A Symbiotic System Approach for the Development of Canadian Oil Sands

And The Potential For Positive Impact On The Decision To Build The Keystone Pipeline

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**Abstract**

We propose a symbiotic systems approach for the development of Canadian Oil Sands. We show, for example, if 20% of Canadian Oil Sands income were to be invested in renewable-energy machines as part of reclamation efforts for the land that is mined, then three significant results can follow. First, we estimate that in 50 years as much CO2 will have been kept from the air from burning coal to make electricity as was released into the air from mining the oil sands and consuming the oil. Second, this proposed investment can be regarded as a better alternative to a “Carbon Tax”. Finally, we show that in a period of excess electricity power generation, the power can be sold back to the grid, power electric underground heaters for liquefying bitumen for extraction without mining operations, or to power operations for cleaning contaminated water of Poly-Aromatic Hydrocarbons (PAH) which can then be hydrocracked into useful compounds.

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# 1 Introduction

## 1.1 Motivation

Beneath the boreal forest in Northern Canada lies the world's 2nd largest oil reserve, known as the oil sands. The oil sands are a mixture of sand and a heavy crude oil called bitumen. Natural bitumen is reported in 598 deposits in 23 countries, with the largest deposits in Canada, Kazakhstan, and Russia. Bitumen reserves are estimated at 249.67 billion barrels out of which 178 billion barrels (70.8%) are in Canada (Alberta) [1].

The Northern Alberta region contains 98% of the Canadian oil sands and they are divided into three regions:

* The Athabasca-Wabiskaw deposits region
* The Cold Lake deposits regions
* The Peace River deposits region

Together, they cover 140,200 square kilometers [2]. It is also estimated by the Government of Canada that these regions hold proven reserves up to 1.75 trillion barrels of bitumen in place [9]. In addition, 173 billon barrels (10%) estimated to be recoverable at current prices using current technology.

Detractors hypothesize that mining, processing, and using the oil from the oil sands will greatly exacerbate global CO2 problems, and extend this argument as a reason for the US to deny permission to grant approval for the Keystone XL pipeline. Proponents say that global CO2 impact will be no different than other sources of oil, and the pipeline is safer than rail shipments. In this paper, we demonstrate how reclamation efforts for mined oil sands land that focus on investment in Wind Turbines and Photovoltaic (PV) installations on the minded land not only could result in significant long term reduction of CO2 emissions by providing power for cleaner extraction methods and enabling coal fired power generation stations to be phased out, but also prove to be a profitable green option for the future of Alberta and the country.

## 1.2 Problem Observation

The Province of Alberta is currently operating a modest at best energy return per area invested. Alberta's Oil Sands are being mined over a vast area which will destroy large swaths of forests releasing even more carbon into the atmosphere while also generating large lagoons of heavily polluted water.

Poisson *et al* [17] recently demonstrated that since the 1990s, the total energy used (invested) in the Canadian oil and gas sector increased approximately 63%, while energy production (return) increased only 18% resulting in a decreased total energy return on investment (EROI) from 16:1 to 11:1. In the spirit of increasing the EROI from this vast resource, we present a possible better EROI for the area and the country.

**Hypothesis:**

*The effect of oil sands utilization on climate change does not have to be negative if, as part of land reclamation of the mined oil sands area, developers of the oil sands resource planned and invested for when the oil sands are depleted. One scenario could include for every square kilometer of land to be reclaimed, a 5 MW wind turbine is installed. The power from the turbine can be used for oil sands production, and it can also be sold to the grid or be used to clean contaminated water in moments of excess power generation. Another possible scenario could include 30% coverage of the land to be reclaimed by PV solar panels.*

Figure 1 below shows an example of the cumulative effect on CO2 emissions over the years of this land reclamation plan, with 50% of the total oil sands land area being reclaimed with wind turbine installations, with a policy of $0.05/kWh reinvestment in purchasing more wind turbines. Similar results are obtained with 30% of the area reclaimed using arrays of PV cells and similar reinvestment policy in purchasing more solar cells in Figure 2.

**Figure 1.** Amount of CO2 offset by $20/bbl investment in wind turbines based on $4/Watt installed, with a policy of $0.05/kWh for purchasing more wind turbines. This graph assumes 50% of the total oil sands land area being reclaimed with wind turbine installations. See the spreadsheet provided in supplemental materials to investigate different costs basis scenarios.

