ECOLOGICAL FISCAL REFORM AND ENERGY CASE STUDY ON RENEWABLE GRID-POWER ELECTRICITY

–Executive Summary and Lessons Learned Report–

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1. INTRODUCTION

The National Round Table on the Environment and the Economy (NRTEE) has initiated a program to examine the role of ecological fiscal reform (EFR) in meeting the challenges of implementing sustainable development in Canada. The first phase of the EFR program, which focussed on the agricultural, transportation and chemical sectors, demonstrated that fiscal policy is one of the most powerful means at the government's disposal to influence outcomes in the economy; if used in a consistent and strategic manner, EFR can promote objectives that have simultaneous economic and environmental benefits.

In the spring of 2003, the NRTEE launched the second phase of its EFR program, which focuses on the potential contribution of EFR to reducing carbon dioxide (CO_2) emissions from energy. The goal of this second phase is to "examine how to reduce energy-based carbon emissions, both in absolute terms and as a ratio of GDP, using fiscal policy without increasing other pollutants." As in the previous phase, this phase of the EFR program includes the development of case studies on three sectors that can contribute significantly to the "decarbonization" of Canada's energy sector: renewable energy, hydrogen and energy efficiency.

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

2. THE RENEWABLE ENERGY CONTEXT

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

This case study adopts the definition of RETs used by the Environmental Choice Program (ECP)—Environment Canada's ecolabelling program—for two reasons:

- the goal of the EFR program specifies that the "decarbonization" of the energy sector not increase other pollutants; and
- an implied goal of this initiative is the promotion of innovation.**[For readers not familiar with the ECP, the links between these two points and the use the ECP definition of RETs may not be obvious. Suggest adding a short explanation.]**

The NRTEE also directed that the case study examine only those RETs that generate electrical power (as opposed to thermal technologies such as solar water heaters) and that are—or will be—tied into the national electricity grid (as opposed to stand-alone systems).

Consequently, this case study examines the following technologies:

- wind turbines;
- 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.

3. GRID-POWER RETS 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 electricity generating capacity (connected to the Canadian grid), technical maturity and costs?

- **POTENTIAL IN CANADA**. What is the long-term maximum generating capacity for each technology and how much of this capacity is achievable by 2010 and 2020?

FUTURE COSTS AND LEARNING TRENDS. What is the projected cost of each technology and what are the learning trends that affect this cost ?

CURRENT STATUS

Table 1 shows Canada's current (2003) installed generating capacity by source, as well as the total share of electricity generated by each source. As illustrated, Canada's installed renewable generating capacity—with large hydro and all biomass installations included—is over 70,000 megawatts (MW), or about 60% of the total; virtually all of this capacity is large hydro.

Table 1
Installed Generating Capacity and Annual Electricity Generation
Canada (2003)

Source	Installed Capacity		Generation	
	megawatts	**%**	**gigawatt hours**	**%**
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
Totals	**118,000**	**100**	**589,500**	**100**

Source: National Energy Board, http://www.neb.gc.ca/energy/SupplyDemand/2003/index_e.htm.

If the ECP's more stringent criteria are used, large hydro and some biomass facilities are excluded and the figure drops significantly. A breakdown of the estimated current (2003) installed generating capacity of ECP-certifiable grid-power RETs is shown in Table 2. In 2003, these RETs generated an estimated 12,100 gigawatt hours (GWh) of electricity, or about 2% of all electricity generated in Canada.

Table 2 (Discussion of the source/background for these numbers found in the full report)
Installed Generating Capacity of ECP-Certifiable Grid-Power RETs
Canada (2003)

RET	Capacity Factor (%)	Installed Capacity (megawatts)	Generation (gigawatt hours/year)	% of Total Grid-Power RET Generation
Wind (On-shore)	35	316	970	8
Hydro*	60	1,800	9,460	78
Solar PV	14	0.092	0.1	0
Landfill Gas	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

* Includes many small hydro sites that may NOT be ECP-certifiable

POTENTIAL IN CANADA

An RET's **technical potential** is its maximum generating capacity over the long term. For example, if wind power has a technical potential of 100,000 MW, this means that wind turbines could supply 100,000 MW of electricity if they were installed in every technically feasible location across the country.

