FINAL REPORT

Complementary Regulations for Deep Greenhouse Gas Reductions in Canada

August 31st, 2008

Prepared for

Alex Long of the

National Round Table on the Environment and the Economy

Submitted by:

J&C Nyboer
15168 91 A Avenue
Surrey, BC
V3R 6X1

Project Team:

Christopher Bataille
Brian Rawson
Jotham Peters
Kevin Tu

This page left blank

1 Summary

1.1 Introduction

In 2007, the National Roundtable on the Environment and the Economy (NRTEE) published *Getting to 2050: Canada's transition to a low-emissions future*, which explored several pathways to deep reductions in Canada's greenhouse gas (GHG) emissions, and also examined the policies necessary to attain medium- and long-term deep reductions in GHG emissions. In particular, based on climate change science and the targets of Canada's contemporary nations, NRTEE explored a 20% reduction from 2006 by 2020, and a 65% reduction by 2050, also known as the "fast and deep" emissions reduction path.

This follow-on project to *Getting to 2050* operates from the assumption, based on the policy criteria of effectiveness and efficiency, that some form of economy-wide emissions pricing will be implemented as the core instrument to achieve a deep emissions reduction target. This could be a downstream cap and trade system with a carbon tax for buildings and transport, an upstream cap and trade system or economy wide carbon tax that covers the GHG content of all fuels to be combusted. However, emissions pricing has known potential failures based on market coverage and function. In addition to these failures the "sticker price" necessary to reach -65% using only emissions pricing may be politically unsupportable, especially when contrasted against likely world emissions credit prices. Alternative instruments are required to supplement the emissions pricing policy.

This project's purpose is to recommend a framework of complementary regulations to deal with the parts of the economy that an emissions pricing system cannot feasibly affect, be it because of lack of feasible market coverage (e.g. well venting in upstream oil and gas, or fugitives from pipelines), clear market failure (e.g. principal agent failures in buildings), or a clear need for policy to induce technology in a GHG reducing direction (e.g. transformation of the transportation system through hybridization and alternative fuels, or R&D into low GHG technologies).

The chosen list of market failures were targeted by combining economic theory on market failure, analysis of Environment Canada's GHG Inventory to find those parts of the economy with the highest probability of market failure and large amounts of emissions, and amenability to administratively and politically feasible policy. The key failures were:

- *market coverage failures* associated with high upstream oil and gas, pipeline emissions, landfill gas and agriculture;
- *market function failures* in residential, commercial and institutional buildings and transportation (i.e. principal agency issues between owners and renters, network effects, and lack of marginal cost pricing);

- *key areas of technology transformation for long term deep GHG reduction where private and social risk and return may not be aligned*, e.g. the need to transform the motive energy for transportation to low and zero GHG sources.

For each of the identified failure areas, various types and strengths of regulation were analyzed using the hybrid CIMS model; the failure areas and their recommended policies are listed in detail at the end of this summary. The most effective and cost efficient regulations for each failure were chosen and then modeled together as an integrated package using CIMS.

CIMS is particularly well suited to simulating a combination of broad economic instruments and technology regulations because of its technologically specific and economically complete structure; it combines technological explicitness at the energy use level, firm and consumer level behavioural realism and equilibrium of energy and goods and services markets. The reference case used for this analysis, including output and energy price assumptions, is that same as that used for the related "*Getting to 2050* Technology Road Map" and "*Getting to 2050* Regional and Sectoral Disaggregation" analyses by J&C Nyboer; the reader is referred to these reports for all details.

1.2 Structure of this report

This report begins with a summary of the results of the integrated analysis, including the effects of the high upstream oil and gas, agriculture, and waste sectors not being included in the emissions pricing system and the package of complementary regulations to address market function failures in buildings, residences and transportation. It then summarizes the regulations for each sector. After this "executive summary", it then reviews the theory behind the economically sound use of regulations for GHG emission reductions, how we targeted sectors for regulation based on the Environment Canada GHG Inventory, and finally describes in detail how we decided upon the regulations for each sector.

1.3 Integrated analysis of the market failure and function regulations

Table 1 illustrates several possible GHG pricing paths to the 20% in 2020 and 65% in 2050 target under varying assumptions, including emission market coverage and application of the complementary regulations. They are somewhat different than related work for the NRTEE (the "Technology Road Map" and "Regional and Sectoral Disaggregation" work), because these results include agriculture sector baseline emissions and emissions reductions in response to emissions pricing or regulations, i.e. the economically perfect pricing path has a long run price of \$320/tonne CO_2e instead of \$300/tonne CO_2e.

Table 1: Projected emissions prices (\$/tonne CO_2e \$2005), all including agriculture

	2011-2015	*2016-2020*	*2021-2025*	*2026-2050*
A) Fully domestic and economically perfect pricing path	18	150	225	320
B) Pricing path if no policy in upstream oil & gas, agriculture and waste	18	250	512	775
C) Pricing path if no policy in agriculture and waste	18	150	350	500
D) Fully domestic w/ complementary regulations pkg.	18	170	250	250
E) Max realistic price path w/ int. permit purchases & comp. regs. pkg.	18	100	200	200

A. *Target met fully domestically with "economically perfect" pricing path (2020 price is \$100/tonne CO_2e, the 2026-2050 price is \$320/tonne CO_2e).* This path represents the hypothetical situation where Canada meets the deep target completely domestically, and emissions pricing works perfectly effectively in all sectors, (i.e. ignoring all market coverage and function failures). The price rises quickly to \$150/tonne CO_2e to meet the 2020 target, and then rises more gradually to \$325/tonne CO_2e in 2026 going out to 2050.

B. *Target met fully domestically, but no policy in upstream oil and gas, agriculture and waste (2020 price is \$250/tonne CO_2e, the 2026-2050 price is \$775/tonne CO_2e).* Well venting, flaring and fugitives in the high upstream oil and gas sector, fugitives from agriculture, and waste methane from landfills do not lend themselves well to emissions pricing, because most of these emissions are related to process methane, not combustion of market fuels. This pricing path shows how the price would have to rise if all emissions reductions were to have to come from the sectors where emissions pricing can be effectively applied. The price rises quickly to \$250/tonne CO_2e to meet the 2020 target, and then keeps on rising to \$775/tonne CO_2e by 2026. This result shows the necessity of including policies to effectively reduce high upstream oil and gas, agriculture and waste emissions, be they with verifiable and additive offsets or regulations.

C. *Target met fully domestically but no policy in agriculture and waste (2020 price is \$150/tonne CO_2e, 2025+ price \$500/tonne CO_2e).* Same discussion as for B), but in this case with the addition of regulations for high upstream well venting, flaring and fugitives management.

D. *Target met fully domestically with complementary regulations to address market coverage and function failures in upstream oil and gas, agriculture, landfill waste, buildings, residences and transportation (2020 price is \$170/tonne CO_2e, 2025+ price \$250/tonne CO_2e).* This path represents the situation where Canada meets the deep target completely domestically, with the aid of regulations to fix all market failures of coverage and function.

E. *Maximum realistic pricing path, with international trading and complementary regulations (2020 price is \$100/tonne CO_2e, 2025+ price \$350/tonne CO_2e).* This path represents probably the most politically realistic path, where international permit prices are \$100/tonne CO_2e in 2020 and \$200/tonne CO_2e in 2050. Canadian abatement actions proceed up to these per tonne cost levels, and the remainder is sourced from international emissions markets. 49 Mt in international credits must be purchased annually in 2020, and 55 Mt in 2050, at a cost of \$4.9 and \$11.0 billion respectively if the global prices were \$100/tonne CO_2e in 2020 and \$200/tonne CO_2e in 2050.

A striking result of this analysis is the outcome of not imposing policy to extend coverage to the high upstream oil and gas (i.e. well venting and non-facility flaring), agriculture and waste sectors. If the target includes these emissions, and other sectors must make up the difference, the price rises to \$500/tonne CO_2e in 2050 if agriculture and waste policy is omitted, and \$775/tonne CO_2e if high upstream oil and gas policy is omitted as well.

The net price effect of the complementary market function failure regulations (i.e. in buildings, residences and transport) when the deep target is to be met completely domestically is to reduce the long run emissions price to \$250/tonne CO_2e from \$320/tonne CO2e, but the near term 2016-2020 price rises from \$150/tonne CO_2e to \$170/tonne CO_2e in order to hit the 2020 target. This somewhat unintuitive result is partly due to firms' and consumers' expectations. With the higher "fast and deep" price (\$320/tonne CO_2e from 2026 onward) they anticipate this price and incorporate it in their decisions, which reduces the 2016-2020 price needed to hit the 2020 target. With the lower "complementary regulations" price they act appropriately, and invest less in long term deep GHG reduction, which raises the 2016-2020 price needed to hit the target.

Figure 1 provides an integrated and sequential look at the impact of the market failure regulations; Table 2 provides the specific emissions in tonnes. The top line is the reference case emissions out to 2050 (1097 Mt including agriculture, but not including halocarbons, nitric and adipic acid emissions and non-agriculture land use change and forestry (LUCF)). The 2020 and 2050 targets (571 and 250 Mt CO_2e) are marked as flat red lines. The next line down from BAU provides the effect of the reduced fast and deep emissions pricing schedule (i.e. post 2026 price of \$250/tonne CO_2e) with no complementary regulations to enhance market coverage. The following lines add:

- venting, flaring and fugitives handling regulations in upstream oil and gas;
- regulations for enclosing and combusting landfill waste gas;
- either regulations or additive and verifiable offsets in agriculture;
- revised buildings and household codes for shell thermal efficiencies; and
- regulations for decarbonising the transport sector.

In total, the complementary regulations meet 30% of the target in 2020, and 15% of the 2050 target. The upstream oil and gas, waste and transport regulations contribute the most direct emissions reductions. The buildings and household shell regulations do not directly contribute significant emissions reductions, as these sectors have largely electrified in the "fast and deep" scenarios, but they do significantly reduce the amount of decarbonized electricity that must be produced using a combination of renewables, nuclear, and fossil fuels with carbon capture and storage.

Figure 1: Integrated modelling of the market coverage regulations with a price of \$170/t in 2020 and long run price of \$250/t CO_2e (MT CO_2e) including agriculture, but not including halocarbons, nitric and adipic acid emissions and non-agriculture land use change and forestry (LUCF))

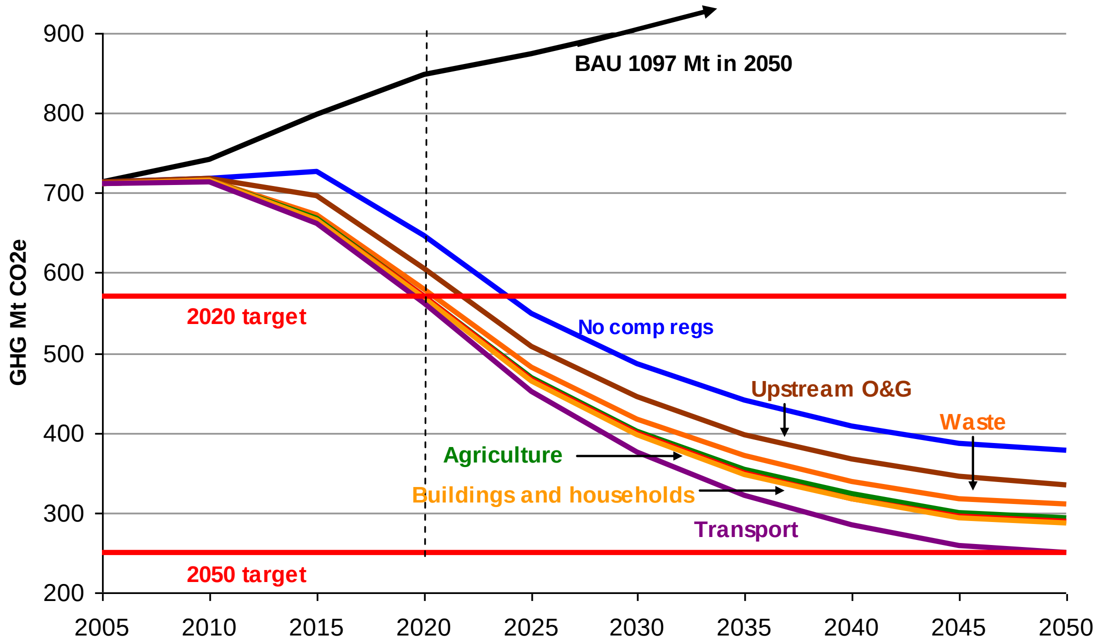


Table 2: Integrated modelling of the market coverage regulations with a price of \$170/t in 2020 and long run price of \$250/t CO_2e (MT CO_2e) including agriculture, but not including halocarbons, nitric and adipic acid emissions and non-agriculture land use change and forestry (LUCF))

	2005	*2010*	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
BAU	714	741	798	849	875	905	945	991	1,040	1,097
No complementary regulations	714	719	727	646	549	486	440	409	387	377
Plus upstream regulations	714	719	697	604	507	444	398	367	345	335
Plus waste regulations	712	715	672	578	481	418	371	340	318	311
Plus agriculture regulations	712	715	668	571	469	402	354	323	301	294
Plus revised buildings codes	712	715	667	570	466	399	350	318	295	288
Plus revised housing codes	712	715	666	568	465	397	348	316	294	287
Plus transportation regulations	712	714	662	561	451	376	321	284	258	249

Figure 1 and Table 2 show the effects of the complementary regulations when the "fast and deep" target is to be met using only domestic measures. If international permit purchases are allowed, and the international permit price does not exceed \$100/t in 2020 and \$200/t in 2050, then the effects of the complementary regulations in Canada are even more marked (Figure 2 and Table 3). In 2020 the complementary regulations achieve 40% of reductions in 2020 and 18% of reductions in 2050. 49 Mt in international credits must be purchased in 2020, and 55 Mt in 2050, at a cost of \$4.9 and \$11.0 billion respectively if the global prices are \$100/t in 2020 and \$200/t in 2050.

