Energy Required to Produce Petroleum Products from Oil Sand Versus Other Petroleum Sources

By

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Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science at the

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ABSTRACT

The purpose of this study is to determine the energy cost of producing petroleum products from oil sand and to compare it to the energy cost of producing petroleum products from conventional crude resources. The energy cost was calculated by breaking the production process into four stages: mining, extracting, refining and transportation. Energy costs for mining and extraction were determined based on the required energy input. The energy costs for refining and transportation of synthetic light crude oil produced from oil sand were calculated by direct comparisons to the energy cost for conventional crude oil production. Refining comparisons were based on change in density. Transportation comparisons were based on distances and methods of travel. The energy cost to produce a barrel of synthetic light crude oil from oil sand was determined to be 22.6% of the energy contained in a barrel of oil. Conventional crude oil had an energy cost of 23.2% of the energy in a barrel of oil.

The conclusion made from these results is not that oil sand production is less energy intensive, but rather that the energy cost to produce petroleum products from oil sand is in the same range as energy cost to produce petroleum products from other sources. Due to rapidly changing technology, oil sand production has had decreasing financial costs and is projected to be the least expensive petroleum resource in North America in the near future. There is a threat to the environment from oil sand production. The threats to the environment include emission of toxic fumes, land destruction and water disruption. The improvement of technology is essential to safeguarding the environment as oil sand production expands. Oil sand is a vast petroleum resource that, due to technological improvements, is an efficient and cost effective petroleum source.

Thesis Supervisor: Timothy Gutowski
Title: Professor of Mechanical Engineering
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1.0 Introduction

Known conventional sources of petroleum have a finite extraction life facilitating the need for new petroleum sources. Oil sand is an abundant petroleum source that has only recently been taken advantage of in the production of crude oil. Oil sand can be consolidated or unconsolidated rock that contains hydro-carbonaceous material.\(^1\) Oil sand, in its natural form, contains Bitumen that can be used to produce petroleum products. It is composed of 12% Bitumen. Bitumen is heavy tar-like oil that is be converted into synthetic light crude oil. Synthetic light crude oil can be used to produce a range of petroleum products demanded by the market.

The largest oil sand deposit is found in Alberta and represents a potential production of 1.6 Trillion barrels of oil, making it one of the largest petroleum sources in the world.\(^2\) Oil sand production begins when it is extracted from the ground using conventional pit mining techniques. The Bitumen must then be extracted from the oil sand using Hydro-transport technology. The sand, clay and other debris are washed away from the Bitumen so that it can be turned into synthetic light crude oil. Bitumen is then upgraded to reduce the density thus increasing its quality. Synthetic light crude oil is the end product of the upgrading process and is comparable to high quality crude oil. Synthetic light crude oil produced from oil sand can then be refined with conventional crude oil into petroleum products.

By 2005, petroleum from oil sand is expected to represent 50 per cent of Canada’s total crude oil output, and 10 per cent of North American production. The energy requirements of oil sand production relative to the energy requirements of conventional crude oil production will be a critical factor in the success of oil sand as a petroleum source. This thesis calculates the energy requirements of petroleum production from oil sand versus conventional crude oil sources. The comparison is broken down into four major production categories: mining, extraction, refining and transportation.

The process for each stage of oil sand production will be defined and analyzed using validated assumptions and comparisons to similar processes that have more historical data. In order to set a benchmark to compare the energy requirements of oil sand production, the energy required for each step to produce petroleum products from

\(^1\) Symposium Papers: Synthetic fuels from Oil Sand and Tar Sand, 14.

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conventional crude oil sources will be determined. Based on the comparison of energy requirements for oil sand versus conventional sources, the feasibility of using oil sand as a long-term efficient petroleum source can be determined.

\[2 \text{ Public Reference Center: Oil Sands.}\]
2.0 Oil Sand

2.1 Oil Sand Market

Oil sand production began in 1962 when the Canadian government authorized the production of 31,000 barrels of oil per day from the province of Alberta. The oil sand market grew modestly at first, but in recent years it has grown at a remarkable rate. The large increase in planned production is fueled by the constant demand for oil and the reduction of known petroleum supplies. According to Canada’s National Energy Board, there are an estimated 300 Billion barrels of petroleum in the form of oil sand in Alberta, Canada. The Athabasca oil sand deposit in Alberta has 15% more oil than Saudi Arabia. The Athabasca oil sand deposit is the largest known petroleum resource.

Currently 29 square miles of oil sand is leased from the government leaving over 80% of the Alberta oil sand fields available for future exploration and lease. The Athabasca oil sand region has a volume of 1.6 trillion barrels of oil. According to the Government of Alberta, the current production of the region is 605,000 barrels per day. The New York Times recently said, “(Oil sand is turning) Canadian Wilderness into what may soon be the continent’s leading oil producing area north of the Gulf of Mexico.”

Currently, 12% of the oil consumed in Canada comes from oil sand.

Oil sand has been discovered in various areas of the Globe. The Orinoco Belt in Venezuela and Alberta, Canada are the two largest oil sand deposits. Oil sand is also found in the United States, Brazil, Trinidad, Russia, China, Madagascar, Albania, and Jordan. Oil sand production is most significant in Alberta. The three major deposits in Alberta constitute 141,000 square kilometers of potential mining.

The major product of the oil sand producing companies is synthetic light crude oil. Bitumen from the oil sands is upgraded into light, high-grade oil known as synthetic crude oil. Synthetic crude oil is in demand by refineries across North America due to

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3 “Oil Sand Athabasca Timeline.” Athabasca Oil Sands.
5 “Oil Sands Process.” Suncor Energy.
10 “Western Oil Sands.”
its high quality and often sells at a premium to benchmark prices due to its high quality relative to conventional crudes.

2.2 Future Growth

The oil sand industry has enjoyed exponential growth in recent years. Oil sand production is expected to nearly double by 2010. Oil sand today accounts for 605,000 barrels/day, but by 2010 the production of oil sand is expected to reach 965,000 barrels/day. Currently, $24 Billion has been invested in oil sand projects extending over the next decade. This large capital commitment will help to ensure the required technological and scale improvements required for oil sand production to meet demand.

In the future, oil sand has the potential to represent a major petroleum source for the United States and the rest of North America. In 2000, Canada surpassed Saudi Arabia as the largest source of petroleum products for the U.S. Oil imports from Canada are not exclusively oil sand; the percentage of Canadian oil exports that derive from oil sand is rapidly increasing. The United States expects to receive 75% of the oil produced from the oil sand deposits in Canada. In the near future, oil sand is projected to supply 10% of North American oil production. Within 5 years more oil will flow from the Alberta oil sand deposits than from the North Slope of Alaska.

