A discussion paper on the oil sands: challenges and opportunities

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Abstract

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The oil sands have become a significant source of secure energy supply and a major economic driver for Canada. As production in the oil sands expands so too has concern about the effects of development on communities, water, land, and air. This paper aims to provide a basis for an informed discussion about the oil sands by examining the current challenges facing development and by reviewing the central issues, both positive and negative facing the industry. This paper isn't meant to provide an exhaustive list of all potential impacts associated with oil sands development or document the oil sands regulatory regime.

Outline

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Disclaimer

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Glossary

AOSTRA	**Alberta Oil Sands Technology and Research Authority**
API	**American Petroleum Institute**
API Gravity	**A measurement of the density of crude oil in degrees**
Bitumen	**Extra-heavy crude oil with a density between ~1015 kg/m^3 to ~970 kg/m^3 or API gravity between 8° to 14°**
CANMET	**Canada Centre for Mineral and Energy Technology**
CCS	**Carbon Capture and Storage**
CHOPS	**Cold Heavy Oil Production with Sand**
CO_2	**Carbon Dioxide**
CSS	**Cyclic Steam Stimulation**
GDP	**Gross Domestic Product**
GHG	**Greenhouse Gas**
EIA	**Energy Information Administration**
ERCB	**Alberta Energy Resources Conservation Board**
Extra-Heavy Crude Oil	**Crude oil with a density greater than 1000 kg/m3 or API gravity less than 10°**
IEA	**International Energy Agency**
NAFTA	**North American Free Trade Agreement**
NEB	**National Energy Board**
NO_X	**Nitrogen Oxides**
Oil Sands	**A naturally occurring substance composed of sand, clay, water and bitumen.**
OECD	**Organisation for Economic Co-operation and Development**
OPEC	**Organisation of Petroleum Exporting Countries**
SAGD	**Steam Assisted Gravity Drainage**
SO_X	**Sulphur Oxides**
VOC	**Volatile Organic Compounds**

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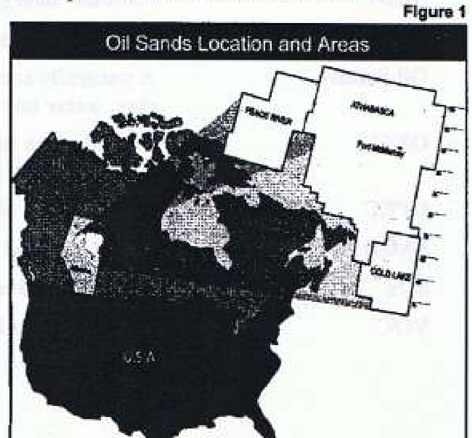
Introduction

Located in Western Canada (Figure 1), beneath about 142,200 square kilometres (km^2) of boreal forests, prairies, and wetlands, lays the second largest known deposit of crude oil in the world[1]. Beneath an area smaller than the State of Florida[2] is an estimated 1.8 trillion barrels of crude oil suspended in a mixture of sand, clay, and water, known as the oil sands. Under current economic conditions and with current technology it is estimated that 170 billion barrels of oil are currently recoverable and ultimately 315 billion barrels of oil could be recovered[3].

Since large scale, commercial oil sands production began in 1967[†] less than 4 percent or 6.9 billion barrels[4] of the total recoverable resource has been produced. With conventional sources of crude oil in decline and forecasters predicting oil to remain a dominant form of energy for decades to come[5], the oil sands is one of a few, largely untapped, resources in the world, and the only one in North America, currently capable of making large scale contributions to our energy security.

As oil prices have increased and production technologies have advanced, such as the advent of horizontal drilling technology, the accessibility and economics of oil sands production has improved. Canada has seen increased investment in the oil sands and increased innovation in extraction technology. In recent years, production technology advancements and the appreciation of world oil prices combined to create a boom in oil sands investment. As interest in the oil sands expanded so too has concern about the impacts of development on communities, water, land and air. Canada is at the forefront of this type of unconventional oil production; trying to balance the obvious benefits of oil sands development with the environmental implications. In Canada, resource developments, such as the oil sands, take place within a substantive regulatory regime, with shared responsibilities between the Federal and Provincial levels of government. This paper is not meant to examine the regulatory or policy aspects of oil sands development, but to review the current issues facing the oil sands sector, and the benefits and drawbacks associated

Figure 1



Source: Alberta. Energy Resources Conservation Board

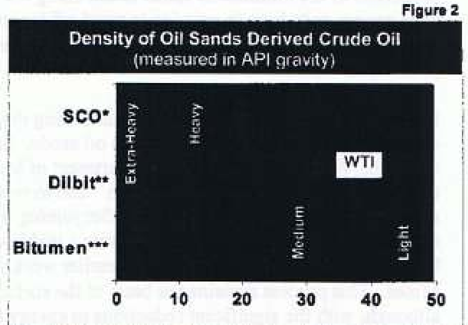
[†] From 1967 to 2009 inclusive.

with the expansion of oil sands production.

The Resource

The extra-heavy crude oil‡ contained in the oil sands is often called bitumen§—a naturally occurring mixture of hydrocarbons. Compared to light crude oil, oil sands crude oil is more dense and viscous due to a higher ratio of carbon atoms to hydrogen atoms. The oil sands are not homogenous and bitumen quality can vary**. Some oil sands crude can be extracted via conventional methods. However, most oil sands crude oil is immobile at room temperature and cannot be extracted using traditional oil production techniques. Instead the oil contained in the oil sands is extracted through surface mining or through the use of in-situ oil sands extraction technology. Also for these reasons some oil sands crude oil is upgraded to lower the density and improve the carbon-to-hydrogen ratio before being transported to refineries (Figure 2). A number of new and existing refineries can, or are changing to be able to, receive heavier forms of crude oil, like bitumen, without the need for upgrading. The upgraded crude oil created via upgrading processes has very low sulphur and few metal contaminants.

Figure 2



* Synthetic Crude Oil (SCO) is upgraded bitumen
** Dilbit or diluted bitumen is bitumen diluted with solvent or condensate to lower the density of bitumen to as to permit transportation via pipeline
*** Bitumen is the raw form of oil sands derived crude oil and is not marketed in its raw form, but is either converted to dilbit or upgraded to SCO prior to export.

The choice of extraction method is determined by the oil sands geology. While some deposits of oil sands extend into the Province of Saskatchewan, the vast majority of the recoverable resources are located in northern Alberta in three main regions: Athabasca, Cold Lake, and Peace River. The Athabasca oil sands deposit is the largest and the only one where the oil sands are shallow enough to permit surface mining. Most oil sands resources must be recovered in-situ or in-place which currently involves drilling into the oil sands and heating the bitumen to allow it to flow. About 20 percent or 34.2 billion barrels of the resource is accessible through mining operations with the remaining 80 percent or 135.6 billion barrels requiring some form of in-situ production technique[6]. Currently about 45 percent of bitumen is produced in-situ (672 thousand barrels per day)

‡ Extra-heavy crude oil is generally categorized as hydrocarbons occurring with a density greater than 1000 kilograms per cubic metre (kg/m^3) or as measured by the American Petroleum Institute's scale (API gravity) less than 10 degrees (°).

§ The density of bitumen generally ranges from ~1015 kg/m^3 to ~970 kg/m^3 or with an API Gravity between 8° to 14°. For comparison light crude oil generally has an API over 35° (850 kg/m^3).

** Quality in crude oil is generally measured by the density of the crude oil, usually measured by API gravity, as well as the content of impurities such as sulphur and metals.

with the remaining 55 percent coming from mining operations (827 thousand barrels per day)[7]. In terms of surface area, the share of mineable oil sands resource does not correlate to land use. Overall, mining is only feasible in about 3.4 percent of the total 142,200 km^2 of oil sands area[8]. For this reason it is expected that most new oil sands growth will come from in-situ operations.

