Global Warming Damages and the Alberta Oil Sands

by

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Abstract

This paper evaluates the impacts of proposed carbon taxes on Canada's oil sands industry. In order to estimate the carbon tax per barrel of emissions, the author combines optimal carbon tax estimates provided by Nordhaus (1994), Shiell (2003), Nordhaus and Yang (1996), and Peck and Teisberg (1992) with oil sands emissions intensities data from the oil sands. The results indicate that the oil sands are very vulnerable to carbon taxes. In a case study of Suncor Energy Inc, the author finds that profit levels would fall by 11% under the most conservative carbon tax estimate while Suncor would experience net losses under the highest carbon tax estimate. The findings also indicate that carbon taxes proposed by the Government of Canada represent a significant subsidy to the oil sands industry.

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I. INTRODUCTION

Canada is one of the major players in the international oil market. Currently, the nation ranks 9th in global oil production, but Canada has the second largest oil reserves after Saudi Arabia (Canadian Association of Petroleum Producers 2005a). Since the first oil sands project in the late 1960s, Canada has seen a massive transformation in the oil industry. As conventional oil reserves begin to decline, the oil industry is reorienting itself toward extraction from the Alberta oil sands. Whereas there are only 2 billion barrels of proven conventional oil reserves in Alberta, "the Athabasca tar sands is estimated to hold more than 175 billion barrels of oil that is economic with current technology" (Harris and Khare: 574). The oil sands promise to become a dominant source of world oil supply over the coming decades, and the environmental impacts of this industry are significant. Oil sands extraction is highly energy intensive and requires vast quantities of Canada's land and water resources. Oil refining and end use also create significant environmental damages.

In order to ensure that oil sands extraction is socially profitable, the environmental costs of production, refining, and end use must be measured. The most administratively simple way to incorporate environmental damages into the price of oil is to impose the environmental costs on producers. The costs can then be passed on to refiners and consumers through higher, more accurate, oil prices. If the industry cannot cover these costs and remain profitable, oil sands extraction is not justified at this time.

A comprehensive study would seek to quantify the air, land, and water impacts at each stage of the oil's lifecycle, and assign a dollar value to these impacts. For the purpose of this paper, analysis will be restricted to greenhouse gas (GHG) damages.

Through a review of the literature, the paper will outline best practices in quantifying the costs of greenhouse gases. The paper will quantify the costs of GHGs per barrel based on the emissions intensity of extraction, upgrading, refining, and end use consumption of oil sands (OS) oil. I will demonstrate that profitability decreases significantly once the global costs of GHG emissions are included. Future research could do a similar analysis of conventional air pollutants, land pollution, and water pollution in order to provide a complete estimate of the environmental costs of the oil sands. Once all environmental externalities are accounted for, it remains to be seen whether an economic case can be made for oil sands extraction.

This is a pressing issue. According to the Globe and Mail's Patrick Brethour: "The capital spending spree [in Alberta's oil sands] is unprecedented in modern Canada, and dwarfs any other industrial project in the nation" (Brethour: B4). Suncor Energy announced plans for $2.5 billion in capital investment in 2005 (Suncor 2005a: 5). It is anticipated that investment in the oil sands will reach $87 billion over the next decade (Brethour: B4). It is conceivable that if all the environmental externalities were factored in to the operating costs, the oil sands projects would no longer appear to be socially profitable. In that case, the massive oil sands investments would represent an enormous misallocation of scarce capital.

While all aspects of environmental damage associated with the oil sands are significant, in the present policy environment GHG emissions merit particular attention. Canada must confront its GHG emissions in an international context due to the global nature of the pollutant. Canada's recent commitment to major emissions reductions under the Kyoto Protocol are likely to be achieved at least partially through restricting industrial emissions. Indeed, according to a National Climate Change Process (NCCP) industry foundation paper, "the CO_2 [carbon dioxide] emissions attributable to the production and consumption of petroleum products were about 207 megatonnes in 1990, or about 45% of total Canadian CO_2 emissions" (Purvin & Gertz: i). Clearly Canada cannot achieve major emissions reductions without the cooperation of this industry. Moreover oil sands production is expected to double by 2015 (National Energy Board: xii). As a result, emissions in the industry are expected to grow significantly, taking Canada even further from its Kyoto targets. This paper will examine both industry averages and Suncor company-level estimates to quantify the potential impacts of emissions taxation on Canada's oil sands industry. Suncor discloses a range of recent production, emissions, and profitability indicators. The analysis of this specific company allows for more up to date and focused estimates than do industry averages.

The paper demonstrates that the lifecycle costs of emissions associated with a barrel of OS oil range from $7 to $40 per barrel depending on the estimate used. This wide range reflects variability in the discount rates, methodologies, and data used by each author. Furthermore, the research shows that the government's Kyoto commitments are highly inconsistent with oil sands development; while the Canadian government has agreed to reduce emissions to 6% below 1990 levels by 2010, emissions from the oil sands will be permitted to rise dramatically over this same period.

The structure of this paper is as follows. An overview of the emissions sources associated with extraction, upgrading, refining, and end use of OS oil will be provided, as will measures of GHG emissions intensities at each stage in the lifecycle. A literature review will measure the economic value of GHGs and identify the most appropriate damage estimates and taxation levels. This information will then be combined to quantify the costs of GHG emissions per barrel and assess the industry's profitability based on this new information. Sensitivity analysis will be conducted to explore outcomes under a range of carbon tax estimates.

II. LIFECYCLE EMISSIONS

The purpose of this section is to provide a brief overview of the lifecycle of OS oil and to provide estimates of the emissions intensities of each stage in the lifecycle. It will also highlight the emissions intensive aspects of the lifecycle. Carbon dioxide, methane, and nitrous oxide are the principal GHG pollutants associated with oil (Clearstone Engineering: xii). The extraction and upgrading process applied in the oil sands causes this type of production to have a higher emissions intensity compared to conventional oil. Both conventional and OS oil have roughly equal emissions in the refining and end use stages, though the synthetic crude from the oil sands has the advantage of being lower in sulphur (Beckman: 4).