Table 3 provides the estimated technical potential of each grid-power RET. The ranges reflect a high level of uncertainty.

Table 3 [Sourcing discussed in full report (as with Table 2)]
Technical Potential of ECP-Certifiable Grid-Power RETs
Canada

RET	Cap Factor (%)	Technical Potential (total, not additional)			
		Installed Capacity (megawatts)		Generation (gigawatt hours/year]	
		Low	High	Low	High

Wind (On-shore)*	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	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

* Off-shore wind is not included because of the lack of independent estimates. See Appendix B.3 of the main report for details.

Practical potential recognizes that an RETs technical potential is hampered by such factors 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 of each grid-power RET. The estimates are based on consideration of several factors and consultations with industry and government. Again, a range is provided.

Table 4
Practical Potential of ECP-Certifiable Grid-Power RETs in Canada

RET	Cap Factor (%)	Practical Potential (total, not additional)									
		Annual Growth in Installed Capacity to Reach Practical Potential (%)*		Installed Capacity (megawatts)				Generation (gigawatt hours/year)			
				2010		2020		2010		2020	
		Min	Max	Low	High	Low	High	Low	High	Low	High
Wind (On-shore)	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	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 potential in 2010 and 2020. The growth rates are not forecasts of installed capacity, but rather the annual growth required to reach the practical potential. See Appendix C of the main report for details.

FUTURE COSTS AND LEARNING TRENDS

[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 practical potential of grid-power RETs. 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 5 presents the estimated levelized costs for each grid-power RET. To ensure consistency among the technologies, all cost data are derived from recent estimates provided by the International Energy Agency (IEA). Again, a range is provided.

Table 5 also provides IEA estimates of cost reductions for each technology over the study period. The forecast levels of cost reduction 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 in Section 4.

Table 5
IEA Cost Reductions and Estimates for ECP-Certifiable Grid-Power RETs*

RET	Cap Factor (%)	Cost Reduction				Cost Estimates					
		Cost Reduction Every 10 Years (%)		Annual Cost Reduction (%)**		Levelized Cost Estimates (¢CAN(2000)/kilowatt hour)					
						2003		2010		2020	
		Min	Max	Min	Max	Low	High	Low	High	Low	High
Wind (On-shore)	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	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

Source: IEA figures as cited in *Background Document for the Green Power Workshop Series, Workshop #4*, Pollution Probe, February 2004, pp. 30–32, http://www.pollutionprobe.org/whatwedo/GPW/calgary/gpwbackgroundercalgary.pdf.
* Cost estimates are for all countries that are members of the Organisation for Economic Cooperation and Development; the wide range of values shown reflects both the diversity of conditions experienced and the high levels of uncertainty.

** Assuming logarithmic cost reductions.

Table 6 presents the share of total electricity generation in Canada in 2010 covered under this case study.

Table 6
Projected Share of Generation by Source
Canada (2010)

Source	**Projected Generation in 2010 (gigawatt hours)**	**Share of Total Generation (%)**
Grid-Power RETs (as *included* in this study)	31,000*	5
Fossil Fuels (coal, gas and oil as *included* in this study)	198,000**	32
Other (nuclear and renewables *excluded* from this study)	394,000	63
Total	623,000**	100

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

4. MODELLING RESULTS

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

- overview of the fiscal instruments assessed;
- overview of the model used to assess the instruments;
- summary of results;
- detailed discussion of the base case and each fiscal instrument; and
- sensitivity analysis results.