The History

For untold years, the indigenous peoples of the Athabasca region made use of the unique properties of the bituminous sands found along the banks of the Athabasca River to seal their canoes or to burn in smudge to ward off insects. However, it was not until Rupert's Land was acquired from the Hudson's Bay Company in 1870 that the idea of commercial production was conceived.

In the early days, interest focused on unlocking the secret to extracting bitumen from the clay, sand, and water that make up the oil sands. Sidney Ells was an early pioneer in this research. Working at the federal Department of Mines, he was the first to demonstrate the commercial application of bitumen[††] and to propose the use of hot water in the separation process[9]. Dr. Karl Clark, after joining the Scientific and Industrial Research Council of Alberta[‡‡], was able to uncover a viable commercial process for separating the bitumen in 1925, following up on his earlier work with Sidney Ells at the Department of Mines. This process remains the basis of the surface mined extraction process used today although, with the significant reductions in energy and water requirements in the last 10 to 20 years, these two inventors would be hard pressed to recognize their initial process[10].

In the 1930s and 1940s interest in the oil sands shifted towards production of bitumen for roofing and road surfacing. Later, during the Second World War there was a great deal of optimism about diesel production. However, following the 1947 discoveries of light sweet petroleum near Leduc, Alberta, interest subsided as companies chose to pursue more economical conventional reserves. Throughout the 1950s and 1960s government and industry continued to investigate the economic feasibility of oil sands production. It wasn't until 1967 that the first "modern" commercial oil sands mining operation began production. The project, called the Great Canadian Oil Sands, was later acquired by a subsidiary of the Sun Oil Company and is known today as Suncor Energy. Shortly thereafter in 1969, Cities Service Athabasca Incorporated, which later became Syncrude, received approval to construct a bitumen extraction facility near Suncor's operation. The plant began operations in 1978, which was followed by the 1979 energy shock which pushed oil prices up until the mid-1980s and helped establish Syncrude. During this same period a number of companies experimented with thermal extraction techniques in areas of the oil sands that are too deep for surface mining. Piloted by Imperial Oil Ltd. in the 1960s, expanded in-situ production began from Imperial's Cold Lake leases in 1985 using cyclic steam stimulation (CSS)[11]. Today the Imperial Cold Lake Project is the

[††] Sidney Ells was able to demonstrate the use of bitumen to pave a road in Edmonton, Alberta. However, this was not cost competitive to other methods of paving at the time and was not pursued.
[‡‡] This later became the Alberta Research Council, which is now Alberta Innovates.

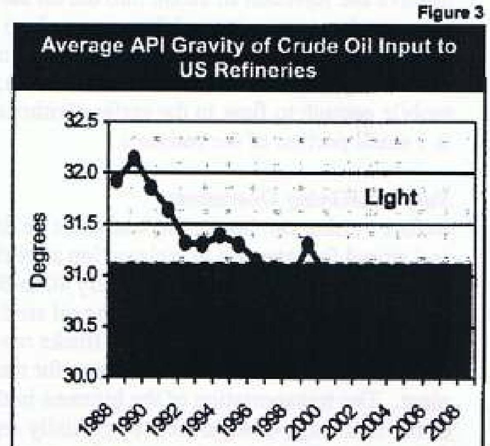
largest in-situ steam extraction operation with production regularly exceeding 140,000 barrels per day.

The energy crises of the 1970s encouraged governments throughout this period and into the mid-1980s to play a more active role in accelerating oil sands development. In addition to a direct investment in Syncrude, oil sands operations enjoyed favourable tax incentives and relief from export tax. In 1974, the Province of Alberta founded the Alberta Oil Sands Technology and Research Authority (AOSTRA) to advance oil sands technology. AOSTRA was instrumental in the advancement of in-situ extraction technologies, such as Steam Assisted Gravity Drainage (SAGD) which has become the dominant in-situ extraction method. AOSTRA is now part of Alberta Innovates[12]. At the federal level the Canada Centre for Mineral and Energy Technology (CANMET) has been instrumental in advancing oil sands recovery, upgrading, and water management.

For the next two decades oil sands investment continued to grow, while government divested itself of direct participation in the oil sands. Today, government investment has shifted from improving the economics of oil sands production towards researching ways to reduce the environmental impacts performance of the sector. The regulatory regime in which the oil sands exist is complex, with the Federal and Provincial governments having shared responsibilities across a number of government departments. However, under the terms of the Constitution of Canada it is the provinces that manage the development of their natural resources, including the oil sands. The federal government plays an important role in protecting the environment. Major project proposals are required to undergo environmental impact assessments, and approvals are granted once all issues have been addressed to the satisfaction of the government.

While the oil sands are unique, the shift towards heavier forms of crude oil is not. Forecasters, such as the National Energy Board (NEB) and the International Energy Agency (IEA) predict that crude slates will become heavier as global production of lighter crude oil sources declines. Canada with its 1.5 million barrels per day[§§] of oil sands production has already experienced a significant shift in the volume of heavy crude oil refined, growing from 19 percent of total crude inputs to Canadian refineries in 2000 to 25 percent by 2006[13]. The United States Energy Information Administration has recorded a similar trend with US refinery inputs falling about 2° API over the past twenty years (Figure 3)[14].

Figure 3



Source: U.S. Energy Information Administration, "*Crude Oil Input Qualities*," http://tonto.eia.doe.gov/dnav/pet/pet_pnp_crq_a_EPC0_YCG_d_m.htm - *accessed February 9, 2010*

[§§] This represents raw crude bitumen production and not marketable oil sands production.

In recent years, the appreciation of oil prices coupled with technological improvements have dramatically improved the economics around oil sands production. This all contributed to a boom in oil sands investment going into the 2008-2009 recession. While the economic downturn contributed to the postponement of several oil sands projects, the NEB forecasts oil sands crude production to rise to 2.8 million barrels per day by 2020. This production will contribute to Canada's overall crude oil production, which is forecast to rise to 3.8 million barrels per day by 2020, despite declining production from other sources[15].

Oil Sands Operations

Each oil sands production method is unique and comes with its own set of benefits and challenges. While mining operations are less energy intensive than in-situ operations, they have a more visible impact on the land and higher water requirements. Conversely, in-situ operations are more energy intensive contributing to higher greenhouse gas (GHG) emissions. They also use less fresh water and have different impacts on the land, contributing to forest fragmentation.

For oil sands near the surface, extraction of bitumen from the sand, clay and water that make up the oil sands involves digging up the oil sands ore, mixing it with warm water and some separating agents and agitating the mixture to separate the bitumen from the sands and clays. For oil sands resources that are too deep for surface mining operations some form of in-situ recovery is required to produce the oil. Most in-situ operations involve the injection of steam into the oil sands deep underground. The steam warms the bitumen, improving its mobility, so much so that it can be recovered through wells. Other in-situ technologies are being tested such as solvent assisted extraction, and toe-to-heel air injection. In some oil sands areas (e.g. Peace River) bitumen can be found that is mobile enough to flow to the surface without the need for steam to heat it. However, this is a small portion of the resource.

Surface Mining Operations

Before mining can begin, the land must be drained and the vegetation and soil removed and stored for later use in reclamation after the mining operation is complete. Once exposed, oil sand seams are typically 40 to 60 metres thick and sit on top of relatively flat limestone. Large shovels dig up the oil sands ore and place it into large trucks with a capacity of up to 400 tonnes. The trucks move the ore to a feeder/crusher where the ore is crushed, then mixed with hot-water for transportation via pipeline to the extraction plant. The transportation of the bitumen in the pipeline is called hydro-transport and acts as the first stage of separation by partially separating the mixture during transportation. Once at the extraction point, the oil sands ore is mixed with more hot water (typically about 50°C) and is then separated into bitumen froth (a mixture of air, oil, water and solids) and two tailings streams: sand tailings and fluid fine tailings (composed of clays and silt). The bitumen rises to the surface of the separation vessel as froth and is skimmed off while the sand settles to the bottom. After a deaeration step, a solvent, usually naphtha or paraffin is typically added as a diluent and the mixture enters a high speed centrifuge to complete the separation. Diluted bitumen is sent to an upgrading unit while the separated material is removed as a third, much smaller tailings slurry (froth treatment tailings) and pumped into holding ponds. Mining extraction is capable of recovering over 90 percent of the resource within the oil sands.