There are two methods of extracting oil from the oil sands: above ground mining and in-situ extraction. Brethour et al. provide a summary of extraction and upgrading techniques (Brethour et al: B5). Above ground mining begins by removing the top layer of earth including all vegetation. The oil sands are shoveled into large trucks and delivered to ore preparation plants. There are emissions from the trucks, excavation equipment, and conveyors used to move sand. The plants mix the sands with water and send the product to primary extraction facilities where bitumen and sand are separated. Secondary extraction then removes water and clay and sends the product to the upgrader. Leftover sand, water, clay, and bitumen are sent to holding ponds and eventually treated;

“certain tailings pond system currently appear to be the source of the vast bulk of the mining related methane [and] VOC…” (Clearstone Engineering: 15).

In in-situ extraction, wells are drilled and steam is injected into the oil deposits. The bitumen liquefies and is then pumped to the surface. It is sent directly to the upgrader.

Upgrading treats the bitumen to remove petroleum coke, naphtha, and sometimes sulphur. The petroleum coke is used as a power source at the utilities plant, and “the utilities plant provides steam, water and power for the rest of the operation.” (Brethour et al: B5). Petroleum coke is a dirty fuel source responsible for significant emissions. The upgraded bitumen is called synthetic crude oil and it is shipped to refineries through pipelines. Refineries then prepare the oil for various end uses including automobile gasoline, aviation fuel, and plastics.

The primary emissions sources in extraction and upgrading have been identified by the NCCP as (1) “50% co-generation of electricity and steam for operations, the steam being used mainly in the extraction process that separates bitumen and sand”, (2) “20% from process furnaces”, and (3) “20% from steam methane reformation” (NCCP: 27).

In-situ techniques will be required to extract the vast majority of oil sands reserves in the future. The Conference Board of Canada reports: “Total established reserves at the end of 2002 were 28.3 billion cubic meters (bcm)… Of the 28.3 bcm, 5.6 bcm were surface minable, while the remaining 22.7 bcm were… in situ” (Beckman: 4). In 2004, 465 thousand barrels per day were mined while 532 thousand were extracted using in-situ technology (Canadian Association of Petroleum Producers 2005b).

Once OS oil has been extracted and upgraded, it continues to create global warming damages in the refining process. Oil refining generated 17 megatonnes of GHG emissions in Canada in 1990 (Purvin & Gertz: i). Petro-Canada reports that 62% of their 2003 GHG emissions are due to combustion; "combustion provides the heat and energy required to convert raw petroleum products into marketable commodities such as natural gas, gasoline, and diesel" (Petro-Canada: 26). Heat and steam generation is very energy intensive, and consequently emissions intensive. Flaring and fugitive emissions also contribute to GHG emissions.

Finally, the vast majority of emissions associated with a barrel of oil arise in end use consumption, as evidenced by the data reported in Table 1. Combustion of gasoline creates high levels of GHG emissions; impacts vary depending on the fuel type and pollution filters installed.

The NCCP (1998) highlights the variability of emissions from oil sands producers. They identify several factors that influence emissions intensity including the position in the lifetime of an extraction site, the distance from markets, the nature of the final products (i.e. aviation fuel vs. motor gasoline), as well as the specific technologies being employed at each site. It is not the intention of this paper to discuss the nuances of the variation in emissions associated with varying technologies, sites, and end products. In identifying emissions charges that should be paid by each oil sands company, clearly a company-level measure of their emissions would be required to define appropriate taxation levels.

This paper provides an estimate of emissions associated with the lifecycle of OS oil, first by considering industry emissions intensities as provided by the NCCP, and subsequently by examining a scenario making use of company level emissions data from Suncor. Suncor is a good candidate for a case study because it is a major oil sands operator and the company's environmental reporting is more detailed than many of the other industry actors. Production and upgrading data reported by the NCCP shows emissions intensity for above ground mining only. The 1995 data is the most recent industry average data available. There is a limited amount of published data on emissions intensities, and despite repeated requests, oil sands companies did not disclose further measurements. There is a need for industry data that provides emissions intensities for above ground mining and in-situ extraction separately. Based on information gathered through communications with industry experts, it appears that the emissions intensities between methods are comparable[1]. Emissions vary widely depending on factors such as venting controls and the specific technology applied to in-situ extraction. Emissions data is recorded in Table 1.

Table 1: Emissions Intensities

	Production & Upgrading (tons CO_2E /barrel)	*Refining (tons CO_2E /barrel)*	*End Useˇ (tons CO_2E /barrel)*	*Total (tons/barrel)*
Industry Average (1)	0.130 *	0.033 *	0.385 *	0.548
Suncor Estimates (2)	0.098	0.036	0.385 *	0.519

ˇ End use emissions do not vary significantly between common uses (i.e. motor gasoline, aviation fuel, residential supply), so the industry average is used in both scenarios.

* Conversions from original data. 1 barrel=0.159 m^3

(1) National Climate Change Process 1998: 83; data for 1995. These averages consider only above ground mining.

(2) 2004 oil sands production & upgrading data from Suncor 2005b: 66; 2004 refining data from Suncor 2005b: 74. End Use data from National Climate Change Process 1998: 83; data for 1995.

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[1] Information provided by the Canadian Association of Petroleum Producers, private correspondence.

III. THE COSTS OF CLIMATE CHANGE

There are a range of market and non-market damages associated with climate change. The major types of market damage include sea level rise, and impacts on agriculture, forestry, and energy demand. Non-market damages include human amenity values, eco-system loss, and extreme weather events. In all instances, countries face differing costs as a result of geography, economic activity, and the fragility of ecosystems. Fankhauser provides a sound overview of the categories of damage (Fankhauser 1995: Chapter 3).

Sea level rise will create damages primarily due to land loss, the loss of capital on that land, fisheries, and migration. Any efforts to avoid land loss will require significant capital expenditures. Fankhauser lists possible land protection measures including: "building of sea walls, levees and dikes, beach nourishment and the elevation of islands" (Fankhauser 1995: 29). This is not likely to be economical in sparsely populated areas, so significant dryland and wetland loss will occur. Fankhauser notes that coastal wetlands are "important ecosystems which are already heavily endangered by current coastal development and water drainage schemes" (Fankhauser 1995: 31).

Fankhauser finds that agricultural impacts are difficult to quantify. Climate change is expected to be beneficial to agriculture in certain areas, but costly in others. Generally, very hot climates are expected to suffer while cooler climates may profit from extended growing seasons. Adaptation represents a large share of the costs, as farmers will alter their crops towards products better suited to the new local climate.

