APPENDICES

A. EXECUTIVE SUMMARY: CASE STUDY ON ENERGY EFFICIENCY

By M.K. Jaccard & Associates

1 INTRODUCTION

Ecological fiscal reform (EFR) is the systematic alignment of fiscal policy with other policy tools for the achievement of simultaneous economic and environmental objectives. This case study explores how fiscal policy can promote the energy efficiency of Canada's industrial sector in a way that leads to long-term reductions in energy-based carbon emissions.

For the purposes of this case study, *industry* is defined as establishments engaged in manufacturing and mining activities. It does not include establishments involved in electrical generation, agriculture or providing services.

Energy efficiency refers to the relationship between the output (service) of a device or a system and the energy put into it. Improved energy efficiency is doing more with equal or less energy input. Energy efficiency analysis can be applied to different aspects of the energy system, including energy-using equipment, major industrial processes, supply technologies, delivery networks, and even urban form and infrastructure. Energy intensity is a common indicator in energy analysis, given that energy efficiency cannot be measured directly at an aggregate level. *Energy intensity* is defined as unit energy per unit output, where output is measured in physical units (gross output) or monetary units (gross domestic product or GDP).

There are various ways of reducing the carbon intensity of energy. Improving energy efficiency will result in lower carbon emissions if, as is often the case, the carbon intensity of energy (tonnes of carbon per gigajoule energy) does not increase significantly.

In designing policies and assessing their impact and costs, it is useful to clearly distinguish between action and policy. An *action* is a change in equipment acquisition, equipment use rate, lifestyle or resource management practice that changes net greenhouse gas (GHG) emissions from what they otherwise would be. This study focuses on energy efficiency actions based on changes in technology acquisition, but it also considers these actions in relation to other actions to decarbonate.

In describing carbon-based emissions for the industry sector, it is useful to use the concepts of direct and indirect emissions. *Direct emissions* are emissions that are produced by a source controlled by the sector, while *indirect emissions* are those resulting from that sector's activity but are produced by an external source. When considering the impact of actions, we consider the combined impact on both indirect and direct emissions, since considering only direct emissions would actually show an increase in emissions for an action such as cogeneration.

2 INDUSTRY SECTOR CHARACTERISTICS

The industrial sector, which includes all mining and manufacturing activities, is the largest GHG-producing sector in Canada. In 2000, it produced direct GHG emissions of 237 Mt carbon dioxide equivalent (CO_2e), the majority of which were energy consumption–based. Energy consumption reflects activity levels, industry structure and the energy efficiency of energy use, while GHG emissions also reflect the GHG intensity of energy use and process-related emissions.

Energy is particularly critical in the production of basic industrial products, which are used to produce goods for final consumption, either within or outside Canada. These primary product industries account for more than 80% of total industrial energy consumption. They include industries such as iron and steel, pulp and paper, metal smelting, petroleum refining, chemical manufacturing and industrial minerals. The remaining industries, which are many and diverse (food processing, transportation equipment manufacturing, etc.), account for only 15% of industrial energy consumption but are responsible for 60% of industrial economic output.

Energy intensity (based on GDP) in Canadian industry generally decreased after 1990 to a level 27% below 1990 levels in 2002. The decline in energy intensity is due both to improved efficiency among energy users as well as to structural change in industry. The term *structural change* in this context refers to a change in product or industry mix that determines total industrial production volume. Between 1995 and 2001, the activity share of less energy-intensive industries has increased while the share represented by more energy-intensive industries has decreased, leading to a decline in total energy use of 11.5% relative to 1995.

Trends based on economic output cannot provide an accurate picture of energy intensity because monetary units are affected by many factors not associated with energy, such as costs of labour or selling price of the final product. Indicators computed for aggregate physical energy intensity suggest a smaller decline in energy intensity relative to the measure based on GDP.

Managers in industry are considered more directly motivated to minimize costs than are residential and commercial consumers. Thus firms may have already pursued many cost-effective options to reduce energy consumption, particularly when energy costs make up a high percentage of total production costs. Some sectors are more physically limited in their ability to reduce energy use, particularly fossil fuel use. Nevertheless, the potential for energy efficiency improvements can still be significant, depending on the industry sector.

3 CURRENT POLICY

Current policies relating to industrial energy efficiency have their roots in the 1970s. The oil price shock of 1973 made energy security a high-priority concern and led to, among other responses, the development of numerous energy efficiency programs internationally and within Canada (e.g., the Canadian Industry Program for Energy Conservation, or CIPEC, and the Industrial Energy Innovators Initiative). Since then, industrial energy efficiency has become closely associated with climate change policy initiatives. It has figured strongly in voluntary efforts by industry to curtail its GHG emissions as part of the Voluntary Challenge and Registry, which was initially launched by government to encourage private and public sector organizations to voluntarily limit their net GHG emissions. Just prior to ratifying the Kyoto Protocol in December 2002, the Government of Canada released the Climate Change Plan for Canada, which established an approach for addressing emissions from large industrial emitters.

The federal budget of 2003 followed up on the Climate Change Plan with allocations to provide long-term support for research and development in emerging energy-efficient technologies ($250 million) and to subsidize industrial energy efficiency actions and carbon offsets ($303 million). Research and development in advanced end-use efficiency technologies is one of the five federal priority areas in science and technology. Outside federal policy and initiatives, provincial governments and Crown utility corporations have also been active in promoting energy efficiency in industry and in climate change policy in general.

The fiscal system may provide a non-level playing field for competing energy investments due to different tax treatments of investments. A special capital cost allowance (CCA) class for “Energy Conservation and Renewable Energy” equipment (Class 43.1) qualifies certain investments for an annual 30% depreciation rate. This class specifically targets combined heat and power systems, high-efficiency gas generation and heat recovery equipment as energy efficiency investments relevant to the industrial sector. Canada does not employ any other tax incentives as part of the personal or corporate income tax system.

Outside the tax system, a few programs operated by government and utilities provide incentives to promote energy efficiency by industry. Most programs are part of broader policies that include information provision. The Climate Change Plan for Canada seeks to develop a tradable permit system that will provide an incentive for decarbonization by large industrial emitters. The government is currently considering how its permit system could be designed to best develop this market. However, it is already operating a pilot “voluntary” emissions trading system, the Pilot Emission Removals, Reductions and Learnings Initiative.

As noted above, the Climate Change Plan provides for direct funding for R&D in energy efficiency technologies. The Office of Energy Research and Development coordinates federal energy research and development activities and directs the Program of Energy Research and Development (which includes a strategy for energy efficiency in industry). The Canmet Energy Technology Centre and the Innovative Research Initiative for Greenhouse Gas Mitigation also fund research programs that include energy efficiency projects. Overall, Canada has favoured fiscal incentives over direct funding to support research and development, and it provides one of the most generous systems among all Organisation for Economic Co-operation and Development countries.

4 ENERGY EFFICIENCY OPPORTUNITIES

Energy use in industry can be understood in terms of generic or auxiliary services and unique processes. Generic or auxiliary energy services are those that are not specific to a particular industry. They fall into four general categories: steam generation systems (boilers and cogenerators), lighting, HVAC (heating, ventilation and air conditioning) systems, and electric motor systems (pumps, fans, compressors or conveyors). Significant reductions can occur through energy efficiency improvements to steam generation systems and to electric motors and their attached auxiliary devices. The efficiency of steam generation varies greatly depending on boiler design, age and fuel used. Substantial energy efficiency improvements can also be achieved by using cogenerators rather than simple steam boilers. Although some potential exists to improve the efficiency of electric motors, there is greater potential to improve the efficiencies of equipment driven by them (pumping, air displacement, compression, conveyance and other types of machine drive).

The remaining energy efficiency opportunities are quite specific to the unique processes of each particular industry. Some industries use large amounts of heat to accomplish their activities. For instance, materials production industries (such as iron, steel, other primary metals and building materials) are characterized by heavy use of direct process heat. Other industries are very dependent on electricity to drive large motors or to generate or purify chemicals or metals in electrolytic cells. Such energy-intensive industries typically have fewer options for energy (or CO_2) reduction than industries that make use of many tens or hundreds of processes, each requiring only a small amount of energy, to transform semi-finished products into their final form.

Many energy-efficient technologies are on the market today. Some have been available for some time but could still see greater uptake. Others are poised to emerge and are currently at demonstration stages or have been applied in a relatively narrow niche (e.g., direct reduction in iron and steel). Still others have not been technically realized and are the subject of active R&D programs (e.g., inert anodes/wetted cathodes in aluminum electrolysis). Technological innovation may be either radical (disruptive) or incremental. Radical technological innovation represents a transition to a new technology or a new paradigm, which often changes the way people think about the product or process. Incremental innovation occurs as small and gradual innovation in existing technologies.

5 CHALLENGES TO ADOPTION

Research during the past 30 years has shown that consumers and firms forgo apparently cost-effective investments in energy efficiency. They appear to discount future savings of energy-efficiency investments at rates well in excess of market rates for borrowing or saving. This phenomenon has often been referred to as the energy-efficiency "gap" and is a critical issue for this case study in evaluating the economic cost and potential for fiscal policy to influence the uptake of energy-efficient technologies.

While there is clearly potential for firms to make energy efficiency improvements, determining the extent of that potential is not easy. New technologies carry a greater potential for failure, and this uncertainty can create a significant investment hurdle for firms considering irreversible investments that can be delayed. Also, different consumers in different locations will face varying acquisition, installation and operating costs, and energy efficiency equipment will be more appropriate in some situations than others.

Understanding the impact of energy efficiency improvements on aggregate energy consumption and on decarbonization is complicated by several factors. First, pursuing energy efficiency can result in decarbonization, but one must keep in mind that primary fuels differ substantially in their carbon emissions. There are also significant “second order” feedbacks that occur between the energy demand and supply sectors in the economy. For instance, the widespread adoption of high-efficiency electric motor and auxiliary systems would affect the demand for electricity, with potential price impacts that would affect energy-related decisions throughout the economy. In cases where energy-efficient technologies achieve substantial market penetration, the resulting lower cost of energy services elicits a rebound effect of increased energy service demand and thus greater energy consumption.

6 MODELLING METHODOLOGY

A variety of energy economy models can be used to develop a baseline of GHG emissions in the industry sector and to estimate how changes in the energy efficiency, fuel type or emission controls of technologies would lead to different levels of GHG emissions. The CIMS model, developed by the Energy and Materials Research Group at Simon Fraser University, is used in this analysis. Unique technologies, processes and technological interactions in the Canadian industry sector are represented in detail. It is therefore possible to explicitly explore the relationship between the underlying process and technology structure of the sector and its aggregate energy use and GHG emissions. CIMS also portrays technology acquisition decisions based on financial cost and behavioural parameters estimated from empirical studies of consumer and business decision making. The model thus differs from those that use a single, *ex ante* (expected) estimate of financial cost as the basis for technology selection and thus do not address the complexities of decision making evidenced by the energy-efficiency gap. The CIMS model is also able to incorporate energy price feedbacks between energy demand and supply sectors, as well as energy service demand feedbacks.

6.1 Model Overview

A CIMS simulation involves six basic steps.