Figure 2: Integrated modelling of the market coverage regulations with a price of \$100/t in 2020 and long run price of \$200/t CO_2e (MT CO_2e) including agriculture,

but not including halocarbons, nitric and adipic acid emissions and non-agriculture land use change and forestry (LUCF))

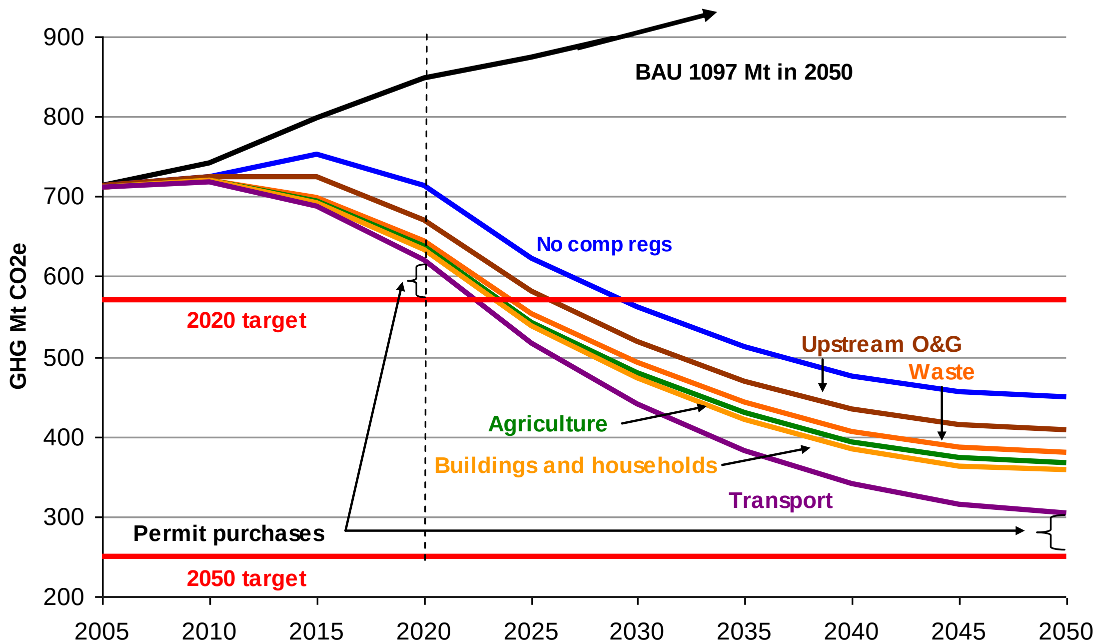


Table 3: Integrated modelling of the market coverage regulations with a price of \$100/t in 2020 and long run price of \$200/t CO_2e (MT CO_2e) including agriculture, but not including halocarbons, nitric and adipic acid emissions and non-agriculture land use change and forestry (LUCF))

	2005	*2010*	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
BAU	714	741	798	849	875	905	945	991	1,040	1,097
No complementary regulations	714	724	754	713	622	561	512	475	456	450
Plus upstream regulations	714	724	724	671	580	519	470	433	414	408
Plus waste regulations	712	721	698	645	554	493	442	406	386	380
Plus agriculture regulations	712	720	694	637	543	479	429	392	372	367
Plus buildings and residences	712	720	691	633	538	473	421	384	364	357
Plus transportation regulations	712	719	689	620	516	440	382	341	314	305

1.4 Summary of the recommended complementary regulations

The follow market failures were targeted, and regulations designed to address the failures:

- **High upstream oil and gas well venting and flaring coverage failures (From a base of 65.7 Mt total emissions in 2005).** Historically, emissions management in the high upstream oil and gas sector was primarily about running wells and gathering systems and disposing of uneconomic quantities of gas mixed with oil while minimizing risks to human health from hydrogen sulfide gas and fire. Gas with low quantities of sulphur and low chance of fire risk was dispersed directly to the atmosphere, while that with high quantities of sulphur and risk of fire was combusted using flares. These management methods meant large quantities of methane, a strong greenhouse gas, were dispersed directly to the atmosphere.

These emissions are also extremely difficult to quantify because they come from numerous sources in remote and primitive conditions, but all estimates show them to be very large. There are several ways to reduce these emissions, already part of normal practice in other contexts, including enclosure and capture of emissions at the well head, separation and transport of gas mixed with oil to gas gathering batteries for sale, and flaring.

- ***Recommended policy:*** For this sector we recommend stringent venting and flaring command and control regulations. All non-safety venting and flaring is to end within a staged schedule, with all safety oriented venting and flaring to be registered, and a pay-to-pollute charge equivalent to the market price for emissions is to be paid. Unregistered atmospheric dispersal will be patrolled as speeding limits are, with severe fines significantly more than the pay to pollute charge to be imposed. We estimate that an aggressive but economic program of regulation could cut emissions by up to two-thirds, around 42 Mt CO_2e per year including pipeline combustion and fugitives (next section).

- **Pipeline combustion market coverage failures (From a base of 10.1 Mt combustion emissions in 2005).** Transport of oil and natural gas by pipeline, especially natural gas, creates significant combustion and fugitive emissions. Natural gas in the pipeline is combusted to run compressors to maintain line pressure, and is also emitted un-combusted as methane while being used to run auxiliary pumps, instruments, etc. A certain amount of gas also leaks through seals, measurement devices, etc. Transmission firms may track some of the gas combusted, as this is no longer available for sale, but the amounts used to run gas actuated auxiliaries and fugitive leaks are extremely hard to measure, as they are from many thousands of sources in very remote conditions.
    - ***Recommended policy:*** We recommend that compressor combustion be included under the broad emissions pricing system, either by direct measurement if possible, or estimation if necessary. For gas actuated devices we recommend that at normal replacement intervals they be replaced with electric or other non-gas driven methods if available. For line leak fugitive regulations we recommend similar recommendations to that for well venting and flaring are recommended, with the proviso that they be somewhat more lenient given the impossibility of completely eliminating line leak fugitives. The estimated reductions are included in the estimate for high upstream oil and gas.

- **Landfill gas fugitive coverage failures (From a base of 28.0 Mt of total emissions in 2005).** Landfills emit significant amounts of methane from anaerobic metabolisation of organic waste by bacteria. Methane (CH_4), molecule for molecule, has GHG factor 23 times that of CO_2. Because these methane emissions are not from combusted market fuels an emissions pricing scheme based on fuel combustion or carbon content will have no direct effect. There are, however, simple measures to reduce these emissions. The methane can be trapped with enclosures and then combusted as a flare, reducing its GHG factor by 23. It can also be used to drive electric generators, displacing other fossil fuel sources of electricity. The question is how to compel these actions to occur, given that emissions pricing based on fuel combustion by itself will have no direct effect.

  - ***Recommended policy:*** Our analysis shows the greatest amount of reductions when all sites have enclosure and combustion regulations, or there is an offset program in place. Use of offsets requires a significant investment in verification procedures, and raises questions of additionality – many sites would be enclosed even in BAU, and use of offsets in this case would create "hot air" credits that will debase the core broad emissions pricing system. Given this, and that most landfills can be enclosed for \$15-\$25/tonne CO_2e , we instead recommend that the federal government, provinces and municipalities across Canada cooperate to institute a system of mandatory enclosure and combustion for all sizes of landfill, with centralization of landfills as necessary to minimize costs. Given that financial and institutional resources may be beyond that of small municipalities, we also recommend that the federal and provincial governments work together to provide aid to municipalities as necessary to carry out the mandatory enclosure regulation. We have estimated that 25-28 Mt CO_2e per year could be reduced this way.

- **Agricultural fugitives (From a base of 57 Mt CO_2 in 2005).** A significant portion of Canada's GHG emissions come from enteric fermentation (25.0 Mt), manure management (8.6 Mt), and agricultural soil management (23.0 Mt). Agricultural emissions reductions can be achieved through significant changes in land use and agricultural practices, including use of no-tillage planting and enclosures for manure management. Because these emissions are not from combusted market fuels and are spread all over Canada from virtually millions of sources, an emissions pricing scheme by itself will have no effect on them.

  - ***Recommended policy:*** There are two options for incenting practices that reduced agricultural emissions: offsets and regulations. Baseline emissions and emissions reductions will be very difficult to estimate for individual farms, however, making it very difficult to verify the additivity of offsets. This has the danger that "hot air" credits will be created that will, through creation of an artificial supply of emissions reductions, debase the greater emissions pricing scheme, especially if it is some form of emissions cap and trade system. Verification of compliance with regulations relating to agricultural practises will also be difficult and may be costly both to implement and enforce, but does not have the danger of debasing the greater emissions pricing mechanism. These regulations could be enforced much the same way speeding laws are, not with continuous compliance but with significantly penalties in the case of being caught during random checks. For these reasons we recommend that regulations relating to agricultural practises be implemented and enforced instead of use of a domestic offset system. We also recommend that federal and provincial resources be made available in the form of education and possibly targeted grants to aid the farming community in transitioning from high to low

GHG emitting practises. We estimate additive and verifiable reductions of 8 Mt in 2020 and 13 Mt in 2050 from this sector.

- **Principal agent failures in the buildings sector (From a base of 36.98 Mt for Commercial and Institutional 36.8 Mt + Residential 42 Mt).** A widely acknowledged market failure is the disconnect between those who determine the day to day use of energy in building structures, and those who own them. The owners of buildings cannot necessarily recover investments in energy efficiency, as they are reaped by renters or leaseholders who determine the energy load and pay the energy bills. Renters or leaseholders, on the other hand, have no incentive to make significant energy efficiency investments, as they do not usually have secure tenure to their residence. Another related reason for buildings regulations is the market consolidation argument; regulations that eliminate a subset of equipment choices may be justified where information or search costs are particularly high, and research has found that application of this type of regulation in certain situations can lead to net benefits to society.[1] Over 50 countries, including Canada, use appliance efficiency standards that are periodically reviewed to account for new technological developments.[2]
    - ***Recommended policy:*** We recommend LEED Standard or equivalent as a base level for all new commercial buildings, and at least a 50% increase in shell efficiency for all residential buildings compared to current and planned codes. Our experiments indicate that even higher levels of residential efficiency may be economic. Our estimates of the emissions reductions associated with these measures in Table 2 are somewhat understated, as these sectors have largely electrified, and the emissions reductions are counted in the electricity sector, which has also largely decarbonized. Our detailed results show that the reduced electricity demand actualizes as greatly reduced electricity costs to the buildings sector.
- **Transportation: Network failures, a lack of marginal cost pricing, and the need to transform the sector from fossil fuels to other motive energy as a key to deep reductions (Affects 135 Mt in road transportation, 8.7 Mt in aviation, and 30 Mt of offroad transport).** By network failures, we refer to the large capital and political investments required to build new transportation infrastructure. Transportation networks are rarely built entirely by private market agents; they typically involve government guidance and funds, justified by the public goods nature of transportation systems (i.e. single users cannot individually effectively pay for and receive transport improvements; they are either built as large "lumpy" projects that benefit all, or not at all). These "lumpy" technology system characteristics can potentially inhibit the use of radically differing transportation technologies (hydrogen as a combustion fuel, etc.). Personal

---

[1] Moxnes, E., 2004. "Estimating customer costs or benefits of energy efficiency standards," *Journal of Economic Psychology*, 25(6), 707–724.

[2] Nadel, S., 2002. "Appliance and equipment efficiency standards," *Annual Review of Energy and Environment*, 27, 159–192.

transportation is also subject to large, indirect lumpy payments by taxpayers for the benefit of drivers, reducing the effect of marginal cost pricing (i.e. only fuel and some maintenance is pay-per-use; insurance is generally paid once a year, and road infrastructure is provided indirectly through taxation). There are also significant public penalties from air pollution created by driver's mobility choices, as well as energy security issues, given that much of the world's motive fuels come from politically unstable regions.

One issue with imposing regulations on top of GHG pricing for fuels is that the transport sector will be effectively double taxed. This may be justified if there are separate market failures to support both" taxes, or if emission pricing based on GHG content of fuels when combusted can be considered to be in ineffective in addressing the market failure. Clear economic reasoning must be supplied, however, to support the regulations on top of the emissions pricing.