In-Situ Operations

These operations generally involve the injection of steam into the ground to heat the bitumen, improving its mobility so it can be extracted back to the surface. There are two methods that use steam injection to extract bitumen, Cyclic Steam Stimulation and Steam Assisted Gravity Drainage.

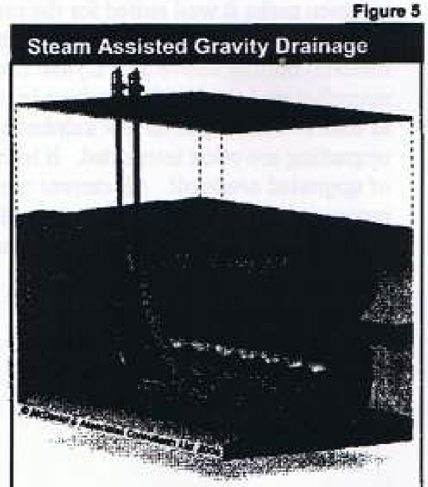
Figure 4

Source: ©Canadian Centre for Energy Information

Cyclic Steam Stimulation

Cyclic Steam Stimulation (CSS) (Figure 4) involves the injection of steam into the oil sand formation at a temperature of about 300 to 340°C and at about one hundred times sea-level atmospheric pressure***. Steam is injected for an extended period and then allowed to soak in for days or weeks. This is followed by a production period when the heated oil and water are pumped to the surface. Once the production rate falls off, the well is put through another cycle of injection, soaking and production. This process is repeated until it is no longer economical. Cycle times are typically 6 to 8 months and the expected oil recovery is 20-25 percent.

Figure 5



Source: Encana

Steam-Assisted Gravity Drainage

Steam assisted gravity drainage (SAGD) (Figure 5) was developed in the 1980s and coincided with improvements in directional drilling technology. In SAGD, two horizontal wells are drilled in the oil sands seam, one at the bottom of the formation and another about 5 metres above it. These wells are typically drilled in groups off central pads and can extend for kilometres in all directions. Steam is injected through the upper well heating the oil sands. With sufficient permeability, the mobilized bitumen and condensed steam drains by gravity to the producing well and is

*** Average injection pressure is 11,000 Kilopascal (kPa), the average atmosphere pressure is assumed to be 101.325 kPa.

subsequently pumped to the surface. SAGD has proven to be a major breakthrough in production technology since it is cheaper than CSS, allows very high oil production rates, and is capable of recovering up to 50 percent of the oil in place.

The above methods are not mutually exclusive. It is becoming common for wells to be put through one CSS injection-soak-production cycle[†††] to condition the formation prior to going to SAGD production. Companies are also experimenting with combining emerging technologies with SAGD to improve recovery rates and lower energy use.

Cold Production

In the oil sands region there are some deposits where the crude oil is mobile enough to flow without the need for steam heating or dilution. While this results in lower GHG emissions and water use, some of these operations are not without their own challenges. In the Cold Lake region, cold heavy oil production with sand (CHOPS) produces large volumes of sand and other types of fluid waste. CHOPS has an oil recovery rate of 5 to 7 percent. Management of this waste is a major component of operating costs. In the Wabasca area of the Athabasca region and the Seal area of the Peace River region, horizontal wells are used to achieve comparable production rates to the CHOPS process in Cold Lake, but without the production of sand on the same scale.

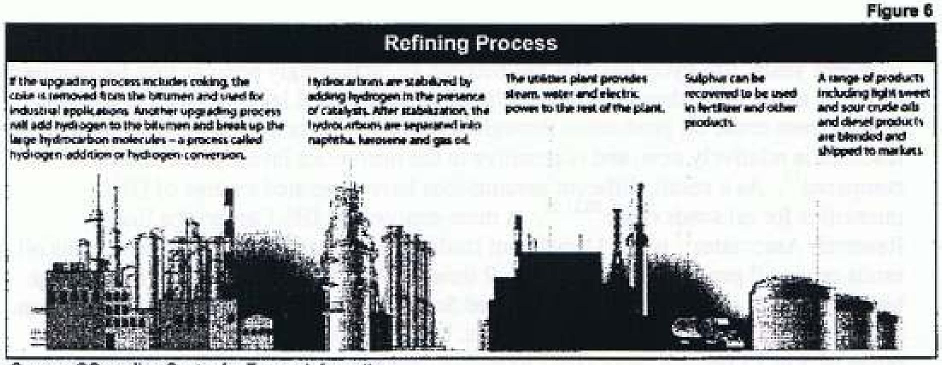
Upgrading

Upgrading is very similar to parts of the refining process as it consists of thermal and catalytic conversion to produce lighter (lower molecular weight) products and hydrotreating to remove sulphur and stabilize the product (Figure 6). In the field, this converts bitumen (API 8° to 14°) into an upgraded crude oil which is comparable to a high-quality, light, crude oil (API greater than 30°)[‡‡‡]. In addition, the properties of bitumen make it well suited for the production of diesel fuel and many upgraders produce finished diesel directly from the bitumen. Upgraded crude oil contains no residue (i.e. material boiling above 525°C) and can be shipped via pipeline to refineries. This manufactured feedstock is unique in the refinery world, and may be a valuable precursor to future fuels due to its low sulphur and low metals content. Mining, extraction and upgrading are often integrated. It takes about 2 tonnes of oil sands ore to make 1 barrel of upgraded crude oil. All current mining operations produce upgraded crude oil. In-situ recovered bitumen is often not upgraded; it is piped to refineries instead, after being diluted with lighter hydrocarbons to meet pipeline specifications for density and viscosity.

[†††] Also referred to as "Huff and Puff".

[‡‡‡] See Figure 3 for comparison of oil sands products.

Figure 6



Source: ©Canadian Centre for Energy Information

Oil Sands Impacts

There are a number of impacts associated with oil sands production. These not only include environmental implications, but also socio-economic impacts. As a result of these impacts concerns have been raised about the scale and the pace of the oil sands development both domestically and internationally. This section will review the impacts, positive and negative, resulting from oil sands development.

Oil Sands and the Environment

There are a number of well documented and well publicized environmental impacts associated with oil sands development. Generally, heavier forms of crude oil, such as that contained in the oil sands, require more energy and resources to produce and refine compared to lighter crude oil, resulting in higher air pollutant and GHG emissions. In addition, the unique nature of oil sands extraction technologies has other environmental challenges associated with production, such as impacts on land and water.

GHG Emissions

In Canada, energy production[§§§] is responsible for about 38 percent of Canada's total GHG emissions[16]. In 2008, oil sands production contributed to just over 1/8 of all energy production emissions in Canada; accounting for about 5 percent of Canada's total GHG emissions or 37.2 megatonnes of CO_2 equivalents in 2008[17].

The GHG emissions from the combustion of fuel derived from crude oil do not vary by source and represent the bulk (70 to 80 percent) of total life-cycle emissions associated with crude oil use[18]. The source of GHG emissions differences among crude oils lay in the differences in emission intensity associated with the extraction, processing, refining and transportation of crude oil to produce finished products, such as gasoline, diesel or heating fuel. GHG emissions associated with the production of finished products can vary significantly, influenced by the quality of the crude oil itself, the extraction method, and the operating conditions.

