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ATHABASCAN OIL SANDS EXTRACTION TECHNIQUES: AN ECONOMIC ANALYSIS OF SURFACE MINING VERSUS SAGD

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Athabascan Oil Sands Extraction Techniques: An Economic Analysis of Surface Mining versus SAGD

I. Introduction

With an estimated 173 billion barrels in oil reserves, Alberta's oil sands are the second largest potential source of oil in the world, second only to the Saudi Arabian oil reserves (3). Oil sands are a mixture of clay, sand, water and bitumen which can be mined and processed to extract the oil-laden bitumen and further refined to produce oil. The oil sands have been mined since the 1960s, but since most of the bitumen in the region cannot be extracted by surface mining, there has been an increase in use of *in situ* techniques—techniques that commonly involve drilling several wells, injecting high-pressure steam and pumping the bitumen to the surface (3).

These extraction techniques have different implications for economic costs—including various environmental costs associated with land use and degradation, air emissions, and water use—which will be assessed by comparing surface mining and a specific method of *in situ* extraction, steam-assisted gravity drainage (SAGD). Some of these costs are external to the bitumen extracting firm, which results in an inefficient choice of extraction method and extraction level. Two policies to redress the externality problems will be discussed: an environmental tax on output or emissions, and provincial land reclamation requirements imposed by the government of Alberta. The results of this discussion will provide policy recommendations within Alberta as well as possible implications for any US production of oil from oil shale and sands.

II. Background of Surface Mining and *In Situ* Methods

The presence of crude bitumen—a mixture of crude oil and other organic compounds that is semi-solid—was first discovered in the Athabasca oil sands in 1719, but commercial production did not occur until the 1960s (13). The first commercially viable production began in 1967 by the Great Canadian Oil Sands Company, now Suncor Energy Corporation (13). Development of oil sands mining was greatly limited until the 1970s when oil prices rose and increased expected net revenues for prospective oil sands producers. Increasing oil prices continue to affect the development of oil sands; without expectations of positive net revenues, producers will not be incentivized to begin costly oil sands projects. Although surface mining has been employed in the Athabascan oil sands region from the beginning of production, there has been an increase in use of *in situ* methods because an estimated 80 percent of bitumen deposits are only recoverable by *in situ* methods.

Surface mining involves mining bitumen ore using an open-pit mining technology, crushing the ore to reduce the size, adding hot water to create an ore slurry, and transporting this ore slurry to be cleaned and processed before it is upgraded to oil (5). *In situ* extraction involves a variety of techniques that involve drilling wells and injecting steam to reduce the viscosity of the bitumen and cause it to flow into the wells, from which it is then extracted and processed before undergoing the upgrading process (5). The most popular method for *in situ* bitumen extraction is steam-assisted gravity drainage (SAGD). This involves drilling two horizontal wells parallel to each other, the first filled with steam, and the lower one collecting the flowing bitumen, which is then pumped to the surface. SAGD is more efficient than previous *in situ* methods and technological developments may increase the efficiency in terms of reducing water and natural gas use, carbon dioxide emissions, as well as increasing the percent of recovered bitumen (8). Due to the potential for increased environmental efficiencies and the widespread use of SAGD, SAGD is used herein as representational of *in situ* methods as appropriate.

III. Surface Mining versus *In Situ* (SAGD) Methods of Extraction

A. Environmental Costs

In situ methods have been cited as more environmentally sustainable than surface mining, but this claim deserves careful consideration. The primary backing for this claim is that surface mining requires a larger land footprint than SAGD; this is supported by data provided by the Pembina Institute (5). However, as the following table demonstrates, *in situ* methods can have more damaging environmental effects than surface mining in some respects.

Table 1: Environmental Effects Comparison of In Situ and Surface Mining

Environmental Measurement	**In Situ**	**Surface Mining**
Cleared Area Intensity (hectares/million barrels)	1.4	**9.4**
NO_X Intensity (grams/barrel)	132	**146**
SO_2 Intensity (grams/barrel)	**112**	30
Water Use Intensity (barrels/barrel)	1.1	**2.1**
Liquid waste material produced (barrels/barrel)	0.4	**1.5**
Greenhouse Gas Intensity (kilograms CO2e/barrel) Range: 64–533 (kg/bbl)	**91**	36

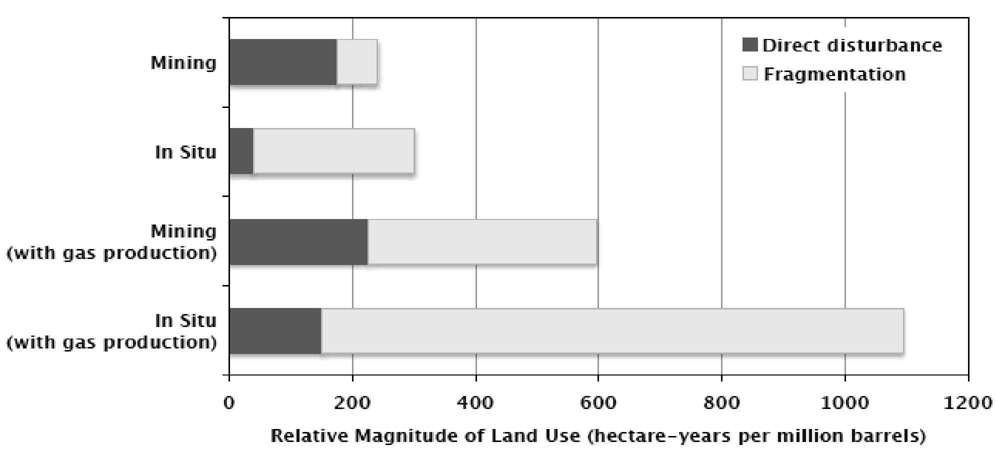
(Adapted from "Mining vs. In Situ Factsheet." Pembina Institute)[1]