Fankhauser suggests that climate change will be beneficial to some aspects of forestry but disadvantageous in other aspects. Increased CO_2 concentrations will contribute to faster growth, but climate may change faster than forests can migrate, resulting in loss of forest cover.

Energy demand is also expected to alter, with higher demand due to increased cooling needs partially offset by reduced heating needs.

Ecosystem loss including species loss is very difficult to estimate. It is not clear exactly which species are endangered, though Fankhauser claims that impacts are expected to be greatest in regions where biodiversity is already threatened.

According to Fankhauser, human amenity is expected to rise in colder climates but to fall in hot climates. A rise in the rate of climate induced death and disease is anticipated as the earth's temperature rises. Valuing such changes requires data on predicted rates of increase in death and disease as well as identifying the appropriate value of a statistical life.

Finally, extreme weather events are expected to become more frequent. Regions that are currently most affected by dangerous weather are most vulnerable to dangerous weather in the future.

Knowledge of the estimated cost of damages resulting from each ton of GHG emissions allows decisions makers to better understand the true costs of a proposed development. Many authors have weighed in on this topic. The present paper focuses on estimates by Nordhaus (1993, 1994), Nordhaus and Yang (1996), Shiell (2003), Fankhauser (1994, 1995), and Peck and Teisberg (1992). Table 2 summarizes the estimates. Given that this is such a young field, global estimates for many anticipated climate change damages are not available. Authors often apply findings from one study, typically in the US, to the world as a whole. While this is not ideal, it is an acceptable point of departure.

Nordhaus develops the Dynamic Integrated Model of Climate and the Economy (DICE), the purpose of which is to "use a Ramsey model of optimal economic growth with certain adjustments and to calculate the optimal path for both capital accumulation and GHG-emission reductions" (Nordhaus 1994: 5). Utility, captured through a discounted utilitarian social welfare function, is maximized subject to a two sector economy-climate model. Discounting is undertaken with a social rate of time preference of 3%, which the author argues is based on empirical observations. Both CO_2 and CFC emissions are determined endogenously in DICE, while other GHGs are exogenous. Endogenous emissions in a given time period are a function of the rate of control, the emissions-output ratio (exogenous and falling over time), and output. Economic damages associated with GHG emissions are based on scientific models of atmospheric accumulation, radiative forcing, and temperature change.

In the DICE model, damage varies with global temperature and temperature is in turn determined by GHG concentrations. Concentration levels rise with production, but are reduced by technological innovations. Estimation of the parameters proceeds from the study of individual sectors in the US. Specific estimates are provided for agriculture, energy, and coastal activities, and another estimate is applied to all other activities. US estimates are then extended to the rest of the world and the data is modified according to each country's activity mix between farming, energy, coastal activities, and all other sectors. It is expected that CO_2 doubling will be associated with a 3°C rise in temperature, and the author assumes the nonlinearity in damage can be represented by a quadratic relationship. Nordhaus reports: “This methodology gives an estimate of the impact of global warming on total output. The lower bound of the impact [of a 3°C rise in temperature] is.72 percent of output for landlocked states with no agriculture. For a country with a great deal of coastal activity and a large part of the economy in agriculture, the loss from a 3°C warming can exceed 4 percent of GNP” (Nordhaus 1994: 53). A global estimate combines country-level estimates based on their share of world GNP, and finds the global losses resulting from CO_2 doubling are equal to 1.33% percent of world product, as reflected in the above damage function.

The abatement cost function is estimated based on previous research. A trend line is fitted through a sample of published estimates in order to estimate the necessary tax rate to achieve any percentage reduction in CO_2. Nordhaus combines this cost function “with engineering estimates of the cost of reducing CFC emissions along with the costs of using forests to sequester CO_2. Combining these three cost functions, we obtain the *cost function for efficiently reducing greenhouse gases*” (Nordhaus 1994: 64).

Nordhaus runs the optimization and examines the net benefits of several different policy responses. Optimizing the model requires a tax on one ton of CO_2E beginning in the range of $5/ton for 1990-99 but rising to $20/ton by 2100. The appropriate tax is $6.77/ton for 2005, in 1989 US dollars, which is equivalent to $13.42 in 2004 Canadian dollars[2].

Nordhaus notes that his model is unrealistic as “it assumes that, through some mechanism, countries internalize in their *national* decision making the *global* costs of their emissions decisions” (Nordhaus 1993: 30). For the purposes of my research this is

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[2] Conversions based the US Department of Labour’s inflation calculator and exchange rate data from the Bank of Canada (average exchange rate for 2004: 1.302).

not a shortcoming. This paper seeks to identify the true global cost of emissions, and this is the appropriate benchmark for national governments as they endeavor to improve their environmental taxation policies.

Building on DICE, Nordhaus and Yang (1996) develop the Regional Integrated Model of Climate and the Economy (RICE). Nordhaus and Yang suggest that RICE is a more realistic model than DICE because it treats each region as a separate decision-maker. The authors explore climate and carbon tax outcomes under a variety of cooperative and non-cooperative scenarios. Cooperative tax rates are very close to the DICE estimates, corroborating Nordhaus' earlier work; however, uncooperative tax rates are very low. The US tax rate without cooperation is estimated to start at $0.65 per ton in 2000, while the tax rate in the European Union is slightly higher at $0.86 per ton (1990 US dollars). Without cooperation, tax rates in developing countries would be close to zero. The cooperative approach is efficient because the global externality is fully internalized. In contrast, the non-cooperative approach is inefficient because each country ignores the international effects of its domestic GHG emissions.

Shiell (2003) focuses on the choice of discount rate and regional weighting in Nordhaus' RICE model, comparing descriptive and prescriptive approaches. The descriptive school argues the appropriate discount rate is the market rate of interest while the prescriptive school uses ethical and political ideals to determine the discount rate. Typically descriptive discount rates are far higher than prescriptive discount rates. Yet Shiell shows that the two approaches can be made to yield similar results if inequality aversion is factored in. Regional weights are used to capture inequality aversion by placing a higher value on income losses experienced in poorer regions. Similarly, since future generations are expected to be richer, a higher degree of inequality aversion will place more of the burden on richer future generations and suggest a lower current carbon tax while a lower degree of inequality aversion will yield the opposite results.