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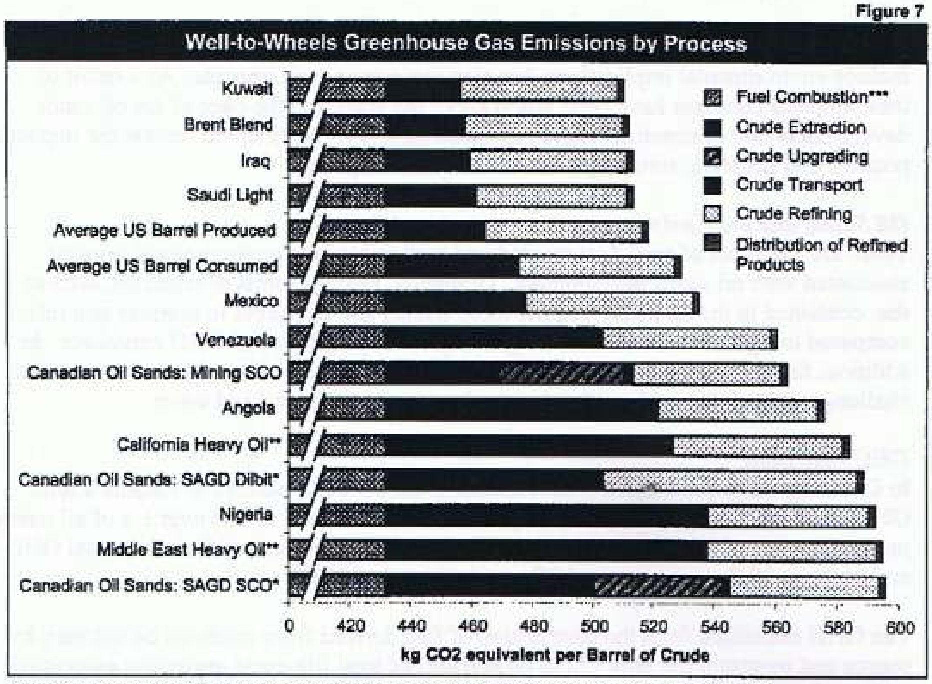
§§§ Energy production includes Electricity and Heat Generation, Fossil Fuels Industries, Mining and Oil & Gas Extraction, Transportation Pipelines, and Fugitive Sources.

In recent years, life-cycle analysis has become an increasingly popular tool for comparing different crude oil pathways, which includes the source and level of GHG emissions arising from crude oil production through to consumption/combustion. This area of research is relatively new, and is sensitive to the operations investigated and fuels compared[19]. As a result, different assumptions have generated a range of GHG intensities for oil sands crude[20,21,22]. A meta-analysis by IHS Cambridge Energy Research Associates[23] using 11 different studies found that on a wells-to-tank basis oil sands crude oil production can be up to 2 times more GHG intensive than the average basket of crude oil consumed in the United States. However, the same study also found that on a total life-cycle or wells-to-wheels, basis, oil sands derived crude oil is in the range of 5 to 15 percent more GHG intensive than the emissions of the average crude oil consumed in the United States (Figure 7).

Figure 7



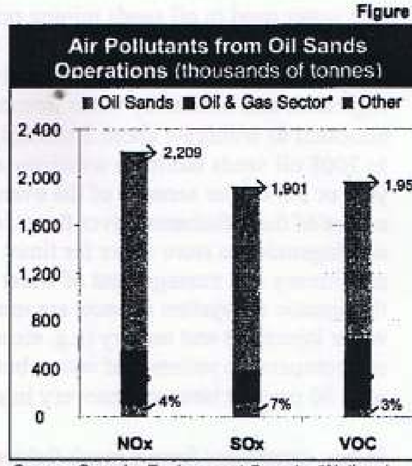
Source: IHS CERA (2009), "*Growth in the Canadian Oil Sands: Finding the New Balance*", Page III-5
*Assumes a steam-oil ratio of 3
**Assumes steam injection is used for production
*** Fuel combustion represents 73 to 85 percent of GHG emissions per barrel of crude or specifically 420 kg CO_2 equivalent per barrel of crude oil.

In the oil sands, in-situ operations are generally more GHG intensive; using large amounts of natural gas to generate steam required to heat the bitumen in place. In mining, extraction and upgrading operations, natural gas and other fuels are required to generate both the heat and electricity to run operations. Upgraders also contribute to GHG emissions through the hydrogen production processes. Hydrogen is used in the conversion of heavy oil components, the removal of sulphur and the stabilization of products, and in the heating of bitumen during coking to increase the hydrogen-carbon ratio. While the industry has historically made significant reductions in GHG emissions intensity of crude oil production, falling 39 percent from 1990 to 2008[24], absolute GHG emissions from the oil sands industry will likely continue to rise - due to anticipated production increases. In the immediate term there is expected to be similar levels of growth in mining and in situ operations, but over the longer term it is expected that since most oil sands deposits are suited for in-situ operations, these new emissions will largely come from increased steam generation from new in-situ operations

The Government of Canada has committed to reducing GHG emissions by 17 percent below 2005 levels by 2020. In order to achieve this objective, GHG emissions will have to be reduced from business as usual forecasts across most if not all sectors of Canada's economy. At the provincial level, Alberta was the first province to implement mandatory GHG reductions and institute a carbon levy which they expect to ratchet up over time. Currently the levy is at $15 per tonne with the revenue generated being redistributed towards clean energy research and development projects.

Experimental alternative extraction technologies, such as the use of solvents in the place of steam, or in-situ combustion, could dramatically reduce GHG emissions associated with in-situ oil sands operations, but these are yet to be proven on a large scale. Governments and industry are also investing in carbon capture and storage to reduce GHG emissions across the chemical, petroleum and electricity sectors. Several projects, involving heavy oil upgraders are advancing and show promise****, but large scale applications in oil sands operations still face a number of challenges. These challenges include the high cost of capturing carbon dioxide (CO_2) from numerous and diffuse sources, along with the infrastructure requirements to transport CO_2 from oil sands facilities to storage sites. CCS projects across all sectors also face challenges, including those related to costs, legal and regulatory frameworks and public acceptance.

Figure 8



Source: Canada, Environment Canada, *"National Pollutant Release Inventory"*, http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm - *accessed on March 23, 2010*

*Includes oil sands mining off-road diesel vehicles

**Does not include downstream emissions

Air Pollutants

In 2007, the oil sands were responsible for about 3 to 7 percent of air pollutants in Canada[25], depending on the type of pollutant (Figure 8). The main air pollutants are nitrogen oxides (NO_X) and sulphur dioxides (SO_X). Emission sources from oil sands facilities include the mobile mining fleet (i.e. trucks etc.), boilers, heaters, turbines and desulfurization plants at upgraders. Tailings ponds, fugitive

**** Shell Quest CCS Project, Aquistore Project, Husky Mervin CO_2-EOR and the proposed North West Upgrader.

emissions, storage tanks and the mine-face are the main sources of Volatile Organic Compounds (VOC), low levels of benzene (C_6H_6) and some levels of GHG emissions.

