chain. Azaron, et al. (2008) used the goal attainment technique to optimize total cost, total cost variance, and financial risk cost of a three echelon supply chain. Chen, et al. (2003) used a two-phase fuzzy decision making process to optimize profit between the supply chain participants, customer service levels, and safe inventory levels. In this dissertation, the utilized method is the mixed-integer programming (MIP) in order to optimize the profit and quality objective function. This method also provides a set of objectives that are Pareto efficient, thus, forming a Pareto frontier.

3.1.6 Environmental Sustainability Oil Supply Chain

Globalization has resulted in pressure on multinational firms to improve environmental performance. As a consequence of this pressure, and the efforts to address it, environmental management issues have become relevant to operations management researchers (Sanchez and McKinley 1998; Murty and Kumar 2003). Geffen and Rothenberg (2000) studied that one potential path for achieving improvement in environmental performance, while maintaining production quality and cost goals at the plant level were unique partnerships with suppliers. Companies have had to integrate other members of the supply chain into their environmental management processes, which was identical to a “green supply chain” (Zhu and Cote 2004). Handfield, et al. (1997) suggested that in order to be successful, environmental management strategies must be integrated into the value chain which includes all of the operational life cycle stages.

3.2 Model Definition

National Science Foundation (NSF) has been funding many researches in the areas of Supply Chain Management (SCM). There are three completed researches funded by NSF that relate to this dissertation such as Muriel (2002), Blackburn (2005), and Williams (2007). Muriel (2002) designed and analyzed algorithms which integrated production plans, inventory control and transportation strategies across the supply chain to reduce system wide costs and enhance service. Blackburn (2005) studied how to make supply chains economically and ecologically sustainable. Williams (2007) managed an international reverse supply chain from a sustainability perspective. Additionally, this dissertation follows the same method as Rodrigo, et al. (2010) which provided a set of objectives that were forming Pareto efficient frontiers. However, in order to optimize the profit and quality objective function, this dissertation utilizes a mixed-integer programming (MIP) model, whilst Rodrigo, et al. (2010) used a ε-constrained method.

As mentioned earlier in Chapter 1, the significance of this dissertation is to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that identifies how other nations such as Indonesia can supply some of the crude oil imports with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. Furthermore, the broader impact is investments into other countries crude oil supply chains can be quantified and optimized, and countries such as Indonesia can be identified as possible candidates for investment for future global crude oil needs.

This dissertation strives to answer the research question of “When is it economically beneficial to invest in the supply chain quality of crude oil from a given nation?”, hypothesizes that the crude oil supply chain quality will impact the crude oil supply chain costs and the environmental sustainability will have an impact on crude oil supply chain costs, and suggests that the crude oil supply chains each of these countries will dictate their ability to provide crude oil. This dissertation has an overall objective to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources and helps PERTAMINA to contribute more funds to the Indonesia's national treasuries as well.

Most companies must decide on conflicting strategies of maximizing short term profits or seeking long term sustainability through high quality standards. Usually supply chain decisions are evaluated by analysis that considers the logistics costs and the quality initiatives independently. This independent decision making process does not effectively determine the impacts of quality defects and can lead to ineffective strategic decisions that do not comprehensively account for the complexity of the problem. The objective of this dissertation is to address that phenomenon by introducing a mixed-integer programming (MIP) model that identifies how other nations such as Indonesia can supply some of the crude oil imports with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. In addition, most optimization decisions are based on forecasts that by definition have some degree of uncertainty. Consequently, the model should take into account uncertainty for robustness and consistency.

A hypothesis statement by definition is an educated guess of a proposed answer to a question that can be verified or rejected through a test statistic. This dissertation proposes two answers of whether or not the crude oil supply chain quality and the environment sustainability will impact the supply chain costs from a research question of

“When is it economically beneficial to invest in the supply chain quality of crude oil from a given nation?” These two hypothesis statement are stated as follow:

Hypothesis Statement #1

H_0: The crude oil supply chain quality will not impact the supply chain costs.

H_1: The crude oil supply chain quality will impact the supply chain costs.

Hypothesis Statement #2

H_0: The environment sustainability will not impact the crude oil supply chain costs.

H_1: The environment sustainability will impact the crude oil supply chain costs.

A statistic test is conducted to determine whether or not the H_0 is verified or rejected for both of the hypothesis statements. The rejection region lies if both supply chain quality and environment sustainability metrics change the supply chain costs by 20 percent.

3.3 Crude Oil Supply Chain Quality Evaluation

In order to meet the dissertation’s objective such that to demonstrate the tradeoff between crude oil supply chain qualities on profits in Indonesia, three specific objectives are investigated. The first specific objective is to evaluate the supply chain factors that determine supply chain quality of crude oil production. Therefore, this dissertation creates a model which represents a crude oil supply chain from Indonesia to the U.S, identifies impacts of supply chain costs on supply chain quality, and establishes a sampling plan of supply chain quality performance.

3.3.1 Crude Oil Supply Chain Model from Indonesia to the U.S.

Indonesia was a member of OPEC from 1962 to 2009. The country suspended the membership due to the need to concentrate on meeting its domestic demand.

Historically, Indonesia was in the 20^{th} rank of oil producers. The Indonesia government faces some challenges including infrastructure inadequacy and complex regulatory environment to attract sufficient investment in order to meet its growing domestic oil consumption. Oil has become an important sector of the country's economy. The U.S EIA stated that the oil industry contributed an estimated 7 percent to Gross Domestic Products (GDP) in 2010 ("Indonesia" 2012). Several reasons that caused Indonesia to become a net importer of both crude oil and petroleum products included growing domestic oil consumption, the natural maturing of oil reserves, and limited investment into reserve replacement. The U.S. EIA explained that Indonesia's total primary energy consumption grew by over 50 percent between 2001 and 2010 and petroleum continues to account for the most significant share of Indonesia's energy mix at less than 30 percent in 2011 ("Indonesia" 2012). Figure 3-1 shows the crude oil supply chain model from Indonesia to the U.S. This dissertation considers that the exploration, production, and refinery processes take place in Indonesia while distribution, marketing, and customer in the U.S.

3.3.1.1 Exploration and Production

At the beginning of 2012, Indonesia had 3.9 billion barrels of proven oil reserves ("Indonesia" 2012). The country's total oil production continued to decline from a high of nearly 1.7 million barrels per day in 1991 to just under 1.0 million barrels per day in 2011 ("Indonesia" 2012). Duri and Minas are the two largest and oldest oil fields and they are located on the eastern coast of Sumatra. Duri began producing in 1952 and currently averages around 185,000 billion barrels per day, whilst Minas field began production in 1955 and currently produces around 70,000 billion barrels per day ("Indonesia" 2012). There are seven international oil companies that operate Indonesia's upstream oil sector such as Chevron, Total, ConocoPhillips, Exxon, and British Petroleum (BP) and two national oil companies including The China National Offshore Oil Corporation (CNOOC) and South Korea's KNOC.

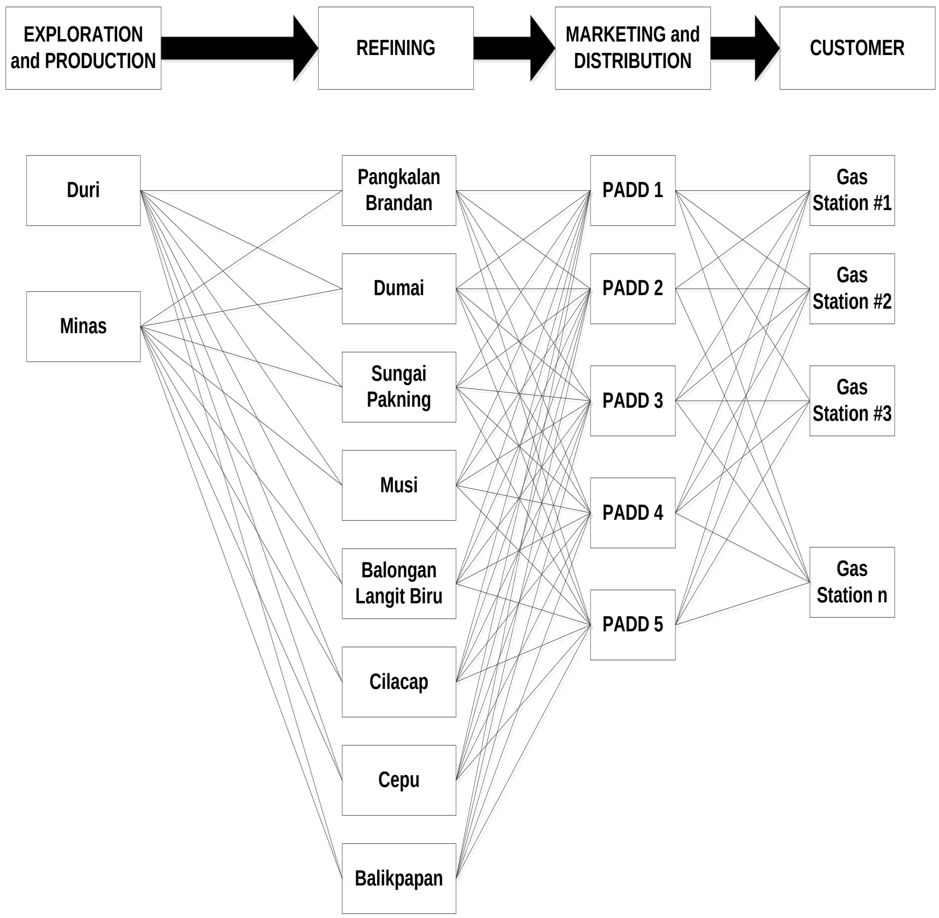

Figure 3-1 Crude Oil Supply Chain from Indonesia to the U.S.