**Figure 2.** Amount of CO2 offset by $20/bbl investment in PV solar panels based on $4/Watt installed, with a policy of $0.05/kWh reinvestment for purchasing more solar cells, with up to a maximum of 15% efficiency. This graph assumes 30% of land area being reclaimed with PV solar cell installations. See the spreadsheet provided in supplemental materials to investigate different costs basis scenarios.

Both scenarios presented have oil sands developers to invest a portion of sales, $20/bbl into renewable energy production. In addition to improving EROI, this proposed investment represents an alternative to a carbon tax because companies are investing in their own future and they benefit from the power generated

This benefits the oil sands companies directly and immediately because they can use the electric power for production of the oil sands instead of having to build more transmission lines, or install mini nuclear reactors [23] to bring power in for which they then have to pay to use. Furthermore, once the number of turbines increases to a point, they can start sending power out on the same power lines they initially had installed to bring power in (are in the process of installing) to develop the oil sands.

# 2 Alberta's Oil Sands Analysis

## 2.1 CO2 Emissions Overview

Per day, oil sands operation release as much CO2 as all the cars in Canada

[8]. According to a report released in 2011 [3], production of oil sands released an estimated of 47.1 million metric tonnes of CO2 into the air. Considering that in 2011, 1.8 million barrels a day were produced, Table 1 estimates the CO2 emissions from oil sands production and oil use:

**CO2 from Oil Sands Production And Oil Use**

|  |  |
| --- | --- |
| **Production** | **Use** |
| Oil produced (Million barrels per year) | 693.5 |
| CO2 to produce the oil (Mega-tonnes/Year) | 50 |
| CO2 attributed to the mining | 0.07 |
| CO2 attributed to consumption of oil sands oil | 0.43 |
| CO2 from oil use (Mega-tonnes/Year) | 298.2 |
| **Total CO2 from Oil sands (Mega-tonnes/Year)** | **348** |

**Table 1.** Estimated total amount of CO2 from Oil Sands Production And Oil Use

## 2.2 The Keystone XL Pipeline

The pipeline is a major milestone in the next phase of extracting oil sands under Canada's Boreal Forest to reach higher prices of overseas markets.

The projected impact of Keystone XL by the U.S Department of State in the “Final Environmental Impact Statement” (FEIS) [4] is stated as:

* Projected 830,000 barrels/day flow
* An additional 147 to 168 million metric tons of greenhouse gas emissions would be annually released

The Canadian Association of Petroleum Producers (CAPP) 2013 Crude Oil Forecast, Markets and Transportation forecasts Canadian crude oil production will more than double to 6.7 million barrels per day by 2030 from 3.2 million barrels per day in 2012. This includes oil sands production of 5.2 million barrels per day by 2030, up from 1.8 million barrels per day in 2012 [19]. Meanwhile, the Environment News Service reported two senators called the Secretary of State John Kerry and the Obama Administration to conduct “an immediate and comprehensive study" of the public health risks to communities from the proposed Keystone XL pipeline would carry diluted bitumen from Alberta across the US-Canada border to refineries on the Texas Gulf Coast [5].

These opposing points of view may be resolved, we hypothesize, with renewable electric power and long term CO2 reduction that would result from the reclamation methods proposed in this paper.

Another benefit of generation significant electric power in-situ is reduced pipeline pumping costs. It has been estimated current transport costs including extra lubricants needed to pump the thick oil through thousands of miles of pipeline add about $18 a barrel to get oil sands crude from Western Canada down to the Gulf Coast on the Keystone XL [26]. If plentiful electric power were available, the case could be made for at least partially refining the oil on site so lighter crude could be more easily pumped through the pipeline.

# 3 Oil Sands EROI Analysis

## 3.1 Oil Sands EROI Overview

Higher oil prices have boosted oil sands revenues, but operating costs have also increased significantly with the rise in energy prices. Currently the cost of production of a barrel of oil sand is in the $40/bbl range and capital costs add another $10-$20/bbl [21].

Natural gas requirements for the oil sands industry are projected to increase to 2.1 billion cubic feet per day in 2015 [22]. Natural gas is combusted on site to fuel steam generation units to provide steam which is pumped underground to reduce the viscosity of the bitumen so it can then be more easily extracted, and the process bitumen that is mined. However, the use of natural gas exposes production to economic risk through the highly variable nature of natural gas cost. In addition, natural gas combustion for steam production is the primary source of greenhouse gas emissions for an in-situ project [24]. If natural gas prices increased to $8/GJ, transportation cost would increase to $6.30 per barrel [28].