Water Use

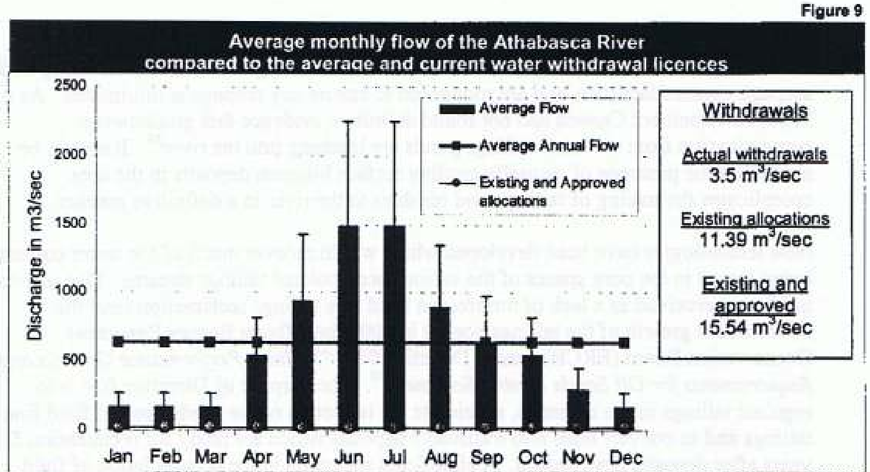
Water is used in oil sands operations to separate the bitumen from the oil sands and in the creation of hydrogen to upgrade the oil and remove impurities. Although most of the water used for separation processes is recycled and reused in the extraction process, there are a number of environmental concerns associated with water usage in the oil sands sector. These concerns include the potential for negative impacts on the aquatic ecosystem from the removal of water from the watershed (surface and groundwater), the creation and expansion of large tailings ponds, and the risk of unplanned releases of contaminants. There is also concern, that the cumulative impacts from expanding and new operations could overwhelm the existing aquatic environment.

In mining operations, it takes approximately 12 to 14 barrels of water to produce one barrel of bitumen. Although most of this is recycled, about 3-4 barrels of water becomes suspended in the tailings and is unavailable for reuse, and has to be made up with "new" water. In other words, oil sands mining operation require about 3-4 barrels of "new" water per barrel of bitumen produced. Much of the unavailable water gets trapped in the pore spaces of the settled solids left over from the extraction process (the exact amount of water depends on the properties of the oil sands ore). Tailings ponds help separate the water from the sand and clays, and provide a large quantity of water at a sufficient level of quality for the extraction process.

The water used in oil sands mining operations comes from the ore, the mine site, rainfall accumulation, but the main source of water comes from Athabasca River watershed of local tributaries and the Athabasca River itself. River water withdrawals are closely regulated, and limited by water licences. All existing and approved oil sands projects are allocated to withdraw about 3 percent of the average annual flow of the Athabasca River. In 2008 oil sands facilities withdrew about 0.7 percent (114 million cubic metres (m^3) per year or 3.5 m^3 per second) of the average annual flow[26] (Figure 9). Given the seasonal nature of the Athabasca River flows, newer oil sands operations are planning contingencies to store water for times when River withdrawals may be limited. Overall, monitoring and management of water use in surface mined oil sands can help ensure that the aquatic ecosystem impacts are minimized. Other operations, such secondary (e.g. water injection) and tertiary (e.g. steam injection) conventional oil recovery methods can use comparable volumes of water, but recover only a fraction of the resource (there is over 90 percent bitumen recovery in surface mined oil sands).

In-situ operations form a much tighter closed loop of water operations than surface mines. Water is converted to steam in boilers, the steam is injected in the oil sands formation, it condenses with the bitumen and both the water and bitumen are recovered back to the surface. Once back on the surface the water is separated from the bitumen, treated and put back into the boilers to generate steam and so on. Once an in-situ facility is in full operation, they are able to recover and reuse about 90 of the water. The remaining 10 percent of the water is lost in the ground or during steam generation.

Figure 9



Source: Flow data from Alberta Environment submission to then Alberta Energy Utilities Board hearing, CNRL Horizon Project, 2003.
Water Allocation data from Alberta Environment (2009).

In-situ operations are increasingly moving to the use of saline/brackish groundwater sources to reduce impacts on surface water. However, the impacts of groundwater withdrawals and re-injection of process water from in-situ operations back into the ground is still being studied.

Alternatives to water-based extraction processes could reduce water dependency for next generation oil sands production technologies; however, these could replace water issues with significant air emissions, either from solvents which might be used or from sulfur dioxide from thermal processes.

Tailings Ponds

Tailings ponds are created at oil sands mining operations from the leftover water, clay and sand of the bitumen separation process. In the over 40 years of commercial development of the oil sands, over 840 million cubic meters of a clay tailings or waste product known as mature fine tailings has accumulated, covering an estimated area of 170 km^2 [27].

The materials within the tailings ponds can take years to settle out and as a result, are placed in large, shallow pools. This allows the sediment (clay, sand and residual bitumen) to settle to the bottom of the pond, enabling the water on top to be skimmed off and reused in extraction operations. The zero discharge policy of the surface mined oil sands operations means that tailings, and especially the fluid fine tailings, continue to accumulate, along with the associated water. Fluid fine tailings are generally defined as the clay and silt suspension that cannot be used in the extraction process.

Concerns have been raised about the potential seepage from the tailings ponds into the local ecosystem[28]. All tailings ponds are constructed with groundwater monitoring and seepage capture facilities, and are monitored to ensure any seepage is minimized. As of 2008, Environment Canada had not found definitive evidence that groundwater contamination from oil sands tailings ponds are leaching into the river[29]. It should be noted that the presence of naturally eroding surface bitumen deposits in the area complicates the tracing of tailing pond residues to the river in a definitive manner.

New technologies have been developed which would recover much of the water currently being stored in the pore spaces of the various accumulated tailings streams. Due to what has been perceived as a lack of progress in fluid fine tailings reclamation (and the concomitant growth of the tailings ponds) in 2009 the Alberta Energy Resources Conservation Board (ERCB) passed Directive 074, "*Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes*"[30]. The purpose of Directive 074 is to regulate tailings in the oil sands, accelerate the reduction of the production of fluid fine tailings and to convert fines into trafficable deposits which are ready for reclamation 5 years after deposits have ceased. A significant reduction in the accumulation of fluid tailings would result in dramatic improvements in recycling rates as water would be freed up for use in the extraction process. This would lead to a corresponding reduction of water withdrawals from the Athabasca River and would represent the first step in reclaiming tailings ponds areas.

According to the Pembina Institute and Water Matters, out of 9 tailings management plans submitted by 6 different companies to the ERCB, only 2 — the Fort Hills Energy mine and the Suncor Millennium/North Steepbank mine—indicate that their operations will be in full and immediate compliance with Directive 074[31]. The other operations have proposed alternative compliance time lines that are currently under review. This regulatory change to have tailings management monitored and regulated as closely as bitumen production and water use will have a significant positive impact on minimizing the environmental effects of oil sands development.

Land Use

Land use impacts differ between mining and in-situ operations. Mining operations require the removal of all vegetation and top soil to access the oil sands. These materials are stored for use later in reclamation purposes. This results in a large scale temporary removal of wildlife and wildlife habitat. In total about 4,746 km^2 of oil sands area are suitable for surface mining. To date, 602 km^2 of land has been affected by mining activity.

In-situ extraction methods are also associated with significant impacts on the affected ecosystems due to habitat loss and forest fragmentation. While in situ operations directly disturb less land than mining operation, some studies have shown that these operations may influence habitat in an area exceeding the direct impacts[32]. With that being said, since in-situ operation do not require the removal of soil nor the creation of tailings ponds, reclamation should be more readily achieved.

Due to the long time frames (e.g. 40 to 60 plus years) and massive scale of oil sands mining projects, reclamation of disturbed land does not happen quickly. The Province of Alberta requires companies to remediate and reclaim land after the oil sands have been extracted. However, techniques are still being developed, and the long term success of oil sands mining site reclamation is a subject of considerable debate. The reclaimed landscape is expected to be different than the original with the potential for end-pit lakes and less peat land. In its place it is expected the reclaimed areas will include forests, prairie, wetlands and other native vegetation to support various land uses such as forestry, wildlife and biodiversity and aboriginal traditional land use[33]. To date 67 km^2 is under active reclamation and 1 km^2 (a previous overburden storage site) has been certified as reclaimed. Although this seems to be a small area, the relatively early stages of oil sands development and the strict definitions for reclaimed land have made this a learning process for both the industry and regulators. Now that some sections have been mined out, larger areas of reclamation can occur and along with that activity technologies for reclamation should improve.