1. *Assessment of Demand*: Technologies are represented in the model in terms of the quantity of service and/or product they provide (e.g., tonnes of paper produced). A forecast of service growth drives the model simulation in five-year increments.
2. *Retirement*: In each future period, a portion of the initial year's technology stock is retired based on age. The residual technology stocks in each period are subtracted from the forecast energy service demand.
3. *New Technology Competition/Retrofit Competition*: Prospective technologies compete for the new investment required to meet service demand based on the minimization of annualized life-cycle costs, which include identified differences in non-financial technology preferences and failure risks. The model allocates market shares among technologies probabilistically to reflect varying acquisition, installation and operating costs and equipment. In each time period, a similar competition occurs prior to new stock purchases to simulate retrofitting of residual stock.
4. *Equilibrium of Energy Supply and Demand*: In each future time period, a cycle occurs between technology choice in the energy demand models and technology choice and energy prices in the supply models, until prices and demand have stabilized at an equilibrium.
5. *Equilibrium of Energy Service Demand*: Once the energy supply and demand cycle has stablized, this step adjusts demand for energy services based on price elasticities. If this adjustment is significant, the whole system is rerun from step 1 with the new demands.

6. *Output*: Total energy, emission and cost information can be derived from the final model results since each technology has net energy use, net energy emissions and costs associated with it.

The CIMS model is used to construct the baseline scenario and to develop two alternative scenarios that estimate how changes in the energy efficiency, fuel type or emission controls of technologies can lead to different levels of GHG emissions in the industry sector.

7 BASELINE SCENARIO

The baseline scenario is developed using the CIMS model according to simulation steps 1, 2, 3 and 6 described in the preceding section (steps 4 and 5 are not used in the case study). The baseline forecast period runs from 2000 (CIMS base year) to 2030. For this study, assumptions regarding economic growth (more specifically, region-specific growth rates for GDP for 2000 to 2020) and future energy prices are adopted from *Canada's Emissions Outlook: An Update* (CEOU).[1] For the simulation past 2020, annual price and growth trends of the 2015–2020 period are assumed to continue to 2030. The emission forecast generated by CIMS is calibrated to the official GHG forecast (as of December 2003), which was formulated since the release of the CEOU.

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A summary of the baseline scenario for the industry sector in Canada is presented in Table 1. Overall, emissions in the industry sector (as defined for this case study) grow by 50% over the 30-year simulation period, with direct emissions increasing and indirect emissions decreasing. The share of electricity produced by cogeneration in the sector increases over the simulation period, particularly in oil sands operations. The oil and gas sector generates the largest increase in GHG emissions, which is driven by a strong growth in oil and gas exports to the United States.

Table 1. Baseline Forecast of GHG Emissions and Energy Consumption, Canada

	2000	**2010**	**2020**	**2030**	**Ave. Annual Growth**
GHG emissions (Mt CO_2e)	288	343	396	453	1.53%
Direct	237	307	358	407	1.82%
Indirect	50	36	38	46	-0.30%
Energy (PJ)	4,239	5,030	5,783	6,579	1.48%

8 ALTERNATIVE SCENARIOS

Two alternative forecasts are produced by simulating two different shadow prices over a 25-year simulation period (2005–2030). We model one price of $15/tonne CO_2e and one of $30/tonne CO_2e to influence a shift in investment patterns. In addition to applying this shadow price to the industry sector sub-models, we also apply the price to the electricity sector so that a carbon price can be reflected in the electricity price seen by the industry subsectors.

Emerging technologies have a greater ability to gain market acceptance in a 25-year time frame. In order to capture the long-term promotion of these technologies through R&D and commercialization support, we adjust the “intangible costs” of a selection of emerging technologies in the model to reflect a more targeted R&D and commercialization effort.

[1] Available on-line at: <www.nrcan.gc.ca/es/ceo/update.htm>.

Simulating a carbon emission shadow price in the industrial sector sub-models indicates the emission reduction potential from energy efficiency actions. This type of simulation reveals the potential for emission reductions that could occur from energy efficiency actions up to a specified marginal abatement cost for carbon. This methodology is built on the principle that the goal (decarbonization) would drive the formulation of an alternative GHG scenario (as simulated by a shadow price for GHG), which would indicate what role energy efficiency investments could play in decarbonization compared with other options. The choice of carbon prices reflects a relatively modest “achievable potential” that could be influenced by fiscal policy.

The Low Carbon I and II scenarios result in GHG reductions of 46 Mt CO_2e and 58 Mt CO_2e by 2030 (see Table 2). Direct emissions make up most of these emission reductions, though the response of indirect emissions to the imposition of a shadow price is stronger than the response of direct emissions (indirect emissions decline by 53% to 62% in 2030, while direct emissions decline by 5% to 7%). Actions behind this strong indirect response include the greater adoption of cogeneration systems and improvements to the overall efficiency of auxiliary motor systems. The metal smelting and refining sector and the petroleum refining and iron and steel subsectors realize the most emission reductions from improved energy efficiency.

Table 2. GHG Emissions and Energy for Alternative Scenarios, Canada

	2000	**2010**	**2020**	**2030**
Total GHG emissions (Mt CO_2e)				
BAU	288	343	396	453
Low Carbon I	288	322	365	407
Low Carbon II	288	316	355	395
Direct GHG emissions (Mt CO_2e)				
BAU	237	307	358	407
Low Carbon I	237	292	339	386
Low Carbon II	237	293	335	378
Indirect GHG emissions (Mt CO_2e)				
BAU	50	36	38	46
Low Carbon I	50	29	26	22
Low Carbon II	50	23	20	17
Energy (PJ)				
BAU	4,239	5,030	5,783	6,579
Low Carbon I	4,239	4,822	5,537	6,298
Low Carbon II	4,239	4,818	5,497	6,232

BAU = business as usual

Where energy-efficient technologies achieve substantial market penetration, the resulting lower cost of energy services produces a rebound effect, driving up energy service demand and increasing energy consumption. The alternative scenarios do not incorporate this effect.

9 ECONOMIC AND POLICY ANALYSIS

The alternative scenario simulations reveal that reductions of up to 58 Mt CO_2e could be achieved by 2030 in part by actions leading to greater energy efficiency by industry. We calculate *ex ante* (expected) financial costs of the scenarios (shown in Table 3), which represent the difference in the net present value of capital, energy and operating and maintenance costs in 2004 (2000 $), discounted at a social discount rate for the period 2005–2030, between the baseline and each alternative scenario. All subsectors show negative costs because the value of energy savings is greater than any increase in upfront capital costs from adopting these measures. Welfare costs may be, and usually are, much higher and are embodied in the technology choices of firms and households.

Because the CIMS simulation did not incorporate final demand feedbacks (step 5 of the CIMS simulation), the results provide only a partial equilibrium portrayal of the response to the shadow price of CO_2e.

Table 3. *Ex Ante* Financial Costs for 2005–2030 ($ billion)

	Low Carbon I	**Low Carbon II**
Chemical products	-4.98	-4.04
Coal mining	-0.99	-2.19
Industrial minerals	-1.16	-2.08
Iron and steel	-1.84	-1.93
Metal smelting and refining	-1.42	-1.76
Mining	-0.26	-0.59
Other manufacturing	-1.92	-2.75
Petroleum crude extraction	-0.04	-0.03
Petroleum refining	-0.19	-0.38
Pulp and paper	-3.39	-4.80
Natural gas industry	-1.45	-4.32
Total	**-17.64**	**-24.87**

Note: Figures are reported in 2000 $.

Pursuing long-term carbon emission reductions by targeting industrial energy efficiency may be accompanied by benefits that go beyond reducing GHG emissions and the ecological harm associated with global warming. First, declining energy intensity will reduce the energy costs per unit of service output, and economic growth will be less constrained by future energy costs. Second, the innovation of more efficient technologies will be encouraged, which may serve as an opportunity to increase exports. Third, negative health effects associated with poor air quality may be reduced.

Ecological fiscal reform as defined in this study (see Introduction) is a broad approach, which can employ suites of instruments in a reinforcing package to support the shift to sustainable development. As described in the NRTEE's report *Toward a Canadian Agenda for Ecological Fiscal Reform: First Steps,* the common purpose of these instruments is to provide incentives for producers and consumers to alter their decisions and behaviour. These instruments either internalize environmental costs or reward more sustainable practices. We relate three key policy tools to the modelling analysis: the application of environmental taxes, tradable permits (as part of market-oriented regulation) and subsidies.

9.1 Environmental Taxes and Tax Shifting

The modelling results directly suggest the application of a GHG tax—a charge paid on each fossil fuel, proportional to the quantity of GHG emissions emitted when it is burned.[2] However, because the carbon price was applied to all GHG emissions represented in the industry subsectors (including process and fugitive emissions), non-fuel combustion emissions were also subjected to the carbon price. The Low Carbon I scenario describes a tax of $15/tonne CO_2e, and the Low Carbon II scenario represents a tax of $30/tonne CO_2e. A GHG tax applied across the industry sector causes each subsector to increase or decrease its emission reduction efforts until each is facing the identical incremental cost for the next unit of reduction.

Revenues from environmental taxes can be used for different purposes: they may be part of general revenues, earmarked for specific environmental projects, redistributed as rebates or used to reduce other taxes. Each option has different costs for different members and sectors of the economy. In practice, environmental tax designs have used varying degrees of refunds, differentials in the tax rates applied to industry and households, and exemptions to address equity and competitiveness concerns.

9.2 Tradable Permits (Market-oriented Regulation)

An important area of policy innovation has been the development of market-oriented regulation, which like a GHG tax allows individual flexibility in achieving a compulsory limit or requirement. Unlike traditional command-and-control regulation, the manner of participation is at the discretion of the firm or household (whether to reduce emissions or acquire the designated technology, or pay others to do so).

The modelling results suggest an emissions cap and tradable permit system applied to all industry sectors through auctioned permits, with a cap equivalent to the emission levels reported in the alternative scenarios: 407 Mt CO_2e in 2030 in Low Carbon I, and 395 Mt CO_2e in Low Carbon II (Table 2). The tradable permit prices correspond with the shadow prices applied in those simulations ($15/tonne CO_2e and $30/tonne CO_2e respectively).

Market-oriented regulation can also be applied in different contexts by, for instance, specifying the desirable market outcome rather than the environmental outcome. Considerable design options also exist with emissions cap and tradable permit systems.

9.3 Subsidies

EFR can support decarbonization through the removal or redirection of existing subsidies and through the provision of new subsidies. Financial support in the form of direct grants, guaranteed or low-interest rate loans, and tax incentives can be used to directly support the greater adoption of energy-efficient technologies and long-term research and development in new energy-efficient technologies.

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[2] A CO_2 tax is specified per tonne of CO_2 emitted, not carbon. It can be easily translated into a carbon tax: 1 tonne of carbon corresponds to 3.67 tonnes of CO_2. A GHG tax covers other GHGs and is measured in tonnes of CO_2e.

The alternative scenarios suggest the impact of a subsidy program that is perfectly designed to target cost-effective actions. The size of the incentive required to target the actions inherent in the model simulation is estimated by calculating the perceived private costs of the alternative scenarios (shown in Table 4). The estimates are made by calculating the area under a curve that plots cumulative emission reductions against rising CO_2e shadow prices. The area under the resulting marginal cost curve, up to the shadow price of the alternative scenario, represents the compensation required to have firms undertake actions that they would not have undertaken otherwise (their perceived private cost).

Table 4. Costs of Incentive (Perceived Private Cost) for 2005–2030 ($ billions)

	Low Carbon I	**Low Carbon II**
Chemical products	0.528	1.284
Coal mining	0.026	0.104
Industrial minerals	0.047	0.194
Iron and steel	0.070	0.158
Metal smelting and refining	0.124	0.309
Mining	0.015	0.036
Other manufacturing	0.189	0.436
Petroleum crude extraction	0.101	0.093
Petroleum refining	0.003	0.026
Pulp and paper	0.203	0.608
Natural gas extraction	0.707	1.636
Total	**2.012**	**4.885**

Note: Figures are reported in 2000 $.