Emissions from this sector are so large and so critical to long deep reductions, however, that they deserve significant attention. If the impacts of climate change dramatically worsen and the need for draconian regulations arrives, this sector will be one of those targeted because of the scale of emissions.

- ***Recommended policy:*** We have recommended national adoption of California's GHG emissions intensity policy out to 2020, gradually increasing in stringency to a virtually zero GHG intensity policy by 2040. This involves either complete electrification of the transport fleet or switching to an alternative liquid or gas motive fuel; biofuel and hydrogen are two candidates. Another unforeseen option may arise, however, and the policy should not dictate what technology is to be chosen, only the maximum GHG intensity of the transport vehicles added to the stock in a given year, with capacity for vehicle makers to trade requirements amongst each other (i.e. if one car makers exceeds the standard, they can sell the excess credits to another maker). The policy delivers 11 Mt CO_2e in 2015, gradually increasing to 68 Mt CO_2e by 2050.

2 Table of Contents

3 Why complementary regulations for a broad emissions pricing policy?

In 2007, the National Roundtable on the Environment and the Economy (NRTEE) published *Getting to 2050: Canada's transition to a low-emissions future*, which explored several pathways to deep reductions in Canada's greenhouse gas (GHG) emissions, and also examined the policies necessary to attain medium- and long-term deep reductions in GHG emissions. In particular, based on climate change science and the targets of Canada's contemporary nations, NRTEE explored a 20% reduction from 2006 by 2020, and a 65% reduction by 2050; this target was also known as "fast and deep".

This follow-on project to *Getting to 2050* operates from the assumption, based on the policy criteria of effectiveness and efficiency, that some form of economy-wide emissions pricing will be implemented as the core instrument to achieve a deep emissions reduction target. This could be a downstream cap and trade with a carbon tax for buildings and transport, an upstream cap and trade or economy wide carbon tax that covers the GHG content of all fuels to be combusted. However, emissions pricing has known potential failures, and in addition to this the "sticker price" necessary to reach -65% from 2005 levels using only emissions pricing may be politically unsupportable, especially when contrasted against likely world emissions credit prices. Hence the need for alternative instruments to supplement the emissions pricing policy.

This project's purpose is to recommend a basic complementary regulations framework to deal with the parts of the economy that an emissions pricing system cannot feasibly affect, be it because of lack of feasible market coverage (e.g. well venting and flaring in upstream oil and gas, or fugitives from pipelines), clear market failure (e.g. principal agent failures in buildings), or a clear need for policy to induce technology in a GHG reducing direction (e.g. transformation of the transportation system through hybridization and alternative fuels, or R&D into low GHG technologies).

The key deliverable of the project is a list of politically and administratively feasible regulations that meet key market failures and affect significant sources of emissions (e.g. solvent emissions accounted for 180 kt of Canada's emissions in 2005, while upstream oil and gas fugitives accounted for 65.0 Mt, hence we will focus more on upstream oil and gas fugitives). These regulations are modeled in conjunction with a broad based emission pricing system using the hybrid CIMS model, which combines technological explicitness, firm and consumer level behavioural realism as well as macroeconomic feedbacks.

3.1 Structure of this report

The report begins with a review of policy criteria and instruments, and how they inform our choice of complementary regulations for an emissions pricing system. Then, using this theoretical review of market failure and Environment Canada's GHG Inventory, we target a list of key market coverage and function failures. We then review each market failure and potential policies to address it separately, including quantitative analysis of the potential emissions reductions associated with the policies. The summary above provides all information on the integrated analysis of the most effective and efficient policies, including their effects on total emissions and the final market clearing price for the broader emissions pricing system. The report finishes with an appendix describing the CIMS model.

All information on the reference case used for this analysis, including output and energy price assumptions, are provided in the related "*Getting to 2050* Technology Road Map" and "*Getting to 2050* Regional and Sectoral Disaggregation" report by J&C Nyboer.

4 Policy criteria and instruments

As reviewed in *Getting to 2050* and the work leading up to it, there are four key criteria for any policy: effectiveness, efficiency, political feasibility and equity, and administrative feasibility (Table 4).

Table 4: Policy evaluation criteria

Criteria	Related questions to be asked of a policy or policy package
Effectiveness at achieving the environmental target	Will the policy package reduce GHG emissions effectively by leveraging investments by firms and individuals? Does the policy directly target the generation of GHGs, or does it do so indirectly (i.e., through improving energy efficiency)? Does the policy package cover all GHG emissions in the economy, or is there scope for emissions leakage?
Economic efficiency	To what extent will emission reductions be reached with the lowest economic costs, considered from the perspectives of the government administrator and the firms/households subject to the measure? Does the policy package create incentives for private sector investment in new low-GHG technologies?
Political acceptability and equity	Will politicians find sufficient support to implement a policy?[3] Will Canada maintain the competitiveness of industries producing goods that are traded in the international marketplace? Do certain segments of society bear an unsupportable portion of the cost of the policy that cannot be compensated for?
Administrative feasibility	Is the measure administratively efficient? Is the burden of administration, reporting, monitoring, and enforcement minimized? Does the policy mesh well with ongoing national and international climate change policy efforts?

The criteria in Table 4 are used to sort through the various policy instruments. The key instruments available for GHG emissions reduction, provided in rough order of least to greatest preference, are:

[3] While equity is encompassed in this question, it is challenging to define this criterion on its own. For instance, S. Cairns notes that "the design of the measure should take into account the effects between sectors, regions, individuals, and generations," and that "in principle, no measure should be constructed in such as way that inequality is worsened for the disadvantaged" (Cairns, 2006, p. 12). This is challenging to operationalize: "Are equal per-capita policy costs equitable? Are equal regional costs equitable? Are costs that reflect each person's contribution to GHG emissions equitable?" We therefore focus on political acceptability.

- **Voluntary approaches** allow individual companies and consumers to determine their own level of emissions reduction effort, and cast government in the roles of information provider, facilitator, role model, or award giver. These policies are politically appealing, but are not environmentally effective, especially for deep GHG reduction targets that would involve significant costs for participants. If all participants do not volunteer, those who do will experience significant costs with no benefit, and thereby be induced to cease the emissions reduction activity. Some types of voluntary policy are useful; in particular, equipment labeling and other information provision and education programs are important to continue, especially where the fiscal costs are low. *However, due to their ineffectiveness, voluntary approaches can be considered of limited usefulness for deep emissions reductions.*

- **Subsidies** from government to firms and individuals improve the financial return to adopting low-GHG technologies. They are politically acceptable, but have poor economic efficiency and environmental effectiveness if applied broadly because the scale of subsidies required to achieve deep reductions would overwhelm government taxation sources, and even if achievable would seriously distort the economy as a consequence. They also have a serious flaw in that firms and consumers that were going to do an emissions reduction action for other reasons may apply for the subsidy, i.e. become "free-riders", thereby increasing the cost of the system. *Subsidies are of limited use as a core emissions reduction instrument but they may, however, have some role in supporting R&D for low GHG technologies; they can be used to ease market failures associated with private costs and public benefits of research and innovation.*

- **Command and control (C&C) regulations** are technology or performance standards enforced through stringent financial or legal penalties. They are generally considered environmentally effective, but are generally not economically efficient if applied broadly because they impose the same cost on all affected parties when the costs of emissions abatement generally vary (i.e. C&C regulations are generally not equimarginal). *For deep emission reductions targets, however, C&C regulations may have important roles as an instrument to address market coverage failures, to correct clear emissions market failures, and to consolidate technological change pushed using other policies.*

- **Emission pricing** comes in various forms, all of which share the characteristic that all affected parties respond to the same price, which makes emissions pricing equimarginal (i.e. cost efficient, or least cost). The various methods of emissions pricing have widely varying characteristics, however, and need to be looked at individually against the policy criteria.

    - **Market-oriented regulations (e.g., cap and trade systems)** set an aggregate regulatory requirement on the entire economy or on a sector of the economy, but allow trading between firms to achieve the requirement. They can be environmentally effective and relatively economically efficient if well designed, but require some administration to monitor trading. There are many different types of market orientated regulations, including cap and trade systems, renewable portfolio standards, and tradable vehicle emissions standards.

- **Offset credit systems.** Offset systems tend to work as subsystems of market orientated regulations, and operate by providing resalable credits to parties that can prove verifiable and additional emission reductions outside the scope of the market orientated regulation. They are used to address emissions that may not be directly priced in a normal cap and trade system; for example they may be used to include process emission reductions in a cap and trade system based on combustion emissions. In terms of their effectiveness, offset systems are highly vulnerable to the verification system used to enforce additionality. At their worst, if they are allowed to sell non-additional "hot air" credits into an otherwise functioning cap and trade system, they may debase the system effectiveness by providing an artificial supply of credits which would reduce the market clearing price, and thus the signal sent by the market to firms and consumers.
- **GHG taxes** require domestic emitters to pay a fixed fee for every tonne of CO_2e released to the atmosphere. They perform well against all criteria except political acceptability, since the public has to date been reluctant to consider new taxes, even if they are revenue neutral.

In the work leading up to *Getting to 2050*, it was established that as broad as possible emission pricing system, with a minimal use of offsets, is the most effective, efficient, and politically and administratively acceptable policy option for achieving any deep emission reduction goal. However, the policy literature also indicates that sector specific regulatory policies can effectively supplement a broad market-based policy.[4] In particular, economic theory indicates that sector-specific policies can improve economic outcomes when the following conditions are present:

- **Substantial portions of emissions are uncovered, i.e. there is a failure of "market coverage."** If the broad market-based policy does not cover the entire economy (e.g. industrial process emissions; landfill gas, agriculture, and upstream oil and gas fugitives; or a downstream cap-and-trade scheme which misses upstream emissions), other policies are required to induce GHG reductions throughout the uncovered potions of the economy. The two main options for addressing these emissions are offsets and C&C regulations.
- **Market failures are present in technology adoption that are not corrected by the imposition of the broad market-based signal.** Important market failures that have been identified by other research include principal-agent problems, where home or building tenants have limited incentive to conserve, and information problems, where adoption of a new technology produces valuable information that cannot be fully captured by the initial adopter (e.g., early

[4] Nordhaus, R. and K. Danish, 2003. "Designing a mandatory greenhouse gas reduction program for the US," Washington: Pew Center on Global Climate Change.

adopters of hybrid vehicles provided valuable information to future adopters for which they were not compensated).[5] The main options for addressing this class of failure are C&C regulations and possibly subsidies.

- **Market failures are present in technology research and development that are not corrected by the imposition of broad market-based signal.** Since the gains to learning investments (e.g., research and development) are not fully appropriable to the investor, the social return on learning investments generally outweighs the private return, leading to socially sub-optimal private investment in new technological development, which is particularly pronounced in the energy sector.[6] Although not explicitly modelled in this report, some public R&D investments are warranted to narrow the gap between the privately optimal and socially optimal investment quantity, and where possible, regulations should be developed and tightened to increase the appropriability of knowledge (both of these occur already in Canada throughout the economy).

Given these theoretical grounds for policies supplementary to a broad based emissions pricing instrument, where and at what scale are emissions pricing instruments likely to fail in Canada, and where and how should complementary regulations be considered?

5 Where would an emissions pricing system likely fail without complementary regulations in Canada?

Based on EC's *2005 GHG Emissions Inventory* for Canada, we have identified the following set of key market coverage and other failures, and the magnitude of emissions that are involved.

Given that market coverage failures are easier to identify and enumerate, as opposed to other market failures, we list the key market coverage failures first. These coverage failures also have some of the clearest, most economically justifiable and politically and administratively feasible policy intervention possibilities, making action on them a high priority.[7]

- **"High upstream" oil and gas fugitive market coverage failures (From a base of 65.7 Mt total emissions in 2005).** Historically, emissions management in the high upstream oil and gas sector was primarily about running wells and gathering

---

5 Jaffe, A. and R. Stavins, 1994, "The energy efficiency gap: What does it mean?," *Energy Policy*, 22(10): 804–810.

6 Globally, the energy sector spends only about US$4.5 billion annually on research and development, and this amount has declined by 50% in the past decade. Public energy R&D investments are also declining in most countries, even as total public R&D investments have increased significantly (Stern et al., 2006. "The Stern Review on the Economics of Climate Change," Prepared for H.M. Treasury, UK, Chapter 16.

7 There is one significant source of fugitive emissions that would not be addressed by an emissions pricing scheme – solvents, which account for 180kt in 2005. Because of the relatively small amount of emissions, and the wide and varied use of solvents, we have not included regulations for their management in this analysis.

systems and disposing of uneconomic quantities of gas mixed with oil while minimizing risks to human health from hydrogen sulfide gas and fire. Gas with low quantities of sulphur and low chance of fire was dispersed directly to the atmosphere, while that with high quantities of sulphur and risk of fire was combusted using flares. These management methods meant large quantities of methane, a strong greenhouse gas, were dispersed directly to the atmosphere. These emissions are also extremely difficult to quantify because they come from numerous sources in remote and primitive conditions, but all estimates show them to be very large. There are several ways to reduce these emissions, already part of normal practice in other contexts: enclosure and capture of emissions at the well head, separation and transport of gas mixed with oil to gas gathering batteries for sale, and flaring.

