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Global Warming Damages and Canada's Oil Sands*

by

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Abstract

The social net benefit of energy investments differs from private profitability by the value of environmental damages, among other things. Estimates of damages associated with greenhouse gas emissions are obtained from the literature, ranging from \$15 to \$64 (\$C 2004) per tonne of carbon. These values are shown to be equivalent to \$2 - \$8 per barrel of crude oil obtained from Canada's oil sands, based on emissions intensities of Suncor Energy Inc. It is estimated that taking these costs into account would lower the social net benefit of Suncor's oil sands production for 2004 – 2005 by a central value of 18 %.

(JEL Q5; keywords: environmental damages, greenhouse gas emissions, oil sands)

Résumé

Le bénéfice social des investissements dans le secteur énergétique diffère du profit privé par la valeur des dommages environnementaux qui y sont liés. Des valeurs estimées pour les dommages associés aux émissions de gaz à effets de serre sont tirées de la littérature, ce qui donne un intervalle de 15\$ à 64\$ (C\$ 2004) par tonne du carbone. Ces valeurs équivalent à 2\$ - 8\$ par baril de pétrole brut en provenance des sables bitumineux, calcul basé sur l'intensité des émissions de Suncor Energy Inc. En tenant compte de ces dommages, le bénéfice net social de Suncor lié à ses activités de sables bitumineux est réduit par une valeur médiane de 18 % en 2004 – 2005.

(JEL Q5; mots clés: les dommages environnementaux, les gaz à effet de serre, les sables bitumineux)

I. Introduction

Canada is one of the major players in the international oil market, ranking eight in global production in 2006 and second in proven oil reserves (Radler 2006). Presently, the Canadian oil industry is undergoing a major transformation. As conventional oil reserves begin to decline, the industry is reorienting itself toward extraction from the oil sands in Northern Alberta. Whereas there are only 5.2 billion barrels of proven conventional reserves in all of Canada, the oil sands are estimated to hold 174 billion barrels of proven reserves (Radler 2006).

Unfortunately, the environmental impacts of oil sands extraction are significant, as it requires large amounts of energy, land and water. For example, Figure 1 presents projected data on upstream sources of greenhouse gas emissions (GHGs) in the energy sector (extraction and upgrading of resources) provided by Natural Resources Canada (2006). As shown, emissions from the oil sands were less than conventional oil in 2004, but are projected to be five times greater than conventional oil in 2020. Part of this increase is due to changes in the relative scale of production between the two sources, while a significant part is also due to differences in emissions intensity. In particular, Woynillowicz et al. (2005, p.22) estimate that production of a barrel of synthetic crude oil from oil sands yields three times more emissions on average than production of a barrel of conventional oil. Of course, refining and end use also create significant emissions of greenhouse gases.

In order to ensure that oil sands extraction is socially beneficial, the environmental costs of production, refining, and end use must be measured. A comprehensive study would seek to quantify the air, land, and water impacts at each stage of oil's lifecycle, and assign a dollar value to these impacts. For the purpose of this paper, analysis will be restricted to damages resulting from the emission of greenhouse gases. Future research could do a similar analysis of conventional air pollutants, land degradation, water pollution and water scarcity in order to provide a complete estimate of the environmental costs of oil sands operations.

Of course, the private case for expansion of the oil sands has already been made. As observed by Brethour (2005), "the capital spending spree is unprecedented in modern Canada, and dwarfs any other industrial project in the nation." It is anticipated that investment in the oil sands will reach $87 billion over the next decade (Brethour et al. 2005). However, it is conceivable that if all the environmental costs were considered, it would be revealed that these oil sands projects were not socially beneficial. In that case, the massive investment in this sector would represent an enormous misallocation of scarce capital.

The paper reviews recent results from the economic literature in order to determine a plausible range for the value of GHG damages. In a simple world, the relationships between pollution emissions and their impacts on the environment would be directly observable, and the equivalent monetary values of these impacts would be easily determined. In reality, of course, the world is never simple. In climate science and economics, estimating impacts and monetary values requires a complex apparatus of mathematical models, including assumptions about functional forms, behaviour and other features, many of which cannot be tested with any great precision. Thus we do not intend that the reader should interpret our results as precise empirical truths, but rather that they are indicative of the range of values that many economists have been considering recently. One might think of this exercise as a thought experiment. Given the range of values, we are interested to know the implications for public policy concerning the oil sands.

With these caveats, we proceed with our survey of GHG damages. Emissions associated with oil occur during extraction, upgrading, transmission, refining, and consumption of the end product. When all of these emissions are attributed to the corresponding barrel of oil, we find that the value of damage ranges from \$2 to \$8 per barrel (\$C 2004), depending upon the modeler's assumptions.

The range of damages is high enough that it has a non-trivial impact on the social net benefit of oil sands production. As a case study, the paper examines data reported by Suncor Energy, a leading Canadian player in the oil sands, for the years 2004-2005. Using standard cost-benefit methodology, we estimate that inclusion of greenhouse damages in the analysis reduces the net benefit of Suncor's operations by a central value of 18 % during this period.

Unfortunately, the range of uncertainty regarding the damage estimate is very wide – the percentage reductions in net social benefit caused by GHG damages range from a low of 4 % to a high value of 33 %. This dispersion is due to uncertainty about the future path of oil prices and abatement technology, as well as to differences in the ethical treatment of different generations and regions. Of course, the numbers would be even less favourable if the costs of other environmental effects were estimated as well. This observation calls into question the wisdom of proceeding with major oil sands investments without first undertaking a more extensive review of all the associated environmental impacts.

The paper describes the various stages of oil sands production and presents estimates of the related emissions intensities in section II. Section III reviews selected literature to assemble a range of estimates of the present value of marginal damages from GHGs. Finally, section IV presents the case study of Suncor.

II. Lifecycle Emissions

This section provides an overview of the lifecycle of oil sands (OS) oil and estimates of the emissions intensities of each stage in the lifecycle. 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 extraction. 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 2004, p.4).

The principal GHGs associated with oil are carbon dioxide, methane, and nitrous oxide (Clearstone Engineering 1999, p.xii). A unified measure of emissions is obtained through the concept of carbon equivalent. The main GHGs are converted into equivalent amounts of CO_2 according to their global warming potential, and these amounts are then expressed in terms of the corresponding mass of carbon.

Brethour et al. (2005) provide a summary of extraction and upgrading techniques. There are two methods of extracting oil from the oil sands: above ground mining and in-situ extraction. Above ground mining begins by removing the top layer of earth. The oil sands are then 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. Clearstone Engineering (1999) indicates that these ponds are currently "the source of the vast bulk of the mining related methane [and] VOC…" (p.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. While mining and in-situ extraction are of comparable importance at present, in the future in-situ techniques will be required to extract the vast majority of oil sands reserves (Beckman 2004, p.4).

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. 2005). Petroleum coke is a dirty fuel source responsible for significant emissions. The upgraded bitumen is called synthetic crude oil and is shipped to refineries through pipelines. Refineries then prepare the oil for various end uses including gasoline, aviation fuel, heating oil and plastics.