These estimates do not include expenditures required to subsidize firms that would have purchased energy-efficient technologies in the baseline scenario ("free riders"). If this effect is incorporated, the subsidy cost of the program is greater. Evaluations of energy efficiency incentive programs suggest that the proportion of free riders can be significant, often in the order of 85% of program recipients. Subsidy programs can therefore require relatively large public expenditures per unit of effect. The administrative costs of program delivery and the transaction costs of firm participation, which depend significantly on the design of the specific measure, have not been considered.

Potential avenues for new subsidies include direct financial transfers (as grants or preferential- or low-interest loans) and tax incentives (e.g., the expansion of CCA 43.1 to include more energy efficiency technologies). The use of revolving loan programs has gained popularity in the commercial and institutional sector in Canada and could be applied in an industry context.

The amount spent on a subsidy will have different effects depending on program design. Financial incentives can be directed to reduce the upfront or the operating costs of energy-efficient investments, and they can be based on prescriptive or custom (performance-based) criteria. Subsidies directed at upfront capital costs recognize that the higher capital cost of energy-efficient technologies can deter investment. Measures that target upfront costs are not based on the actual performance of the investment in meeting the desired policy objective. Performance-based subsidies can be more flexible in allowing firms to meet "demonstrated" improvements in energy efficiency or carbon emission reduction.

Another factor to consider in designing subsidies is differences in how firms respond to incentive tools. Small and medium-sized enterprises, which may not have the capital required to make use of tax incentives, may find more value in loans, loan guarantees and interest rate subsidies, as well as the support provided by private sector incentive mechanisms such as energy performance contracts, leases and venture capital.

10 POLICY DESIGN CONSIDERATIONS

The choice of fiscal policy tools and the ultimate design of a policy package involve many considerations. For instance, the policy package that realizes environmental benefits in the most cost-effective way may be difficult to administer or politically unfeasible. We offer a general assessment of how the fiscal policy tools discussed above stack up against common policy design criteria.

10.1 Effectiveness in Reaching Environmental Targets

An emissions cap and tradable permit is the most effective policy tool for realizing the environmental objective, because it specifies the emission reduction. A subsidy, on the other hand, may fail to achieve sufficient reductions if it is too low or not directed properly. In both cases, poor design can weaken the intended policy impacts. Broad-based economic instruments (taxes and permit systems) are more efficient than subsidies in preventing the rebound effect, encouraging a long-term carbon emission reduction in the energy system.

10.2 Economic Effectiveness

A uniform carbon tax or an emissions cap and tradable permit system is theoretically the most efficient way to achieve a decarbonization objective, because the least expensive reductions throughout the economy are undertaken first. A subsidy may go to firms with higher reduction costs (unless it is allocated via a bidding process), and it can require large public expenditures per unit of effect due to free riders. Also, a subsidy requires that revenue be raised somewhere else in the economy, which can also produce "dead weight" losses.

10.3 Administrative Feasibility

Fiscal policy design should consider the burden on firms in either complying with a tax or market-oriented regulation, or in applying for grants and submitting tax credit claims. This burden may be particularly onerous for smaller firms. Data must be available to ensure proper program monitoring and evaluation, which should focus on impacts (i.e., carbon emission reductions) rather than processes and outputs (e.g., number of applications, program recipients).

10.4 Political Acceptability

Concern about political acceptability has limited the use of policy tools such as GHG taxes to achieve decarbonization, even in countries where they are currently applied. The use of subsidies avoids imposing costs on firms by instead enhancing the ability of energy-efficient technologies to compete. However, the government must acquire the funds from somewhere else in the economy, which has led to criticism. Tax incentives are a less visible form of public subsidy.

Industry groups have generally lobbied for voluntary and tax incentive approaches in climate change policy, arguing that new measures must be situated within an overall framework that is consistent with the broad fiscal and economic direction of the country.

10.5 Distributional and Competitiveness Impacts

With a GHG tax or emissions cap and tradable permit, the manner of participation is at the discretion of the firm. Competitiveness impacts will arise if the policy imposes different levels of costs on competing firms; this may occur if policies and regulations differ at the country or subnational levels or if firms have different specific carbon intensities, substitution possibilities and trade levels.

Policy design is critical in minimizing distributional and competitiveness impacts. For instance, sector-specific market-oriented regulation can minimize average price increases, because only a small percentage of the market is devoted to the newer, higher-cost technologies and manufacturers will average these costs with their lower-cost, conventional technologies in determining prices.

10.6 Technological Innovation

The level of technological innovation of environmentally related technologies will be below the theoretical socially optimal level in the presence of externalities such as environmental damage. This reality provides an argument for the use environmental taxes and market-based instruments that internalize this externality and provide a "pull" to innovation and deployment. Other policies that support innovation directly by lowering the costs of R&D (e.g., by subsidizing R&D expenditures or encouraging joint ventures) may be most valuable at the earliest stage of deployment. However, subsidies run the risk of supporting private R&D that would have taken place anyway and supporting inappropriate technologies.

11 CONCLUSIONS

The potential for industrial energy efficiency actions to contribute to the decarbonization of the energy system is complex: it depends on the degree to which technical potential can be further developed through innovation; the degree to which energy efficiency technology and habits can be adopted; the degree to which this adoption translates into reduced aggregate energy use; and the carbon-intensity of conserved energy. The adoption of energy efficiency as a way to lower energy-based carbon emissions in industry is further complicated by the fact that energy efficiency is only one among a number of options that industry can use to reduce carbon-based emissions.

In developing policy recommendations in this case study, it was important to evaluate the specific focus on promoting industrial energy efficiency in the context of a broader focus on the objective of decarbonization. The alternative scenario simulations demonstrate that improved energy efficiency in industry is closely interrelated with fuel switching and other means of reducing carbon emissions, suggesting that energy efficiency should be considered among other actions in moving toward a decarbonized energy system.

However, focusing on energy efficiency alone as the means of achieving decarbonization in industry may run the risk of orienting incentives and efforts in a direction that is not cost-effective.

Our evaluation of specific policy tools indicates that no one policy tool is optimal in its performance against the criteria of environmental effectiveness, economic efficiency, administrative feasibility and political acceptability. Rather, it suggests that a portfolio of policy instruments can enable a government to combine the strengths, while compensating for the weaknesses, of individual policy instruments. Such a policy package should focus on measures that would be politically acceptable today while nonetheless influencing technological innovation. Considerable potential exists to use ecological fiscal reform to create conditions under which “winners” can emerge and attract sufficient investment in order to develop and be widely adopted.

With this in mind, we recommend an emphasis on tradable permits (as part of market-oriented regulation) to drive fundamental change, with a complementary role for subsidies in supporting energy-efficient technologies. Subsidies, and tax incentives in particular, score well on public acceptability and may be effective if designed carefully and with an understanding of relative costs in different sectors and activities in the economy. Nevertheless, the impact and cost (including free-rider costs) should be realistically assessed in the design of any program. Tax incentives and direct grants should also be designed to minimize government’s role in picking technologies (by being more performance-based) and to minimize the transaction costs of program participation.

There is a history of policy support for promoting energy efficiency through information and awareness programs and through subsidies for research and development. Voluntary programs have laid the groundwork for EFR policies in stimulating awareness of decarbonization opportunities; they will also provide needed complements to any new fiscal policy initiatives that are developed. There may be a role, too, for EFR to connect with traditional command-and-control policy. While fiscal policy can drive technological gains, standards that phase out the sale of inefficient equipment can serve to consolidate change.

12 LESSONS LEARNED

- While energy efficiency can be considered a path toward long-term carbon emission reductions of the energy system that can be targeted immediately through the greater diffusion of technologies already in the market, it is also important to consider how energy-efficient technologies can fit into the long-term picture though continued innovation and commercialization.
- Energy efficiency is not necessarily the most cost-effective option available for reducing carbon emissions in the industry sector. Other means include fuel switching, reducing fugitive emissions, reducing process emissions, and the capture and storage of CO_2. While a significant share of the emission reductions occurs through increased energy efficiency in the modelling results, considerable reductions also occur through other means. Focusing on energy efficiency alone as the means of achieving decarbonization in industry may run the risk of orienting incentives and efforts in a direction that is not cost-effective.
- Promoting greater energy efficiency is not a new policy objective, but it has been actively pursued in many countries over the past 30 years. Considerable experience can be gained from understanding the successes and failures of these efforts. For example, research shows a gap between the level of investment in energy efficiency that appears cost-effective and the lower level of investment that is actually occurring. This "efficiency gap" is a critical issue for this case study, particularly in estimating an alternative carbon emission scenario, as well as evaluating the economic cost and potential of fiscal policy to influence the uptake of energy-efficient technologies. This is an emerging analytical area that has only recently been incorporated into technology simulation modelling.
- Technical energy efficiency gains do not translate directly into reduced carbon emissions. The potential for industrial energy efficiency actions to contribute to long-term carbon emission reductions in the energy system is complex and is based on the following four factors.
    1. *The degree to which technical potential can be further developed:* Our energy system is far from its maximum technical potential for second law efficiency, but how and when will technologies and systems be developed?
    2. *The degree to which this potential can be adopted:* Mature energy-efficient technologies that appear cost-effective are available but have not transformed the market. To what degree will energy-efficient technologies, systems and practices be adopted?
    3. *The degree to which this adoption translates into reduced aggregate energy use:* Lower-cost energy services from energy efficiency investments elicit a rebound effect of increased energy service demand and thus greater energy consumption.
    4. *The carbon-intensity of conserved energy:* Reductions in carbon emissions will depend on the carbon-intensity of energy. For instance, the impact of improved electrical end-use efficiency will be considerably different depending on whether that electricity was generated by hydropower or thermal generation.
- The modelling work in the case study sought to analyze the complex relationships noted in the preceding point. Models are inevitably wrong in that they cannot possibly incorporate all information and relationships of potential importance, nor

accurately depict all uncertainties.[3] Still, one can look to the modelling results to suggest the ability to harness the energy efficiency potential of current and emerging technologies, the role energy efficiency can play among other options to decarbonize industry, and the relative long-term carbon emission reduction potentials of various subsectors.

- Modelling the long-term potential for policy to increase energy efficiency adoption suggests a dynamic analysis that could consider how technological innovation and perhaps even consumer and firm preferences may be influenced by policy. This analysis was beyond the capability of the case study, but it is an emerging research direction that should be noted.
- The results of the alternative scenarios reflect the magnitude of the carbon price that was modelled, that is, a $250 price for carbon would have revealed a different reduction potential. While higher carbon prices have greater long-term carbon emission reduction potential, they tend to show diminishing returns (less additional emission reduction for each additional dollar per tonne of carbon).
- The long-run potential for energy efficiency to contribute to a decarbonized energy system will be constrained by what it will cost to produce a clean energy supply. Energy price represents an upper bound constraint on the contribution of energy efficiency.

[3] Energy use in the industry sector is particularly complex given the large number of end uses and interactions between energy-using and -producing processes.

B. EXECUTIVE SUMMARY: CASE STUDY ON RENEWABLE GRID–POWER ELECTRICITY

By Marbek Resource Consultants in association with Resources for the Future

1 INTRODUCTION

This case study analyzes the role that fiscal policy can play in promoting the long-term development of Canada's renewable energy sector. Ecological fiscal reform (EFR) is recognized as a lever for promoting and, where appropriate, accelerating the use of renewable energy technologies in order to make long-term reductions in energy-based carbon emissions. This case study addresses the renewable energy sector and explores the ability or "traction" of five fiscal instruments to improve the uptake or deployment of grid-power renewable energy technologies (RETs) in Canada.