- **Pipeline combustion market coverage failures (From a base of 10.1 Mt combustion emissions in 2005).** Transport of oil and natural gas by pipeline, especially natural gas, creates significant combustion and fugitive emissions. Natural gas in the pipeline is combusted to run compressors to maintain line pressure, and is also emitted un-combusted as methane while being used to run auxiliary pumps, instruments, etc. A certain amount of gas also leaks through seals, measurement devices, etc. Transmission firms may track some of the gas combusted, as this is no longer available for sale, but the amounts used to run gas actuated auxiliaries and fugitive leaks are extremely hard to measure, as they are from many thousands of sources in very remote conditions.
- **Agriculture fugitives market coverage failure (From a base of 57.0 Mt total emissions in 2005).** A significant portion of Canada's GHG emissions come from enteric fermentation (25.0 Mt), manure management (8.6 Mt), and agricultural soil management (23.0 Mt). Agricultural emissions reductions can be achieved through significant changes in land use and agricultural practices, including use of no-tillage planting and enclosures for manure management. Because these emissions are not from combusted market fuels and are spread all over Canada from virtually millions of sources, an emissions pricing scheme by itself will have no effect on them.
- **Landfill gas fugitive market coverage failures (From a base of 28.0 Mt of total emissions in 2005).** Landfills emit significant amounts of methane from anaerobic metabolisation by bacteria. Methane (CH_4), molecule for molecule, has GHG factor 23 times that of CO_2. Because these methane emissions are not from combusted market fuels an emissions pricing scheme will have no direct effect on them. However, there are simple measures to reduce these emissions. The methane can be trapped with enclosures, and then combusted as a flare, reducing its GHG factor by 23. It can also be used to drive electric generators, displacing other fossil fuel sources of electricity. The question is how to compel these actions to occur, given that emissions pricing by itself will have no direct effect.
- **Principal agent market function failures in the buildings sector (Commercial and Institutional 36.8 Mt + Residential 42 Mt).** A widely acknowledged market failure is the disconnect between those who determine the day to day use

of energy in building structures, and those who own them. The owners of buildings cannot necessarily recover investments in energy efficiency, as they are reaped by renters or leaseholders who determine the energy load and pay the energy bills. Renters or leaseholders, on the other hand, have no incentive to make significant energy efficiency investments, as they do not usually have secure tenure to their residence. Another related reason for buildings regulations is the market consolidation argument; regulations that eliminate a subset of equipment choices may be justified where information or search costs are particularly high, and research has found that application of this type of regulation in certain situations can lead to net benefits to society.[8] Over 50 countries, including Canada, use appliance efficiency standards that are periodically reviewed to account for new technological developments.[9]

- **Transportation: Network failures, a lack of marginal cost pricing, and the need to transform the sector from fossil fuels to other motive energy as a key to deep reductions (Affects 135 Mt in road transportation, 8.7 Mt in aviation, and 30 Mt of offroad transport).** By network failures, we refer to the large capital and political investments required to build new transportation infrastructure. Transportation networks are rarely built entirely by private market agents; they typically involve government guidance and funds, justified by the public goods nature of transportation systems (i.e. single users cannot individually effectively pay for and receive transport improvements; they are either built as large "lumpy" projects that benefit all, or not at all). These "lumpy" technology system characteristics can potentially inhibit the use of radically differing transportation technologies (hydrogen as a combustion fuel, etc.). Personal transportation is also subject to large, indirect lumpy payments by taxpayers for the benefit of drivers, reducing the effect of marginal cost pricing (i.e. only the fuel and some maintenance is pay-per-use; insurance is generally paid once a year, and road infrastructure is provided indirectly through taxation). There are also significant public penalties from air pollution created from driver's mobility choices, and energy security issues as well, given that much of the world key motive fuel source comes from politically unstable regions.

  One issue with imposing regulations on top of GHG pricing for fuels is that the transport sector will be effectively double taxed. This may be justified if there are separate market failures to support both taxes, or if emission pricing based on GHG content of fuels when combusted can be considered to be in ineffective in addressing the market failure. Clear economic reasoning must be supplied, however, to support the regulations on top of the emissions pricing.

  Emissions from this sector are so large and so critical to long deep reductions, however, that they deserve significant attention. If the impacts of climate change dramatically worsen and the need for draconian regulations arrives, this sector will be one of those targeted because of the scale of emissions.

[8] Moxnes, E., 2004. "Estimating customer costs or benefits of energy efficiency standards," *Journal of Economic Psychology*, 25(6), 707–724.

[9] Nadel, S., 2002. "Appliance and equipment efficiency standards," *Annual Review of Energy and Environment*, 27, 159–192.

- **Other market failures present in technology research and development and not corrected by the imposition of broad market-based signal.** Since the gains to learning investments (e.g., research and development) are not fully appropriable to the investor, the social return on learning investments generally outweighs the private return, leading to socially sub-optimal private investment in new technological development. Although not explicitly modelled in this report, some public R&D investments are probably warranted to narrow the gap between the privately optimal and socially optimal investment quantity, and where possible, regulations should be developed and tightened to increase the appropriability of knowledge (both of these occur already in Canada throughout the economy). While we fully acknowledge possible market failures having to with R&D, they are extremely difficult to quantify, and in this project we will focus on clear, quantifiable market failures, amenable to policy, associated with large volumes of GHGs.

5.1 Method

Sector by sector method

In following sections for each market failure we provide a method for addressing how these emissions may be reduced. Because these methods are specific to the emissions pricing market failures of the individual sectors, our methods for analyzing and addressing the market failures and our resulting regulations are specific to the failures, and are treated as distinct subject areas.

A key principle of economic efficiency is that policies are equimarginal, i.e. they have the same imposed strength on all firms and consumers. If this isn't so the actions performed by individual firms, sectors and consumers can have differing costs at the margin, implying a more costly than necessary effort to hit the target. The equimarginal principle applies whether the policy is a price or regulation. While emissions prices have a direct "sticker price" that can be measured and evaluated, regulations, which carry just as real a "shadow price", do not generally have easily evaluable "sticker prices". The "shadow price" of regulations can be calculated, however, and we use this characteristic to find a set of regulations to address the market failures described in this section. This method is highly individual to the failures and sectors, however, and so is described directly in the analysis.

Integrated Methodology

To complete this analysis, we combine the effective and cost efficient regulations associated with each market failure as package of complementary regulations. We chose the regulations based on:

- the additional absolute emissions reductions due to the regulations in an environment with pre-existing emissions pricing on all market fossil fuels;
- the cost of the regulations, on a total, average and marginal cost basis based on both valued added (capital and labour) and input cost (capital, labour and energy), and how they related to the broad emissions market price;
- the technical, political and administrative feasibility of the regulations.

6 Market coverage failures – oil and gas, agriculture and landfill waste

6.1 High upstream oil & gas combustion and fugitive market coverage failures

6.1.1 Introduction

Canada's oil and gas industry is a major source of greenhouse gas (GHG) emissions. Over the last 15 years, the industry has undergone significant change, motivated by a combination of evolving commodity prices, available technology, industry best practices, and regulatory policies. While emissions reductions have been achieved in many cases, these have been overwhelmed by industry growth. A wealth of very economical emissions reductions have been tapped (so-called "low hanging fruit"), but further reductions are necessary to meet international commitments and minimize environmental impacts. This report outlines the required steps for further GHG emissions reduction, and illustrates the costs of implementing these reductions.

6.1.2 Targeted Sources

GHG emissions from Canada's oil and gas industry are organized into two different categories in Canada's national inventory: energy consumption and fugitive emissions. More appropriate descriptions would be energy consumption and atmospheric dispersal.

Energy consumption includes all use of fossil fuels for the many different heat and motive energy requirements for converting raw hydrocarbons into useful energy feed stocks and delivering them to customers. For virtually the entire industry, these energy requirements are minimized as a course of normal business practices as the energy sources (primarily natural gas and diesel) are valuable, high-quality fuels whose use reduces profits. These emissions, amounting to 68 Mt CO_2 e in 2006[10], are generated in an atmosphere of control, where industry's economic best interest aligns with GHG emissions mitigation.

At the other end of the spectrum is atmospheric dispersal. These emissions include venting, flaring and fugitive (intentional and unintentional equipment leakage) emissions. In 2006, these emissions amounted to 66 Mt CO_2e[11], slightly less than half of total oil and gas industry emissions. These emissions are uneconomical to capture and pose little or no harm other than their global warming potential. This risk is difficult to monetize, so emission reduction opportunities are not integrated into normal business investment considerations. In addition, many of these emissions sources are difficult or impossible to

[10] Environment Canada, Canada's 2006 Greenhouse Gas Inventory – A Summary of Trends, May 2008, p. 6.

[11] Ibid.

accurately measure. Production accounting systems designed by Canada's various industry regulators do not assess these emissions in a consistent manner, especially for venting. These emissions occur throughout the oil and gas industry, however, processing, refining, transportation and distribution elements are targeted for regulation and these sources will be controlled. Where atmospheric dispersal emissions need to be further addressed are at the hundreds of thousands of wells, tens of thousands of batteries, and hundreds of gathering systems operating upstream of the more regulated processing and refining facilities.

6.1.3 Geographical distribution

Canada's oil and gas industry and resultant emissions are concentrated in Alberta (61 Mt CO_2e in 2000[12]), with significant contribution from Saskatchewan (15 Mt) and British Columbia (7 Mt). The remainder (and approximately 2 Mt emissions) is from facilities in Newfoundland and Labrador, Nova Scotia, Northwest Territories, Ontario, Manitoba and Yukon Territory.

6.1.4 Industry sub-sector distribution

Industry sub-sectors are ranked below in terms of the mass of air dispersal emissions.

Table 5: Upstream Oil and Gas Fugitive Emissions

Rank	**Sub-sector**	**Atmospheric Dispersal Emissions (Mt CO_2 e)**	**Atmospheric Dispersal as share of total GHG emissions (%)**	**Significant Sources & Activities (*may not match dispersal emissions due to rounding and/or unlisted minor sources*)**
1	Heavy Crude Oil from Cold Production	17.2	92	Venting from crude bitumen batteries (9.2 Mt), oil sands surface venting (3.0 Mt), venting from heavy oil wells, wells (2.3 Mt), fugitive emissions from heavy oil wells (0.9 Mt), flaring (0.7 Mt)
2	Natural Gas Production	10.6	52	Gas battery venting emissions (3.4 Mt), gas battery fugitive emissions (3.2 Mt), gathering system fugitive emissions (1.5 Mt), gathering system venting (0.9 Mt), flaring (0.3 Mt)
3	Light and Medium Crude Oil Production	7.4	73	Oil battery venting (3.3 Mt), oil battery flaring (2.3 Mt), fugitive emissions (2.0 Mt)
4	Accidents and Equipment Failures	4.2	100	Surface casing vent flows (3.2 Mt), pipeline ruptures (0.8 Mt)

[12] Clearstone Engineering, A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H2S) Emissions by the Upstream Oil and Gas Industry, Volume 1, Overview of the GHG Emissions Inventory, Canadian Association of Petroleum Producers, September 2004, p. 19.

Rank	Sub-sector	Atmospheric Dispersal Emissions (Mt CO_2 e)	Atmospheric Dispersal as share of total GHG emissions (%)	Significant Sources & Activities (*may not match dispersal emissions due to rounding and/or unlisted minor sources*)
5	Heavy Crude Oil from Thermal Production	1.1	15	Venting (0.8 Mt), flaring (0.3 Mt)
6	Well Tests	0.9	90	Flaring (0.9 Mt)
7	Well Servicing	0.2	40	Lowdown treatments (0.2 Mt)
8	Well Drilling	0.0	1	Only minor sources

6.1.5 Best Practices

These venting, fugitive and flaring emissions must be put in historical perspective. In the past toxicity, sulphur emissions and odor were the primary air emissions issues addressed by regulation, and this was done primarily if the gas was "sour" (contained significant quantities of hydrogen supplied or H_2S). Methane by itself is a non-toxic odourless gas, often referred to as "sweet" natural gas. For the last several decades, the only risk associated with methane losses were fires. When methane from associated gas (also called solution gas) cannot be captured economically as an energy source, industry best practices, enforced by regulators, was to mitigate this fire risk by dispersing small quantities of gas directly to atmosphere (where the volumes were insufficient to maintain combustion), or flare the associated gas (where volumes were significant). With industry and regulators now recognizing global warming risks, efforts to reduce these emissions are being addressed. However, this change is slow since it is not in the economic best interest of either the producers or the regulators (whose revenues accrue from produced energy) to capture these non-economic gas flows.