The growth of oil sand depends on its ability to develop new technologies as needed to keep up with supply and to address rising environmental concerns. The major producers in the industry have taken steps to ensure that the future of oil sand as a petroleum source is secure. Syncrude has invested in the largest pit-mining machinery in the world to increase production. Oil sand production development has also been focused on mining the oil sand that is not able to be pit mined. In-situ methods have been developed to mine oil sand far below the surface. In-situ mining injects steam into oil sand using large vertical shafts and the Bitumen is extracted directly from the sand. The steam condenses to form an emulsion with the Bitumen that can be pumped from the ground using wells. Mining sites using this technology are currently under development in Alberta.

15 “Future” Athabasca Oil Sands.
“The oil sands industry is an economic ‘gold mine’ for Alberta, Canada and the world alike.”\textsuperscript{16} The Canadian Government and other major oil sand technology investors recognize the potential of oil sand on the global petroleum market. The steps needed to secure oil sand production growth into the next 30 years are being undertaken in a very aggressive manner.

2.3 Environmental Implications

Petroleum product production has a negative effect on the environment. The mining of oil sand possesses many of the negative environmental impacts found with other petroleum or element extraction processes. The three major areas of environmental concern are air quality, water management, and land reclamation.\textsuperscript{17} Each of these areas presents a potential risk to the environment that if not controlled or eliminated could politically and environmentally limit the growth of oil sand production.

Refining of oil sand presents a potential risk of air quality degradation through the emission of sulphur dioxide, carbon dioxide, nitrogen oxides and water vapor. The gas emissions of oil sand production have the potential to change not only the local but also the global climate because they are greenhouse gases. Carbon dioxide presents the most significant threat. Due to improved technology, the toxic emissions per barrel of oil have significantly decreased and are projected to continue to do so. Oil sand production has increased in volume in recent years. Oil sand production is expected to grow at very high rates in the future. Oil sand production is increasing at a higher percentage rate than carbon dioxide emissions per barrel is decreasing. The net effect is that carbon dioxide emissions from oil sand production have been increasing and current projections expect the amount of carbon dioxide released into the atmosphere from oil sand production to increase. Figure 2.1 shows the decrease in carbon dioxide emissions per barrel and the increase in net carbon dioxide emissions.

\textsuperscript{16} “Future” Athabasca Oil Sands.
\textsuperscript{17} “Environment.” Athabasca Oil Sands.
CO2 Emissions for Syncrude

![Graph showing CO2 emissions from the Syncrude mine in Alberta, Canada.](image)

Figure 2.1 – CO2 emissions from the Syncrude mine in Alberta, Canada. Left scale shows tones per barrel. Right scale shows tones per year.¹⁸

Water is an essential part of the oil sand production process. Water used to process oil sand is taken from the Athabasca River. The water used in oil sand production is never returned to the environment. The Aurora Syncrude mine uses 13,300 cubic meters of water per hour. The water used in processing oil sand comes from within the plant and from the Athabasca River. The plant recycles 70% of the water needed, but 4,000 cubic meters per hour must be drawn from the river. The amount of water drawn by the plant is significantly less than the guidelines set by the Canadian environmental agencies, but the effect of drawing water from the river is an important environmental concern. The pit mining of oil sand can interfere with the natural flow of rivers. This is a situation that must be addressed on an individual case basis. There is a potential for the mining of oil sand to disrupt the natural flow of water.

Land reclamation is a major concern with any pit mining operation. When the pit mining of an area is completed the land is stripped of all nutrients. Oil sand mining firms claim to be committed to returning the land to its original condition reversing any ecosystem damage. Pit mining has major economic costs and despite the reclamation, not all damage to the environment can be reversed. Some reclaimed land is well restored. A former Syncrude mine is now home to a herd of Bison and Crane Lake, a former Suncor

¹⁸ “Energy Efficiency and CO2.” Syncrude.
mine, has 129 different species of birds that now inhabit the area. Not all of the oil sand sites have been reclaimed. As oil sand mining progresses, it will be important that the land is restored. An oil sand pit mine after excavation is shown on the left side of figure 2.2. The right side of the figure shows the same site after it has been reclaimed.

Figure 2.2 – The image on the left is a pit-mine after excavation. The image on the right is the same pit mine after it has been reclaimed.¹⁹

The energy cost of land reclamation is assumed to be equal to the energy required to mine the oil sand. The energy required to mine the oil sand, discussed in section 4.1, is insignificant compared to the energy extracted from the oil sand. From an economic and energy cost perspective, the cost of reclamation is determined not to be a deterrent to oil sand production.

The major firms and the Canadian Government established stringent conditions for each area of environmental concern. Canada signed the Kyoto Treaty relating to the emission of greenhouse gases. This accord will force the oil sand production process to become environmentally friendly or to decrease capacity. Self-implementation of environmental regulations has proven effective, but the government also closely monitors actions related to environmental issues. In the past, the environmental impact of oil sand mining has not posed a major barrier to expansion. Improved technology will be essential to preventing the environmental impact from limiting oil sand production in the future.

2.4 Financial Expense

Oil sand production has greatly reduced operational costs in the recent past making production highly profitable. The production of oil sand is efficient from an

¹⁹ "Environment.” Syncrude.
economic basis. Operational cost have decreased due to increased production, more experience and improvements in technology. Oil sand production has greatly increased in recent years allowing production firms to take advantage of economies of scale to reduce cost per unit. Mining oil sand for oil began only 40 years ago and the exponential learning curve is starting to make an effect on the efficiency with which oil sand can be turned into crude oil. The most significant effect on the decrease in operational costs is the implementation of new technology. The major technology improved to production is Hydro-transport extraction methods. By extracting the Bitumen from oil sand at a lower temperature while transporting it to the upgrading plant the energy, and therefore financial, costs have been significantly decreased.

For oil sand production to be economically feasible the operational cost to produce oil sand must be comparable to the operational cost of conventional crude oil. Synthetic light crude oil and conventional light crude oil sell at the same price. If oil sand production does not have comparable operational costs it will have lower profit margins than conventional oil production making it unattractive to produce synthetic light crude oil. The refiner acquisition cost and average operational cost per barrel to produce synthetic light crude oil are shown in figure 2.3. Refiner acquisition cost is the price that refineries are willing to pay for synthetic light crude oil.