2 THE RENEWABLE ENERGY CONTEXT

The focus of the current study is on renewable energy technologies. However, the term *renewable energy technologies* is commonly used interchangeably throughout the literature with terms such as *clean energy*, *green power*, *alternative energy* and *low-impact technologies*. While there is considerable overlap in the technologies included within each group, they are not identical. In practice, these definitional differences can become quite important when dealing with the RET policy and technology eligibility issues.

After some discussion of the scope of RETs to be used in this case study, it was concluded that the Environmental Choice Program (ECP)'s EcoLogo definition provided the best available match with the overall goals of this study. This conclusion was based on consideration of two factors:

- the goal of the NRTEE's EFR initiative clearly states that "long-term carbon emissions reduction" should not result in increased loading of other pollutants; and
- An implied goal of this initiative is the promotion of innovation.

In addition, to provide a focused output, the NRTEE directed the study team to examine only those RETs that generate electrical power (as opposed to thermal technologies such as solar hot water heaters). In a similar vein, the NRTEE directed the study team to look only at those RETs that are, or will be, tied into the national electricity grid (as opposed to stand-alone systems).

Consequently, the following technologies are considered in this case study:

- wind turbines (onshore and offshore);
- low-impact hydro;
- grid-connected photovoltaics (PV);
- landfill gas (for electricity generation);
- biomass (for electricity generation);
- ocean energy, including wave and tidal power conversion technologies; and

- geothermal.

For this case study, the term *RET* refers to renewable grid-power technologies or grid-power RETs.

3 Renewable Grid Power in Canada

The study addresses three key areas with respect to grid-power RETs:

- *Current status:* What is the current status of each technology in terms of installed Canadian grid electricity generating capacity, technical maturity and costs?
- *Future potential in Canada:* What is considered the long-term upper-limit capacity for each technology and how much of this upper limit is practically achievable by 2010 and 2020?
- *Renewable power technology costs and learning trends:* What are the current and projected future costs for the targeted technologies and what are the learning trends that impact these costs?

3.1 Current Status

Table 1 shows the current total installed electricity generation capacity in Canada as well as the total share of electricity generated by each source in 2003. As illustrated, if the estimate includes large hydro and all biomass installations, then Canada's total installed base of renewable electricity generation capacity is over 70,000 MW, or about 60% of the total; virtually all of this capacity is large hydro.

Table 1
Installed Electricity Capacity and Annual Electricity Generation in Canada in 2003

Source	Installed capacity		Generation	
	MW	Share	GWh	Share
Hydro	**68,100**	**58%**	**346,000**	**59%**
Nuclear	**12,600**	**11%**	**81,700**	**14%**
Coal	**16,600**	**14%**	**109,400**	**19%**
Oil	**7,500**	**6%**	**14,200**	**2%**
Natural gas	**11,000**	**9%**	**29,100**	**5%**
Wind and biomass	**2,200**	**2%**	**9,100**	**2%**
Total	118,000	100%	589,500	100%

Note: Figures may not sum due to rounding.
Source: National Energy Board <
www.neb.gc.ca/energy/SupplyDemand/2003/index_e.htm>.

If the more stringent low-impact environmental criteria defined by the Environmental Choice Program (ECP) are used, then large hydro and some of the biomass facilities are excluded. (A summary of the ECP criteria is presented at the end of this appendix.) A breakdown of the estimated current (2003) installed base of EcoLogo-certifiable grid-power RETs is shown in Table 2. In 2003, these renewable energy technologies generated an estimated 12,100 GWh of electricity or about 2% of Canada's total electricity generation.

Table 2
Current Installed Base of ECP Grid-Power RETs in Canada in 2003

Grid-power RET (EcoLogo-certifiable)	Current installed base			
	Cap factor	Capacity (MW)	Supply (GWh/yr)	Share of total grid-power RET supply
Wind (onshore)	35%	316	970	8%
Hydro*	60%	1,800	9,460	78%
Solar PV	14%	0.092	0.1	0%
Landfill gas (LFG)	90%	85	670	6%
Biomass	80%	128	900	7%
Wave	35%	0	0	0%
Tidal	35%	0	0	0%
Geothermal (large)	95%	0	0	0%
Total		2,300	12,100	100%

Notes:
1. Installed capacities are for grid-power electricity and potentially could be EcoLogo-certifiable.
2. Figures may not sum due to rounding.

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*Includes many existing small hydro sites that may not be EcoLogo-certifiable.

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3.2 Future Potential in Canada

Technical potential refers to the long-term upper limit of total installed capacity for a given technology. For example, if wind power has a technical potential of 100,000 MW, it means that this is the maximum total generating capacity that wind turbines could supply if they were installed in every technically feasible location across the country.

Table 3 provides an indication of the estimated technical potential for each technology. In each case, a range is provided, which reflects the relatively high level of uncertainty that exists.

Table 3
Technical Resource Potential of Grid-Power RETs in Canada

Grid-power RET (EcoLogo-certifiable)	Cap factor	Technical resource potential (total, not additional)			
		Capacity (MW)		Supply (GWh/yr)	
		Low	High	Low	High
Wind (onshore)*	35%	28,000	100,000	85,800	306,600
Low-impact hydro	60%	11,000	14,000	57,800	73,600
Solar PV	14%	9,800	100,000	12,000	122,600
Landfill gas (LFG)	90%	350	700	2,700	5,500
Biomass	80%	6,800	79,300	47,700	555,600
Wave	35%	10,100	16,100	31,000	49,400
Tidal	35%	2,500	23,500	7,700	72,100
Geothermal (large)	95%	No data	3,000	No data	25,000

*Offshore not included due to lack of independent estimates.

Practical potential is necessarily a subset of technical potential. It recognizes that the ability to capture the technical potential within any given period will be affected by factors such as grid access and capacity; zoning and permitting; technological advances; financing; market demand and acceptance; and design, manufacturing and installation capacity.[1]

Table 4 provides the estimated practical potential. The estimates were developed based on broad consideration of a number of factors, complemented by consultations with industry and government personnel. As with all figures, the estimates are given in ranges to reflect the high level of uncertainty.

[1] It is widely recognized that issues related to grid access, grid capacity and the costs of grid extension will be particularly influential in determining the amount of grid-power RETs that can be practically developed. While these issues are beginning to be addressed in some regions, they are far from being resolved at this time. Further consideration of these issues is well beyond the scope of this case study.

Table 4
Estimated Practical Resource Potential of Grid-Power RETs in Canada

Grid-power RET (EcoLogo-certifiable)	Cap factor	Practical resource potential (total, not additional)									
		Annual growth in deployment to fill practical potential *		Capacity (MW)				Supply (GWh/yr)			
				2010		2020		2010		2020	
		Min.	Max.	Low	High	Low	High	Low	High	Low	High
Wind (onshore)	35%	25%	64%	5,000	10,000	15,000	40,000	15,300	30,700	46,000	122,600
Low-impact hydro	60%	18%	27%	5,600	9,000	9,800	no data	29,400	47,300	51,500	no data
Solar PV	14%	152%	347%	60	265	225	3,295	100	300	300	4,000
Landfill gas (LFG)	90%	10%	17%	170	no data	250	no data	1,300	no data	2,000	no data
Biomass	80%	42%	73%	1,500	2,000	no data	6,000	10,500	14,000	no data	42,000
Wave	35%	0%	infinite	0	20	4	no data	0	60	12	no data
Tidal	35%	infinite	infinite	4	300	50	2,000	12	900	200	6,100
Geothermal (Large)	95%	infinite	infinite	100	600	1,500	no data	800	5,000	12,500	no data

* Assuming logarithmic growth and based on practical resource potential numbers in 2010 and 2020. The growth rates are not forecasts of a base case of renewable supply, but rather the growth required on an annual basis to satisfy the practical potential. Refer to the full case study for details on the data presented (available at <www.nrtee-trnee.ca/eng/index_e.htm>).

3.3 Renewable Energy Technology Costs and Learning Trends

A summary of the expected levelized costs for each of the targeted grid-power RETs is presented in Table 5. To ensure consistency among the technologies, all cost data are derived from recent estimates provided by the International Energy Agency (IEA). And, to reflect the cost uncertainties involved, the data are expressed as a range. Table 5 also provides a summary of IEA estimates of forecast cost reductions for each technology over the study period. The forecast cost reductions are based on learning theory. This theory, which is well supported by empirical data, defines the link between the increase in installed capacity and the rate of cost decrease.

The practical potential and levelized costs are used in modelling the fiscal instruments. The results of the modelling are discussed below in Section 4.

Table 5
IEA Cost Reduction and Estimates for Targeted Grid-Power RETs

Grid-power RET (EcoLogo-certifiable)	Cap factor	Cost reduction				Cost estimates					
		Cost reduction every 10 yrs*		Annual cost reduction*		Levelized cost estimates (2000 cents/kWh)					
						2003		2010		2020	
		Min	Max	Min	Max	Low	High	Low	High	Low	High
Wind (onshore)	35%	25%	25%	3%	3%	3.8	15.1	3.0	11.3	1.9	8.5
Low-impact Hydro	60%	0%	13%	0%	1%	2.5	18.8	2.5	16.3	2.3	15.2
Solar PV	14%	30%	50%	4%	7%	22.6	100.3	12.5	50.2	7.5	30.1
Landfill gas (LFG)	90%	0%	20%	0%	2%	2.5	18.8	2.5	15.1	2.3	13.5
Biomass	80%	0%	20%	0%	2%	2.5	18.8	2.5	15.1	2.3	13.5
Wave	35%	no data	no data	no data	no data	4.4	7.6	no data	no data	no data	no data
Tidal	35%	no data	no data	no data	no data	4.7	9.6	no data	no data	no data	no data
Geothermal (Large)	95%	10%	25%	1%	3%	2.5	15.1	2.5	12.5	2.1	10.3

Note: Cost estimates are for all OECD countries; the wide range of values reflects both the diversity of conditions experienced and the high levels of uncertainty.

* Assuming logarithmic cost reductions

Source: IEA figures cited by Martin Tampier in “Background Document for the Green Power Workshop Series, Workshop 4,” Prepared for Pollution Probe and the Summerhill Group, February 2004, pp. 30–32.

Finally, the share of total electricity generation in Canada in 2010 covered under this case study is presented in Table 6. As can be seen, the case study is concerned only with 37% of electrical generation in Canada in 2010.

Table 6
Projected Share of Grid-Power RETs and Fossil Fuel Generation in 2010

Electricity-generating technology	Projected electricity generation in 2010 (GWh)	Share of total generation
Grid-power RETs (as *included* in this study)	31,000*	5%
Fossil fuels (coal, gas, oil as *included* in this study)	198,000**	32%
Other (nuclear and renewables *excluded* from this study)	394,000	63%
Total	623,000**	100%

*2003. National Energy Board, *Canada's Energy Future: Scenarios for Supply and Demand to 2025 (Techno-Vert Scenario)* <www.neb-one.gc.ca/energy/SupplyDemand/2003/index_e.htm>.
**1999. Natural Resources Canada, *Canada's Emissions Outlook: An Update* <www.nrcan.gc.ca/es/ceo/update.htm>.