The cleared area intensity is greater for surface mining than for SAGD and other *in situ* methods for several reasons. Using surface mining, oil sands are mined using trucks and shovels

1 Note that this calculation does not include the water recycled by surface mining efforts and *in situ* methods. The total water use intensity would thus be higher than the figures shown here.

from the surface, whereas for SAGD, several wells are drilled into deep oil sands deposits and the bitumen is pumped out. However, the type of land disturbance caused by each is very different. With surface mining, the direct impact is on the land that is mined and the tailing ponds created. With SAGD, the impact includes power lines, pipelines, seismic lines, and roads, all of which degrade the habitat of the surrounding area by forest fragmentation–a process that leaves “islands” of forest habitats disconnected from other forests. This process results in an area that is significantly larger than that of surface mining efforts, as seen in Graph 1(5). The estimates of long-term forest fragmentation are larger for *in situ* projects than are those for surface mining, especially when the conversion process of bitumen to gas is considered. For both surface mining and SAGD the environmental costs associated with land use and forest fragmentation create an externality that results in an inefficient amount of oil sands leased to producers, unless these costs are fully captured by the costs of land lease agreements to oil sands producers. Additionally, the differences in these environmental costs between *in situ* projects and surface mining might warrant different policy treatments.

Graph 1 : Mining vs. In Situ Land Use



(“Mining vs. In Situ Factsheet,” Pembina Institute)

Another environmental consideration is that the Athabasca oil sands deposit is situated wholly within a boreal forest, which is already subject to degradation due to conventional oil and gas production as well as logging operations (16). The boreal forest is an area of interconnected forest and wetlands that has significant value to Canadian wildlife and biodiversity. The concern with oil sands operations is that the landscape is altered so significantly that some organizations question if the land can ever be fully restored (1). The value of the boreal forest can be estimated in two categories: first, natural capital accounts, which include the market and non-market values of stocks and flows of forests, wildlife, wetlands, and water resources. Second, ecosystem service accounts, including recreation and cultural use, water supply, raw materials, atmospheric and climate stabilization, waste treatment, etc. (1). The Pembina Institute on behalf of the Canadian Boreal Initiative estimates the economic value of boreal region in the following table.

Table 2: Summary of Boreal Region Market and Non-Market Economic Value

Account Type	**Annual market value of accounts**
• Net market value of boreal natural capital extraction in 2002 • $ / hectare of the boreal ecosystem land base	• $37.8 billion • $83.63
• Total non-market value of boreal ecosystem services in the year 2002 • $ / hectare of the boreal ecosystem land base	• $93.2 billion • $159
Sum of values:	• $131 billion • $242.63/hectare

(Adapted from "Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems," Canadian Boreal Initiative. For a complete breakdown of economic value of boreal ecosystems, see Appendix 1)[2]

The average price of a hectare of boreal forestland sold in 2009-2010 fiscal year was $133.42 compared to the $242.63 value given by the boreal forest, which suggests that the social

2 The Canadian Boreal Initiative concluded that the estimates are insufficient and modest. Potential values of the boreal forest may be higher.

value of the land purchased is not being internalized in the purchase price, and hence there may be an externality problem (5). In section B, various methods of addressing this potential externality problem will be addressed.

The second environmental impact is air emissions. Surface mining releases more nitrogen oxides than do *in situ* methods, but the sulfur dioxide emissions for *in situ* methods are three times those of surface mining (Table 1). The difference between the two emissions of NO_x and SO_x arises largely from differences in type of natural gas used; the commercial gas mixture employed by surface mining to create a bitumen slurry has a lower sulfur content than the mixture used by *in situ* operations (5). Sulfur dioxide can have serious health and environmental effects, including acid rain. Alberta has three air quality objectives for sulfur dioxide: there is a one-hour objective of 172 parts per billion (ppb), a 24-hour objective of 57 ppb, and a mean annual objective of 11 ppb (3). There has only been one instance of sulfur dioxide emissions that have exceeded these objectives in Alberta, and this instance was unrelated to oil sands production; a shift in extraction practices from mining to *in situ* methods, would increase sulfur dioxide emissions and hence the potential for violations of these objectives (3).

One significant way in which SAGD is preferable to surface mining is that SAGD requires significantly less water. The Alberta government currently has licensed one percent of the Athabasca river flow to the oil sands industry, but current use is closer to .2 percent (6)[3]. SAGD reuses 90 to 95 percent of water use, while surface mining processes recycle very little (6). This is because surface mining leaves the vast majority of water in tailing ponds that are very difficult to recover and can be toxic to surrounding wildlife. This difference in water usage also

3 All current and future mineable sands projects are projected to withdraw less than three percent of the Athabasca River flow. This quantity is lower for projected *in situ* operations (Best ##).

explains the disparity between quantities of liquid waste produced by the two methods (Table 1). While studies are generally inconclusive about the leakage effects of these tailing ponds on surrounding water sources, there is the potential for detrimental health effects including higher incidences of certain cancers (14).

The final environmental impact to consider is the additional greenhouse gas emissions produced by SAGD (Table 1). SAGD's carbon dioxide emissions are larger due to the higher amount of energy required to extract a barrel of bitumen by SAGD. The steps required to extract and convert bitumen are more complicated than for surface mining, and both methods have higher input to output energy ratios than traditional crude oil. Greenhouse gas emissions impose a variety of market and non-market costs associated with climate change (including impacts on energy demand, agriculture, forestry, sea levels, etc.), an estimation of the cost of damages from GHG emissions is provided from “Global Warming Damages and Canada's Oil Sands” (12). The following table provides various estimates of present value estimates (effective 2000) of marginal damages caused by greenhouse gases.