![Operating Expense and Product Cost for Oil Sand](image)

**Figure 2.3** – Refiner acquisition price versus operational cost per barrel to produce synthetic light crude oil from oil sand.

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Refriner acquisition cost is very volatile and dependent on numerous political and economic factors. Oil sand producers therefore must focus on cost reduction to increase profit margins. The average cost per barrel has had a significant decrease in the past few years and with implementation of current technology it is expected to continue a rapid decrease. The cost per barrel is an average for all oil sand production. The majority of current production uses old technology that causes the cost to increase significantly. The phasing out of existing production methods will cause cost decreases. Suncor has operational costs of $9 a barrel and an average selling price of $30.20 Suncor has a goal to reduce operational costs to $5.50 per barrel in the near future, making it the lowest-cost oil producer in North America.

20 "Suncor Annual Report 2001."
3.0 Oil Sand Production

Oil sand can be produced into synthetic light crude oil using various technologies, but all of the different processes can be divided into the same four major phases. The first phase is the mining of the raw oil sand by removing it from the ground using pit-mining technology. Once the oil sand is removed from the ground the Bitumen must be separated from the other materials in oil sand so that petroleum product production can begin. After the sand and other by-products are removed from the oil sand, the Bitumen can be upgraded in the third stage of oil sand production. Upgrading is the process of turning the heavy, tar-like Bitumen into usable light crude oil. The light crude oil is then sent through the fourth and final stage. The final stage is the refining of light crude oil into an array of petroleum products. Oil sand in the various stages of the production process is shown in figure 3.1. The image on the right is raw oil sand before extraction. Bitumen is the heavy tar-like substance shown in the center image. Synthetic light crude oil produced from oil sand is shown it the figure on the right. The synthetic light crude oil is so refined that it is transparent.

![Figure 3.1 - The transition of oil sand (right) into Bitumen (center) and then finally into the finished product of synthetic light crude oil (left).](image)

In recent years, there has been implementation of significant technological improvements to the oil sand production process. The mines in Northern Alberta will be analyzed for this study because they are on the cutting edge of this new technology. The Aurora mine, operated by Syncrude, is one of the largest mines to utilize the new

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21 "Oil Sand: Why We're Here." Syncrude.
technology that will become the standard for oil sand production in the near future. The oil sand mines using the most current technology were used for this study because the purpose is to determine the energy efficiency of oil sand production in the future, not the current global efficiency.

The stages of oil sand production are separated by purpose and geographic location. The mining stage occurs at the site where the oil sand is located. Extraction begins at the mining site and finishes at the upgrading plant. Upgrading takes place at the upgrading plant typically located a short distance from the mining site. Many mining sites will feed into one centrally located upgrading facility. The Aurora mine used for this study is located 35km from its upgrading plant. The final stage of oil sand production, refining, takes place at a refining plant. Upgrading plants are not typically located near refineries and transportation of crude oil via pipeline is necessary.

3.1 Mining

Oil sand is mined from the ground using existing pit-mining techniques on a very large scale. Only the oil sand that can be pit mined is used for petroleum product production because of the large expense associated with mining oil sand from the deep below the earth’s surface. Oil sand with over 75 meters of overburden is considered unable to be pit mined. In Alberta, only 7% of the oil sand deposits can be pit-mined. Before the mining of oil sand can begin it must be exposed to the surface of the earth. The overburden, muskeg and water soaked soil covering the oil sand deposits is removed. Oil sand is then mined using electrical dragline shovels and large dump trucks. The dragline shovels dig 56 cubic yards with each scoop using 360ft booms. The trucks used to transport the oil sand are typically 240ton to 380ton mechanical or electric drive Caterpillar trucks with an average power output of 3,000hp. Figure 3.2 illustrates the size and interaction of a dragline and two 360ton trucks at the mining site.

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22 “Aurora Project.” Syncrude.
23 “Mining.” Athabasca Oil Sands.
25 “Expanding to Aurora.” Syncrude.
Figure 3.2 – Dragline mining oil sand and dumping it into two 360ton dump trucks at the Aurora Mine. For scale, the truck tires are 4m high.\textsuperscript{26}

The trucks deposit the oil sand into large crushers located on the mining site. The crushers operate using large rollers to break the oil sand down from a more solid form into loose sand that can be transported easily. The crushers operate at a peak rate of 11,000 tones per hour.\textsuperscript{27} Before transporting the oil sand from the mining site it is send through sizing machines that sift the sand using large screens to remove and large pieces of material or rocks that could cause damage down the process line.\textsuperscript{28} Once the oil sand has been removed from the earth and broken down into loose sand it is ready for extraction of Bitumen.

3.2 Extraction

Extraction of Bitumen from oil sand began in 1920 when an Alberta Scientist placed oil sand into a home washing machine to mix it with hot water, causing the bitumen to float to the surface.\textsuperscript{29} Today, oil sand extraction begins at the mining location with a process called Hydro-transport.\textsuperscript{30} Hydro-transport extraction begins by mixing the broken down oil sand with hot water to create slurry. The oil sand is mixed into hot water at 35°C in mixing boxes that resemble large pots.\textsuperscript{31} The oil sand and hot water slurry can then be easily pumped via pipeline to the primary separation vessel and upgrading facility. While the oil sand is being pumped to the upgrading facility the hot...

\textsuperscript{26} "Mining." Syncrude.
\textsuperscript{27} "Expanding to Aurora." Syncrude.
\textsuperscript{28} "Hydrotransport." Syncrude.
\textsuperscript{29} "Canada is Unlocking Petroleum from Sand." New York Times.
\textsuperscript{30} "Hydrotransport." Syncrude.
\textsuperscript{31} "Expanding to Aurora." Syncrude.
water is breaking the sand and other deposits away from the Bitumen. This begins the extraction process. An illustration of the oil sand entering the mixing box is shown in figure 3.3.

![Image of oil sand entering mixing box](image.jpg)

Figure 3.3 – Oil sand dumped into the mixing box filled with hot water.\(^{32}\)

Before the hydro-transport technology was implemented the oil sand was taken to the upgrading facility via long conveyor belts. Once the oil sand arrived at the upgrading facility, the bitumen had to be extracted from the oil sand. This process was both problematic and energy intensive. When hydro-transport began it operated using water at 85° C consuming 40% more energy than the current process.\(^{33}\) Despite the high temperature, original hydro-transport methods were an efficiency improvement over conveyor belts because it removes the Bitumen from the oil sand while transporting it. The energy required to pump the slurry is minimal because, the viscous properties of the oil sand slurry is assumed to be very close to that of water due to the high concentration of water compared to oil sand.\(^{34}\) The removal of conveyor belts and reduction of slurry operating temperature have served to greatly reduce the overall energy requirements of oil sand production.