The model is estimated for several scenarios. Scenario 1 is business as usual; that is, no specific actions are undertaken to limit GHG emissions. Scenario 2 is the descriptive scenario with a 3% rate of time preference and neutral regional welfare weights. Scenario 3 is prescriptive, with minimal inequality aversion, the rate of time preference equal to zero and with differentiated welfare weights by region. Scenario 4 uses the Rawlsian maximin principle which represents the limiting case of total aversion to inequality. Scenario 5 is similar to scenario 3 but neutral regional weights are used (Shiell: 1440-1441). Differentiated weights value damages differently depending on the income level of the region. Scenarios 1 and 4 result in a zero carbon tax. Scenario 4 yields this result because the maximin principle promotes equality by valuing the welfare of the least affluent. As it is anticipated that future generations will be wealthier than the present, all carbon taxes will be applied to future generations. Scenario 2's results are consistent with Nordhaus' earlier findings. Shiell reports that scenarios 5 and 3 "show significantly higher initial carbon taxes, at $104 and $38 [1990 US dollars], respectively, owing to the lower rate of time preference in these scenarios" (Shiell: 1441). Scenario 3 is more appropriate than 5 due to the differentiated welfare weights. For the purpose of analysis in this paper, the $38 estimate is used.

Peck and Teisberg (1992) extend the Global 2100 model developed by Manne and Richels by including a damage cost function. The model, called CETA (Carbon Emissions Trajectory Assessment), maximizes discounted utility over a specified time period where utility is a function of consumption. A 3% rate of time preference is used to discount utility. The authors employ a nested production function, with inputs of capital, labour, and two types of energy – electric and non-electric. The aggregate energy input is scaled using an 'autonomous energy-efficiency index'. Consumption is equal to the production remaining after energy, environmental, and investment costs are covered.

CETA's modeling of the evolution of energy sources over time is very sophisticated[3]. The use of various electric and non-electric energy sources is modeled using a range of constraints based on quantity remaining, time of availability, and the scale available. The authors identify synfuels (highly emissions intensive synthetic liquids extracted from coal) as well as electric and non-electric backstop technologies as the major long-term energy sources. Backstop technologies are non-emitting renewable energy sources such as geothermal, wind, and solar.

GHGs are decomposed into carbon dioxide, methane, nitrous oxides, and CFCs. All emissions except CO_2 are modeled as being determined outside of the CETA model. The authors consider several future scenarios on emissions growth rates for GHGs and a range of theories on CO_2 accumulation. The connection between GHG concentrations and global warming is illustrated by modeling temperature as a function of each GHG.

Global warming costs are typically separated into market and non-market damages. The authors do not quantify these costs themselves, and instead rely on data presented by Nordhaus (Nordhaus 1991). The authors use both linear and exponential functions to examine future trajectories, where the exponential function implies a higher rate of damage growth for higher temperatures. Peck and Teisberg do not identify either

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[3] This energy submodel is borrowed from Manne and Richels.

representation as more accurate. The authors note that they fail to connect damage to the *rate* of temperature change.

The authors run their model and compare emissions for the following scenarios: business as usual, optimization using a linear damage function, and optimization using an exponential damage function. Until 2060, there is little difference in emissions under each scenario. The authors conclude "even with high and nonlinear damages, it still makes sense to consume all of the oil and gas and accept the carbon emissions associated with that consumption" (Peck and Teisberg 1992: 72-73). The optimal carbon tax/ton in the linear case begins at slightly over $5 for 1990, is closer to $7.50 in 2005, and reaches only $35/ton by 2200 (1990 US dollars). Peck and Teisberg suggest the slow climb is due to the logarithmic relation between CO_2 and temperature; CO_2 emissions have a decreasing marginal impact on temperature (Peck & Teisberg 1992: 73, footnote 14). However, in the case of the exponential damage function, the carbon tax is approximately $15 in 2005, reaches $50 in 2040, and flattens out at $208.50 in 2100. At $208.50, the backstop technology becomes economical. While the exponential case still involves the use of synfuels, they are phased out earlier than in the case of linear damages (Peck & Teisberg 1992: 74).

Fankhauser (1994, 1995) makes use of the framework laid out by Nordhaus to estimate the marginal damages associated with climate change. However, Fankhauser is able to improve on many of the more controversial aspects of previous research, primarily by capturing the uncertainties associated with many of the relevant parameters. Fankhauser builds a stochastic model that is able to incorporate both best guess estimates and the range of possible outcomes. He argues a stochastic model is most appropriate for developing a climate-economy model because it is able to incorporate more information. Stochastic models estimate the damage probability distribution, rather than a single best guess (Fankhauser 1994: 158). However, unlike the DICE and CETA optimal control models, the stochastic model is unable to identify optimal CO_2 taxes.

Since emissions create damage over their entire lifespan, Fankhauser models the damage per ton of emissions as a present value of the flow of damage over time. In order to estimate the social damage of an extra ton of emissions, the author looks at the present value of damage with and without the extra ton of emissions. The difference calculated is the marginal social cost of emissions.

Future emissions for each GHG are estimated separately depending on the type and source of emission. Fankhauser's estimates are referenced from the Intergovernmental Panel on Climate Change's 1992 report. Business as usual estimates "do not incorporate measures which might be taken to reduce the emission of greenhouse gases, although they cover measures to combat air pollution and ozone layer depletion, which will affect emissions indirectly" (Fankhauser 1994: 166). Future emissions are modeled as evolving based on business as usual estimates with a certain probability and as being controlled under a climate change agreement with the remaining probability.

Fankhauser's damage function is non-linear; it captures the amplified effects of temperature changes occurring at an earlier date compared with those occurring further into the future and also allows for variations in damage depending on the speed of temperature change. Market-based damage is expected to rise in proportion to GNP while non-market values are expected to increase with wealth according to willingness to pay.

Based on previous research, the author estimates market and non-market damages to represent 38% and 62% of damages respectively.

Fankhauser converts investment goods to consumption units and then applies the social rate of time preference (SRTP) to discount both. Fankhauser identifies the best guess SRTP as 0.5% with a range of 0 to 3%. The estimate is based on a review of the literature, though there is no precise argument for a value of 0.5%.

