Case Study on the Role of Fiscal Policy in Hydrogen Development

Economic Analysis

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Table of Contents

Introduction

This report is the second of two reports related to the Case Study on the Role of Fiscal Policy in Hydrogen Development. The first report, the Baseline Report, presents background information on the state of hydrogen development in Canada and around the world, describes Canada's current policy framework related to hydrogen and evaluates fiscal policy options for facilitating hydrogen development in Canada. The policy evaluation completed in the Baseline Report resulted in the identification of seven fiscal policies capable of providing a direct incentive to hydrogen technologies while explicitly addressing a barrier currently limiting technology penetration.[1] The seven policies are investment tax credits, producer tax credits, accelerated capital cost allowances, research and development, grants, consumer tax credits and pilot projects.[2]

As will be demonstrated in the Reference Case Results chapter of this report, without government intervention, the hydrogen technologies considered in this analysis realize relatively little market penetration. Initial modelling undertaken as part of this exercise indicated that the major barrier to increased market penetration of hydrogen is the price differential between hydrogen and competing technologies. The fiscal policies simulated in this analysis were thus chosen for their ability to narrow the price gap described above and increase the competitiveness of hydrogen. To that end, we focused our evaluation on producer incentives designed to reduce the cost of hydrogen production and consumer incentives to reduce the cost of end-use hydrogen technologies. In terms of the seven policies listed above, all of them could be designed either as producer or consumer incentives. However, producer tax credits, consumer tax credits and/or grants to hydrogen producers and consumers are the policies that provide the most direct link from a modelling perspective to the cost of producing hydrogen and purchasing hydrogen technologies. The policies simulated in this exercise therefore most closely resemble those of either a producer tax credit or grant, or a consumer tax credit or grant. The purpose of this report is to present the results of the modelling exercise undertaken to test the impact of these fiscal policies on the market penetration of select hydrogen technologies over a period of time.

Following this Introduction, the Modelling Framework and Scenarios chapter defines the fiscal scenarios that were simulated and describes the modelling approach employed in this study. The Reference Case Results chapter, which presents the modelling outputs for the business as usual, is followed by the Fiscal Policy Evaluation chapter, which compares the fiscal policy results with the Reference Case results. The final chapter summarizes and interprets the results, and identify next steps in this study as well as key areas for future research.

This outline doesn't mention the Greenhouse Gas Emissions chapter. (p. 13)

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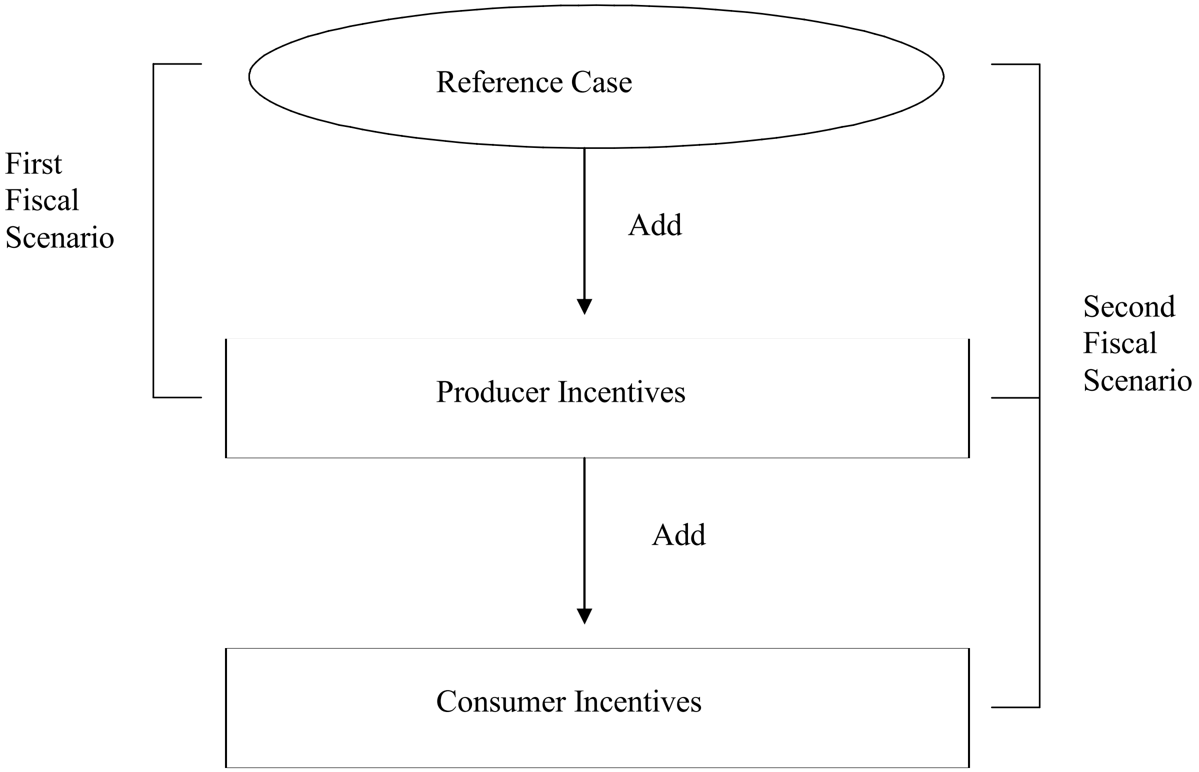
[1] Note that the use of these policies does not preclude the use of other fiscal policies as a means to increase penetration of hydrogen technologies.

[2] See the Baseline Report for descriptions of these and other fiscal policies.

Modelling Framework and Scenarios

The general framework for the modelling analysis employed in this research is described in the flow chart below. The modelling began with the completion of a "Reference Case" modelling run. The Reference Case is essentially a business as usual scenario. It is a projection of how the economy and the energy sector will evolve if we continue on our current path of development. The Reference Case is calibrated to *Canada's Emissions Outlook, An Update* (CEOU),[3] and therefore does not account for any significant government policies associated with Kyoto greenhouse gas emission reduction targets other than those policies that were already in place when the CEOU was developed. In addition, the Reference Case does not account for the potential for technological breakthroughs or possible developments in hydrogen technologies in other regions such as the United States, Germany or Japan (global leaders in hydrogen developments). Canada will inevitably be influenced by developments and breakthroughs in other regions, yet the results presented in this report do not account for the possibility of such changes. It is important to keep these factors in mind when interpreting the Reference Case results of this analysis. Once we completed the Reference Case modelling run, we then added producer incentives to the Reference Case and completed a second run. For the third run, we combined the Reference Case and producer incentives with consumer incentives.

Figure 1 General Modelling Framework



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[3] http://www.nrcan.gc.ca/es/ceo/update.htm

Within the framework described in Figure 1 above, six key scenarios were simulated using the Energy 2020 model.[4] Two scenarios are Reference Cases and four scenarios involve fiscal policy stimulus. Table 1 below presents the hydrogen pathways that were incorporated into the Reference Cases and Fiscal Scenario runs. The Reference Cases reflect two different business as usual scenarios, each describing a different hydrogen production method for transportation applications: hydrogen production using steam methane reformers (SMR) (Pathway 2 in Table 1), and hydrogen production using electrolyzers (Pathway 3 in Table 1). Both of the Reference Cases include Pathway 1- fuel cells in the residential and commercial sectors.

Table 1 Hydrogen Pathways Incorporated into Energy 2020[5]

FUEL SOURCE	PRODUCTION	STORAGE	END-USE
1. Natural gas from pipeline			Fuel cells SOFC[6] (residential, commercial)
2. Natural gas from pipeline	Decentralized SMR	Compressor and tanks at fuelling stations	Fuel cell LDV[7] or fuel cell transit bus or ICE[8] LDV
3. Electricity from grid or specific plant	Decentralized electrolyzer	Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV

More specifically, the six modelling scenarios that were completed as part of this analysis are described below.

1. **SMR Reference Case** – For this run, hydrogen was produced using steam methane reformers and was available for use in fuel cell vehicles (light-duty vehicles and buses) and internal combustion engine light-duty vehicles. As well, stationary fuel cells were available for use in buildings (residential and commercial).
2. **SMR Reference Case with Producer Incentives** – This run was the same as the SMR Reference Case described above, with the addition of producer incentives to lower the cost of hydrogen production.
3. **SMR Reference Case with Producer and Consumer Incentives** – This run included hydrogen production using SMRs, fuel cell vehicles, hydrogen internal combustion engines and fuel cells in buildings along with producer incentives. In addition, it included the simulation of consumer incentives designed to increase the penetration of hydrogen using vehicles as well as the number of fuel cells employed in buildings.
4. **Electrolyzer Reference Case** – This is the second Reference Case. For this Reference Case, hydrogen was produced using electrolyzers and was available for use in fuel cell vehicles (light-duty vehicles and buses) and internal combustion engine light-duty vehicles. As well, stationary fuel cells were available for use in buildings (residential and commercial).

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[4] For a detailed description of the Energy 2020 model, refer to Appendix A of the Baseline Report of this case study.

[5] Capital and operating costs, utilization, and natural gas and electricity consumption for the technologies associated with these pathways can be found in Appendix B of the Baseline Report.

[6] Solid oxide fuel cell.

[7] Light-duty vehicle.

[8] Internal combustion engine.

5. **Electrolyzer Reference Case with Producer Incentives** – This run was the same as the electrolyzer Reference Case described above, with the addition of producer incentives to lower the cost of hydrogen production.
6. **Electrolyzer Reference Case with Producer and Consumer Incentives** – This run included hydrogen production using electrolyzers, fuel cell vehicles, hydrogen internal combustion engines and fuel cells in buildings along with producer incentives. In addition, it included the simulation of consumer incentives designed to increase the penetration of hydrogen using vehicles as well as the number of fuel cells employed in buildings.

Note that the modelling results presented in this report focus on those sectors to which the hydrogen pathways are relevant and that are most directly affected by the fiscal policy scenarios. Thus, results include modelling outputs for the residential, commercial and transportation sectors.

Fiscal Scenarios

Of the modelling scenarios described above, four of them represent the fiscal scenarios simulated in this analysis. The table below identifies the four fiscal scenarios, and the producer and consumer incentives are described in more detail following the table.

Table 2 Fiscal Scenarios Simulated Using Energy 2020

FISCAL SCENARIOS
1. SMR Reference Case + Producer Incentives
2. SMR Reference Case + Producer Incentives + Consumer Incentives
3. Electrolyzer Reference Case + Producer Incentives
4. Electrolyzer Reference Case + Producer Incentives + Consumer Incentives

Producer Incentives

To simulate the producer incentives, a producer tax credit or grant designed to lower the cost of hydrogen production was simulated. The cost of hydrogen fuel was initially decreased by 10%. The same modelling run was subsequently repeated with a 25% decrease in hydrogen fuel.[9] To simplify the presentation of the results and give a better sense of the impact of the fiscal policy, in this report we focus on the impact of the 25% producer tax credit. The tax credit was applied in every year using the Energy 2020 model, beginning in 2000 and extending to 2020.

Consumer Incentives

Consumer incentives took the form of reductions in the purchase price of hydrogen-related vehicles and stationary fuel cells. The price of fuel cell vehicles (light-duty vehicles and buses), hydrogen internal combustion engines (light-duty vehicles), and stationary fuel cells for residential and commercial applications were reduced by 10% and subsequently by 25%. To simplify the presentation of the results in this report, we focus on the impact of reducing relevant prices by 25%.

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[9] The range of incentives simulated here (10% to 25%) was chosen as it was the range typically explored in the federal government's analysis and modelling work related to climate change.

This reduction could be accomplished through use of a consumer tax credit awarded against income tax when taxes are filed or a grant awarded at the time of purchase. As was the case with the producer incentive, the consumer incentives were applied on an annual basis using the Energy 2020 model, beginning in 2000 and extending to 2020.

Note that the Fiscal Scenario results presented in this report reflect the impact of the *combination* of producer incentives and consumer incentives. In addition, it is important to note that the results presented in this report concentrate on the year 2030. The version of the Energy 2020 model used in this analysis (the one calibrated to *Canada's Emissions Outlook, An Update*) only runs to 2020. However, to allow for a sufficient amount of time for the hydrogen technologies to actually penetrate the market and for comparability of results with those of other studies completed on behalf of the NRTEE (studies on the role of fiscal policies for renewables and energy efficiency), the results were extrapolated exogenously to 2030. The extrapolation was based on the trend in penetration that took place within the Energy 2020 model up to 2020.

Reference Case Results

This chapter presents the modelling output for the Reference Cases. As was described earlier in this report, the key difference between the two Reference Cases is the hydrogen production method that is employed for transportation applications. The method of production determines the price of hydrogen fuel for vehicles, which subsequently has an effect on the penetration of transportation-related hydrogen technologies (fuel cell buses and light-duty vehicles and hydrogen ICE light-duty vehicles). In the case of the transportation results, therefore, energy demand and hydrogen price will vary between the SMR and the electrolyzer Reference Cases. For this reason, results for the transportation sector are presented for both of the Reference Cases. The hydrogen production method for transportation does not impact the price or penetration of the stationary fuel cells included in this analysis. There is therefore no difference in the model outputs for the commercial and residential sectors between the SMR Reference Case and the Electrolyzer Reference Case, and thus only one set of results are presented for the stationary fuel cells.

Transportation Sector

As is described above, hydrogen prices vary between the SMR and the electrolyzer Reference Cases. Table 3 presents hydrogen prices for the transportation sector on a regional basis for 2010, 2020 and 2030 (for a description of how these figures were derived, refer to Appendix A). In comparing the SMR and electrolyzer prices, it is clear that in some regions SMR is the cheaper production option, while in other regions, electrolysis is cheaper. For each of 2010, 2020 and 2030, the cheaper hydrogen price in each region is shaded in the table below. The shading reveals that in 2010 and 2020 SMR hydrogen is cheaper than electrolysis hydrogen in most regions (except Quebec, Newfoundland and New Brunswick). By 2030, however, electrolysis becomes a cheaper option in several regions (British Columbia, Manitoba and Nova Scotia) where it wasn't cheaper in 2010. For reference, these costs are compared in the Summary and Interpretation section to the costs of gasoline contained within the Energy 2020 model.

Table 3 Reference Case Hydrogen Prices, 2010, 2020, 2030 by Region, 2000$/kg

Region	**SMR Reference Case 2010**	**SMR Reference Case 2020**	**SMR Reference Case 2030**	**Elec Reference Case 2010**	**Elec Reference Case 2020**	**Elec Reference Case 2030**
Ontario	6.22	6.53	6.88	7.07	7.34	7.86
Quebec	6.76	7.18	7.64	6.49	6.90	7.53
BC	6.56	6.86	7.20	6.97	6.91	6.94
Alberta	5.70	5.89	6.10	7.18	7.04	6.93
Manitoba	6.02	6.32	6.63	6.03	6.17	6.26
Saskatchewan	6.06	6.29	6.54	7.11	6.98	6.92
NB	6.74	7.12	7.53	6.58	6.64	6.80
Nova Scotia	6.81	7.18	7.57	7.28	7.15	7.22
Newfoundland	6.77	7.25	7.56	6.41	7.50	6.75
PEI	6.85	7.33	7.83	8.83	9.81	10.82
Yukon	6.56	7.02	7.50	11.21	12.65	14.11
NWT	7.32	7.89	8.50	17.21	19.64	22.13
Nunavut	7.19	7.77	8.37	17.09	19.52	22.01

Table 4 shows the amount of energy demand associated with hydrogen technologies in the two Reference Cases for 2010, 2020 and 2030. As the figures indicate, the amount of energy associated with hydrogen technologies increased in both Reference Cases between 2010 and 2030. This is caused by decreasing hydrogen and vehicle costs, increasing availability of the technologies and the time required for vehicle stock turnover. Energy demand associated with the SMR Reference Case is slightly higher than the Electrolyzer Reference Case due to the generally lower cost for hydrogen fuel. From a regional perspective, energy demand is highest in Ontario, Quebec, British Columbia and Alberta, where the cost of hydrogen fuel is the lowest. While it appears that Ontario experiences a higher level of penetration than other regions, hydrogen demand as a percent of total transportation energy demand in Ontario is comparable to other regions.

Table 4 Hydrogen-Related Energy Demand[10] in the Transportation Sector by Region and Scenario, PJ/yr

Region	**SMR Reference Case 2010**	**SMR Reference Case 2020**	**SMR Reference Case 2030**	**Elec Reference Case 2010**	**Elec Reference Case 2020**	**Elec Reference Case 2030**
Ontario	9.09	14.59	23.57	8.86	13.92	22.16
Quebec	4.84	8.11	13.29	4.97	8.39	13.78
BC	3.33	5.07	7.91	3.22	4.95	7.78
Alberta	2.88	5.34	9.27	2.72	4.86	8.27
Manitoba	0.96	1.44	2.25	0.99	1.48	2.30
Saskatchewan	1.47	2.20	3.44	1.45	2.12	3.26
NB	0.66	1.05	1.72	0.69	1.12	1.85
Nova Scotia	0.69	1.12	1.82	0.69	1.14	1.86
Newfoundland	0.29	0.46	0.72	0.31	0.46	0.70
PEI	0.13	0.19	0.30	0.12	0.17	0.24
Yukon	0.01	0.01	0.02	0.01	0.01	0.01
NWT	0.02	0.03	0.04	0.02	0.02	0.02
Nunavut	0.01	0.01	0.02	0.01	0.01	0.01
TOTAL	24.37	39.62	64.36	24.06	38.65	62.24

While the above table focuses on energy demand associated with hydrogen in the transportation sector on a regional basis, the table below presents energy demand for each of the relevant hydrogen technologies and their competing conventional technologies. The hydrogen ICE vehicles experience the greatest level of penetration, accounting for 35.22 PJ of energy demand in 2030 in the SMR Reference Case and 33.12 PJ of demand in the 2030 Electrolyzer Reference Case. This is due to the lower cost that is initially assumed for hydrogen ICEs compared with fuel cell vehicles. Energy demand associated with fuel cell vehicles is slightly less at 26.46 PJ and 26.21 PJ in 2030 for the SMR and Electrolyzer Reference Cases, respectively. Demand associated with fuel cell buses remains fairly constant over the study period because the price difference between diesel and hydrogen is greater than the price difference between gasoline and hydrogen. In other words, relative to gasoline-powered vehicles, there is less incentive for vehicles using diesel to switch to hydrogen.