Once the slurry has reached the upgrading plant, the Bitumen must be separated from the water and sand. Primary separation of the slurry contents occurs in a heating pot or primary separation vessel where the contents separate into layers. The Bitumen rises to the top and is removed from the heating pot. The froth of Bitumen removed from

\(^{32}\)“Image Library.” Syncrude.

\(^{33}\)“Expanding to Aurora.” Syncrude.

\(^{34}\)“Hydrotransport.” Syncrude.
the heating pot is then treated with Naphtha. Naphtha is used in the treatment of petroleum and other chemicals; it is a mixture of volatile and flammable hydrocarbons distilled from petroleum, tar and natural gas.\textsuperscript{35} The froth of diluted Bitumen is then put through a centrifuge or plate settler to remove the Naphtha, solids and water tailings. The hydro-transport line with oil sand and water entering the primary separation vessel is shown in figure 3.4.

![Image](image-url)

Figure 3.4 – Hydro-transport line and primary separation vessel (on right) at Aurora Mine in Alberta, Canada. \textsuperscript{36}

The by products of this process are Bitumen, sand, Naphtha, and water. The sand and water tailings are placed in lakes to separate; water is eventually reused in the extraction process. The Naphtha is reused in the process as soon as it is removed. The Bitumen contains only a small amount of diluents and is sent to be upgraded into usable crude oil. The chemical composition of Bitumen is 83.2% Carbon, 10.4% Hydrogen, 4.8% sulphur, 0.94% Oxygen and 0.36% Nitrogen.\textsuperscript{37} The breakdown of Bitumen into its elements is shown in figure 3.5.

\textsuperscript{35} Dictionary.com.
\textsuperscript{36} “Image Library.” Syncrude.
\textsuperscript{37} “Frequently Asked Questions.” Athabasca Oil Sands.
3.3 Upgrading

The Bitumen removed from the oil sand cannot be turned directly into petroleum products. Bitumen is a heavy tar like oil that will not even flow without being heated. It must first be cracked into synthetic light crude oil that is similar to light crude oil received from any other petroleum source.

Diluted Bitumen is placed into a distillation recovery unit where it is heated and separates into Naphtha, light gas oil and Atmospheric Topped Bitumen. The Naphtha is recycled back into the process. The Bitumen is then sent into a vacuum distillation unit where the process is repeated and more light gas oils are distilled off. The Bitumen remaining after the remaining light gas oils have been removed is sent to the LC-Finer. In the LC-Finer the Bitumen is reacted with Hydrogen to produce light gas oil. The Bitumen that is not turned into light gas oil in the LC-Finer is sent to the cokers for further processing.38

The Bitumen is placed into a coker where it is split into fractions. The coker heats the Bitumen to high temperatures to thermally crack the long chain molecules. The remaining diluents, Sulfur, Nitrogen and Naphtha are distilled off in hydrotreaters. The

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38 "Upgrading." Syncrude.
hydrotreaters cause the oil to react with Hydrogen at high temperatures and pressures. Light gas oil is distilled off while Bitumen is heated and removed.\footnote{Upgrading.” Syncrude.}

Once the upgrading process is completed, all of the Bitumen from the extraction process is turned into synthetic light crude oil. The synthetic light crude oil is 31° to 33° API gravity crude oil with 0.1 to 0.2 percent sulphur.\footnote{“Upgrading.” Syncrude.} API gravity is a measure of crude oil quality.\footnote{“Upgrading.” Syncrude.} Crude oil from oil sand has a low percentage of sulphur. This is a refining benefit over crude oil from other petroleum sources that have 8 percent sulphur residue.\footnote{“Upgrading.” Syncrude.} Crude oil made from Bitumen is of equal or greater quality to crude oil from other petroleum sources.

\subsection{3.4 Refining}

Synthetic light crude oil is then sent via pipeline to refineries in Edmonton, Canada and the Mid-Western United States where it is treated along with crude oil from other petroleum sources.\footnote{“Canada Country Analysis Brief.”} Figure 3.6 shows the Canadian pipeline network that ships crude oil from oil sand to refineries.\footnote{“Canadian Oil Pipelines and Refining Capacity.”}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{map.png}
\caption{Map of Canadian pipelines. Pipelines originating in Alberta (AB) may carry oil from oil sand.\footnote{“Canada.” United States Energy Information Administration.}}
\end{figure}
The crude oil is refined into gasoline, jet fuel, diesel fuel, clothing, paints, home heating oil, compact discs, adhesives, and plywood. Synthetic crude light crude oil has the same refining requirements as light crude oil of comparable quality from any petroleum source.

46 "Our Product: Syncrude Sweet Blend." Syncrude.
4.0 Oil Sand Production Energy Requirements

In order to produce petroleum products from oil sand a large amount of energy must be expended in the process as work. The energy requirements for oil sand production can be broken down into four major categories, or steps in the process. The first three categories are the same as described in the oil sand production process: mining, extraction and upgrading. The forth category of energy consumption is the transportation of the finished crude oil. The sum of these three categories will result in the energy cost to produce a barrel of light crude oil from oil sand as show in equation 1. All calculations for energy requirements will be denoted in MJ of energy used per barrel of synthetic light crude oil, the final product.

\[
\frac{E_{\text{Cost}}}{\text{Barrel OilSand}} = \frac{E_{\text{Cost}}}{\text{Barrel OS\textsubscript{Mining}}} + \frac{E_{\text{Cost}}}{\text{Barrel OS\textsubscript{Extraction}}} + \frac{E_{\text{Cost}}}{\text{Barrel OS\textsubscript{Upgrading}}} + \frac{E_{\text{Cost}}}{\text{Barrel OS\textsubscript{Trans.}}} \tag{1}
\]

The refining process is not considered in the energy cost of producing petroleum products from oil sand. The oil sand production process energy accounting goes from the ground to the point where synthetic light crude oil enters the refinery. The refining of light crude oil produced from oil sand or other petroleum sources is the same assuming that the crude oil is of comparable quality. Oil Sand in refined at several refineries in both the United States and Canada. These refineries have different efficiencies and different end products, but they all have the same input: light crude oil. The large number of variables and products created by including the refining process will create error in the final answer, but not provide any additional insight.

