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Extraction of Energy Resources—Exploitation of the Canadian Oil Sands

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Abstract

Considerable reserves of oil sands are located in northern Alberta. Exploitation of these reserves has been instrumental in the development of the Alberta economy. Mining and processing techniques, including "*in situ*" processing and surface mining/aqueous treatment, are presented. Oil assisted flotation and solvent extraction are discussed as possible future processing alternatives. Subsequent froth treatment and refining methods are described. The rapid expansion of bitumen processing in the Fort McMurray area has drastically affected Alberta's economic, political and social policy. Corresponding strain has been placed on the regional ecosystem. A comparison between wind and bitumen as sources of energy is offered.

Keywords

Bitumen, Oil Sand, Solvent Extraction, Thermal Recovery, Wind Energy

1. Introduction

Alberta is the only province in Canada with no accumulated dept and triple A credit rating [1]. The major explanation is the exploitation of the world's largest reserve of bitumen in the Athabasca, Cold Lake and Peace River regions of Northern Alberta near the city of Fort McMurray (**Figure 1**). In total, the deposits underlie an area of approximately 141,000 square kilometers [2].

Bitumen is a dense, viscous, hydrocarbon liquid that can be used to supply petroleum refineries producing gasoline and diesel fuel. In the Athabasca region, there is a layer of clay and shale (sand) above the limestone floor. This layer of sand is saturated with bitumen. The mixture of sand and bitumen has been termed as "oil sand" [1].

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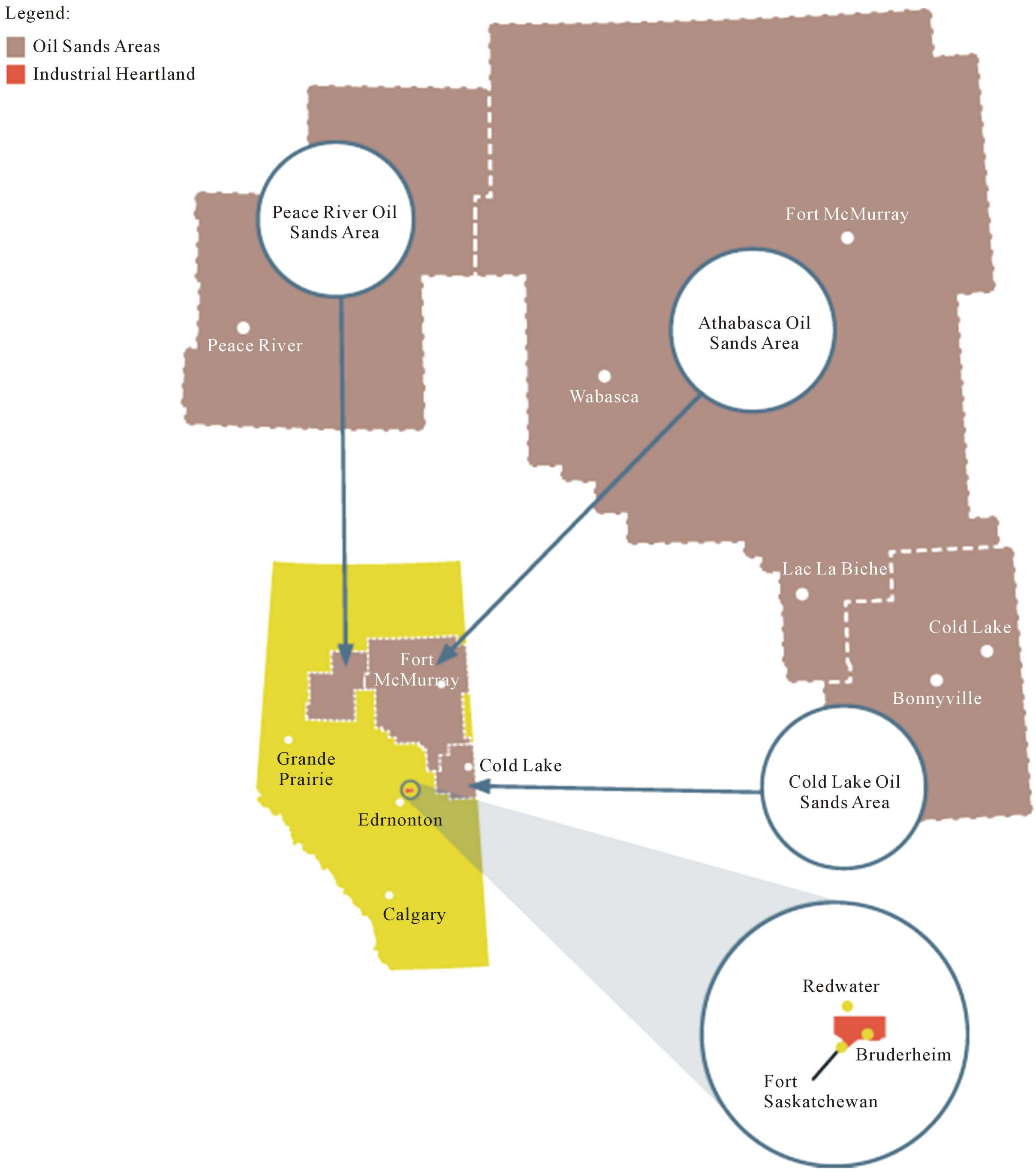

Figure 1. Map of Alberta, showing location of oil sand mining operations [1].