Table 3: Present Value of Marginal Damages [4]

Source of Estimate	**US $ (1990)/ ton of carbon**	**C$ (2004) / ton of carbon**
Tol (2005), Upper Bound	86	144.74
Tol (2005), Lower Bound	43	72.37
Nordhaus and Boyer (2000)	9.13	15.37
Shiell (2003)	38	63.96

(From Shiell and Loney, “Global Warming Damages and Canada's Oil Sands,” 2007)

The range of estimates is large primarily due to methodological differences[5]. Shiell and Loney

4 Notes: Estimates effective 2000, Nordhaus and Boyer follows under an optimal emissions scenario, and the third column is estimated using the 2004 exchange rate of 1.259 CAD to USD.

5 Shiell and Loney describe the differences between the estimates in great detail in “Global Warming Damages and

examined the impact of the low estimates of damages (Nordhaus and Boyer) and the higher estimates of damages (Shiell)[6] on the net benefits of Suncor Energy Inc. They found that the net benefits were much lower than the firm's benefits, as shown in the following table.

Table 4: Suncor Social Benefits and Costs

C$ (2004) per barrel		
	2004	2005
Price	49.78	60.8
Capital cost	9.63	9.63
Other inputs and expenses	14.98	14.98
Combined costs	24.61	24.61
Net benefits (damages=0)	**25.17**	**36.19**
GHG damages (N&B 2000)	2	2
% of net (damages=0)	7.9	5.5
Adjusted net benefit (NB^S)	**23.17**	**34.19**
GHG damages (Shiell 2003)	8.31	8.31
% of net (damages=0)	33	23
Adjusted net benefit (NB^S)	**16.86**	**27.88**

(adapted from Shiell and Loney, "Global Warming Damages and Canada's Oil Sands," 2007)

Even using the lower Nordhaus and Boyer estimate of marginal damage cost, the effects of greenhouse gas damages on the net benefit is significant, with a lower bound percentage of 5.5 for 2005. The net benefit would decrease further based upon the effects of additional environmental costs mentioned earlier. After considering the extent of environmental damages that may not be internalized by the oil sands production firm, two possible solutions to this externality problem will be addressed in the following section.

Canada's Oil Sands," 2007.

6 Although not stated explicitly, the choice to compare N&B with Shiell rather than Tol appears to be due to the comparative methodological similarities.

B. Production Cost Differences between Surface Mining and SAGD

As illustrated in the previous section, there are differences in various environmental costs associated with surface mining and SAGD bitumen extraction from oil sands. There are also distinct production cost differences between surface mining and SAGD. Table 5 lists the costs from a report by the Canada's National Energy Board.

Table 5: Comparison of Mining and SAGD Production Costs, Measured in C$(2005) / Barrel at the Plant Gate

Bitumen Recovery Type	Operating Cost	Supply Cost
Mining/Extraction	9 to 12	18 to 20
Steam Assisted Gravity Drainage (SAGD)	10 to 14	18 to 22

(Adapted from "Canada's Oil Sands: Opportunities and Challenges to 2015: an Update," Canada's National Energy Board, June 2006)

The operating cost component reflects the cash costs of operation (roughly, the average variable costs), while supply cost includes this operating cost as well costs associated with production, including: capital costs, taxes, royalties, and rate of return on investment (roughly, the average total cost). These are stated as a range due to differences in site-specific variables such as project size, depth of bitumen reserves and the quality of reservoir (4). While the range of total supply cost appears close for the two extraction methods, there are production cost sensitivities that are method-specific[7]. The report concluded that both mining efforts and SAGD efforts were profitable for firms at 2006 oil prices (4).

IV. Comparison of an Environmental Tax and Alberta's Provincial Land Reclamation Requirements

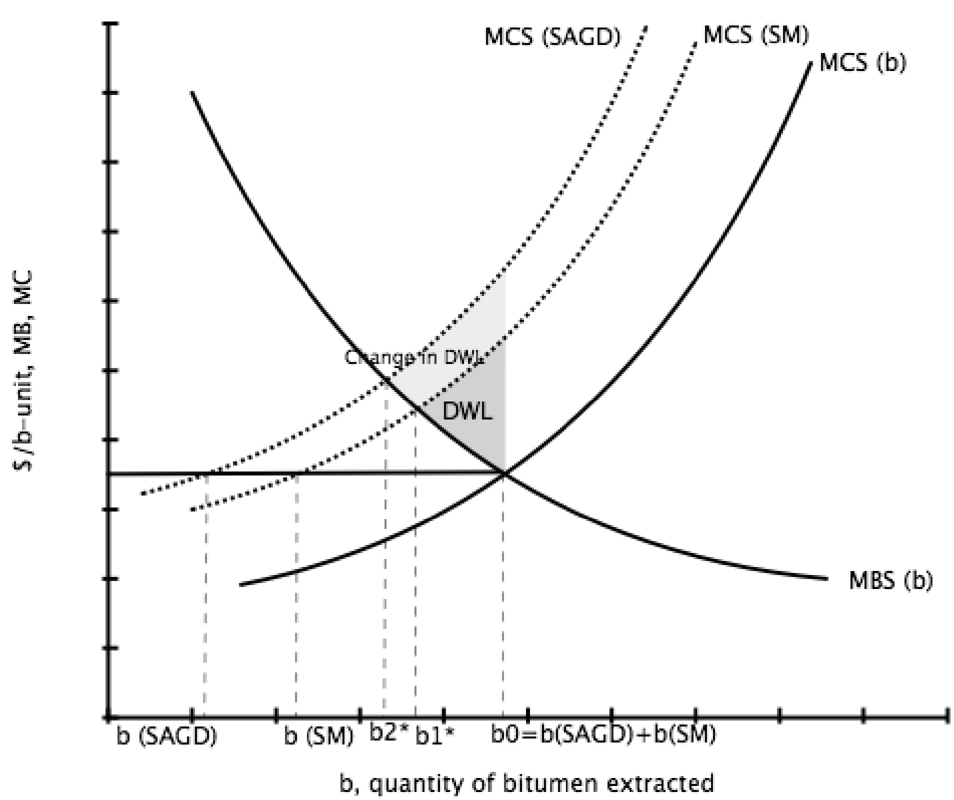
A. Externality Nature of Environmental Damages

7 Both surface mining and SAGD require natural gas, but SAGD requires a larger quantity, and therefore is more sensitive to price increases in natural gas.