4.1 FISCAL INSTRUMENTS ASSESSED

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

- An **emissions price**, which is analogous to an emissions trading permit system or a carbon tax. Under this scenario, a shadow price of $10/tonne is placed on CO_2 emissions; this is 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.

- A **renewable portfolio standard (RPS)**, which requires that utilities purchase green certificates, or the equivalent, so that renewables generation increases relative to fossil fuel generation. The model compares the uptake of renewables attributable to an RPS relative to generation from fossil fuels (i.e., not relative to all electrical generation). Constraints are not placed on technologies or regional shares of the total RPS. Instead, prices are used as the determinant for the type of technology that is supplied at the prevailing electricity price.

- A **renewable generation subsidy**, which is modeled as a direct subsidy for grid-power RET producers on a per kilowatt hour (kWh) basis. In practice, this 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.

- A **combination of RPS and generation subsidy**, modelled in tandem. We let the RPS be the dominant policy, since the RPS is meaningless if the subsidy encourages more renewable generation than required. The price of the green certificates is offset in part by the subsidy. This outcome will therefore trigger distributional shifts in terms of cost imposition.

- A **subsidy for research and development (R&D)**, which is a program to reduce the future cost of renewable generation. The model identifies the annual increase in renewables R&D required to achieve the emissions 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 solves for the policy level that would achieve the carbon target.

4.2 OVERVIEW OF THE MODEL

The case study uses Resources for the Future's unified analytical model to assess the impact of the fiscal instruments on greenhouse gas emissions and the development and diffusion of grid-power RETs. This model was developed and tested for the United States' Environmental Protection Agency to assess the preferred fiscal instruments for promoting RETs.

The model includes two sectors of the electricity generation industry: one that emits CO_2 and one that does not. Both are assumed to be perfectly competitive and supplying an identical product, electricity. As the marginal technology, fossil fuel generation sets the overall market price of electricity. 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 stages. Investment in knowledge takes place in the first stage, producing technological change and innovation that lowers the cost of renewable generation in the second.

The CO_2-emitting sector relies on fossil fuels. As the mature technology, fossil fuel generation is assumed to realize only negligible productivity improvements from new R&D.[2] Its marginal production costs are assumed to be constant with respect to output, and to increase with reductions in emissions intensity. The representative firm chooses emissions 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 emissions 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.

The non-emitting sector uses RETs. 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. As the young technologies, RETs become less expensive over time as the knowledge stock increases. There are two ways to increase the knowledge stock: investments in R&D and "learning by doing" (LBD), which is a function of total output during the first stage in the model. The representative renewable energy firm chooses output in each stage and R&D investments to maximize profits. In the first stage, it produces until the marginal cost of production

[2] While it is not strictly true that fossil fuel technologies will experience no technological advance, incorporating a rate of advance in the model would complicate the analysis without adding substantial insight.

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 all fiscal instruments have the same emissions reduction target in this case study, we hold the environmental effects constant across the policy scenarios. By displacing fossil fuels, the fiscal instruments are expected to have several 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
- the benefits of mitigating climate change, 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.

4.3 SUMMARY OF RESULTS

The results are a function of how the energy market is influenced by each instrument. In the model, results differ according to changes in three **decarbonization drivers**: renewables penetration, the carbon intensity of fossil fuel generation and total electricity demand.

The results in Table 7 can be traced back to an instrument's ability to affect one or all of the decarbonization drivers. Generally, an instrument will be more economically efficient if it affects all three drivers.

Each numbered item in the first column of Table 7 is defined as follows:

1. **No policy base case**. Our model predicts that with no policy, renewable energy generation will increase from 13% to 17% of included generation in the second stage, which corresponds to a 5% emissions reduction. Subsequent policy scenarios will target a 12% reduction overall from the combined emissions in the two stages of the no policy case.

2. **Policy level for 12% emissions reduction**. This row provides an estimate of the size of the fiscal instrument required to achieve the emissions reduction target.