4.1 Mining

The mining of oil sand is totally dependent on energy input from outside sources. It is assumed that the energy input into a system to perform a function is equal to the energy required to perform that function. This is the principle used to calculate the energy requirements to mine a barrel of oil sand. The principle steps in the mining process use electrical energy. Electrical machines perform the digging of the oil sand, the crushing and sizing of the oil sand.\textsuperscript{47} The energy cost per barrel of crude oil from oil

\textsuperscript{47} "Mining." Syncrude.

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sand is assumed to be equal to the amount of energy used in utilities per day divided by the numbers of barrels produced per day. The result is multiplied by the efficiency of energy use as shown in equation 2.

\[
\text{E.Cost OilSand}_{mine} = \left( \frac{\text{Utilities Used}}{\text{Barrels/Day}} \right) \left( \frac{\text{Efficiency}_{EnergyUse}}{\text{Day}} \right)
\]

The energy input to the Syncrude Aurora mine was used to calculate the energy required to mine a barrel of crude oil from oil sand. Due to the remote location of the mine it is supported by its own 80MW electrical power plant. The energy use efficiency is assumed to be 56%. The electrical power is generated using steam generators retrofitted with duct burners. The steam generator efficiency is 40%; the duct burners operate on the back of the steam generator cycle with an efficiency of 40%. The duct burners increase the efficiency of the system from the standard steam generator efficiency of 40% to 56%.\(^\text{48}\)

The only machinery used in the mining of oil sand that does not run off of the power plant electrical supply is the diesel dump trucks. To account for the energy requirements of the trucks the amount of electrical utilities used per day is increased by 25%. This assumption is valid because many of the trucks are electric and the trucks that are mechanical only produce 3000hp burning diesel fuel. The energy requirements of the trucks are small compared to the energy requirements of the dragline and other electrical machinery. The energy drains on the power plant not associated with the production of oil sand is assumed to be negligible.

The electrical energy required to mine oil sand is 74.3MJ per barrel of light crude oil produced. This value is based on the Aurora mine producing 145,205 barrels per day and using 80MW of power with 56% efficiency. The energy allowance for dump trucks is 25% of the electrical energy or 18.6MJ. The total energy requirement to mine oil sand is 92.8MJ. The values and calculation are shown in table 4.1.

\(^{48}\) "Issue Identification Report: Island Empire Energy Center."

Glanfield, 24
<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrels of crude mined/day</td>
<td>145,205</td>
<td>Output for Syncrude Aurora Mine</td>
</tr>
<tr>
<td>Electricity resources used/day</td>
<td>6,912,000 MJ</td>
<td>Based on 80MW power supply to Aurora Mine</td>
</tr>
<tr>
<td>Efficiency of energy use</td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td><strong>Electrical Energy required to mine</strong></td>
<td>74.3 MJ</td>
<td></td>
</tr>
<tr>
<td>Allowance for Diesel Trucks</td>
<td>18.6 MJ</td>
<td>25% of Electrical Energy</td>
</tr>
<tr>
<td><strong>Total Energy required to mine</strong></td>
<td>92.8 MJ</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1 – Energy required to mine oil sand at Syncrude Aurora Mine in Alberta.

4.2 Extraction

The energy required to extract Bitumen from oil sand through hydrotransportation can be broken down into four major categories. Electrical energy input to create slurry from Bitumen and water in the mixing box. Energy required to pump the slurry along the pipeline. Energy required to maintain the slurry temperature in the heating pot during separation. Steam energy input to heat the water and Bitumen slurry to 35°C.

The electrical energy input required for extraction that goes into the mixing box at the mining site is taken into consideration with the estimate of energy required to mine. Energy used to pump the slurry is also taken into account with the energy input estimate for the mining. The extraction electrical energy comes from the 80MW plant used to power the mining activities. The energy required to heat the Bitumen in the heating pot is minimal and assume close to zero because the slurry enters the heating pot at its peak temperature and a slight temperature decrease is acceptable.

For calculation purposes, the steam energy required to heat the slurry is the only extraction energy required to produce a barrel of crude oil from oil sand. Employing simple thermodynamics the energy required to heat the slurry can be found. The energy required to heat a substance is equal to the product of mass, specific heat, and temperature change as shown in equation 3.49

\[
\text{Energy} = \text{mass} \times C \times \Delta T
\]  

49 Cravalho, Smith, Brisson, McKinley.
The hydro-transport extraction process at the Syncrude Aurora plant processes 174,179,472 kg/day of slurry.\textsuperscript{50} The specific heat of the water is assumed to be equal to the specific heat of water because the slurry consists predominantly of water. The value for specific heat of water is 4.181 KJ/KGK.\textsuperscript{51} The slurry is heated from an average ambient temperature of 15° C to 35° C. The heating energy requirement for extraction is 100MJ per barrel of finished light crude oil. The efficiency of the heating system is assumed to be similar to the efficiency of comparable steam generation systems.\textsuperscript{52} The resulting energy required to extract is 133.7MJ per barrel. The calculations for extraction energy requirements are shown in table 4.2.

<table>
<thead>
<tr>
<th>Energy Required for Extraction</th>
<th>Value</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrels of crude mined/day</td>
<td>145,205</td>
<td></td>
<td>Output for Syncrude Aurora Mine</td>
</tr>
<tr>
<td>Slurry flow rate</td>
<td>174,179,472</td>
<td>kg/day</td>
<td>Flow rate for Syncrude Aurora Mine</td>
</tr>
<tr>
<td>Total Steam Energy per kg</td>
<td>0.0836</td>
<td>MJ</td>
<td>Q=mc(T2-T1); m=1kg (see text)</td>
</tr>
<tr>
<td>Steam Energy per day</td>
<td>14,564,887.4</td>
<td>MJ</td>
<td>Equation 3</td>
</tr>
<tr>
<td>Energy required to heat</td>
<td>100.3</td>
<td>MJ</td>
<td></td>
</tr>
<tr>
<td>Electrical Energy</td>
<td>-</td>
<td>MJ</td>
<td>Taken into consideration with mining energy estimate</td>
</tr>
<tr>
<td>Efficiency of steam generator</td>
<td>75%</td>
<td></td>
<td>“Steam Efficiency Guide for Energy Managers”</td>
</tr>
<tr>
<td>Energy required to extract</td>
<td>133.7</td>
<td>MJ</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2 – Calculations for extraction energy requirements for Syncrude Aurora Mine in Alberta, Canada.