Chevron and PERTAMINA were the two largest oil producers which accounted for more than 45 percent and 17 percent, respectively of the country's total crude production in 2012 ("Indonesia" 2012). The Cepu Block of East and Central Java is Indonesia's most recent discovery which contains three significant oil reserves such as Banyu Urip, Jumbaran, and Cendana. The U.S. EIA stated that ExxonMobil operates the Cepu PSC with 45 percent interest in a joint venture with PERTAMINA's Exploration and Development unit (45 percent working interest) and four local government companies (10 percent interest) ("Indonesia" 2012). Banyu Urip is the only operating field in the Cepu Block and it produced about 20 billion barrels per day ("Indonesia" 2012). The East Java Basin with a joint operating agreement between PERTAMINA and PetroChina produces significant quantities of oil besides Duri and Minas. Figure 3-2 shows Indonesia proven oil reserves in 2012 ("Indonesia" 2012).

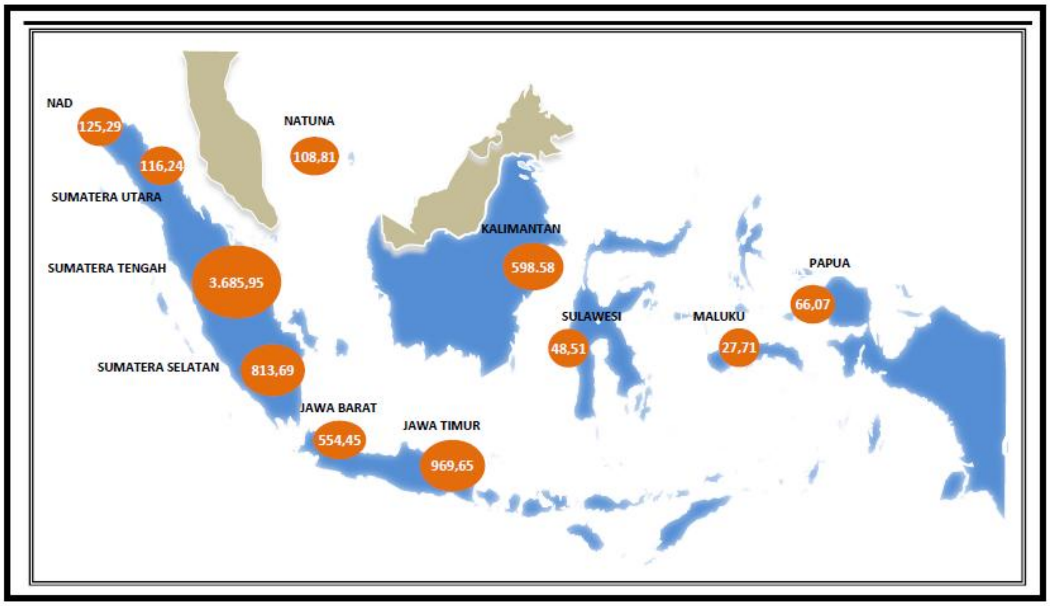

Figure 3-2 Indonesia Proven Oil Reserves in 2012. Source: DitJen MIGAS, January 13, 2013. Web.

3.3.1.2 Refineries

Indonesia has a refinery capacity of an estimated one million barrels per day ("Indonesia" 2012). PERTAMINA owns eight refineries including Pangkalan Brandan, Dumai, Sungai Pakning, Musi, Balongan Langit Biru, Cilacap, Cepu, and Balikpapan. Those refineries make up the country's refinery capacity and the majorities are located on Java and Sumatra islands. Cilacap in Central Java, Balikpapan in East Kalimantan, and Balongan in West Java are the largest refineries. Refinery outputs supply the domestic market, but they meet only about 70 percent of domestic consumption ("Indonesia"

2012). The President Susilo Bambang Yudhono has just approved the plan of building two additional refineries in Bontang City, East Kalimantan. This plan was proposed by the Minister of Energy and Mineral Resources. Figure 3-3 shows all Indonesia refineries and their capacity in 2011.

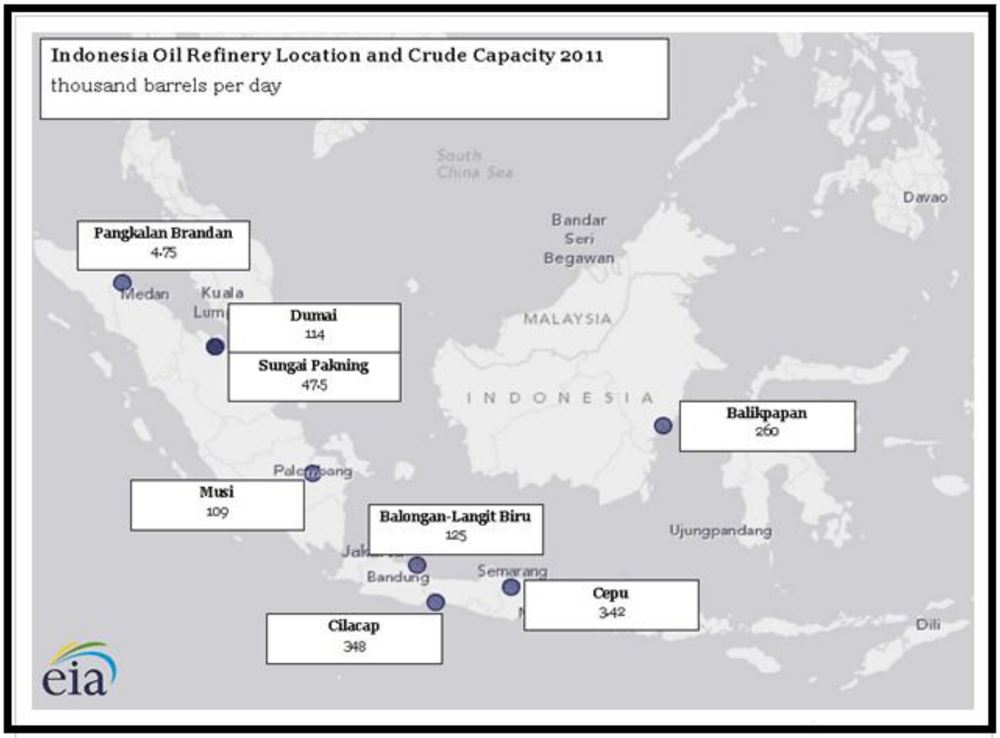

Figure 3-3 Indonesia Oil Refinery Location and Crude Capacity in 2011. Source: U.S. EIA, January 16, 2013. Web.

3.3.1.3 Pipelines and Petroleum Administration for Defense Districts (PADDs)

The U.S. EIA stated that the U.S. consumed an estimated 18.8 million barrels per day (MMbd) of petroleum products ("Oil: Explained" 2012). Pipeline networks are complex and they are placed to move crude oil from their exploration sites to their refineries, and also move petroleum products such as gasoline, diesel, kerosene, and jet fuel from their refineries to their customers. Crude oil and refined products travel in long distances. Thus, a vast logistical route plays a key role to oil market. The world oil markets characterize as resources versus demand interplay. This means that oil producing countries supply consuming countries. Pipelines are the primary player in the U.S. oil transportation mode.

In the first half of 20th century, the U.S. Northeast consumed the most oil. A lot of the oil came from fields along the Gulf of Mexico. After extracting, this oil was shipped in tankers around Florida and up the Atlantic Coast to refineries. This process continued up to World War II. When German U-boats began sinking the tankers, another way to ship the oil was needed. The solution was to use overland pipelines so that the supply could continue uninterrupted. It turned out that this method was more economical than tankers because it moved more oil faster, and thus continued after the war. Pipelines helped the post-war economy grow.

Domestically, pipelines move approximately two thirds of all oil ("Pipeline 101" 2012). This equals almost 15 billion barrels annually ("Pipeline 101" 2012). This includes both upstream after extraction and also to refineries. In the U.S. oil industry, pipelines are necessary in order supply the end user with an affordable product. This affordability can be seen when looking at relative unit shipping costs. Compared to other goods, oil moved through pipelines is almost 20 percent of all shipments and 2 percent off all costs ("Pipeline 101" 2012). Also the U.S has the more pipeline than any other country.

Suppliers decide the method to transport oil according to which is the cheapest. Trucks cost the most when shipping over great distances so they are typically only used for the last phase in the end product distribution. One example of the end product is short movements between fuel farms and gas stations. Here fuel is piped to holding tanks, where it is then pumped into waiting tanker trucks. The trucks then drive a few miles to the station and unload it into underground storage tanks. Also trucks are used when there is not enough supply to warrant constructing a dedicated pipeline. When this occurs, the trucks take the oil from the well to tanks and when enough oil is in the tank it can then be transported by pipeline. Even though it's only a minor amount, trucks are still needed to complete the supply chain in many areas.

Another mode of transportation is railroad. The cost is more comparable to pipelines than trucking. However, it is not as accessible as trucks because there are fewer miles of railroad than roadway. A third alternative is to transport by river. Here tanks are placed on barges and, in the case of imported oil sent upstream to further distribution. Of the three methods, river transport costs are closest to pipelines. However, river systems are fixed and building canals is much costlier than constructing a pipeline over the same distance.

For the purposes of petroleum transport, the U.S. is divided into five districts. These are known as Petroleum Administration for Defense Districts or PADDs. This was created during World War II in order to apportion gasoline to the Armed Forces. The U.S. EIA states PADDs as follow: PADD1 is the East Coast; PADD2 is the Midwest; PADD3 is the Gulf Coast; PADD4 is the Rocky Mountain Region; and PADD5 is the West Coast ("PADD Regions" 2012) – see Figure 3-4. Trench explained that PADD3 supplies estimated at 55 percent of the U.S. crude oil production and 47 percent of the country's petroleum products (4). Thus, PADD3 is the largest supply area of the U.S. domestically and also the largest supplier in inter-regional trade which is accounted for 90 percent of crude oil shipments and 80 percent of petroleum products shipments (Trench 4).

PADD1 does not have local crude oil production and has very limited refineries. However, this area has the highest regional demand of non-feedstock for refined products. Its refineries processes come from other PADD regions. Moreover, PADD1's output is supplemented by refined products from PADD3 and imports from other countries. Trench stated that PADD1 receives more than 60 percent of refined products from other PADDs and almost entire refined products imported into the U.S. (4).