3. **Electricity price ($/kWh).** This row indicates the impact of the fiscal measure on the annual price of electricity in the first (2010 to 2015) and second (2015 to 2030) stages.

4. **Carbon emissions (megatonnes).** Annual estimates of CO_2 emissions for the last years of the first and second stages.

   Carbon reductions are influenced by the three drivers in the following ways:

   - renewable penetration displaces fossil generation when an instrument reduces renewable generate 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); and
   - an increase in the electricity price reduces total electricity demand, which displaces fossil fuel generation.

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

5. **Renewable generation (megawatt hours 10^11).** This row indicates electricity generation from grid-power RETs during each stage. Renewable generation is a function of production cost differentials between renewables and fossil fuels. Instruments affect the cost differential by subsidizing renewable generation, promoting innovations that reduce the cost of renewable generation, and/or taxing fossil fuel production. Instruments that promote innovation reduce renewable costs and carbon emissions in the second stage.

6. **Fossil fuel generation (megawatt hours 10^11).** As with renewable generation, fossil fuel generation is altered when the fiscal instruments change the cost of production. Fossil fuel generation is also altered by reductions in total demand, which occur when an instrument increases the price of electricity.

7. **Total electricity generation (megawatt hours 10^11).** Total generation includes fossil fuel and renewable generation; changes indicate that the instrument influences total demand through electricity price increases.

8. **Renewable R&D ($million/year).** Total R&D spending by the public and private sectors.

9. **Additional renewables cost reduction**. This row indicates the percent reduction in the cost of renewable generation.

10. **ΔConsumer surplus ($million/year).** This is the net cost to the consumer, 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.

11. **ΔProducer surplus ($million/year).** This is the change in total profits 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 electricity price.

12. **ΔTransfers ($million/year).** This is the change in government revenues for both stages. A positive number is revenue and a negative number is a disbursement.

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

- **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 because it has the lowest welfare cost.

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

Source: Marbek and Resources for the Future.
Note: Figures may not add because of rounding.
* This is 9% of all annual Canadian generation.

4.4 DETAILED RESULTS BY INSTRUMENT

BASE CASE

The base case provides the reference from which the percentage changes are estimated in Table 6. Renewables penetration is forecast based on the relative costs of fossil fuel and renewable generation. Renewables penetration increases over time as innovation reduces the cost of renewable generation.

Total electricity generation is fixed in both stages in the base case;[3] increased renewables penetration therefore decreases the carbon intensity of all generation, from 106 megatonnes/year in the first stage to 101 megatonnes/year in the second stage.

EMISSIONS PRICE

An emissions price works to reduce emissions by reflecting their cost, either in terms of environmental damages (as with a carbon tax) or in terms of 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. Because the price of fossil energy includes the cost of the carbon associated with that form of generation, the price of electricity rises. This signals **consumers** to reduce their energy use (by, for example, using more energy efficient appliances). It also increases the price received by **renewable energy producers**, encouraging production and investment in RETs.

- **Consumers** face the highest electricity prices and consumer surplus loss under the emissions price scenario. Because many consumers are also taxpayers, the amount of government transfers also affects them.

- For **renewable electricity generators**, the emissions price has a modest but significant impact on renewable generation, production costs and the producer surplus. This impact is relatively consistent across both stages.

- For **fossil fuel electricity generators**, the emissions price is the only instrument with an incentive to reduce emissions intensity. Although profits for the fossil sector are not modeled—rather, they are assumed to be driven to zero in the long run by the market—the potential costs to the fossil sector of an emissions price would depend on its ability to pass on to consumers the production costs increases from carbon abatement (i.e., moving from coal to gas), as well as any windfall gains from being allocated emissions permits.

- For **government**, significant revenue could be raised under the emissions price, either through a carbon tax or through the allocation or auctioning of carbon permits under an emissions trading system. This is the only scenario with the potential for significant increases in government revenue. It also represents the value of the emissions rents, which are available to be allocated to consumers,

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

generators and their shareholders, funds for transition assistance, or taxpayers more generally.