4.3 Upgrading

Upgrading Bitumen to light crude oil is similar to cracking heavy oil from a different petroleum source. The process of cracking a barrel of heavy oil reduces the density of the oil by breaking the long chain molecules that make up heavy oil. The oil is heated and mixed with other chemicals to thermally crack the bonds in the molecules changing the composition of the heavy oil to a less dense liquid. The heavy crude oil is turned into light crude oil that can then be refined into petroleum products. The process of upgrading a barrel of Bitumen to light crude oil, described in section 3.3, goes through a process similar to cracking heavy oil.

\textsuperscript{50} “Aurora Mine Opening Photos” Syncrude.
\textsuperscript{51} Incropera and DeWitt.
\textsuperscript{52} “Steam Efficiency Guide for Energy Managers.”
The basis of comparison for relating the refining of heavy crude oil to the upgrading of bitumen is the change in API gravity. API gravity rates crude oil based on density into three categories: light, medium and heavy.\(^{53}\) API gravity is an arbitrary scale developed by the American Petroleum Institute that expresses the density of the oil. The less the specific gravity of the oil the higher API gravity; Bitumen and heavy oil would have a low API gravity and light crude oil would have a high API gravity. API gravity is calculated from specific gravity as shown in equation 4.\(^{54}\)

\[
\text{API Gravity} = \left( \frac{141.5}{\text{Specific gravity at 60}^\circ \text{ F}} \right) - 131.5
\]

Bitumen from the Alberta oil sand has API gravity of 8\(^{\circ}\) and is upgraded to light crude oil with API gravity greater than 24\(^{\circ}\).\(^{55}\) Synthetic light crude oil from the Aurora mine has an API gravity of 33\(^{\circ}\).\(^{56}\) Heavy oil is refined from API gravity 0\(^{\circ}\) to 20\(^{\circ}\) to light crude oil with API gravity greater than 24\(^{\circ}\).\(^{57}\) The assumed API gravity and calculation for change in API gravity is shown in table 4.3.

<table>
<thead>
<tr>
<th>API Gravity</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>8(^{\circ}) [<a href="http://www.syncrude.com/who_we_are/01_06.html">http://www.syncrude.com/who_we_are/01_06.html</a>]</td>
</tr>
<tr>
<td>Upgraded Bitumen</td>
<td>33(^{\circ}) [<a href="http://www.eia.doe.gov/oiaf/archive/aeo01/assumption/tb71.html">http://www.eia.doe.gov/oiaf/archive/aeo01/assumption/tb71.html</a>]</td>
</tr>
<tr>
<td>Oil Sand Change</td>
<td>25(^{\circ})</td>
</tr>
<tr>
<td>Heavy Oil</td>
<td>11(^{\circ}) [<a href="http://www.pcf.ab.ca/quick_answers/crude_oil/whatis.asp">http://www.pcf.ab.ca/quick_answers/crude_oil/whatis.asp</a>][<a href="http://www.eia.doe.gov/emeu/cabs/canafull.html">http://www.eia.doe.gov/emeu/cabs/canafull.html</a>]</td>
</tr>
<tr>
<td>Refined Heavy Oil</td>
<td>33(^{\circ}) [<a href="http://www.gasandoil.com/goc/news/ntl15181.htm">http://www.gasandoil.com/goc/news/ntl15181.htm</a>]</td>
</tr>
<tr>
<td>Heavy Oil Change</td>
<td>22(^{\circ})</td>
</tr>
</tbody>
</table>

Table 4.3 – API gravity assumptions for Bitumen, Bitumen upgraded to light crude oil, heavy oil and heavy oil refined to light crude oil.

Using the ratio of change in API gravity of oil sand to the change in API gravity of heavy oil the energy cost to upgrade oil sand is related to the energy cost to refine heavy oil as shown in equation 5.

\(^{53}\) “Introduction to Oil.” Government of Alberta.
\(^{54}\) “Minertrading.com.”
\(^{56}\) “Upgrading.” Syncrude.
\(^{57}\) “Venezuela's Heavy Crude May Cause Problems in OPEC Compliance.” & “Energy Information Administration.”

Glanfield, 27
The assumption supporting this argument is that the relationship between API gravity change and the energy cost to crack oil is close to one when the ratio of API gravity change for oil sand and heavy oil is close to one. This assumption is valid because the process of cracking oil revolves around heating it to a temperature where the bonds can be thermally cracked. The denser the oil the higher the temperature must be and a higher temperature relates directly to a higher energy cost.

The difference in API gravity change for heavy oil and oil sand is only 6.4% of the crude oil API gravity scale. The starting API gravity of oil sand is only 3° heavier than the starting API gravity of heavy oil on the 47° crude oil API gravity scale. The final API gravity is for light crude oil is the same for both oil sand and heavy oil so that the product produced from each source can be compared.

The energy required to crack a barrel of heavy oil is 865.1 MJ. Using the API gravities from table 4.3 results in 983MJ per barrel required to upgrade Bitumen to light crude oil. The energy required to crack a barrel of heavy oil is discussed in section 6.

Table 4.4 calculates energy required to upgrade Bitumen to synthetic light crude oil.

| API gravity change of Bitumen  | 25  | Deg | See table 4.3 |
| API gravity change of heavy oil | 33  | Deg | See table 4.3 |
| Energy required to crack one barrel of heavy oil | 865.1 | MJ | MIT Lab for Energy and the Environment - On the Road to 2020 |
| **Energy required to upgrade** | **983.0** | **MJ** |

Table 4.4 – Calculation of the energy required to upgrade Bitumen to light crude oil.

4.4 Transportation

The energy required to transport the crude oil from the Alberta oil sand field was estimated to be half of the energy required to transport petroleum from its source to the refinery. The crude oil from the Alberta oil sand fields is shipped via pipeline to

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refineries in the US and Canada as shown in figure 3.4. The close geographic location of oil sand relative to other petroleum sources will cause it to be less energy intensive to ship. Oil is often in very remote locations and has to be shipped via pipeline and tanker. From the case studies discussed in section 5, the North Slope of Alaska and the Northern Gulf of Mexico both require shipment via tanker and either pipeline or truck resulting in high transportation costs.

The energy required to transport oil from other petroleum sources is 66MJ per barrel as discussed in section 5.\textsuperscript{59} The energy required to transport oil from oil and is half of that value or 33MJ per barrel.