Table 1 presents estimates of emissions intensities for each activity in the lifecycle of OS oil: extraction and upgrading (E&U), transmission (i.e. pipelines), refining and marketing (R&M), and end use (i.e. consumption of refined products). Data are provided for the industry as a whole and E&U data are also provided for Suncor. The industry average data are taken from the National Climate Change Process (1998) and date from 1995. The data for extraction and upgrading refer to above ground mining only. Clearly, more recent data would be desirable, as would data on in-situ extraction. Unfortunately, such data are not publicly available.[1] Private communications with industry experts indicate that the emissions intensities between mining and in situ extraction are comparable.[2] As for individual companies, Suncor is a good candidate for a case study because it is a major oil sands operator and its public reporting is quite detailed. The E&U value is based on data from Suncor (2005, p.66).

Adjustments are also required to make the published intensity data for R&M and end use comparable with that for E&U and transmission. The former categories refer to units of refined product while the latter categories refer to crude oil and other products which are inputs to R&M and end use. The conversion to refined products depends upon the grade of the input, the refined product in question, and the refinery. We calculate these adjustments based on data for Suncor but not for the industry as a whole. Thus the values in the industry row of Table 1 cannot be added together, while the values for Suncor can be added to yield a measure of total emissions intensity. Details of the adjustments are provided in Appendix A. Note that the vast majority of

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[1] Natural Resources Canada, Energy Branch, Analysis and Modeling Group, personal communication.
[2] Canadian Association of Petroleum Producers, personal communication.

emissions associated with a barrel of product from Suncor – approximately 75 percent – arise in extraction and upgrading.

III. The Costs of Climate Change

There are a range of market and non-market damages associated with climate change, including impacts on agriculture, forestry, energy demand, sea level, human amenity, ecosystem services, and extreme weather events. In all instances, countries face differing costs as a result of geography, economic activity mix, and the fragility of ecosystems. Fankhauser (1995, ch.3) provides an overview of the categories of damage.

Knowledge of the estimated cost of damages from each tonne of GHG emissions allows decision makers to better understand the true costs of a proposed development. Economists have been actively researching in this field since at least the early 1990's. At the micro level, a typical approach has been to assess the effect on a particular sector in a particular location of a doubling in the global atmospheric concentration of carbon. These types of results can then be aggregated at the macro level to produce a damage function – a mathematical formula which indicates how aggregate damages would vary in response to variations in global average temperature.

Since GHG's are long-lived in the atmosphere, the emission of an additional tonne today results in a flow of damages lasting many years. Therefore the appropriate measure of marginal damage (damage from the last tonne of pollution emitted) is a present value, which aggregates all the associated flows into an equivalent value in the initial period. One of the most important factors in such calculations is the choice of a discount rate for weighting values in different periods. We discuss this matter in greater depth below.

Another important consideration is whose damages matter. One might argue that the Canadian government should only be concerned about effects on Canadians, and indeed in practice this might be the case. However, as the effects of GHGs are understood to be global, the most efficient response is to control them at the global level. Therefore, we take a global perspective in the present study, presenting damage estimates for the world as a whole.

It is also important to state clearly one's assumptions about the policy scenario under which damages are measured, because damages are an increasing function of the atmospheric stock of pollution and different scenarios entail different atmospheric stocks. Numerous scenarios have been considered in the literature, including business-as-usual (no regulatory control), emissions stabilization, concentration stabilization, and optimal emissions control. For example, the Kyoto Protocol represents a policy of emissions stabilization at a specified level for a particular subset of countries.

The business-as-usual scenario is expected to yield the largest value of marginal damage, since it yields the highest emission flows and thus the largest atmospheric stock of pollution in every period. Policies with regulatory controls correspond with lower flows and stocks and therefore also lower values of marginal damage. The optimal control scenario balances the benefits of reduced damages with the economic costs of reducing emissions, in a manner consistent with intertemporal maximization of social welfare. This optimizing calculation is conducted with an integrated assessment model, which combines the dynamic properties of the global economic and climatic systems with the ethical principles articulated by the modeller.

Which scenario is appropriate depends upon the intended use for the damage estimate. For our purpose of measuring the social net benefit of oil sands extraction, we consider the optimal control scenario to be the most appropriate, as it assumes that all agents will be controlling their emissions in an optimal fashion. In contrast, one could argue that the present situation bears more resemblance to the business-as-usual scenario, with the exception perhaps of the European Union. However, evaluating oil sands operations against such a backdrop would imply that only these firms were to be held responsible for their emissions and, further, that they were responsible for the last units of emission in the economy – the most damaging. We find both of these implications inappropriate. First, it is inefficient to hold one group of producers responsible for their emissions while exempting others. Second, from an economic standpoint, the physical source of emissions is not an important consideration of who should abate; rather, it is the relative cost of abatement that matters. Thus, although the many recent proposals for expansion of the oil sands clearly entail new emissions of GHGs, it does not follow prima facie that these candidates should be the first to abate. In any case, our test case in section IV is based on Suncor, which has been in operation for many years and thus would not be singled out under a “last-in first-out” rule.

Table 2 summarizes some recent estimates from the literature on marginal damages. Tol (2005) surveys 27 studies which yield 94 alterative estimates reflecting various assumptions. Some of these studies are more rigorous than others, and some assumptions more compelling. Thus it is useful to weight these results according to their plausibility. Table 2 presents Tol’s quality-weighted mean, $144.74 / tonne of carbon, and peer-reviewed-only mean, $72.37 / tonne of carbon (all values $C 2004). The first value gives higher weights to estimates from studies that score higher on a list of desirable methodological attributes, while the second performs the same weighting on estimates from peer-reviewed papers only. Tol explains the lower estimate associated with the peer-reviewed papers by noting, "it appears that studies with better methods yield lower estimates with smaller uncertainties than do studies with worse methods" (p.2072). Nonetheless, we note that some of the most prominent contributions to this literature have been in the form of books and thus have not been formally refereed (e.g. Nordhaus 1994, Nordhaus and Boyer 2000, Cline 1992).

Tol's means are significantly higher than the other values reported in Table 2, those of Nordhaus and Boyer (2000) and Shiell (2003). This outcome reflects, among other things, the distinction discussed above between business-as-usual and optimal control scenarios. In particular, Tol's means reflect many studies which measure damages in the context of business-as-usual (e.g. Fankhauser 1994). In contrast, Nordhaus and Boyer (2000) and Shiell (2003) are both based on the optimal control of emissions over time. For this reason, our calculations in section IV will be based on these sources, rather than Tol.[3]

The value presented for Nordhaus and Boyer (2000) corresponds with the RICE 99 model (Regional Integrated Model of the Climate and Economy). Shiell (2003) is based upon the earlier version of RICE presented in Nordhaus and Yang (1996).

Alone or with various co-authors, Nordhaus has figured among the leading practitioners of integrated assessment modeling for almost two decades (see for example Nordhaus (1991), Nordhaus (1994), Nordhaus and Yang (1996), and Nordhaus and Boyer (2000)). These efforts have not gone without criticism. For example:

- Cline (1992, 1999) criticizes Nordhaus' use of a positive rate of pure time preference.
- Tol (1994) criticizes Nordhaus' decision to limit the effects of climate impacts to the production side of the economy only, ignoring direct impacts on individuals' utility.