- From **society's perspective**, 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 to economy-wide competitiveness. Reserving some permits for allocation to trade-exposed sectors that are electricity intensive could mitigate this impact.

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

RENEWABLE PORTFOLIO STANDARD

The RPS requires that total electricity generation include a minimum share of renewable generation. Although there are several ways to implement an RPS (e.g., 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 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 producers is equal to the total effective tax paid by fossil generators, so no net revenues are raised or lost by the government.

Since the RPS does not favour any fossil fuel technology, there is no incentive to reduce emissions intensity in that sector. Consumer prices rise because of the effective tax on fossil energy to fund the renewables subsidy (i.e., buy green certificates), but not as much as with an emissions price.

Although more renewable energy is generated under the RPS than under the emissions price, the timing of that generation differs. Normally, when prices are fixed renewable generation expands as costs fall over time. However, the RPS fixes the renewables share in both periods and over time this share becomes easier to meet. The effective tax and subsidy therefore 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 over time as a result of innovation; 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, but 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).

- **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 the result of 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, electricity) is higher in the first stage but lower in the second.

- For **renewable producers**, the RPS increases renewable generation at a uniform rate in both stages, which is not surprising since the RPS fixes the share of renewables in both stages. Producer profits are high. While there is certainty in terms of market share for the renewables sector, there is less stability in terms of prices, and less flexibility in terms of the timing of renewable 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 to lowering costs in the second stage is lower, 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.

- For **fossil fuel generators**, the share of all generation remains steady in the two stages; it's lower than in other scenarios in the first stage and higher in the second. 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 the sector is not able to pass along the full costs of green certificates to consumers.

- For **government**, the RPS has no impact.

- From **society's perspective**, the welfare costs are greater than under the emissions price and generation subsidy, but lower than under the R&D subsidy and the combined RPS and generation subsidy. This ranking does not necessarily hold under all circumstances, but rather depends on the particular trade-off between the extra costs of encouraging more effort up front 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.

- Looking **beyond the electricity sector**, the increase in electricity prices could cause economy-wide competitiveness (which could lead to decreased productivity or reduced exports, for example). This economy-wide competitiveness would not be as severe as under the emissions price, particularly in the second stage of the RPS.

RENEWABLE GENERATION SUBSIDY

This fiscal instrument includes a range of policies that subsidize renewable generation (e.g., tax credits, direct subsidies). They do nothing, however, to reduce the emissions intensity of fossil fuel generation. As well, they have no impact on the price of electricity; consumers are therefore not encouraged to reduced demand and, in turn, carbon emissions. Hence, much more effort must be expended on higher priced renewables to displace fossil generation and meet the carbon reduction target.

- **Consumer prices** are not affected because all of the reductions are supplied through lower renewables costs, which do not affect the fossil fuel sector directly. Consumers are indirectly affected because their tax revenue funds a portion of the subsidy.

- For **renewable producers**, the generation subsidy has the largest impact on profits, since it encourages the displacement of fossil fuel generation more than the preceding scenarios. On-going innovation is stimulated by the greater scope to reduce production costs at the higher output levels induced by the price premium.

- For **fossil fuel generators**, the generation subsidy has a similar impact on fossil generation as the emissions price, since the additional renewable generation is partly offset by additional demand. The decline in fossil fuel generation is slightly larger in the second stage because innovation dramatically increases the competitiveness of renewables. That fossil fuel generation may be lower with the subsidy than with the emissions price—with no increase in electricity prices—may seem surprising. 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.

- For **government**, the subsidy required to achieve the emissions reduction target is a significant disbursement.

- From **society's perspective**, the welfare costs are greater than under the emissions price, but less than under all other scenarios. There is more uncertainty, however, that the emissions target will be met with the generation subsidy than under the preceding scenarios, for two reasons:

    - The scope and speed of cost reductions in renewable generation is likely more uncertain than the cost of abatement in the fossil sector or the extent of conservation by consumers.