4.5 Results

Production of light synthetic crude oil from oil sand takes place in four phases. The first phase is mining where electrical and mechanical energy is the input. The second phase is extraction using electrical and steam energy. Upgrading takes the Bitumen and converts it into light crude oil by reducing the density or API gravity of the oil. The final stage in delivery of light crude oil is the transportation to the refinery via pipeline. The energy required for each of these stages in the oil sand production process is summarized in table 4.5.

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Required/barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>92.8 MJ</td>
</tr>
<tr>
<td>Hydro-transport</td>
<td>133.7 MJ</td>
</tr>
<tr>
<td>Refining</td>
<td>983.0 MJ</td>
</tr>
<tr>
<td>Transportation</td>
<td>33.1 MJ</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,243 MJ</strong></td>
</tr>
</tbody>
</table>

Table 4.5 – Summary of energy requirement for each step in the oil sand production process.

The total energy required for the oil sand production process is 1,243MJ per barrel. This value is obtained by summing energy requirements for each phase as shown in equation 1 reproduced below.

\[
\text{E.Cost}_{\text{OilSand}} = \frac{\text{E.Cost}}{\text{Barrel}} \times \text{OS}_{\text{Mining}} + \frac{\text{E.Cost}}{\text{Barrel}} \times \text{OS}_{\text{Extraction}} + \frac{\text{E.Cost}}{\text{Barrel}} \times \text{OS}_{\text{Upgrading}} + \frac{\text{E.Cost}}{\text{Barrel}} \times \text{OS}_{\text{Trans}} \quad (1)
\]

\textsuperscript{58} Malcolm Weiss, John Heywood, Elisabeth Drake, Andreas Shafer and Felix AuYeung.
\textsuperscript{59} Malcolm Weiss, John Heywood, Elisabeth Drake, Andreas Shafer and Felix AuYeung.
5.0 Petroleum Production

The majority of petroleum products are produced from crude oil pumped directly from the ground. Conventional crude oil pumped from the ground is the primary competition for synthetic crude oil produced from oil sand. The methods and energy requirements to produce crude oil from oil sand must be compared to the methods and energy requirements of producing crude oil via drilling. Oil sand production is compared to three major petroleum sources in North America to establish the usefulness of oil sand as a petroleum source. The three sites are Prudhoe Bay in Alaska, the Permian Basin in West Texas and the Northern Gulf of Mexico. These sites were chosen because they represent a spread of the various production methods. The crude oil produced at each site is of varying quality, but all can be compared to synthetic crude oil produced from oil sand. All of the drilling and oil sand sites are in Northern America; this makes it possible to disregard political issues and facilitates assumptions regarding transportation cost.

There are three major stages in the production of crude oil. The first stage is drilling the well; this requires several steps. The required depth of a well varies depending on the geographic location. To begin drilling a well a rig must first be constructed. If the desired location is over water an offshore oilrig must be constructed resulting in major financial costs. The oilrig then drills the hole and the machinery and casings necessary to pump the oil are installed. A cut-view of the installed machinery for a rod pumping well is shown in figure 5.1. Depending on the geography of the location, a number of directional wells can be drilled from one oilrig. The technology and applications of oil well drilling technology is vast, but for the purposes of energy accounting comparison only the basics of oil well drilling are considered. Once the well is completed the oil must be pumped from the ground using either electrical or steam power. Figure 5.1 shows a rod pump. After being extracted from the ground the oil must be shipped to refineries via tanker, pipeline or truck. The transportation cost for remote drilling sites can be significant.

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60 "Upstream Regional Overview: North America."
61 "Picture an Oil Well." California Conservation.
Prudhoe Bay operates both offshore and onshore oilrigs. In 2000, the oil production was 334M barrels. Up to 30 wells are drilled from each platform to an average depth of 10,500ft. Gas lift valves are also typically installed in Prudhoe Bay wells to allow for further oil excavation in the future. The crude is then pumped from the source and if it is on an offshore rig it is pumped onto land via pipeline. Oil from Prudhoe Bay is collected and transported via the trans-Alaskan pipeline to Valdez. Once the oil reaches Valdez, the majority of it is taken via tanker to refineries in the Western United States, Japan and other destinations.

The requirements to produce crude oil from the Permian Basin in West Texas are different than in other areas. The geography of the landscape dictates the need for varied extraction methods. Shallow development wells are common in oil exploration in the San Andres Dolomite. Each oilrig in West Texas can drill on a 20-acre spacing. The average well is drilled to 5,000ft before being fitted with the proper collars and machinery for extraction. A sucker-rod pump, similar to the one in figure 5.1, is used to pump crude oil from the ground. Sucker-rod pumps extract oil at a rate of 20 to 40 bbl/day (3 to 6 m³/day). Once removed from the ground, the crude oil is sent to holding tanks where it can be stored until it is shipped to a refinery via pipeline or truck. West

---

62 "Picture an Oil Well." California Conservation.
63 "Pipeline Facts." Alaska Pipeline Service Company.
64 Donohue, 74.
Texas intermediate crude is comparable to Syncrude Sweet Blend produced from oil sand.\textsuperscript{66}

The Northern Gulf of Mexico is host to a large amount of petroleum that must be drilled from offshore oilrigs. Large offshore oilrigs employ directional drilling to use multiple lines from one rig. The cost of installing an offshore oilrig is significant. It is very energy intensive to construct and install the large platforms required to drill and pump the oil found beneath the ocean floor. The oil is pumped from the ground to large holding tanks aboard the oilrig. The oil must then be pumped to a tanker for transportation to the refinery.\textsuperscript{67}

\textsuperscript{66} Donohue, 72.
\textsuperscript{66} "Upstream Regional Overview: North America."
\textsuperscript{67} Donohue, 4.
6.0 Petroleum Production Energy Requirements

The energy required to produce petroleum products from crude oil found in the ground is the sum of the energy required to mine, extract and refine the oil. In 2020, it is estimated that the energy required to get crude oil will be 4% of the amount of energy that is in the finished product. The value of 4% is a global average. Oil sand is only compared to oil wells in North America so this estimate is increased to 6%. North American oil mining is more energy intensive than mining in the Middle East and other major petroleum producing areas. The basis for the assumption is not to that the per barrel energy cost is 50% higher, but rather that the global average of the energy cost is a weighted average and the United States is not a major petroleum producing country. While the relative increase in energy cost per barrel may be small, the areas with lowest energy cost carry a much larger weight in the average skewing it to the low side. Refining is estimated to cost 16% of the energy in the finished product. Transportation costs are expected to be 1.2%. The result is that the energy required to get oil from the ground to the pump is 23.2% of the energy contained in that oil.\(^6\) The results of the calculations made under these assumptions are shown in table 6.1.