In total, there are 2.5 trillion barrels of proven oil reserves in northern Alberta. This quantity of proven reserves is greater than the oil reserves of Saudi Arabia. At the current rate of oil consumption in Canada, the Athabasca reserves could sustain Canada's oil needs for 400 years. It is predicted that the Alberta oil sand reserves will account for 60% of Canadian oil production by the year 2010 [1].

This article will describe mining and processing techniques specific to Canadian oil sand operations. The economics of oil sand exploitation will be outlined with emphasis on Canada's place in the world market. Subsequently, the environmental impact of oil sand exploitation will be presented leading to a comparison between reserves, energy potential and environmental impacts of oil sand exploitation and wind energy exploitation.

2. Oil Sand Exploitation

The Canadian Oil Sand mining operations can be divided into 2 different categories: "surface mining" and "*in situ*" processing. Surface mining operations remove the bitumen sand from the ground and transport the ore to a processing operation to separate bitumen and sand. *In situ* operations separate the bitumen from the sand without removing the sand from the ground [3].

The selection of mining method depends on the depth of the bitumen deposit, or more specifically the overburden ratio. Overburden is a term used to describe the thickness of non-valuable material above the target deposit. The overburden ratio is defined as the ratio between the thickness of the overburden and the thickness of the bitumen deposit (in **Figure 2**). When the overburden ratio is low (below 1) [3] meaning the deposit is close to the surface, mining and subsequent bitumen/sand separation is the selected technique. In cases where the deposit is deeper below the surface, in situ processing becomes the preferred selection [3].

Surface mining/processing operations tend to be relatively expensive due to the massive quantities of material that must be negotiated. However the surface mining operations tend to yield high recoveries compared to the less expensive *in situ* operations.

2.1. *In Situ* Processing

The goal of bitumen processing is to achieve a high purity bitumen product, eliminating the sand that is naturally mixed with the bitumen in the deposit. Certain methods are able to make this separation without removing the sand from the ground. These methods are called *in situ* processing. While variations exist, all methods involve injection of energy into the ore body, forcing bitumen to exit. The methods all involve drilling two different wells into the ore body. The first well, called the injection well, is where energy is injected into the ore body. The second well, called the production well, is where the bitumen rises to the surface for refining [1].

2.1.1. Thermal Recovery

In thermal recovery methods, energy is injected in the form of heat. The heat is generated by combustion of the hydrocarbon fuel in the reserve. As heat is generated by the combustion, temperature increases, reducing the viscosity of the bitumen making it more mobile. The bitumen is forced out the production well where it is recovered. Additionally, the high temperatures tend to cause coking of the oil so that the bitumen becomes an upgraded product as it moved towards the production well [1]. Steam Assisted Gravity Drainage (**Figure 3**) is the

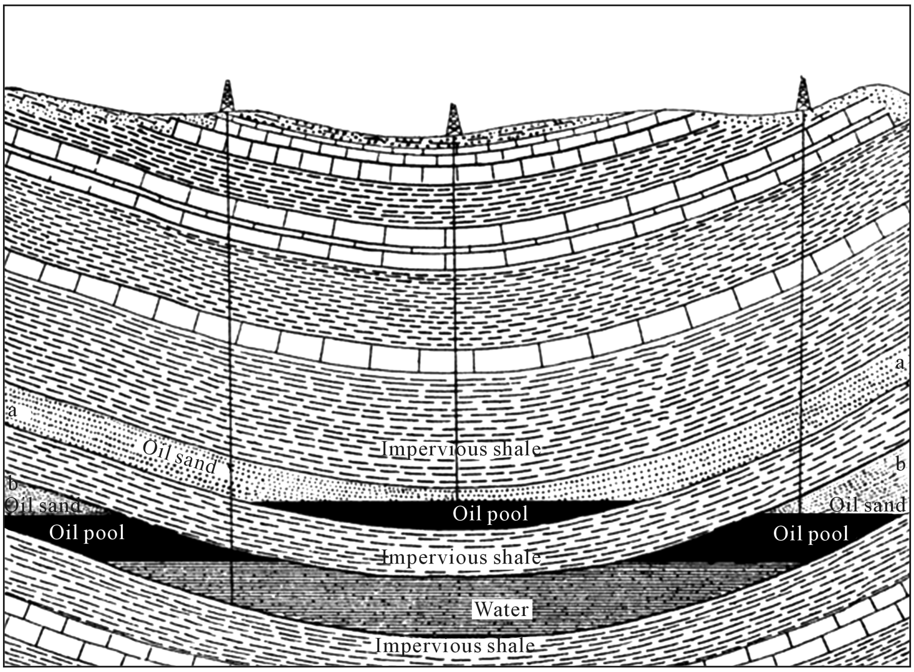

Figure 2. Diagram showing geological structure of oil sands reserves [1].