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

There is also uncertainty about the revenue required to meet the emissions reduction target. If the cost of renewable generation falls more than expected, a high subsidy would reduce emissions by more than the target. If costs do not fall as expected, either emissions targets will not be met, and some public funds will be saved, or the subsidy must be increased.

A COMBINATION OF RPS AND GENERATION SUBSIDY

Particularly in renewable energy, a combination of policies is often implemented, partly because of the overlapping jurisdictions of federal, provincial and local governments, and perhaps out of a diversification motive. We have estimated the effects of putting an RPS and a renewable production subsidy in place simultaneously. The key result is that the subsidy weakens the effect of the RPS 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 producer, there are now two subsidies—the value of a green certificate and the direct subsidy. Because the direct subsidy boosts renewable generation, the equilibrium price of a green certificate does not need to be as high to reach the RPS (as compared with the RPS alone). Consequently, when the policy target is a portfolio share, a direct subsidy to renewables primarily offsets the burden to fossil producers and consumers instead.

Because we assume the RPS drives this scenario, the results are quite similar to those under the RPS alone. The slight differences are as follows:

- **Consumer prices** are slightly lower. Despite the additional electricity demand, emissions are also lower in the first stage—this results from the fact that the standard must be raised to offset the loss of conservation incentive, leading to even more reductions in the first stage and less in the second.
- **Renewable generation** is 0.5% higher and R&D spending is 1.5% higher.
- **Fossil fuel generation** is almost exactly the same as under the RSP alone.
- The **government** spends just over $1 billion on a subsidy that has little or no effect on behaviour, given the presence of the RPS.
- From **society's perspective**, to the extent that the subsidy does affect behaviour, it tends to lower prices and raise welfare costs. The weaker conservation incentive and the additional front-loading of emissions reduction efforts by increasing the RPS are the cause of the increase in welfare costs, from 1.8 to 1.83 times that under the emissions price.

RENEWABLE R&D SUBSIDY

The renewable R&D subsidy uses current investments in reducing costs to increase future renewable generation. Because it does not change any price incentives for demand or production, nor does it change current costs, all the burden of emissions reduction is placed on future displacement of fossil generation by renewable 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 uncertain.

- **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 renewables sector through tax revenues that fund the R&D subsidy.

- For **renewable producers**, the second stage of the R&D subsidy induces the highest increase in renewable generation of all the scenarios. This increase is driven exclusively by innovation that decreases the cost of renewable generation. However, the degree to which Canadian learning by doing and R&D can drive cost decreases is uncertain. Although such cost decreases are observed in Canada and internationally, it is not certain that Canadian R&D alone will decrease costs enough to increase renewable generation by the amount predicted in this scenario. One reason for this uncertainty is that innovation in renewable generation generally occurs internationally and is imported into Canada. This uncertainty in the ability of domestic R&D subsidies to achieve the penetration predicted in the model only reinforces the result that this policy is a much more costly method for achieving emissions reductions.

- For **fossil fuel generators**, the R&D subsidy does not affect electricity prices, but does significantly reduce fossil fuel generation in the second stage. Fossil fuel generators could therefore face costs associated with stranded assets or variable costs resulting from lower capacity utilization (these costs are not modelled). 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 has the potential for costs to be minimized.

- For **government**, the R&D subsidy requires the largest disbursement of all the instruments. That said, promoting innovation is a government policy and therefore R&D subsidies are generally *part* of the desired policy approach to decarbonization. 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 with an R&D subsidy.

- From **society's perspective**, the welfare costs are greatest under the R&D subsidy.

Another negative consequence of this scenario is uncertainty. For similar reasons to 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 renewables uptake in either stage. Given the general uncertainty about the success of innovation—particularly domestic innovation—it is highly uncertain that a domestic R&D program alone could significantly reduce CO_2 emissions by increasing renewable generation. Instead, an R&D subsidy could be viewed as a complementary instrument that can be used to achieve longer-term societal goals such as promoting innovation.