Fankhauser's model is used to run Monte Carlo simulations. Fankhauser reports "damage per tonne of emission is rising over time, from about 20 $/tC [ton of carbon] between 1991 and 2000 to about 28 $/tC in the decade 2021-2030. The rise is mainly due to income and population growth…" (Fankhauser 1994: 174). The estimate for the current period, 2001-2010 is 22.8 $/tC (US 1990 dollars). The associated standard errors indicate that the results are quite uncertain. The author notes that the damage probability "distribution is skewed to the right, even for the runs neglecting the possibility of a climate catastrophe" (Fankhauser 1994: 180). This indicates that a high-damage outcome is more likely than a low-damage outcome. The skewedness is further exaggerated when the model includes the potential for extreme climate change events.

The author compares his findings to those of Nordhaus and Peck and Teisberg. The assumption of a 0.5% time preference rate is an important difference between the studies. Also, Nordhaus and Peck and Teisberg report best guesses while Fankhauser's stochastic model reports expected values. However, the theory would suggest that Fankhauser's estimates should not be compared with those of other authors because Nordhaus and Peck and Teisberg estimate optimal taxes while Fankhauser estimates only marginal damage. Marginal damages must be combined with marginal abatement costs in order to estimate optimal taxes.

Fankhauser reports separate damage estimates for methane and N_2O. Fankhauser points out that there is limited scientific justification for the conversion to CO_2 equivalents based on global warming potential, or relative radiative forcing, since damage is not a linear function of radiative forcing (Fankhauser 1994: 177). However, for the purpose of this analysis, CO_2E will provide an adequate approximation.

Table 2: Summary of Estimates

	Marginal Damage	*Optimal Tax/Ton Carbon*	*2004 Equivalent**	*Rate of Time Preference*	*Model Type*
Nordhaus (1994)	---	$6.77 (2005 estimate; 1989 US dollars)	$10.31 US $13.42 Cdn	3%	DICE
Peck & Teisberg (1992) - linear damage	---	~$7.50 (2005 estimate; 1990 US dollars)	$10.84 US $14.11 Cdn	3%	CETA
Peck & Teisberg (1992) - exponential damage	---	~$15 (2005 estimate; 1990 US dollars)	$21.68 US $28.22 Cdn	3%	CETA
Fankhauser (1994) - CO_2	$22.8 (2001-2010 estimate; 1990 US dollars)	---	$32.95 US $42.88 Cdn	0.5%	Stochastic
Fankhauser (1994) - CH_4	$129 (2001-2010 estimate; 1990 US dollars)	---	$186.44 US $242.65 Cdn	0.5%	Stochastic
Fankhauser (1994) - N_20	$3379 (2001-2010 estimate; 1990 US dollars)	---	$4883.65 US $6356.07 Cdn	0.5%	Stochastic
Shiell (2003)	---	$38 (2000 estimate; 1990 US dollars)	$54.92 US $71.48 Cdn	0%	RICE

* Conversion from the original estimate to 2004 US dollars is based on price indices provided by the US Department of Labour. Conversion to 2004 Canadian dollars based on Bank of Canada data (average exchange rate for 2004: 1.302).

IV. SYNTHESIS

There is wide variation in the results reported by the above authors. To a large extent, the difference in findings between authors is due to the use of different rates of time preference. Other important differences include the treatment of uncertainty and the comprehensiveness of damage estimates.

Rate of Time Preference

There is great debate concerning the appropriate discount rate for very long-term investments. Some economists argue that the current average return on investments is the appropriate rate to use because this represents the opportunity cost. Others suggest that it is not realistic to anticipate the current rate of return on investment to persist over centuries.

Nordhaus (1993, 1994) uses a 3% discount rate on utility, while Fankhauser (1994) and Cline (1998, 1999) advocate the use of the social rate of time preference (SRTP). The SRTP can be used for long time horizons, and it is applied to consumption units rather than utility. The formula is $SRTP = \rho + \theta g$ where ρ is the pure rate of time preference, θ is the elasticity of marginal utility, and g is growth rate in consumption per capita. In the context of the SRTP, Nordhaus' 3% utility discount rate is equivalent to $\rho=3\%$. Few authors who advocate the use of SRTP believe that ρ should be positive over the space of generations. However, it can be argued that the second term should be positive if per capita consumption is expected to be higher in future periods. In this case, future generations would experience a smaller increase in utility resulting from marginal increases in consumption due to decreasing marginal utility. Cline estimates θ at 1.5, claiming that "the econometric literature suggests that indeed this elasticity is in the range of one to two, although it is an admittedly elusive parameter" (Cline 1999: 133). Cline estimates growth per capita at 1% annually, though he also observes that these values may vary between developing and developed countries. Based on Cline's estimates, the SRTP = 1.5%. Shiell is equivalent to Cline in this framework. The equivalent value using Nordhaus' assumption of ρ=3% would be SRTP=4.5%, and using Fankhauser's best guess estimate of ρ=0.5% it is SRTP=2%.

Nordhaus believes current estimates reveal the real return on investment is no less than 6% annually (Nordhaus 1999: 147). However, Cline argues "the empirical, and thus descriptive, evidence shows that the real rate of return at which consumers can transfer consumption into the future is the risk-free real rate on treasury bills, which historically has been close to zero" (Cline 1998: 98). Some economists suggest that it is more efficient to invest money at the current market rate of return and put aside this money to compensate climate change victims in future periods. Cline argues that this "promises something that cannot be delivered: that today's generation and all intervening generations will keep intact an investment fund that is capable of continued real returns at today's level, to generate a distant-future payment that will compensate a future generation for damage inflicted" (Cline 1999: 134). Cline proposes a compromise of discounting at the market rate over a 30 year time horizon but then changing to the SRTP for longer horizons.

Nordhaus advocates a different approach than Cline, suggesting that in instances where the implications of CBA are ethically unacceptable, several modifications to the approach could be made. He evaluates several alternatives and identifies setting a climate target as the most efficient option and altering the discount rate as a highly inefficient option. Operating at a 6% discount rate, adaptations necessary to reach any climate target will be postponed to future time periods. However, Nordhaus does not directly respond to Cline's argument that it is impossible to commit future generations to transferring funds to the generations that will incur significant climate change costs. Thus, on balance, it appears that using Cline's SRTP is the most compelling approach.