When an externality is not internalized, a market will reach an inefficient equilibrium. In the case of oil sands development, unless the additional costs associated with bitumen extraction are internalized by producers, bitumen will be over-extracted. The following graph demonstrates the change in output required for efficiency, from b_0 to b_1 and the associated dead-weight loss of production of a quantity that exceeds the efficient level.

In the following graph, the marginal costs of bitumen extraction employing surface mining and SAGD techniques are different, and both are higher than the marginal costs to the industry. For analysis purposes, the hypothetical assumption is that the marginal costs of bitumen extraction under SAGD are higher, although the alternative may be true.

Graph 2: Inefficient Bitumen Extraction, $MC(b)^{SAGD} > MC(b)^{MINING}$



Without complete information about the environmental cost differences between SAGD and surface mining it is not possible to extrapolate whether the marginal costs are different. If there is a distinction between the two, there will be a corresponding difference in the quantity of bitumen extracted. However, under both scenarios there is need for government intervention to force producers to internalize costs associated with extraction of bitumen[8].

B. Environmental Tax as a Solution to Emissions Problem of Extraction

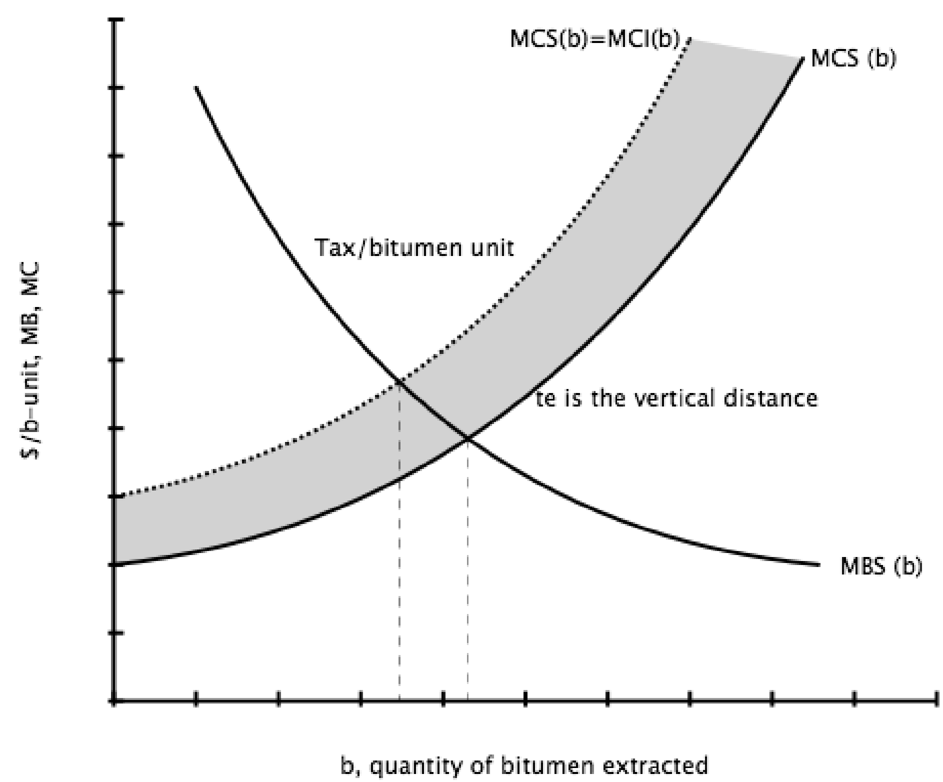
The externality problem arises because of a difference between the marginal cost to the industry and the societal marginal cost, which results in an equilibrium where marginal social benefit (MB^S) does not equal marginal social cost (MC^S). The societal marginal benefit is often captured by the demand function, assuming no demand-side externalities. The efficient outcome is at the quantity where marginal social benefit and marginal social cost are equal. The goal with an environmental tax is to promote environmentally sustainable production by addressing the market failure by forcing the producers to internalize the cost. To reconcile the difference between MC^S and the marginal cost to industry (MC^I), a tax per unit can be applied to reduce or increase output to the efficient level—this is the concept behind a Pigouvian tax (15). Thus, the Albertan government is able to address the overproduction by applying a tax based on output of bitumen extracted from the Athabascan oil sands. Currently Alberta requires companies that emit more than 100,000 tons of GHG / annum to either reduce emissions by 12 percent, purchase an offset, or pay $15 CAD per ton into a technology fund (3). A Pigouvian tax on the other hand would apply to all GHG emitting production firms rather than only the largest ones.

There are several assumptions underlying the environmental tax: 1) there is a fixed

8 For continuity purposes with the environmental tax graphs, a supply-side externality is shown here reflected on the marginal cost curve. In Appendix 2, the externality is reflected on the marginal extraction cost curve.

amount of pollution emitted (ɤ) per unit of bitumen extracted[9], and this is a uniformly-mixed pollutant, where the damage caused by the pollutant is dependent on the total amount, and is not sensitive to where and/or when it is emitted, 2) the amount of damage caused by pollution is known, 3) administrative costs are low, 4) the market is perfectly competitive, and all requirements for perfect competition thus hold, 5) MC^S reflects the total amount of damages caused by extraction of a unit of bitumen—that is to say, MC^S captures both static fund pollutants along with stock pollutants, which impose damage over time (15). Under these assumptions, the following graph demonstrates how an environmental tax can cause the industry to internalize the costs.