4.5 SENSITIVITY ANALYSIS

To further test the robustness of the results, a sensitivity analysis was conducted with respect to the following:

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

- **An increase in the baseline price of natural gas**. The sensitivity results indicate that increasing natural gas prices have a minimal impact on the results. Increasing gas prices could, however, increase the price of electricity.

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 FISCAL INSTRUMENTS IS LINKED TO THEIR ABILITY TO INFLUENCE THE ENTIRE ELECTRICITY MARKET AND THE THREE DECARBONISING DRIVERS IN PARTICULAR. A FISCAL INSTRUMENT WILL GENERALLY BE MORE EFFICIENT AND EFFECTIVE IF IT SIGNALS TO MULTIPLE AGENTS IN THE ELECTRICITY MARKET THAT CARBON IS MORE EXPENSIVE: FOSSIL FUEL PRODUCERS WILL REDUCE THEIR EMISSIONS INTENSITY, RENEWABLE PRODUCERS WILL PRODUCE MORE WHEN THE PRICE DIFFERENTIAL BETWEEN RENEWABLE GENERATION AND FOSSIL FUEL

GENERATION DECREASES, AND CONSUMERS WILL CONSERVE. THIS FINDING HOLDS UNDER MULTIPLE INPUT ASSUMPTIONS AND EXPLAINS WHY AN EMISSION PRICE IS PREFERABLE TO AN RPS OR RENEWABLE GENERATION SUBSIDY [AND TO THE COMBO AND R&D SUBSIDY?]. A GOOD EXAMPLE OF THE INCREASED RISK IN USING A SINGLE INSTRUMENT IS HIGHLIGHTED BY THE R&D SCENARIO, IN WHICH THE REDUCTION OF EMISSIONS RELIES ENTIRELY ON THE ABILITY OF DOMESTIC R&D INVESTMENTS TO PRODUCE INNOVATION THAT REDUCES THE COST OF RENEWABLE GENERATION. ALTHOUGH R&D SPENDING IS EXPECTED TO REDUCE THE COST OF RENEWABLE GENERATION, THERE IS UNCERTAINTY ABOUT THE SCOPE OF THE REDUCTIONS AND THEREFORE THE EFFECTIVENESS OF THE FISCAL INSTRUMENT.

5. LESSONS LEARNED

Our results show that a wide range of fiscal instruments can be used to decarbonise the economy and increase the installed generating capacity of grid-power RETs. Lessons learned include the following:

1. **Fiscal instruments are most economically efficient and environmentally effective if they are comprehensively applied and target all actors in a market**. Each fiscal instrument examined in this case study has a different impact on the three decarbonization drivers:

    - **Renewables penetration**, which is how much Canadian electricity is generated from renewable sources;

    - **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**.

    The success of a fiscal instrument rests on its ability to influence the entire electricity market and these three decarbonization drivers in particular.

    - The **emissions price** is the most effective at influencing the market and its drivers. It provides the means to attenuate negative effects.

    - The **RPS** ensures a high penetration rate for renewables in the short and longer terms but has only a slight influence on consumer behaviour.

    - The **renewable generation subsidy** ensures an even higher penetration rate for renewables, but does not influence consumer behaviour or encourage electricity producers to permanently lower carbon intensity.

    - A **mix of RPS and generation subsidy** produces a slightly better result than the RPS or the subsidy alone; however, the welfare cost is very high because of the significant government disbursements.

    - The **renewable R&D subsidy** has a considerable positive impact on the renewables sector, but does nothing to influence the other drivers or assure market penetration in the long run.

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

3. **Innovation reduces the cost of renewable generation.** Innovation in RETs—primarily from international sources—will reduce the cost of renewable generation in Canada. Thus, the installed generating capacity of renewables in Canada is expected to grow over time, even without a change in policy.