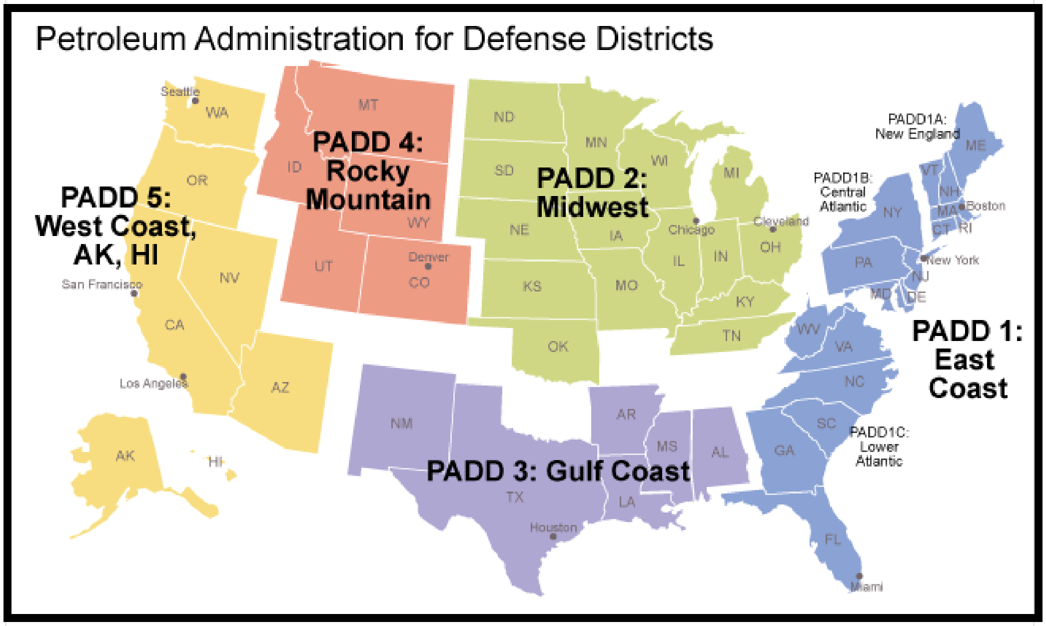

Figure 3-4 PADD Regions. Source: U.S. EIA, February 18, 2013. Web.

PADD2 has regional crude oil productions. Its oil production processes crude oil from Canada that transported using pipelines, then ships the crude oil locally through PADD3. 88 percent of PADD2's refinery input is supplied from other regions (Trench 4). PADD4 is the lowest consumer of petroleum products. This region imports crude oil from Canada to supplement its local refineries production. The inter-regional trade is an important factor for PADD4 to balance its region's supply and demand because of several reasons such as PADD4 has steep topography, thin oil infrastructure, and long distances of pipelines. PADD5 is separated logistically from the rest of the regions. The Alaskan North Slope oil reserves dominate PADD5's crude oil supply which is accounted for 55 percent of PADD5 production (Trench 6). This percentage went down from 65 percent when the Alaskan reserves were in peak in the late 1980s (Trench 6). Most of

PADD's oil production comes from California that has unique product quality and California is the largest consuming state.

Trench explained that pipelines transported all of the U.S. crude oil and estimated at 75 percent of the petroleum products moved between PADDs (6). Pipelines from PADD3 carry crude oil to PADD2 and refined products to PADD1 and PADD4. Canada supplies approximately 1 million barrels per day to PADD2 and PADD4 refineries which were accounted for about 25 percent and 30 percent, respectively of the two regions' crude oil (Trench 6). Pipelines are the vital organ with PADDs because pipelines move crude oil from producing reserves to refineries, then move refined products from refineries to small regional distribution centers or even directly to customers. Figure 3-5 and 3-6 show pipelines map of both crude oil and refined products.

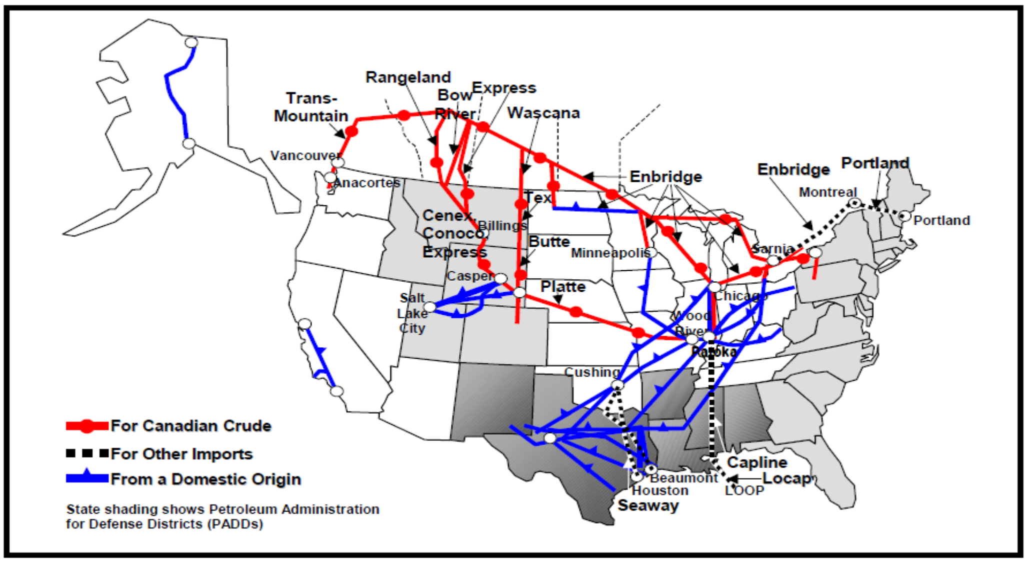

Figure 3-5 Crude Oil Pipelines. Source: Allegro Energy Group, January 19, 2013. Web.

3.3.1.4 World Oil Transit Chokepoints

Chokepoints are restricted channels along global sea routes and very critical to the global energy security because oil traded in such a high volume – see Figure 3-7.

The U.S. EIA stated that the total world oil production amounted to approximately 87 million barrels per day and over one half was moved by tankers on fixed maritime routes in 2011 (“World Chokepoint” 2012). The oil global markets depend on reliable transport. Any disruptions in a chokepoint can cause to substantial increases in total oil costs. In addition, chokepoints leave oil tankers to potential susceptible to piracy, terrorist attacks, and shipping accidents that lead to oil spills. Piracy is the biggest threat to oil tankers in this Strait.

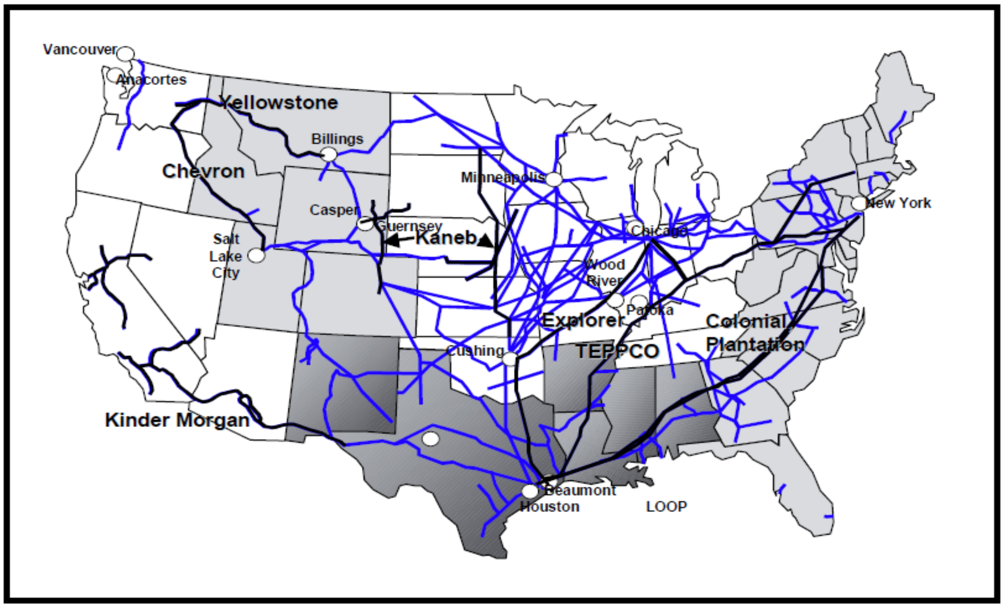

Figure 3-6 Refined Products Pipelines. Source: Allegro Energy Group, January 19, 2013. Web.

The Strait of Malacca is one of the world’s most strategic chokepoints by volume of oil transit. This strait links the Indian Ocean to the South China Sea and Pacific Ocean. It is the shortest sea route between the Middle East and growing Asian markets such as China, Japan, South Korea, and the Pacific Rim. Malacca is located between Indonesia, Malaysia, and Singapore. Most of oil shipments through the Strait of Malacca supply two of the world’s fastest growing economies including China and Indonesia. The U.S. EIA explained that the Strait of Malacca is the key chokepoint in Asia with an estimated 15.2 million barrels per day flow in 2011, compared to 13.8 million barrels per day in 2007, and crude oil makes up about 90 percent of flows, with the remainder being petroleum products ("World Chokepoint" 2012).

Malacca has its narrowest point in the Phillips Channel of the Singapore Strait which creates a natural bottleneck and potential for collisions, grounding, or oil spills. Over 60,000 vessels transit the Strait of Malacca per year ("World Chokepoint" 2012). Nearly half of the world's fleet requires rerouting through Indonesia, the Lombok Strait or Sunda Strait, if there were any blockages in the Malacca. There have been some proposals to build pipelines as an alternative transport route for crude oil imports from the Middle East to bypass the Strait of Malacca. The U.S. EIA stated that those proposed pipelines capacity were expected to reach about 440,000 billion barrels per day ("World Chokepoint" 2012).