It should be noted that there are several advantages to postponing action to future periods. Lind (1999) identifies the following benefits: improved information, technology advancements, and an increase in resources available for the present generation (Lind 1999: 175). Lind also notes that research does not closely examine the negative impacts of redirecting investments away from higher return activities (Lind 1999: 197). For example, education in developing countries may have a drastically higher return compared to GHG abatement; however, the idea of redirecting resources for climate change abatement towards education in the developing world is not being considered, so this argument is not particularly relevant. In an earlier paper, Lind and Schuler (1998) suggest that investments in information may be the most valuable contribution that the current generation can make, noting that "the best that current generations can do is establish and maintain the necessary stocks of assets that form prerequisites for sustainability and continue the formation and trial use of international organizations and mechanisms that might deal with the problem as its severity becomes more apparently widespread" (Lind and Schuler 1998: 91).

Uncertainty

While both best guess and expected outcomes are important for analysis, the expected value of climate change damages is the appropriate value for determining tax rates. The expected value is higher than the best guess because there is a greater probability of very negative outcomes compared with the probability of relatively neutral outcomes (Fankhauser 1994: 180). Fankhauser states "In our model the difference between the expected value and a non-random best guess is about 25%. Encompassing extreme events thus appears to be crucial, and expected value estimates should be favoured over best guess assessments" (Fankhauser 1994: 176). Taxes should reflect the true risk of climate change rather that the most likely outcome. Fankhauser's stochastic model captures expected outcome while the other authors look at best guess estimates.

Potential catastrophic outcomes are treated differently between models. Some models exclude these outcomes from analysis. Nordhaus argues that the crucial climate change risks are not related to a gradual rise in temperature, but rather to extreme but unlikely outcomes (Nordhaus 2000: 507). Fankhauser's model incorporates these costly but unlikely outcomes.

Damage Estimates

Nordhaus restricts the estimations of climate change damages to four sectors of the economy: agriculture, energy, coastal activities, and other. By assessing the category 'other', Nordhaus is not as rigorous in quantifying damages as Fankhauser, who examines many categories of damage including sea level rise, dryland loss, coastal wetland loss, species and ecosystem loss, agriculture, forestry, fisheries, energy, water, human amenity, air pollution, migration, natural disasters, and morbidity and mortality.

Some authors argue that there is a tendency for studies to underreport on benefits associated with global warming. Nordhaus reports that studies of the damages associated with global *cooling* identified many damage categories that are not picked up as beneficial in global warming studies (Nordhaus 1994: 59). This criticism could be applied to all of the models analyzed in this paper.

Nordhaus qualifies his damage estimates: "the calculations omit other potential market failures, such as ozone depletion, air pollution, and research and development..., which might reinforce the logic behind GHG reduction or carbon taxes" (Nordhaus 1994: 97). The same qualification could be made of damage estimates reported by other authors. Peck and Teisberg's management of the energy sector is more rigorous than that used by other authors, but damage valuation is borrowed from Nordhaus to a large extent.

Mendelsohn notes the failure of many studies to capture adaptation, which should offset some of the damage costs (Mendelsohn 1998: 230). This is an important weakness of the studies, and as new information on adaptation becomes available, damage estimates should be refined.

V. ANALYSIS

Taxation

A Pigouvian tax captures the cost of an externality and charges that cost to the producer of the externality. The carbon taxes reported in this paper are examples of Pigouvian taxes. Estimated taxes per barrel range from Nordhaus' low end estimate of $7.36 to Shiell's high end estimate of $39.19 (2004 Canadian dollars)[4]. This assumes that all taxes are applied to the initial source. Then producers may pass on a portion of these costs to refiners and end users through higher prices. Cost estimates are provided in Table 3a and 3b. Table 3a shows total tax per barrel, and Table 3b shows tax per barrel on only production and upgrading emissions. These estimates are calculated by multiplying the

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[4] See Table 3a.

estimated damage or carbon tax per ton (Table 2) by the emissions intensity data (Table 1) in order to estimate the level of damage or carbon tax per barrel.

If taxes are applied downstream, i.e. at the point of emission, oil sands producers would only pay for their own emissions, and then refiners and end users would pay the government directly for the remaining emissions. In this instance, oil sands companies would pay a tax ranging from \$1.75 (Nordhaus) to \$9.30 (Shiell)[5]. Downstream imposition of taxes provides greater incentives to reduce emissions because it gives each business or individual more control over costs. For example, a refinery may find it more economical to reduce its own CO_2 emissions rather than pay an emissions tax. However, if the producers pass on the tax to the refinery in the form of higher prices, the refinery does not have this incentive to abate. Government may still decide that upstream imposition is preferable because the logistics may be simpler.

Table 3a: Total Cost of Emissions per Barrel

	*Currency (2004)**	*Fankhauser*	*Nordhaus*	*Peck and Teisberg - linear*	*Peck and Teisberg - power*	*Shiell*
Industry Average	**US**	\$18.06	\$5.65	\$5.94	\$11.88	\$30.10
	Cdn	\$23.51	\$7.36	\$7.73	\$15.47	\$39.19
Suncor Estimates	**US**	\$17.10	\$5.35	\$5.63	\$11.25	\$28.50
	Cdn	\$22.27	\$6.97	\$7.32	\$14.65	\$37.11
*Exchange rate from Bank of Canada. Average 2004 exchange rate: 1.302						

Table 3b: Costs of Emissions per Barrel - Extraction and Upgrading Only

	*Currency (2004)**	*Fankhauser*	*Nordhaus*	*Peck and Teisberg - linear*	*Peck and Teisberg - power*	*Shiell*
Industry Average	**US**	\$4.28	\$1.34	\$1.41	\$2.82	\$7.14
	Cdn	\$5.58	\$1.75	\$1.83	\$3.67	\$9.30
Suncor Estimates	**US**	\$3.23	\$1.01	\$1.06	\$2.12	\$5.38
	Cdn	\$4.20	\$1.32	\$1.38	\$2.77	\$7.01
*Exchange rate from Bank of Canada. Average 2004 exchange rate: 1.302						

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[5] See Table 3b.