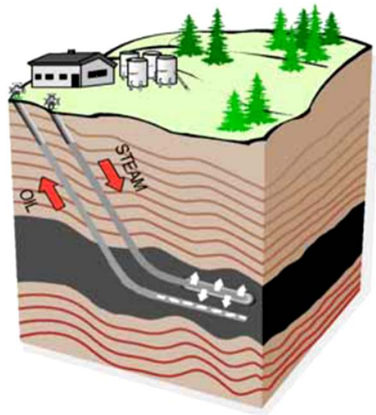

Figure 3. Steam assisted gravity drainage method of *in situ* processing.

most common technique of *in situ* processing of the Athabasca oil sands.

2.1.2. Forward Combustion and Water Flood

In forward combustion and water flood, water is added as ignition takes place to increase the temperature of the bitumen ore body. The presence of water helps spread the heat generated within the ore body, allowing the temperature increase to expand throughout the deposit [4].

In situ processing is actually the cheapest method of bitumen processing, since tons of sand and overburden need not be removed from the earth. The main drawback of *in situ* processing is the poor recovery. As a result, much of the bitumen is surface mined, where recoveries of above 90 percent are common. However, 90 percent of the bitumen reserves in the Athabasca region are located at significant depths, thus *in situ* processing is become more important as surface deposit are depleted.

2.2. Surface Mining and Processing

2.2.1. Surface Mining

For shallow reserves (<75 m) surface mining is used. In this method, the deposit is mined and transported to a processing plant for bitumen/sand separation. These processes occur mostly in the Athabasca river region north of Fort McMurray. It is estimated that only 10% of the bitumen reserves in the Athabasca region are economically recoverable by surface mining. Historically, surface mining has accounted for the majority of the bitumen production; however the fraction treated by surface mining is decreasing. Before 1995, up to 75% of bitumen production was by surface mining. By 2002, the contribution of surface mining was reduced to 64% [5].

The initial step in a surface mining operation is to remove the overburden. In the Athabasca region, this overburden is composed of wet muskeg lying above rock, sand and clay. Soil that is deemed suitable is separated and stockpiled for future land reclamation [3].

The subsequent phase involves digging and transporting the bitumen/sand mixture to a processing plant. Material transportation is characterized by the use of large scale machinery. Large hydraulic shovels lift oil sand into mining trucks capable of transporting a 400 tonne load. These trucks transport oil sand to preparation facilities where the particle size of the material is reduced to specification by crushing. The comminuted material is transferred to the processing plant by either conveyor belt or through a piping system called hydrotransport.

2.2.2. Basics of Aqueous Processing

Processing steps have been designed and developed to separate the bitumen from sand. Separation begins as oil sand is mixed with water and process reagents. Initially, oil sand in water forms lumps. High temperature and shear stress allow layers of the lumps to detach and spread within the water causing the oil sand lumps to eventually disappear. The sheared layers contain sand grains coated with bitumen. As sand particles are naturally hydrophilic, the bitumen coating on the surface of the sand thins. The hydrophilic nature of the sand is unique to the Athabasca region. Other oil sand deposits like those in Utah, or Venezuela cannot be water wet. This is why water-based recovery techniques can only be economically applied for Canadian oil sands [6]. It should be noted that controversy still exists as to the exact nature of the sand surface properties [7].

Bitumen is naturally hydrophobic and so as the bitumen leaves the sand particle; it forms a bitumen droplet in the water. As the bitumen surfaces have a thermodynamic affinity for other bitumen surfaces compared to contact with water, these bitumen droplets tend to aggregate, forming larger droplets. The final step of the process is to recover the bitumen in one stream while rejecting the sand in a second stream. This is achieved by what is known as gravity separation and flotation in the oil sand industry. At high temperatures, the density of bitumen is slightly less than that of water. As a result, the bitumen is driven to rise above the water. Air additions, either by injection or entrainment, contact the bitumen promoting flotation. At low temperatures, the bitumen will attach to the bubble but retain its droplet form. At higher temperatures decreased viscosity allows the bitumen to engulf the bubble forming a stronger attachment. The final result is a valuable bitumen rich stream and a non-valuable sand slurry [8].

2.2.3. Conventional Hot Water Processes

The first of these processes to be employed on a commercial scale, named The Clack Hot Water Process, was developed in the 1930s. This technique, applied by both Syncrude and Suncor was the start of the aqueous processing strategy that is unique to the Canadian oil sands. In this process, bitumen liberation and aeration occurs in a tumbler. The oil sand is mixed with water, reagents and caustic in a tumbler. The mixture is heated to 85 degrees Celsius. The process of mixing inside the tumbler is called conditioning. After conditioning, the aerated bitumen is allowed to rise above the balance of the mixture by gravity in what is called a separation vessel [9].