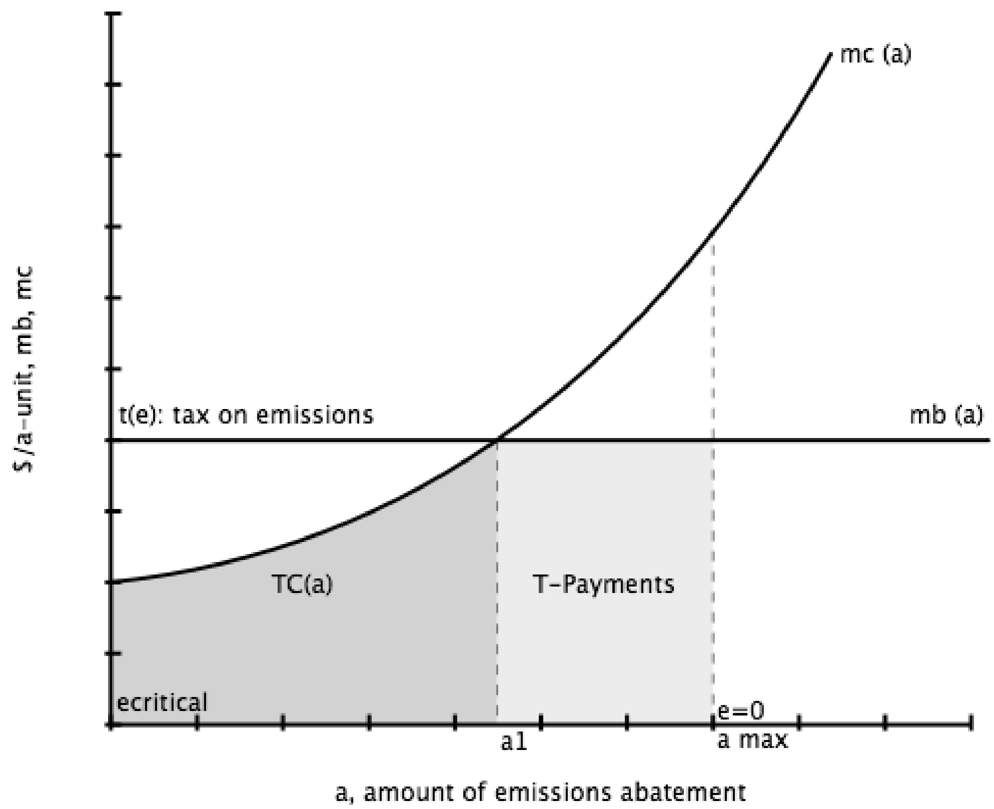
<u>Graph 3: Environmental Tax on Bitumen Output</u>



9 In this situation, t_e is equivalent to t_q=ɤ*t_e

If the level of tax increases the marginal costs to the industry by an amount equivalent to the difference between the MC^I and MC^S, then quantity of bitumen extracted will similarly fall to the efficient level. An environmental tax can also be applied in the form of an emissions tax on oil sands producers, and will likely induce the firm to effect a strategy that minimizes the $TC^F(e)=TC^F(a)+t(e)*e$, as shown in Graph 4.

Graph 4: Emissions Tax on an Individual Source



Under an emissions tax, an individual oil sands producer will increase abatement to a_1, lowering emissions, and will continue to emit from a_1 to a_{max}. The firm will continue to emit the remainder and make tax payments because the mc(a) exceeds mb(a) beyond that point. Under an emissions tax, the firm has incentive to reduce emissions and increase abatement to a_1, which is larger than the abatement level of zero that the firm would undertake without a tax. As an incentive-based system, an emissions tax contrasts that of Alberta's provincial land reclamation requirements, which are a form of command-and-control regulation.

C. Alberta's Provincial Land Reclamation Requirements as a Solution

While an environmental tax might address the GHG, SO_2 and NO_X emissions of oil sands producers, Alberta has implemented strict guidelines for oil sands producers to restore the land used for bitumen extraction and address this potential externality problem. Since the average price per hectare of land in the region by public auction was lower than the value estimated in the Canadian Boreal Institute report, there appears to be an externality problem.

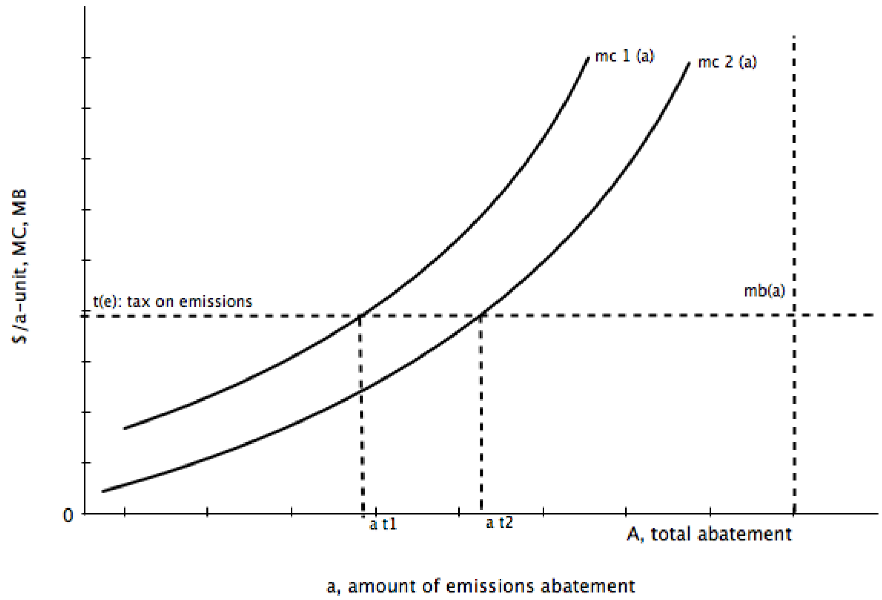
The land reclamation requirements for oil sands production are fairly stringent. Before a mining project is approved, the company must develop a plan detailing how the affected areas will be reclaimed, and provide a reclamation security bond as collateral to guarantee the reclamation efforts. Before production begins, land is cleared of vegetation, trees are harvested by the forest industry, and some smaller wood may be conserved for use in reclamation. During production, companies are required to store soils that have been disturbed to use in future reclamation. Once production on the land has been completed, it often takes long periods of time before any reclamation efforts can be initiated; this is particularly true for tailing ponds left behind by surface mining. These ponds contain particles of bitumen and other toxic substances that are suspended in the water and require time for the particles to settle before any reclamation efforts can be attempted. Once the waiting period is over, land may be temporarily reclaimed and revegetated to grasses for the purpose of erosion control until further reclamation can occur. At this point, oil sands companies must use local plant species to encourage the return of boreal forest ecosystems, which are then closely monitored. If the results of the monitoring are favorable, then regulators will issue certification of reclamation to the oil sands company, and the land is returned to Canada as public land (11). As of June 2009 there were approximately 5,012 oil sands agreements with Alberta of approximately 82,542 km^2, but only 67 km^2 of this area has been reclaimed or is undergoing active reclamation (11).