[3] Most valuation exercises ask what is the maximum amount an individual would be willing to pay to avoid a deterioration in the environment (WTP) rather than what is the minimum amount the individual would be willing to accept in compensation if the deterioration occurred (WTA). In general, the two values are not the same, and in exercises where both are estimated, it is usually found that WTA > WTP. A referee argued that, in the case of climate change, the relevant concept is WTA rather than WTP. Thus, we may have reason to believe that the values reported in Table 2 are underestimates of the appropriate values.

- Grubb et al. (1995) highlight the assumption of exogenous technical change in Nordhaus' models and explore the effect of induced technical change.
- Chapman et al. (1995) analyse the influence of the rate of time preference, the exogenous rate of decarbonisation, and the climate sensitivity parameter.
- Azar and Sterner (1996) analyze the sensitivity of Nordhaus' damage estimates to the rate of time preference and distributional weights.
- Chakravorty et al. (1997) explore the interplay between increasing prices for non-renewable fossil fuels, technical change and substitution into non-polluting backstop technologies such as photovoltaics.
- Neumayer (1999) criticizes the underlying assumption that manufactured goods can compensate for reductions in environmental quality.
- Azar and Lindgren (2003) argue that the possibility of low probability, catastrophic events significantly alters the optimal near-term level of abatement.
- Shiell (2003) contrasts the descriptive approach to discounting and regional weighting used by Nordhaus with a prescriptive approach based on a social welfare function.
- Dore and Burton (2003) criticize Nordhaus for modelling climate change as a marginal change from the status quo rather than a discrete change. Further, they argue that such policy analyses should be understood as thought experiments contingent upon their particular functional forms and assumptions.
- Mendelsohn (2004) argues that the damage estimates in Nordhaus and Boyer (2000) are too pessimistic, as they neglect opportunities for adaptation and the likelihood of positive net benefits associated with moderate warming.

The foregoing criticisms can be grouped into two broad categories. The first category – consisting of Cline, Tol, Grubb et al., Chapman et al., Azar and Sterner, Chakravorty et al., Shiell, and Mendelsohn – focuses on specific features of Nordhaus' model. The second category – consisting of Neumayer, Azar and Lindgren, Dore and Burton – focuses on methodological foundations.

Among the first category, we find the criticisms regarding the rate of time preference and regional weighting particularly compelling, and we elaborate below in the context of Shiell (2003). The remaining issues in this category, concerning direct utility impacts, climate sensitivity, damage estimates, technical change, and induced substitution, are still evolving in the literature, and more recent versions of the models (i.e. Nordhaus and Boyer 2000) have been informed in part by these developments. While certainly the results presented in Table 2 do not represent the last word on these issues, nonetheless we believe they represent a reasonable place to start, given the current state of knowledge.

In the second category of criticisms, Dore and Burton (2003) argue that any results obtained from economic modeling exercises are contingent upon the specific functional forms and assumptions employed, and further we cannot expect these results to be robust to changes in functional forms or assumptions because the underlying model of general equilibrium is not "structurally stable". Similarly, Azar and Lindgren (2003) argue that "the uncertainty about the impacts is so large that basically any optimal outcome can be justified" (p.253). Nonetheless, Dore and Burton offer that a particular model can be viewed as a thought experiment, and the results obtained can be interpreted in this context. The value of such results depends upon the relevance which the reader attaches to the thought experiment. For example, if the reader believes that the assumptions of the model are empirically true, then she will give similar credence to the damage estimates. Alternatively, the reader may simply be interested to know what would be the result of applying a common set of assumptions or a widely accepted model to a particular problem, without holding any particular view or perhaps even harbouring some scepticism about the empirical accuracy of those assumptions.

It is this latter context which offers the greatest generality to our results. Certainly Nordhaus' modeling efforts are among the most widely known and thoroughly researched in the literature, and the alternative approaches to discounting and regional weighting proposed in Shiell (2003) have wide support as well. Thus, while it would be too strong to claim a consensus on these matters, nonetheless it is interesting to investigate the implications of these results for a cost-benefit analysis of specific projects in the Canadian oil sands. In particular, we would like to know whether these estimates of greenhouse damages are sufficient, on their own, to make the social net benefit of oil sands exploitation negative. If so, then the implications for public policy are serious. If not, then the lesson for researchers is that it would be worthwhile to proceed to develop monetary estimates of damages from other environmental impacts, such as land and water use, in order to obtain a more complete picture.

In contrast to Dore and Burton (2003), we do not find the methodological critique of Neumayer (1999) to be persuasive. In brief, his argument revolves around the degree of substitutability between man-made goods and natural amenities and services. According to the "strong sustainability" school invoked by Neumayer, these two categories of goods are perfect complements; i.e. no amount of man-made goods can substitute for goods provided by nature. For example, in the context of climate change, investment in dykes and seawalls cannot provide any relief from rising sea levels. We find this view implausible. Rather, it seems evident that there is some scope for substitution, and therefore the relevant empirical question is how much substitution is possible and at what cost. Furthermore, if, as Mendelsohn (2004) and others argue, some regions stand to benefit from atmospheric warming, then it follows that the strong sustainability constraint would not come into play anyway. Finally, Neumayer's argument that adjusting the social discount rate would lead to inefficient outcomes has been addressed in Shiell (2003).

The RICE 99 model presented in Nordhaus and Boyer (2000) divides the world into eight regions – U.S., OECD Europe, Other High Income, Russia & Eastern Europe, Middle Income, Low Middle Income, China, and Low Income. Shiell (2003) divides the world into four regions – UJE (U.S.+ Japan + Europe), former Soviet Union, China, and ROW (rest of the world). Regions can either make decisions non-cooperatively, to advance their own interests, or they can cooperate with other regions to maximize global welfare. We present the cooperative results in Table 2, since these (i) correspond with the globally optimal control of GHGs, and (ii) reflect the full value of the pollution externality.

Decision making is modeled as the optimization of an inter-temporal welfare function. In both RICE and RICE 99, the welfare function has the utilitarian form

$$W = \sum_{j,t} \frac{\psi_{jt} N_{jt} u(c_{jt})}{(1+\delta)^t}$$

where $u(c_{jt})$ represents individual utility derived from per capita consumption, c_{jt}, in region j at time t, N_{jt} represents the population of region j at time t, δ represents the pure rate of time preference (discount rate on utility), and ψ_{jt} represents an additional regional weight. The summation notation reflects the utilitarian form in which individual utilities are aggregated over regions and time, with appropriate weights. Individual utility in this case is a logarithmic function of per capita consumption.

Nordhaus and Boyer (2000) and Shiell (2003) differ principally in the rate of time preference and the regional weights they apply to individual utilities. Nordhaus and Boyer employ a rate of time preference which starts at 3 percent per year ($\delta = 0.03$) then declines gradually over time.[4] The positive value of time preference means that progressively less weight is given to individual utility the further it is in the future.