A first major modification made to The Clack Hot Water Process, was the use of pipelines to deliver slurry directly from the mining operation. This process, called hydrotransport allows the time for bitumen transport between the mine and milling operations to be used as conditioning time. In some cases, the tumbler stage can be eliminated. In these cases, the slurry is delivered directly to the gravity separation vessel [10].

The general trend in bitumen separation processes is towards lower temperature and lower energy requirements. In most cases, The Clark Hot Water Process has been replaced by a process achieved at 50 degrees Celsius, known as The Warm Water Process. Recent development of a process called Low Energy Extraction has begun. These processes, which are hydrotransport based, operate at temperatures below 35 degrees [10].

2.2.4. Gravity Separation and Flotation

Most modern operations apply gravity separation and flotation in two separate stages. In the first stage, slurry is delivered to a large tank. In this tank, called the Primary Separation Vessel (PSV), as seen from **Figure 4**, the slurry is separated into 3 streams. The bitumen/air agglomerates, being the least dense, rise to the top of the vessel and are recovered as a froth. Coarse sands and other solids, having the largest density, settle to the bottom of

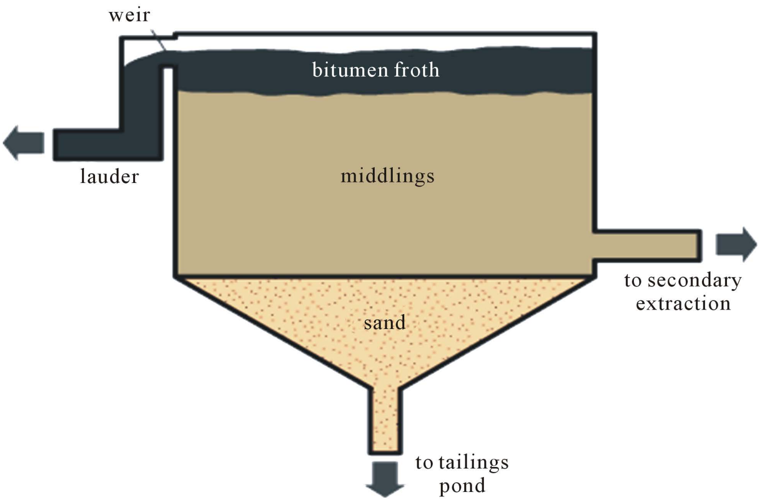

Figure 4. Diagram of a conventional primary separation vessel (PSV).

the PSV. Material of intermediate density, called middlings, are collected into a third stream and sent to flotation cells for further bitumen recovery. In these flotation cells, air is delivered to the machine establishing bubble dispersions for bitumen-air attachment, allowing bitumen froth to be recovered at the top of the flotation machines while the remaining pulp exits through the bottom of the machines. The recovered bitumen froth is re-circulated to the PSV for further processing.

2.2.5. Froth Treatment

The bitumen froth that is recovered by the aqueous treatment is not pure and therefore requires further treatment. In addition to bitumen, the froth contains water and air bubbles. The goal of froth processing is to eliminate the water and air without losing bitumen. The specific requirements of froth processing are dictated by downstream processing methods [11].

Early commercial operations (1970s) used crude thermal processes that were not bothered by small amounts of remnant impurities in the froth. As a result, the first commercial froth treatment was based on a two stage centrifuge unit to break the froth and produce a final bitumen product that was 1 to 2 percent mineral and 5 to 15 percent water. Very rapidly, it was realized that there were significant benefits to reducing the water content in this bitumen product. Using chemical emulsion breakers, the water content was reduced. This centrifuge process was further improved by incorporating a gravity-settling device to scalp some of the oil, thereby reducing the reliance on the centrifuge units. This improvement was incorporated into circuits in the early 1980s [12].

Today, the most crucial aspect of the froth treatment process is the choice of reagent scheme. Reagents are known within the industry as diluents or solvents. The Naphtha process was an initial froth treatment process, based on the use of a chemical for which the process was named. Naphtha contains a chemical called paraffin, which acts to dissolve the bitumen, creating a mixture of diluent and bitumen in a hydrocarbon phase of uniform composition. The composition of the diluent will tend to control the dissolution of bitumen. By this action, the diluent reduces both the density and viscosity of the hydrocarbon phase, resulting in a high product quality (94% to 95% hydrocarbon) at high recoveries (~98%) [12].