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[10] This is the sum of energy demand associated with fuel cell buses, fuel cell light-duty vehicles and hydrogen internal combustion engine light-duty vehicles.

Table 5 Transportation Energy Demand in Canada by Select Mode, PJ/yr

MODE	SMR Reference Case 2010	SMR Reference Case 2020	SMR Reference Case 2030	Elec Reference Case 2010	Elec Reference Case 2020	Elec Reference Case 2030
Personal LDV	1,580.94	1,795.99	1,999.39	1,580.88	1,796.38	2,000.54
Fuel Cell LDV	9.07	16.11	26.46	8.89	15.90	26.21
Hydrogen ICE LDV	12.54	20.77	35.22	12.18	19.77	33.12
Transit Buses	14.71	16.72	18.61	14.71	16.72	18.62
Fuel Cell Buses	2.76	2.74	2.68	2.99	2.98	2.91

It is useful to consider the Reference Case results not only in terms of energy demand trends, but also according to the number of vehicles that penetrate the market. Table 6 shows the number of vehicles in 2010, 2020 and 2030 under each of the Reference Cases. As the figures indicate, in both of the Reference Cases, the number of hydrogen vehicles increased over time, with fuel cell light-duty vehicles accounting for a total of 82,688 vehicles in 2030 in the SMR Reference Case and 81,906 vehicles in 2030 in the Electrolyzer Reference Case.

Table 6 Number of Vehicles in Canada by Select Mode

MODE	SMR Reference Case 2010	SMR Reference Case 2020	SMR Reference Case 2030	Elec Reference Case 2010	Elec Reference Case 2020	Elec Reference Case 2030
Personal LDV	9,633,863	10,944,325	12,183,795	9,633,497	10,946,702	12,190,803
Fuel Cell LDV	28,344	50,344	82,688	27,781	49,688	81,906
Hydrogen ICE LDV	27,991	46,362	78,616	27,188	44,130	73,929
Transit Buses	3,226	3,667	4,081	3,226	3,667	4,083
Fuel Cell Buses	332	329	322	359	358	350

In addition to considering results in absolute terms, as is done in the table above, to get a better sense of the penetration of the hydrogen technologies, it is useful to consider the share of total demand attributable to particular transportation modes. Table 7 shows that for both Reference Cases there is a slight shift in demand from personal light-duty vehicles[11] to fuel cell vehicles and hydrogen ICE vehicles. The share of energy demand attributable to fuel cell vehicles and hydrogen ICE vehicles increases between 2010 and 2030 for both Reference Cases. The change in demand associated with fuel cell buses and conventional buses is less significant.

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[11] The Energy 2020 model includes light-duty fleet vehicles within the personal vehicles category.

Table 7 Percent of Transportation[12] Energy Demand in Canada for Select Modes[13]

MODE	SMR Reference Case 2010	SMR Reference Case 2020	SMR Reference Case 2030	Elec Reference Case 2010	Elec Reference Case 2020	Elec Reference Case 2030
Personal LDV	95.86%	95.27%	94.19%	95.88%	95.32%	94.47%
Fuel Cell LDV	0.55%	0.85%	1.33%	0.54%	0.84%	1.24%
Hydrogen ICE LDV	0.76%	1.10%	1.77%	0.74%	1.05%	1.56%
Transit Buses	0.89%	0.89%	0.88%	0.89%	0.89%	0.88%
Fuel Cell Buses	0.17%	0.15%	0.12%	0.18%	0.16%	0.14%

Stationary Fuel Cells

As was described in the Modelling Framework and Scenarios chapter of this report, stationary fuel cells were introduced to both the residential and commercial sectors. Table 8 presents energy demand associated with stationary fuel cells in the Reference Case[14] for the residential and commercial sectors combined by region. Total energy consumption associated with these technologies increased from 2.38 PJ in 2015 to 3.02 PJ in 2030. Alberta and Ontario realized the greatest penetration of stationary fuel cells. This is largely due to the relatively high electricity prices compared to natural gas in these regions compared to the rest of Canada. Penetration in eastern and northern regions is constrained by limited access to natural gas in those areas.

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[12] Energy consumption associated with transportation in the context does not include transportation demand from industrial or commercial activities.

[13] Percentages do not add to 100% because we have only included those modes of direct relevance to this study; for example, we did not present results for changes in marine and train.

[14] Recall that results only vary between the SMR Reference Case and the Electrolysis Reference Case for the transportation sector. The trend in stationary fuel cells is identical between the SMR and Electrolysis Reference Cases.

Table 8 Demand Associated with Stationary Fuel Cells in Canada, PJ/yr

REGION	2015	2020	2025	2030
Ontario	0.307	0.437	0.618	0.793
Quebec	0.000	0.000	0.000	0.000
BC	0.045	0.038	0.052	0.060
Alberta	1.984	1.535	1.966	2.114
Manitoba	0.000	0.001	0.001	0.001
Saskatchewan	0.041	0.032	0.042	0.047
NB	0.000	0.000	0.000	0.000
Nova Scotia	0.000	0.000	0.000	0.000
Newfoundland	0.000	0.000	0.000	0.000
PEI	0.000	0.000	0.000	0.000
Yukon	0.000	0.000	0.000	0.000
NWT	0.000	0.000	0.000	0.000
Nunavut	0.000	0.000	0.000	0.000
TOTAL	2.377	2.043	2.678	3.015

In addition to regional trends, it is useful to consider the trend in stationary fuel cell penetration by relevant sector. As Table 9 shows, energy demand associated with stationary fuel cells was higher for the residential sector than for the commercial sector. The higher level of penetration in the residential sector relative to the commercial sector is due to relatively lower electricity prices in the commercial sector, which make switching to stationary fuel cells less economical. Table 9 also demonstrates that the amount of penetration of the stationary fuel cells in the Reference Case is relatively small compared with total residential and commercial energy demand. The penetration is mainly limited by the high relative cost assumed for stationary fuel cells until 2030 compared with the cost of electricity. As a percent of total energy consumption in the residential and commercial sectors, energy demand associated with stationary fuel cells increased, although even in 2030 they still only account for a small portion of total energy consumption.

Table 9 Stationary Fuel Cells Energy Demand by Sector

REGION	2012	2014	2015	2016	2018	2020	2025	2030
Residential (PJ/yr)	1.03	2.20	2.14	2.05	1.89	1.80	2.34	2.61
Commercial (PJ/yr)	0.10	0.23	0.23	0.23	0.23	0.24	0.34	0.41
TOTAL (PJ/yr)	1.12	2.43	2.38	2.28	2.12	2.04	2.68	3.01
Res as a Share of Total Res Demand	0.07%	0.15%	0.14%	0.13%	0.12%	0.11%	0.15%	0.16%
Com as a Share of Total Com Demand	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.03%	0.03%

In the following tables we present regional results by sector. Table 10 shows the penetration of stationary fuel cells used by the residential sector for the Reference Case. The penetration of stationary fuel cells is driven by the price difference between electricity from the grid and the cost of the stationary fuel cells as well as the cost of natural gas. Thus, regions with the smallest difference between the price of electricity and the cost of the stationary fuel cells (i.e., regions with high electricity prices) and regions with relatively cheap natural gas will realize the greatest level of penetration. Stationary fuel cell penetration is highest in Alberta, the province with the lowest natural gas prices in Canada. Penetration is also realized in Ontario and Saskatchewan.

Table 10 Number of Stationary Fuel Cells in Canada, Residential

REGION	**2015**	**2020**	**2025**	**2030**
Ontario	648	908	1,236	1,594
Quebec	0	0	0	0
BC	99	121	156	195
Alberta	5,420	4,194	4,788	5,037
Manitoba	0	0	0	0
Saskatchewan	96	75	88	96
NB	0	0	0	0
Nova Scotia	0	0	0	0
Newfoundland	0	0	0	0
PEI	0	0	0	0
Yukon	0	0	0	0
NWT	0	0	0	0
Nunavut	0	0	0	0
TOTAL	6,265	5,298	6,268	6,922

Table 11 shows the same results for the commercial sector. In this case, the number of stationary fuel cells in use in the Reference Case is greatest in Ontario (a region with high electricity prices), with Alberta, British Columbia and Saskatchewan also realizing limited penetration.

Table 11 Number of Stationary Fuel Cells in Canada, Commercial

REGION	**2015**	**2020**	**2025**	**2030**
Ontario	5	7	10	13
Quebec	0	0	0	0
BC	1	0	1	1
Alberta	8	6	7	8
Manitoba	0	0	0	0
Saskatchewan	0	0	0	1
NB	0	0	0	0
Nova Scotia	0	0	0	0
Newfoundland	0	0	0	0
PEI	0	0	0	0
Yukon	0	0	0	0
NWT	0	0	0	0
Nunavut	0	0	0	0
TOTAL	14	13	18	22

Greenhouse Gas Emissions

This section presents the total greenhouse gas emissions for each category of interest in the Energy 2020 model for the two Reference Cases. The results of the Reference Cases will form the basis of comparison for the Fiscal Scenario results presented in the next section of this report. Table 12 shows greenhouse gas emissions for the transportation sector for the two Reference Cases including all vehicle types, not just hydrogen vehicles. This includes all light-duty vehicles and buses in Canada, but not medium or heavy-duty industrial or commercial vehicles including ships or planes. As expected, due to the relatively low penetration of hydrogen vehicles, the total sector emissions are very similar between the two Reference Cases. The slight difference in emissions between the two cases is largely due to the demand response to slightly different hydrogen prices (shown in Table 3 above) between the two hydrogen production methods as well as the difference in emissions associated with hydrogen production via SMR versus Electrolyzers.

Table 12 Transportation Sector[15] Greenhouse Gas Emissions, Megatonnes/yr

SECTOR	2010	2015	2020	2025	2030
SMR Reference Case	202.42	217.39	233.75	250.04	266.41
Electrolyzer Reference Case	204.13	219.18	235.85	252.44	269.11

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[15] Greenhouse Gas emissions associated with transportation in this context does not include transportation emissions from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

Table 13 shows a regional breakdown of greenhouse gas emissions associated with the transportation sector for both of the reference cases for 2010, 2020 and 2030.

Table 13 Transportation Sector[16] Greenhouse Gas Emissions, Megatonnes/yr

SECTOR	SMR Reference Case 2010	SMR Reference Case 2020	SMR Reference Case 2030	Elec Reference Case 2010	Elec Reference Case 2020	Elec Reference Case 2030
Ontario	64.58	75.67	87.85	65.22	76.45	88.87
Quebec	35.95	41.95	50.00	36.31	42.41	50.60
BC	29.12	33.25	37.60	29.35	33.52	37.93
Alberta	36.06	42.19	48.42	36.26	42.45	48.78
Manitoba	7.20	8.18	8.12	7.27	8.26	8.22
Saskatchewan	11.25	12.22	12.15	11.35	12.34	12.29
NB	5.74	6.46	7.32	5.78	6.51	7.37
Nova Scotia	6.46	7.32	8.10	6.49	7.37	8.17
Newfoundland	4.44	4.74	4.94	4.46	4.76	4.96
PEI	0.88	0.94	0.97	0.89	0.95	0.98
Yukon	0.19	0.21	0.24	0.19	0.21	0.24
NWT	0.40	0.44	0.49	0.40	0.44	0.49
Nunavut	0.16	0.18	0.21	0.16	0.18	0.21
TOTAL	202.42	233.75	266.41	204.13	235.85	269.11

Table 14 shows total greenhouse gas emissions for the sectors of relevance to stationary fuel cells. These are the sectors that experienced changes in greenhouse gas emissions as penetration of stationary fuel cells took place and include the residential, commercial and electric utility sectors.[17]

Table 14 Greenhouse Gas Emissions for Sectors Associated with Stationary Fuel Cells, Megatonnes/yr

SECTOR	2010	2015	2020	2025	2030
Residential	49.19	50.16	53.12	55.12	57.43
Commercial	60.01	61.29	62.10	63.21	64.24
Electric Utilities	130.73	141.25	140.23	147.64	152.38
TOTAL	239.93	252.69	255.45	265.98	274.05

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[16] Greenhouse Gas emissions associated with transportation in this context does not include transportation emissions from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

[17] As penetration of fuel cells increases, a shift in emissions from the electric utilities sector to the residential and commercial sectors occurs.

Table 15 shows the trend in emissions over time from a regional perspective. The emissions below are the sum of emissions associated with the residential, commercial and electric utilities sectors.

Table 15 Total Stationary Emissions (Residential, Commercial and Electric Utilities) by Region, Megatonnes/yr

SECTOR	2010	2015	2020	2025	2030
Ontario	82.86	88.46	86.99	88.78	89.62
Quebec	15.63	15.61	14.59	14.04	13.34
BC	14.54	15.32	17.33	18.75	20.36
Alberta	73.57	77.29	79.09	81.80	84.24
Manitoba	4.99	3.96	4.95	5.08	5.47
Saskatchewan	21.69	21.92	22.31	22.62	22.96
NB	11.56	15.02	14.58	15.95	16.79
Nova Scotia	8.47	8.52	9.06	9.29	9.65
Newfoundland	4.24	4.21	4.01	3.89	3.74
PEI	0.55	0.47	0.49	0.50	0.51
Yukon	0.35	0.37	0.39	0.41	0.43
NWT	1.19	1.26	1.34	1.42	1.50
Nunavut	0.30	0.28	0.31	0.34	0.37
TOTAL	239.93	252.69	255.45	262.87	269.00

The table below shows the sum of greenhouse gas emissions associated with the residential, commercial, electric utilities and transportation sectors in Canada by region for 2010, 2020 and 2030. The table differentiates between the SMR and Electrolyzer cases because of the difference in emissions between these two scenarios for the transportation sector.

Table 16 Total Greenhouse Gas Emissions by Region, Residential, Commercial, Electric Utilities and Transportation Combined, Megatonnes/yr

REGION	SMR Reference Case 2010	SMR Reference Case 2020	SMR Reference Case 2030	Elec Reference Case 2010	Elec Reference Case 2020	Elec Reference Case 2030
Ontario	147.43	162.66	167.72	148.07	163.44	173.49
Quebec	51.58	56.55	60.11	51.94	57.01	63.49
BC	43.67	50.58	57.43	43.90	50.82	58.71
Alberta	109.63	121.28	128.88	109.83	121.54	130.87
Manitoba	12.19	13.13	14.89	12.26	13.21	14.83
Saskatchewan	32.93	34.53	35.08	33.04	34.65	35.29
NB	17.29	21.04	20.72	17.33	21.08	21.22
Nova Scotia	14.93	16.38	17.93	14.97	16.43	18.22
Newfoundland	8.68	8.75	8.45	8.70	8.77	8.64
PEI	1.44	1.43	1.48	1.44	1.44	1.50
Yukon	0.52	0.60	0.66	0.54	0.60	0.67
NWT	1.58	1.79	1.98	1.58	1.79	1.98
Nunavut	0.46	0.50	0.57	0.46	0.50	0.57
TOTAL	422.34	489.20	540.46	444.05	491.30	538.10

Fiscal Policy Evaluation

This chapter describes the impact of the fiscal policies. The results associated with the fiscal policies, referred to below as the Fiscal Scenario, include both the *producer tax credit* and *the consumer incentives*. For each relevant category of output (transportation, stationary and greenhouse gas emissions), Reference Case results as well as the results associated with the Fiscal Scenario are presented. In the case of the transportation sector, where the two hydrogen production methods lead to different outputs, results are presented for the SMR and Electrolyzer Reference Cases as well as the SMR and Electrolyzer Fiscal Scenarios. Results are also presented for costs in terms of the cost per tonne of greenhouse gas emissions reduced. The results focus on the impact of the Fiscal Scenario in the year 2030.

Transportation

It is useful to begin by considering the impact of the producer tax credit on the price of hydrogen for both hydrogen production methods by region. Table 17 compares hydrogen prices in 2030 for the Reference Cases with the Fiscal Scenario for each region. Since the producer tax credit is simulated as a percent reduction in the price of hydrogen, those regions with relatively higher hydrogen prices in the Reference Case realize a greater absolute reduction in the price of hydrogen. It is worth noting that hydrogen production from electrolysis is cheaper in Quebec and Manitoba, regions that rely heavily on hydropower for electricity generation. Ninety-seven percent of electricity in Quebec is from hydro and 99% of electricity in Manitoba is from hydro.[18]

Table 17 Hydrogen Prices by Region for 2030[19], 2000$/kg

REGION	SMR Reference Case	SMR Fiscal Scenario	Change from Reference	Elec Reference Case	Elec Fiscal Scenario	Change from Reference
Ontario	6.88	5.39	1.49	7.86	5.94	1.91
Quebec	7.64	6.01	1.63	7.53	5.80	1.73
British Columbia	7.20	5.69	1.50	6.94	5.45	1.49
Alberta	6.10	4.78	1.32	6.93	5.39	1.54
Manitoba	6.63	5.22	1.41	6.26	5.03	1.23
Saskatchewan	6.54	5.17	1.38	6.92	5.44	1.48
New Brunswick	7.53	5.94	1.59	6.80	5.43	1.37
Nova Scotia	7.57	5.95	1.62	7.22	5.50	1.72
Newfoundland	7.56	6.12	1.44	6.75	6.77	-0.02
PEI	7.83	6.12	1.71	10.82	8.36	2.46
Yukon Territory	7.50	5.80	1.70	14.11	10.76	3.35
NWT	8.50	6.57	1.93	22.13	16.76	5.36
Nunavut	8.37	6.45	1.92	22.01	16.64	5.36

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[18] https://www.davidsuzuki.org/files/WOL/ElectricityMap.pdf

[19] Note that the drop in hydrogen price shown in the table above is slightly less than 25% because the reduction in cost took place before taxes.

The decline in the price of hydrogen leads to a decline in energy demand from the transportation sector for all regions as the penetration of fuel cells increases and efficiency gains are realized. Nationally, the Fiscal Scenario leads to a decline in total transportation demand of 0.29% in the case of the SMR hydrogen production and 0.33% in the case of electrolyzer hydrogen production (Table 18).