Cumulative Impacts

On an individual basis, the environmental impacts associated with an oil sands operation may be comparable to other natural resource operations, such as mining or conventional oil and gas production. However, on a cumulative scale there has been a significant amount of concern raised over the ability of the oil sands region to sustain the continued rapid expansion of oil sands development. Research is ongoing into oil sands impacts, both on an individual scale and on a cumulative scale.

Under the *Canadian Environmental Assessment Act* project proponents are required to include a cumulative impact assessment as part of the Environmental Assessment process. However, some argue that the project specific focus of the *Act* may not be effective at addressing cumulative effects which arise from a number of projects, rather than one in isolation. The Alberta Government, through its *Land Stewardship Act*, will create regional plans for the 7 watersheds in the province[34]. Each plan will review and establish regional thresholds and targets for a wide range of land, air, and water parameters. When completed the regional plans will form the basis for managing cumulative effects. Specific limits will be reflected in provincial regulatory permits issued for projects within a specific region.

Oil Sands and Socio-Economic Impacts

In addition to the environmental impacts, there are also important socio-economic affects, both positive and negative, which underscore the complexity of the oil sands. While the economic and environmental impacts are often the focus of discussion, the social impacts (discussed later) associated with oil sands development and the pace of develop are also important.

Economic Development

The energy sector is a major economic driver for Canada, accounting for 6.8 percent of Canada's GDP (2008)[35] and directly employing 276,000[††††] or about 1.9 percent of total

[††††] Does not include downstream petroleum product retailing.

direct employment in Canada[36]. In 2008, about 145,000 people were directly employed in the mining, oil and gas extraction sector, which includes the oil sands[37]. Regionally, the oil and gas industry is responsible for nearly 28 percent of Alberta's GDP[30] and employs nearly one in six Albertans[38].

From 1999 to 2008, an estimated $91 billion was invested in the oil sands industry. In 2008, estimated investment in the oil sands industry reached a record $20.7 billion. However, investment in the oil sands industry is expected to have declined to $13.5 billion in 2009[39]. Although oil sands production is higher-cost than more traditional oil production, the industry has been able to attract significant investment due the magnitude of the largely untapped resource, the lower exploration cost, proximity to the U.S. market, and the stability of operating in an open and accessible oil marketplace.

Figure 10

Oil Sands Contribution to Canada (over the next 25 years)

	Contribution to GDP ($ millions)	Thousand Person Years of Employment*
Alberta	1,574,530	8,817
Manitoba	11,548	215
Newfoundland & Labrador	2,055	43
Nova Scotia	3,256	63
Ontario	54,850	812
Quebec	23,172	376
Yukon Territory	423	6
Canada	1,738,259	11,419

Source: CERI (July 2009), "Economic Impacts of the Petroleum Industry in Canada"

*A person-year of employment means one person is employed full-time for one year.

With all this investment the oil sands has become a major economic driver for Alberta, Canada and North America. Aboriginal communities have also benefited from the economic development associated with oil sands activity. According to the Alberta Government as of 2008 there were over 1,500 Aboriginal people employed‡‡‡‡ by oil sands operations and the value of contracts between Aboriginal businesses and oil sands companies was $575 million[40].

Overall, oil sands development accounts for about 2 per cent of Canadian GDP and is forecast to grow. In 2007, oil exports alone generated nearly $70 billion for the Canadian economy. Currently the oil sands industry contributes towards 112,000 jobs across Canada[41] and according to the Canadian Energy Research Institute over the next 25 years it is expected to contribute over 11 million person years of employment§§§§ to Canada and $1.7 trillion to the Canadian economy (Figure 10)[42].

Energy Security

For geographic and economic reasons, Canada produces and exports oil in the West and imports oil in the East, although there is notable offshore production from the Atlantic coast. While Canada holds about 13 percent of the world's proven oil reserves, Canada has not nationalized its oil industry, has no government controlled national oil company, and is not a member of Organisation of the Petroleum Exporting Countries (OPEC).

‡‡‡‡ This does not include construction-related employment

§§§§ A person-year of employment is defined as one person being employed full-time for one year.

Canada, as an oil importer as well as an oil exporter, participates in international energy security arrangements under the North American Free Trade Agreement (NAFTA) and the IEA.

On balance, Canada is a large net exporter of crude oil, importing about 807 thousand barrels per day and exporting on average 1.88 million barrels per day in 2009[43]. Currently about half of the crude oil used by Canadian refiners comes from imports, with nearly half of that originating from OPEC member countries[44].

The IEA World Energy Outlook 2009 reference case scenario predicts that, between now and 2030; oil demand will continue to grow by 1 percent annually[45]. The IEA expects that most of this growth will come from developing nations such as China and India and not from Organisation for Economic Co-operation and Development (OECD) countries.

High spare production capacity gives the market comfort that adequate supply can be maintained even in the face of possible supply disruptions. The world presently has higher than normal excess production capacity[46], which was exacerbated by a drop in global demand resulting from the 2008/09 recession. Most economists expect the global market for oil to tighten again, and the world to remain dependent on a few large producing nations for future production growth.

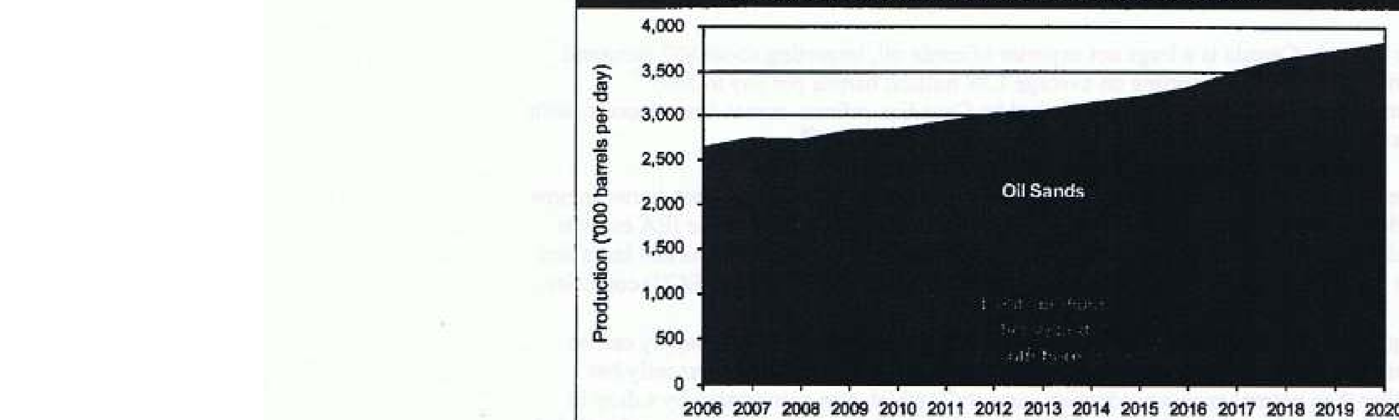
At the same time, Canada, unlike other non-OPEC is experiencing a significant increase in production due to rising oil sands output. Over the next 20 years, Canada's production of light conventional crude oil is anticipated to be halved. However, the rise in oil sands production is expected to more than offset the decline in conventional output. Production from other non-OPEC regions such as Mexico and the North Sea[*****] is also declining[47]. Without production from the oil sands, Canada and North America would increasingly be reliant on OPEC suppliers.

With 170 billion barrels of currently accessible crude oil[48], the oil sands are one of a few, largely untapped, sources of crude oil in the world, and the only source in North America currently capable of making large scale contributions to overall energy security. The NEB forecasts oil sands production (Figure 11) could increase from 1.2 million barrels per day in 2008 to 2.8 million b/d by 2020[49].

[*****] Includes: Denmark, Germany (offshore), Netherlands (offshore), Norway and United Kingdom (offshore).