The Paraffin Froth Treatment (PFT) was developed as an alternative froth treatment process. The chemical additions in this process are similar to those of the Naphtha process, but the circuit configuration was refined. Initially a single stage mixer-settler was used. This process produced a product that was too clean to send to downstream refining, at recoveries that were too low to be acceptable. To increase recoveries, second and third stages of mixing and settling were added. The current PFT is able to produce a product with very low water and solids content, though never matching the recoveries of the Naphtha process. The selected method tends to reflect the downstream requirements [13].

2.2.6. Current Problems/New Ideas

One of the major challenges faced by bitumen processing operations is the high degree of feed variability. In particular, certain feed compositions tend to result is very low recoveries. These ores are known as "weathered" ores, characterized by large amounts of fine sands. For such ores, bitumen cannot be recovered effectively using conventional hot water treatments. With typical bitumen ores, recoveries of ninety percent and above can be achieved. When processing the "weathered" ores, called "poor processing" ores, recoveries as low as 20 percent are not uncommon. Major research is underway to develop new processing strategies to deal with these poor processing ores [14] [15].

One solution that has been proposed is the use of oil-coated bubbles. Techniques are under development to pre-coat bubbles with a layer of oil. The presence of oil on the bubble surface is expected to increase the stability of bubble-bitumen attachment. On a laboratory scale this process, termed oil-assisted flotation, has been found to improve recovery while processing "weathered" ores from 20 percent to above 65 percent, shown on **Figure 5**. To date, no economical means of applying this process in industry have been presented [13] [16].

Solvent extraction (SX) is a widely applied technique for metal recovery. This process is being considered for bitumen processing. In SX a solvent (typically organic) extracts a target species from solution. In 1985 major research was undertaken to develop the Dravo Process. This process is a version of solvent extraction that is specially configured for oil sands processing. At the time it was found that the process was less economically efficient compared to hot water processing. Research is now underway investigating the possibility of implementing a hot water recovery process, assisted by use of a solvent [11]. A major cost in conventional aqueous processing is the energy cost of heating the water. Major research towards development of lower temperature

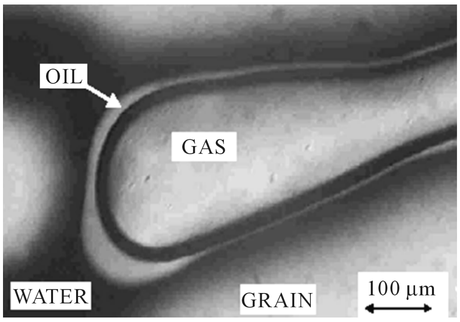

Figure 5. Image of an oil-coated bubble for oil-assisted flotation [16].

processes is underway. These techniques involve in-line air injection and chemical addition. In general, these processes tend to resemble conventional flotation circuits [17].

2.3. Upgrading and Refining

The bitumen that is produced through the mining and processing methods described above is a dense, viscous product. As a result, shipment of this product to existing oil refineries in Edmonton, Montreal, Vancouver or Toronto is not feasible. In any event, conventional oil refineries are not properly designed to process bitumen.

2.3.1. Coking

Bitumen's high viscosity is due to the large molecular size of the chemical. Upgrading processes aim to break these large molecules, thus reducing bitumen viscosity. The most cost effective way to accomplish this is by heating the bitumen, called thermal upgrading [1].

Bitumen is heated to a temperature of 465 - 530 degrees Celsius inside a covered vessel. At this temperature, the large bitumen molecules will not boil, but will crack. The daughter molecules from the cracked bitumen vaporize and report to a condenser. The product remaining in the vessel is called "coke", and the process is known as "coking". The main goal is to recover large amounts of the distilled liquid. The remaining coke is of little value [1].

A continuous version of the process has been developed where hot bitumen is injected into a reactor. Steam is passed through the reactor at high velocity. The reactor contains small coke spheres. As the bitumen enters, reactions occur quickly caused by the fast moving steam. Broken molecules evaporate and rise to a condenser section. The coke deposits on the spheres. As the spheres grow, they deposit at the bottom of the reactor and are removed. New spheres are added to maintain the process [1].

Studies are underway towards establishment of new methods to produce a refining liquid. In particular, a process known as hydrocracking, employing hydrogen injection is being investigated. The process takes place at high temperature and high pressure (120 to 240 atmospheres). Studies have shown that this process may facilitate the production of more refining liquid and less coke. However, the process tends to be too expensive to be applicable at this time [18].

2.3.2. Catalytic Conversion

Processes exist whereby the thermal upgrading process can be enhanced by use of a catalyst. The process takes advantage of the catalytic surface area to induce molecular breakage. This process, called Catalytic Conversion, tends to be more expensive than conventional thermal upgrading, but is capable of producing more upgraded hydrocarbon [14].

2.3.3. Distillation

Distillation processes follow the molecular breakage stage of the upgrading process. The goal of distillation is to sort liquids and gasses into their components taking advantage of the range in material boiling points (*i.e.*, lighter material with a lower boiling point is collected as a vapor at the top of the distillation column, while denser materials with a higher boiling point is collected as a liquid at the bottom of the column) [3].