4 Economic and Policy Analysis—Application to Canada

This section presents the modelling results for each of the fiscal instruments. The discussion is organized and presented as follows:

1. Overview of the fiscal instruments that are assessed
2. Overview of the Resources for the Future (RFF) model used to assess the instruments
3. Summary of results (including a road map for understanding the results)
4. Detailed discussion of the base case and each fiscal instrument
5. Sensitivity analysis results

4.1 Fiscal Instruments Assessed

In collaboration with the NRTEE, a base case and five fiscal instruments were selected and modelled. The five instruments are:

1. *An emissions price*, which is analogous to an emissions trading permit system or a carbon tax. Under this scenario, a shadow price is placed on carbon equivalent to \$10/tonne CO_2. This shadow price is equivalent to the cost of an emissions trading permit or the tax rate on carbon. The emissions price is applied uniformly across all fossil fuel generation in Canada in 2010.

2. *A renewable portfolio standard (RPS),* which requires utilities to buy green certificates, or the equivalent, so that renewable generation increases relative to fossil fuel generation. The model compares renewable generation attributable to an RPS with generation from fossil fuels (i.e., not all electrical generation). Constraints are not placed on technologies or regional shares of the total RPS. Instead, the prevailing electricity price determines the type of technology used to generate electricity.

3. *A renewable generation subsidy (RGS),* which is modelled as a direct subsidy from government to grid-power RET producers on a per-kWh basis. In practice, a subsidy could include any fiscal instrument that lowers the cost of production for producers, such as a direct production subsidy or a capital cost allowance.

4. *A combination of RPS and generation subsidy,* modelled in tandem. We let the RPS be the dominant policy, since the standard is meaningless if the subsidy encourages more renewable generation than required. A notable feature of this combination is that the price of the green certificates is offset in part by the subsidy, in contrast to the situation where the instruments are implemented in isolation. This outcome will therefore trigger some redistribution of costs.

5. *An R&D subsidy,* which is a program to reduce the future cost of renewable generation. As such, the instrument can be anticipated to have a greater impact in future periods. The model identifies the annual increase in renewable energy R&D required to achieve the emission reduction target.

In the model, the levels of the instruments, such as an RPS target (i.e., 10% of generation from renewables) or a subsidy level (i.e., $0.01 per kWh), are solved endogenously. Each instrument is required to achieve a common emission reduction (or policy target), and then the model indicates the policy level that would achieve the carbon target.

4.2 Overview of RFF Renewable Energy Uptake Model

The RFF unified analytical model was employed to assess the impacts of the fiscal instruments on reducing greenhouse gas emissions, as well as the development and diffusion of renewable energy. This model was developed and tested for the U.S. Environmental Protection Agency to assess the preferred fiscal instruments for promoting renewable energy technologies. The analytical model includes two sectors, one emitting and one non-emitting, and both are assumed to be perfectly competitive and supplying an identical product, electricity. Fossil fuel production is the marginal technology, setting the overall market price; thus, to the extent that renewable energy is competitive, it displaces fossil fuel generation in future policy periods.

The model has two stages: a short-term stage covering 2010 to 2015, and a longer-term stage covering 2015 to 2030. Electricity generation, consumption and emissions occur in both, while investment in knowledge takes place in the first stage, followed by technological change and innovation that lowers the cost of renewable generation in the second.

The carbon-emitting sector of the electrical generation industry relies on fossil fuels. These are a mature technology, and the productivity improvements available through new R&D are assumed to be negligible.[2] The marginal production costs of the sector are assumed to be constant with respect to output, increasing with reductions in emission intensity. The representative firm chooses an emission intensity to equate the additional costs of abatement to the price of emissions. The full marginal costs of generation then include both the marginal production costs, given the emission intensity choice, and any effective tax, such as the price of the emissions or carbon embodied in an extra unit of output, or the cost of green certificates under an RPS. As long as fossil fuel generation occurs, the competitive market price must equal the sum of these marginal costs.

Another sector of the industry generates without emissions by using renewable resources. Unlike the fossil supply curve, which is flat and set at the long-term marginal cost of electricity, the renewable supply curve slopes upward, reflecting marginal production costs that increase with output. Because renewables are a young technology, the costs of renewable power shift down over time as the knowledge stock increases. There are two ways to increase the knowledge stock: through investments in R&D and "learning by doing," which is a function of total output during the first stage in the model. The representative renewable energy firm chooses output in each stage as well as R&D investment to maximize profits. In the first stage, it produces until the marginal cost of production equals the value it receives from additional output, including the competitive market price, any production subsidy, and the contribution of such output to future cost reduction through learning by doing. The firm also invests in research until the discounted returns from R&D equal investment costs on the margin.

Since we target equivalent emission reductions for each of the fiscal instruments, we hold the environmental effects constant across the policy scenarios. While we calculate the costs of achieving emission targets in this case study, the benefits of the fiscal instruments are not estimated. The fiscal instruments through their displacement of fossil fuel can be expected to trigger a number of environmental and economic benefits, including:

- improved ambient air quality and reduced carbon in the atmosphere;
- avoided ambient air quality impacts on sensitive ecosystem and health receptors and the associated economic value of the avoided damages; and
- climate change mitigation benefits such as avoided ecosystem, health and economic damages stemming from extreme weather events, temperature changes and sea-level rise and the associated economic value of the avoided damages.

While they are important in assessing the desirability of the fiscal instruments from a social perspective, the benefits are in a sense fixed in the case study because of the stipulation of a common emission target that all instruments achieve.

[2] While it is not strictly true that fossil fuel technologies will experience no further technological advance, incorporation of a positive but slower relative rate of advance in fossil fuels would complicate the analysis without adding substantial additional insights.

4.3 Summary Results

When reviewing the summary results, it is useful to understand that the outcomes are a function of how each instrument influences the energy market. In the model, outcomes differ due to changes in three decarbonization drivers: renewable power penetration, the carbon intensity of fossil fuel generation and total electricity demand.

The outcomes listed in Table 7 can be traced back to an instrument's ability to affect one or all of the three decarbonization drivers in the electricity market. Generally speaking, an instrument will be more economically efficient if it targets all of these three drivers. For purposes of comparison, the base case indicators are provided to allow for comparison with the policy scenarios. In the no-policy base case, our model predicts that renewable energy generation will increase from 13% to 17% of included generation in the second stage, which corresponds to a 5% emission reduction. Subsequent policy scenarios will target a 12% reduction overall from the combined emissions in the two stages of the no-policy case.

The numbered items in the first column of Table 7 are defined as follows:

1. *Policy level for 12% emission reduction:* This row provides an estimate of the size of the fiscal instrument required to achieve the carbon reduction target:

    - For the emissions price, a tax of $10/tonne CO_2 would achieve the 12% reduction in total carbon emissions from the base case.
    - For the RPS, a portfolio standard of 24% would achieve the 12% carbon reduction. This 24% is the final share of renewable power generation in the generation covered by this case study—which consists of both renewable and fossil fuel generation but excludes major hydro and nuclear.
    - For the RGS, a value of about $0.006/kWh achieves the policy objective of a 12% carbon reduction.
    - When combined with a subsidy of $0.002, the RPS needs to be set at a slightly higher target of 24.2%.
    - For the R&D subsidy, a program that increases R&D spending by 61% annually above the base case R&D levels would achieve the target.

2. *Electricity price ($/kWh):* This row indicates the impact of the fiscal measure on the annual price of electricity in the first and second stages (2015 and 2030, respectively).

3. *Carbon emissions (Mt):* Carbon emissions are presented as annual estimates in megatonnes of CO_2 for the last years in the first and second stages. Carbon reductions are influenced by the three drivers in the following ways:

    - Renewable power penetration displaces fossil generation when an instrument reduces renewable production costs relative to fossil generation costs.

- The carbon intensity of fossil fuel generation is reduced when carbon is priced in the fossil sector (i.e., abatement from natural gas generation that displaces coal).
- An increase in the electricity price reduces total electricity demand, which displaces output from fossil fuels.

For each scenario, carbon emissions are estimated by multiplying the "on margin" emission intensity of fossil fuel by the quantity of fossil fuel supplied.

4. *Renewable output (MWh 10^11):* This row indicates the output of renewable generation in the two stages. Renewable output is a function of production cost differentials between renewables and fossil fuels. Instruments affect the cost differential through subsidizing renewable generation, inducing renewable production cost decreases through innovation, and/or taxing fossil fuel production. Instruments that promote innovation reduce renewable costs and carbon emissions in the second stage.

5. *Fossil output (MWh 10^11):* As with renewable output, fossil fuel output is altered by the instruments through price changes in production costs. Fossil output is also altered by total demand reductions, which occur when an instrument increases the price of electricity.

6. *Total electricity output (MWh 10^11):* Total generation includes fossil and renewable output; changes indicate that the instrument influences final demand through electricity price increases.

7. *Renewable R&D ($M):* Expenditures are expressed in millions of dollars annually in total R&D spending by the public and private sectors.

8. *Additional renewable cost reduction:* This row indicates the percent reduction in the cost of the renewable supply below the base case.

9. *ΔConsumer surplus ($M):* This is the net consumer cost of the instrument measured as the change in the present value of the total cost to consumers for both stages. The consumer surplus is negative and is present when the instrument increases the price of electricity.

10. *ΔProducer surplus ($M):* This is the change in the measure of total profit in the renewable sector for both stages. Renewable sector profits increase when the instrument raises the price received by renewable generation, either by a subsidy or a tax on fossil generation. When this occurs, profits can be made if some renewable production costs are below the instrument electricity price in the scenario.

11. *ΔTransfers ($M):* This is the change in government revenues, where a positive number is revenue and a negative one is a disbursement. Again, the estimate is a total cost for both stages.

12. *ΔWelfare (excluding environmental benefits) ($M):* This is the change in social welfare and is a proxy for the societal cost of the instrument. It is the sum of consumer and producer surpluses and transfers. It is an important metric, since all scenarios achieve the same carbon reduction target, yet have differing social costs.

13. *ΔWelfare relative to emissions price:* This is simply a ratio that indicates the welfare costs of each scenario compared with the emissions price scenario. The emissions price is selected as the basis for comparison since it has the lowest welfare cost.

Table 7
Summary of Modelling Results for Fiscal Instruments (2000 $)

	Base case	Emissions price	Renewable portfolio standard	Renewable generation subsidy	Combination RPS and RGS	Renewable research subsidy
1. Policy level for 12% emissions reduction		$10/t CO_2	24% of generation in case*	$0.006	RPS = 24.21%, RGS = $0.002	61%
2. Electricity price ($/kWh) 1st stage 2nd stage	 $0.092 $0.092	 $0.097 $0.097	 $0.095 $0.093	 $0.092 $0.092	 0.095 0.092	 0.092 0.092
3. Carbon emissions (Mt CO_2) 1st stage 2nd stage	 106 101	 98.10 84.40	 91.00 91.90	 98.97 83.50	 91.08 91.95	 104.00 77.40
4. Renewable output (MWh 10^11) 1st stage 2nd stage	 0.29 0.38	 0.40 0.66	 0.54 0.55	 0.42 0.72	 0.55 0.55	 0.31 0.83
5. Fossil output (MWh 10^11) 1st stage 2nd stage	 2.00 1.91	 1.85 1.59	 1.71 1.73	 1.87 1.57	 1.72 1.73	 1.98 1.46
6. Total electricity output (MWh 10^11) 1st stage 2nd stage	 2.29 2.29	 2.25 2.25	 2.26 2.28	 2.29 2.29	 2.27 2.29	 2.29 2.29
7. Renewable R&D ($M) 8. Additional renewable cost reduction	$129 0%	$450 15%	$320 13%	$533 16%	$325 13%	$1,576 26%
9. ΔConsumer surplus ($M) 10. ΔProducer surplus ($M) 11. ΔTransfers ($M) 12. ΔWelfare—no benefits measured ($M) (9+10+11=12)	$0 $0 $0 **$0**	($11,690) $2,215 $8,896 **($579)**	($4,521) $3,480 $0 **($1,041)**	$0 $2,846 ($3,557) **($711)**	($3,533) $3,547 ($1,072) **($1,058)**	0 $1,590 ($3,890) **($2,300)**
13. ΔWelfare relative to emissions price	-	1.00	1.80	1.23	1.83	3.97

Note: Figures may not sum due to rounding.
* This is 9% of all annual Canadian generation

4.4 Detailed Results by Instrument

4.4.1 Base Case

The base case provides the reference from which the percentage changes are estimated in Table 7. Renewable power penetration is forecast based on the relative costs of fossil fuel and renewable production. The base line penetration of renewables increases over time, reflecting decreasing renewable power production costs due to innovation.