Table 18 Transportation Demand[20] by Region, 2030

REGION	SMR Reference Case (PJ/yr)	SMR Fiscal Scenario (PJ/yr)	Change from Reference Case	Elec Reference Case (PJ/yr)	Elec Fiscal Scenario (PJ/yr)	Change from Reference Case
Ontario	761.76	759.69	-0.27%	761.54	759.11	-0.32%
Quebec	385.93	384.94	-0.26%	386.41	385.60	-0.21%
British Columbia	257.52	256.77	-0.29%	257.57	256.79	-0.30%
Alberta	349.34	347.97	-0.39%	349.00	347.37	-0.47%
Manitoba	83.89	83.56	-0.39%	83.98	83.68	-0.36%
Saskatchewan	126.46	125.98	-0.38%	126.52	126.02	-0.40%
New Brunswick	58.16	58.08	-0.13%	57.92	57.70	-0.39%
Nova Scotia	58.65	58.57	-0.13%	58.45	58.25	-0.33%
Newfoundland	23.42	23.38	-0.18%	23.33	23.23	-0.43%
PEI	10.09	10.06	-0.26%	10.05	9.99	-0.56%
Yukon Territory	0.74	0.74	0.09%	0.73	0.73	-0.66%
NWT	1.65	1.64	-0.19%	1.64	1.62	-0.84%
Nunavut	0.62	0.62	0.06%	0.61	0.61	-0.75%
TOTAL	2,118.21	2,112.00	-0.29%	2,117.75	2,110.70	-0.33%

While energy demand in the transportation sector declined as a result of the penetration of the hydrogen-related vehicles and associated efficiency gains, energy demand associated with hydrogen itself increased. Table 19 describes hydrogen-related energy demand for the Reference Cases and the Fiscal Scenario for 2030. For each region, hydrogen-related energy demand is higher for the relatively cheaper hydrogen production method. For example, in Quebec hydrogen from electrolysis is cheaper than hydrogen from SMR. Thus, the hydrogen-related energy demand associated with the electrolyzers (versus the SMR) is higher for both the Reference Case and the Fiscal Scenario in Quebec. On a national scale, energy demand associated with hydrogen-related vehicles increased significantly, by almost 50% in both the SMR and Electrolyzer cases. Regionally, the increase in demand associated with hydrogen was fairly uniform, with Alberta seeing a slightly higher increase than the other regions.

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[20] Energy consumption associated with transportation in this context does not include transportation demand from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

Table 19 Hydrogen-Related Energy Demand[21] in the Transportation Sector by Region, 2030

REGION	SMR Reference Case (PJ/yr)	SMR Fiscal Scenario (PJ/yr)	Change from Reference Case	Elec Reference Case (PJ/yr)	Elec Fiscal Scenario (PJ/yr)	Change from Reference Case
Ontario	23.57	34.87	47.96%	22.16	32.96	48.75%
Quebec	13.29	19.62	47.64%	13.78	20.29	47.18%
British Columbia	7.91	11.71	48.06%	7.78	11.54	48.31%
Alberta	9.27	14.32	54.48%	8.27	12.88	55.80%
Manitoba	2.25	3.41	51.80%	2.30	3.49	51.55%
Saskatchewan	3.44	5.30	54.06%	3.26	5.04	54.59%
New Brunswick	1.72	2.61	51.87%	1.85	2.78	50.55%
Nova Scotia	1.82	2.74	50.85%	1.86	2.78	49.72%
Newfoundland	0.72	1.09	51.19%	0.70	1.05	50.59%
PEI	0.30	0.45	53.13%	0.24	0.36	48.76%
Yukon Territory	0.02	0.03	51.34%	0.01	0.02	92.44%
NWT	0.04	0.07	53.99%	0.02	0.04	57.88%
Nunavut	0.02	0.03	46.04%	0.01	0.02	52.39%
TOTAL	64.36	96.26	49.56%	62.24	93.25	49.81%

It is useful to look at the change in key modes of transportation for a more detailed picture of the impact of the Fiscal Scenario on particular hydrogen technologies. The table below shows energy demand associated with key modes of transport for Canada as a whole for the Reference Cases and the Fiscal Scenario. The figures demonstrate that the Fiscal Scenario leads to a reduction in demand for non-hydrogen personal automobiles and transit buses and an increase in demand for fuel cell buses, fuel cell light-duty cars and hydrogen internal combustion engine vehicles. While energy demand associated with the hydrogen vehicles is not significant in absolute terms, the increase in demand on a percentage basis relative to the Reference Cases is substantial.

Table 20 Transportation Energy Demand in Canada by Select Mode, 2030

MODE	SMR Reference Case (PJ/yr)	SMR Fiscal Scenario (PJ/yr)	Change from Reference Case	Elec Reference Case (PJ/yr)	Elec Fiscal Scenario (PJ/yr)	Change from Reference Case
Personal LDV	1,999.39	1,962.39	-1.85%	2,000.54	1,963.51	-1.85%
Fuel Cell LDV	26.46	41.60	57.23%	26.21	41.19	57.16%
Hydrogen ICE LDV	35.22	50.17	42.46%	33.12	47.20	42.51%
Transit Buses	18.61	18.26	-1.88%	18.62	18.27	-1.88%
Fuel Cell Buses	2.68	4.49	67.12%	2.91	4.86	66.72%

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[21] This is the sum of energy demand associated with fuel cell buses, fuel cell light-duty vehicles and hydrogen internal combustion engine light-duty vehicles.

The table below presents the share of transportation energy demand attributable to hydrogen-related vehicles (the sum of demand associated with fuel cell vehicles, hydrogen ICE vehicles and fuel cell buses) for each of the Reference Cases and the Fiscal Scenario. The figures show an increase in the share of total transportation energy demand associated with hydrogen-related vehicles and a decline in the share of energy demand associated with conventional cars and buses.

Table 21 Share of Transportation Energy Demand[22] by Mode,[23] 2030

MODE	SMR Reference Case	SMR Fiscal Scenario	Change from Reference Case	Elec Reference Case	Elec Fiscal Scenario	Change from Reference Case
Personal LDV	94.19%	92.60%	-1.69%	94.465%	93.03%	-1.52%
Fuel Cell LDV	1.33%	2.11%	58.67%	1.238%	1.95%	57.68%
Hydrogen ICE LDV	1.77%	2.54%	43.29%	1.564%	2.24%	42.98%
Transit Buses	0.88%	0.86%	-1.72%	0.879%	0.87%	-1.55%
Fuel Cell Buses	0.12%	0.21%	70.55%	0.138%	0.23%	67.28%

Because fuel cell vehicles are more efficient than conventional vehicles, a fuel cell vehicle will travel further than a conventional vehicle given the same amount of energy consumption. For this reason, it is necessary to consider not only the amount of energy demand associated with hydrogen vehicles, as is shown in Table 21 above, but also the change in the physical stock of fuel cell vehicles as a result of the Fiscal Scenario. Table 22 shows the number of vehicles for key modes for Canada for 2030. The table demonstrates the increase in hydrogen-related vehicles between the Reference Case and the Fiscal Scenario. For example, the number of fuel cell light-duty vehicles increased by 47,312 between the Reference Case and the Fiscal Scenario for SMR hydrogen production. The increase in fuel cell light-duty vehicles was slightly less for electrolyzer hydrogen production. The number of fuel cell buses and hydrogen internal combustion engine LDVs also increased as a result of the Fiscal Scenario. It is worth noting that the overall number of light-duty vehicles decreased between the Reference Case and the Fiscal Scenario. The decline in the number of light-duty vehicles is largely the result of limited funds for investing in personal vehicles. In other words, the residential and commercial sectors have limited money available to invest in vehicles. When they invest in a more expensive vehicle (for example, a hydrogen fuel cell vehicle), total investment in second cars declines.

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[22] Energy consumption associated with transportation in this context does not include transportation demand from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

[23] Percentages do not add to 100% because we have only included those modes of direct relevance to this study; for example, we did not present results for changes in marine and train.

Table 22 Number of Vehicles in Canada by Select Mode, 2030

MODE	SMR Reference Case	SMR Fiscal Scenario	Change from Reference Case	Elec Reference Case	Elec Fiscal Scenario	Change from Reference Case
Personal LDV	12,183,795	11,958,326	-225,469	12,190,803	11,965,151	-225,652
Fuel Cell LDV	82,688	130,000	47,312	81,906	128,719	46,813
Hydrogen ICE LDV	78,616	111,987	33,371	73,929	105,357	31,428
Transit Buses	4,081	4,004	-77	4,083	4,007	-76
Fuel Cell Buses	322	540	218	350	584	234

Stationary Fuel Cells

The tables in this section describe the impact of the Fiscal Scenario on stationary fuel cells introduced in the residential and commercial sectors. Table 23 shows the change in demand associated with stationary fuel cells by region for the Reference Case and the Fiscal Scenario. The lack of penetration in several regions is due to limited availability of natural gas. Other regions realized significant penetration of stationary fuel cells on a percentage increase basis, even while the total energy associated with stationary fuel cells in absolute terms remains fairly low.

Table 23 Demand Associated with Stationary Fuel Cells in Canada, 2030

REGION	Reference Case (PJ/yr)	Fiscal Scenario (PJ/yr)	Change from Reference Case
Ontario	0.793	3.714	368%
Quebec	0.000	0.000	NA
British Columbia	0.060	0.359	500%
Alberta	2.114	12.814	506%
Manitoba	0.001	0.005	499%
Saskatchewan	0.047	0.361	675%
New Brunswick	0.000	0.000	NA
Nova Scotia	0.000	0.000	NA
Newfoundland	0.000	0.000	NA
PEI	0.000	0.000	NA
Yukon Territory	0.000	0.000	NA
NWT	0.000	0.000	NA
Nunavut	0.000	0.000	NA
TOTAL	3.015	17.254	472%

Table 24 shows the penetration of the stationary fuel cells on a sectoral basis rather than a regional basis. The table shows energy demand associated with stationary fuel cells in the Reference Case and the Fiscal Scenario as well as the change in demand between the two. Both the residential and the commercial sectors saw a fairly significant increase in energy demand associated with the fuel cells. As a percent of total sectoral energy demand, the demand associated with stationary fuel cells also increased for both the residential and the commercial sectors.

Table 24 Demand Associated with Stationary Fuel Cells by Sector, 2030

REGION	**Reference Case (PJ/yr)**	**Fiscal Scenario (PJ/yr)**	**Change from Reference Case**
Residential (PJ/yr)	2.61	14.45	454%
Commercial (PJ/yr)	0.41	2.81	592%
TOTAL (PJ/yr)	3.01	17.25	472%
Res as a Share of Total Res Demand	0.16%	0.87%	450%
Com as a Share of Total Com Demand	0.03%	0.21%	591%

As was done for the transportation sector results, it is useful to consider the number of stationary fuel cells that penetrate the market as a result of the Fiscal Scenario. To that end, Table 25 shows the number of stationary fuel cells in 2030 for both the Reference Case and the Fiscal Scenario for the residential sector. These figures indicate that the Fiscal Scenario was effective at increasing the penetration of stationary fuel cells in the residential sector. The total number of stationary fuel cells in use in Canada increased by 15,770 as a result of the Fiscal Scenario. Alberta realizes the greatest increase in the number of stationary fuel cells with increases taking place in Ontario, British Columbia and Saskatchewan as well.

Table 25 Number of Stationary Fuel Cells in 2030, Residential Sector

REGION	**Reference Case**	**Fiscal Scenario**	**Change from Reference Case**
Ontario	1,594	6,242	4,648
Quebec	0	0	0
British Columbia	195	415	221
Alberta	5,037	15,579	10,542
Manitoba	0	0	0
Saskatchewan	96	456	360
New Brunswick	0	0	0
Nova Scotia	0	0	0
Newfoundland	0	0	0
PEI	0	0	0
Yukon Territory	0	0	0
NWT	0	0	0
Nunavut	0	0	0
TOTAL	6,922	22,692	15,770

Table 26 shows the number of stationary fuel cells in use in 2030 for the commercial sector under both the Reference Case and the Fiscal Scenario. As was the case with the residential sector, here the Fiscal Scenario results in an increase in the number of fuel cells. The number of fuel cells in use in the commercial sector increased by 90 units as a result of the Fiscal Scenario. On a regional basis, increases were realized in Ontario, British Columbia, Alberta and Saskatchewan.

Table 26 Number of Stationary Fuel Cells in 2030, Commercial Sector

REGION	Reference Case	Fiscal Scenario	Change from Reference Case
Ontario	13	60	46
Quebec	0	0	0
British Columbia	1	3	2
Alberta	8	47	39
Manitoba	0	0	0
Saskatchewan	1	3	2
New Brunswick	0	0	0
Nova Scotia	0	0	0
Newfoundland	0	0	0
PEI	0	0	0
Yukon Territory	0	0	0
NWT	0	0	0
Nunavut	0	0	0
TOTAL	22	112	90

Greenhouse Gas Emissions

Table 27 shows emissions associated with all light-duty vehicles and buses within the transportation sector for both the Reference Cases and the Fiscal Scenario for the year 2030. Note that the figures encompass both emissions associated with hydrogen production and emissions associated with hydrogen consumption. The results indicate a decrease in emissions in the case of hydrogen production from SMR and an increase in emissions in the case of hydrogen production using electrolysis. The increase is due to the fact that new electricity to power the electrolyzers is generally assumed to be coming from combined-cycle natural gas units in the Energy 2020 model.[24]

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[24] The increase in emissions in the case of hydrogen from electrolyzers is consistent with work completed in the United States. See for example, the May 2004 issue of *Scientific American*, which contains an article titled “Questions about a Hydrogen Economy.”

Table 27 Transportation[25] Greenhouse Gas Emissions, 2030

SECTOR	Reference Case (MT/yr)	Fiscal Scenario (MT/yr)	Change from Reference Case
SMR	266.41	265.17	-0.465%
Electrolyzer	269.11	269.34	0.085%

Table 28 shows the change in transportation-related emissions as a result of the Fiscal Scenario by region for 2030. Again, the emissions figures include both hydrogen production and consumption emissions. Generally speaking, each province also shows a similar decrease in emissions for the SMR case, and a similar increase in emissions for the electrolysis case. The increase in emissions in the electrolyzer case is the result of assumptions inherent in the model. More specifically, as was described above, marginal electricity used to produce hydrogen in the electrolyzer case is assumed to be from natural gas. The use of natural gas to produce electricity leads to an increase in total emissions when emissions associated with both the production and consumption of hydrogen are taken into account. The one exception to this trend is Alberta, where emission reductions are achieved even in the electrolyzer case. This is the result of reductions in emissions that are achieved when electricity at the margin comes from natural gas rather than coal, the source fuel for the majority of existing electricity demand in the province.

Table 28 Transportation[26] Greenhouse Gas Emissions by Region, 2030

SECTOR	SMR Reference Case (MT/yr)	SMR Fiscal Scenario (MT/yr)	Change from Reference Case	Elec Reference Case (MT/yr)	Elec Fiscal Scenario (MT/yr)	Change from Reference Case
Ontario	87.85	87.43	-0.48%	88.87	88.97	0.11%
Quebec	50.00	49.75	-0.50%	50.60	50.67	0.14%
BC	37.60	37.47	-0.35%	37.93	37.98	0.13%
Alberta	48.42	48.18	-0.50%	48.78	48.75	-0.06%
Manitoba	8.12	8.08	-0.49%	8.22	8.23	0.12%
Saskatchewan	12.15	12.08	-0.58%	12.29	12.30	0.08%
NB	7.32	7.29	-0.41%	7.37	7.38	0.14%
Nova Scotia	8.10	8.07	-0.37%	8.17	8.18	0.12%
Newfoundland	4.94	4.92	-0.40%	4.96	4.96	0.00%
PEI	0.97	0.96	-1.03%	0.98	0.98	0.00%
Yukon	0.24	0.24	0.00%	0.24	0.24	0.00%
NWT	0.49	0.49	0.00%	0.49	0.49	0.00%
Nunavut	0.21	0.21	0.00%	0.21	0.21	0.00%
TOTAL	266.41	265.17	-0.47%	269.11	269.34	0.09%

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[25] Greenhouse Gas emissions associated with transportation in this context does not include transportation emissions from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

[26] Greenhouse Gas emissions associated with transportation in this context does not include transportation emissions from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

Table 29 shows just those emissions associated with the use of the hydrogen vehicles (as opposed to including the emissions associated with the production of hydrogen as well). As expected, consumption emissions decline as a result of the Fiscal Scenario for both the electrolyzer and the SMR case. The results presented in Table 29 represent those that would be realized if the hydrogen was produced from a source that was not associated with greenhouse gas emissions such as wind or nuclear power.

Table 29 Transportation[27] Greenhouse Gas Emissions by Region (Consumption Only), 2030

SECTOR	SMR Reference Case (MT/yr)	SMR Fiscal Scenario (MT/yr)	Change from Reference Case	Elec Reference Case (MT/yr)	Elec Fiscal Scenario (MT/yr)	Change from Reference Case
Ontario	86.89	85.95	-1.08%	86.94	86.00	-1.08%
Quebec	49.46	48.93	-1.07%	49.45	48.91	-1.09%
BC	37.28	36.97	-0.83%	37.28	36.98	-0.80%
Alberta	48.08	47.63	-0.94%	48.10	47.66	-0.91%
Manitoba	8.04	7.95	-1.12%	8.04	7.95	-1.12%
Saskatchewan	12.03	11.88	-1.25%	12.03	11.89	-1.16%
NB	7.25	7.18	-0.97%	7.22	7.14	-1.11%
Nova Scotia	8.04	7.97	-0.87%	8.02	7.94	-1.00%
Newfoundland	4.91	4.88	-0.61%	4.90	4.87	-0.61%
PEI	0.96	0.95	-1.04%	0.96	0.95	-1.04%
Yukon	0.24	0.24	0.00%	0.24	0.23	-4.17%
NWT	0.49	0.49	0.00%	0.49	0.49	0.00%
Nunavut	0.21	0.21	0.00%	0.21	0.21	0.00%
TOTAL	263.86	261.21	-1.00%	263.88	261.22	-1.01%

Table 30 shows the impact of the Fiscal Scenario on emissions associated with the residential, commercial and electric utility sectors. These are the sectors that experience changes in emissions as a result of an increase in penetration of stationary fuel cells. The increase in emissions associated with the residential sector is offset by reduced emissions in the electric utilities sector as fuel cells are used to generate power in houses and less energy is demanded from the electrical grid. The decrease in emissions in the case of the commercial sector is due to movements away from oil and LPG as the use of stationary fuel cells increases.

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[27] Greenhouse Gas emissions associated with transportation in this context does not include transportation emissions from industrial or commercial activities with the exception of light-duty fleet vehicles and buses.