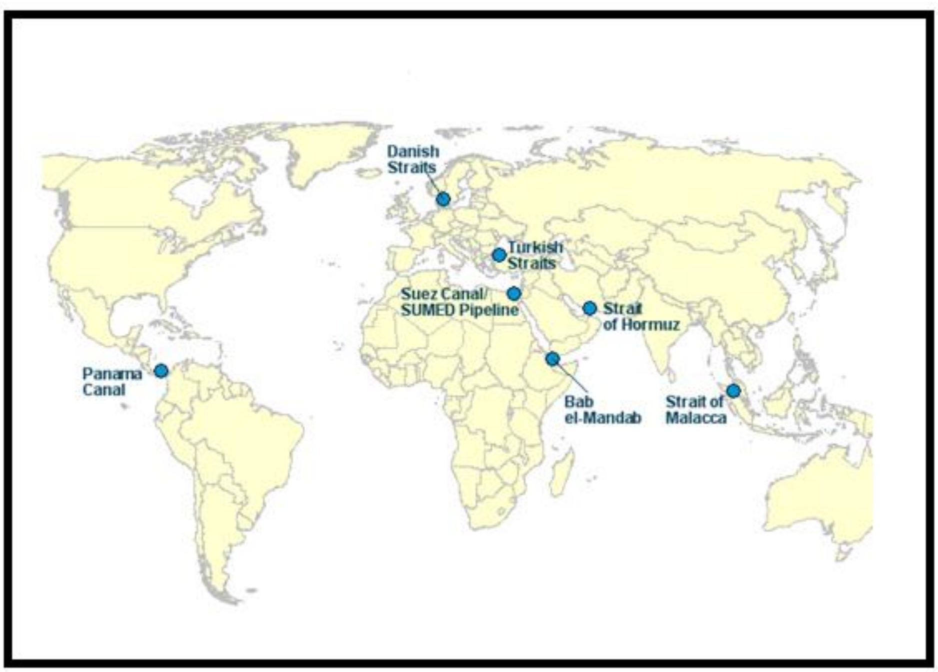

Figure 3-7 World Oil Transit Chokepoints. Source: U.S.EIA, January 28, 2013. Web.

3.3.1.5 Distribution, Marketing, and Customer

Distribution and marketing of petroleum products involve the movement of refined products such as gasoline, diesel, heating oil, kerosene, and jet fuel from the refinery to the end customers. Similar to crude oil, petroleum products are bought and sold throughout the chain of distribution. This distribution and marketing also represent a relatively small share of the price paid by customers. The U.S. EIA stated that the distribution and marketing of gasoline typically represent less than 15 percent of the pump price paid by the average motorist ("Today's Crude Oil" 2006). Gasoline, which represents nearly 45 percent of the domestic production of all refined products, is the petroleum product most demanded by the U.S. customers ("Today's Crude Oil" 2006).

There are almost 169,000 retail gasoline outlets in the U.S., selling 17 different formulations of gasoline designed to meet different air quality standards around the country ("Petroleum Products" 2012). While the cost of crude oil is the largest single component of the retail price of gasoline, gasoline prices ultimately are established by the forces of supply and demand, with retail prices reflecting local, state, and federal taxes and the value added to the distribution of gasoline as it moves from the refinery to the ultimate customer. For any particular retailer, a number of factors go into determining the pump price, including the location of the station, delivery costs, the commercial arrangements with the station's supplier, whether the station sells branded or unbranded gasoline, the size of the station, and taxes.

Competition in the retail sector is intense. The overwhelming trend has been increasing efficiency with which gasoline is delivered to the customer. The rapid entry of hyper marketers such as Wal-Mart and Costco, into the retail gasoline sector is the most current evidence of the level of competition found within this segment of the industry. Prices, of course, can do vary among stations for a number of reasons, including location advantages, with respect to the flow of traffic or proximity to locations like shopping malls that attracts large number of motorists; cost differences among stations such as rent, insurance, and wages; and the commercial arrangements under which the station is supplied with product.

Any retailer’s pump price, however, must be competitive with local retail stations to attract customers. That is, retail pricing behavior ultimately by the fact that pump prices are transparent and, therefore, readily known by motorists. Stations that set prices and are not competitive quickly lose business as motorists change their buying patterns. There is a common, often implicit, belief that retail prices are or should be based on what the dealer has paid for the gasoline in his storage tanks. This misconstrues how competitive markets work. As noted, prices for petroleum products such as gasoline are a function of current as well as expected future supply and demand conditions, not historical costs.

This is true even at the local level. If a retailer, for example, has relatively full tanks, but other stations are forced to raise their prices due to increasing wholesale prices, the retailer will have an incentive to raise prices even before the retailer’s own actual costs have increased based on the expectation that the retailer’s future replacement costs will be higher. That is, the market is telling the retailer that the cost of gasoline has increased and, therefore, so has the retailer’s cost of replacing existing inventory. This is sometimes referred to as the retailer’s opportunity cost which means that the retailer must replace whatever inventory is sold with higher supply cost. In contrast, however, when wholesale prices are falling and other retailers are lowering their prices, the same retailer faces the choices of either lower retail prices, thereby, lower margins on existing inventory, or accept lower sales.

The actual retail pricing decisions are much more complicated due, in part, to the multiple pricing related factors noted earlier. What cannot be lost, however, is the fact retail marketing is a very competitive sector of the industry. Consequently, retail prices are forced to respond to the competition. The price changes arise as a consequence of many factors, for example, Hurricanes Katrina and Rita in 2005. Shortly after the storms, prices for all petroleum products, including gasoline, rose as a consequence of the damage suffered by Gulf Coast refineries. The expectation that the supply of products would be less readily available gave rise to higher prices. However, as imports started arriving from foreign and domestic refineries came back on line, prices once again declined.

3.3.2 Impact of Crude Oil Supply Chain Costs on Supply Chain Quality

The goal of a business is to make money or profit. In order to maximize profit, a company must minimize costs. Chima stated that all benefits and costs must be weighed on each decision that a company makes along its supply chain (27). Most oil companies are facing the same challenge which lies on putting oil reserves into production and delivering final products to customers at the lowest cost possible (Chima 28). In the oil industry, the exploration and production sectors produce the same petroleum products for all competing companies, due to a narrow product differentiation. As a result, oil companies cannot introduce an exciting new product to distinguish themselves from one another. However, the companies must have the ability to adapt a solid supply chain model that can economically locate and produce oil efficiently to set apart themselves from their competitors. Thus, oil companies need to plan all significant operations in advanced and manages their costs throughout the entire supply chain to enhance the profit margin.

In general, every business requires two types of costs in producing its products or services such as fixed and variable costs. Fixed costs are expenses that are always fixed. These costs do not vary with the amount of the product produced and are independent regardless of the outcome of the operation. In the oil industry, fixed costs that occur on each its supply chain node include equipment leasing and operation costs. On the other hand, variable costs are dependent on sales. An increasing in the quantity of products produced means an increase in the variable costs. Since the variable costs usually the amount spent in producing a certain product, the selling price should be higher than the variable costs. The profit obtained in sales will contribute in recovering the value spent in the fixed costs. It is important to distinguish between fixed and variable costs in order to make a right decision in pricing and to know which costs should be accounted for. Fixed costs do not vary, thus, they are often ignored. This dissertation focuses on the variable costs, especially transportation costs because they vary on the demand and distance traveled.

Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer. Transportation is an important supply chain driver because products are rarely produced and consumed in the same location. Transportation is also a significant component of the costs incurred by most supply chain. Chopra and Meindl stated that transportation activity represented more than 10 percent of the Gross Domestic Product (GDP) of the U.S. in 2002 (2007).

The role of transportation is even more significant in the oil industry because the supply chain occurs within a global marketplace, which facilitates oil movement from where it is produced, to where it is refined into petroleum products, to where those products are ultimately sold to customers (“Today’s Crude Oil” 2006). Moreover, the existing global marketplace reflects both sellers and buyers to the market in order to get the lowest transportation costs from sellers to buyers for each type of crude oil.

3.3.3 Crude Oil Supply Chain Quality Performance Sampling Plan

As mentioned earlier that the transportation sector is the primary customer of total energy use in the U.S. and definitely drives the value of oil. There are several types of transportation modes in the oil industry such as pipelines, trucks, railroad, and barges. Pipelines are the primary players in the U.S. transportation mode. Petroleum products cannot reach their millions of customers across the country without pipelines. Oil sellers and buyers prefer to use pipelines due to the economic costs. Trucking is the most expensive transportation mode in the oil industry because trucking costs increase with distance. Railroad prices are competitive with pipeline prices. However, railroads are sometimes limited geographically. In considering all transportation modes include pipelines, trucks, railroads, and barges, it is pipelines which are the most cost effective method, as such; this mode has the greatest impact on oil supply chain cost.

Quality by definition is meeting customer's expectations in terms of fitness for use, delivery, and price. Many organizations emphasize quality as a means to stay competitive in the marketplace over the long run. They view having a reputation of high quality as representing future market share for new customers and maintaining market share for existing customers over their lifetime. Further, improving quality can provide long term financial savings. In order for a supply chain to remain profitable, quality from suppliers must be considered on the decision making process. Competing strategies of increasing profit as opposed to increasing quality will require many tradeoffs. Thus, quality is important all along the supply chain because the main objective of supply chain is to maximize customer service.

There are three quality metrics that are considered for pipelines performance. The first metric is the failure of a pipeline segment. This involved a complete loss of a particular segment of a pipeline to transport crude oil. Possible causes include unplanned maintenance, accidental excavation damage, or sabotage. The second metric is the loss of crude oil transmission compressor. This focuses on partial reductions in deliverability due to removal from service of one or more crude oil compressor. Possible causes include forced outage of a compressor driver, an explosion or fire in the compressor station, or the failure of ancillary systems. The third metric is the loss of deliverability from storage facilities. This includes the loss of deliverability from one or more of the major underground storage fields.

The United States of Environmental Protection Agency (EPA) classifies two types of wastes in the case of crude oil including exempt and non-exempt wastes. EPA defines exempt wastes as follow:

> Wastes that are generated before the end point of primary field operations are exempt. The term end point of initial product separation means the point at which crude oil leaves the last vessel in the tank battery associated with the wells. This tank battery separates crude oil from the produced water and/or gas (1993).