The marginal damage estimates provided by Fankhauser identify the actual costs associated with current emissions. While this is not the optimal tax rate, it is an important indicator of the scale of the externality. In contrast, the optimal tax is the point of intersection between the marginal damage curve and the marginal cost of abatement curve; i.e. it reflects marginal damage after an optimal amount of abatement has occurred. The relevant damage and abatement cost curves are aggregate rather than sector specific. Since GHGs are uniformly mixed pollutants, it is appropriate to apply a uniform carbon tax or permit price to all sectors. Applying Fankhauser's estimate of the marginal damages of CO_2 to the estimated industry average CO_2E per barrel, the estimated marginal damage per barrel is $23.51 (2004 Canadian dollars). This suggests that at the present time, the world is subsidizing each barrel of OS oil that is produced, upgraded, refined, and then consumed to the tune of $23.51. This is a global subsidy, and not a Canadian subsidy, since the damages are global in nature. Considering only the damage associated with production and upgrading, the estimate is $5.58. In 2004, total oil sands production was 997 thousand barrels per day, or 363.9 million barrels per year (Canadian Association of Petroleum Producers, 2005b). At this production level, the 2004 global subsidy to the oil sands was $8.6 billion dollars for total emissions or $2 billion for emissions associated with extraction and upgrading only. This does not capture any of the externalities associated with other aspects of environmental impact such as land degradation and intensive use of water resources.

Profitability

Suncor and Syncrude are the two biggest actors in the oil sands. In 2004, Suncor reported total operating costs of $18.35 Cdn per barrel (Suncor 2005a: 52) and Syncrude reported total operating costs of $18.61 Cdn per barrel (Syncrude 2005: 6). However, these data do not cover the costs of items such as royalties and transportation. In order to estimate the total profit per barrel, total net earnings data must be divided by total production data. Suncor reports 2004 net earnings from the oil sands of $995 million Cdn and 2004 production of 226.5 thousand barrels per day or 82.7 million barrels annually (Suncor 2005a: 36). So, Suncor's profit from one barrel of OS oil in 2004 was approximately $12.04 Cdn.

If Suncor paid for the lifecycle costs of emissions, profits would fall by 58% to $5.07, using Nordhaus' conservative carbon tax estimate of $6.97 per barrel based on Suncor emissions intensity data. If Suncor only paid the costs associated with extraction and upgrading, profits would fall by 11% to $10.72, using Nordhaus' estimate of $1.32. Note that in both instances, Suncor would remain profitable.

Under Shiell's higher estimate, Suncor would not be able to make profit if it absorbed all the costs. If Canada is the only country to institute a carbon tax and the entire tax is imposed at the initial source, Canadian companies would not be able to compete internationally. However, if there is no globally coordinated response, it is much more likely that Canada would impose taxes at the point of emissions. In this case, Suncor would pay $7.01 by Shiell's estimate for Suncor, and profits would narrow by 58% to $5.03 per barrel.

If the price of oil does fall as predicted by some analysts (Beckman: 6), clearly there will be a greater percentage reduction in profits. Equally, if environmental innovation identifies more economical methods of reducing GHG emissions, the optimal tax rates may fall and profits would be less affected. The authors surveyed in this paper treat technological change as exogenous, but in fact there will likely be an endogenous effect as firms respond to carbon taxes by investing in research and development. David Popp (2004) examines endogenous technological change in more detail. To the extent that technological change exceeds that captured in the models, the optimal tax rates and the resulting impacts on oil sands profitability in future periods may be overstated.

The preceding analysis assumes that emissions intensity levels to do not fall immediately in response to a carbon tax. According to Figure 1, the above calculations presume that Suncor maintains its pre-tax emissions level E^ and pays the carbon tax on associated with this emissions level (a+b+c+d). In fact, Suncor would reduce emissions to E*. It would then pay the carbon tax on the emissions level E* (a+b) and pay the abatement costs equal to c. This represents a savings equal to d. While the marginal damage function (MD) does not vary between firms, it is difficult to estimate the shape of Suncor's marginal abatement cost function (MAC), and as a result the relative sizes of areas a, b, c, and d are not known. Statements from Suncor claiming that the company is already aggressively pursuing emissions reductions suggest that area d is in fact small (Suncor 2004).

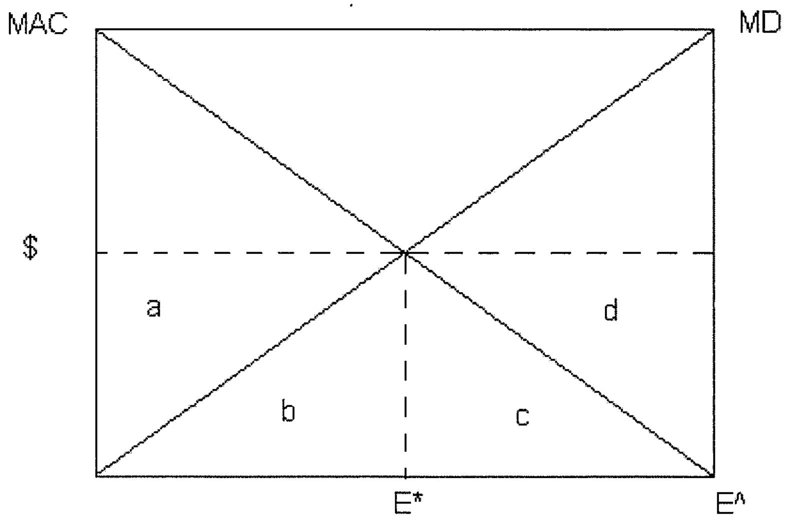

Figure 1.

Sensitivity analysis can be undertaken to explore this issue. Table 4 reports outcomes under three different scenarios. In Scenario 1 it is assumed that the MD and MAC functions are linear, with area d equal in size to areas a, b, and c. In this case, above compliance costs are over reported by 25%. Scenario 2 assumes that marginal damages and marginal abatement cost curves are convex. In this case areas a and d are larger than areas b and c. For the purpose of analysis, it is assumed that a and d are twice as large as b and c, in which case compliance costs are over-reported by 33.3%. Scenario 3 assumes that Suncor is currently operating below E^, as indicated by corporate disclosures. This suggests that areas c and d are smaller than areas a and b. In this analysis, the assumption is that c and d are half the size of a and b, so compliance costs are overstated by 16.6%. Note that the carbon cost per barrel is no longer paid only in taxes; a portion of the costs are associated with abatement in each of the scenarios. Under all scenarios, carbon taxes will still have a major impact on Suncor's bottom line.

Table 4.