<table>
<thead>
<tr>
<th></th>
<th>Energy Req/barrel</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>331   MJ</td>
<td>6% of energy delivered</td>
</tr>
<tr>
<td>Refining</td>
<td>882   MJ</td>
<td>16% of energy delivered</td>
</tr>
<tr>
<td>Transportation</td>
<td>66    MJ</td>
<td>1.2% of energy delivered</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,278</strong> MJ</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.1 – Results of energy required to extract and refine oil.

The energy required per barrel of oil is a percentage of the energy delivered. For the purposes of calculation it is assumed that the only petroleum product produced is gasoline. Gasoline is a popular petroleum product and its stored energy is a median of other petroleum products. There is 5,510MJ of energy in each barrel of gasoline.\(^6\) This value results in a total energy requirement of 1,278MJ per barrel to produce petroleum products from crude oil. The energy required to mine crude oil is 331MJ per barrel. The energy required to refine crude oil to petroleum products is the largest energy requirement at 882 MJ per barrel. The energy cost to transport the crude oil is 66MJ per barrel.

\(^6\) Malcolm Weiss, John Heywood, Elisabeth Drake, Andreas Shafer and Felix AuYeung.

\(^6\) "Energy Information Administration Annual Review"
7.0 Energy Accounting Comparison

The energy required to produce petroleum products using oil sand is comparable to the amount of energy required when using other petroleum sources. To produce light crude oil from oil sand it cost 22.6% of the energy delivered by that product, but if other petroleum sources are used it requires 23.2% of the energy delivered. The conclusion made from this data is not that oil sand production is less energy intensive, but rather that the energy cost to produce petroleum products from oil sand is in the same range as energy cost to produce petroleum products from other sources. The energy requirements for each phase of petroleum product production are shown in table 7.1. Figure 7.1 shows the energy requirements for oil sand production versus petroleum production for each phase.

<table>
<thead>
<tr>
<th></th>
<th>Oil Sand</th>
<th>Petroleum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E/barrel(MJ)</td>
<td>% of Energy</td>
</tr>
<tr>
<td>Mining</td>
<td>93</td>
<td>1.7%</td>
</tr>
<tr>
<td>Extraction</td>
<td>134</td>
<td>2.4%</td>
</tr>
<tr>
<td>Refining/Upgrading</td>
<td>983</td>
<td>17.8%</td>
</tr>
<tr>
<td>Transportation</td>
<td>33</td>
<td>0.6%</td>
</tr>
<tr>
<td>Total</td>
<td>1,243</td>
<td>22.6%</td>
</tr>
</tbody>
</table>

Table 7.1 – Energy requirements for each phase of petroleum product production for crude oil from oil sand and other petroleum sources.

Energy Requirements for Stages of Oil Production

![Energy Requirements for Stages of Oil Production](image)

Figure 7.1 - Energy requirements for each phase of petroleum product production for crude oil from oil sand versus other petroleum sources.
Oil sand production has a lower mining and transportation energy requirement than conventional petroleum sources, but oil sand production has higher energy costs to refine and upgrade. The mining of oil sand requires 1.7% of the energy contained in the oil, but petroleum drilling required 6% of the energy contained in the oil. The oil mined from oil sand has the additional cost of 2.4% to extract the Bitumen from the sand. The energy required to mine and extract oil sand is still 1.9% less than the energy required to extract oil from other sources. The cost to upgrade Bitumen to synthetic crude oil is higher than the cost to refine heavier crude oils. It takes 11% more energy to upgrade Bitumen than to refine heavy crude oil; this translates into 1.8% of the energy in a barrel. Transportation costs for synthetic crude oil produced from oil sand is half of the energy cost to transport crude oil from other sources. The major difference in transportation cost is a function of the distance of the petroleum source. The breakdown of energy cost for oil sand and petroleum is shown in figure 7.2.

![Energy Requirement Breakdown for Oil Sand Production](image)

![Energy Requirement Breakdown for Petroleum Production](image)

Figure 7.2 – Production phase breakdown for the energy required to produce petroleum products from oil sand versus other petroleum sources.

The figures clearly illustrate two important conclusions from the comparison. For oil sand production refining is a significantly larger percentage of the total energy requirement than it is for petroleum production. Mining and extraction in oil sand production is less of the total energy cost than mining for petroleum production.
8.0 Conclusion

Oil sand was found to have comparable energy requirements for production into petroleum products as that for conventional crude. The implication of this finding validates the exploration and investment in oil sand as a major petroleum source in the future. The financial incentive to mine oil sand is positive and in the near future profit margins are expected to increase making oil sand one of the least expensive petroleum sources in North America. Environmental impacts of mining operations are a major concern. Oil sand mining presents a threat to the environment that must be controlled through the implementation of technology. Oil sand is a vast and unused petroleum source. Production of petroleum products from oil sand is a positive energy investment that should prove to have constantly increasing profit margins in the future.

The major political and economic advantages of oil sand petroleum products to the United States were not discussed in this study. The United States is currently heavily dependent on the Middle East for oil. With the increase in oil exports from Canada the United States could become significantly less dependent on the Middle East. In the current state of the world it is risky for the United States to be dependent on the Middle East. Canadian oil sand production has the potential to reduce the dependence of the United States on the Middle East to a manageable amount.

This report does not investigate the current average energy costs of oil sand production, but rather focuses on the expected future average energy cost of oil sand production. This is accomplished by examining the most current oil sand production technology. Future work should be done on the rapidly changing technology and scale of oil sand production. Oil sand production is a relatively young technology and in the near future the efficiency of production should increase. The increase in oil sand production and improved technology will cause the financial and energy costs of oil sand production to decrease making it an even more profitable investment.

The threat of oil sand mining on the environment must be considered in the future expansion of oil sand. Further work should be done into how oil sand production can be made more environmentally friendly. A failure to refine the oil sand production to protect the environment could limit its growth. The energy requirements and environmental impact of oil sand production could be refined through fieldwork.
Working at the site of production would provide a better estimate as to the energy efficiency of the process. Refining the energy cost of oil sand production would allow conclusions about the future of oil sand to be further validated or refined.
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