Figure 11

Forecast Breakdown of Canadian Crude Oil Production



Source: Canada. National Energy Board (2009), "*Canada's Energy Future: Reference Case and Scenarios to 2030*," http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/nrgyftr-eng.html#s4, Table A3.14

Pace of Development

Over the past decade the Regional Municipality of Wood Buffalo, located in the heart of the Athabasca oil sands region, experienced tremendous population growth, more than doubling from about 43,000 in 1999 to 103,000 by 2008[50]. This level of growth taxes existing infrastructure and contributes to social impacts, regional inflation and lower productivity. The Government of Alberta allocated approximately $816 million ($396 million in February 2007 and $420 million in January 2008) to various projects in the Fort McMurray-Wood Buffalo region to alleviate the pressures of rapid growth associated with oil sands development and to enhance the quality of life of local residents. The recent economic downturn has eased this pressure, but it is expected that the pace of development will pick up as the economy recovers. Discussions are ongoing on how to better plan and prepare for oil sands development in anticipation of a return of significant investment as the economy recovers.

Health

Concern has been raised within the vicinity and downstream of oil sands mining operations regarding the potential deterioration of the local fish and wildlife as well as other ecosystem disturbances. Other concerns have been expressed about the rate of illness, particularly regarding the occurrence of certain types of cancer among the residents of the community of Fort Chipewyan. Fort Chipewyan is located on the western tip of Lake Athabasca adjacent to Wood Buffalo National Park, approximately 230 km North of Fort McMurray.

While some studies have found toxins in the water[51], determination of whether contaminants found in the local water are anthropogenic is difficult to discern due to the naturally occurring contact between oil sands and the local watershed. Research as well as regional monitoring has expanded. To date, ongoing regional water monitoring has not found evidence to indicate an increase in the level of water toxicity, which has remained within acceptable parameters. Governments continue to study this issue and Environment Canada is investing in new technology which should be able to determine the nature of the reported toxicity[52].

A number of factors can influence the occurrence of illness; this includes environmental and hereditary factors such as air, water, diet, lifestyle as well as family history and genetics. As of 2008, Health Canada and Alberta Health and Wellness had not found sufficient evidence to "substantiate elevated incidence of disease and autoimmune illness in Fort Chipewyan"[53]. The Alberta Cancer Board and Alberta Health and Wellness continue to study the issue and to investigate community illness rates.

Traditional Aboriginal Land Use

There are "17 First Nations with a combined population of 16,000 people living on-reserve and 6 Métis settlements with approximately 6,000 residents" living within the oil sands areas[54]. Aboriginals groups whose traditional lands are in close proximity to oil sands development, particularly within the Athabasca region have expressed concerns similar to those of other residents and environmental groups regarding public health, the pace of development, and environmental impacts. However within the Aboriginal context they have additional concerns with how these impacts may affect their traditional activities.

Aboriginal and Treaty Rights have been enshrined in the Constitution of Canada. Subsequent interpretations of these rights have determined that the Crown owes a duty to consult aboriginal groups if it contemplates conduct which could adversely impact them. Federal and provincial governments share responsibility to consult aboriginal groups depending on the nature of the potential impact. Both have developed policies to help ensure aboriginal concerns are heard and their rights are respected with respect to resource development. Beaver Lake and some other First Nations and Metis groups have also expressed the view that governments may not have upheld their responsibility to consult aboriginal groups on oil sands development. Litigation articulating the concerns of Beaver Lake First Nation in particular is being advanced which cites the cumulative effects, amongst other concerns resulting from several years of oil sands development on their traditional activities[55].

Conclusion

This paper has outlined some of the benefits and challenges around the development of the oil sands in Canada. The scale and of the resources and the impacts associated with its development have put the oil sands at the nexus of the debate around our desire for sustainable development and our current reliance on fossil fuels. Given the importance of the oil sands to North America's economy and to energy security, both the Governments of Canada and Alberta are seeking better ways to manage oil sands development and mitigate the environmental and social challenges.

For the most part, the story around oil sands development has been driven by technological innovation. Innovation first made oil sands production commercially viable, then it was used to bring down production costs and expand reserves. Today, governments and industry are investing significantly in technologies that will reduce the environmental impacts of oil sands development. Governments are also developing more stringent regulations to drive the commercialization of new technologies in the sector.

Canada, as both a leading energy producer and importer, is challenged with developing energy policies capable of driving a transition to a lower-carbon economy, while also making fossil fuels "cleaner". This balance is needed to continue the viability of resources that are required to meet energy demand and provide exports, which also provide livelihoods to Canadians and tax revenues for governments. While the growing scale of oil sands development has brought increasing attention to its impacts, it is also important to assess these impacts to those of other sources of crude oil. For the future, the pace of oil sands development – and public acceptance – may be a function of how quickly industry can bring new technologies to bear to address the environmental impacts by reducing GHG emissions, decreasing water use, limiting tailings ponds, etc.

References

[1] U.S. Energy Information Administration (2009), "*International Petroleum (Oil) Reserves and Resources*", http://www.eia.doe.gov/emeu/international/oilreserves.html - *accessed February 9, 2010*

[2] U.S. Census Bureau, "*State & Country Quickfacts*", http://quickfacts.census.gov – *accessed June 21, 2010.*

[3] Alberta. Energy Resources Conservation Board (2010), "*Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2010-2019,*" Report ST98-2010, http://www.ercb.ca/docs/products/STs/st98_current.pdf (page 2)

[4] Alberta. Energy Resources Conservation Board (2010), "*Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2010-2019,*" Report ST98-2010, http://www.ercb.ca/docs/products/STs/st98_current.pdf (page 2)

[5] International Energy Agency (2009), "*World Energy Outlook 2008*", Reference Case Scenario (page 92)

[6] Alberta. Energy Resources Conservation Board (2010), "*Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2009-2018,*" Report ST-98, http://www.ercb.ca/docs/products/STs/st98_current.pdf (page 2-2)

[7] Alberta. Energy Resources Conservation Board (2010), "*Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2010-2019,*" Report ST98-2010, Table 2.2, http://www.ercb.ca/docs/products/STs/st98_current.pdf (page 2-3)

[8] Alberta. Alberta Environment (September 2009), "*Environmental Management of Alberta's Oil Sands,*" http://environment.gov.ab.ca/info/library/8042.pdf - *accessed on June 17, 2010*

[9] Alberta Online Encyclopedia, "*Alberta's Heroes of Resource Development: Sydney Ells,*" http://www.abheritage.ca/abresources/history/history_heroes_hydro_ells.html - *accessed March 9, 2010*

[10] Alberta Online Encyclopedia, "*Alberta's Heroes of Resource Development: Karl Clark,*" http://www.abheritage.ca/abresources/history/history_heroes_hydro_clark.html - *accessed March 9, 2010*

[11] Imperial Oil, http://www.imperialoil.ca/Canada-English/ThisIs/Operations/TI_O_OilSands.asp - *accessed March 8, 2010*

[12] Alberta. Alberta Innovates, http://www.albertainnovates.ca/energy/about-us/history - *accessed June 17, 2010*

[13] Canada. Natural Resources Canada (November 2008), "Canadian Refining and Oil Security," http://www.nrcan.gc.ca/eneene/sources/petpet/refstrarafsur-eng.php, Section 7.5 – *accessed June 29, 2010*

[14] U.S. Energy Information Administration, "*Crude Oil Input Qualities,*" http://tonto.eia.doe.gov/dnav/pet/pet_pnp_crq_a_EPC0_YCG_d_m.htm - *accessed February 9, 2010*

[15] Canada. National Energy Board (2009), "*Canada's Energy Future: Reference Case and Scenarios to 2030*", http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/nrgyftr-eng.html#s4

[16] Canada. Environment Canada (2010), "*National Inventory Report 1990-2008: Greenhouse Gas Sources and Sinks in Canada,*" http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=492D914C-2EAB-47AB-A045-C62B2CDACC29, (Table A8-2)