Although the government contends that reclaimed lands have been restored to productive value, the Canadian Boreal Initiative is doubtful that the Boreal peatland can ever be fully restored (2). Similarly, the standard of restoration to "productive value" status is different from a stricter standard of restoring the land to its pre-mining state, as suggested by differences in the value per hectare of market and non-market valuations of boreal ecosystems of Table 2 and Appendix 1. Another problem with application of this form of regulation is that it is an across-the-board technology based standard, that is, a standard that is applied to all oil sands producers and the methods to achieve reclamation are determined by regulators. A performance-based-standard and/or a point-by-point system is theoretically preferable because although the standards are uniform, the firm has flexibility in how to achieve the standard.

D. Comparison of Environmental Tax and Land Reclamation Requirements

To compare an environmental tax and the land reclamation requirements by the regulatory agencies of Alberta additional factors should be considered, including: cost-effectiveness, information required, political/equity concerns, and incentives for adopting more efficient technologies. Under an environmental tax like the emissions tax shown above, cost-effectiveness—where total cost is minimized—is achieved, as shown in the following graph for the case of two polluters, whose individual abatements sum to A, total abatement.

Graph 5: Cost-Effectiveness of an Emissions Tax



Since the condition of cost-effectiveness treat marginal costs of different firms are equalized at their different levels of marginal abatement effort, an emissions tax achieves cost-effectiveness. A technology-based standard that is across-the-board can be cost-effective if all polluters have the same MC(a) and the regulator specifies an abatement method that is cost-minimizing.

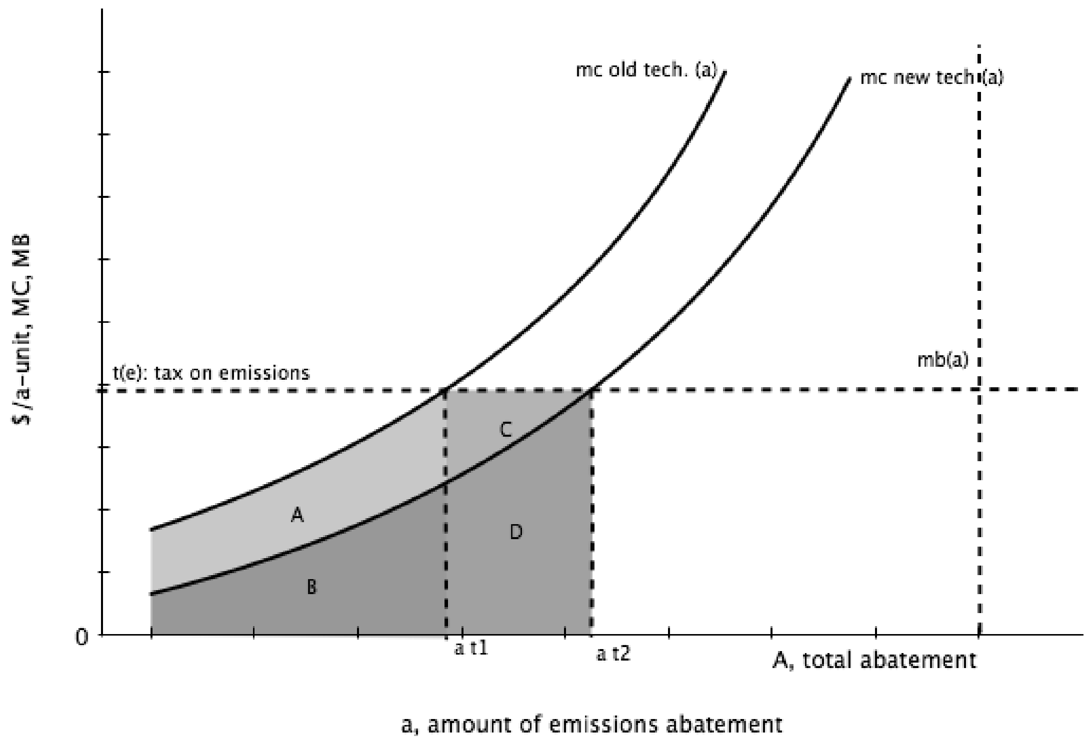
A second important consideration between the two methods of regulatory approaches is the amount of information required. Under an environmental tax, damages associated with production of a good or emissions must be known, several key assumptions mentioned earlier must hold, and regulators must consider the "potential leakage" of the tax on producers (for example, if the tax is set too high, producers may go to regions without a tax). Under a technology-based across-the-board standard, regulators must have the target in mind (for example, total level of abatement), and must also set the method of achieving this standard. However, there can also be leakage effects under a technology-based across-the-board standard that are likely greater than under an environmental tax, *ceteris paribus*. Thomas Bathold (2004) argues that it is easier to decide on total abatement (individual abatement standards, either performance-based or technology-based) than it is to ascertain the appropriate tax level, and thus command and control regulatory activities may be preferable to and offer more certainty than tax solutions (2).