4. **RETs are immature technologies with uncertain costs and practical potential.** Any model of RETs should address the significant uncertainty in predicting their cost and practical potential.

5. **RETs are at different stages of technological development.** Some instruments, such as an RPS, can be effective at deploying RETs that are commercially viable in the short term; R&D subsidies are better suited to RETs still in development.

6. **The temporal impacts of the EFR instruments differ.** The path of emissions reductions and renewables 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. **Each fiscal instrument has a different impact on producers, consumers, government and society (*see* Table 8).** Simply comparing the cost of each instrument can mask these differences.

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

9. **The instrument's long-term durability is important.** This is particularly true when start-up capital costs are high and returns on investment must be established before the project begins.

Table 8
Summary of the Effects of Each Fiscal Instrument on Producers, Consumers, Government and Society

	Base Case	**Emissions Price**	**Renewable Portfolio Standard (RPS)**	**Renewable Generation Subsidy**	**Combination RPS and Renewable Generation Subsidy**	**Renewable R&D Subsidy**
To **reduce CO_2 emissions by 12%** from 2010 to 2030, you would see . . .	(No attempt to reach target)	Emitters pay **$10** for each tonne of CO_2	**24%** of generation come from renewable sources (this is 9% of annual Canadian generation)	A government subsidy of **$0.006** for each kWh of renewable generation	An RPS at **24.21%** and a subsidy of **$0.002/kWh**	The public and private sectors increase their R&D spending by **61%**
Impact on electricity production	Renewables gain some market share; CO_2 emissions reduced by 5%	Renewables penetrate slightly more quickly than in the base case; electricity producers work hardest on reducing carbon emissions	A greater penetration of renewables than with the emissions price; costly for electricity producers at first but this cost decreases over time	A greater penetration of renewables than with the emissions price; not a driver for reducing emissions intensity (= ↑ efficiency)	A slightly greater penetration of renewables; fossil fuel generation unchanged	A high penetration of renewables near the end of the second stage
Impact on consumers	Status quo	Electricity prices rise the most; conservation emphasized; negative impacts on some sectors	Overall electricity prices are lower than with the emissions price, but rise and then fall; conservation not emphasized	Electricity prices remain the same; conservation not emphasized	Electricity prices slightly lower than with the subsidy alone; conservation not emphasized	Electricity prices remain unchanged; conservation not emphasized
Impact on government	Status quo	Revenues raised (as government collects on emissions price); could redistribute to affected sectors	No government revenues raised, lost or transferred	Significant disbursements	Significant disbursements ($1 billion)	Significant disbursements [
Impact on the renewable sector	Status quo—some continued penetration	Generation increases and production costs decrease; some increase in profit; R&D levels high	More generation increase and slightly more profit than under emissions price, but less R&D	Greater profits as more production lowers costs; high investment in R&D	Generation and R&D slightly higher	Highest potential penetration (near end of second stage) with high R&D
Impact on Canadian societal welfare*	Status quo	Lowest welfare cost	Greater welfare cost than with emissions price and less than with generation subsidy	Second highest welfare cost	Welfare cost slightly lower than with generation subsidy	Highest welfare cost
Level of uncertainty in reaching target	Target is not achieved	Low; all decarbonization drivers are acted on to achieve the target	Medium; only two decarbonisation drivers are affected	Medium-high; only one decarbonisation driver affected	Medium; only two decarbonisation drivers affected	High; only one decarbonisation driver affected and penetration not

	Base Case	Emissions Price	Renewable Portfolio Standard (RPS)	Renewable Generation Subsidy	Combination RPS and Renewable Generation Subsidy	Renewable R&D Subsidy
						assured

* Calculated as the cost to consumers + the losses/profits of electricity producers (both renewable and fossil fuel) + net government revenues. **Excludes** environmental costs/benefits (e.g., the costs of adapting to climate change).