Nordhaus and Boyer also employ "Negishi" regional weights, ψ_{jt}. The Negishi form of regional weight is designed to neutralize the effect of diminishing marginal utility of consumption in the choice of the optimal policy. Diminishing marginal utility is the property by which rich agents derive less benefit from an additional unit of consumption than poor agents do. When operative, this property can be used to justify large transfers of resources from rich to poor, or, where such transfers are not possible, the implementation of policies which favour poorer regions. By neutralizing this effect, the Negishi weights remove the incentive to use greenhouse policy as a means of redistribution, the argument being that redistribution would be better carried out by direct transfers.

Proceeding in this manner, Nordhaus and Boyer estimate a present value of marginal damage of $15.37 / tonne of carbon. This value is shown in Table 2.

The approach to discounting employed by Nordhaus and Boyer has been labeled descriptive by Arrow et al. (1996). The argument is that the 3 percent value of δ is descriptive of actual preferences for tradeoffs revealed in the market.[5] Shiell (2003) suggests that this label may be extended to the use of the Negishi weights as well.

An ethical justification for the descriptive approach emerges if transfers can be made between generations (i.e. over time) and between regions. In this case, an efficient approach to policy would involve compensation paid by those who create externalities to those who suffer from them. The tradeoffs embodied in descriptive discounting and regional weights are consistent with such an approach, since they reflect the actual rates at which compensation can be transferred across time and between regions. In contrast, if such compensation cannot or simply is not paid, then the discounting and regional weights must be interpreted as global preference parameters. This case is less appealing on ethical grounds, as it involves discriminating against future generations and the present poor *a priori*.

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[4] For example, δ is 2.3 percent in 2100 and 1.8 percent in 2200.

[5] For a contrary view of the appropriate descriptive value of δ, see Cline (1999).

Lind (1995) argues that large scale, long term compensation payments across generations are not feasible, since the time scale involved in global warming is so long that a promise to maintain dedicated funds cannot be made with any credibility. Similarly, Shiell (2003) argues that large scale transfers between regions are equally unlikely, due to difficulties in identifying and matching beneficiaries and victims and also weakness of oversight in recipient countries.

Therefore Shiell (2003) investigates the effect of choosing discounting and regional weights on an ethical basis – the prescriptive approach in the lexicon of Arrow et al. (1996). To do this, Shiell distinguishes between an idealized policy maker, who is motivated by ethical concerns, and private agents who pursue their self-interest in the market place. In this approach, private agents are characterized by a rate of time preference of 3 percent, reflecting a bias toward the present. Market forces lead to a Nash equilibrium among the regions. In contrast, the policy maker sets his rate of time preference to zero, so that all utility values are weighted equally, and the Negishi weights are removed, so that a given benefit or damage is given greater weight if it accrues to the poor than to the rich. The policy maker chooses the values of policy variables for each period to maximize inter-temporal welfare, taking into account the equilibrium feedback from the private economy. Proceeding in this manner, Shiell estimates a present value of marginal damage of $63.96 / tonne of carbon. This value is shown in Table 2.

If this were the end of the story, then it would be necessary to choose between the descriptive and prescriptive approaches, depending upon which seemed more compelling. In fact, Shiell also introduces a third dimension of equity in the form of inequality aversion, with the result that the divergent values reported in Table 2 emerge as special cases of a unified approach. In this view, the low value of $15.37 associated with Nordhaus and Boyer and the higher value of $63.96 associated with Shiell in the table can be interpreted as the end points of a range of values associated with different levels of inequality aversion.[6] Therefore we consider the range of values $15.37 – $63.96 as plausible estimates of marginal damage.

The information in Table 2 can be combined with the emissions intensities presented in Table 1 to yield damage estimates per barrel. Presenting the data in this fashion is useful, since oil prices and firms' output are quoted in terms of barrels. The data are contained in Table 3. The

[6] The result is explained as follows. The autonomous progress of technical change in the models means that future generations are richer ceteris paribus. A higher value of inequality aversion translates into greater concern for the less well off, i.e. the present generation. Technically, the discount rate on future generations is higher, which results in a lower present value of damage.

first two columns of Table 3 present estimates for Suncor based on the total emissions associated with a barrel of output. Column one presents the low estimate of damages, corresponding with Nordhaus and Boyer (2000), while column two presents the high estimate, corresponding with Shiell (2003). The third and fourth columns present damages for both the industry as a whole and Suncor based on extraction and upgrading only.

IV. Social Net Benefit of Oil Sands Extraction

In light of the relatively high emission levels of oil sands production, it is natural to seek to compare the size of the external costs of these emissions with the other costs and benefits associated with the activity. Cost-benefit analysis is the technique that economists use to determine whether a given activity results in a net benefit or net cost for society. To reflect the social perspective, inputs are evaluated in terms of their opportunity costs, output is evaluated in terms of consumers' willingness to pay for the product, and external effects such as pollution impacts are accounted for by means of equivalent monetary values.

In this section, we use data published by Suncor, a leading player in the Canadian oil sands, as the basis for a case study of the social net benefit of oil sands extraction. Our study is limited in two major respects. First, among all the external effects associated with the oil sands, we only account for GHG emissions. In particular, we do not account for costs associated with water use, land degradation or other emissions. Second, our measure of net benefit is limited to the period 2004-2005. In the context of long-lived investments such as those found in the oil sands, a full cost-benefit analysis would require knowledge of the lifetime stream of costs and benefits, which could then be compared on the basis of present value. Unfortunately, such a full accounting of Suncor's operations is beyond the scope of the paper. However, we are able to use our estimates for 2004-2005 as the basis for projections to obtain some partial insight into the long-term net benefit of Suncor's operations.

Business-as-usual damages 2004-2005

Table 4 summarizes our calculation of the net benefit of Suncor's operations in 2004-2005. Line items corresponding with gross benefit, capital costs, and other inputs and expenses are based on data available in Suncor's 2005 Annual Report and elsewhere.

Gross benefit is calculated as the product of the average unhedged output price in the year (Suncor Energy Inc. 2006, p.99) and gross production volume (Suncor Energy Inc. 2005, p.66). In contrast, Suncor's statement of gross revenues is based on actual sale prices which include the effect of hedging activities (Suncor Energy Inc. 2006). We believe that the unhedged or spot price provides the appropriate measure of social benefit from consumption, since it better reflects consumer's willingness to pay for the marginal unit. Of course only the last unit is marginal; for infra-marginal units we should also estimate the consumer surplus (excess of demand price over sale price). Nonetheless, the approximation error is likely small since Suncor's total output represents only a small fraction of total world output.