Similarly, Bathold argues that there are serious equity and political concerns associated with taxation rather than command and control regulatory action. From a politician's perspective, a tax imposes a visible cost, but the benefits associated with a reduction in output are not immediately clear, because the market adjusts output, and because firms choose their abatement in a private fashion. With command-and-control regulation, the benefits (a reduction in emissions) are obvious, and the costs are internalized by the industry and consumers of these goods and services. Bathold summarizes this difference with the adage: taxation creates only losers, and command-and-control creates both winners and losers. He also raises equity concerns when comparing the two methods; should the tax be on producers or consumers of the good, on the source of the problem[10] or on derivatives that exacerbate it.

However, one benefit of environmental taxes is that they provide more incentives for firms to switch to more efficient technologies. Under an emissions tax, if there is a technological improvement that lowers the marginal cost of abatement by making it easier to control the emissions produced, firms will adopt the new technology and subsequently abate more (and thus emit less). Therefore the firm will consider the net tax savings when deciding to adopt the new technology. A technology-based, across-the-board standard does not encourage, or even allow a firm to change to a more efficient technology. The incentives for firms to increase abatement under an emissions tax is demonstrated in Graph 7.

10 This is relevant when γ is not constant. Here: $t_e > t_q$.

Graph 6: Increased Abatement Under Emissions Tax with Technological Change



Under the old technology, the firm would abate to level a (t)1, with total cost of areas A+B. If this was the technology-based standard, the firm will face a cost of area A+B. If the technology-based standard does not adjust to prescribe the new technology, the firm has no savings, since adopting the new technology will put the firm out of compliance. With a change to new technology, for the same level of abatement, the total cost decreases by area A. However, the firm will increase abatement to level a(t)2, with an additional increase in total avoided tax costs of areas C and D. However, to increase abatement to a(t)2, the firm incurs abatement costs of area D. Therefore, area C represents the net cost savings of the new technology for additional abatement under the emissions tax. Hence, under an emissions tax, there is an incentive for firms to change to a more efficient control technology, because this will reduce the marginal cost of abatement. This is not the case under a technology-based, across-the-board standard.

With all of the additional considerations between an environmental tax and Alberta's provincial land reclamation requirements, the two methods of regulatory control may be complementary rather than substitutes for one another; an environmental tax largely addresses the emissions externalities of bitumen extraction, whereas land reclamation requirements address the land-related externalities.

V. Omissions and Conclusion

Although this paper attempted to include estimates of as many environmental costs associated with oil sands production as possible, many estimates of environmental were unavailable or inconclusive. However, estimates are preferable to an alternative decision making process which assumes that external environmental costs are zero for land degradation and pollution. Additional areas for further research would include studies of reclaimed land areas to ascertain the success of provincial land reclamation standards, possible issues of market power as a source of market failure in the oil sands industry, an examination of quality of crude produced, and other solutions to the externality problem, such as a cap-and-trade emissions allowances system.

Ultimately, this paper does not offer a definitive conclusion about which method of bitumen extraction, SAGD or surface mining, has higher economic costs, including environmental costs. However, the claims that *in situ* methods are inherently more environmentally friendly are certainly challenged by the estimates used in this paper. Given current technology, SAGD may have a higher overall cost than surface mining. The comparison of an environmental tax incentive-based system and the command-and-control land reclamation methods entail some difficulties, though they may complement each other rather than substitute for one another when applied to particular environmental problems in a way that exploits their advantages in a given setting. With oil prices rebounding after the drop in the latter part of 2007, it is likely that there will be increased interest in oil sands development and technologies, including oil shale in the U.S. With this increased interest, additional consideration of the environmental costs associated with production is necessary.

Appendix 1

Table 6: Summary of Natural Capital Economic Values for Canada's Boreal Region

Boreal Ecosystem Wealth Natural Capital Accounts	Monetary Economic Values and Regrettable Costs[11] (2002 $ per annum)
Forests	Market values: • $14.9 billion in estimated market value of forestry-related GDP in the boreal region (est. 2002) Costs: • $150 million in estimated cost of carbon emissions from forest industry activity in the boreal region (deduction against forestry-related GDP) Non-market values: • $5.4 billion in value of pest control services by birds • $4.5 billion for nature-related activities • $1.85 billion for annual net carbon sequestration (excludes peatlands) • $575 million in subsistence value for Aboriginal peoples • $79 million in non-timber forest products • $18 million for watershed service (i.e., municipal water use) • $12 million for passive conservation value
Wetlands and peatlands	Non-market values: • $77.0 billion for flood control and water filtering by peatlands only • $3.4 billion for flood control, water filtering, and biodiversity value by non-peatland wetlands • $383 million for estimated annual replacement cost value of peatlands sequestering carbon
Minerals and subsoil assets	Market values: • $14.5 billion in GDP from mining, and oil and gas activities in the boreal region (est. 2002) Costs: • $541 million in federal government expenditures as estimated subsidies to oil and gas sector in the boreal region • $474 million in government expenditures as estimated subsidies to mining sector in the boreal region
Water resources	Market values: • $19.5 billion in GDP for hydroelectric generation from dams and reservoirs in the