High natural gas prices have encouraged companies to use natural gas more efficiently and to look for alternative fuels. Many attempts have been made in the past to show how nuclear power may be used to supply the energy demand created by the growth of development in the oil sands regions, including installation of newly proposed Molten Salt Nuclear Reactors [24]. In 2013, there was discussion about including mini nuclear reactors from Toshiba to mine oil sands with the initial deployment projected by 2020 [23].

We propose a better EROI by investing in renewable energy systems emplaced on land to be reclaimed from mining activities. In the short term, companies would be able to insert electric heaters in the ground to make the oil flow instead of having to inject steam, and at least refining of the heavy oil could be done so it could be sent through the pipeline in lighter form. In the long term, it would be possible to send power generated out along the power lines that recently have been built to provide power to the oil sands region, thus enabling coal-fired power plants in the other regions to be phased out.

## 3.2 CO2 Offset by Investing in Wind Energy

The installation of one 5MW wind turbine per square kilometer in a total of

70,100 kilometers square land area (50 % of the Alberta Oil sands area), would require an investment of about 20% of the portion of oil sales (e.g., $20/bbl with $0.05/kWh reinvestment into purchasing more wind turbines). The number of wind turbines installed would grow rapidly over the years, which would offset the CO2 created by mining and using the oil sands oil in approximately 54 years.

Furthermore, it is common for the return on investment (ROI) period for a wind turbine to be about 10 years [33], which means the $20/bbl invested is actually fully recouped in 10 years and then onward the wind turbine becomes a net income producer [33].

Installing wind turbines in this region also need not reduce the amount of forest being replanted given tall towers because the surface footprint of a large wind turbine is relatively small. Comparing the net carbon captured by the forest area of a turbine’s footprint compared to the carbon offset of a turbine, we find that the CO2 captured from the boreal forest is about 26.2 tonnes/km2 [13] compared to a CO2 offset by having a large wind turbine, which saves 8500 tonnes/year/MW by not burning coal to produce energy generated by wind. Therefore, there is a strong motivation for oil sands land mining reclamation to not to just replant the forest, but to plant forest *and* a large high hub height wind turbine every square kilometer.

Figure 3 and Figure 4 show different scenarios for different percentage of investments.

**Figure 3.** Amounts of CO2 offset with different investments in Wind Energy, assuming a life expectancy of 20 years, and a $0.05/kWh reinvestment into purchasing more wind turbines.

**Figure 4.** Amounts of CO2 offset with different investments in Wind Energy, assuming a life expectancy of 20 years, and a $0.07/kWh reinvestment into purchasing more wind turbines.

**Technical Details**

|  |  |
| --- | --- |
| **Description** | **Value** |
| Turbine Peak Power (MW) | 5 |
| Capacity factor | 40% |
| Land area per turbine (km2) | 1 |
| Percent land area for wind turbines | 50 % |
| Area of wind farm (km2) | 70,100 |
| (Square Miles) | 27,383 |
| Square size (miles x miles) | 165 |
| Number of turbines to be built for land area | 70,100 |
| Average Power generated (GW) | 198 |
| Average annual energy produced (TWHr) | 1,734 |
| **CO2 saved by wind turbines (mega tonnes/year)** | **1,684** |

**Table 2.** Amount of CO2 saved by Wind Turbines

**Estimated Results for Wind Energy**

|  |  |  |
| --- | --- | --- |
|  | **Reinvestment Policy** | |
| $0.05/kWh | $0.07/kWh |
| **Investment Amount**  **($/bbl)** | **Estimated Time**  **(Years)** | **Estimated Time**  **(Years)** |
| 10 | 113 | 61 |
| 15 | 73 | 48 |
| 20 | 54 | 39.5 |
| 25 | 43 | 34 |
| 30 | 36 | 30 |

**Table 3.** Estimated timeline for 100% CO2 offset for Wind Energy with a $0.05/kWh Reinvestment Policy or a $0.07/kWh Reinvestment Policy, and the $X amount allocated to wind energy.

These above results are dependent on three parameters: the percentage of investment per barrel of oil sand ($/bbl), the life expectancy of wind turbines, and the reinvestment amount for new equipment ($/kWh). If we invest the same amount each year eventually we hit a steady state for number of turbines vs. carbon emissions. The ability to achieve a 100% offset is very sensitive to the $/kWh reinvestment. For example, with 20-year life expectancy and $0/kWh of reinvestment we need the percentage of investment per barrel to be bigger than $45/bbl to reach 100% ever.