Changes implemented in the industry since global warming was recognized as a tangible risk primarily dealt with flaring reductions. This flaring reduction was motivated primarily by factors unrelated to climate change issues: the need to reduce sulphur emissions, and the recognition that many single-well flares did not adequately combust and disperse potentially harmful hydrocarbons. The volumes of gas flared was reduced significantly, thanks to regulation that required associated gas from individual wells to be piped to local batteries or gas processing facilities, where in many cases, the accumulated gas volumes were more economical to either re-inject into the reservoir or sweeten (remove sulphur to meet sales gas pipeline specifications) rather than flare. Even when flaring remained the most economical choice, it was an improvement as the combined gas from multiple wells increased flare gas flow rate, improving combustion efficiency at the battery flares.

6.1.6 Complementary Policy Measures for Further Reductions

Now that industry greenhouse gas emissions are being regulated, further emissions reductions are necessary. While energy consumption is the obvious target since it is measured and monitored, this energy consumption is required by the industry. Emissions from energy consumption can only be reduced through moderate energy efficiency gains and capital stock turnover. However, targeting venting, flaring and fugitive emissions will be highly effective since these activities are production by-products that can be regulated without impinging on energy production capabilities. There are a couple barriers to address: how are regulations implemented and who pays for the emissions reduction.

6.1.7 How can emissions be controlled?

Venting and fugitive emissions sources can be captured using existing technology. It's simply not financially viable when the current cost for venting is free. But through the appropriate use of regulation, the incentive to use and improve venting and fugitive emission controls will increase. Systems to capture vent gas at wells and batteries would be very similar to gas recovery units used at petroleum storage facilities, which capture gas, compress it, and send it to other equipment (heaters, flares, etc.). In dispersed oil and gas wells, batteries and gathering systems, this gas may be used to offset other fossil fuel consumption, re-injected into reservoirs or "sweetened" and sold into natural gas systems.

Flaring is more regulated and reporting flare volumes is mandatory in all jurisdictions. However, the same incentives for capturing fugitive and vent emissions could also be applied to many flares, especially those at wells and batteries. With the right regulation, more of these gas volumes will be re-injected into the reservoir, used to offset other fossil fuels, or "sweetened" and sold into natural gas systems. Emergency flaring will have to be accurately defined in any regulation, and no process flaring should occur at any battery or gas gathering system – all processing must be in process facilities captured by reporting systems such as the Canadian Environmental Protection Act Section 71 reporting.

6.1.8 What regulations are appropriate?

An effective regulation would penalize producers with wells, batteries and/or gas gathering system equipment that emit measurable quantities of venting or fugitive emissions, or flare associated gas. The regulation should penalize emitters, regardless of flow rates. It is costly and challenging to measure fugitive and venting emission flow rates, but detecting the presence of methane and attributing it to a producer is much easier and more cost effective. A reasonable tolerance threshold (such as 10% above the lower detection limit of methane detection equipment) would be applied to venting and fugitive emissions. There would be no threshold for flaring.

Fiscal penalties would be required. First time offenders should be given only a warning, but repeat offenders should face penalties that are more expensive than implementing venting and fugitive gas capture methods. Where flaring is continued, fiscal penalties should be crafted to exceed the costs of re-injecting the associated gas. When venting or fugitive emissions are detected by the regulator, the producer will be notified, fined (or issued a formal warning for a first-time offence), and given a realistic time-frame to eliminate the emission source. This could vary depending on the emission source, but three months would be a reasonable time-frame for most equipment repairs.

Venting and fugitive emissions occurring at individual wells and batteries, regardless of production focus (bitumen, heavy oil, light oil or gas), must also be addressed. It is also important to acknowledge that measuring these emissions is costly and difficult to audit. Therefore, it is only essential to identify venting and fugitive sources, not necessarily the volumes that are released. To put this in perspective, monitoring equipment to measure the volume of leakage requires measuring a quantity of emission over time. By only measuring the presence of emissions, the time-factor is eliminated and equipment can be used to more efficiently monitor many different emissions sources. Appropriate detection techniques would include hand-held gas sniffers and proven remote sensing technology such as differential absorption light (DIAL) systems. For producers concerned about limiting costs, many fugitive and venting sources may be detected with very inexpensive techniques, notably the bubble test (using tubing and a clear container filled with water is the primary technique for detecting surface casing vent flows, and splashing a soap-and-water solution over suspect fittings is a simple and effective technique for detecting small gas leaks in most fittings).

Abandoned wells would also need to be included in the GHG reduction regulations. Legal systems establishing responsibility for abandoned wells leaking hydrogen sulphide are well established. The registration of well location and ownership is perhaps the most well-documented feature of the Canadian oil and gas industry. The addition of regulations for wells leaking emitting methane would not be onerously difficult.

There are a lot of facilities to cover, with millions of potential emissions sources. Alberta alone has +200,000 wells, +18,000 oil batteries, +10,000 gas batteries and +100 gas gathering systems. Inspectors will have to act like traffic police, not monitoring every car or facility, but targeting regions or operators with poor compliance records.

Today, based on regulatory history, the various provincial jurisdictions have different fugitive accounting systems and different regulatory goals. The transition to a national greenhouse gas reduction strategy may require a common national framework that respects the provinces’ jurisdiction over natural resources, including enforcement, while providing guidelines and resource support from the federal government. This would also reduce political debate over who regulates the industry, as most Canadian oil and gas production is currently regulated provincially while greenhouse gas emissions from most of the industry will be regulated nationally. Of course, implementing GHG reduction orientated fugitive regulations will require additional inspection capacity, as it affects hundreds of thousands of wells, tens of thousands of batteries, and hundreds of gas gathering systems. It is not expected to be a revenue neutral application. There is very little revenue recycling (where fees from industry are recycled to reward best practices). It will be a burden similar to policing highways, where inspectors point out the errors in emissions control, and fines go to general revenues, independent from the inspection jurisdiction issuing the fine.

6.1.9 Are there any exceptions?

Exceptions should be discouraged in all situations. However certain operating conditions with limited emission reduction options must be addressed.

6.1.9.1 Pneumatic controls operated with raw natural gas.

Some wells, batteries or gathering systems require gas-operated pneumatic controls. In many instances, these control systems may be converted to compressed air with an electric compressor[13], but in remote locations or locations without reliable electricity supplies (to power the compressor), the controls remain in gas service with subsequent methane venting. In these facilities, gas capture systems may not be feasible. However, to encourage the use of gas-efficient control systems, a pay-to-pollute system with fees equivalent to the broad emission pricing system price may be appropriate. Producers bear the burden of third-party-verifying the volumes of gas emitted through the systems. However, this alternate fee system should only be applied to systems that meet specific conditions relating to the quality and availability of grid electricity. If electricity is available, electric compressors may be used for control systems.

6.1.9.2 Remote bitumen, crude oil and/or produced water storage tanks

Tank storage systems for bitumen, crude, or produced water all require tank venting systems. Depending on the individual characteristics of the hydrocarbon reservoir, dissolved gases including methane may be vented from these tanks. In situations where grid electricity is available, vapour recovery units may be installed to capture these emissions. However, in remote locations without access to grid electricity, this may not be viable. In these cases, a pay-to-pollute system of fees equivalent to the broad emission pricing system may be appropriate. Producers must bear the financial burden of third-party-verifying the vented gas volumes. Like the exception for certain pneumatic control applications, this exception should only be applied where the well or battery is in a location where grid electricity is not reasonably accessible.

6.1.10 How should these regulations be implemented?

As alluded to earlier, these regulations would best be implemented as a national standard which must be enforced by provincial or other local regulatory authorities. Resources must be allocated to cover the inspection costs as fines for emissions should go to general revenues and not the inspecting jurisdiction. Like all regulations involving changes in best practices, they cannot be implemented instantaneously. A period of 24 months between policy announcement and inspection commencement is appropriate. To grandfather older equipment and still reduce emissions, a cascading level of inspection is suggested.

[13] Current regional electricity sources may generate more greenhouse gas emissions than would be emitted by venting methane. However, electricity generation facilities offer excellent opportunities for implementing carbon capture and storage, using renewable fuels, or other emissions reduction initiatives, which will be addressed by other future regulations.

Table 6: Cascading level of fugitive inspection regulations

Inspection Year	Regulation Process	Compliance facilities.
Year -1	Policy announced. No inspections.	None
Year 0	Inspection system implemented, including overhead and training.	None, but optional inspections may occur (no fines issued).
Year 1	First compliance year: fines issued.	All new facilities (wells, batteries, and gas gathering systems)
Year 2	Inspection system expanded to meet demand.	All facilities less than five years old.
Year 3	Continued expansion.	All facilities less than 10 years old.
Year 4	Continued expansion.	All facilities less than 15 years old.
Year 5	Inspection system at full capacity.	All facilities, regardless of age.

Since compliance must be achieved, penalties for non-compliance should not be reduced to the point where they lack effectiveness. At the same time, inspection system development must be closely managed as it grows, and audited like any other government agency.

6.1.11 Who pays for the emissions reductions?

While the inspection system is the burden of all taxpayers, the emissions reductions must be the burden of oil and gas producers. The cost of these emission reductions will range from inconsequential to quite expensive. Of course, producers are responsible for paying fines for non-compliance. These fines will be significant, and will incent producers to implement vapour recovery systems and fugitive emissions controls, as well as further flaring reductions.

For oil producers the costs associated with emissions reduction actions are relatively insignificant compared to the profitability of producing oil at current commodity prices. For gas producers, however, current commodity prices may not provide enough incentive to operate all facilities in a venting- and fugitive-emissions-free manner. Some producers may opt to shut in or abandon some facilities rather than implement necessary changes. While this may be a burden on the producer, there may be long term social benefits because these marginally profitable facilities would not likely receive the investment in regular maintenance to ensure that small methane leaks do not become large methane leaks. These marginally profitable wells are primarily shallow gas fields in and around southern and eastern Alberta and western Saskatchewan, drilled as early as the 1880’s.

The cost of re-cementing or re-sealing abandoned wells leaking methane will be the responsibility of the registered owner, as if these wells were leaking hydrogen sulphide or contaminating fresh-water aquifers.

Where methane venting is necessary for operations (pneumatic controls or tank storage in non-electrified remote locations), the producer would be held responsible for pay-to-pollute costs at the going broad emissions pricing system price equivalent as well as for third party verification of the reported emissions.

6.2 Landfill gas and agriculture fugitives market coverage failures

6.2.1 Landfill gas fugitive emissions

Landfill produces significant amounts of methane from anaerobic metabolisation of waste materials. Emissions, while significant (28.0 Mt in 2005), are hard to estimate as they vary widely by composition of a given landfill and its construction. A key characteristic of landfill gas emissions is that they would be unaffected by an emissions pricing policy based on fuel carbon content (i.e. downstream or upstream cap and trade systems, or a carbon tax). Because the methane comes from waste materials, not an energy feedstock, there is no automatic accounting of emissions. Measuring the methane emissions is also extremely difficult without an enclosure, forcing regulators to resort to very imperfect estimates.

The only effective emissions reduction option is enclosure of the landfill and combustion of the captured methane, either as a flare or to generate electricity using a turbine. The cost of enclosure varies with the size and location, but is generally low for the majority of landfills. Landfills are run by municipalities, however, and their resources and institutional capacity vary enormously across Canada.

To impose an emissions opportunity cost on landfill gas emissions government must either offer to count them into an offset system or estimate a carbon tax charge based on the size and other characteristics of the landfill. Another option is to simply regulate that all landfills of a given size be enclosed, perhaps with financial aid and other resources from the federal and provincial governments.

We have chosen to model four cases:

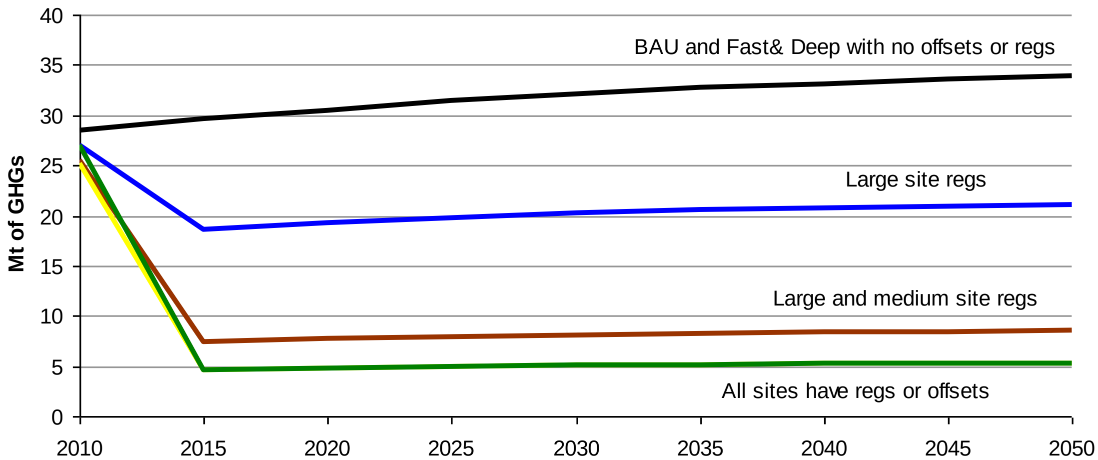
- Where an offsets program is operated, with the offsets being generated based on the emissions price schedule.
- Where all large landfills must be enclosed, and the methane combusted.
- Where all large and medium size landfills must be enclosed, and the methane combusted.
- Where all large, medium and small landfills must be enclosed, and the methane combusted.