As for production, we use the gross measure rather than net in our calculation of benefits, since (i.) this is the basis for the calculation of emission intensities used in Table 1, and (ii.) we account for expenditures on internal consumption of crude oil (the difference between net and gross consumption) under "other inputs and expenses". For 2004, Suncor's average unhedged sale price was \$49.78 / barrel, and gross production was 84.13 million barrels. For 2005, production was atypical due to a major fire in January. Therefore, rather than relying on reported production and cost values, we have opted for a counter-factual scenario based on 2004 production levels and costs, with production evaluated at 2005 prices. Suncor's average unhedged sale price in 2005 was \$62.68 / barrel, which deflates to \$60.80 when expressed in 2004 dollars.[7]

We have had to exercise particular care in accounting for capital costs in our measure of social profitability. Suncor's financial statements provide accounting measures of annual depreciation charges and capital employed but these do not correspond with economic concepts of depreciation and real capital stock. Fortunately, the statements provide retrospective data on capital expenditures in nominal dollars, which can be used to construct an estimate of the real capital stock available in 2004. Appendix B provides a summary of the data and the assumptions used for this task. Our central estimate of Suncor's capital stock in 2004 is \$5400 million (\$C 2004). Moore et al. (2004) estimate the real marginal product of capital at approximately 5% per annum, based on the performance of corporate bonds. Using this figure, we estimate the opportunity cost of this capital stock at \$270 million. In addition, we assume an annual

[7] Authors' calculation using GDP deflator, Statistics Canada, CANSIM database, V3860248.

depreciation rate of 10% (see Appendix B), which yields a depreciation charge of $540 million in 2004.

Other inputs and expenses include the following line items from Suncor Energy Inc. (2006): purchases of crude oil and products (p.70); operating, selling and general (p.70); accretion of asset retirement obligations (p.70); and overburden amortization (p.75). Transportation is not included, since the average sale price used to calculate gross benefits is net of transportation costs. These outlays can be taken as equivalent to the opportunity costs of the associated inputs, based on the assumption of competitive markets.

Net benefit exclusive of GHG damages is calculated as the difference between gross benefits, capital costs, and other inputs and expenses. For 2004, this value is $2118 million or $25.17 per barrel; for 2005, the value is $3045 million or $36.19 per barrel ($C 2004), the increase reflecting the higher price of crude oil in 2005.

We adjust this measure of net benefit by subtracting the monetary value of damages of GHG emissions, from Table 3.[8] We attribute the total life-cycle costs of GHG emissions to the corresponding barrel of oil, rather than just the costs associated with upgrading and extraction. This approach requires that the social net benefits associated with downstream activities such as refining and end use be zero. A fuller accounting would estimate the net benefit of a final consumption good, such as automobile trips or home heating, rather than an intermediate good such as crude oil. Such an approach would account for costs and benefits associated with all stages of production of the final good, including extraction, upgrading, refining, marketing and end use. However, the two approaches are equivalent provided the balance of costs and benefits in the downstream activities is zero. We do not test the plausibility of this assumption. However, casual reflection suggests it may not be unreasonable. On the one hand, significant excise taxes on final goods such as gasoline suggest the existence of positive net benefits, as the taxes create a spread between consumers' willingness-to-pay for the good and the cost of production. On the other hand, the existence of external costs associated with pollution, noise and congestion, as well as the costs of public infrastructure, suggest that these net benefits on downstream activities may be fully offset.

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[8] Natural resource economists will note that we have made no attempt to estimate the user cost of Suncor's resource base. User cost is defined as the minimum value of net benefit which must be earned in order to compensate for increasing resource scarcity. We justify this omission on the grounds that accounting for GHG damages will

Using the low estimate of GHG damages (Nordhaus and Boyer 2000), we calculate that net benefit is reduced by 7.9% in 2004 to a level of $1950 million or $23.17 per barrel; in 2005 net benefit is reduced by 5.5% to a level of $2877 million or $34.19 per barrel. Using the high estimate of GHG damages (Shiell 2003), we calculate that net benefit is reduced by 33.0% in 2004 to a level of $1419 million or $16.86 per barrel; in 2005 it is reduced by 23.0% to a level of $2346 million or $27.88 per barrel.

Optimal firm response

These calculations assume that the firm does not change its behaviour in any way. In fact, if companies were required to take damages into account, through for example a carbon tax or an emission permit system, they would have a strong incentive to reduce emissions below current levels. Indeed, the damage estimates presented in Table 3 are measured after firms have undertaken optimal amounts of emissions abatement. Assuming that some abatement activities would be less expensive than the tax or permit price, it follows that the estimates provided above are too high.

This argument can be illustrated with the aid of Figure 2, which shows hypothetical marginal damage (MD) and marginal abatement cost curves (MAC) for a firm. Emissions per barrel are measured along the horizontal axis, with $\hat{E}$ representing emissions in the absence of a tax or permit regime. The value of the tax (or permit price) is represented by t, which is equal to MD when set at the optimal level. The MD curve is horizontal, as the firm's emissions are assumed to represent only a small fraction of aggregate world emissions.

The damage estimates presented in Table 3 correspond with the area *a*+*b*+*c*. In fact, under a tax or permit regime, firms would have an incentive to abate to E*. In this case, the firm would incur an abatement cost equal to area *b* (the MAC curve is read from right to left), while the value of remaining damages would be only *a*. For simplicity, we continue to refer to the sum *a*+*b* as damages, even though *b* represents the cost of abatement.[9] Thus, under a tax or permit regime, the value of damages per barrel would be *c* dollars less than the estimates presented in Table 3.

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increase per barrel costs in all periods, and therefore the user cost will shrink in an (almost) offsetting fashion as a result.

[9] In terms of calculating the social net benefit, it does not really matter what labels one gives to these components, since they both represent costs which are not taken into account in the baseline scenario.

Knowledge of Suncor's MAC curve would make it possible to adjust the estimates in an appropriate fashion. Unfortunately, this information is not publicly available, and indeed the company may not know it with great certainty either. Instead, we will undertake sensitivity analysis, employing a range of possible – and one hopes plausible – values. Table 5 presents the results under four assumptions about the size of the overestimate, c: 5%, 10%, and 20% and 30%. The base estimates (i.e. $c = 0\,\%$) are also reproduced for comparison. Public statements by Suncor and others suggest that companies are already aggressively pursuing emissions reductions[10]. If true, then one would expect c to be small. On the other hand, innovations such as CO_2 sequestration, discussed in Ebner (2007), may mean that c will turn out to be relatively large at some future date.

Table 5 indicates that the impact of climate change damages on the net benefit of Suncor's oil sands operations ranges from small to large depending upon the output price, the estimate of damages, and the size of c. The small impact corresponds with the 2005 output price, Nordhaus and Boyer damages, and $c = 30\,\%$. In this case, damages reduce net benefit by only 3.9 %. The large impact corresponds with the 2004 output price, Shiell damages, and $c = 0\,\%$. In this case, damages reduce net benefit by 33.0 %.

In light of the uncertainties, taking an average of the two extreme values – 18.5 % – does not seem unreasonable as a central estimate. The wide variation between the estimates flows from both the usual uncertainties concerning the behaviour of future values – e.g. prices, technology – and the underlying ethical values embedded in the approaches to discounting and regional weighting in the estimation of the GHG damages. Much as we would like greater precision, we will probably have to learn to live without it, since ethical values are inherently subjective and our ability to predict the future is not likely to improve any time soon.