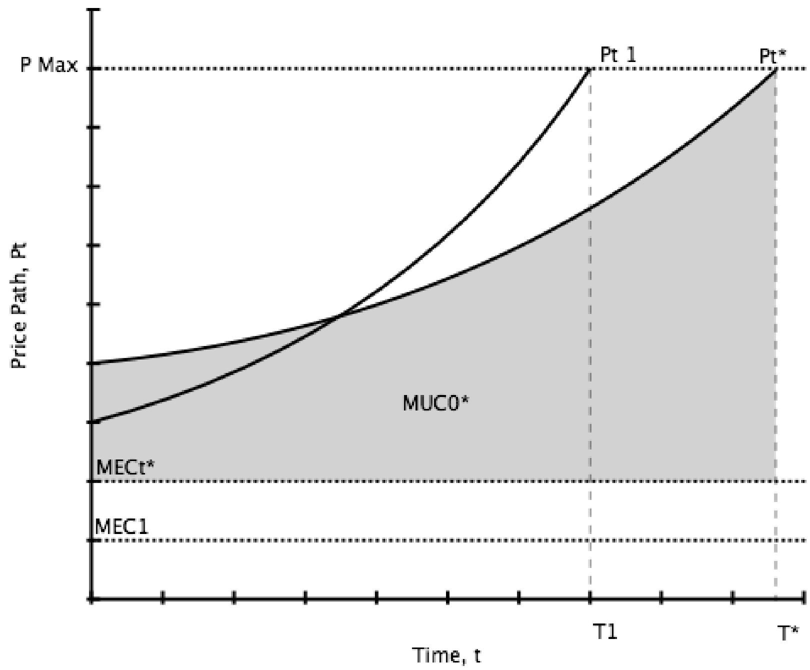
11 Note: The study defines regrettable costs as: “either environmental or societal costs associated with market-based activities (e.g., forest industry operations”

	Boreal Shield ecozone (est. 2002)
Waste production (emissions to air, land, and water)	Costs: • $9.9 billion in estimated air pollution costs to human health
Less cost of pollution and subsidies: • Air pollution costs • Government subsidies to mining sector • Federal government subsidies to oil and gas sector • Forest sector carbon emission costs	• - $9.9 billion • - $474 million • - $541 million • - $150 million
NET Market value of boreal natural capital extraction	• **$37.8 billion**
TOTAL non-market value of boreal ecosystem services	• **$93.2 billion**
RATIO of non-market to market values	• **2.5**

("Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems," Canadian Boreal Initiative)

Appendix 2

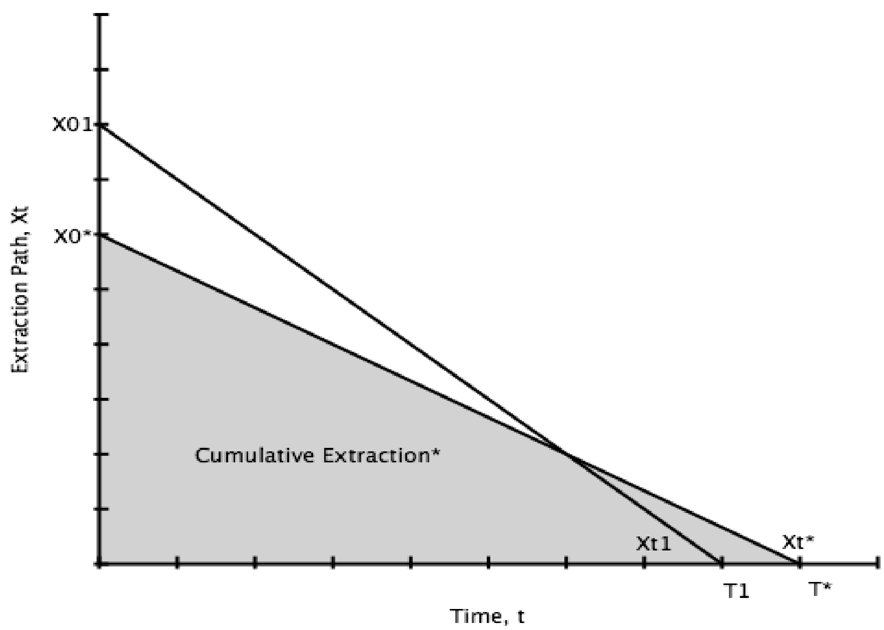
Graph 7: Time Path of Price with Environmental Externality



If there is an environmental externality associated with the extraction of a unit of renewable resource (as there is here, with bitumen extraction), then the marginal extraction curve of the industry, MEC^I will be lower than the efficient extraction curve, MECt* (assuming constant MEC functions). This results in an equilibrium price path, Pt2 that begins lower than the efficient level, $Pt_{1.}$ Pt_1 achieves the maximum price, P_{max}, at terminal time period T_1. At this time period, the demand function for bitumen intersects the price axis and there is a quantity demanded of 0. When this occurs, there is economic exhaustion of the good. If the environmental costs of extraction were fully internalized by the oil sands industry, then the price path would be slightly higher, Pt*, and would equal the P_{max} at a later terminal time period, T*.

The area under the Pt* curve is the marginal user cost MUC 0*, which is based on the idea that present consumption affects future use. The MUC is equal to the present value, discounted foregone marginal net benefits of future use, that is: MR / (1+r)f. The presence of an environmental externality also affects the extraction path.

<u>Graph 8: Time Path of Extraction with Environmental Externality</u>



Because the higher MEC* affects the terminal time period, T*, extraction at present levels should also be lower: $X^* < X_1$ which ends at an earlier terminal period, T_1. However, this does not affect the cumulative extraction, which is the area under the extraction curve. The area under the X_1 curve is the same as X_0*, which suggests that an environmental externality does not result in less extraction, but rather affects the terminal period, T and current prices. Under both extraction graphs, physical exhaustion is achieved because the entire stock of current reserves available is extracted.

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