2.3.4. Hydrotreating

The final stage of the refining process is called hydrotreating. In this process, the feed is heated to above 300 degree Celsius and passed in contact with catalytic pellets to saturate the hydrocarbon molecules with hydrogen. Hydrotreating is also capable of removing the remaining sulphur and nitrogen impurities. The result is a stable, crude oil product that can be shipped for conventional final refining [3].

3. Oil Sand Economics

Although oil sands processing started nearly 40 years ago production has only in recent years become lucrative. Conventional crude oil costs in the area of $3/barrel to produce in comparison to $10 - 20/barrel for oil sands production [2]. Syncrude Canada Ltd., Canada's largest Oil sands processor quotes operating costs at approximately $18/barrel while Suncor (2nd largest) states that their 2004 operating costs were $11.98/barrel [2]. The cost was much too high in the past but the spike in oil price over the past decade has created a push to continue expansion of the Alberta reserves. In early years oil sands production was uneconomical as processing costs made it impossible to compete on the global market. The cost of oil sands production has typically been considered cost-effective when oil prices are above $23/barrel [2]. Improved mining practice, and more effective processing techniques coupled with increasing price and demand will most probably drop that figure into the teens. It has even been forecasted that by 2015 costs could be as low as 8 - 10 $/barrel of crude [2]. Mike Ashar, executive vice president Suncor Energy, states that high operating costs are definitely associated with oil sands processing. He also notes that conventional oil production generally have high exploration costs while oil sand exploration cost are minimal primarily due to their proximity to the surface. The global average costs for oil exploration is $11 US/barrel [2].

3.1. Oil Sand Companies and Expansion

Over the past decade many of the largest oil companies in the world have come to realize the significance of the Anthabasca reserves and the viability of the extraction technologies used to process oil sands. There are currently roughly 30 companies working in Alberta in the oil sands business. They produce over one million barrels per day. In the next decade this figure is expected to rise to three million barrels per day [2]. The three largest oil sand companies are Syncrude Ltd., Suncor Energy Inc. and Albian Sands. As shown on **Figure 6**, Syncrude is the largest Canadian oil producer and one of every eight liters of gasoline sold in Canada comes from its oil [2].

Figure 6. The construction of a new coker at Syncrude's oil sands plant, the largest oil sands operation in the world, is part of an $8 billion expansion.

Oil sands production is expected to triple over the next decade. This increase in production is associated with massive expansion by almost all the major companies involved. Alberta officials say industry invested $24 billion in the tar sands from 1996 to 2002, with $70 billion of additional investment announced through 2020 [2]. According to the Canadian Association of Petroleum Producers $5.5 billion was invested in the oil sands industry in 2003 alone.

These three and many other companies plan extensive expansion in the coming years to increase production and improve technology. Shown below (**Table 1**) is a list of the major companies involved in oil sands processing, their production rates and projected investments:

3.2. Oil Sand Politics

World politics will definitely play an important role in determining the future of the oil sands as everyone is looking to secure oil for the future. Oil production is expected to peak in the next 10 years and this worries many as energy sources begin to diminish. Investors are definitely attracted to the oil sands as they are located in a politically stable region of the world. Canada's "stable government, predictable investment conditions, highly developed infrastructure, integrated pipeline networks, (and) free and open trade" make Alberta a very appealing area in which to invest. Canada is already the largest supplier of oil to the United States [2]. The White House's 2001 report on national energy policy called Canada's oil sands "a pillar of sustained North American energy and economic security" [2]. The United States see Canada as an important source of crude oil in the future especially as America's own resources are in decline.

China has recently expressed interest in the oil sands as they look to supply their countries' ever increasing need for energy. To date, China only holds small stakes in the oil sands but is expected to broaden their reach in the business. There was talk in 2004 of oil sands investment by the Chinese government but it did not materialize. China seemed to opt to remain as minority stakeholders in private companies in an attempt to tap business expertise and technology without causing controversy surrounding government interference.

Politics within Canada may also be stretched as the province of Alberta holds most of the political power surrounding Canada's oil sands. Economic wealth could easily translate into political power given the importance of the oil sands as an energy supply on the world economy. Ottawa may have trouble dictating national policy as Alberta keeps tight control over its natural resources. There is and will continue to be economic gains in the western provinces which could negatively impact the eastern provinces.

Alberta established a royalty system for oil sands operations in 1997. The system favors start-up operations and companies that invest in its operations. The royalty is roughly equal to 1 percent of a company's gross rev-

Table 1. Major oil sand processors, production and investment [2] (bpd = barrels per day, bbpd = barrels of bitumen per day).