Projections over time

Of course, a two-year picture of net benefits does not provide reliable guidance as to the lifetime value of Suncor's activity. Nonetheless, we can use our 2004-2005 snapshot as the basis for projections, both backward and forward in time, which can provide some insight into the longer-term viability of Suncor's operations. Figure 3 provides such projections in terms of the price of crude oil received by Suncor and the company's unit cost. These projections are

[10] See for example Suncor (2004, p.5).

anchored by the 2004-2005 values reported in Table 4(b) (line items "price" and the sum of "combined costs" and "GHG damages"), which are reproduced in the figure for reference. As well, we have reproduced the 2006 average price received by Suncor.[11]

The backward projection of price follows the time trend of the Alberta average wellhead price, reported in CAPP (2007, Table 05-02A).[12] The forward projection of price follows the trend proposed by Natural Resources Canada (2006) for West Texas Intermediate crude.[13] This forward projection entails a moderation of price following the sharp run-up since 2003. The rationale for moderation is based on two possible scenarios. In the first, geopolitical tensions ease, and price falls as a direct consequence. In the second, geopolitical tensions remain, but the high price stimulates new sources of supply, which in turn causes the price to moderate.

Unit costs are projected based on both the Nordhaus and Boyer (2000) estimate of damages and the Shiell (2003) estimate. The history of the oil sands has been characterized by steadily declining unit costs of production, due to learning and technological innovation. Thus, for demonstration, we assume a conjectural decline rate of 2% per annum, which corresponds with the cost falling by half every 35 years.[14] Applying this rate to the 2004 values of unit cost results in a steadily increasing backward projection and a steadily falling forward projection.

Inspection of Figure 3 makes it clear that, with the exception of 1983-85, cost dominated price consistently prior to 2000. Furthermore, this result appears to be reasonably robust to changes in the assumption of the decline rate used in the construction of the cost trends (in particular rates in excess of 1%). Thus, it would appear that, prior to 2000, Suncor's operations resulted in a negative net benefit (i.e. a net cost) for society, since accounting for GHG damages alone among all the pollution and resource degradation costs was sufficient (or close to sufficient) to turn the balance negative.

After 2000, the story is reversed: price has consistently dominated costs since that time and it appears set to continue to dominate despite the forecast moderation in price. This outcome

[11] Suncor (2007, p.105) reports an average price per barrel in 2006 of $68.03, which is equivalent to $64.54 in $C(2004) using the GDP deflator, Statistics Canada, CANSIM database, V3860248.
[12] The trend has been shifted vertically to intersect Suncor's average price per barrel in 2004, which differs slightly from the Alberta average.
[13] Natural Resources Canada (2006) projects values for 2010, 2015 and 2020. We have interpolated between these points to extend our graph in Figure 3. We have also shifted the trend vertically to intersect Suncor's average price in 2006.
[14] To test this conjecture, we conducted a simple regression of Suncor's "operating, selling and general" line item per barrel against time for the years 1994 – 2004. Using the logarithmic dependent variable form, we obtained an annual decline rate of 2.19 %.

raises the possibility that Suncor's operations could result in a positive net benefit over the long term. However, it would be necessary to account for all related pollution and resource costs to determine whether the balance were truly positive in this range. More research is warranted to address this question.

V. Conclusion

The estimated value of damages associated with GHG emissions from OS oil are reasonably large, ranging from $15 to $64 per tonne of carbon, or $2 to $8 per barrel of oil ($C 2004). If these damages were factored in to the social cost-benefit analysis, the net benefit of oil sands extraction would decrease, as demonstrated in the case of Suncor. Based on 2004-2005 data, our analysis indicates that a central estimate of 18 % for the impact of climate change damages on net benefit would not be unreasonable, although the estimates vary widely.

These results call into question the wisdom of planning major investments in the oil sands without first quantifying the value of all environmental impacts. Of course, one could argue that if Canada were to prohibit further development of the oil sands, the investment would simply move elsewhere, resulting in no net improvement in the global environment. Nonetheless, the problem remains that, at the global level, exploitation of the oil sands may in fact reduce aggregate welfare rather than increase it. In the absence of better information, we simply do not know.

There is a need for more detailed data on GHG emissions from the oil sands. 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. Future research is needed to value the environmental damages and scarcity effects associated with other air pollutants, water use, and land use. Once all these effects are measured, the true costs of exploiting Canada's oil sands can be calculated. It remains to be seen whether oil sands development is a socially beneficial endeavour.

Appendix A

Input-based Emissions Intensities for Refining and Marketing (R&M) and End Use

The emissions intensities for R&M and end use which are published in National Climate Change Process (1998, p.83) are based on volumes of refined product. Our objective is to adjust these measures to correspond with volumes of refinery inputs rather than outputs. These adjustments are tailored to our case study of Suncor. In principle, they could be replicated for the industry as a whole, but we do not undertake such an exercise here.

Let i index the product type emanating from Suncor's upgrader. In particular, $i \in \{sw, so, dies, bit\}$ where "sw" indicates synthetic light, sweet crude, "so" indicates light, sour crude, "dies" indicates diesel, and "bit" indicates bitumen. Let x_i denote the volume of product of type i and $x = \sum_i x_i$ the aggregate volume from the upgrader. Define v_i as the volume of refined product produced from input i and f_i as the conversion factor, i.e.

$$v_i = f_i x_i . \tag{A1}$$

Further, define e_{ia} as the GHG emissions associated with product i in activity *a* and r_{ia} as the emissions intensity based on volumes of refined product. For our purposes, there are two activities: refining and marketing (R&M) and end use (END). Then

$$e_{ia} = r_{ia} v_i . \tag{A2}$$

Substituting (A1) into (A2) yields

$$e_{ia} = r_{ia} f_i x_i . \tag{A3}$$

It follows that $r_{ia} f_i$ is the emissions intensity based on the input volume x_i.

Now define r_a as the average emissions intensity for activity *a* over all the product types and volumes supplied by Suncor; i.e.

$$\sum_i e_{ia} = r_a x .$$

Substituting from (A3) and re-arranging yields

$$r_a = \sum_i r_{ia} f_i \left(\frac{x_i}{x} \right). \tag{A4}$$

We need estimates of r_a for $a \in \{R\,\&\,M, END\}$, which means we need to find data for r_{ia}, f_i and x_i / x. For the emissions intensities, National Climate Change Process (1998, p.83), provides national average data for 1995. The values are 0.0332 for refining and marketing and

3.85×10^{-4} for end use (tonnes carbon per barrel of refined product)[15]. These values are used for all $r_{i\alpha}$ with the exception of $r_{dies,R\&M}$. In this case, a value of zero is used, since no further refining is needed for this product.