Table 30 Greenhouse Gas Emissions for Sectors Associated with Stationary Fuel Cells, 2030

SECTOR	**Reference Case (MT/yr)**	**Fiscal Scenario (MT/yr)**	**Change from Reference Case**
Residential	57.43	57.54	0.19%
Commercial	64.24	64.22	-0.03%
Electric Utilities	152.38	151.58	-0.53%
TOTAL	274.05	273.34	-0.26%

Table 31 shows greenhouse gas emissions for the residential, commercial and electric utility sectors combined by region. The increase in emissions in Alberta is explained by the fact that as the residential and commercial sectors install and employ stationary fuel cells, less electricity is demanded from the local grid. This allows electricity generators to export more power to BC, and therefore electricity demand does not decrease in the province. The emissions associated with the demand being exported to BC are linked to Alberta rather than BC. This also helps explain the decline in emissions in BC. Specifically, the decline in BC is due to the combined effect of (1) the increased penetration of stationary fuel cells in the province displaces some utility electricity generation, and (2) the fact that more energy is being imported from Alberta as opposed to being generated locally.

Table 31 Total Stationary Greenhouse Gas Emissions (Residential, Commercial and Electric Utilities) by Region, Megatonnes/yr, 2030

SECTOR	**Reference Case (MT/yr)**	**Fiscal Scenario (MT/yr)**	**Change from Reference Case**
Ontario	92.78	92.61	-0.18%
Quebec	13.80	13.80	0.00%
BC	19.77	19.20	-2.88%
Alberta	85.07	85.28	0.25%
Manitoba	4.47	4.47	0.00%
Saskatchewan	22.88	22.84	-0.17%
NB	18.54	18.54	0.00%
Nova Scotia	9.43	9.43	0.00%
Newfoundland	3.82	3.82	0.00%
PEI	0.43	0.43	0.00%
Yukon	0.43	0.43	0.00%
NWT	1.50	1.50	0.00%
Nunavut	0.32	0.32	0.00%
TOTAL	274.05	273.35	-0.26%

Table 32 shows greenhouse gas emissions for each region for the residential, commercial, electric utilities and transportation sectors combined. The figures in the table demonstrate the reduction in total emissions in the case of SMR hydrogen production. In the case of electrolyzer hydrogen production, emission reductions are not achieved because of increases in emissions associated with hydrogen production. If we were to account only for the emissions associated with hydrogen consumption (i.e., if we were to assume the hydrogen is produced from a zero-emissions source such as wind power or nuclear energy), we would see a reduction in total emissions for both the SMR and electrolyzer cases. Note that in Alberta, even in the electrolyzer case total emissions decline. This is the result of emission reductions achieved in the transportation sector that outweigh the increase in emissions associated with the residential and commercial sectors.

Table 32 Total Greenhouse Gas Emissions by Region, Residential, Commercial, Electric Utilities and Transportation[28] Combined, Megatonnes/yr, 2030

REGION	SMR Reference Case (MT/yr)	SMR Fiscal Scenario (MT/yr)	Change from Reference Case	Elec Reference Case (MT/yr)	Elec Fiscal Scenario (MT/yr)	Change from Reference Case
Ontario	171.88	171.42	-0.27%	172.9	172.97	0.04%
Quebec	62.55	62.3	-0.40%	63.15	63.22	0.11%
BC	58.95	58.73	-0.37%	59.29	59.25	-0.07%
Alberta	131.09	130.93	-0.12%	131.46	131.5	0.03%
Manitoba	15.07	15.03	-0.27%	15.17	15.18	0.07%
Saskatchewan	35.25	35.31	0.17%	35.39	35.53	0.40%
NB	21	20.97	-0.14%	21.06	21.07	0.05%
Nova Scotia	18.22	18.2	-0.11%	18.29	18.3	0.05%
Newfoundland	8.54	8.53	-0.12%	8.56	8.56	0.00%
PEI	1.5	1.49	-0.67%	1.51	1.51	0.00%
Yukon	0.67	0.67	0.00%	0.67	0.67	0.00%
NWT	2	2	0.00%	2	2	0.00%
Nunavut	0.58	0.58	0.00%	0.58	0.58	0.00%
TOTAL	527.31	526.16	-0.22%	530.01	530.34	0.06%

In addition to examining trends in greenhouse gas emissions, it is helpful to consider the impact of hydrogen penetration on criteria air contaminants. Generally speaking, life-cycle criteria air contaminant emissions will decrease as much if not more than greenhouse gas emissions when comparing hydrogen vehicles to gasoline vehicles. Compared to diesel vehicles, these pollutants will be decreased significantly more than the associated decrease in greenhouse gas emissions.[29] It is expected that the life-cycle criteria air contaminant emissions from a stationary fuel cell (fuelled by

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[28] Transportation emissions in this table include both emissions associated with hydrogen production and emissions associated with hydrogen consumption.

[29] Row, J., et. al. June 2002. *Life-Cycle Value Assessment of Fuel Supply Options for Fuel Cell Vehicles in Canada.* Pembina Institute.

natural gas) will be no worse than those from a combined-cycle natural gas power plant and separate natural gas furnace or boiler, and may even be better due to the higher system efficiency and lack of emission controls on small heating units.

Emission Reduction Costs

In this section we present emission reduction cost results for the transportation, residential, commercial and utility sectors. The cost results are presented as dollars per tonne of greenhouse gas emissions reduced. The figures presented below represent the costs to producers and consumers who invest and operate hydrogen technologies as a result of the introduction of the fiscal incentives. They do not include costs associated with those who purchase fuel cell technologies in the absence of fiscal policy stimulus (i.e., they do not account for costs associated with hydrogen technology penetration realized in the Reference Cases). In other words, the costs reflect the capital, operating and maintenance, and fuel costs for producers and consumers that purchase fuel cell technologies *after* the fiscal incentives are in place net of government subsidies.

For the transportation sector, we focus results on the two regions that realized the greatest penetration of hydrogen-related technologies, Alberta and Ontario. Results for other regions followed similar trends to Alberta and Ontario. Table 33 shows cost figures for emission reductions taking place in the transportation sector for the province of Alberta for SMR hydrogen. The "Consumption" figures indicate the cost per tonne of greenhouse gas emissions reduced, taking into account only those emissions associated with driving the hydrogen-related vehicles. The "Total" figure shows the cost per tonne of reduction, taking into account emissions associated with the use of the vehicles, and also the production of hydrogen. The "consumption" figures represent the cost per tonne reduction for hydrogen from a zero emission source such as wind or nuclear power.

The figures presented below indicate that the emission reductions achieved as a result of the penetration of the hydrogen technologies come at fairly high costs. This is due to the combined impact of the high costs associated with producing hydrogen and purchasing hydrogen technologies and the limited emission reductions achieved with limited penetration of hydrogen technologies in absolute terms.

The results in Table 33 indicate that emission reductions come at the least cost for the fuel cell buses. Cost results for the fuel cell light-duty vehicle and the hydrogen internal combustion engine light-duty vehicle are similar. The NAs in the table below indicate instances where the greenhouse gas emissions associated with the production of hydrogen lead to an increase in the total emissions. In other words, in the case of the hydrogen internal combustion engine, the gains in efficiency associated with the vehicle relative to a conventional car are not great enough to offset the emissions associated with the production of hydrogen using SMR. In such cases, it is impossible to calculate cost per tonne reduction (as such reductions do not actually occur).

Table 33 Cost per Tonne of Greenhouse Gas Emissions Reduced, Transportation Sector, SMR Case, Alberta, 2000$

SECTOR	2010	2015	2020	2025	2030
Fuel Cell Bus, Consumption	849.06	995.97	965.54	937.08	906.70
Fuel Cell Bus, Total	926.79	1,086.75	1,053.14	1,021.64	988.06
Fuel Cell Car, Consumption	1,134.83	1,387.76	1,406.78	1,428.15	1,447.43
Fuel Cell Car, Total	5,089.90	6,139.12	6,138.14	6,134.62	6,129.95
Hydrogen ICE, Consumption	1,321.37	1,197.65	1,464.58	1,730.55	1,998.00
Hydrogen ICE, Total	NA	NA	NA	NA	NA

Table 34 shows the same information as above for hydrogen production from electrolyzers (rather than SMR). The results here follow a similar trend to those above, yet in the case of the fuel cell car, when accounting for emissions associated with hydrogen production, a cost per tonne could not be established. As was stated above, this is due to the fact that once emissions associated with hydrogen production were taken into account, an increase in greenhouse gas emissions actually occurred. This is due to the fact that the electricity used to produce the hydrogen is generally assumed to come from natural gas in the Energy 2020 model.

Table 34 Cost per Tonne of Greenhouse Gas Emissions Reduced, Transportation Sector, Electrolyzer Case, Alberta, 2000$

SECTOR	2010	2015	2020	2025	2030
Fuel Cell Bus, Consumption	857.74	1,005.14	974.59	946.34	916.05
Fuel Cell Bus, Total	1,033.29	1,211.16	1,175.23	1,141.55	1,105.62
Fuel Cell Car, Consumption	1,215.27	1,472.74	1,490.67	1,513.96	1,534.07
Fuel Cell Car, Total	NA	NA	NA	NA	NA
Hydrogen ICE, Consumption	1,446.92	1,329.29	1,595.27	1,864.91	2,134.33
Hydrogen ICE, Total	NA	NA	NA	NA	NA

In addition to presenting results for Alberta, Tables 35 and 36 show the cost per tonne of greenhouse gas emissions reduced for Ontario for the SMR case and the electrolyzer case respectively. The cost results for Ontario follow the same trend as Alberta, although emission reductions in Ontario are achieved at slightly less cost.

Table 35 Cost per Tonne of Greenhouse Gas Emissions Reduced, Transportation Sector, SMR Case, Ontario, 2000$

SECTOR	2010	2015	2020	2025	2030
Fuel Cell Bus, Consumption	706.11	832.58	815.56	800.12	783.14
Fuel Cell Bus, Total	774.20	912.42	893.21	875.70	856.52
Fuel Cell Car, Consumption	830.33	1,040.47	1,048.61	1,058.77	1,066.98
Fuel Cell Car, Total	3,768.17	4,640.56	4,577.90	4,515.19	4,451.34
Hydrogen ICE, Consumption	1,037.55	927.92	1,162.84	1,396.76	1,631.90
Hydrogen ICE, Total	NA	NA	NA	NA	NA

Table 36 Cost per Tonne of Greenhouse Gas Emissions Reduced, Transportation Sector, Electrolyzer Case, Ontario, 2000$

SECTOR	2010	2015	2020	2025	2030
Fuel Cell Bus, Consumption	711.42	837.92	822.35	808.21	792.65
Fuel Cell Bus, Total	868.28	1,022.55	1,001.61	982.46	961.53
Fuel Cell Car, Consumption	877.39	1,087.82	1,108.80	1,130.46	1,151.33
Fuel Cell Car, Total	NA	NA	NA	NA	NA
Hydrogen ICE, Consumption	1,110.99	1,001.71	1,256.64	1,508.50	1,763.35
Hydrogen ICE, Total	NA	NA	NA	NA	NA

Finally, Table 37 presents cost results for the stationary fuel cells. The table below shows only those regions for which penetration of stationary fuel cells occurred. Nationally, emission reductions associated with stationary fuel cells came at a much lower cost than those associated with the transportation sector. However, the national cost figure masks significant variations in costs between provinces. For example, in Alberta, it was not possible to calculate the cost per tonne of greenhouse gas emissions reduced as total emissions associated with the residential, commercial and electric utility sectors actually increased. For British Columbia, the cost of greenhouse gas emission reductions is partly driven by the decline in the deregulated Alberta price of electricity (as the penetration of stationary fuel cells took place in Alberta and less electricity was demanded from the grid, the price of electricity declined). The drop in electricity prices in Alberta led to electricity imports into BC, which resulted in additional reductions in emissions in that province (the emissions associated with the imported electricity are associated with Alberta rather than BC). These emission reductions are achieved at relatively low costs, which results in low costs per tonne of emissions reduced. In Ontario and Saskatchewan, the increase in stationary fuel cells means that some of the more expensive (less economically efficient fossil fuel based) plants no longer need to operate. This results in a reduction in the price of electricity in these two regions and the dollar savings from the stationary fuel cells is less. Due to interprovincial electricity import dynamics from hydropower-based regions (and the use of nuclear power in Ontario), the emission reductions on the electric side diminish as the penetration of fuel cells takes place into the future. This means that over time, consumers pay a lot for the fuel cells but society gets few added emission savings.

Table 37 Regional Cost Results, Cost per Tonne, 2000$

REGION	2015	2020	2025	2030
Ontario	360.12	675.22	913.66	1,171.93
BC	12.50	6.34	13.50	14.93
Alberta	NA	NA	NA	NA
Manitoba	312.69	421.94	322.94	372.13
Saskatchewan	126.38	578.10	1,216.35	1,670.50
Canada	293.08	495.17	726.93	944.17

Summary and Interpretation

The implementation of the fiscal policies designed to reduce the cost of hydrogen production, stationary fuel cells, fuel cell vehicles and buses, and hydrogen internal combustion engines resulted in an increase in energy demand associated with the hydrogen technologies in all relevant sectors.

In the transportation sector, three key factors determine the level of penetration that occurred: capital costs, operating costs (the cost of hydrogen fuel) and availability of hydrogen technologies and fuel.[30] For fuel cell buses, where operating costs constitute a greater portion of total cost, the cost per tonne of greenhouse gas emissions reduced was smaller than for light-duty vehicles. In contrast, for fuel cell cars and hydrogen internal combustion engine cars, where the capital costs are more significant than operating costs, the costs per tonne of greenhouse gas emissions reduced were greater than for fuel cell buses. Thus, in the case of the transportation sector, emission reductions were achieved at a lower cost for technologies dominated by operating costs and at a higher cost for technologies dominated by capital costs. Ultimately, reducing the capital costs for hydrogen-related vehicles as well as hydrogen production costs led to a decline in total transportation energy demand. This was the result of efficiency gains realized as a shift from conventional cars and buses to fuel cell cars and buses as well as hydrogen ICE vehicles took place. Thus, despite the decline in overall transportation demand as a result of the Fiscal Scenario, energy demand associated with the hydrogen-related vehicles increased.

While the energy demand associated with hydrogen technologies in the Fiscal Scenario was not significant in absolute terms (constituting between 0.03 and 34.87 PJ of demand in 2030, depending on the particular region), the increase in hydrogen-related energy demand resulting from the introduction of the Fiscal Scenario was significant. Nationally, energy demand associated with hydrogen-related vehicles increased from 64.36 PJ in 2030 in the SMR Reference Case (62.24 PJ in 2030 in the Electrolyzer Reference Case) to 96.26 PJ in 2030 in the SMR Fiscal Scenario (93.25 PJ in 2030 in the Electrolyzer Fiscal Scenario), an increase of almost 50%. In terms of number of vehicles, the Fiscal Scenario led to an increase of 47,312 fuel cell vehicles, 33,371 hydrogen ICE vehicles and 218 fuel cell buses in the case of hydrogen production from SMR. Similar results were realized for hydrogen production using electrolyzers. On a regional basis, the Fiscal Scenario resulted in an increase of over 45% in hydrogen-related energy demand for most provinces and territories. Alberta realized the greatest increase (over 54%) due to the smaller price gap between the price of hydrogen and that of gasoline in the province (Table 38).

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[30] Availability was not a limiting factor in this analysis as market penetration did not reach the maximum amount assumed allowable in the model.

Table 38 Price of Hydrogen[31] vs. Gasoline by Region for 2030, 2000$/GJ

REGION	Hydrogen	Gasoline	Difference
Ontario	38.53	21.81	16.72
Quebec	42.91	23.57	19.34
British Columbia	40.67	21.45	19.22
Alberta	34.11	19.48	14.63
Manitoba	37.26	20.33	16.93
Saskatchewan	36.91	21.88	15.04
New Brunswick	42.45	22.69	19.76
Nova Scotia	42.52	23.81	18.71
Newfoundland	43.68	25.84	17.84
PEI	43.73	21.60	22.13
Yukon Territory	41.45	21.45	20.00
NWT	46.92	21.45	25.48
Nunavut	46.08	21.45	24.63

Like the transportation sector, the commercial and residential sectors realized an increase in the energy demand associated with stationary fuel cells as a result of the fiscal policies. Energy demand from stationary fuel cells in the residential sector increased from 2.61 PJ in 2030 in the Reference Case to 14.45 PJ in 2030 in the Fiscal Scenario, an increase of 454%. Similarly, for the commercial sector, energy demand from stationary fuel cells increased from 0.41 PJ in 2030 in the Reference Case to 2.81 PJ in 2030 in the Fiscal Scenario, an increase of 592%. In terms of the number of stationary fuel cells being introduced to the residential and commercial sectors, in the residential sector, 15,770 more stationary fuel cells were introduced by 2030 as a result of the Fiscal Scenario. For the commercial sector, that increase was 90.

On a regional basis, the increase in energy demand associated with stationary fuel cells was most significant in Ontario, Alberta, British Columbia and Saskatchewan, with Alberta realizing the greatest increase (10,542 stationary fuel cells in the residential sector and 39 stationary fuel cells in the commercial sector in 2030). Energy demand from stationary fuel cells in Alberta was 2.11 PJ in 2030 in the Reference Case and increased to 12.81 PJ in 2030 in the Fiscal Scenario. Stationary fuel cell penetration was limited in Manitoba and Quebec, where the cost of energy generation from the fuel cells was not low enough to compete with the relatively inexpensive electricity generated from hydropower in these provinces. Stationary fuel cell penetration was also restricted in eastern and northern regions, where natural gas availability is limited. The key factor contributing to the relatively high penetration of stationary fuel cells in Alberta, both in the Reference Case and the Fiscal Scenario, is the price of natural gas compared to electricity in the province. Alberta boasts the lowest natural gas prices in all of Canada. Thus, in this province, more so than any other region, the

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[31] For this table, the price of hydrogen represents either the SMR or electrolyzer hydrogen price, depending on which was cheaper in the year 2020. For most regions, SMR was the cheaper hydrogen production option. Regions that favoured hydrogen production from electrolyzers include Quebec, Manitoba, New Brunswick and Nova Scotia. The prices shown in the table above include taxes.

differential between the cost of electricity[32] and the cost of natural gas is the lowest. This makes stationary fuel cells that use natural gas as their source fuel more economical in Alberta and explains the significantly higher energy demand associated with stationary fuel cells in this region relative to others.