Pipelines are not part of primary field operations, thus, oil wastes that are generated by pipelines are non-exempt. Failure of a pipeline segment caused by accidental excavation damage is an example of non-exempt wastes, which will result in costing oil companies to pay fines to the EPA as well as settlement to the surrounding environment. This pipeline segment failure is chosen as the sampling plan of supply chain quality level performance. Table 3-1 shows the sampling plan of pipeline quality level performance from scale 1 to 3. Level 1 describes that pipelines are causing non-exempt wastes because they are damaged – see Figure 3-8. Contrary, level 3 describes new pipelines and they do not cause any non-exempt wastes – see Figure 3-9.

Table 3-1 Pipelines Quality Level Performance

Quality Level	Pipeline Quality Description
1	Damaged and Causing Non-Exempt Wastes
2	Damaged and Not Causing Non-Exempt Wastes
3	New and Not Causing Non-Exempt Wastes

Figure 3-8 Damaged Oil Pipeline. Source: Business Day, February 11, 2013. Web.

Figure 3-9 New Oil Pipeline. Source: Business Day, February 11, 2013. Web.

3.4 Crude Oil Supply Chain Environmental Sustainability Evaluation

The second specific objective is evaluating sampling plans that balances the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia. Similar with the supply chain quality evaluation earlier, this dissertation identifies impacts of supply chain costs on environmental sustainability and establishes a sampling plan of environmental sustainability performance.

3.4.1 Impact of Crude Oil Supply Chain Costs on Environmental Sustainability

Globalization has resulted in pressure on multinational firms to improve environmental performance. In order to achieve improvement in environmental performance, a company must integrate its environmental management strategies, while maintaining production quality and cost goals, into the supply chain which includes all of the operational life cycle stages such as unique partnerships with suppliers. Environmental sustainability has been defined as "meeting the needs of the present without compromising the ability of the future generations to meet their needs" (World Commission on Environment and Development 1987).

For oil companies, the concept of sustainability is most appropriately used when evaluating their business strategies. Sustainability of a business concerns the degree to which they not only reduce negative impacts on the natural environment through their operations, but also invest in business practices that promote policies to make wide reaching progress toward sustainable development. In the industry, the operations of oil companies are examined for their impact on the surrounding environment annually. To distinguish from the above definition of sustainability, environmentally conscious operations refer to green operations. However, green operations are not necessarily sustainable in the long run, but minimizing the negative impact of operational processes is still environmentally conscious. Company operations deal with energy usage necessary for operating refineries, emissions, and waste. Meanwhile, sustainability of the products deals with oil, natural gas, and possible alternatives to fossil fuels.

In the oil industry exploration and production processes, sustainability involves the products, and as such, the petroleum industry itself is environmentally unsustainable because like all fossil fuels, oil is a limited resource. Additionally, drilling in previously undisturbed areas requires clearing vegetation in order to build roads, to haul in equipment, and to construct wells. Wildlife is displaced. All of these actions are temporary and when the oil field reservoir is depleted, the area could be restored to its pre-developed condition. Indirect permanent effect comes from exhaust gases emitted by construction and haul vehicles. Also, drilling in the ocean has the potential for accidents as in the case of Deepwater Horizon explosion in the Gulf of Mexico. The subsequent oil spill killed an unknown numbers of fish and birds. This was the largest spill in history and caused a great harm to the environment. It was a single event which can be recovered from. At this time, any permanent impacts to sustainability are not fully known, but history shows that over time, in some instances decades, nature recovers. In the refining process, sustainability deals with the company operations which involve in energy usage necessary for operating refineries, emissions, and waste. For example, refinery produces waste gases that cannot be recaptured and are emitted into the atmosphere. This is an instance of an unsustainable practice. Sustainability involved in pipelines, both above and below ground have the potential to break and spill petroleum during transport into the surrounding environment. Some risks of accidental spills of oil have the potential to pollute water, contaminate soil, harm species, and affect livelihoods.

3.4.2 Environmental Sustainability Performance Sampling Plan

Oil companies need to plan all significant operations in advanced and manages their costs throughout the entire supply chain to enhance the profit margin. Both sustainability that deals either with oil companies' processes or products, will have positive and negative impacts on the supply chain costs. An example of the negative impact is definitely the disastrous British Petroleum (BP) drill explosion and oil spill in 2010 which impacted wildlife in the Gulf of Mexico. This accident resulted in damaging the environment as well as costing BP a settlement of billions of dollars. Contrary, an example of the positive impact is the ability to be able to preserve the productivity of oil itself as a natural resource asset which leads to supply chain costs savings.

Unlike the quality metrics which focused on pipelines performance, this dissertation considers refining process as a good candidate to determine its sustainability metrics. Refinery is a complex process. In this process, crude oil is heated and broken down into its components. Then, the conversion process transforms lower-valued products into higher-valued products by removing impurities. This conversion process dictates the different types of crude oil, thus, distinguishing the differences in refineries. The refining sector of the oil industry has significantly affected the crude oil global marketplace due to the demand growth of petroleum products. As the petroleum products demand increases, the demand for conversion capacity increases. Refineries affect supply chain profit margin such that refineries' variable costs vary on the petroleum products demand.

There are two sustainability metrics that are considered for refineries performance. The first metric is the refining operations which deal with energy usage necessary for operating refineries, emissions, and waste. The second metric is the refining products which deal with oil to fossil fuels. Refining processes that deal with energy usage are chosen as environmental sustainability according to the performance sampling plan – see Table 3-2. Level 4 describes that the refinery has a high energy usage for its operations while level 6 describes that the refinery has a low energy usage for its operations.

Table 3-2 Refinery Sustainability Level Performance

Sustainability Level	Refinery Sustainability Description
4	High Energy Usage Consumption
5	Medium Energy Usage Consumption
6	Low Energy Usage Consumption

3.5 Economic (Quality) and Environmental (Sustainability) Incentives Evaluation

The third specific objective is evaluating the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. Therefore, this dissertation establishes a mixed-integer programming (MIP) baseline models and an efficient frontier curve, which incorporate both sampling plans of pipeline quality and refinery sustainability performance. The efficient frontier curve determines the minimum supply chain costs with respect to pipeline quality and refinery sustainability.

This dissertation has an overall objective to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources and helps PERTAMINA to contribute more funds to the Indonesia's national treasuries as well. The U.S. government, crude oil refining companies, and other stakeholders are finding it necessary to invest infrastructure and buy crude oil from Indonesia. In order to invest the oil infrastructure, they must design or redesign a crude oil supply chain network which facilitates oil movement from where it is produced, to where it is refined into petroleum products, to where those products are ultimately sold to customers. This dissertation considers that the exploration, production, and refinery processes take place in Indonesia while distribution and marketing to customers in the U.S. Therefore, the objective of the supply chain network is to minimize the sum of exploration, production, and refinery operations and transportation costs while maintaining a high quality of pipeline and acceptable energy usage in the refining process.

The crude oil supply chain model from Indonesia to the U.S. consists of two exploration and production locations, Duri and Minas, and eight refineries locations, Pangkalan Brandan, Dumai, Sungai Pakning, Musi, Balangan Langit Biru, Cilacap, Cepu, and Balikpapan. Pipelines are utilized to transport crude oil from Duri and Minas to the eight Indonesia's refineries as well as to import refined products from those refineries to the U.S. Petroleum Administration for Defense Districts (PADDs). PADDs then distributed refined products such as gasoline, kerosene, jet fuel, and diesel to the end customers. The pipeline segment failure is chosen as the sampling plan of supply chain quality level performance. This sampling plan has three quality levels which determine the pipelines' conditions. The refining processes that deal with energy usage are chosen as the environmental sustainability sampling plan performance. This sampling plan has three sustainability levels which explain whether the refinery has a low, medium, or high energy usage for its operations.

There are possibilities of 12 scenarios that can be generated from above information. Table 3-3 summarizes all of the scenarios. The middle level of each sampling plan, level 2 for the pipeline quality and level 5 for the refinery sustainability, is considered as the baseline level. Four terminologies are defined to distinguish Duri/Minas pipeline quality and Duri/Minas refinery sustainability.

Terminologies:

QP_{Duri} = Pipeline Quality at Duri location

QE_{Duri} = Refinery Sustainability at Duri location

QP_{Minas} = Pipeline Quality at Minas location

QE_{Minas} = Refinery Sustainability at Minas location

Table 3-3 Scenarios Summary

Exploration / Production Location	**Sampling Plan**	**Performance Level**	**Scenario #**
Duri	Pipeline Quality (QP_{Duri})	1	1
		2 (Baseline)	2
		3	3
	Refinery Sustainability (QE_{Duri})	4	4
		5 (Baseline)	5
		6	6
Minas	Pipeline Quality (QP_{Minas})	1	7
		2 (Baseline)	8
		3	9
	Refinery Sustainability (QE_{Minas})	4	10
		5 (Baseline)	11
		6	12

Data are obtained from the U.S. EIA, OPEC, PERTAMINA, and BP MIGAS. These data include distances from Duri/Minas to each refinery, fixed/variable costs to open small/large refinery for each refinery location, small/large refinery capacity, pipeline demand, transportation costs per pipeline per mile. Distances, pipeline demand, and transportation costs per pipeline per mile do not affect both pipeline quality and refinery sustainability. Pipeline quality and refinery sustainability impact both fixed/variable costs and small/large refinery capacity.