Company	Current Production	Projected Production	unit	Investment (billion CAN$)
Syncrude Canada Ltd.	238,000[4]	350,000 (2006)	bpd	8
Suncor Energy Inc.	226,500[23]	400,000 (2008)	bpd	2.8
Albion Sands Energy Inc.	155,000[24]		bbpd	5.7
Canadian Natural Resources Ltd.		300,000 (2010)	bpd	6.8 - 8
Shell Canada Ltd.		200,000 (2010)	bbpd	
SynEnCo Energy		100,000 (2009)	bbpd	3.5
ConocoPhilips Canada		100,000 (2013)	bbpd	0.3
Imperial Oil Ltd/Exxon mobile Ltd.		100,000 (2010)	bpd	5 - 8
Encana Corp.		70,000 (2007)	bbpd	0.4
Husky Energy		50,000 (2008)	bbpd	1.6
LP/UTS Energy Corp.		50,000 (2009)	bbpd	2

enue. The project attempts to help industry with cash flow issues related to start-up and continued process development which entail major capital costs. Revenue from this program has totaled more than $1.3 billion (Canadian) since 2003 [2]. The executive vice president of Suncor Energy notes that Alberta and the federal governments introduced royalty and fiscal regimes which "recognize the large scale, up-front capital investments required for oil sands development and the long-term nature of project payouts—for both the project developers and the economy as a whole" [2].

3.3. Northern Alberta

The oil sands have completely changed the physical and social landscape of the Fort McMurray area. The oil sands boom has brought with it many workers from across the country and around the world. Lodging is a definite issue as more people have arrived than there are beds. Housing prices have doubled in the past years increasing the average house price to nearly 360,000 $. Certain operations have had to opt for fly-in/out positions to fill the vacancies. In an attempt to respond to the needs of the community the government of Alberta released nearly 1000 acres of Crown land in 2005 for new housing and highway improvements [5].

It has been said that retailers have had difficulty recruiting people to work in stores and shops at $15 an hour because the local wage structure has been so skewed by high-paying petroleum companies [2]. The social systems are being strained as the health-care and school systems are being stretched by rapid expansion.

4. Environmental Impact of Oil Sands Exploitation

As is the case with most mining, metallurgical or petroleum operations, there is a range of environmental concerns surrounding oil sands exploitation. These concerns can be divided into 5 categories: greenhouse gas emissions, acidic and volatile compound emissions, habitat fragmentation, water use and quality, tailings disposal. Each of these aspects will be discussed briefly. Subsequently, actions to address these environmental issues will be described.

4.1. Greenhouse Gas Emissions

Greenhouse gasses are gasses that when emitted into the environment contribute to warming of the atmosphere. Worldwide concern regarding the production and emission of these greenhouse gases has been growing in recent years. Processing of Canadian oil sands results in greenhouse gas production at every stage in their life cycle, removal of overburden, energy input during processing, vapor release during refining and eventual combustion as a final product. It is estimated that carbon dioxide (the most common greenhouse gas) emissions during bitumen processing are 15% higher than those associated with processing of conventional oil reserves [2].

It is expected that the expansion of the oil sands industry in Canada will be hindered by requirements to reduce greenhouse gas emissions. It has been predicted that production costs could increase as high as three dollars per barrel due to regulations regarding greenhouse gas emissions. A proposed solution to limit the greenhouse gas production associated with bitumen mining and processing would be the implementation of nuclear energy. To date, no action has been taken towards implementation of this solution.

4.2. Acidic Gas and Volatile Compound Emissions

Sulphur dioxide (SO_2) is emitted during bitumen production, from burning of petroleum coke or the use of diesel equipment. Sulphur dioxide emissions reduce air quality and result in acid rain, which has harmful effects on local plant and animal life. In Alberta, SO_2 emissions are governmentally regulated. Technological developments in control of SO_2 have allowed production to double without increasing emissions. Typical desulphurization units can remove roughly 95% of the SO_2 produced during coke burning [5].

Nitrogen oxides are also emitted throughout the oil sands operations. These gases tend to have similar environmental impacts compared to SO_2. Emission of these gases is provincially regulated and controlled primarily by use of low nitrogen oxide emitting technology.

Solvents used to extract bitumen from sand tend to accumulate in tailings ponds. Volatilization of organic compounds from tailings ponds is another major environmental concern. Significant research efforts are underway towards the development of techniques to recover solvents before they are discharged into the tailings ponds.

4.3. Habitat Fragmentation

Bitumen processing operations take place in the middle of the Canadian boreal forest. This vegetative region accounts for approximately 35% of Canada's land mass and is considered to play an important role in global carbon dioxide management [2]. Of equal importance, this region is host to a wide variety of fauna and flora. Oil sands exploitation is considered to be a threat to the local ecosystem. Overburden removal during open pit mining has significant visual impacts on the landscape. While more visually pleasing, *in situ* extraction can be equally disruptive to natural environments. Because of the potential for environmental damage, all new operations must include environmental impact assessments.