As the penetration of hydrogen technologies increased as a result of the Fiscal Scenario, greenhouse gas emissions associated with the transportation, residential and commercial sectors declined. For the transportation sector, emission reductions equalled 1,240 kilotonnes in 2030 for hydrogen production using SMR. If we assume that hydrogen is produced from a source not associated with greenhouse gas emissions (i.e., wind or nuclear power), the emission reductions that could be achieved would increase to 2,650 kilotonnes in 2030. The penetration of stationary fuel cells in the residential and commercial sectors led to a decline in emissions of 710 kilotonnes from these sectors by 2030. Taking into account the impact of the mobile and stationary fuel cells, total greenhouse gas emissions in Canada declined by 1,940 kilotonnes for hydrogen production from SMR. These figures include 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 greenhouse gas emission sources) leads to reductions in emissions of 3,360 kilotonnes in the SMR case and 3,370 kilotonnes in the electrolyzer case.

The modelling analysis revealed that the reduction in emissions that occurred as a result of the penetration of hydrogen-related technologies came at a fairly high cost on a per tonne basis. This is due to the combined effect of the limited greenhouse gas emission reductions that were actually realized and the existing cost barriers associated with hydrogen technologies. The producer and consumer incentives that were simulated had the effect of reducing the capital and operating costs by 25% each. However, given the high capital costs associated with hydrogen technologies (initially 50% more than conventional technologies in the case of the transportation sector), the magnitude of funds required to reduce these costs by 25% was significant. The combination of the high costs for the policy and the relatively limited emission reductions that were achieved results in high costs per tonne of reduction.

The results described above indicate that fiscal policy is capable of facilitating an increase in the market penetration of hydrogen technologies in the transportation, residential and commercial sectors. In all regions for all sectors, the introduction of fiscal policies leads to an increase in energy demand associated with hydrogen technologies. This result holds true on an absolute basis and also as a percent of total energy, where the hydrogen technologies captured a greater share of total energy with fiscal policies in place. Despite these trends, even with the fiscal policies, the penetration of the hydrogen technologies was still relatively minor and the reduction in greenhouse gas emissions that was achieved was relatively small. The main reason for the limited penetration of hydrogen technologies is the high costs of purchasing and operating these technologies relative to conventional competing technologies. Nonetheless, a number of specific observations related to the results of this analysis are warranted:

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[32] The fuel cell is used to generate both heat and electricity, and thus the cost of the fuel cell, including natural gas as the source fuel, is competing with both electricity and heating fuel prices for market share.

1. In cases where the operating costs constitute a significant portion of the total cost of a hydrogen technology, as in the case of a fuel cell bus - which runs all day and sometimes during the night – greenhouse gas emissions were achieved at relatively lower costs. From a fiscal policy perspective, both the producer and consumer incentives have an impact on the penetration of such technologies as both capital and operating costs play a significant role in the total cost calculation for the technology investment. A fiscal policy that reduced capital and operating costs further would result in increased market penetration. Such policies combined with efficiency improvements (as a result of research and development investments for example) would lead to more emission reductions due to the combined impact of increased penetration and reductions in emissions per kilometre driven.

2. In the case of fuel cell cars and hydrogen internal combustion engine cars, where the total cost of the vehicle is dominated by capital costs, emission reductions were achieved at a very high price. From a fiscal policy perspective, the consumer tax credit was the key incentive for purchasing a hydrogen-related vehicle. Because fuel costs are a small part of the total cost calculation for such vehicles, the producer incentive had little impact on the penetration of this technology. As was described above, combining reductions in the cost of purchasing hydrogen-related vehicles with efficiency improvements would lead to increased reductions in greenhouse gas emissions.

3. The fiscal policies were more effective at overcoming economic barriers associated with stationary fuel cells in regions with either high electricity prices or low natural gas prices (or both). Thus, fiscal policies geared towards stationary fuel will be more successful if targeted at regions with high electricity prices and/or low natural gas prices.

4. Given current technology parameters (both cost and efficiency parameters), emission reductions associated with stationary fuel cells proved to be more economical than emission reductions from the transportation sector. Indeed, the economic hurdles associated with the transportation sector were too significant for the fiscal policies to overcome. Research indicates that fuel cells will likely be introduced at a greater scale in the residential and small commercial sectors than the transportation sector in the near term. For example, the United States Department of Energy Hydrogen Posture plan predicts that fuel cells will be used in stationary distributed power between 2010 and 2020 and that personal fuel cell vehicles will not be introduced to the market until between 2020 and 2030.

5. Ultimately, despite the reduction in technology and production costs by 25% each, the penetration of hydrogen technologies over the study period in Canada was relatively small. This is due to the fact that the barriers currently limiting hydrogen production go beyond the purely economic. Barriers related to technology development also exist. Thus, in addition to reductions in capital and operating costs for hydrogen technologies (as was done in this analysis), efficiency gains need to take place and, for vehicles, fuelling infrastructure needs to be established to increase the availability of hydrogen vehicle technologies. Given the need for both reductions in capital and operating costs and increased efficiency standards, fiscal policies that focus on research and development are likely to be the most effective method of increasing the market penetration of hydrogen technologies in the near term. This conclusion is consistent with current thinking in the United States.[33] Over time, as technology developments take place and efficiency gains are made, fiscal policy can shift to focus more on reducing end-user and producer costs explicitly, including the cost to establish a suitable fuelling network.

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[33] See, for example, the United States Department of Energy, Hydrogen Posture Plan.

The results of this analysis indicate the kind of penetration that may be realized given certain levels of government investment in the form of producer and consumer incentives. However, it is important to recognize that there is uncertainty associated with the results of this analysis and additional research is required to further evaluate the full extent of the role of fiscal policy in facilitating hydrogen development in Canada. When reviewing the results of this analysis, it is important to keep in mind the uncertainty associated with the model inputs related to emerging technologies. Presently, there is little relevant historical data from which to base much of the technology data included in the Baseline Report. None of the hydrogen technologies introduced to the Energy 2020 model have been introduced to the market in any significant way, and therefore all of the parameters and assumptions associated with these inputs have been estimated based on the best available information from publicly available literature and discussions with industry experts. Much of the data and many of the assumptions have been based on targeted or expected performance and costs, as well as conceptualized applications. Small changes in some of the technology parameter assumptions could have significant impacts on the results of this analysis. For example, a relatively small increase in the energy efficiency (even 10%) of the hydrogen technologies could increase the penetration of the technologies significantly, especially when combined with reductions in capital costs. The availability of hydrogen vehicles will also likely play a big factor in market penetration, and depending on the support for development of a fuelling infrastructure, hydrogen vehicles could be available to much more or much less than the 10% of the light-duty vehicle fleet assumed in this analysis.

In addition, a key source of uncertainty is the fact that for the purposes of this analysis, the Energy 2020 model was calibrated to *Canada's Emissions Outlook, An Update* (CEOU). The CEOU was completed in 1999 and the assumptions on energy prices contained in the outlook are consistent with the wisdom and analytical modelling undertaken in the late 1990s. The actual prices of key energy commodities have, however, been different in recent years than those portrayed in the CEOU. Most energy prices are considerably higher, with the price of oil and the price of gas being approximately 30% and 140% higher in 2000 respectively than forecasted in the CEOU. Relative energy prices impact the penetration of hydrogen in two ways. First, where these energy fuels are being used as inputs in the production of hydrogen, it affects the cost of production, and therefore the final price of hydrogen. Second, energy prices affect the price of competing fuels, and changes in such prices may result in hydrogen becoming more or less competitive. The final effect on the price of hydrogen depends on the cost of hydrogen production technologies and the price of competing commodities, among other factors. If natural gas is being used as the source of hydrogen in either the SMR or electrolyzer process (as it is in this modelling exercise), and the natural gas is overpriced, the production cost of hydrogen will also necessarily be high. On the other hand, if the price of gasoline, the competing fuel, is also high, the effect of higher production costs on market penetration may be reduced. In the end, we know that the CEOU is not a perfect reflection of today's fuel prices, but we do not know what effect revised prices would have on a modelling exercise examining the penetration of hydrogen technologies. Future analysis should use a more up-to-date set of fuel prices to investigate the impact of fiscal policies on hydrogen penetration.

Related to the known uncertainty associated with the calibration to the CEOU, described above, there is uncertainty associated with what the future energy mix will be in Canada and the potential for policy changes related to reducing greenhouse gas emissions. For example, assumptions contained in the CEOU on future energy mixes may be incorrect. We are presently uncertain of the role that natural gas, nuclear and renewable energy will play in Canada's energy future. In addition, the federal government has committed to reducing greenhouse gas emissions to meet Kyoto targets, but it is still unclear how these reductions will be achieved and what government policies will be introduced to accomplish them. A set of government policies designed to reduce greenhouse gas emissions might have the effect of significantly increasing the cost of carbon-based fuels. Such actions would change the outcome of this analysis significantly. The results of this study show that the use of hydrogen has the ability to reduce greenhouse gas emissions. To accomplish significant reductions, however, hydrogen needs to be produced from renewable energy sources. Taking the way hydrogen is produced today and projecting into the future, as was done in this analysis, will not result in significant greenhouse gas emission reductions. It will become important to move beyond the use of *Canada's Emissions Outlook, An Update* and test a host of different hydrogen production methods to evaluate the full extent of emission reductions that might be realized in a carbon-constrained hydrogen economy in Canada. For example, this study considered hydrogen production from steam methane reformers and electrolyzers, yet there is potential to reduce greenhouse gas emissions significantly by switching away from fossil-based energy sources and towards unconventional energy sources such as biomass.

As was stated above, additional research is required to evaluate the full extent of the role of fiscal policy on hydrogen development in Canada. This project is a first step in what we hope will be an ongoing investigation in this area of research. In this analysis, we have considered the impact of a discrete set of fiscal policies on key hydrogen pathways. Future research should investigate the impact of greater producer and consumer incentives on the penetration of the hydrogen pathways included in this analysis. In addition, future research should consider the impact of fiscal policy on other hydrogen technologies and pathways. In a previous EFR and Hydrogen Scoping Meeting, members of the scoping group identified several hydrogen pathways as worthy of analysis and modelling consideration. We do not disagree with this opinion. However, for the purposes of this project, there was a need to limit the number of pathways included in the Energy 2020 model. Thus, a number of pathways that would be useful to investigate were deemed outside the scope of this initial analysis. These pathways are described in Appendix D at the back of this report along with a brief discussion of the potential role of the pathway in Canada's future hydrogen economy and the use of fiscal policy to facilitate development of the particular pathway. Future research should consider the impact of fiscal policies on these pathways, both individually and in a marketplace where they compete against one another.

It would also be useful to test the impact of fiscal policies specifically targeted at hydrogen technologies in combination with other types of policies (such as information, education or marketing programs) as well as a broad-based policy for reducing greenhouse gas emissions (tradable permits or a carbon tax for example). To increase penetration of stationary fuel cells it would be valuable to test the effect of electricity market reform and net metering. In addition, as was touched on above, it would be useful to consider the role of alternative energy sources, including biomass, in hydrogen production and the associated reductions in greenhouse gas emissions. In terms of future research related to the cost estimates presented in this report, it would be useful to expand the analysis to include a comparison with the cost of carbon capture and storage, the societal costs associated with greenhouse gas emissions and the benefits associated with reducing criteria air contaminants. The current analysis considers only market costs and does not attempt to account for broader societal costs associated with climate change or degraded local air quality. Given the potentially significant role that hydrogen could play in improving local air quality, an analysis of the potential for hydrogen to reduce criteria air contaminants in Canada would be beneficial.

This analysis has tested the impact of a specific set of fiscal policies on the penetration of key hydrogen technologies in Canada. In conclusion, it is worth noting that because of the extent and diversity of barriers that currently limit hydrogen developments in Canada, there will be a role not just for fiscal policies but for other types of policies as well. To overcome barriers related to the need for codes and standards, governments will need to work directly with industry and relevant international bodies. It may also be necessary to make adjustments to electricity markets to facilitate hydrogen developments. Likewise, information and education programs may be needed to increase consumer confidence in these relatively new and innovative technologies. In the end, the government will need to pursue a mix of not only fiscal policies (research and development and producer and consumer tax incentives for example), but other programs as well.

Appendices

A. Price of Hydrogen Calculations
B. Supplemental Reference Case Results
C. Supplemental Fiscal Scenario Results
D. Pathways Not Modeled
E. Useful Conversions

A. Price of Hydrogen Calculations

Price of hydrogen:
Price of hydrogen = Production costs + Decentralized compression costs + Dispenser costs + Fuel tax

Production, decentralized compression, dispenser and tax cost calculation:
Total cost = Annualized capital cost + (Fixed operating cost / Utilization) + (Natural gas cost * Natural gas consumption) + (Electricity cost * Electricity consumption)

Annualized capital cost = Capital cost * Capital charge rate (15%) / Utilization

Natural gas cost and electricity costs are supplied by Energy 2020

Fuel tax (by province and territory) = [(Provincial/territorial gasoline tax + Federal gasoline tax) * Energy density of gasoline + (Provincial/territorial diesel tax + Federal diesel tax) * Energy density of diesel] / 2 * (1 + GST + PST for Quebec, New Brunswick, Nova Scotia and Newfoundland)

B. Supplemental Reference Case Results

Hydrogen Prices

SMR Reference Case 2000$/kg

	2005	2010	2015	2020	2025	2030
Ontario	6.06	6.22	6.35	6.53	6.71	6.88
Quebec	6.61	6.76	6.95	7.18	7.41	7.64
British Columbia	6.34	6.56	6.70	6.86	7.03	7.20
Alberta	5.55	5.70	5.78	5.89	5.99	6.10
Manitoba	5.91	6.02	6.17	6.32	6.48	6.63
Saskatchewan	5.96	6.06	6.17	6.29	6.42	6.54
New Brunswick	6.63	6.74	6.92	7.12	7.33	7.53
Nova Scotia	6.72	6.81	6.97	7.18	7.37	7.57
Newfoundland	6.62	6.77	7.09	7.25	7.40	7.56
PEI	6.60	6.85	7.08	7.33	7.58	7.83
Yukon Territory	6.31	6.56	6.78	7.02	7.26	7.50
NWT	7.03	7.32	7.59	7.89	8.19	8.50
Nunavut	6.90	7.19	7.47	7.77	8.07	8.37

Electrolyzer Reference Case, 2000$/kg

REGION	2005	2010	2015	2020	2025	2030
Ontario	6.90	7.07	7.08	7.34	7.59	7.86
Quebec	6.91	6.49	6.58	6.90	7.21	7.53
BC	6.60	6.97	6.95	6.91	6.94	6.94
Alberta	6.83	7.18	7.14	7.04	7.00	6.93
Manitoba	6.41	6.03	6.13	6.17	6.24	6.26
Saskatchewan	7.40	7.11	7.02	6.98	6.96	6.92
NB	7.35	6.58	6.59	6.64	6.74	6.80
Nova Scotia	8.35	7.28	7.10	7.15	7.18	7.22
Newfoundland	6.90	6.41	7.87	7.50	7.13	6.75
PEI	8.37	8.83	9.31	9.81	10.31	10.82
Yukon Territory	10.54	11.21	11.92	12.65	13.38	14.11
NWT	16.09	17.21	18.39	19.64	20.88	22.13
Nunavut	15.96	17.09	18.27	19.52	20.76	22.01

Transportation

SMR Transportation Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	547.92	572.70	618.28	666.17	714.17	761.76
Quebec	292.08	305.26	325.44	345.63	365.93	385.93
BC	197.42	206.64	219.67	232.36	245.04	257.52
Alberta	251.40	265.34	289.81	309.65	329.42	349.34
Manitoba	67.33	70.00	73.83	77.18	80.57	83.89
Saskatchewan	99.04	102.91	108.64	114.58	120.54	126.46
NB	43.14	45.36	47.16	50.84	54.51	58.16
Nova Scotia	46.36	48.53	51.50	53.89	56.26	58.65
Newfoundland	20.33	21.12	22.20	22.60	23.03	23.42
PEI	8.78	9.17	9.48	9.68	9.89	10.09
Yukon Territory	0.52	0.56	0.60	0.65	0.70	0.74
NWT	1.18	1.27	1.37	1.46	1.55	1.65
Nunavut	0.40	0.44	0.48	0.53	0.58	0.62
TOTAL	1,575.91	1,649.29	1,768.46	1,885.25	2,002.17	2,118.21

Electrolyzer Transportation Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	547.92	572.70	618.27	666.02	713.87	761.54
Quebec	292.08	305.35	325.57	345.83	366.19	386.41
British Columbia	197.42	206.57	219.60	232.29	244.97	257.57
Alberta	251.40	265.32	289.78	309.54	329.23	349.00
Manitoba	67.33	70.03	73.86	77.22	80.62	83.98
Saskatchewan	99.04	102.95	108.68	114.62	120.58	126.52
New Brunswick	43.14	45.19	46.99	50.64	54.28	57.92
Nova Scotia	46.36	48.34	51.31	53.70	56.06	58.45
Newfoundland	20.33	21.05	22.12	22.51	22.93	23.33
PEI	8.78	9.13	9.44	9.64	9.85	10.05
Yukon Territory	0.52	0.55	0.60	0.64	0.69	0.73
NWT	1.18	1.27	1.36	1.46	1.55	1.64
Nunavut	0.40	0.44	0.48	0.53	0.57	0.61
TOTAL	1,575.91	1,648.89	1,768.04	1,884.65	2,001.38	2,117.75

SMR Transportation Demand by Select Mode, PJ/yr

MODE	2005	2010	2015	2020	2025	2030
Personal LDV	1,533.25	1,580.94	1,694.32	1,795.99	1,897.94	1,999.39
Fuel Cell LDV	-	9.07	10.84	16.11	21.19	26.46
Hydrogen ICE LDV	-	12.54	13.55	20.77	28.01	35.22
Transit Buses	14.25	14.71	15.77	16.72	17.67	18.61
Fuel Cell Buses	-	2.76	2.78	2.74	2.72	2.68

Electrolyzer Transportation Demand by Select Mode, PJ/yr

MODE	2005	2010	2015	2020	2025	2030
Personal LDV	1,533.25	1,580.88	1,694.32	1,796.38	1,898.70	2,000.54
Fuel Cell LDV	-	8.89	10.66	15.90	20.96	26.21
Hydrogen ICE LDV	-	12.18	13.10	19.77	26.46	33.12
Transit Buses	14.25	14.71	15.77	16.72	17.67	18.62
Fuel Cell Buses	-	2.99	3.01	2.98	2.95	2.91