Total electricity output remains fixed in both periods in the base case,[3] and thus increased penetration of renewables decreases the carbon intensity of overall generation. This reduction is captured as a decrease in carbon emissions over time, from an annual level of 106 Mt in the first stage to 101 Mt in the second stage.

4.4.2 Emissions Price

An emissions price works to reduce emissions by reflecting their cost, either in environmental damage (as with an environmental levy) or opportunity cost elsewhere in the economy (as with an emissions cap-and-trade system). This price sends a signal to everyone in the energy market to conserve carbon. *Fossil energy producers* can reduce costs by boosting efficiency or switching to lower-carbon fuels and processes. Since the price of fossil energy will then incorporate the cost of the carbon associated with that form of generation, the price of electricity will also rise, creating two effects. First, it signals *consumers* to conserve and take advantage of opportunities to reduce their demand by, for example, adopting more energy-efficient appliances. Second, it increases the price received by *renewable energy producers*, encouraging production and investment in non-emitting generation technologies. From a distributional perspective:

1. Consumers incur the highest electricity price increase and consumer surplus loss under the emissions price. Since consumers are also taxpayers, the use of the revenues (i.e., transfers) is important in assessing the net effect on households.

2. For renewable energy producers, the emissions price has a modest but significant impact on renewable output, production cost decreases and producer surplus. The impact is also relatively consistent across stages.

3. For fossil fuel electricity generators, the emissions price is the only policy with an incentive to reduce emission intensity. Although profits for the fossil sector are not modelled—rather, they are assumed to be driven to zero in the long run by the market—the potential costs to the fossil sector under an emissions price would depend on its ability to pass along the production cost increases due to carbon abatement (i.e., coal to gas) to consumers, as well as any windfall gains from permit allocation.

4. For government, significant transfers or revenue could be raised under the emissions price, either through a tax-based system that collects revenue or through the allocation or auctioning of carbon permits under an emissions trading system. This is the only modelled scenario where significant government revenue potential exists. It also represents the value of the emissions rents, which are available to be allocated to consumers, generators and their shareholders, funds for transition assistance, or taxpayers more generally.

5. For society as a whole, welfare costs are lowest with the emissions price, making it the preferred option. One negative consequence of this scenario, not incorporated into this single-sector analysis, is that the increase in electricity prices could lead

[3] It is recognized that electrical production is increasing over time, but total electricity output in the model is fixed in both stages so that the demand and supply responses of the policies can be better understood.

to economy-wide competitiveness. Reserving some permits for allocation to trade-exposed sectors that are electricity-intensive could mitigate these impacts.

6. An advantage of a cap-and-trade system is certainty in reaching the carbon target; however, uncertainty will then manifest itself in the price. All the other policies face challenges in setting a policy level that would achieve the emissions target with certainty.

4.4.3 Renewable Portfolio Standard

The renewable portfolio standard requires total electricity generation to be based on a minimum share of renewable sources. Although such a market share requirement can be implemented in several ways—quota obligations for retailers, green certificates for fossil generators—the general effect is the same. As long as the market would not meet the requirement on its own, renewable energy producers receive a price premium (the value of the green certificates they generate), while fossil energy producers receive a negative one (the cost of the green certificates they must buy in proportion to their generation). Moreover, the total subsidy to renewable energy producers is equal to the total effective tax paid by fossil energy generators, so no net revenues are raised or lost by the government.

Since the RPS does not distinguish among fossil generation technologies, there is no incentive to reduce emission intensity in that sector. Consumer prices rise due to the effective tax on fossil energy to fund the renewable subsidy (i.e., buy green certificates), but not as much as with the emissions price instrument. Although under the RPS more renewable energy is generated than under the emissions price, the timing of that generation is changed. Normally, when prices are fixed, as costs fall over time renewable generation expands. However, the RPS fixes the share of renewables in both periods, and over time this becomes easier to meet; hence, the effective tax and subsidy fall (i.e., the price of green certificates falls), while total electricity generation increases with the reduced price (the market price is equal to the price of electricity plus the price of green certificates, which fall due to innovation over time; therefore, electricity prices fall and final demand increases). Renewables then get a bigger boost in the first period and less in the second. The larger current subsidy may enable more learning by doing; however, recognizing that the support will fall in the future, investment in cost-reducing R&D may be smaller (this result is borne out in our scenarios). From a distributional perspective:

1. Consumers experience some electricity price increase and consumer surplus loss under the RPS. This effect is about 80% as large as with the emissions price in the first stage, and nearly negligible in the second. The electricity price rise is due to the purchase of renewable power in the form of green certificates (or the equivalent) by the fossil sector. Since renewables become cheaper with technical innovation, the cost of green certificates (and thereby consumer prices) is higher in the first stage but lower in the second as the cost of renewable supply decreases.

2. For renewable energy producers, the RPS induces a high uniform penetration through both periods, which is not surprising since the RPS fixes the share of renewables in both periods. Producer profits are also high, indicating the potential for the sector to benefit under an RPS. While there is certainty in terms of market share for the renewable sector, there is less stability in prices and less flexibility in

the timing of renewable energy generation. Furthermore, the fact that the implicit subsidy falls over time with cost decreases means that incentives for innovation may be muted—indeed, our model predicts *less* R&D spending than under the emissions price. Although more renewable generation is needed overall, so much is done in the first stage that the return on lowering costs in the second stage is reduced, both because of the lower second-stage output (relative to the other policy scenarios) and also possibly because of greater learning by doing in the first stage, which can substitute for R&D.

3. For fossil fuel generators, output shares remain steady in the two periods, with lower output in the first stage and higher output in the second compared with other scenarios. In other words, cost reductions in renewables allow for fossil sector expansion. Still, short-term transitional costs could be expected to be greater under the RPS than in other scenarios. Actual potential costs to the fossil sector under an RPS will be higher if it is not fully able to pass along the costs of green certificates to consumers.

4. For government, the RPS has a neutral impact, with no revenue and no program disbursements.

5. For society as a whole, the welfare costs are greater than with the emissions price and generation subsidy, but lower than with the combination and R&D subsidy. This ranking does not necessarily hold in all circumstances but rather depends on the particular trade-off between the extra costs of encouraging more effort upfront and the inefficiencies of not giving consumers incentives to conserve. Indeed, if one coped with the former problem by optimally designing the RPS requirement to increase over time, the RPS could be made to dominate the subsidy always, due to the presence of the modest conservation incentive.

6. Looking beyond the electricity sector, the increase in electricity prices risks causing some economy-wide competitiveness impacts such as decreased productivity or reduced exports, but these effects will be less severe than with the emissions price, particularly in the second stage.

4.4.4 Renewable Generation Subsidy

This fiscal instrument includes a range of possible policies that subsidize renewable energy generation (e.g., tax credits or direct subsidies) to encourage the expansion of carbon-free generation; however, they do nothing to encourage conservation or reduce the emission intensity of fossil generators. As well, there is no impact on the price of electricity, and thus consumers are not encouraged to reduce demand and therefore carbon emissions. Hence, much more effort must be expended on higher-priced renewables to displace fossil generation and meet the carbon reduction target. From a distributional perspective:

1. Consumer prices are not affected in the subsidy scenario, since all of the reductions are supplied through lower renewable energy costs, which do not affect the fossil fuel sector directly. Consumers would be indirectly affected since it is their tax revenue that funds some portion of the subsidy transferred to the renewable sector.

2. For renewable energy producers, the generation subsidy has the largest impact on profits, since they must be encouraged to displace more fossil output than in the preceding scenarios. Ongoing innovation is stimulated by the greater scope for reducing production costs at the higher output levels induced by the price premium.

3. For fossil fuel generators, the impact of the generation subsidy on fossil output is similar to that of the emissions price, since the additional renewable energy generation is partly offset by additional demand. The decline in output is slightly larger in the second stage, due to the more dramatic increase in the competitiveness of renewables from innovation. It might seem surprising that fossil output may be lower with the subsidy than with the emissions price, since the electricity price increase is absent. However, since the fossil sector lacks an opportunity to adjust its own emissions, the full burden of reductions falls on renewables to displace fossil output.

4. For government, the subsidy required to achieve the emission reduction target is a significant disbursement.

5. For society as a whole, welfare costs are greater than with the emissions price. With respect to reaching the emissions target, the renewable subsidy is likely to suffer from greater uncertainty than the preceding policies. Although not modelled, the reasoning is twofold:

    - First, the uncertainty over the scope and speed of cost reductions in renewables is likely to be greater than uncertainty surrounding the costs of abatement in the fossil sector or the extent of conservation by consumers.

    - Second, even if all cost uncertainties were similar, the reliance on only one method of emission reductions raises overall uncertainty. In a broader scenario, if innovation does not lower renewable energy production costs significantly, one could engage in relatively more emission abatement or conservation, whichever turns out to have the lower costs.

The renewable subsidy alone has more uncertainty regarding how much emissions will be reduced. It also has more uncertainty regarding the revenue requirement. If costs fall more than expected, a high subsidy would induce an oversupply relative to the carbon target, reflecting additional efficiency loss, as well as lost public funds. If costs do not fall as expected, either the emissions targets will not be met (and some public funds will be saved) or the subsidy must be increased even more to meet them, requiring greater-than-expected outlays.

4.4.5 A Combination of RPS and RGS

Renewable energy is often addressed by a combination of policies. Reasons include the overlapping jurisdictions of the federal, provincial and local governments and, perhaps, a desire for diversification. We have estimated the effects of placing a portfolio standard and a renewable production subsidy in place simultaneously. The key result is that the subsidy weakens the effect of the portfolio standard and raises costs slightly.

With both policies, the fossil fuel producer must still purchase green certificates for every unit of electricity generated. For the renewable energy producer, there are now two subsidies—the value of a green certificate and the direct subsidy. Since the direct subsidy boosts renewable supply, the equilibrium price of a green certificate does not need to be as high to reach the portfolio standard (compared with the RPS implemented in isolation). Consequently, when the policy target is a portfolio share, a direct subsidy to renewables primarily offsets the burden to fossil producers and consumers instead.

Since we assume the RPS is the driving policy instrument in our combination scenario, the distributional effects are quite similar to those of the RPS alone. The slight differences are as follows:

1. Consumer prices are slightly lower. Despite the additional electricity demand, emissions are also lower in the first stage—this is because the standard must be raised to offset the loss of conservation incentive, leading to even more reduction in the first stage and less in the second.