Table 7 and Figure 3 provides base emissions with no policy, and emissions with each of the four policy options: large site enclosure regulations, large and medium site enclosure regulations, regulations for all sites and offsets based on “Fast and Deep” prices.

Table 7: Emissions from landfills (Mt CO_2e)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
BAU and Fast&Deep with no regs or offsets	29	30	31	31	32	33	33	34	34
Large site regulations	27	19	19	20	20	21	21	21	21
medium & large site regulations	26	7	8	8	8	8	8	8	9
Regulations for all sites	25	5	5	5	5	5	5	5	5
Fast&Deep pricing, with offsets	27	5	5	5	5	5	5	5	5

Figure 3: Emissions reductions from landfills



6.2.1.1 Recommended policy

Our analysis shows that the greatest amount of reductions come when all sites have enclosure and combustion regulations, or if there is an offset program in place. However, the offset program is based on the very high “fast and deep” pricing schedule, which may not become a reality. Use of offsets also requires a significant investment in verification procedures, and raises questions of additionality – many sites would be enclosed even in BAU, and use of offsets in this case would create “hot air” credits that will debase the core broad emissions pricing system. Given this, and that most landfills can be enclosed for $15-$25/tonne CO_2e , we instead recommend that the federal government, provinces and municipalities across Canada cooperate to institute a system of mandatory enclosure and combustion for all sizes of landfill, with centralization of landfills as necessary to minimize costs. Given that financial and institutional resources may be beyond that of small municipalities, we also recommend that the federal and provincial governments work together to provide aid to municipalities as necessary to carry out the mandatory enclosure regulation.

6.2.2 Agriculture fugitive emissions

A significant portion of Canada’s GHG emissions come from enteric fermentation (25.0 Mt), manure management (8.6 Mt), and agricultural soil management (23.0 Mt). Because these emissions are not from combusted market fuels and are spread all over Canada from virtually millions of sources, an emissions pricing scheme by itself will have no effect on them. If the deep emissions target is to included these emissions, they too must be reduced by significant amount, or other sectors must reduce emissions more to compensate.

To ascertain the significance of the presence or absence of policy to induce emission reductions in the agricultural sector, in the integrated analysis we ran the CIMS model, which includes accounting for agricultural emissions and the possibility of endogenous emissions reductions, under two scenarios where agricultural baseline emissions were included in calculation of the -20 by 2020 and -65% by 2050 target. In the first scenario agricultural emissions experience an emissions price, indicating the efficient level of reductions from this sector for a given per tonne carbon price, and in the second they do not, and other sectors must compensate.

6.2.2.1 Recommended policy

Agricultural emissions reductions can be achieved through significant changes in land use and agricultural practices, including use of no-tillage planting and enclosures for manure management. Baseline emissions and emissions reductions will be very difficult to estimate for individual farms, making it very difficult to verify the additivity of offsets from agricultural practises. Inability to confirm the additivity of offsets has the additional danger of "hot air" credits being created that will, through creation of an artificial supply of emissions reductions, debase the greater emissions pricing scheme.

Verification of compliance with regulations relating to agricultural practises will also be difficult and may be costly both to implement and enforce, but do not have the danger of debasing the greater emissions pricing mechanism. These regulations could be enforced much the same way speeding laws are, not with continuous compliance but with significantly penalties in the case of being caught during random checks. For these reasons we recommend that regulations relating to agricultural practises be implemented and enforced instead of use of a domestic offset system to create an emissions opportunity price for agricultural emissions reductions. We also recommend that federal and provincial resources be made available in the form of education and possibly targeted grants to aid the farming community in transitioning from high to low GHG emitting practises.

7 Market failures in buildings and transportation

The scale of the principal agent, network and lack of marginal cost pricing failures in buildings and transportation are much harder to calculate than the market coverage failures addressed in previous sections. These sectors experience direct emissions pricing under the broad emissions pricing system, and all further regulation must be carefully tied to market failures that the emissions pricing does not directly attack, i.e. it addresses the externality of using the atmosphere as waste receptacle for GHGs, but it does not address the fact the emissions price may not translate from those who experience it (building operators) to those who can do something about the GHG intensity of the building (the owners).

For these reasons calculation of marginal "shadow" costs of potential regulations in the buildings and transport sectors for comparison to the broad emissions price take on a key role in assessing the level of regulations to impose, if any. The following sections on commercial and institutional buildings, residences, and transportation document calculations of the average and marginal costs of various levels of possible regulations in these sectors. These calculations were used to assess the level of regulation to impose in the integrated analysis. Our decision criteria were based on:

- the additional absolute emissions reductions due to the regulations in an environment with pre-existing emissions pricing on all market fossil fuels;
- the cost of the regulations, on a total, average and marginal cost basis based on both valued added (capital and labour) and input cost (capital, labour and energy), and how they related to broad emissions pricing system price;
- the technical, political and administrative feasibility of the regulations.

7.1 Commercial and Institutional Buildings

For the commercial and institutional buildings sector we assessed the effects of:

- the "fast and deep" emissions price, including all direct combustion and its system wide effect on relative electricity and fossil fuel prices
- the addition of the basic LEED® standard as a regulation for all new buildings
- the subsequent addition of LEED® Silver, Gold, and Platinum standards

We analyzed the effects of the LEED® environmental buildings standards system because of its widespread recognition in the building community and elsewhere. There may be some issue with this, because the LEED® standards are based on whole building system environmental performance, not just energy use and greenhouse gas emissions; increases in LEED® level do not necessarily lead to improved GHG performance. However, given the industry and public name recognition and momentum of this environmental standard, we decided it was the best choice for the analysis.

Table 8 and Table 9 summarizes our results, with costs based on sector value added (capital and labour) and input costs (capital, labour and energy). We found the BAU and policy GHG emissions in each case, the emissions reductions, total costs, average costs and marginal costs for each level of regulation. On a sector value added (GDP) basis, which for lack of a better welfare measure can be seen as the societal point of view on costs, we found marginal costs were reasonable (up to about \$750/tonne CO_2e in 2050) up to the basic LEED® level, after which marginal tonnes ofCO_2e became excessively expensive (Table 8). On an input cost basis, which includes energy (an intermediate input from society's point of view, but a direct cost from the sector's point of view), we found marginal costs to be negative up to the LEED® Platinum level in later years, at which they became strongly positive (\$16,000/tonne CO_2e in 2050) (Table 9). This somewhat paradoxical result is because while emissions did not fall, total system costs (capital, labour and energy) fell, creating a negative marginal cost for emissions up to LEED® Gold.

Table 8: Analysis of commercial GHG regulations within the "fast and deep" emissions pricing environment (GDP cost version)

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
$/tonne CO2e	15	115	215	300	300	300	300	300
Emissions (Mt CO2e)								
BAU	37.7	40.6	43.1	46.9	51.5	56.1	60.9	65.7
F&D, no regs	31.9	28.5	23.6	21.4	18.6	17.3	17.0	17.7
F&D, LEED	30.5	26.2	20.7	17.9	14.7	13.1	12.7	12.9
F&D, LEED silver	30.5	26.2	20.6	17.9	14.6	13.0	12.7	12.8
F&D, LEED gold	30.3	26.0	20.4	17.6	14.4	12.9	12.6	12.8
F&D, LEED platinum	30.2	25.8	20.2	17.4	14.1	12.7	12.5	12.7
Reductions compared to BAU (Mt CO2e)								
F&D, no regs	5.8	12.1	19.4	25.5	32.9	38.9	43.8	48.0
F&D, LEED	7.2	14.4	22.4	29.0	36.9	43.0	48.1	52.9
F&D, LEED silver	7.2	14.5	22.4	29.1	37.0	43.1	48.2	52.9
F&D, LEED gold	7.3	14.7	22.6	29.3	37.2	43.2	48.2	52.9
F&D, LEED platinum	7.5	14.9	22.9	29.5	37.4	43.4	48.3	53.0
Increase in capital and labour costs compared to BAU ($millions 2005)								
F&D, no regs	73	183	321	450	645	830	993	1,129
F&D, LEED	490	1,036	1,587	2,099	2,727	3,421	4,119	4,853
F&D, LEED silver	593	1,269	1,948	2,580	3,349	4,174	4,997	5,856
F&D, LEED gold	823	1,713	2,600	3,433	4,442	5,494	6,537	7,626
F&D, LEED platinum	1,447	3,094	4,731	6,285	8,159	10,030	11,866	13,778
Average costs ($/tonne CO2e)								
F&D, no regs	13	15	17	18	20	21	23	24
F&D, LEED*	***68***	***72***	***71***	***72***	***74***	***79***	***86***	***92***
F&D, LEED silver	82	88	87	89	91	97	104	111
F&D, LEED gold	112	117	115	117	120	127	135	144
F&D, LEED platinum	194	208	207	213	218	231	245	260
Marginal costs($/tonne CO2e)								
F&D, no regs	13	15	17	18	20	21	23	24
F&D, LEED*	***306***	***373***	***432***	***478***	***530***	***621***	***723***	***769***
F&D, LEED silver	2,206	2,924	3,977	5,060	6,692	10,502	21,693	42,295
F&D, LEED gold	1,883	2,485	3,320	4,194	5,577	9,341	21,654	42,953
F&D, LEED platinum	4,663	6,597	9,107	11,698	15,713	25,741	56,757	112,381

*regulation selected for integrated analysis

Table 9: Analysis of commercial GHG regulations within the "fast and deep" emissions pricing environment (Input cost version)

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
$/tonne CO2e	15	115	215	300	300	300	300	300
Costs ($millions 2005)								
BAU Capital (5 years)	95,302	109,885	121,330	116,560	135,485	151,258	163,015	181,114
BAU O&M	586	622	652	679	717	761	806	851
BAU Energy	17,873	19,405	20,727	22,446	24,539	26,801	29,167	31,594
BAU Total (capital/5)	37,520	42,004	45,646	46,436	52,353	57,813	62,576	68,668
Emissions (Mt CO2e)								
BAU	37.7	40.6	43.1	46.9	51.5	56.1	60.9	65.7
F&D - no regs	31.9	28.5	23.6	21.4	18.6	17.3	17.0	17.7
F&D - LEED	30.5	26.2	20.7	17.9	14.7	13.1	12.7	12.9
F&D - LEED silver	30.5	26.2	20.6	17.9	14.6	13.0	12.7	12.8
F&D - LEED gold	30.3	26.0	20.4	17.6	14.4	12.9	12.6	12.8
F&D - LEED platinum	30.2	25.8	20.2	17.4	14.1	12.7	12.5	12.7
Emissions reductions compared to BAU (Mt CO2e)								
F&D - no regs	5.8	12.1	19.4	25.5	32.9	38.9	43.8	48.0
F&D - LEED	7.2	14.4	22.4	29.0	36.9	43.0	48.1	52.9
F&D - LEED silver	7.2	14.5	22.4	29.1	37.0	43.1	48.2	52.9
F&D - LEED gold	7.3	14.7	22.6	29.3	37.2	43.2	48.2	52.9
F&D - LEED platinum	7.5	14.9	22.9	29.5	37.4	43.4	48.3	53.0
Increase in capital, labour and energy costs compared to BAU ($millions 2005)								
F&D - no regs	-105	-239	-527	-878	-1,318	-1,881	-2,418	-2,895
F&D - LEED	429	108	-467	-1,123	-1,692	-2,331	-3,039	-3,626
F&D - LEED silver	570	232	-406	-1,126	-1,710	-2,400	-3,143	-3,746
F&D - LEED gold	871	387	-362	-1,188	-1,796	-2,571	-3,368	-3,998
F&D - LEED platinum	1,876	1,485	587	-408	-867	-1,740	-2,550	-3,107
Average costs ($/tonne CO2e)								
F&D - no regs	-18	-20	-27	-34	-40	-48	-55	-60
F&D - LEED*	***75***	***24***	***3***	***-8***	***-10***	***-10***	***-13***	***-14***
F&D - LEED silver	20	9	3	0	0	-2	-2	-2
F&D - LEED gold	41	11	2	-2	-2	-4	-5	-5
F&D - LEED platinum	135	74	41	26	25	19	17	17
Marginal costs ($/tonne CO2e)								
F&D - no regs	-18	-20	-27	-34	-40	-48	-55	-60
F&D - LEED*	***393***	***152***	***20***	***-71***	***-95***	***-108***	***-144***	***-151***
F&D - LEED silver	3018	1552	678	-32	-186	-974	-2575	-5050
F&D - LEED gold	2460	867	223	-308	-439	-1206	-3153	-6124
F&D - LEED platinum	7513	5243	4054	3199	3926	4717	8710	16269

*regulation selected for integrated analysis

Perhaps most importantly from a policy perspective, both tables show results where costs are strongly positive in early years when marginally larger capital investments are made compared to BAU, leading to lesser costs and even negative costs compared to BAU in later years as energy saving accumulate. High up front costs with significant long term paybacks for society may justify social action through regulation and possibly subsidies; society’s discount rate is typically valued at 2-3%, while that for individual and firms is never less than 6-7%, and more commonly >14% for firms and >20% for consumers.