Residential

Total Residential Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	582.90	578.90	613.02	648.61	663.06	686.94
Quebec	313.00	313.80	328.70	344.70	352.28	363.56
BC	129.10	129.40	134.43	139.70	142.27	146.05
Alberta	175.20	171.91	176.08	177.96	178.70	180.11
Manitoba	55.00	53.70	55.70	57.70	58.03	59.11
Saskatchewan	63.10	62.20	63.53	64.73	64.94	65.61
NB	39.20	39.60	40.50	41.20	41.84	42.53
Nova Scotia	45.70	46.60	47.90	49.00	50.06	51.18
Newfoundland	27.60	28.40	28.90	29.60	30.22	30.86
PEI	7.90	8.00	8.20	8.30	8.46	8.61
Yukon	1.79	1.90	2.01	2.14	2.25	2.37
NWT	6.58	6.99	7.42	7.87	8.28	8.71
Nunavut	2.04	2.26	2.49	2.75	2.97	3.20
TOTAL	1,449.12	1,443.66	1,508.89	1,574.26	1,603.36	1,648.84

Total Residential Demand by Fuel Type, PJ/yr

FUEL	2005	2010	2015	2020	2025	2030
Electric	553.07	572.77	609.00	646.53	674.15	706.14
Gas	673.21	642.46	659.65	676.83	670.06	673.92
Coal	2.50	2.80	2.90	2.70	2.93	3.00
Oil	107.23	102.43	114.84	124.59	128.32	135.12
Biomass	92.30	95.70	98.30	103.80	106.42	110.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00
LPG	20.80	27.50	24.20	19.80	21.47	20.58
TOTAL	1,449.12	1,443.66	1,508.89	1,574.26	1,603.36	1,648.84

Commercial

Total Commercial Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	445.28	472.59	503.86	538.28	567.01	598.06
Quebec	225.14	232.21	245.31	259.84	269.69	281.53
BC	137.56	149.11	154.32	160.42	168.68	175.90
Alberta	160.36	157.59	156.03	154.51	152.34	150.45
Manitoba	48.49	46.77	44.22	41.79	39.63	37.34
Saskatchewan	48.94	47.45	45.98	44.49	43.00	41.52
NB	17.06	17.47	17.97	18.87	19.27	19.86
Nova Scotia	22.17	23.37	23.67	23.57	24.37	24.80
Newfoundland	11.67	11.87	12.17	12.47	12.72	12.99
PEI	3.60	3.60	3.60	3.50	3.51	3.48
Yukon	1.35	1.43	1.52	1.61	1.69	1.78
NWT	4.96	5.26	5.59	5.93	6.24	6.56
Nunavut	1.54	1.70	1.88	2.07	2.24	2.41
TOTAL	1,128.12	1,170.41	1,216.11	1,267.36	1,310.39	1,356.70

Total Commercial Demand by Fuel Type, PJ/yr

FUEL	2005	2010	2015	2020	2025	2030
Electric	516.71	546.18	578.35	584.76	641.92	673.55
Gas	495.11	502.03	511.08	513.85	533.11	543.17
Coal	0.02	0.02	0.03	0.03	0.03	0.03
Oil	58.37	60.26	61.23	61.36	63.36	64.51
Biomass	-	-	-	-	-	-
Solar	0.02	0.03	0.03	0.03	0.04	0.05
LPG	57.88	61.89	65.39	66.01	72.33	75.87
TOTAL	1,128.12	1,170.41	1,216.11	1,226.04	1,310.79	1,357.18

C. Supplemental Fiscal Scenario Results

These results describe the combined impact of producer incentives and the consumer incentives.

Hydrogen Prices

SMR Fiscal Scenario 2000$/kg

REGION	2005	2010	2015	2020	2025	2030
Ontario	4.82	4.94	5.04	5.07	5.28	5.39
Quebec	5.27	5.39	5.53	5.56	5.85	6.01
BC	5.09	5.25	5.35	5.37	5.58	5.69
Alberta	4.38	4.50	4.56	4.57	4.71	4.78
Manitoba	4.68	4.76	4.87	4.90	5.10	5.22
Saskatchewan	4.76	4.83	4.91	4.93	5.08	5.17
NB	5.28	5.36	5.50	5.53	5.80	5.94
Nova Scotia	5.35	5.42	5.54	5.57	5.82	5.95
Newfoundland	5.28	5.39	5.64	5.66	5.95	6.12
PEI	5.22	5.41	5.58	5.62	5.94	6.12
Yukon	4.94	5.12	5.29	5.32	5.63	5.80
NWT	5.51	5.72	5.92	5.97	6.36	6.57
Nunavut	5.38	5.60	5.80	5.85	6.24	6.45

Electrolyzer Fiscal Scenario 2000$/kg

REGION	2005	2010	2015	2020	2025	2030
Ontario	5.45	5.58	5.59	5.78	5.84	5.94
Quebec	5.50	5.19	5.25	5.49	5.62	5.80
BC	5.28	5.56	5.54	5.51	5.49	5.45
Alberta	5.35	5.61	5.58	5.51	5.46	5.39
Manitoba	5.05	4.77	4.85	4.87	4.98	5.03
Saskatchewan	5.83	5.62	5.55	5.52	5.48	5.44
NB	5.82	5.24	5.25	5.29	5.37	5.43
Nova Scotia	6.57	5.77	5.63	5.67	5.56	5.50
Newfoundland	5.50	5.13	6.22	5.94	6.51	6.77
PEI	6.55	6.89	7.25	7.63	7.99	8.36
Yukon	8.11	8.61	9.14	9.69	10.22	10.76
NWT	12.30	13.14	14.03	14.96	15.86	16.76
Nunavut	12.18	13.02	13.91	14.84	15.74	16.64

Transportation

SMR Transportation Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	547.92	571.95	617.16	664.74	712.45	759.69
Quebec	292.08	304.92	324.89	344.94	365.10	384.94
BC	197.42	206.29	219.20	231.80	244.40	256.77
Alberta	251.40	264.81	289.07	308.70	328.27	347.97
Manitoba	67.33	69.81	73.61	76.93	80.28	83.56
Saskatchewan	99.04	102.59	108.28	114.18	120.10	125.98
NB	43.14	45.32	47.11	50.78	54.45	58.08
Nova Scotia	46.36	48.49	51.44	53.83	56.19	58.57
Newfoundland	20.33	21.10	22.17	22.57	22.99	23.38
PEI	8.78	9.16	9.46	9.66	9.87	10.06
Yukon	0.52	0.56	0.60	0.65	0.70	0.74
NWT	1.18	1.27	1.37	1.46	1.55	1.64
Nunavut	0.40	0.44	0.48	0.53	0.58	0.62
TOTAL	1,575.91	1,646.71	1,764.87	1,880.79	1,996.91	2,112.00

Electrolyzer Transportation Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	547.92	571.86	617.06	664.39	711.86	759.11
Quebec	292.08	305.05	325.07	345.23	365.50	385.60
BC	197.42	206.19	219.10	231.70	244.29	256.79
Alberta	251.40	264.74	288.97	308.46	327.88	347.37
Manitoba	67.33	69.85	73.65	76.98	80.35	83.68
Saskatchewan	99.04	102.62	108.31	114.21	120.12	126.02
NB	43.14	45.11	46.87	50.49	54.09	57.70
Nova Scotia	46.36	48.25	51.18	53.55	55.89	58.25
Newfoundland	20.33	21.01	22.06	22.44	22.84	23.23
PEI	8.78	9.11	9.41	9.60	9.80	9.99
Yukon	0.52	0.55	0.60	0.64	0.68	0.73
NWT	1.18	1.26	1.36	1.45	1.53	1.62
Nunavut	0.40	0.44	0.48	0.52	0.57	0.61
TOTAL	1,575.91	1,646.05	1,764.13	1,879.67	1,995.40	2,110.70

SMR Transportation Demand by Select Mode, PJ/yr

MODE	2005	2010	2015	2020	2025	2030
Personal LDV	1,533.25	1,570.51	1,680.83	1,774.61	1,868.85	1,962.39
Fuel Cell LDV	-	11.98	15.12	24.05	32.67	41.60
Hydrogen ICE LDV	-	16.53	18.17	28.83	39.52	50.17
Transit Buses	14.25	14.61	15.65	16.52	17.39	18.26
Fuel Cell Buses	-	4.01	4.14	4.25	4.38	4.49

Electrolyzer Transportation Demand by Select Mode, PJ/yr

MODE	2005	2010	2015	2020	2025	2030
Personal LDV	1,533.25	1,570.33	1,680.71	1,774.91	1,869.55	1,963.51
Fuel Cell LDV	-	11.70	14.84	23.72	32.30	41.19
Hydrogen ICE LDV	-	16.01	17.52	27.41	37.32	47.20
Transit Buses	14.25	14.61	15.65	16.52	17.40	18.27
Fuel Cell Buses	-	4.33	4.47	4.59	4.73	4.86

Residential

Residential Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	582.90	578.90	613.75	649.55	664.37	688.62
Quebec	313.00	313.80	328.70	344.70	352.28	363.56
BC	129.10	129.40	134.55	139.71	142.40	146.20
Alberta	175.20	171.91	180.92	181.75	185.74	188.85
Manitoba	55.00	53.70	55.70	57.70	58.03	59.11
Saskatchewan	63.10	62.20	63.66	64.83	65.12	65.84
NB	39.20	39.60	40.50	41.20	41.84	42.53
Nova Scotia	45.70	46.60	47.90	49.00	50.06	51.18
Newfoundland	27.60	28.40	28.90	29.60	30.22	30.86
PEI	7.90	8.00	8.20	8.30	8.46	8.61
Yukon	1.79	1.90	2.01	2.14	2.25	2.37
NWT	6.58	6.99	7.42	7.87	8.28	8.71
Nunavut	2.04	2.26	2.49	2.75	2.97	3.20
TOTAL	1,449.12	1,443.66	1,514.71	1,579.10	1,612.03	1,659.64

Residential Demand by Fuel Type, PJ/yr

FUEL	2005	2010	2015	2020	2025	2030
Electric	553.07	572.77	609.08	646.71	674.38	706.43
Gas	673.21	642.46	665.38	681.50	678.51	684.43
Coal	2.50	2.80	2.90	2.70	2.93	3.00
Oil	107.23	102.43	114.84	124.59	128.32	135.12
Biomass	92.30	95.70	98.30	103.80	106.42	110.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00
LPG	20.80	27.50	24.20	19.80	21.46	20.58
TOTAL	1,449.12	1,443.66	1,514.71	1,579.10	1,612.03	1,659.64

Commercial

Commercial Demand by Region, PJ/yr

REGION	2005	2010	2015	2020	2025	2030
Ontario	445.28	472.59	504.20	538.75	567.64	598.87
Quebec	225.14	232.21	245.31	259.84	269.69	281.53
BC	137.56	149.11	154.38	160.47	168.78	176.03
Alberta	160.36	157.59	156.68	155.02	153.29	151.64
Manitoba	48.49	46.77	44.22	41.79	39.63	37.34
Saskatchewan	48.94	47.45	46.01	44.52	43.06	41.59
NB	17.06	17.47	17.97	18.87	19.27	19.86
Nova Scotia	22.17	23.37	23.67	23.57	24.37	24.80
Newfoundland	11.67	11.87	12.17	12.47	12.72	12.99
PEI	3.60	3.60	3.60	3.50	3.51	3.48
Yukon	1.35	1.43	1.52	1.61	1.69	1.78
NWT	4.96	5.26	5.59	5.93	6.24	6.56
Nunavut	1.54	1.70	1.88	2.07	2.24	2.41
TOTAL	1,128.12	1,170.41	1,217.19	1,268.42	1,312.12	1,358.89

Commercial Demand by Fuel Type, PJ/yr

FUEL	2005	2010	2015	2020	2025	2030
Electric	516.71	546.18	578.35	611.36	641.98	673.62
Gas	495.11	502.03	512.16	526.44	534.73	545.22
Coal	0.02	0.02	0.03	0.03	0.03	0.03
Oil	58.37	60.26	61.23	61.95	63.36	64.51
Biomass	-	-	-	-	-	-
Solar	0.02	0.03	0.03	0.04	0.04	0.05
LPG	57.88	61.89	65.40	68.60	72.33	75.87
TOTAL	1,128.12	1,170.41	1,217.19	1,268.42	1,312.47	1,359.30

D. Pathways Not Modelled

Several hydrogen transportation pathways were identified as being commercially advanced and capable of reducing greenhouse gas emissions, yet due to the need to prioritize the number of runs that could actually be modelled, these hydrogen transportation pathways were deemed outside the scope of this modelling exercise. They are nonetheless considered worthy of additional consideration and are presented and numbered in the table below.

Hydrogen Transportation Pathways for Further Discussion

FUEL SOURCE	PRODUCTION	STORAGE	TRANSPORTATION	STORAGE	END-USE
1. Natural gas from pipeline	Centralized SMR	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
2. Electricity from grid or specific plant	Centralized electrolyzer	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
3. Methanol from offshore natural gas	Decentralized methanol reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
4. Gasoline	Decentralized gasoline reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
5. Methanol from offshore natural gas					Methanol fuel cell LDV
6. Gasoline					Gasoline fuel cell LDV

The roles of these pathways in Canada's transition towards a hydrogen economy, grouped according to the method of hydrogen production and processing, are described below. For each set of pathways, we include a comment on the potential of the pathway to reduce greenhouse gas emissions and the role that fiscal policy might play in facilitating the development of the pathway. The focus with respect to fiscal policies is on the key options identified in the Baseline Report as useful for directly increasing the market penetration of hydrogen technologies and associated pathways. These include investment tax credits, producer tax credits, accelerated capital cost allowances (ACCA), research and development, grants, consumer tax credits and pilot projects.

On-board Fuel Processing – Pathways 5 and 6

On-board processing of gasoline, methanol, or another liquid hydrocarbon for fuel cell vehicles is seen as a potential transition pathway towards fuel cell vehicles (FCVs) with on-board hydrogen storage. They are also expected to have the potential to reduce life-cycle greenhouse gas emissions when compared with conventional vehicles (25% lower for gasoline FCVs and 30% lower for methanol FCVs when compared with gasoline ICE vehicles[34]) if the technology reaches established performance targets. The advantages of using on-board processing of liquid hydrocarbons as a first step include the fact that they provide comparable vehicle range to current gasoline vehicles, and they could use some of the existing fuel production and distribution system to deliver the fuel to the vehicle. As was described in the Baseline Report, on-board fuel processing has been demonstrated in a handful of prototype vehicles, but there is uncertainty as to whether these technologies will overcome their technical and economic challenges soon enough to be used as an effective transition to hydrogen FCVs.

Fiscal policy can play a role in facilitating the development of these pathways. Of the key fiscal policies identified in the Baseline Report, the most relevant policies for these particular pathways are funds for research and development, grants and pilot projects. Research and development is needed to overcome remaining technical hurdles and grants and pilot projects can be designed to test the technologies in real-world situations.

Off-board Hydrocarbon Reforming – Pathways 1, 3 and 4

Decentralized reforming of hydrocarbons to produce hydrogen off-board the vehicle is a step closer to the end-goals for the hydrogen economy than on-board fuel processing. These pathways (3 and 4) introduce hydrogen storage and dispensing and would allow the fuelling stations and vehicles to be easily integrated with other fuel sources including low-impact renewable energy. Life-cycle greenhouse gas emissions for natural gas reforming-based FCVs can be more than 40% lower than gasoline ICEVs.[35] Small-scale reformer technology is at different stages of development depending on the feedstock. Methanol reformers are commercially available, whereas small-scale natural gas reformers suitable for fuelling station applications are still under development. Hydrogen storage and dispensing technologies have been demonstrated widely, although development continues in order to store hydrogen at pressures that may be necessary to achieve the required range for all vehicles.

Centralized reforming of hydrocarbons (pathway 1) is a step further towards the end-goal of a hydrogen economy than decentralized reforming as it requires a large demand and a hydrogen distribution infrastructure, both important elements to large-scale use of hydrogen in the transportation sector. The technologies used in these pathways are commercially mature, but the challenge with implementing them is to create the necessary level of demand for hydrogen within a particular area.

Because of the relatively higher level of technological development of these pathways, key fiscal policies for facilitating market penetration include pilot projects to establish and test technologies, research and development to address remaining technical hurdles, and accelerated capital cost

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[34] General Motors Corporation, 2001. *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel / Vehicle Systems – North American Analysis.*

[35] Ibid.

allowances, grants and investment tax credits to reduce remaining cost barriers. Producer tax credits will also be important to decrease the cost of hydrogen production.

Electrolysis Pathways – Pathway 2

The electrolysis pathways can play many different roles in the development of a hydrogen economy, depending on the source of electricity. If conventional coal powerplants are the electricity source, the result will be a large increase in life-cycle greenhouse gas emissions. If conventional natural gas powerplants are the electricity source, then there is little change in life-cycle greenhouse gas emissions, and the only real benefit obtained from this pathway would be the establishment of infrastructure to transition to a lower-impact electricity source in the future. If a low-impact renewable energy source is used, then there would be almost a complete elimination of fuel-cycle greenhouse gas emissions and this pathway would essentially be the last step in transitioning to a low-impact renewable hydrogen economy. Electrolysis technology is currently commercially available, although the same constraints regarding hydrogen storage and large-scale hydrogen production that were raised for the reforming pathways apply to the electrolysis pathways. The development of new electricity sources, particularly low-impact renewable resources, is also a constraint to the development of this pathway. It should be mentioned that there is some uncertainty as to whether transportation is truly the most appropriate use for new sources of low-impact renewable electricity, or if displacing current conventional electricity sources is a better use.

As is the case with the previous hydrogen pathways, fiscal policies can facilitate market penetration of hydrogen technologies associated with electrolysis pathways. Producer tax credits will be useful to reduce the cost of producing hydrogen via electrolysis. Such policies may specify different levels of incentive for different source fuels depending on the impact on life-cycle greenhouse gas emissions. For example, the producer tax credit might be highest for hydrogen production from renewable energy sources, lower for hydrogen production from natural gas and zero for hydrogen production from coal. This kind of policy design is important to ensure that over the long term, Canada is transitioning to a lower-carbon hydrogen future. Other relevant fiscal policies include research and development, accelerated capital cost allowances, grants, investment tax credits and pilot projects. Research and development can help overcome remaining technical barriers for this pathway. Grants, ACCA and investment tax credits can lower capital costs and incite investment in relevant technologies. And pilot projects can help set up and test the technologies in real-world settings.