2. Renewable energy production is 0.5% higher and R&D spending is 1.5% higher.

3. For fossil fuel generators, output is nearly unchanged relative to the portfolio standard alone. This is because, even though the fossil fuel producer has to buy more certificates, the cost of these certificates is lower because the subsidy has generated a greater supply of them.

4. Perhaps the most telling effect is that the government in this combination scenario spends just over $1 billion on a subsidy that has little or no effect on behaviour, given the presence of the RPS.

5. From society's perspective, to the extent the subsidy does affect behaviour, it tends to lower prices and raise overall welfare costs. The weaker conservation incentive and the additional frontloading of emission reduction efforts (through increases in the RPS) lead to an increase in welfare costs, from 1.80 to 1.83 times that of the emissions price.

4.4.6 Renewable Research Subsidy

The renewable research subsidy uses current investments in reducing costs to increase future renewable energy production. Since it does not change any price incentives for demand or production, or change current costs, all the burden of emission reductions is placed on future displacement of fossil by renewable energy generation. Furthermore, given the lack of future production incentives, the required cost reductions are large and the required investments even larger. The ability of an R&D subsidy alone to deliver all of this is clearly an area of uncertainty. From a distributional perspective:

1. Consumers do not experience electricity price increases and consumer surplus losses under the R&D subsidy. As with the generation subsidy, they indirectly contribute to the renewable sector through tax contributions to fund the R&D subsidy.

2. For renewable energy producers, the R&D subsidy induces the highest penetration in the second stage. This penetration is driven exclusively by innovation and cost decreases from renewable production. An important caveat is the degree to which

Canadian learning by doing and R&D can drive cost decreases in renewables. While such production cost decreases are observed in Canada and internationally, it is not certain that Canadian R&D alone can reduce costs sufficiently to achieve the high levels of renewable power penetration predicted in this scenario. As a general observation, innovation in renewable production occurs internationally and is imported into Canada. This uncertainty regarding the ability of domestic R&D subsidies to achieve the penetration predicted in the model only reinforces the conclusion that this policy is a much more costly method for achieving emission reductions.

3. For fossil fuel generators, the R&D subsidy does not affect electricity price, but it does significantly reduce fossil output in the second stage. Although not modelled, costs associated with stranded assets or variable costs due to lower capacity utilization could arise. But transaction costs associated with decreased fossil demand are likely lower in this scenario, since a majority of reductions occur in the second stage. Thus, the transition period for the fossil sector to adjust to decreased demand is long and there is potential for costs to be minimized.

4. For government, the R&D subsidy requires the largest disbursement of the instruments. That said, promoting innovation is a government policy, and therefore R&D programs are generally part of a desirable policy approach to long-term carbon emission reductions. However, given the longer-term nature of the reductions associated with R&D, a government faced with a carbon reduction target would likely not achieve significant reductions in the short-term under an R&D program.

5. From society's perspective, welfare costs are greatest under the R&D subsidy. Another negative consequence of this scenario is uncertainty. As with the renewable generation subsidy, the uncertainty of renewable cost reductions makes this a relatively risky policy for promoting carbon reductions—all the more so, since in the absence of cost reductions, there is no incentive for additional uptake of renewables in either stage. Given the uncertainty over innovation success in general and the impact of domestic efforts in particular, it is highly uncertain that a domestic R&D program alone could achieve a significant carbon reduction target through renewable generation. Instead, an R&D subsidy can be seen as a complementary instrument that could be used to achieve longer-term societal goals such as promoting innovation.

4.5 Sensitivity Analysis

To further test the robustness of the results presented in the preceding discussion, a sensitivity analysis was conducted for the following factors:

1. *An increase in the baseline price of electricity:* The sensitivity analysis shows that the differential between renewables price and the electricity price is an important determinant of the size of the welfare cost. As well, this differential affects the desirability of an RPS compared with a renewable generation subsidy. These results can also be expected when the price of renewables changes, that is, a decrease in the price of renewables would produce results that are directionally similar to an increase in the electricity price.

2. *An increase in the baseline price of natural gas:* The sensitivity results indicate that increasing natural gas prices have a minimal impact on the outcomes with respect to the reference case. As discussed in the previous scenario, however, increasing gas prices could increase the price of electricity, and the response would be similar to an electricity price increase.

The sensitivity testing concludes that the results are robust to changing key variable assumptions. Indeed, our core observation holds: the economic efficiency and environmental effectiveness of the EFR instruments are linked to their ability to influence the entire electricity market and the three decarbonizing drivers in particular. As a general rule, an EFR instrument will be more efficient and effective if it signals to multiple agents in the electricity market that carbon is more expensive: fossil producers will reduce their emission intensity; renewable power producers will supply more output when the price differential between renewable and fossil generation decreases; and consumers will take measures to conserve electricity, reduce demand and displace fossil output. This finding holds under multiple input assumptions and explains why an emissions price is preferable to either an RPS or RGS. A good example of the increased risk in using a single instrument is highlighted by the R&D instrument scenario, where the emission reduction is entirely dependent on the ability of R&D investments to reduce renewable energy costs through innovation. While cost reductions can be expected from R&D spending, the scope and scale of the cost reductions are questionable, thus increasing the overall uncertainty in the instrument.

5 Lessons Learned

Unquestionably, EFR instruments have traction with respect to decarbonizing electricity and increasing the uptake of renewables. Our results indicate that a wide range of EFR instruments can be used to decarbonize the economy and increase the installed capacity of renewable technologies. Important lessons learned include the following:

1. *Instruments are most economically efficient and environmentally effective if they are comprehensively applied and target all actors in a market:* Each EFR instrument outlined in the case study has different impacts on the three principal elements of a electricity market:

    - renewable power penetration, which is how much of total Canadian electricity generation is supplied by renewable power;

    - the carbon intensity of fossil fuel generation, which is how much carbon a unit of electricity generated by fossil fuels contains. Carbon intensity can be reduced by using natural gas instead of coal, for example; and

    - total electricity demand, where consumers can reduce their electricity demand by practising energy conservation.

    The success of one or more EFR instruments will rest on their ability to continue to influence the entire electricity market and these three decarbonization drivers in particular. Of the EFR options presented:

- the emissions price is the most effective at influencing the market and its drivers. It provides the means for attenuating negative effects;
- the renewable portfolio standard ensures a high penetration rate for renewables in the short and longer terms but only marginally influences consumer behaviour;
- the renewable generation subsidy ensures an even higher penetration rate for renewables, but it does not influence consumer behaviour or encourage electricity producers to work toward lower, permanent carbon emission intensities;
- a mix of RPS and RGS produces a slightly better result than the RPS or the RGS alone—however, the welfare cost is very high due to significant government disbursements to achieve the result; and
- the renewable research subsidy has considerable positive impact on the renewable sector, but it does nothing to influence the other drivers or assure market penetration in the long run.

2. *A small portion of renewable energy technologies are competitive with fossil fuel generation now:* Given that some renewables are competitive now, EFR instruments can be expected to increase the installed capacity of renewables in Canada to some degree. However, ambitious carbon reductions will require binding EFR instruments that close the price gap between fossil generation and renewable technologies.

3. *Innovation reduces renewable energy costs:* Innovation in renewable technologies will primarily come from international sources and ultimately reduce renewable supply costs in Canada. Thus the installed capacity of renewables in Canada can be expected to grow over time in the absence of EFR polices.

4. *Renewables are an immature technology with uncertain costs and practical potential:* Any modelling effort that targets renewables is faced with significant uncertainty in forecasting price and practical potential. This uncertainty is unavoidable, and the modelling should address uncertainty.

5. *Renewables are at different stages of technological development:* This implies that some instruments, such as an RPS, can be effective in deploying renewable technologies that are commercially viable in the short term, whereas R&D subsidies are better suited to targeting technologies still in the developmental stage.

6. *The temporal impacts of the EFR instruments differ:* The path of emission reductions and renewable power penetration can vary significantly between instruments. Instruments that require reductions from renewables in the short term will necessarily be more costly than instruments that target longer-term reductions. This effect occurs when the price of renewable supply drops over time.

7. *The distributional consequences of the EFR instruments differ significantly:* Comparing overall instrument costs can mask the distributional consequences of an

EFR instrument. Table 8 provides an overview of the distributional consequences of the instruments included in this case study.

8. *Program design and detail matter, but they are not captured in the analysis:* We assessed the EFR instruments at a high level but observe that enabling conditions significantly affect outcomes. Enabling conditions such as local permitting, regulations, transmission distance and access to the grid all affect the technical and economic feasibility of the renewable supply and ultimately the predicted results of the EFR instruments. Simply assuming that the EFR instruments will achieve cost-effective carbon reductions without a clear understanding of the enabling conditions for and barriers to the uptake of renewables is highly risky policy.

9. *Policy certainty and durability over the longer term are important:* Policy certainty or the durability of the EFR instrument over the longer term is an important driver of renewable uptake. This is particularly the case for renewables where startup capital costs are high and investment returns must be established prior to project implementation.

Table 8
Summary of Distributional Results

	I. Base case	II. Emissions price	III. Renewable portfolio standard (RPS)	IV. Renewable generation subsidy (RGS)	V. Combination RPS and RGS	VI. Renewable research subsidy
To achieve a 12% carbon emissions reduction target from 2010 to 2030, you would see...	(No attempt to reach target)	Emitters pay $10 for each tonne of CO_2	Renewables have 24% share of case study generation (9% of annual total Canadian generation)	The government subsidizes at $0.006 for each kWh generated by renewables	An RPS at 24.21% and a RGS at $0.002	The public and private sectors increase their R&D spending by 61%
Impacts on electricity production	Renewables gain some market share; carbon reduced by 5%	Renewables penetrate slightly more quickly than I; electricity producers work hardest on reducing carbon emissions	A greater penetration of renewables than II; costly for electricity producers at first but cost falls over time	A greater penetration of renewables than II; not a driver for ↓ emissions intensity (= ↑ efficiency)	Sslightly more renewables in the mix; fossil fuel–generated output remains unchanged	High penetration of renewables near end of time frame only
Impacts on consumers	Status quo	Electricity prices rise the most; conservation emphasized; negative impacts on some sectors	Overall electricity prices are lower than II, but rise and then fall; conservation not emphasized	Electricity prices remain the same; conservation not emphasized	Electricity prices slightly lower than IV; conservation not emphasized	Electricity prices remain unchanged; conservation not emphasized
Impacts on government	Status quo	Revenues raised (as government collects on emissions price); could be redistributed to affected sectors	No government revenues raised, lost or transferred	Government makes significant disbursements of tax $ to fund the subsidy	Government makes disbursements ($1 billion) to fund the subsidy	Government makes significant disbursements of tax $ to fund R&D for renewables
Impacts on the renewable sector	Status quo; some continued penetration	Output ↑; production costs ↓; some profit; R&D levels high	More output ↑ than II; slightly more profit than II; but less R&D is done	Greater profits as more production lowers costs; high investment in R&D	Output slightly higher; R&D also rises	Highest potential penetration near end of time frame with high R&D
Impacts on Canadian societal	Status quo	Overall lowest welfare costs of the five options	Greater welfare costs than II and lower than	Second highest welfare costs	Welfare costs slightly lower than IV	Highest welfare costs

	I. Base case	II. Emissions price	III. Renewable portfolio standard (RPS)	IV. Renewable generation subsidy (RGS)	V. Combination RPS and RGS	VI. Renewable research subsidy
*welfare**			IV			
Level of uncertainty in reaching target	Target is not achieved	Low; all decarbonization drivers are acted on to work toward target	Medium; only two decarbonization drivers affected	Medium-high; only one decarbonization driver affected	Medium; only two decarbonization drivers affected	High, due to reliance on one decarbonization driver (penetration not assured)

** = adding together (1) the costs to consumers and (2) the losses/profits of electricity producers (both renewable and fossil fuel) and (3) the net government revenues, but excluding environmental costs/benefits (e.g., the costs of adapting to climate change are not included here)*

ENVIRONMENTAL CHOICE CRITERIA FOR RENEWABLE LOW-IMPACT ELECTRICITY

Summary only; for full technical criteria, see "Electricity Generation" at <*www.environmentalchoice.com*>.