Moving to the integrated analysis, we decided, based on the lack of increase in emissions performance with increasing LEED levels, to use the basic LEED standard for our integrated modelling. There are other societal reasons that LEED Silver, Gold or Platinum could be chosen, but not based solely on GHG emissions reduction.

7.2 Residences

For this residential buildings sector we assessed the effects of:

- the "fast and deep" emissions price, including all direct combustion and its system wide effect on relative electricity and fossil fuel prices;
- the addition of a standard that mandated a 30% increase building shell efficiency;
- the addition of a standard that mandated a 50% increase building shell efficiency.

We focused on building shell efficiency because there are strong indications that in a deep emission reduction environment, with strong emissions pricing, that households will efficiently switch to electricity and ground source heat pump from natural gas furnaces and heating oil purely under the influence of the emission pricing system. Heating choices, especially the switch to electricity, are in the long run largely within the choice of households. Shell efficiency, especially when the home is purchased second hand, is largely out of the decision making power of households. Shell efficiency also has the benefit of improving the cooling efficiency of the home, especially with increasing space cooling demand across Canada.

Table 10: Analysis of residential GHG regulations within the "fast and deep" emissions pricing environment (GDP cost version)

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
$/tonne CO2e	15	115	215	300	300	300	300	300
Emissions (Mt CO2e)								
BAU	39.0	39.6	40.8	40.6	40.0	39.9	39.7	38.7
F&D, no regs	28.2	20.9	13.1	7.3	4.3	3.1	2.4	1.8
F&D - res, 30% shell eff. inc.	28.1	20.7	12.8	7.0	4.1	3.0	2.3	1.7
F&D - res, 50% shell eff. inc.	27.8	20.3	12.4	6.7	4.0	2.9	2.2	1.7
Emissions reductions compared to BAU (Mt CO2e)								
F&D, no regs	10.7	18.7	27.7	33.3	35.7	36.9	37.3	36.9
F&D - res, 30% shell eff. inc.	10.9	19.0	28.0	33.6	35.9	37.0	37.4	37.0
F&D - res, 50% shell eff. inc.	11.1	19.3	28.4	33.9	36.0	37.0	37.4	37.0
Increase in capital and labour costs compared to BAU ($millions 2005)								
F&D, no regs	114	143	272	381	330	274	147	-3
F&D - res, 30% shell eff. inc.	698	699	595	367	21	-255	-546	-838
F&D - res, 50% shell eff. inc.	1356	115	205	288	246	261	230	201
Average costs ($/t CO2e)								
F&D, no regs	11	8	10	11	9	7	4	0
F&D - res, 30% shell eff. inc.	64	37	21	11	1	-7	-15	-23
F&D - res, 50% shell eff. inc.*	***122***	***6***	***7***	***9***	***7***	***7***	***6***	***5***
Marginal costs ($/t CO2e)								
F&D, no regs	11	8	10	11	9	7	4	0
F&D - res, 30% shell eff. inc.	3254	2476	989	-48	-1661	-3979	-5360	-6934
F&D - res, 50% shell eff. inc.*	***2987***	***-1745***	***-1030***	***-265***	***1807***	***12254***	***31269***	***79366***

*regulation selected for integrated analysis

Table 10 and Table 11 show that on a GDP cost basis, the 50% standard is most beneficial in the short run, and the 30% standard in the long run. On an input cost basis, perhaps more relevant for the residential sector, both standards generate strong negative costs, with those for the 50% standard being larger. Both standards have substantial upfront capital costs, counter balanced by larger energy saving in the long run. Most of these negative costs manifest as reduced electricity use in a deep reductions environment, as residences have largely switched to electric heating and electricity can be made largely GHG free using a combination of renewables, hydropower, nuclear and fossil fuels using carbon capture and storage. Weighing these factors, we used the 50% shell standard for our integrated analysis.

Table 11: Analysis of residential GHG regulations within the "fast and deep" emissions pricing environment (Input cost version)

	2015	2020	2025	2030	2035	2040	2045	2050
\$/tonne CO_2e	15	115	215	300	300	300	300	300
			Costs (\$millions 2005)					
BAU Capital (5 years)	76,104	86,097	100,907	121,266	148,495	180,791	216,088	265,702
BAU O&M	1,517	1,800	2,164	2,562	3,050	3,657	4,415	5,366
BAU Energy	25,593	27,504	29,671	31,710	34,058	37,090	40,792	45,383
BAU Total (capital/5)	42,331	46,523	52,017	58,525	66,808	76,905	88,424	103,889
			Emissions (Mt CO2e)					
BAU	39.0	39.6	40.8	40.6	40.0	39.9	39.7	38.7
F&D, no regs	28.2	20.9	13.1	7.3	4.3	3.1	2.4	1.8
F&D- 30% shell eff. inc.	28.1	20.7	12.8	7.0	4.1	3.0	2.3	1.7
F&D- 50% shell eff. inc.	27.8	20.3	12.4	6.7	4.0	2.9	2.2	1.7
			Emissions reductions compared to BAU (Mt CO2e)					
F&D, no regs	10.7	18.7	27.7	33.3	35.7	36.9	37.3	36.9
F&D- 30% shell eff. inc.	10.9	19.0	28.0	33.6	35.9	37.0	37.4	37.0
F&D- 50% shell eff. inc.	11.1	19.3	28.4	33.9	36.0	37.0	37.4	37.0
			Capital, labour and energy costs (\$millions 2005)					
F&D, no regs	709	1,662	2,704	2,951	2,388	2,032	1,303	446
F&D- 30% shell eff. inc.	751	-383	-1,170	-1,766	-2,019	-2,007	-2,033	-2,026
F&D- 50% shell eff. inc.	1,161	-967	-878	-981	-1,114	-1,202	-1,294	-1,396
			Average costs (\$/t CO2e)					
F&D, no regs	66	89	98	89	67	55	35	12
F&D- 30% shell eff. inc.	69	-20	-42	-53	-56	-54	-54	-55
F&D- 50% shell eff. inc*.	***104***	***-50***	***-31***	***-29***	***-31***	***-32***	***-35***	***-38***
			Marginal costs (\$/t CO2e)					
F&D, no regs	66	89	98	89	67	55	35	12
F&D- 30% shell eff. inc.	4,188	- 1,704	- 3,579	- 6,128	- 10,866	- 15,084	- 15,729	- 16,819
F&D- 50% shell eff. inc.*	***5,271***	***- 2,888***	***- 2,322***	***- 3,286***	***- 8,943***	***- 28,537***	***- 52,106***	***- 106,560***

*regulation selected for integrated analysis

As a final comment, any form of deep emissions pricing, combined with access to some form of low or GHG free electricity, generates very strong switching to electricity in the residential and commercial sectors. Point of use emissions virtually disappear. This dynamics occurs whether or not there is large expansions of hydropower, other renewables, fossil fuel use with CCS or nuclear.

7.3 Transportation

Regulations in the transport sector are particularly significant because of the follow-on effects in the petroleum refining and crude oil extraction. We have chosen in this analysis to keep Canadian crude oil production stable based on existing rents (excess of price over production cost) and the fact Canada is unlikely to be the world marginal cost producers, especially from a political stability point of view. We have, however, allowed petroleum refining output to change. The technological transformation to a low and zero GHG transportation system is key to a worldwide deep reduction in GHG emissions.

The regulations we have analyzed in this sector are based on the recently announced California GHG emissions standard (Table 12).[14] We have modelled five levels of transport GHG policy:

- one solely based on the "fast and deep" combustion emissions price;
- another with emissions price supplemented by the California emissions standard;
- another level with twice the stringency of California's standard;
- another four times the announced standard, and finally,
- one more that starts out at the California level, follows it to 2020, and then gradually increases to demand virtually zero GHG emissions by 2040.

Table 12: The California GHG transportation emissions standard, and variants in a deep GHG reduction environment (kg CO_2e/km)

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
California	*0.172*	*0.139*	*0.129*	*0.119*	*0.109*	*0.099*	*0.089*	*0.079*
Half California	0.086	0.069	0.065	0.060	0.055	0.050	0.045	0.040
Quarter California	0.074	0.043	0.037	0.026	0.027	0.022	0.017	0.014
Cal, then zero by 2040	0.167	0.049	0.022	0.007	0.003	0.001	0.001	0.001

Table 13 and Table 14 describe the emissions and costs results of our analysis from a GDP (capital and labour) and input cost basis (GDP plus energy as an intermediate input).

A key result of our analysis is that the announced California standard is almost entirely subsumed in the "fast and deep" emissions price path after 2015. It is also insufficient to reach the 20% by 2020 reduction goal. The "fast and deep" price path actually reduces emissions to half the California standard by 2030. To be binding in the "fast and deep" emissions environment the standard must be increased to four times its announced value.

Analysis of the marginal costs under both costing environments show that the financial marginal costs are quite reasonable, and generally less than that for the economy wide pricing system. For this reason, and because of its widespread ramifications for economy wide emissions, we chose to use the last option, where the California standard is used to 2020, and then the standard steadily increased to a zero GHG requirement by 2040.

[14] California Air Resources Board Technical Assessment, January 2, 2008. *Comparison of greenhouse gas reductions under CAFÉ standards and ARB regulations adopted pursuant to AB1493*

Table 13: Analysis of transportation GHG regulations within the "fast and deep" emissions pricing environment (Input cost version)

	2015	2020	2025	2030	2035	2040	2045	2050
$/tonne CO2e	15	115	215	300	300	300	300	300
			Costs ($millions 2005)					
BAU Capital (5 years)	274,369	310,731	431,257	395,193	412,940	457,564	521,238	507,007
BAU O&M	57,330	65,808	72,303	78,428	85,904	93,719	101,171	108,254
BAU Energy	77,758	76,747	82,823	88,577	92,151	96,890	101,939	108,210
BAU Total (capital/5)	189,961	204,701	241,377	246,044	260,643	282,122	307,357	317,866
			Emissions (Mt CO2e)					
BAU	230	253	262	263	271	282	295	312
F&D- no regs	204.9	189.0	139.7	106.6	84.5	78.0	75.6	73.1
F&D- cal 1	200.2	182.5	134.6	103.6	83.9	78.4	75.6	73.1
F&D- half cal	172.0	147.4	102.3	83.0	78.4	77.9	75.6	73.0
F&D- quarter cal	171.1	144.7	93.4	68.0	59.2	55.6	52.1	49.6
F&D- Cal to 2020, 0 by ‘40	171.1	144.3	90.4	61.9	49.7	43.7	39.5	37.5
			Emission reductions compared to BAU (Mt CO2e)					
F&D- no regs	24.9	63.8	121.8	156.7	186.8	204.4	219.4	239.3
F&D- cal 1	29.6	70.3	126.9	159.7	187.4	204.0	219.3	239.3
F&D- half cal	57.8	105.4	159.2	180.2	193.0	204.5	219.4	239.3
F&D- quarter cal	58.6	108.1	168.1	195.3	212.2	226.8	242.9	262.7
F&D- Cal to 2020, 0 by ‘40	58.6	108.5	171.1	201.4	221.6	238.7	255.5	274.9
			Change in capital, labour and energy costs compared to BAU ($millions 2005)					
F&D- no regs	-19,069	-30,259	-37,893	-32,350	-25,464	-23,181	-21,211	-19,983
F&D- cal 1	-2,182	1,029	887	890	445	813	256	-274
F&D- half cal	-15,800	-5,245	9,264	9,509	1,111	1,926	4,336	-512
F&D- quarter cal	-1,920	-5,728	-8,722	-1,378	2,507	1,043	1,344	4,378
F&D- Cal to 2020, 0 by ‘40	0	-1,713	-7,324	-6,044	-591	548	401	2,706
			Average costs ($/t CO2e)					
F&D- no regs	-766	-474	-311	-206	-136	-113	-97	-84
F&D- cal 1	-74	15	7	6	2	4	1	-1
F&D- half cal	-274	-50	58	53	6	9	20	-2
F&D- quarter cal	-33	-53	-52	-7	12	5	6	17
F&D- Cal to 2020, 0 by ‘40*	***0***	***-16***	***-43***	***-30***	***-3***	***2***	***2***	***10***
			Marginal costs ($/t CO2e)					
F&D- no regs	-766	-474	-311	-206	-136	-113	-97	-84
F&D- cal 1	-465	158	173	295	775	-1,707	-4,186	18,583
F&D- half cal	-561	-149	287	463	201	3,908	90,784	-7,344
F&D- quarter cal	-2,187	-2,138	-982	-92	130	47	57	187
F&D- Cal to 2020, 0 by ‘40*	***2,507***	***-4,472***	***-2,456***	***-988***	***-63***	***46***	***32***	***222***