Table 3-4 From Oil Reserve and To Refinery Distances

To Refinery / From Oil Reserve	**Distances (Miles)**	
	Duri	Minas
Pangkalan Brandan	129	134
Dumai	22	25
Sungai Pakning	25	15
Musi	98	88
Balangan Langit Biru	215	198
Cilacap	363	372
Cepu	487	503
Balikpapan	850	845

Table 3-5 Transportation Costs per Pipelines per Mile

To Refinery / From Oil Reserve	**Costs / Pipeline – Mile ($)**	
	Duri	Minas
Pangkalan Brandan	0.34	0.44
Dumai	0.15	0.08
Sungai Pakning	0.56	0.45
Musi	0.78	0.65
Balangan Langit Biru	1.05	0.88
Cilacap	1.22	1.01
Cepu	1.67	1.56
Balikpapan	2.01	1.88

Table 3-6 Pipeline Demand

Refinery	Pipeline Demand (Million Barrels per Day / MMbd)
Pangkalan Brandan	378
Dumai	268
Sungai Pakning	334
Musi	408
Balangan Langit Biru	878
Cilacap	985
Cepu	1397
Balikpapan	1670

Table 3-7 Fixed and Variable Costs for QP_{Duri}

Refinery	Small Refinery – Costs (Thousand $)		Large Refinery – Costs (Thousand $)	
	Fixed	Variable	Fixed	Variable
Pangkalan Brandan	95	0.103	125	0.111
Dumai	55	0.011	68	0.015
Sungai Pakning	76	0.101	88	0.109
Musi	89	0.096	100	0.119
Balangan Langit Biru	106	0.012	200	0.200
Cilacap	175	0.018	250	0.250
Cepu	166	0.010	234	0.015
Balikpapan	189	0.014	245	0.018

Table 3-8 Fixed and Variable Costs for QE_{Duri}

Refinery	Small Refinery – Costs (Thousand $)		Large Refinery – Costs (Thousand $)	
	Fixed	Variable	Fixed	Variable
Pangkalan Brandan	95	0.099	125	0.123
Dumai	55	0.009	68	0.167
Sungai Pakning	76	0.102	88	0.104
Musi	89	0.105	100	0.112
Balangan Langit Biru	106	0.024	200	0.038

Table 3-8–*Continued*

Cilacap	175	0.012	250	0.034
Cepu	166	0.034	234	0.045
Balikpapan	189	0.020	245	0.065

Table 3-9 Fixed and Variable Costs for QP_{Minas}

Refinery	**Small Refinery – Costs (Thousand $)**		**Large Refinery – Costs (Thousand $)**	
	Fixed	**Variable**	**Fixed**	**Variable**
Pangkalan Brandan	95	0.100	125	0.104
Dumai	55	0.030	68	0.045
Sungai Pakning	76	0.099	88	0.107
Musi	89	0.098	100	0.135
Balangan Langit Biru	106	0.102	200	0.145
Cilacap	175	0.108	250	0.134
Cepu	166	0.100	234	0.124
Balikpapan	189	0.090	245	0.123

Table 3-10 Fixed and Variable Costs for QE_{Minas}

Refinery	**Small Refinery – Costs (Thousand $)**		**Large Refinery – Costs (Thousand $)**	
	Fixed	**Variable**	**Fixed**	**Variable**
Pangkalan Brandan	95	0.098	125	0.125
Dumai	55	0.070	68	0.100
Sungai Pakning	76	0.089	88	0.135
Musi	89	0.089	100	0.154
Balangan Langit Biru	106	0.087	200	0.176
Cilacap	175	0.097	250	0.108
Cepu	166	0.104	234	0.116
Balikpapan	189	0.097	245	0.154

Table 3-11 Refinery Capacity

Refinery	Refinery Capacity (Million Barrels per Day / MMbd)	
	Small	Large
Pangkalan Brandan	2500	7500
Dumai	1750	6000
Sungai Pakning	2000	6500
Musi	2000	8000
Balangan Langit Biru	2400	6800
Cilacap	2000	7200
Cepu	1500	5500
Balikpapan	1200	4500

Locating refineries is an application of mixed-integer programming. This dissertation utilizes Solver of Microsoft Excel to minimize the sum of exploration, production, and refinery operations and transportation costs while maintaining a high quality of pipeline and acceptable energy usage in the refining process. Although it is a strategic planning problem, next year's oil demand is assumed fixed. Eight refineries locations and their distances to the Duri oil field are listed in the "Distances" section. At each location, the oil company has the choice of selecting among no refinery, a small refinery, or a large refinery. In the "Refinery Options" section, a fixed cost and a variable cost for outbound flows are associated with each refinery. These flows are measured in truckloads for the year up to the stated capacity of the refinery option. All costs are measured in thousands of dollars. The demands for full pipeline shipments for next year, along with oil flows from the refineries to meet them, are listed in the "Flows" section. The costs of the refineries selected in the optimal solution are calculated in the "Refinery Capacity and Cost" section.

The choices at each location are modeled by two 0 – 1 variables. For example, CepuSM = 1 if a small refinery is selected at Cepu location; 0 otherwise. CepuLG = 1 if large refinery is selected at Cepu location; 0 otherwise. This imposes the logical constraint CepuSM + CepuLG ≤ 1, which states that at most one of the two refinery options at Cepu may be selected. From the “Refinery Options” section, If CepuSM = 1, the model will open the small refinery at Cepu with a fixed cost of $185,000, a variable cost of $74 for each pipeline shipped from refinery, and a capacity for next year of 300,000 barrels per day. If CepuLG = 1, the model will open the large refinery at Cepu with a fixed cost of $395,000, a variable cost of $84 for each pipeline shipped from refinery, and a capacity for next year of 342,000 barrels per day. If both CepuSM = 0 and CepuLG = 0, no refinery will be opened in Cepu.

In “Refinery Options” section, the adjustable cells C20 to J20 correspond to the SM (Small) 0 – 1 variables, whereas the cells C24 to J24 correspond to the LG (Large) 0 – 1 variables. The inequalities given in cells C25 to J25 pertain to the eight logical constraints, one for each location, similar to Cepu. These choices are translated into cost and capacity data in “Refinery Capacity and Cost” section. Specifically, the constraints in the cells C39 to J39 and C44 to J44 constrain the output of each refinery to be less than or equal to the capacity implied by the selection of 0 – 1 variables in “Refinery Options” section. For example, the value in cell I24 is 1 or equivalently because CepuLG = 1, the outbound flow at the Cepu location is constrained by I44 to less than or equal to 342,000 barrels per day. Because the flow out of Cepu is from a large refinery, its cost computed in I43 using the fixed and variable costs for that large refinery given in “Refinery Options” section. Finally, this outbound flow must equal to the outbound flow from Cepu given in I32 of “Flows” section.

“Flows” section contains the adjustable cells corresponding to flows from refinery to Duri oil field. For example, row 31 corresponds to Duri, which is supplied with --- barrels per day from a refinery in Cepu. At the bottom of “Flows” section, the transportation costs incurred for shipments out of each refinery. For each refinery location, the sum of the products of the flows in “Flows” is computed with the distances in “Distance” section. This sum-product gives the projected total pipeline-miles for shipments out of each refinery next year, which is multiplied by cost per pipeline-mile.

The “Refinery Capacity and Costs” section is related to the choice of 0 – 1 variables at each location from “Refinery Options” to the costs incurred at those facilities. In these calculations, if there is positive flow out a refinery in the “Flows,” it is forced to be priced by the cost function implicitly chosen in the “Refinery Options” by the selection of a 0 – 1 variable to equal 1. Finally, the objective function to be minimized is the sum of the transportation costs in cells C33 to J33, the small refinery costs in cells C38 to J38, and the large refinery costs in cells C43 to J43.

Chapter 4

Results

The New York Times explained that the United States increased its dependence on oil from Saudi Arabia by more than 20 percent last year (Krauss 2012). The United States of Energy Information Administration (U.S. EIA) stated that oil from Saudi Arabia was accounted for 14 percent of the U.S. crude oil and petroleum products in 2012 ("Oil: Explained" 2012). This was problematic due to the fact that 14 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia. Governments, crude oil refining companies, and other stakeholders were finding it necessary to invest infrastructure and buy crude oil from other nations including Indonesia. According to the U.S. EIA, oil from Indonesia was accounted for only 0.24 percent of the U.S. crude oil and petroleum products in 2011 ("Oil: Explained" 2012).

The objective of this dissertation was to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that supported decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it became more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources. In order to meet the objective, three specific objectives were investigated such as evaluate the supply chain factors that determine supply chain quality of crude oil production; evaluate sampling plans that balances the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia; and evaluate the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. The results of each specific objective are presented in detail in the subsequent sections.

4.1 Crude Oil Supply Chain Quality Evaluation

In order to meet the first specific objective of evaluating some supply chain factors that could determine supply chain quality of crude oil production, this dissertation created a crude oil supply chain model from Indonesia to the U.S, identified impacts of supply chain costs on supply chain quality, and established a sampling plan of supply chain quality performance. Many literature reviews and informative facts about the Indonesian and American oil industry were reviewed to determine the best fit model of crude oil supply chain from Indonesia to the U.S. Figure 3-1 (pg. 58) showed that best fit crude oil supply chain model. This dissertation considered that the exploration, production, and refinery processes took place in Indonesia while distribution, marketing, and customer in the U.S.

There were many small and big oil reserves across Indonesia's archipelagos. Duri and Minas were selected as the representatives of crude oil exploration and production processes in the model. These representatives were the largest and oldest oil fields in Indonesia which were located on the eastern coast of Sumatra. Duri began producing in 1952 and currently averages around 185,000 billion barrels per day ("Indonesia" 2012), while Minas field began production in 1955 and currently produces around 70,000 billion barrels per day ("Indonesia" 2012). Indonesia had a refinery capacity at an estimated one million barrels per day ("Indonesia" 2012). Eight refineries owned by PERTAMINA including Pangkalan Brandan, Dumai, Sungai Pakning, Musi, Balangan Langit Biru, Cilacap, Cepu, and Balikpapan made up the country's refinery capacity, thus, these refineries were chosen as the representatives of the model's crude oil refinery processes. Pipelines were utilized to transport crude oil from Duri and Minas to the eight Indonesia's refineries as well as to import refined products from those refineries to the U.S. Petroleum Administration for Defense Districts (PADDs). PADDs then distributed refined products such as gasoline, kerosene, jet fuel, and diesel to the end customers.