4.4. Water Use and Quality

Oil sands processing requires large amounts of water. Efforts are made to recycle the majority of water used in the process; however, losses of approximately 10% are un-avoidable. The extensive water use is beginning to cause public concern regarding water cleanliness. These concerns are heightened as water level in lakes and rivers has been steadily dropping. The situation may also stress provincial ties as most of Saskatchewan's water reserves pass through Alberta. Under current conditions, both provinces have sufficient supply to satisfy their needs, however, threats of drought may reduce the supply and increase the importance of careful water regulation.

4.5. Tailings Disposal

The water based processing techniques that are unique to the Canadian oil sands operations produce massive amounts of process tailings. These tailings consist of water, un-extracted bitumen and sand components. Tailings are typically discharged into ponds. Environmental concerns regarding tailings dams include leakage of harmful species into ground water and surrounding soil and surface water. Areas near tailings ponds are closely monitored to ensure that no pollutants escape. Land reclamation processes are also common whereby the tailings ponds are either converted into artificial lakes, or dried to produce a vegetated landscape.

As the oil sand industry continuous to expand in Northern Alberta, co-operative research will continue to take place towards development and management of environmental impacts of the processing activities.

5. Comparison to Wind Energy

As world supplies of oil diminish and environmental concerns regarding fossil fuel combustion increase, increased attention has been placed on the discovery of alternative energy sources. One of these alternative energy sources is wind. Using wind mills, mechanical wind energy can be converted into electricity and used as a source of power. This portion of the article will compare bitumen and wind as sources of energy. The comparison will be broken down into three categories: reserves, energy potential and environmental considerations.

5.1. Reserves

One of the main concerns surrounding the oil industry, since its conception, is the fact that oil, as a fossil fuel, will eventually be entirely consumed. While the bitumen reserves in Canada are relatively large, they will eventually be depleted. Estimates predict several hundred years before the world supply of gasoline is completely consumed.

In contrast, the world supply of wind is not expected to diminish. As a result, the world capacity to extract energy from wind should only increase as exploitive technology develops. One shortcoming of the wind energy reserves is that they cannot be transported in the same fashion as oil or bitumen reserves. While, crude oil can be shipped worldwide, electricity generated by wind power is limited to the electrical power infrastructure of the area. Therefore, while wind energy may be a viable energy source in certain locations, it will not replace fossil fuels as the universal energy source.

5.2. Power Potential

One of the more attractive benefits of fossil fuel combustion is the substantial energy capacity of these substances. In contrast, wind energy has only a small potential impact on the total energy market.

In Canada, wind energy accounts for 570 MW. It is predicted that the maximum power generation by wind energy in Canada is 50,000 MW [19]. To compare, let us consider the power capacity from bitumen production. For a conservative estimate we will consider a production rate of 500,000 barrels of crude oil produced from Canadian bitumen reserves per day. At this production rate, bitumen could generate 21,000,000 MW. Therefore, it would take 420 countries operating at Canada's maximum capacity for wind energy to match a conservative estimate of the bitumen power capacity.

$$500{,}000\ \text{bpd} \times \frac{158\ \text{l}}{\text{b}} \times \frac{0.9\ \text{kg}}{\text{l}} \times \frac{2.2\ \text{lb}}{\text{kg}} \times \frac{19000\ \text{btu}}{\text{lb}} \times \frac{0.293\ \text{kwh}}{\text{btu}} \times 24\ \text{hr} \times \frac{1\ \text{Mw}}{1000\ \text{kw}} = 21{,}000{,}000\ \text{Mw} \tag{1}$$

5.3. Environmental Considerations

Perhaps the most powerful force behind the decline of fossil fuels as a source of energy, apart from diminished reserves, is the environmental issues surrounding production and combustion. The previous section outlined the numerous environmental concerns that are associated with bitumen processing. In light of these concerns, efforts are being made to develop new sources of energy that are less damaging to the environment. Wind energy is one of these potential sources.

The main environmental benefit of wind energy is that it does not directly result in emission of greenhouse gasses. However, wind energy is not without environmental consequence. The major consequence is the expansive land requirements to construct sufficient infrastructure. The land requirements have negative impacts on animal migration and natural vegetation. However, in spite of these drawbacks, wind energy is certainly perceived as being more environmentally friendly when compared to bitumen processing.

While it seems that wind may be a viable method to compliment other energy sources, the power capacity is not sufficient to replace the fossil fuels as the major energy source.

6. Conclusions

A major bitumen reserve is located in the Athabasca, Cold Lake and Peace River regions of Northern Alberta. These bitumen reserves account for a considerable portion of the world oil reserves. Canadian oil sands can be surface mined and employed by a unique aqueous processing technique. As oil sand reserves near the surface become depleted, *in situ* extraction of bitumen will become increasingly important. Refining operations exist in the Fort McMurray region to produce a bitumen product that can be shipped to the major refineries for production of gasoline or diesel fuel.

Major concerns exist regarding the environmental impact of bitumen processing, however regulations are in place to monitor pollution. More efficient processing techniques are being explored to allow oil sands expansion while decreasing environmental impact.

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