For the conversion factors, f_i, we obtained the following unpublished data from Natural Resources Canada on the typical product yield from each grade of crude oil input in cracking refineries. The focus on cracking refineries seems appropriate, since most of the product coming out of Suncor's upgrader is already highly refined and therefore does not require further coking.[16] Synthetic light sweet is characterized in the data by an API of 31.5 and sulphur content of 0.15%. Light sour is characterized by an API of 35.0 and sulphur content of 1.17%. For bitumen, we use a category corresponding with "very heavy" – API of 20.9 and sulphur content of 3.29%. For the typical slate of refined products, one unit of synthetic light sweet yields on average 1.0275 units of refined product, one unit of light sour yields 1.0206 units of product, and one unit of "very heavy" yields 1.0235 units of product.[17]

For the output shares, x_i/x, we use data from Suncor (2006). For 2004, the shares are: light, sweet crude 50.8 %; light, sour crude 33.2 %; diesel 12.3 %; bitumen 3.7 %.[18]

Substituting these values into (A4) yields $r_{R\&M} = 0.0298$ and $r_{END} = 3.93 \times 10^{-4}$ (tonnes carbon / barrel). These values are reported in Table 1. Note that the emissions intensities reported in National Climate Change Process (1998, p.83) are based on the national mix of refined products in production (R&M) and end use. Our calculations assume that the yield of refined products from Suncor's output is the same as this national mix. Further research is required to determine the validity of this assumption. Nonetheless, we suggest that it is not unreasonable as a first approximation.

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[15] Conversion from m^3 to barrels by the authors. Conversion factor: 1 barrel = 0.159 m^3.
[16] The exception is bitumen. However, this product constitutes less than 5 percent of Suncor's output.
[17] The "typical slate" varies by input type. Values are estimates of average performance across refineries.
[18] The five-year average data for 2000-2004 are virtually identical.

Appendix B

Estimation of Suncor's Real Capital Stock for 2004

Suncor's financial statements provide 5-year retrospective data on capital expenditures, which we have used to construct an estimate of the real capital stock in use in 2004. By consulting the statements for 1991, 1996, 2001, and 2005, we have constructed an unbroken time series on capital expenditure for the eighteen year period 1987-2004. The statements for 2001 and 2005 are available on Suncor's website (www.suncor.ca). The statement for 1996 was obtained from SEDAR (www.sedar.com), the on-line archive of financial information maintained by the Canadian Securities Administrators. The 1991 statement is not publicly available; data from this statement were obtained from Suncor staff.

The nominal values of capital expenditure are shown in the INV column of Table B1. A conjectural extrapolation has been added for the years 1980-86. The effect of this extrapolation is minor, due to the force of depreciation, as can be seen in the final row of the table.

These nominal values are converted into $C 2004 by dividing by the relevant price index (column PX). This price index is constructed as the simple average of four price indices provided in Statistics Canada's CANSIM database: (1) V91344 machinery and equipment purchased by mining, quarries and oil wells; (2) V91380 machinery and equipment purchased by petroleum and coal products industries; (3) V7717855 construction of industrial structures, Edmonton; (4) V1574443 second-stage iron and steel products.

The real values of capital expenditures ($C 2004) are shown in fourth and fifth columns of Table B1 (INV $2004 actual and adjusted). The adjustment pertains to expenditures on installations which were not yet operational in 2004. In particular, as of 2004, $1215 million had been spent on the following installations in this category: Millennium vacuum unit, Firebag Stage 2, Coker unit, Firebag cogeneration and expansion (Suncor Energy Inc. 2006, p.26). Since this portion of the capital stock is not related to the flow of output in 2004-2005, it is appropriate that it be omitted. Further, since it has not yet begun depreciating, the aggregate value can be deducted from the 2004 entry, rather than allocating it among the actual years of expenditure.

Aggregating annual expenditures into a single measure of the capital stock requires assumptions about depreciation. Following Fraumeni (1997), we assume geometric depreciation at a constant annual rate. Fraumeni (1997) presents estimates of depreciation rates for different types of equipment and structures, which are used by the U.S. Bureau of Economic Analysis. For “mining and oil field machinery” the estimated rate is 15%, while for “industrial buildings” the rate is 3.14%. Table B1 provides estimates for rates of 8%, 10%, 12% and 15% (columns INV DEP). Since we do not know the breakdown of Suncor’s capital expenditures by type, we can only conjecture the true value of the aggregate depreciation rate. For our purpose, we have chosen an intermediate value of 10%. Proceeding under this assumption, we calculate an aggregate capital stock in 2004 of approximately $5400 million.

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Table 1: Emissions Intensities (tonnes carbon / barrel)[1]

	E & U	Transmission	R & M[4]	End Use[4]	Total
Industry[2]	0.1299	0.0015	0.0332	0.0004	--
Suncor[3]	0.0983	0.0015	0.0298	0.0004	0.1300

Definitions: E&U – extraction and upgrading; R&M – refining and marketing.

(1) Converted from source data by authors. 1 barrel = 0.159 m^3

(2) Industry average, National Climate Change Process (1998), p.83. Data for 1995, above ground mining only.

(3) E&U value for 2004, from Suncor (2005), p. 66. Other values are industry averages.

(4) Industry values correspond with output volumes (refined product). Values for Suncor have been adjusted to correspond with input volumes. See the appendix for details.

Table 2: Present Value of Marginal Damages[1]

Source	$US (1990)/ tonne carbon	$C (2004)/ tonne carbon (5)
Tol (2005)	86.00[2]	144.74
Tol (2005)	43.00[3]	72.37
Nordhaus & Boyer (2000)	9.13[4]	15.37
Shiell (2003)	38.00[4]	63.96

(1) Estimates effective 2000.
(2) Quality-weighted mean.
(3) Peer-reviewed-only mean.
(4) Optimal emissions scenario.
(5) Authors' calculation, using the GDP deflator (US Dept. of Commerce, Bureau of Economic Analysis) and $C/US PPP exchange rate for 2004 of 1.259 (Heston et al. 2006).

Table 3: Greenhouse Damages of OS Oil ($C 2004/barrel)

	Total		Extraction and Upgrading	
	N & B (2000)	Shiell (2003)	N & B (2000)	Shiell (2003)
Industry	--	--	2.00	8.31
Suncor	2.00	8.31	1.51	6.29

Table 4: Social Benefits and Costs
Suncor Energy Inc.

(a.) $C million 2004

	2004	2005
Gross benefit (1)	4188	5115
Capital costs		
- opportunity cost	270	270
- depreciation	540	540
Other inputs & expenses (2)		
- purchases	75	75
- operating, selling, general	939	939
- asset retirement	21	21
- overburden	225	225
Net benefit (no damage)	2118	3045
GHG damages (N&B 2000)	168	168
% of net (no damage)	7.9	5.5
Adjusted net benefit	1950	2877
GHG damages (Shiell 2003)	699	699
% of net (no damage)	33.0	23.0
Adjusted net benefit	1419	2346

(b.) $C 2004 per barrel

	2004	2005
Price	49.78	60.80
Capital cost	9.63	9.63
Other inputs & expenses	14.98	14.98
Combined costs	24.61	24.61
Net benefit (no damage)	25.17	36.19
GHG damages (N&B 2000)	2.00	2.00
% of net (no damage)	7.9	5.5
Adjusted net benefit	23.17	34.19
GHG damages (Shiell 2003)	8.31	8.31
% of net (no damage)	33.0	23.0
Adjusted net benefit	16.86	27.88

(1) Average sale price (unhedged) × gross production. Data from Suncor Energy Inc. (2006, p.99) and (2005, p.66).
(2) Data from Suncor Energy Inc. (2006).