*regulation selected for integrated analysis

Table 14: Analysis of transportation GHG regulations within the "fast and deep" emissions pricing environment (GDP cost version)

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
$/tonne CO2e	15	115	215	300	300	300	300	300
				Emissions (Mt CO2e)				
BAU	230	253	262	263	271	282	295	312
F&D- no regs	204.9	189.0	139.7	106.6	84.5	78.0	75.6	73.1
F&D- cal 1	200.2	182.5	134.6	103.6	83.9	78.4	75.6	73.1
F&D- half cal	172.0	147.4	102.3	83.0	78.4	77.9	75.6	73.0
F&D- quarter cal	171.1	144.7	93.4	68.0	59.2	55.6	52.1	49.6
F&D- Cal to 2020, 0 by ‘40	171.1	144.3	90.4	61.9	49.7	43.7	39.5	37.5
				Reductions (Mt CO2e)				
BAU	0	0	0	0	0	0	0	0
F&D- no regs	24.9	63.8	121.8	156.7	186.8	204.4	219.4	239.3
F&D- cal 1	29.6	70.3	126.9	159.7	187.4	204.0	219.3	239.3
F&D- half cal	57.8	105.4	159.2	180.2	193.0	204.5	219.4	239.3
F&D- quarter cal	58.6	108.1	168.1	195.3	212.2	226.8	242.9	262.7
F&D- Cal to 2020, 0 by ‘40	58.6	108.5	171.1	201.4	221.6	238.7	255.5	274.9
				Costs ($millions 2005)				
F&D- no regs	71,899	66,448	68,439	74,904	84,342	93,641	101,075	108,023
F&D- cal 1	71,225	66,460	68,593	75,230	84,488	93,755	101,196	108,044
F&D- half cal	66,934	65,315	71,291	79,945	87,524	94,741	101,482	108,110
F&D- quarter cal	66,494	64,065	69,498	79,995	89,070	96,761	103,346	109,828
F&D- Cal to 2020, 0 by ‘40	66,494	63,717	68,125	78,919	89,070	97,548	104,401	110,947
				Average costs ($/t CO2e)				
F&D- no regs	2,888	1,042	562	478	451	458	461	451
F&D- cal 1	2,407	945	541	471	451	460	461	452
F&D- half cal	1,159	619	448	444	454	463	463	452
F&D- quarter cal	1,134	593	413	410	420	427	425	418
F&D- Cal to 2020, 0 by ‘40*	***1,134***	***587***	***398***	***392***	***402***	***409***	***409***	***404***
				Marginal costs ($/t CO2e)				
F&D- no regs	2,888	1,042	562	478	451	458	461	451
F&D- cal 1	-143	2	30	108	255	-240	-1,973	-1,410
F&D- half cal	-152	-33	83	230	548	2,000	5,990	951
F&D- quarter cal	-501	-467	-202	3	80	90	79	73
F&D- Cal to 2020, 0 by ‘40*	***110***	***-907***	***-461***	***-176***	***-0***	***66***	***84***	***92***

*regulation selected for integrated analysis

8 Appendix - CIMS model description

8.1.1.1 Introduction to the CIMS model

CIMS has a detailed representation of technologies that produce goods and services throughout the economy and attempts to simulate capital stock turnover and choice between these technologies realistically. It also includes a representation of equilibrium feedbacks, such that supply and demand for energy intensive goods and services adjusts to reflect policy.
CIMS simulations reflect the energy, economic and physical output, GHG emissions, and CAC emissions from its sub-models as shown in Table 15. CIMS does not include adipic and nitric acid, solvents or hydrofluorocarbon (HFC) emissions. CIMS covers nearly all CAC emissions in Canada except those from open sources (like forest fires, soils, and dust from roads).

Table 15: Sector Sub-models in CIMS

Sector	BC	Alberta	Sask.	Manitoba	Ontario	Quebec	Atlantic
Residential	■	■	■	■	■	■	■
Commercial/Institutional	■	■	■	■	■	■	■
Personal Transportation	■	■	■	■	■	■	■
Freight Transportation	■	■	■	■	■	■	■
Industry							
Chemical Products	■	■			■	■	
Industrial Minerals	■	■			■	■	■
Iron and Steel					■	■	
Non-Ferrous Metal Smelting*	■			■	■	■	■
Metals and Mineral Mining	■		■	■	■	■	■
Other Manufacturing	■	■	■	■	■	■	■
Pulp and Paper	■	■			■	■	■
Energy Supply							
Coal Mining	■	■	■				■
Electricity Generation	■	■	■	■	■	■	■
Natural Gas Extraction	■	■	■	■	■	■	■
Petroleum Crude Extraction	■	■	■		■		■
Petroleum Refining	■	■	■		■	■	■
Agriculture & Waste	■	■	■	■	■	■	■

* Metal smelting includes Aluminium.

8.1.1.2 Model structure and simulation of capital stock turnover

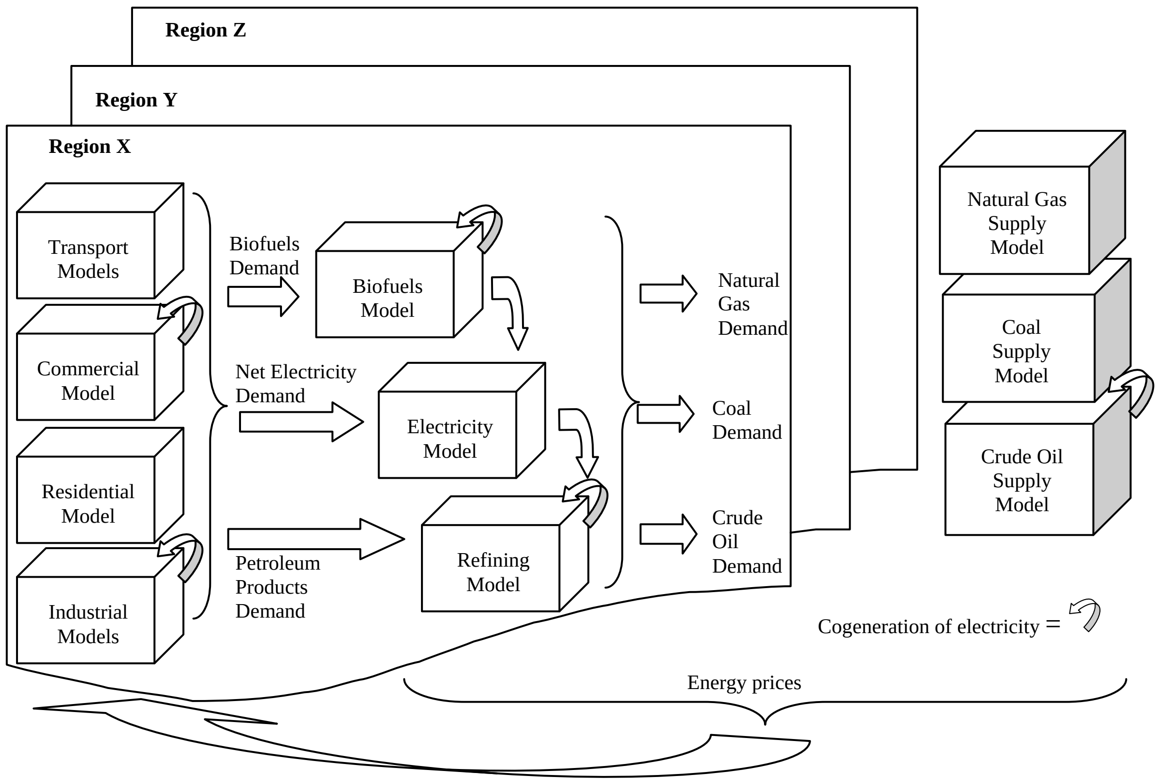
As a technology vintage model, CIMS tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight about the future. This is particularly important for understanding the implications of alternative time paths for emissions reductions. The model calculates energy costs (and emissions) for each energy service in the economy, such as heated commercial floor space or person kilometres travelled. In each time period, capital stocks are retired according to an age-dependent function (although retrofit of un-retired stocks is possible if warranted by changing economic conditions), and demand for new stocks grows or declines depending on the initial exogenous forecast of economic output, and then the subsequent interplay of energy supply-demand with the macroeconomic module. A model simulation iterates between energy supply-demand and the macroeconomic module until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent five-year period of a complete run.

CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory means from capturing all of a market. Instead of basing its simulation of technology choices only on financial costs and social discount rates, CIMS applies a definition of LCC that differs from that of bottom-up analysis by including intangible costs that reflect consumer and business preferences and the implicit discount rates revealed by real-world technology acquisition behaviour.

8.1.1.3 Equilibrium feedbacks in CIMS

CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs is skewed toward energy supply, energy intensive industries, and key energy end-uses in the residential, commercial/institutional and transportation sectors. CIMS estimates the effect of a policy by comparing a business-as-usual forecast to one where the policy is added to the simulation. The model solves for the policy effect in two phases in each run period. In the first phase, an energy policy (e.g., ranging from a national emissions price to a technology specific constraint or subsidy, or some combination thereof) is first applied to the final goods and services production side of the economy, where goods and services producers and consumers choose capital stocks based on CIMS' technological choice functions. Based on this initial run, the model then calculates the demand for electricity, refined petroleum products and primary energy commodities, and calculates their cost of production. If the price of any of these commodities has changed by a threshold amount from the business-as-usual case, then supply and demand are considered to be out of equilibrium, and the model is re-run based on prices calculated from the new costs of production. The model will re-run until a new equilibrium set of energy prices and demands is reached. Figure 4 provides a schematic of this process. For this project, while the quantities produced of all energy commodities were set endogenously using demand and supply balancing, endogenous pricing was used only for electricity and refined petroleum products; natural gas, crude oil and coal prices remained at exogenously forecast levels (described later in this section), since Canada is assumed to be a price-taker for these fuels.

Figure 4: CIMS energy supply and demand flow model



In the second phase, once a new set of energy prices and demands under policy has been found, the model measures how the cost of producing traded goods and services has changed given the new energy prices and other effects of the policy. For internationally traded goods, such as lumber and passenger vehicles, CIMS adjusts demand using price elasticities that provide a long-run demand response that blends domestic and international demand for these goods (the "Armington" specification).[15] Freight transportation is driven by changes in the combined value added of the industrial sectors, while personal transportation is adjusted using a personal kilometres-travelled elasticity (-0.02). Residential and commercial floor space is adjusted by a sequential substitution of home energy consumption vs. other goods (0.5), consumption vs. savings (1.29) and goods vs. leisure (0.82). If demand for any good or service has shifted more than a threshold amount, supply and demand are considered to be out of balance and the model re-runs using these new demands. The model continues re-running until both energy and goods and services supply and demand come into balance, and repeats this balancing procedure in each subsequent five-year period of a complete run.

8.1.1.4 Empirical basis of parameter values

Technical and market literature provide the conventional bottom-up data on the costs and energy efficiency of new technologies. Because there are few detailed surveys of the annual energy consumption of the individual capital stocks tracked by the model

[15] CIMS' Armington elasticities are econometrically estimated from 1960-1990 data. If price changes fall outside of these historic ranges, the elasticities offer less certainty.

(especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based GHGs emissions are calculated directly from CIMS' estimates of fuel consumption and the GHG coefficient of the fuel type. Process-based GHGs emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of GHGs, and reports these emissions in terms of carbon dioxide equivalents.[16]

Both process-based and fuel-based CAC emissions are estimated in CIMS. Emissions factors come from the US Environmental Protection Agency's FIRE 6.23 and AP-42 databases, the MOBIL 6 database, calculations based on Canada's National Pollutant Release Inventory, emissions data from Transport Canada, and the California Air Resources Board.

Estimation of behavioural parameters is through a combination of literature review, judgment, and meta-analysis, supplemented with the use of discrete choice surveys for estimating models whose parameters can be transposed into behavioural parameters in CIMS.

8.1.1.5 Simulating endogenous technological change with CIMS

CIMS includes two functions for simulating endogenous change in individual technologies' characteristics in response to policy: a declining capital cost function and a declining intangible cost function. The declining capital cost function links a technology's financial cost in future periods to its cumulative production, reflecting economies-of-learning and scale (e.g., the observed decline in the cost of wind turbines as their global cumulative production has risen). The declining capital cost function is composed of two additive components: one that captures Canadian cumulative production and one that captures global cumulative production. The declining intangible cost function links the intangible costs of a technology in a given period with its market share in the previous period, reflecting improved availability of information and decreased perceptions of risk as new technologies become increasingly integrated into the wider economy (e.g., the "champion effect" in markets for new technologies); if a popular and well respected community member adopts a new technology, the rest of the community becomes more likely to adopt the technology.

---

[16] CIMS uses the 2001 100-year global warming potential estimates from Intergovernmental Panel on Climate Change, 2001, "Climate Change 2001: The Scientific Basis", Cambridge, UK, Cambridge University Press.