The goal of a business was to make money or profit. . Thus, oil companies needed to plan all significant operations in advanced and managed their costs throughout the entire supply chain to enhance the profit margin. Studies have shown that variable costs affect profit margin. Thus, this dissertation focused on the variable costs, especially transportation costs because they varied on the demand and distance traveled. In considering all transportation modes include pipelines, trucks, railroads, and barges, it was pipelines which were the most cost effective method, as such; this mode had the greatest impact on oil supply chain cost. Three quality metrics were considered for pipelines performance such as failure of a pipeline segment, loss of crude oil transmission compressor, and loss of deliverability from storage facilities. Failure of a pipeline segment caused by accidental excavation damage was chosen as the sampling plan of supply chain quality level performance because this failure produced non-exempt wastes that could affect transportation costs and ultimately supply chain costs.

4.2 Crude Oil Supply Chain Environmental Sustainability Evaluation

The second specific objective was evaluating sampling plans that balanced the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia. Similar with the supply chain quality evaluation earlier, this dissertation identified impacts of supply chain costs on environmental sustainability and established a sampling plan of environmental sustainability performance.

Globalization pressured multinational firms to improve environmental performance. In order to achieve improvement in environmental performance, a company needed to integrate its environmental management strategies, while maintaining production quality and cost goals, into the supply chain. In the oil industry's, exploration and production processes, sustainability is involved in the products, as such, the petroleum industry itself was environmentally unsustainable because like all fossil fuels, oil was a limited resource. Additionally, drilling in previously undisturbed areas required clearing vegetation in order to build roads, to haul in equipment, and to construct wells. Also, drilling in the ocean had the potential for oil spills killing an unknown numbers of fish and birds. The refining process, sustainability dealt with the company operations which involved in energy usage necessary for operating refineries, emissions, and waste. Sustainability involved in pipelines such that they, both above and below ground, had the potential to break and spill petroleum during transport into the surrounding environment. Some risks of accidental spills of oil had the potential to pollute water, contaminate soil, harm species, and affect livelihoods.

Unlike the quality metrics which focused on pipelines performance, this dissertation considered refining process to determine its sustainability metrics. The refining sector of the oil industry had significantly affected the crude oil global marketplace due to the demand growth of petroleum products. As the petroleum products demand increased, the demand for conversion capacity increased. Two sustainability metrics were considered for refineries performance such as the refining operations which dealt with energy usage necessary for operating refineries, emissions, and waste and the refining products which dealt with oil to fossil fuels. Refining operations dealt with energy usage was chosen as environmental sustainability performance sampling plan because these refining processes affected supply chain profit margin such that refineries' variable costs varied on the petroleum products demand.

4.3 Economic (Quality) and Environmental (Sustainability) Incentives Evaluation

The third specific objective was evaluating the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. Therefore, this dissertation established a mixed-integer programming (MIP) baseline model and an efficient frontier curve. The baseline model ran several scenarios which incorporated both sampling plans of pipeline quality and refinery sustainability performance. The efficient frontier curve determined the minimum supply chain costs with respect to pipeline quality and refinery sustainability.

Table 4-1 Pipeline Quality QP_{Duri}

Quality Level	Supply Chain Cost ($)
1	$6,567,500
2	$11,493,125
3	$16,418,750

Table 4-2 Refinery Sustainability QE_{Duri}

Sustainability Level	Supply Chain Cost ($)
4	$9,851,250
5	$13,135,000
6	$16,416,750