		Scenario 1	Scenario 2	Scenario 3
Over reporting of Compliance Costs		25%	33.3%	16.6%
Revised Carbon Cost Per Barrel: Lifecycle Emissions Costs	**Nordhaus**	$5.23	$4.64	$5.81
	Shiell	$27.83	$24.72	$30.95
Revised Profit Levels: Lifecycle Emissions Costs	**Nordhaus**	$6.81	$7.40	$6.23
	Shiell	Negative	Negative	Negative
Revised Carbon Cost Per Barrel: Extracting and Upgrading Emissions Costs	**Nordhaus**	$0.99	$0.88	$1.10
	Shiell	$5.26	$4.67	$5.85
Revised Profit Levels: Extracting & Upgrading Emissions Costs	**Nordhaus**	$11.05	$11.16	$10.94
	Shiell	$6.78	$7.37	$6.19

These findings indicate how vulnerable this industry is to environmental taxation. This paper considers only one of the industry's several environmental impacts; if Pigouvian taxes on water degradation, land use, and conventional air pollutants are also imposed, it appears likely that the industry would not remain profitable.

Government Commitments

The Canadian Government committed to a $15/ton price cap for Canada's upstream oil and gas sector, which is equivalent to $8.22/barrel according to industry averages[6] (Government of Canada 2005: 40). According the majority of findings reported in Table 2, this cap represents a subsidy.

The carbon tax estimates provided by authors represent the tax level that will lead to optimal emissions; that is, where the benefit of one more unit of emissions equals the cost of damage associated with that extra unit. This is not the same as the tax necessary to drive emissions down to Kyoto target levels. Nordhaus and Boyer demonstrate that Kyoto emissions cuts go much further than economic cost-benefit analysis would advise (Nordhaus & Boyer: 22), so the tax necessary to reach Kyoto commitments will be far higher than those identified in the literature on optimal tax levels. Nordhaus and Boyer consider several possible Kyoto scenarios with varying degrees of emissions trading and evaluate them in terms of "how efficiency, where efficiency, when efficiency, and why efficiency" (Nordhaus & Boyer: 10). These measures capture the efficiency of the method used to achieve the stated reductions, the location where emissions are reduced, the timing of the reduction, and the economic rational behind the emissions reduction target. The authors find that the Kyoto temperature targets can be met at a minimum global cost of $109 billion[7]. However under the Kyoto framework, even if there was global permit trading, the cost of achieving these same temperature targets would be $173 billion. At only 1.6 times the minimum cost, global trading under the Kyoto Protocol would be relatively efficient (Nordhaus & Boyer: 17). However, the cost of reaching the same temperature target could be up to 14 times the minimum if no permit trading takes place. Their RICE model predicts the 2010 price of a one ton carbon permit will range from a minimum of $31.99 with global trade to a maximum of $270.97 with OECD trade[8] (2004 Cdn dollars). Under all of these scenarios, the Canadian government's $15 Cdn/ton commitment represents a large subsidy. On a per barrel basis, the estimated taxes are $17.53 with global trade, and $148.49 with OECD trade.

The government has also guaranteed that emissions intensity targets for 2010 will be no more than 15% below business as usual. In order to explore the divergence between this requirement and the 6% below 1990 commitment, consider the total emissions of

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[6] While it is not explicitly stated, for the purpose of this paper I will assume this is $15 nominal.

[7] In order to estimate the $109 billion cost figure, the authors optimized the RICE model subject to the post-2100 temperature trajectory that is implicit in the Kyoto Protocol.

[8] The authors provide estimates of $17 with global trade, $144 with OECD trade, and $127 without trade all in 1990 US dollars; prices are equalized in all regions. These estimates were converted to 2004 Canadian dollars using data from the US Department of Labour and the Bank of Canada.

Suncor over time. Note that Suncor only provides emissions intensity forecasts to 2008. The following data is provided (Suncor 2004: 29):

- Total gross GHG emissions in 1990 were 4.866 million tons CO_2E
- Under business as usual estimates, Suncor forecasts emissions for 2008 as 22.766 million tons.
- Suncor forecasts actual results achieved for 2008 as 12.107 million tons. This represents a reduction of 46% from business as usual.

The government only requires a reduction of 15% below business as usual intensity, which would mean emissions in 2008 were 19.35 million tons. In 2008 Suncor's GHG emissions will have increased 250% from 1990 levels if Suncor's forecast is accurate, and 400% if they only meet the government's standards. So, while the Canadian government has committed to decreasing emissions 6% below 1990 levels by 2010, one of Canada's biggest oil and gas players will be permitted to allow their emissions to rise four fold. Under such circumstances it is difficult to imagine the government meeting its Kyoto commitments. Furthermore, it is important to note that these estimates do not capture end use GHG emissions, which represent the majority of GHG emissions.

VI. CONCLUSION

While all carbon tax and GHG damage estimates carry a large degree of uncertainty, estimates still provide a valuable tool for climate change policy development. In contrast to Kyoto's arbitrary goal, carbon tax estimates look at tradeoffs between GHG damage and the costs of abatement. If these carbon tax estimates are implemented, society will move towards an optimal emissions level. The present uncertainty is not a persuasive reason to postpone action. As newer, more sophisticated estimates are developed, and greater certainty emerges, taxes can become more accurate.

The estimated costs of GHG emissions are large, ranging from $13 to $71 per ton (2004 Cdn dollars). If these costs are added to the conventional private costs, the profitability of Canada's oil sands companies will decrease significantly. By most estimates, government commitments to cap carbon taxes (or permit prices) at $15 per ton represent a large subsidy to the oil industry.

This industry is very vulnerable to government actions on climate change. To date, the government's policy towards oil sands development and GHG taxation is highly inconsistent with Canada's commitments under the Kyoto Protocol. While Canada is committed to reducing emissions to 6% below 1990 levels by 2010, one of Canada's leading oil sands companies is permitted to increase emissions by 400% in that same time frame.

There is a need for more detailed data on GHG emissions from the oil industry. Site level data would identify the efficiency of different extraction and upgrading technologies and provide more clarity on the variability of emissions between in-situ extraction and above ground mining. Also, data with and without emissions offsets would provide more clarity. Future research into Canada's oil sands is needed to value the environmental damages associated with other air pollutants, water use, and land use. Once all these damages are measured, the true costs of Canada's oil sands can be calculated. It remains to be seen whether Alberta's oil sands development is a socially profitable endeavor.

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