It should be noted that there are also several stationary fuel cell technologies that were outside the scope of this study to model, but will nonetheless play an important role in the development of this industry and should be investigated in future work. Of primary interest in the future development of stationary fuel cell products are proton exchange membrane (PEM) fuel cells and molten carbonate fuel cells.

As the pathways and associated technologies described above move towards commercialization, the implementation of consumer tax credits and grants for end-users will become increasingly important. These will facilitate real market penetration and increase demand for these new and innovative technologies. As demand increases, economies of scale will be gained and prices will decline.

E. Useful Conversions

HYDROGEN			
1	kW	0.609	kg/day
1	GJ	7.052	kg
1	$/kg	0.14	$/GJ
NATURAL GAS			
1	kW	1.575	kg/day
1	GJ	18.230	kg
METHANOL			
1	kW	4.320	kg/day
1	GJ	50.000	kg
GASOLINE			
1	kW	1.942	kg/day
1	GJ	22.472	kg
DIESEL			
1	kW	2.419	kg/day
1	GJ	27.993	kg

Case Study on the Role of Fiscal Policy in Hydrogen Development

Baseline Report

May 10, 2004

Pembina Institute and the Canadian Energy Research Institute

National Round Table
on the Environment
and the Economy

Table ronde nationale
sur l'environnement
et l'économie

Table of Contents

Introduction

The National Round Table on the Environment and the Economy (NRTEE) has identified ecological fiscal reform (EFR) as one of the government's most powerful tools for influencing economic and environmental outcomes. The NRTEE has defined EFR as *a strategy that redirects a government's taxation and expenditure programs to create an integrated set of incentives to support the shift to sustainable development.* Many believe this policy lever has not been used to its full capacity to address challenges related to climate change and energy use. To explore EFR in this regard, the objective of the NRTEE's EFR and Energy program is to develop and promote fiscal policy that consistently and systematically reduces energy-based carbon emissions in Canada, both in absolute terms and as a ratio to gross domestic product, without increasing other pollutants. From the assumption that a number of emerging technologies have the potential to help in the achievement of this long-term objective, the NRTEE has commissioned this study on hydrogen. It is joined with two others that are looking at the role of fiscal policy in promoting renewable power and in energy efficiency, respectively.

The hydrogen sector, as defined for the purposes of this project, is *any energy system where the primary fuel, at some point within the process, is hydrogen.* Fuel cells, because they use hydrogen as their primary fuel (even though in a typical stationary fuel cell application, hydrogen only exists for a short time and is contained completely within the fuel cell system), are a major component of this sector. This definition purposely excludes some of the most common uses of hydrogen today. For example, hydrogen used in an oil refinery to produce gasoline and other fuel products is not included as hydrogen is not the primary fuel source, oil is. Hydrogen used for medical or manufacturing purposes is also not included.

Hydrogen is envisaged as a key energy source in the long run and is recognized for the role it could play in reducing carbon emissions in the future. While challenges related to hydrogen technologies are continually being overcome, numerous technological challenges persist. In addition, the relatively high capital cost of these technologies remains a key barrier to significant market penetration. While Canada, along with the United States, the United Kingdom, Japan and Germany, is a leader in hydrogen technology developments, without major policy interventions, mass commercialization and associated long-term economic benefits of hydrogen energy in Canada are unlikely.

Fiscal policy can play an important role in accelerating hydrogen energy market penetration in Canada. However, key questions that need addressing relate to the type of EFR appropriate in promoting the long-term development of this sector and the effectiveness of such policies in reducing carbon emissions over time. To begin to answer these questions, the EFR and Hydrogen Development Case Study will examine the role that fiscal policy can play in promoting hydrogen-based energy systems. More specifically, the purpose of this research is to provide a detailed look at the emerging hydrogen economy with respect to its expected path of development, as well as the ability of EFR at the federal level to enhance this development.

This report describes in detail the baseline conditions from which key ecological fiscal reform policies will be evaluated. Specifically, in this report we describe the current state of hydrogen development, potential hydrogen pathways, and the current policy framework related to hydrogen, and we complete an initial assessment of fiscal policies for facilitating hydrogen development in

Canada. The Economic Analysis Report, which accompanies this Baseline Report, presents results of a modelling exercise undertaken to evaluate the impact of a set of hydrogen-oriented fiscal policy scenarios.

This report begins with a description of the methodology employed in this analysis. We then describe the hydrogen sector, as it currently exists in Canada, and the potential for market development over time. Following this, the Hydrogen Pathways section describes the hydrogen economy in the context of a host of energy pathways and describes specific applications for further consideration in this analysis. The policy context currently governing hydrogen developments in Canada is subsequently described along with the barriers limiting further market penetration of hydrogen technologies in Canada. We then describe the role that fiscal policies can play in overcoming these barriers and evaluate an extensive list of policies according to a set of evaluative criteria. The outcome of this evaluation is a refined set of the most promising fiscal policies for facilitating market penetration of hydrogen technologies in Canada. A sub-set of these fiscal policies will be evaluated using the Energy 2020 model, which we describe in the final section of the report. We conclude by summarizing the Baseline Report and identifying next steps in the policy analysis.

Methodology

The following tasks were completed as part of the baseline assessment of hydrogen development in Canada.

Establish a Baseline for Hydrogen Development

The first step in this analysis was to establish a baseline for hydrogen development in Canada. This includes a discussion of key sectoral characteristics and a description of the current level of technological development for all major applications (portable, stationary and mobile) and stages including hydrogen production, storage, transportation and use. This was accomplished using a combination of a literature review, contact with industry experts and work previously completed by the Pembina Institute in this field.

Identify Alternative Hydrogen Pathways

The second step in this analysis was to identify and assess a comprehensive set of hydrogen pathways that can be realized over approximately the next 30 years (up to 2030). A hydrogen pathway comprises different combinations of energy sources, conversion technologies, transportation and storage devices and end-use products. We began by identifying an extensive set of pathways through which hydrogen could be developed in Canada. We then assessed these pathways according to the likelihood of the pathway being realized, data availability and the impact the particular pathway could have on national carbon emissions. The end result was a manageable list of pathways for further consideration and modelling.

Obtain Technology Parameters and Modify Model

For each of the pathways, we then collected detailed technology parameters for input into the Energy 2020 model (the model that will be employed to evaluate fiscal policy scenarios in the next stage of this research). Model parameters included capital costs, operating and maintenance costs, fuel costs, energy use efficiencies, the portion of the market with access to hydrogen technologies and energy use in the production of hydrogen. This information was collected through a combination of literature review and consultation with experts. Technology parameters for each of the pathways were then incorporated into the Energy 2020 model. Based on these parameters and the model's representation of how consumers behave, the model will determine the market share of the hydrogen technologies in various uses (stationary and mobile) given fiscal policy stimulus.

Describe the Current Policy Framework

The federal government in Canada has already implemented a number of policies related to hydrogen technologies. Thus, before investigating the role of additional policies, it was necessary to first understand the key policies currently in place. To that end, the third step in this analysis was to identify and describe the key fiscal policies currently governing hydrogen developments in Canada.

Identify the Barriers to Hydrogen Developments

The fourth step in this analysis was to identify the barriers, both technological and economic, that currently limit hydrogen technology market penetration in Canada. This was accomplished through a combination of literature review and expert consultation.

Evaluate Fiscal Policies for Hydrogen Development

Once the barriers were identified, it was then necessary to develop an extensive list of fiscal policies that can be employed to overcome these barriers. Thus, the next step in the analysis was to develop a list of fiscal policies and evaluate these policies according to a set of criteria, which included the ability to address a barrier identified in the previous step. The evaluation was used to narrow the list of potential fiscal policy options to only those that offer the greatest potential to increase market penetration of hydrogen technologies in Canada. These policies were further evaluated in the Economic Analysis segment of this research.

The State of the Hydrogen Sector

The hydrogen sector, as defined for this study, is undergoing development in many countries around the world. Development stages range from early research to pre-commercialization and commercialization, with new technologies and products being discovered, advanced and introduced to the marketplace every year. Because the focus in this study is the impact of hydrogen technologies between now and 2030, only the most commercially advanced technologies are discussed in this section.

Developments in hydrogen energy technologies are primarily focused on three end-use sectors: transportation; stationary electricity and heat generation (both for primary and back-up power); and portable power applications. Each of these applications is described in the sections that follow.

Portable Power Applications

Portable power applications are undergoing considerable technological development worldwide. Many research organizations and firms view the portable power sector as an area where hydrogen and fuel cells can offer improved performance compared with conventional technologies, such as batteries, due to their use of an external fuel supply, which may allow longer run-times. There are also expectations from some that the portable power market will provide fuel cells with an early method of commercialization, due to its relatively high cost of power. This will likely serve to further the development of fuel cells and other enabling technologies, as real-world experiences in producing commercial products will result in valuable learnings for fuel cell developers. In addition, early market application of fuel cells and hydrogen provides an opportunity to increase consumer confidence and provide a level of familiarity with the technology that future fuel cell products will benefit from.

Despite the importance of this sector to fuel cell development, portable power applications are not analyzed in this study. Relative to the transportation and stationary sectors, the portable power sector will not have a significant impact on national carbon emissions and it is for this reason that it does not warrant further analysis in this study.

Stationary Electricity and Heat Generation

The development of stationary electricity and heat generation using hydrogen fuel has focused on the use of fuel cell technologies. Comparatively little development has occurred with regards to using hydrogen in other electricity and heat generation technologies, such as stationary internal combustion engines, boilers, turbines and furnaces. The hydrogen fuel supply for fuel cells is most commonly anticipated to be from existing natural gas infrastructure. The majority of the stationary fuel cell products being demonstrated, including those discussed below, therefore include a natural gas reformer or pre-reformer.

Research in this area has focused on several different types of fuel cells:

- **Alkaline fuel cells** (AFC) have been used most prominently in the United States' space program; however, their intolerance to impurities has resulted in little development for terrestrial applications.[1]

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[1] Smithsonian Institute, "Collecting the History of Fuel Cells: A Smithsonian Research Project." Accessed 1 Feb 02 at http://americanhistory.si.edu/csr/fuelcells/index.htm

- **Phosphoric acid fuel cells** have been commercial since 1990 with about 250 units sold worldwide.[2] However, the primary supplier of these systems, UTC Fuel Cells, has shifted much of their development efforts to Proton exchange membrane fuel cells in recent years.[3]
- **Proton exchange membrane** (PEM) fuel cells have been demonstrated in field trials by many companies. Small (1–10 kW) PEM products are considered to be the next closest to commercialization of the non-commercial fuel cell technologies. Large (100–2000 kW) products are also under development and have been demonstrated in several applications.
- **Solid oxide fuel cells** (SOFC) are reaching pre-commercialization with several hundreds of residential stationary power units (about 1 kW) being tested in Europe and larger units (250 kW or above) being evaluated by various utility companies worldwide.[4]
- **Large molten carbonate fuel cells** (MCFC) have also been demonstrated in field trials by a few companies.
- **Direct methanol fuel cells**, which use methanol as a fuel, have been demonstrated on an experimental level.

Electricity is the primary product for all fuel cell types, whereas the use of the output heat depends on the amount of heat, its temperature and the intended application. Combined heat and power (CHP) applications have been proposed for PEM, solid oxide, and molten carbonate fuel cell technologies. The solid oxide and molten carbonate systems operate at higher temperatures than the PEM systems, and therefore are more likely to be applicable to a wider range of CHP applications.

Transportation

For the transportation sector, the number of technologies being developed for use with hydrogen fuel are much more diverse. They include technologies for hydrogen production, storage, transportation, refuelling and use. At this time, the developmental stage for each of these technology categories ranges from basic research to having been commercially available for a number of years; additional details are presented in the sections that follow.

1. **Hydrogen Production** – Hydrogen production can occur through a wide variety of methods, although only those at or near commercialization have been investigated for this study. Hydrogen production from natural gas, electricity and methanol are relatively well-established processes. Further development is required, however, to allow these technologies to supply a vehicle fuelling infrastructure. In particular, the ability to supply hydrogen to a distributed network of fuelling stations and the high purity requirements for PEM fuel cells are issues currently being addressed with new product developments.

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[2] Fuel Cell Today website, 22 May 02, "Fuel Cell Market Survey: Stationary Applications," accessed 18 Oct 02 at www.fuelcelltoday.com

[3] The reasons for this change could be attributed to several factors including a decrease in demand since 1993, a dependence on government subsidies for sales, limited durability of 40,000 hours (or five years), and the need for the products to be re-engineered to reduce capital costs. [Source: Cropper, M., Why is interest in phosphoric acid fuel cells falling? Fuel Cell Today, www.fuelcelltoday.com, 8 Oct 03.]

[4] Colson-Inam, S., "Solid Oxide Fuel Cells. Ready to market?", Cell Expert North America, 07 Jan 04, accessed 23 Jan 04 at www.fuelcelltoday.com

Fuelling station reformers (both centralized and decentralized) fuelled by natural gas or methanol have been demonstrated in field trials on a limited basis. In contrast, decentralized electrolysis units are commercially available, although currently at a relatively high cost due to low production volumes. Methanol and gasoline reformers on-board the vehicle have been demonstrated in a few vehicles at this time, although there is still uncertainty as to whether they will reach prescribed cost and performance targets set out by the United States Department of Energy (DOE). According to the United States DOE, "on board fuel processing presents serious technical and economic challenges of its own that may not be overcome in the required 'transition' time frame. Consequently, DOE is deciding whether to continue onboard fuel processing research and development beyond 2004".[5]

2. **Hydrogen Storage** – While hydrogen storage is a well-established industrial technology, to be suitable for transportation applications higher energy and volumetric densities and relatively low costs are needed. At present, there are a number of different storage types that may be suitable for this application; compressed and liquefied hydrogen are the two most common methods currently used. Liquefied hydrogen is fairly well established within current areas of use and focus is on trying to achieve higher pressures for storing gaseous hydrogen. Three hundred and fifty bar storage is currently being demonstrated in various applications, whereas 700 bar storage is a target for many developers. Advancements in gaseous hydrogen storage include the development of high-pressure hydrogen compressors, valves, seals and storage tanks. Another alternative to hydrogen storage is to store liquid hydrocarbons such as methanol or gasoline and then reform them to hydrogen at a point further downstream, as described in the Hydrogen Production section above.

   Each storage medium has different advantages and disadvantages, and it is still uncertain as to which ones will reach commercial application. The majority of vehicle and refuelling demonstrations up to this point have used 350 bar compressed hydrogen, but this results in relatively limited range with the current demonstration vehicles, and many believe that 700 bar compressed hydrogen is required to achieve comparable ranges to gasoline vehicles.

3. **Hydrogen Transportation** – Hydrogen transportation is again a well-established industrial process and can occur by truck or pipeline. The primary issue with transporting hydrogen is the relatively high initial costs during periods when hydrogen demand at fuelling stations is relatively low. Until demand increases, transporting relatively small amounts of hydrogen will be very expensive. In the meantime, there is a need to combine information related to transporting other fuels by truck and pipeline with knowledge related to hydrogen storage and pipelining to decrease the cost of transporting this fuel. Currently, the amount of hydrogen consumed in North America is approximately 2% of the total oil consumed on an energy basis.[6]

4. **Hydrogen Refuelling** – Hydrogen dispensers for refuelling vehicles are a relatively new technology and have been demonstrated at several refuelling stations around the world. Standardization for the interface between the nozzle and the vehicle, one of the more critical

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[5] United States Department of Energy website, accessed 23 Jan 04, www.eere.energy.gov/hydrogenandfuelcells/fuelcells/transportation.html

[6] Manitoba Energy Development Initiative, *Preliminary Hydrogen Opportunities Report*, Manitoba Energy, Science and Technology, April 2003, http://www.gov.mb.ca/est/energy/hydrogen/hy_report.pdf

features of hydrogen dispensers, is currently being worked on. Developments in this area are required before commercialization can take place.

5. **Hydrogen Use** – Two different types of engines for hydrogen vehicles have seen the most development over the past few years: fuel cell and internal combustion. Fuel cell vehicles have been demonstrated by most of the large automobile manufacturers (light-duty vehicles primarily) and some urban transit companies. The California Fuel Cell Partnership is the largest of these demonstration projects with eight automotive manufacturers engaged with many other technology, fuel and government organizations. Beyond demonstration, both Toyota and Honda have leased fuel cell vehicles to government agencies, although only in limited quantities and at a very high price. The number of fuel cell bus demonstration vehicles produced since 1993 is 65, with 30 of those buses scheduled to be delivered in 2003/04 to two European Commission projects: Clean Urban Transport for Europe (CUTE) and the Ecological City Transport System (ECTOS).

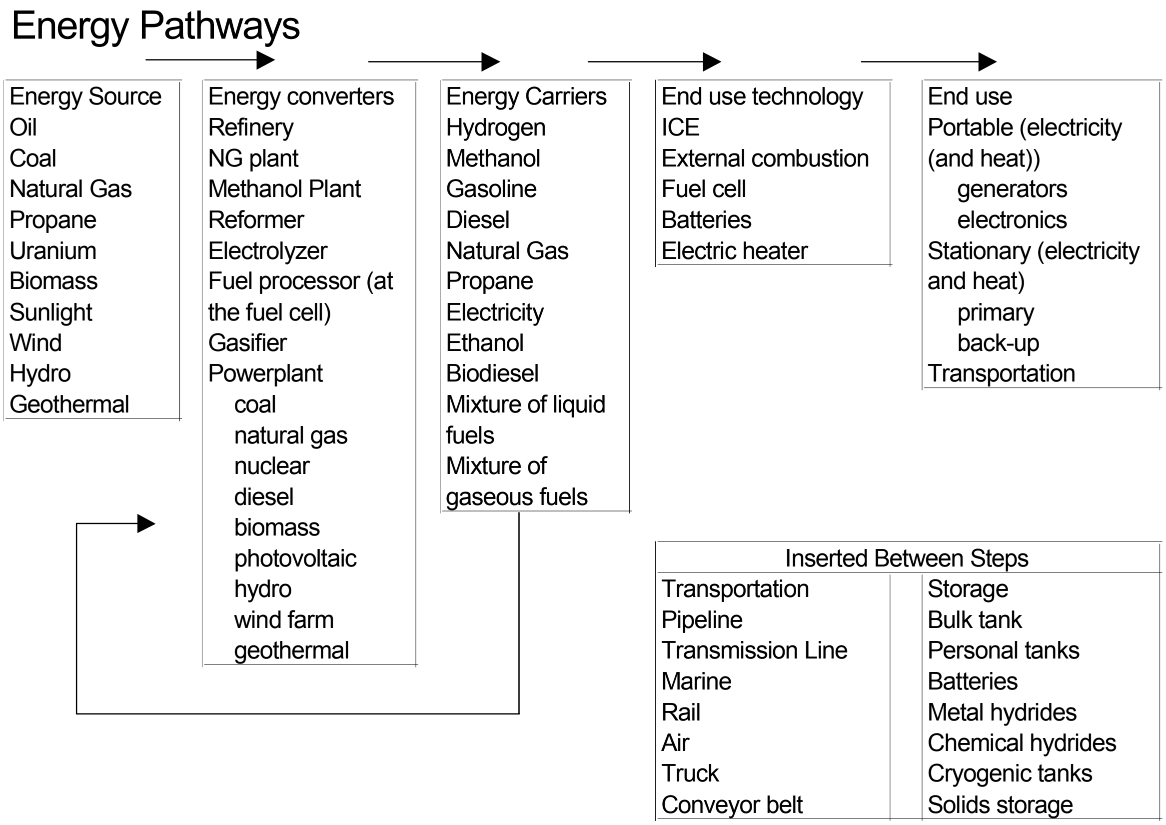
   Hydrogen internal combustion engine (ICE) vehicles have been demonstrated mostly through aftermarket conversions, although Ford demonstrated an original hydrogen ICE light-duty vehicle. The technology to convert ICE engines to run on hydrogen is currently commercially available from a handful of aftermarket conversion companies, and is anticipated by some to be an early market application of hydrogen vehicles.