**Assumptions**

* **Wind Turbine Peak Power**
  + The choice of 5 MW/km2 is conservative as forthcoming are 7 MW turbines, although they will require larger spacing. Even 10 MW turbines are under consideration for production.
* **Wind Turbine Capacity Factor**
  + NRELs median capacity factor to be 40% for onshore wind turbines
  + With higher hub heights increasing, up to 140m, wind turbine net capacity factor could rise to 50%
* **Land area per turbine**
  + Land area assumed to cover 1 km2 per turbine, many wind farms actually place up to two turbines in this area.
* **Percent land area for wind turbines**
  + Assumption to cover 50% of the total Alberta oil sands area
* **Reinvestment Policy** 
  + Assumption to reinvest $0.05/kWh or $0.07/kWh into wind equipment purchasing. This also includes the maintenance of wind turbines

## 

## 3.3 CO2 Saved from Investing in Solar Energy

If one were to invest 20% of the portion of oil sales (e.g., about $20/bbl for this scenario) covering 30% of the total PV Solar area farm (15% of the total Oil Sand Region), then this approach would in fact never offset the CO2 created by mining and using the oil sands oil. This is due to the decommission period of the solar panels. The panels are never cost effective enough to offset the CO2 emitted.

Figure 5 and Figure 6 show different scenarios for different percentage of investments.

**Figure 5.** Amounts of CO2 offset with different investments in Solar Energy, assuming a life expectancy of 25 years, and a $0.05/kWh reinvestment into purchasing more solar panels.

**Figure 6.** Amounts of CO2 offset with different investments in Solar Energy, assuming a life expectancy of 25 years, and a $0.07/kWh reinvestment into purchasing more solar panels.

**Technical Details**

|  |  |
| --- | --- |
| **Description** | **Value** |
| Percent land area assumed covered by PV fields | 15% |
| Area of PV farm (km2) | 14,020 |
| (Square miles) | 5,477 |
| Square size (miles x miles) | 74 |
| Density of coverage on land designated for PV fields | 30% |
| Area of PV cells (m2) | 6,309,000,000 |
| PV cell efficiency | 15% |
| Average 24/7 solar insolation April (Wh/m2/day) |  |
| June | 6,250 |
| January | 1,389 |
| Average power (assumes 24/7 operation made possible with storage technology) (GW) |  |
| June | 164 |
| January | 37 |
| Average | 100.405 |
| **CO2 saved by not burning coal to produce energy generated by solar (Mega-tonnes/year)** | **854** |

**Table 4.** Amount of CO2 saved by not burning coal to produce energy by Solar

**Estimated Results for Solar Energy**

|  |  |  |
| --- | --- | --- |
|  | **Reinvestment Policy** | |
| $0.05/kWh | $0.07/kWh |
| **Investment Amount**  **($/bbl)** | **Estimated Time**  **(Years)** | **Estimated Time**  **(Years)** |
| 10 |  |  |
| 15 |  |  |
| 20 |  |  |
| 25 |  |  |
| 30 |  |  |

**Table 3.** Estimated timeline for 100% CO2 offset for Wind Energy with a $0.05/kWh Reinvestment Policy or a $0.07/kWh Reinvestment Policy, and the $X amount allocated to solar energy. Total offset never reached.

Similarly, the behavior of these results are controlled by the ($/bbl) investment, the life expectancy of the solar cells, and the ($/kWh) reinvestment into purchasing more solar cells. The assumptions here are reasonable, but readers can investigate the results from other values using the spreadsheet provided as part of the supplemental materials.

**Assumptions**

* **Peak Power of PV cell**
  + Assumption to be a 200W peak power solar photovoltaic panel.
* **Percent land covered by PV fields**
  + Assumption to cover 15% of land area
* **Density of coverage on land designated for PV fields**
  + Assumption to cover 30% of land area
* **Efficiency of PV fields**
  + For this analysis, OPV efficiency was estimated to be a conservative 15%.
  + PV cell efficiency is expected to reach 23% by 2015 [20]
* **Cost of installation of PV fields**
  + Estimated to be $4/W installed
* **Reinvestment Policy**
  + Assumption to reinvest $0.05/kWh or $0.07/kWh into solar equipment purchasing. This also includes the maintenance of solar panels

## 3.3 CO2 offset Calculation

The CO2 offset percentage is obtained with the following formula:

To compute the amount of CRCS (Cumulative Ration Carbon Saved):

Where:

* from Table 2

To compute the standard CB (Carbon Burned) term:

Where:

* from Table 1

## 3.4 Possible Utilizations with Excess Power Generated

The biggest challenge in Alberta’s Oil Sand industry is that there are not enough pipelines to transport the oil to Western Canada and Southern U.S. refiners. Consequently, much of the oil is finding its way out of Alberta on trains and even trucks, which can be [two or three times more expensive](http://www.businessweek.com/articles/2013-06-13/amid-u-dot-s-dot-oil-boom-railroads-are-beating-pipelines-in-crude-transport) than pipeline costs [26]. The Keystone XL environmental review included a wide variety of cost estimates that with rail shipments to the Gulf Coast, it costs between $15-$20 a barrel [27]. This further justifies the investment in renewable energy systems as part of land reclamation if it helps overcome objections to the Keystone XL pipeline

**Selling Electricity Back to the Grid**

About 41 percent of Alberta’s installed electricity generation capacity is from coal, almost 40 percent from natural gas, and almost 8 percent from wind [25]. On a long term basis, it would possible to send excess power generated by reclaimed land renewable energy systems out along same power lines that currently are bringing power into the oil sands region.

**Cleaning Contaminated Water**

The Athabasca River is part of the third largest watershed in the world. Processing one barrel of bitumen requires approximately three barrels of water [8]. The contaminated water is then pumped into giant man-made tailings ponds alongside the shore with no plans for their eventual cleanup

The contaminated water is produced from the process used to turn bitumen into diesel and other fuels. Reservoirs filled with oil sands wastewater are predicted to cover almost 62,000 acres by 2020 [14].

These waters are contaminated with “[Polycyclic Aromatic Hydrocarbons](http://en.wikipedia.org/wiki/Polycyclic_aromatic_hydrocarbons)” or PAHs. These aromatic organic molecules can be hydrocracked by adding hydrogen to enable the PAHs to be turned into useful products such as plastics and pesticides. The renewable energy harvested by the wind and solar systems could be used to power the cracking process and clean up the contaminated water.

**Powering Underground Electric Heaters as an Alternative to Pumping Steam Underground for Bitumen Extraction**

Another use for the excess wind power could implement Shell Oil’s patent on installing heaters encased in pipe to liquefy the oil, so that it can be pumped to the surface [29]. Wind power varies with the wind, which is relatively slowly changing variable, while solar power can change suddenly with a passing cloud. In either case, to be part of a base load supply of power sent out along power lines, excess power must be stored immediately. The former can be accommodated over power lines with pumped storage hydro-systems or batteries. The latter is often more difficult, however underground electric heaters can use even wildly fluctuating power to lower bitumen viscosity so it can flow and be extracted from wells. The nature of the underground strata gives it a very long time constant to absorb and diffuse the energy [30,31].

## 3.5 An Alternative to a Carbon Tax

The percentage of oil revenues to be invested ($/bbl) into renewable energy systems as part of land reclamation efforts is a business and an environment friendly alternative to a carbon tax. Instead of paying a tax to the government, which removes value from a company ledger, this approach allows companies to invest in assets for its own present and future value, and thus could negate the perceived need by many for a carbon tax.

Currently, there are no tax incentives available that are specific to oil sands production. There may be industry-wide tax breaks, but they are the same for conventional oil production and for bitumen production [21]. On the other hand, the CO2-intensive nature of oil sands mining and production incites many to call for a carbon tax that could add at least $2 to a barrel of Western Canadian heavy crude, which President Obama might use as a concession to his base if he were to approve the Keystone XL [26].

Note there are about 0.5 tonnes of CO2 that can be attributed to the mining (0.07 tonnes) and consumption (0.43 tonnes) of oil sands oil (from Table 1), and some put the cost of CO2 to be up to $34/tonne or more [32]. If indeed as weather patterns continue to deteriorate and the latter cost were to come to be, a direct investment in renewables as an alternative to the tax would be much easier to justify.

# 6 Conclusion

This paper showed that a symbiotic approach to short and long term energy needs can lead to an overall reduction in atmospheric CO2. It is appears to be economical and politically prudent to undertake as soon as possible a project to install a reasonable number of wind turbines on reclaimed land in order to better investigate the hypothesis presented here to ascertain true costs, risks, and benefits with respect to ultimately widespread application of this reclamation strategy.

In addition, a more detailed business analysis (short and long term return of investment ROI) of the hypotheses presented here should be developed, including:

1. The requirement of investing a significant percentage of gross income from oil sands into renewable energy sources as part of land reclamation and to provide electricity for extracting and processing oil sands, cleaning up contaminated water, and selling excess electricity back to the grid.
2. The ability of a) above to encourage the US to approve of the Keystone pipeline which would save significant rail transportation costs
3. The time effect cost of releasing more CO2 in the short term in exchange for a longer term greater cumulative reduction in CO2.

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