Table 4-3 Pipeline Quality QP_{Minas}

Quality Level	Supply Chain Cost ($)
1	$2,485,000
2	$4,348,750
3	$6,212,500

Table 4-4 Refinery Sustainability QE_{Minas}

Quality Level	Supply Chain Cost ($)
1	$3,727,500
2	$4,970,000
3	$6,212,500

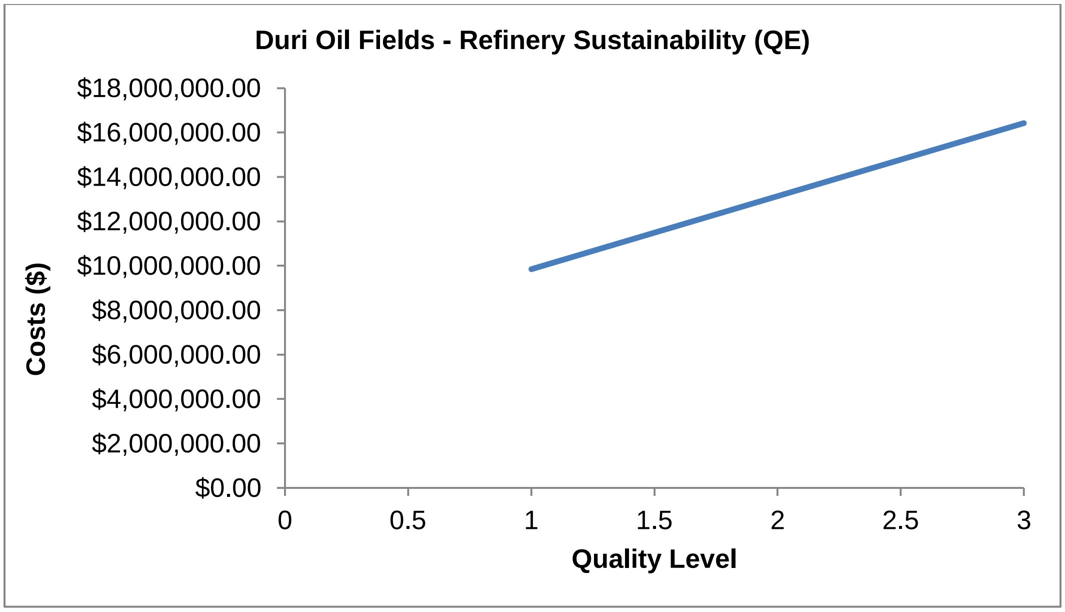

Figure 4-1 Efficient Frontier of QE_{Duri}

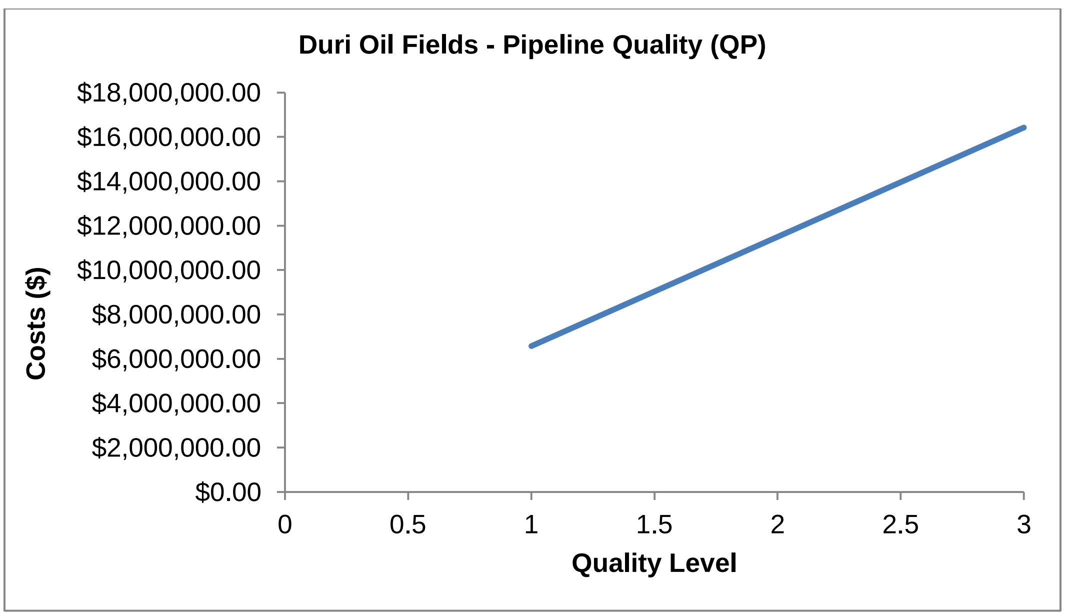

Figure 4-2 Efficient Frontier of QP_{Duri}

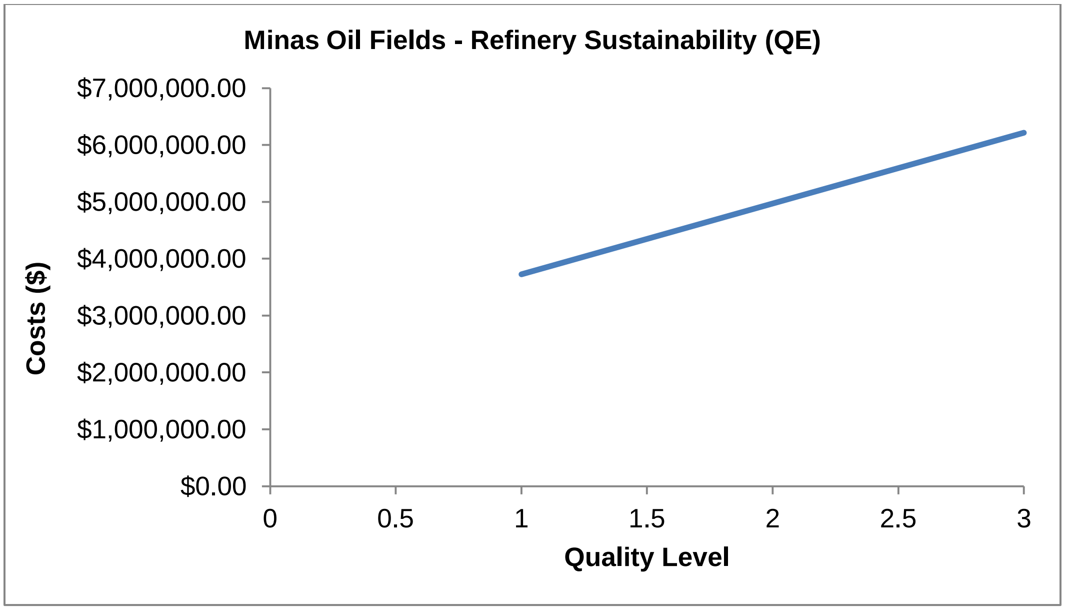

Figure 4-3 Efficient Frontier of QE_{Minas}

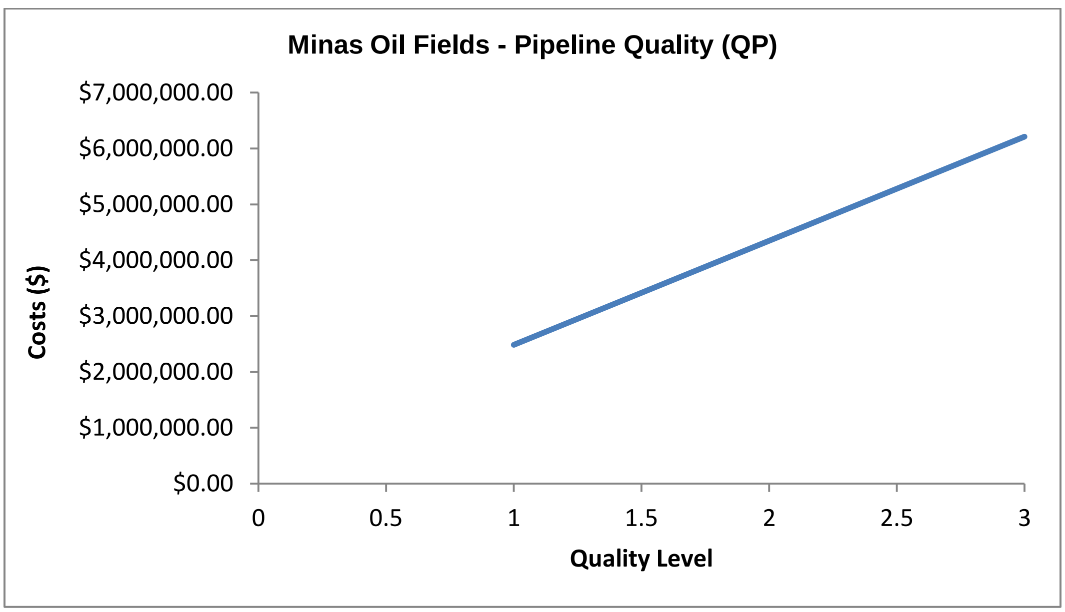

Figure 4-4 Efficient Frontier of QP_{Minas}

Chapter 5

Contribution to the Body of Knowledge

5.1 Conclusion

The New York Times explained that the United States increased its dependence on oil from Saudi Arabia by more than 20 percent last year (Krauss 2012). The United States of Energy Information Administration (U.S. EIA) stated that oil from Saudi Arabia was accounted for 14 percent of the U.S. crude oil and petroleum products in 2012 ("Oil: Explained" 2012). This was problematic due to the fact that 14 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia. Governments, crude oil refining companies, and other stakeholders were finding it necessary to invest infrastructure and buy crude oil from other nations including Indonesia. The significance of this dissertation was to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that identified how other nations such as Indonesia could supply some of crude oil imports with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs.

The objective of this dissertation was to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that supported decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil in Indonesia so that it became more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources. In order to meet the objective, three specific objectives were investigated. The first specific objective was evaluating some supply chain factors that could determine supply chain quality of crude oil production. Thus, this dissertation created a crude oil supply chain model from Indonesia to the U.S, identified impacts of supply chain costs on supply chain quality, and established a sampling plan of supply chain quality performance. The second specific objective was evaluating sampling plans that balanced the tradeoffs among various economic and environmental incentives for crude oil suppliers in Indonesia. Similar with the supply chain quality evaluation earlier, this dissertation identified impacts of supply chain costs on environmental sustainability and established a sampling plan of environmental sustainability performance. The third specific objective was evaluating the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. Therefore, this dissertation established a mixed-integer programming (MIP) baseline model and an efficient frontier curve. The baseline model ran several scenarios which incorporated both sampling plans of pipeline quality and refinery sustainability performance. The efficient frontier curve determined the minimum supply chain costs with respect to pipeline quality and refinery sustainability.

This dissertation proposed a research question of "When is it economically beneficial to invest in the supply chain quality of crude oil from a given nation?" and suggested that the crude oil supply chains each of these countries dictated their ability to provide crude oil. Two hypothesis statements were constructed to answer the research question such that whether or not the crude oil supply chain quality and the environmental sustainability impacted the supply chain costs. Both of the null hypothesis statements were rejected because the crude oil supply chain quality impacted the supply chain costs and the environmental sustainability impacted the supply chain costs.

5.2 Limitations and Areas of Disciplines

There are some limitations for this dissertation such as data availability and dissertation's scope. The United States of Energy Information Administration (U.S. EIA), the Organization of Petroleum Exporting Countries (OPEC), and the United States of

Environmental Protection Agency (EPA) provide numerous useful preliminary data and facts of the American oil industry. Contrary, the Indonesian oil industry is very limited due to lack of preliminary data collection and information from PERTAMINA and BP MIGAS. This dissertation focuses only on Indonesia and the U.S. oil industry. Therefore, the scope of this dissertation is already broad enough considering the nature of supply chain activities on both countries. Future work can be conducted as the continuation of this dissertation which uses the proposed model that includes other countries.

This dissertation follows several areas of disciplines including optimization methodology, quality control principle, and Supply Chain Management (SCM) application. Optimization methodology helps to develop the mixed-integer programming (MIP) model that identifies how other nations such as Indonesia can supply some of the crude oil imports with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. Quality control principle provides basic understanding on identifying and characterizing both economic and environmental incentives sampling plan for crude oil supply chain in Indonesia. SCM application explains on how the oil supply chain works within a global marketplace that facilitates oil movement from where it is produced, to where it is refined into petroleum products, to where those products are ultimately sold to customers.

5.3 Intellectual Merit and Broader Impact

The intellectual merit of this dissertation is a mixed-integer programming (MIP) model that demonstrates the tradeoffs between supply chain quality and supply chain profit for Indonesia that can be expanded to other nations. Furthermore, the broader impact is investments into other countries crude oil supply chains can be quantified and optimized, and countries such as Indonesia can be identified as possible candidates for investment for future global crude oil needs.

Appendix A

U.S. Petroleum and Other Liquids Production, Estimated Consumption, and Net Imports

from 2000 – 2011

U.S. Petroleum and Other Liquids Production, Estimated Consumption, and Net Imports from 2000 – 2011 (Million Barrels per Day)

Year	Production	Estimated Consumption	Net Imports
2000	8.783793607	19.6989253	10.41906011
2001	8.686382575	19.64710208	10.90043274
2002	8.719845068	19.75965414	10.54683929
2003	8.55419189	20.03070268	11.23774488
2004	8.497956475	20.7282771	12.09683527
2005	8.140283123	20.80279123	12.54890945
2006	8.163435589	20.69726532	12.39113022
2007	8.291763452	20.69475778	12.02724058
2008	8.364449727	19.50590902	11.09009754
2009	8.980583863	18.78864159	9.653836055
2010	9.489669863	19.19167778	9.43486726
2011	9.883794849	18.87709723	8.432203123

Preliminary Data: U.S. EIA, October 21, 2012, Web.

Appendix B

U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, and Indonesia in 2011

U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, and Indonesia in 2011 (Thousand Barrels)

Year	Net Imports	Saudi Arabia	Canada	Indonesia
2000	3,813,376	575,274	661,351	17,604
2001	3,978,617	606,753	667,374	18,763
2002	3,849,461	566,512	719,334	19,320
2003	4,101,791	647,666	756,354	13,609
2004	4,427,468	570,137	782,598	16,475
2005	4,580,351	560,823	796,219	8,664
2006	4,522,521	534,143	858,839	9,967
2007	4,393,078	541,987	895,976	9,943
2008	4,067,602	559,750	912,263	8,068
2009	3,528,307	366,605	904,914	7,524
2010	3,445,848	400,127	925,428	13,660
2011	3,108,958	436,020	1,020,604	7,527

Preliminary Data: U.S. EIA, October 21, 2012, Web.

Appendix C

World Primary Energy Supply in 2010

World Primary Energy Supply in 2010

Energy	Year		
	2009	**2010**	**2020**
Oil	79.0	81.0	89.7
Coal	66.3	68.8	84.3
Natural Gas	51.0	53.1	66.5
Nuclear	14.1	14.3	16.0
Renewable	1.6	16.1	3.8
TOTAL	**212.0**	**233.3**	**260.3**

Preliminary Data: OPEC World Oil Outlook 2012, January 14, 2013, Web.

Appendix D

Crude Oil and Gasoline Prices History from 1990 to 2012

Crude Oil and Gasoline Prices History from 1990 to 2012 ($ / Gallon)

Year	Price ($/gallon)	
	Gasoline	Crude Oil
1990	2.00	1.23
1991	1.88	1.01
1992	1.80	0.96
1993	1.72	0.82
1994	1.69	0.77
1995	1.69	0.83
1996	1.78	0.97
1997	1.74	0.85
1998	1.47	0.55
1999	1.59	0.76
2000	2.01	1.19
2001	1.87	0.92
2002	1.74	0.97
2003	1.97	1.11
2004	2.28	1.40
2005	2.70	1.85
2006	2.97	2.16
2007	3.14	2.39
2008	3.52	3.17
2009	2.54	2.03
2010	2.96	2.57
2011	3.64	3.37
2012	3.67	3.25

Preliminary Data: U.S. EIA, February 18, 2013, Web.

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Biographical Information

Restu P. Sunarto-Bussey was born in Jakarta, Indonesia. She came to the United States as an exchange student at Boswell High School in Fort Worth, Texas. Her interest in the Industrial Engineering field starts when she joined a facility tour of a local manufacturer in high school. She was amazed to see something being made that people worldwide could use. She obtained both of her bachelor and master degree in Industrial Engineering from the University of Texas at Arlington in 2005 and 2008, respectively. While an undergraduate, she interned at Haggar Clothing Co. distribution center facility. During the master's program her career as an Industrial Engineer began at Alcoa Fujikura Ltd. where she gained valuable knowledge and experience in a manufacturing environment. Restu's passion in the field continued growing during her doctoral assistantship program with the Texas Manufacturing Assistance Center (TMAC) which she involved in various projects of helping manufacturers to improve their processes. Currently, she is working at Alcoa Inc. Davenport Works Division in Riverdale, Iowa.