[17] Canada. Environment Canada (2010), provided by request

[18] IHS CERA (2009), "*Growth in the Canadian Oil Sands: Finding the New Balance,*" http://www.cera.com/aspx/cda/client/knowledgeArea/serviceDescription.aspx?KID=228, (Page III-2)

[19] Alex D. Charpentier; Joule A. Bergerson; Heather L. MacLean (2009), "*Understanding the Canadian Oil Sands Industry's Greenhouse Gas Emissions,*" Environmental Research Letters, (Vol. 4 No. 1)

[20] Jacobs Consultancy Life Cycle Associates prepared for Alberta Energy Research Institute (July 2009), "*Life Cycle Assessment Comparisons of North American and Imported Crudes,*" http://www.albertainnovates.ca/energy/major-initiatives/lca

[21] U.S. National Energy Technology Laboratory (November 2008), "*Development of Baseline Data and Analysis of Life Cycle Report Greenhouse Gas Emissions of Petroleum-Based Fuels,*" http://www.netl.doe.gov/energy-analyses/pubs/NETL%20LCA%20Petroleum-Based%20Fuels%20Nov%202008.pdf

[22] Canada. Natural Resources Canada prepared by (S&T)[2] Consultants Inc. (March 2007) "*2007 Crude Oil Production Update for GHGenius*," http://www.ghgenius.ca/reports/2007CrudeOilUpdateReport.pdf
[23] IHS CERA (2009), "*Growth in the Canadian Oil Sands: Finding the New Balance,*" http://www.cera.com/aspx/cda/client/knowledgeArea/serviceDescription.aspx?KID=228 (Page V-2)

[24] Canada. Environment Canada (2010), "*National Inventory Report 1990-2008: Greenhouse Gas Sources and Sinks in Canada*," http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=492D914C-2EAB-47AB-A045-C62B2CDACC29, (Part I Page 69)
[25] Canada. Environment Canada (2009), "*National Pollutant Release Inventory,*" http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm - *accessed on March 23, 2010*

[26] Canada. Alberta Environment, provided by request.

[27] Alberta. Energy Resources Conservation Board (June 17, 2010), "*New Release: ERCB Conditionally Approves Suncor Plan to Reduce Fluid Tailings*," http://www.ercb.ca/docs/new/newsrel/2010/nr2010-08.pdf - *accessed June 29, 2010*
[28] Environmental Defence (2008), "*11 Million Litres a Day: The Tar Sands' Leaking Legacy*," http://www.environmentaldefence.ca/reports/pdf/TailingsReport_FinalDec8.pdf - *accessed June 21, 2010*

[29] Canada. Office of the Auditor General of Canada (2008), "*Response to Petition No. 238,*" http://www.oag-bvg.gc.ca/internet/English/pet_238_e_30190.html - *accessed June 21, 2010*

[30] Alberta. Energy Resources Conservation Board (2009), "*Directive 074,*" www.ercb.ca/docs/documents/directives/directive074.pdf - *accessed June 23, 2010*

[31] Pembina Institute and Water Matters (2009), "*Tailings Plan Review*", http://pubs.pembina.org/reports/tailings-plan-review-report.pdf - *accessed May 21, 2010*

[32] Sarah M Jordaan, David W Keith and Brad Stelfox (2009), "*Quantifying land use of oil sands production: a life cycle perspective*" Environmental Research Letters, (Vol 4 No. 2)

[33] Alberta. Alberta Environment prepared by Cumulative Environmental Management Association (2006), "*Land Capability Classification System for Forest Ecosystems in the Oil Sands, 3rd Edition*" http://www.cemaonline.ca/index.php/cema-recommendations/land-capability - *accessed June 21, 2010*
[34] Alberta. Alberta Sustainable Resource Development, Land-use Framework, http://www.landuse.alberta.ca/AboutLanduseFramework/Default.aspx - *accessed June 15, 2010*

[35] Canada. Statistics Canada (2008), CANSIM, (Table 228-0003)

[36] Canada. Natural Resources Canada, "Important Facts on Canada's Natural Resources," http://www.nrcan-rncan.gc.ca/stat/index-eng.php - *accessed June 30, 2010*
[37] Alberta. Department of Energy, http://www.energy.alberta.ca/OilSands/791.asp

[38] Alberta. Department of Energy, http://www.energy.alberta.ca/OurBusiness.asp

[39] Canada. Statistics Canada (2010), "*Private and public investment*," http://www.statcan.gc.ca/pub/61-205-x/61-205-x2010000-eng.pdf, (Table 2-2 Non-Conventional oil extraction: capital expenditures) - *accessed June 29, 2010*

[40] Alberta. Alberta Environment, "*Factsheet: Aboriginal involvement in the oil sands*," http://oilsands.alberta.ca/documents/Aboriginal_fact_sheet.pdf - *accessed June 21, 2010*
[41] Canadian Association of Petroleum Producers (Sept 2009), "*Oil Sands: An Important Asset Generating Benefits Across Canada*," http://www.capp.ca/getdoc.aspx?DocId=159087&DT=NTV – *accessed February 15, 2010*

[42] Canadian Energy Research Institute (July 2009), "*Economic Impacts of the Petroleum Industry in Canada*," http://www.ceri.ca/#EconomicImpactsofthePetroleumIndustryinCanada

[43] Canada. Statistics Canada, "Energy Statistics Handbook, First Quarter, 2010," http://www.statcan.gc.ca/pub/57-601-x/57-601-x2010001-eng.pdf

[44] Canada. Natural Resources Canada, "*Crude Oil Market*," http://www.nrcan.gc.ca/eneene/sources/crubru/tracom-eng.php - *accessed March 9, 2010*

[45] International Energy Agency (2009), "*World Energy Outlook 2009*," Reference Case Scenario (page 81)

[46] International Energy Agency (June 2010), "*OPEC spare capacity estimated at 6.06 million barrels per day in May 2010*", Oil Market Report, (Page 20)

[47] U.S. Energy Information Administration, "International Energy Statistics," Production, http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=&syid=1990&eyid=2009&unit=TBPD – *accessed June 21, 2010*

[48] Alberta. Energy Resources Conservation Board (2009), "*Alberta's Energy Reserves 2008 and Supply/Demand Outlook 2009-2018*," Report ST-98, http://www.ercb.ca/docs/products/STs/st98-2009.pdf

[49] Canada. National Energy Board (2009), "*Canada's Energy Future: Reference Case and Scenarios to 2030*," http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/nrgyftr-eng.html#s4, (Table A3.14: Oil Production Outlook by Province),

[50] Regional Municipality of Wood Buffalo, "Municipal Census," http://www.woodbuffalo.ab.ca/business/demographics/demographics.asp - *accessed February, 10 2010.*

[51] Erin N. Kelly, Jeffery W. Short, David W. Schindler, Peter V. Hodson, Mingsheng Ma, Alvin K. Kwan, and Barbra L. Fortin (2009), "*Oil Sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries,*" National Academy Science U S A. 2009 Dec 29;106(52):22346-51.

[52] Canwest News Service (June 21, 2010), "*$1M Machine May Settle Debate Over Toxins*," http://www.financialpost.com/todays-paper/machine+settle+debate+over+toxins/3180943/story.html - *accessed June 23, 2010*

[53] Canada. Office of the Auditor General of Canada (2008), "*Response to Petition No. 238*," http://www.oag-bvg.gc.ca/internet/English/pet_238_e_30190.html - *accessed June 21, 2010*

[54] Alberta. Alberta Environment, "*Factsheet: Aboriginal involvement in the oil sands*," http://oilsands.alberta.ca/documents/Aboriginal_fact_sheet.pdf - *accessed June 21, 2010*

[55] Beaver Lake Cree Nation (May 14, 2008), "*Press Release: Beaver Lake Cree Nation Draws a Line in the (Oil) Sand*," http://www.beaverlakecreenation.ca/ - *accessed June 14, 2010*