Renewable Low-Impact Electricity

From a consumer perspective, electricity is clean, cheap and has no visible environmental consequences. If we look beyond the outlets in our walls, however, environmental costs become apparent. In Canada, the major methods of generating electricity include burning fossil fuels, harnessing the power of water and using nuclear power. Each power source has consequences for the environment, from creating acid rain to flooding lands to disposing of radioactive waste. The Environmental Choice Program has made a commitment to promoting electrical energy sources that have greatly reduced environmental impacts. The ECP recognizes electricity that has been generated from naturally occurring energy sources (such as the wind and the sun) and from power sources that, with the proper controls, add little in the way of environmental burdens (such as less intrusive hydro and certain biomass combustion).

Certification Criteria

All Sources

- The facility must be operating, reliable, non-temporary and practical.
- During project planning and development, appropriate consultation with communities and stakeholders must have occurred, and prior or conflicting land use, biodiversity losses and scenic, recreational and cultural values must have been addressed.
- No adverse impacts can be created for any species recognized as endangered or threatened.
- Supplementary non-renewable fuels must not be used in more than 2% of the fuel heat input required for generation.
- Sales levels of ECP-certified electricity must not exceed production/supply levels.

Specific Sources (additional criteria to those listed above)

- Solar (cadmium-containing wastes must be properly disposed of or recycled)
- Wind (protection of concentrations of birds including endangered bird species)
- Water (compliance with regulatory licences; protection of indigenous species and habitat; requirements for head pond water levels, water flows, water quality and water temperature; measures to minimize fish mortality and to ensure fish migration patterns)
- Biomass (use only wood wastes, agricultural wastes and/or dedicated energy crops; requirements for rates of harvest and environmental management systems/practices; maximum levels for emissions of air pollutants)
- Biogas (maximum levels for emissions of air pollutants; leachate management)
- Other technologies that use media such as hydrogen or compressed air to control, store and/or convert renewable energy
- Geothermal technologies

C. EXECUTIVE SUMMARY: CASE STUDY ON HYDROGEN TECHNOLOGIES

By the Pembina Institute and the Canadian Energy Research Institute

1 OVERVIEW

The Pembina Institute and the Canadian Energy Research Institute (CERI) were commissioned to complete a study on the role of fiscal policy in promoting development of hydrogen technologies and reducing greenhouse gas emissions in Canada. This exercise produced two studies, a baseline report and an economic analysis report.

The *baseline report* describes the state of development of hydrogen technologies in Canada and the existing policy framework, and it provides an initial evaluation of a range of fiscal policy options for promoting the development of hydrogen technologies. The report identifies six fiscal policies capable of providing direct incentives for the development of hydrogen technologies while explicitly addressing a major barrier limiting the technology's market penetration. The six fiscal policies are investment tax credits, producer tax credits, accelerated capital cost allowances, research and development grants, consumer tax credits and pilot projects. The initial evaluation focuses on producer incentives, designed to reduce the production cost of hydrogen technologies, and consumer incentives, designed to reduce the end-use cost of hydrogen technologies. More specifically, the fiscal policies considered in this analysis reduced the cost of hydrogen production, stationary fuel cells, fuel-cell vehicles and buses, and hydrogen internal combustion engine (ICE) vehicles.

The *economic analysis report* presents the results of the modelling exercise undertaken to test the impact of these fiscal policies on particular hydrogen technologies.

A national macroeconomic model—CERI's Energy 2020 model—was used to test the effect of the producer and consumer incentives on the market penetration of hydrogen technologies and associated GHG emissions. The model simulated two methods of hydrogen production: steam methane reformers (SMRs) and electrolysis. The modelling began with a reference case (or business-as-usual model), to which producer and consumer incentives were added (the fiscal scenario model). The results presented below and in the economic analysis report reflect the impact of a combination of producer and consumer incentives equivalent to a 25% decrease in production costs. For the transportation sector, the two different methods of hydrogen production were simulated and the fiscal results presented for both.

In all relevant sectors, the fiscal policies increase the demand for energy associated with hydrogen technologies. In the transportation sector, while the absolute energy demand associated with hydrogen technologies is not significant—constituting between 0.03 and 34.87 petajoules (PJ) of demand in 2030, depending on the particular region—the increase in hydrogen-related energy demand *is* significant. Nationally, energy demand associated with hydrogen-related vehicles increases from 64.36 PJ in 2030 in the SMR reference case and 62.24 PJ in 2030 in the electrolysis reference case, to 96.26 PJ in 2030 in the SMR fiscal scenario model and 93.25 PJ in 2030 in the electrolysis fiscal scenario model. This is an increase of almost 50%. In terms of the number of vehicles, the SMR fiscal scenario model leads to an increase of 47,312 fuel-cell vehicles, 33,371 hydrogen ICE vehicles and 218 fuel-cell buses. Similar results are realized for hydrogen production using electrolysis. On a regional basis, the fiscal scenario model results in an increase of over 45% in hydrogen-related energy demand for most provinces and territories.

Like the transportation sector, the residential building sector and the commercial sector realize an increase in energy demand associated with stationary fuel cells following the application of fiscal policies. In the residential building sector, energy demand from stationary fuel cells increases from 2.61 PJ in 2030 in the reference case to 14.45 PJ in 2030 in the fiscal scenario model, for an increase of 454%. Similarly, in the commercial sector, energy demand from stationary fuel cells increases from 0.41 PJ in 2030 in the reference case to 2.81 PJ in 2030 in the fiscal scenario model, for an increase of 592%. In terms of numbers of stationary fuel cells, the fiscal scenario model leads to an increase of 15,770 stationary fuel cells in the residential sector by 2030, with an increase of 90 in the commercial sector.

In the fiscal scenario model, GHG emissions associated with the transportation, residential and commercial sectors decline as the market penetration of hydrogen technologies increases. In the transportation sector, reductions in emissions equal 1,240 kt in 2030 for hydrogen produced from SMRs. If the hydrogen is produced from a source with almost no GHG emissions (i.e., wind or nuclear power), the reductions in emissions increase to 2,650 kt in 2030. The penetration of stationary fuel cells into the residential and commercial sectors leads to a decline in GHG emissions of 710 kt from these sectors in 2030. Taking into account the impact of mobile and stationary fuel cells, total GHG emissions in Canada decline by 1,940 kt for hydrogen produced from SMRs. These figures include GHG emissions associated with hydrogen production. Taking into account only those emissions associated with hydrogen consumption (i.e., assuming that the hydrogen is produced from zero-GHG emission sources, or that any GHG emissions are captured), emissions decline by 3,360 kt for hydrogen produced by SMRs and 3,370 kt for hydrogen produced by electrolysis.

The modelling analysis reveals that the reduction in GHG emissions as a result of the market penetration of hydrogen technologies comes at a fairly high cost per tonne. This high cost is due to the combined effect of the limited reductions in GHG emissions that are actually realized and the existing cost barriers associated with the development of hydrogen technologies. The producer and consumer incentives reduce capital and operating costs by 25% each; however, given the high costs associated with hydrogen technologies (initially 50% more than the capital costs associated with conventional technologies in the transportation sector), the investment required to achieve these reduced costs is significant.

This analysis reveals that fiscal policy could facilitate an increase in the market penetration of hydrogen technologies in the transportation, residential and commercial sectors. For all sectors, and in all regions in Canada, the introduction of fiscal policies leads to increased demand for energy associated with hydrogen technologies. This result holds true on an absolute basis and also as a percentage of total energy, with hydrogen technologies capturing a greater share of total energy when fiscal policies are in place. Despite these results, the market penetration of hydrogen technologies is still relatively minor and the reduction in GHG emissions that is achieved is also relatively small, even with the fiscal policies.

2 LESSONS LEARNED

The time horizon for the hydrogen technologies included in this modelling exercise is longer than that for the technologies considered in the two other EFR case studies (i.e., energy-efficient and renewable energy technologies). Even over a 30-year period, relatively little market penetration of hydrogen technologies occurs. Reduced costs and technological improvements would increase the competitiveness of hydrogen technologies.

1. Given the long time frame associated with hydrogen technologies, any reductions in GHG emissions that result will also take place over a long time period.

2. The successful market penetration of hydrogen technologies does not guarantee significant reductions in GHG emissions. Consideration of source fuel and energy pathway is key if hydrogen is to be part of a plan to reduce GHG emissions. If the intention is to increase penetration of hydrogen technologies and reduce GHG emissions at the same time, then a focus on low-emission hydrogen sources is necessary (e.g., renewable energy, natural gas reformers and systems that capture carbon emissions).

3. Cost and technology barriers are still significant for some technologies and are expected to remain so for the next 10 to 20 years.[1]

4. Given the current cost barriers associated with hydrogen technologies, any reductions in GHG emissions that are achieved come at a very high cost. If the main objective of fiscal policy is to reduce GHG emissions in the near future, focusing on other methods to reduce GHG emissions is likely more cost-effective than focusing on hydrogen technologies.

5. It may be most effective to focus fiscal policies aimed at increasing the market penetration of hydrogen technologies on technological improvements (research and development, demonstration projects) and cost reductions. As indicated in item 2, above, the application of fiscal policies to hydrogen technologies will not necessarily ensure reductions in GHG emissions unless the source fuel and energy pathway is taken into account in policy design.

6. In the transportation sector, increasing the market penetration of hydrogen technologies will require a focus not only on cost reductions and improvements in efficiency but also on the supply and availability of hydrogen fuel and hydrogen-related vehicles. There may be a role for fiscal policies targeted at manufacturers and retailers in this regard, although that is outside the scope of this analysis.

7. The development of hydrogen technologies in Canada is and will be largely influenced by trends in other countries, such as the United States, Japan and Germany. While such trends were not taken into account in this analysis, it is useful to keep this factor in mind in interpreting the results.

8. From a methodological point of view, the calibration of the Energy 2020 model to *Canada's Emissions Outlook: An Update* (CEOU),[2] introduces an inherent level of uncertainty into the modelling results. We already know that the fuel prices contained in

the CEOU are incorrect. The effect of this error on the model results is uncertain.

9. There are gaps in data when it comes to the technology parameters and predictions of market availability for hydrogen technologies. For any technologies that are not yet commercially available or even in real-world operation, assumptions made regarding both costs and performance are often based on best predictions by technology researchers and developers. Thus there is high uncertainty with these parameters. The modelling results are also highly dependent on assumptions about when particular technologies will be available in the marketplace and access to supporting services such as refuelling infrastructure. There is a wide range of predictions and speculation on when these new technologies will become available.

Endnotes

1 According to the U.S. Department of Energy's *Hydrogen Posture Plan* (2004), the introduction into the transportation market of personal vehicles that use hydrogen is not expected to occur until after 2020. Hydrogen use in commercial fleets and distributed combined heat and power (CHP) are on the same timeline.

2 Analysis and Modelling Group, *Canada's Emissions Outlook: An Update* (Ottawa: National Climate Change Process, December 1999).