Table 5: Social Net Benefit – Suncor Energy Inc
($C 2004/barrel)

(a.) 2004

	Damage Overestimate (unaccounted abatement)				
	0%	5%	10%	20%	30%
No damages	25.17	--	--	--	--
N&B (2000)	23.17	23.27	23.37	23.57	23.77
Shiell (2003)	16.86	17.28	17.69	18.52	19.35

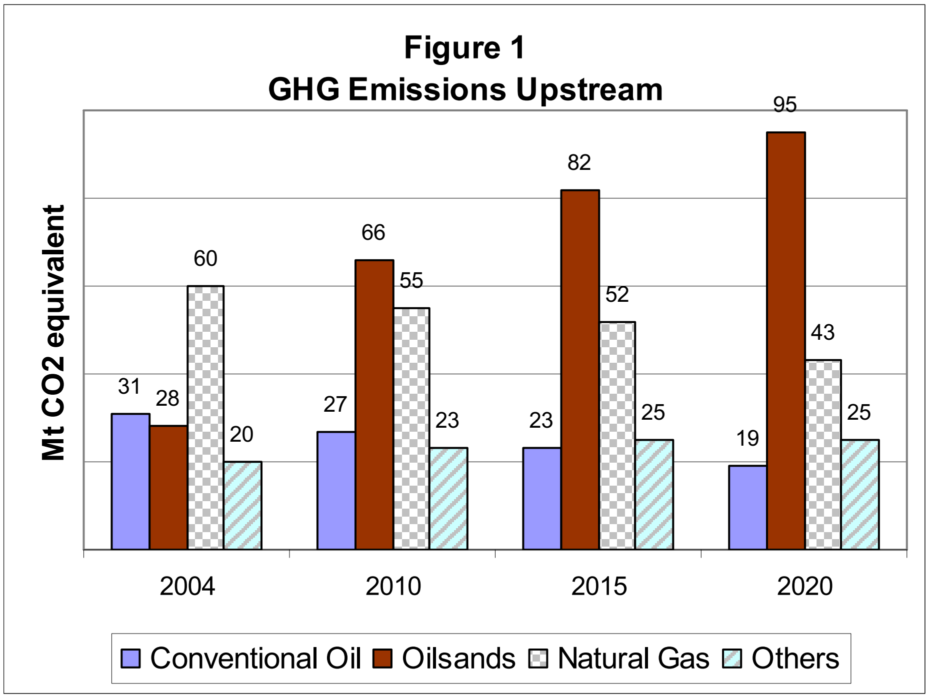
(b.) 2005

	Damage Overestimate (unaccounted abatement)				
	0%	5%	10%	20%	30%
No damages	36.19	--	--	--	--
N&B (2000)	34.19	34.29	34.39	34.59	34.79
Shiell (2003)	27.88	28.30	28.71	29.54	30.37

Table B1: Estimate of Suncor's Real Capital Stock ($C 2004)

Year	INV	PX	INV $2004		INV DEP			
			actual	adj (1)	δ = 0.08	δ = 0.10	δ = 0.12	δ = 0.15
1980	20	66.0	30.3	30.3	4.1	2.4	1.4	0.6
1981	20	66.0	30.3	30.3	4.5	2.7	1.6	0.7
1982	20	66.0	30.3	30.3	4.8	3.0	1.8	0.8
1983	20	66.0	30.3	30.3	5.3	3.3	2.1	1.0
1984	20	66.0	30.3	30.3	5.7	3.7	2.4	1.2
1985	20	66.0	30.3	30.3	6.2	4.1	2.7	1.4
1986	20	66.0	30.3	30.3	6.8	4.5	3.0	1.6
1987	35	67.6	51.8	51.8	12.5	8.6	5.9	3.3
1988	68	68.7	98.9	98.9	26.1	18.3	12.8	7.3
1989	41	72.1	56.9	56.9	16.3	11.7	8.4	5.0
1990	31	73.2	42.4	42.4	13.2	9.7	7.1	4.4
1991	76	72.5	104.8	104.8	35.4	26.6	19.9	12.7
1992	65	73.8	88.1	88.1	32.4	24.9	19.0	12.5
1993	116	76.5	151.6	151.6	60.6	47.6	37.2	25.4
1994	103	81.0	127.2	127.2	55.3	44.4	35.4	25.0
1995	193	85.0	227.1	227.1	107.3	88.0	71.9	52.6
1996	321	85.8	374.2	374.2	192.0	161.1	134.6	102.0
1997	491	88.3	556.0	556.0	310.2	265.9	227.2	178.2
1998	507	92.1	550.6	550.6	333.9	292.6	255.7	207.7
1999	1057	92.7	1140.4	1140.4	751.6	673.4	601.8	506.0
2000	1808	94.6	1911.3	1911.3	1369.2	1254.0	1146.2	997.7
2001	1495	96.1	1556.4	1556.4	1212.0	1134.6	1060.7	955.8
2002	618	97.6	632.9	632.9	535.7	512.6	490.1	457.3
2003	953	94.9	1004.7	1004.7	924.3	904.2	884.1	854.0
2004	1119	100.0	1119.0	-96.0	-96.0	-96.0	-96.0	-96.0
2005	1948	102.8	1895.7					
aggregate K 2004					5891.9	5382.3	4921.9	4310.8
+ pre 1987 conjecture					5929.2	**5406.1**	4936.9	4318.2

INV: capital and exploration expenditures, Suncor annual reports (1980-86 conjectured).
PX: price index, 2004 = 100.
INV DEP: investment figures adjusted for depreciation to 2004
(1) As of 2004, $1215 million had been spent on capital projects which were not yet operational (Millenium vacuum unit, Firebag Stage 2, Coker unit, Firebag cogeneration and expansion). Source: Suncor (2006, p.26).



Source: Background data for Natural Resources Canada (2006), Fig. EM3, p.57.

Figure 2

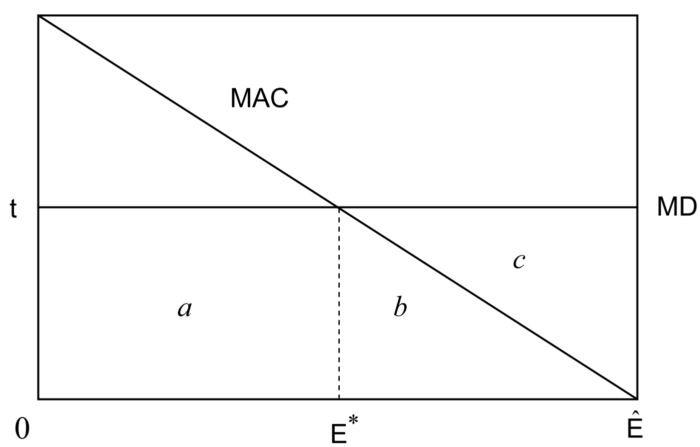


Figure 3
Suncor, Projections of Benefits and Costs