The above discussion describes the range of applications (portable, stationary and transportation) for hydrogen technologies as well as the many stages of hydrogen development that currently exist. In the section that follows, we put these applications into the context of other energy pathways and identify several key hydrogen pathways for further consideration and modelling.

Hydrogen Pathways

Adding the hydrogen sector to an existing national energy model, as is needed in this analysis, requires that a discrete number of end-uses and corresponding energy pathways be prioritized. To define a list of hydrogen pathways for research, a comprehensive set of energy pathways was first established. These are presented in the figure below. An energy pathway comprises some combination of an energy source, energy converter, energy carrier, end-use technology and end-use. Thus, hydrogen, as an energy carrier, can be combined with any number of energy sources, energy converters, end use technologies and end-uses to form a hydrogen pathway.

Figure 1 Multiple Energy Pathways and Associated Components



As is demonstrated in the figure above, there are numerous hydrogen pathways upon which the role of fiscal policies could be evaluated. However, adding all such pathways to the energy model used in this study was not feasible within the scope of this project. The pathways thus needed to be limited to those pathways associated with well-developed technologies for which data was available. The pathways given further consideration in this analysis, shown in Table 2, were selected according to (1) their ability to reduce carbon emissions and (2) their stage of development.

Table 1: Hydrogen Pathways for Further Consideration

FUEL SOURCE	PRODUCTION	STORAGE	TRANSPORTATION	STORAGE	END-USE
Natural gas from pipeline					Fuel cells SOFC (residential, commercial)
Natural gas from pipeline					Fuel cells MCFC (residential, commercial)
Natural gas from pipeline					Fuel cells PEM (residential, commercial)
Natural gas from pipeline	Decentralized SMR			Compressor and tanks at fuelling stations	Fuel cell LDV[7] or fuel cell transit bus or ICE LDV
Electricity from grid or specific plant	Decentralized electrolyzer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Natural gas from pipeline	Centralized SMR	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Electricity from grid or specific plant	Centralized electrolyzer	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Methanol from offshore natural gas	Decentralized methanol reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Gasoline[8]	Decentralized gasoline reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Methanol from offshore natural gas					Methanol fuel cell LDV
Gasoline					Gasoline fuel cell LDV

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[7] Light-duty vehicle.

[8] Or a similar low sulphur oil derived hydrocarbon fuel such as naphtha.

Not all of the pathways presented above could be incorporated into the Energy 2020 model within the scope of this project. The pathways ultimately chosen for modelling thus include the *most commercially advanced* hydrogen production (steam methane reformers and electrolyzers) and end-use technologies (fuel cells and internal combustion engines), focusing on early market applications for vehicles (decentralized hydrogen production) that do not require a large hydrogen vehicle base. SOFC fuel cells were selected for use in the stationary sector by the NRTEE Project Scoping Group since, at the time of selection, they were considered the most likely technology for use in the defined applications within Canada. These pathways are summarized in Table 2. These pathways will be used to establish benchmarks for hydrogen technology penetration under fiscal policy stimulus. Those pathways that could not be modelled, summarized in Table 3, will be addressed qualitatively.[9]

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[9] Pathways not included in the table are left for future research and analysis.

Table 2: Hydrogen Pathways for Incorporation into Energy 2020

FUEL SOURCE	PRODUCTION	STORAGE	TRANSPORTATION	STORAGE	END-USE
Natural gas from pipeline					Fuel cells SOFC (residential, commercial)
Natural gas from pipeline	Decentralized SMR			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Electricity from grid or specific plant	Decentralized electrolyzer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV

Table 3: Hydrogen Pathways for Further Discussion

FUEL SOURCE	PRODUCTION	STORAGE	TRANSPORTATION	STORAGE	END-USE
Natural gas from pipeline					Fuel cells MCFC (residential, commercial)
Natural gas from pipeline					Fuel cells PEM (residential, commercial)
Natural gas from pipeline	Centralized SMR	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Electricity from grid or specific plant	Centralized electrolyzer	Compressor and tanks or liquefier and cryogenic storage	Pipeline or tube trailer or cryogenic tanker truck	Compressor, tanks and possibly cryogenic storage at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Methanol from offshore natural gas	Decentralized methanol reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Gasoline	Decentralized gasoline reformer			Compressor and tanks at fuelling stations	Fuel cell LDV or fuel cell transit bus or ICE LDV
Methanol from offshore natural gas					Methanol fuel cell LDV
Gasoline					Gasoline fuel cell LDV

Current Policy Framework

Before analyzing the impact of new fiscal policies on the market penetration of hydrogen technologies, it is important to consider the policy framework that already exists in Canada with respect to these technologies. Each of the table components below describes a hydrogen-related policy that is currently in place in Canada.[10] The policies are largely focused on the federal level as this is of most relevance to the current study. Also worth noting is the focus of government support in the form of direct expenditure either through grants, support for research and development or demonstration projects. There are very few tax initiatives (for example credits, refunds and exemptions) targeted at the hydrogen sector in Canada. The policies also demonstrate a focus on hydrogen technology development in British Columbia.[11]

Table 4 Hydrogen Fiscal Policy Framework in Canada

NAME OF INITIATIVE: Technology Partnerships Canada (TPC)
Description: TPC is a technology investment fund for research, development and innovation. The program is designed to encourage private sector investment, and maintain and grow the technology base and technological capabilities of Canadian industry.
Jurisdiction: Federal
Year of implementation: 1996
Objective: To increase economic growth, create jobs and wealth, and support sustainable development in Canada.

NAME OF INITIATIVE: Partnership between Western Economic Diversification Canada (WEDC), National Research Council Innovation Centre, and Fuel Cells Canada
Description: The federal government invested $2.7 million to help Fuel Cells Canada develop six new research laboratories in Vancouver. Western Economic Diversification is contributing $1 million and the National Research Council of Canada (NRC) $1.7 million towards the new hydrogen-safe laboratories located at NRC's Fuel Cell Technology Centre at the University of British Columbia. In June 2003, Fuel Cells Canada announced that it received a $1.5 million contribution from WEDC.
Jurisdiction: Federal
Year of implementation: 2002
Objective: To further develop the fuel cell cluster in Vancouver, British Columbia.

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[10] For a review of international fiscal policy examples and precedents visit: http://strategis.ic.gc.ca/epic/internet/inmse-epe.nsf/vwGeneratedInterE/h_ep00018e.html

[11] For more information see the following publication: Taylor, Amy, Jesse Row and Mark Winfield. 2002. *A Fiscal Framework for a Fuel Cell and Hydrogen Economy: A review of international fiscal policy and program examples and precedents.* A report prepared for Industry Canada and available at: http://strategis.ic.gc.ca/epic/internet/inmse-epe.nsf/vwGeneratedInterE/h_ep00018e.html

NAME OF INITIATIVE: Western Economic Partnership Agreement (WEPA)
Description: The federal and B.C. governments agreed, under WEPA, to invest $13 million in the fuel cell industry. Several projects were funded through WEPA: • Six fuel cell projects in British Columbia received $5.2 million. • A $980,000 contribution established Fuel Cells Canada. • Almost $4.6 million was invested in testing and evaluating fuel cell bus engines.
Jurisdiction: British Columbia with funding from the federal government
Year of implementation: 2000 to 2003
Objective: The objective of WEPA is to extend the international competitiveness of the B.C. economy and provide economic development opportunities for communities throughout the province.

NAME OF INITIATIVE: Canadian Transportation Fuel Cell Alliance (CTFCA)[12]
Description: This is a $23 million federal government initiative that will demonstrate and evaluate fuelling options for fuel cell vehicles in Canada.
Jurisdiction: Federal
Year of implementation: 2001
Objective: To demonstrate greenhouse gas emission reductions and evaluate different fuelling routes for fuel cell vehicles, and to develop the necessary supporting framework for fuelling infrastructure, including technical standards, codes, training, certification and safety.

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[12] This is part of Action Plan 2000, described in more detail in the next section of the table.

NAME OF INITIATIVE: National Research Council (NRC) Fuel Cell Program
Description: NRC's Fuel Cell Program is a cross-Canada program delivered by NRC institutes across Canada to serve Canadian industry. The Innovation Center at the University of British Columbia is one component of the program and is the administrative headquarters. In collaboration with industry, universities and other government agencies, the program provides research and innovation support in the areas of component development, system integration and manufacturing, design, and environmental control and assessment of fuels research. In August 1999, the federal government provided $30 million to further strengthen the fuel cell industry's research and development, including $14 million managed by the Natural Sciences and Engineering Council (NSERC) and NRC, designed to lever private sector support for new industry collaborations with researchers in NRC institutes and Canadian universities; $10 million from NSERC and $4 million from NRC for the creation of a Network Coordination Office; funding for the creation of five Industrial Research Chairs; targeted project funding for university research that involves collaboration with Canadian industry and NRC institutes; and support for the training and education of students through Industrial Postgraduate Scholarships. The Innovation Center is a strategic partnership between the NRC, NSERC and Natural Resources Canada (NRCan). In 2002, Minister of Industry Allan Rock announced $20 million in additional funding to fuel cell research and development at its NRC Innovation Center.
Jurisdiction: Federal
Year of implementation: 1999
Objective: To strengthen university research capacity in the area of fuel cells; link industries, universities and NRC institutes to encourage collaborative research; ensure effective and efficient technology transfer to industry; and provide scientific career and skills development opportunities to young Canadians.

NAME OF INITIATIVE: Vancouver Fuel Cell Vehicle Program
Description: This three year, $5.8 million initiative will test vehicles' performance, durability and reliability and help accelerate the commercialization of fuel cell vehicles. The Government of Canada is supporting this initiative through a $2 million contribution by NRCan, the Technology Early Action Measures (TEAM) component of the Climate Change Fund and Technology Partnerships Canada.
Jurisdiction: Federal
Year of implementation: 2003
Objective: To demonstrate five third-generation Ford fuel cell vehicles in "real world" conditions.

NAME OF INITIATIVE: Innovation Excellence

Description: $20 million will be invested in advancing Canada's leadership, through support for research, development and proof-of-concept demonstrations in hydrogen technologies. The Canadian Fuel Cell Commercialization Roadmap will provide strategic direction for these investments. This is one of three components of the Government of Canada's investment in the foundations of the hydrogen economy.

Jurisdiction: Federal

Year of implementation: 2003

Objective: To reduce costs and improve the reliability, durability and longevity of hydrogen technologies, including production, distribution and storage technologies and those involving different energy pathways.

NAME OF INITIATIVE: Partnership for a Hydrogen Infrastructure Through Sustainable Development Technology Canada

Description: Sustainable Development Technology Canada will invest $50 million to expand its investments in partnerships that are demonstrating the potential of hydrogen. Sustainable Development Technology Canada will act as a primary catalyst to build a hydrogen infrastructure in Canada.

Jurisdiction: Federal

Year of implementation: 2003

Objective: To develop partnerships related to early development and demonstration of technological solutions addressing climate change and air quality.

NAME OF INITIATIVE: Capital Equipment for Scientific Research and Experimental Development

Description: Eligible capital expenditures for the provision of premises, facilities or equipment used for scientific research and experimental development in Canada may be fully deducted in the year they are incurred.

Jurisdiction: Federal and provincial

Year of implementation: N/A

Objective: To encourage research and development in Canada that will lead to new, improved or technologically advanced products or processes.

NAME OF INITIATIVE: Capital Cost Allowance

Description: A capital cost allowance provides a deduction against income for depreciated property. Many classes of depreciable property exist. Fuel cell and hydrogen technologies currently qualify for a 30% declining balance capital cost allowance.

Jurisdiction: Federal

Year of implementation: N/A

Objective: To account for the depreciation of capital investments over time and make it more attractive for investors to undertake capital investments.

NAME OF INITIATIVE: Vehicles Powered by Alternative Fuels (Ontario)

Description: People who purchase or lease new or used vehicles may qualify for a refund of retail sales tax (RST) if the vehicles operate or are converted to operate:

- On electrical energy
- On propane, natural gas, ethanol, methanol, or other manufactured gases; or
- As dual-powered vehicles (vehicles that use one of the alternative fuels mentioned above and that can also be powered by gasoline or diesel fuel).

In addition to the 8% RST, the tax for fuel conservation (TFFC) paid on new passenger cars or new sport utility vehicles may be refunded if the vehicles operate or are converted to operate exclusively on an alternative fuel. Hybrid vehicles operating on both gas and electricity also qualify for the refund.

Jurisdiction: Ontario

Year of implementation: 1996

Objective: To increase sales of alternatively powered vehicles.

NAME OF INITIATIVE: B.C. Tax Credit for Alternative Fuel Vehicles and Alternative Motor Fuel Tax Concessions
Description: Several provisions are provided in B.C. for alternative fuels and alternative fuel vehicles. Alternative fuel vehicles qualify for a partial refund of the provincial social service tax. Alternative fuel vehicles that are passenger vehicles and that are subject to the 8%, 9% or 10% provincial sales tax rates may be eligible for a reduced tax rate. Kits to convert motor vehicles to eligible alternative fuels, and services to install, repair and maintain such equipment, are exempt from tax. And there are exemptions and preferential tax rates for certain alternative fuels that are environmentally preferable to gasoline or diesel fuel. Qualifying alternative fuel vehicles include those that operate exclusively on electricity, ethanol, methanol, natural gas or propane; as hybrid electric vehicles that are propelled by a combination of stored electricity and gasoline, diesel, hydrogen, natural gas, propane, methanol or ethanol; or as bi-fuel vehicles that have two separate fuel storage tanks so the vehicles can be propelled by an alternative fuel or by gasoline or diesel fuel.
Jurisdiction: Provincial
Year of implementation: Refunds, reduced rates and exemptions were introduced and revised in 2001 and 2002.
Objective: To increase purchases of alternative fuel vehicles and alternative fuels in British Columbia.

While the focus of this study is on fiscal policies rather than regulations, it is worth highlighting regulatory initiatives related to hydrogen technologies. Key government departments working on codes and standards in Canada are Natural Resources Canada and Transport Canada.[13] Natural Resources Canada is responsible for developing codes and standards related to technology performance and efficiency, while Transport Canada focuses on the development of safety standards and regulations. Currently, there are no internationally recognized codes and standards for hydrogen technologies. Transport Canada is undertaking a study to develop fuel system standards for hydrogen-fuelled vehicles and related work is taking place internationally. Specifically, a draft regulation has been prepared by the United Nations related to hydrogen-fuelled road vehicles. Canada, as a signatory to a 1998 UN resolution, would be obligated to adopt this regulation.[14]

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13 Canadian Fuel Cell Commercialization Roadmap.

14 http://www.tc.gc.ca/tdc/projects/road/e/5468.htm

Barriers to Hydrogen Development

While the policies described above are in place to address, at least to a certain degree, current barriers for hydrogen development, technical and economic barriers continue to limit the market penetration of hydrogen technologies in Canada. The table below presents current barriers associated with hydrogen development. The barriers are grouped according to whether they are explicitly related to hydrogen fuel and/or infrastructure, fuel cell technologies, or both. In addition, the barriers are identified as either technical or economic.

Table 5 Barriers Limiting Hydrogen Development in Canada

SECTOR	ECONOMIC	TECHNICAL
Hydrogen Fuel / Infrastructure	Cost of hydrogen production.[A] Cost of hydrogen distribution.	Storage, compressors and distribution network.[B] Fuel reformers and processors.[C] Emission reductions depend on source of hydrogen.
Fuel Cell Technologies	Cost of materials and components. Cost of production. Current market design for electricity.[D]	Durability, perfecting manufacturing processes and improving performance.[E] Maintenance support.[F]
Hydrogen Fuel / Infrastructure and Fuel Cell Technologies	The need for capital investment and financing. Limited scale of operation.	The need for codes and standards.[G] Integration with other systems.[H]

A The higher anticipated cost of hydrogen technologies, compared with incumbent technologies, is due to several factors, including limited economies of scale (both for the manufacture of hydrogen and fuel cell technologies, and for the distribution of hydrogen).

B The handling of hydrogen gas at pressures as high as 700 bar (approx. 10,000 psi) is relatively uncommon. The technologies to do this safely and economically still need to be developed.

C Small-scale steam methane reformers and on-board gasoline and methanol fuel processors require further development in order to meet cost and performance targets.

D For example, if a homeowner installed a fuel cell in their home, they could not connect it to the electricity grid in the region. The homeowner would therefore not benefit from the ability to put any excess electricity they were able to generate through use of their fuel cell onto the grid for financial gains.

E Fuel cells have yet to be used widely in commercial applications for long periods of time. To accomplish this, the performance of fuel cells will need to be improved, particularly their tolerance to varying operating conditions and their longevity. The costs will also need to be reduced through the development and implementation of large-scale manufacturing facilities.

F Consumer acceptance of fuel cells will depend on both the product itself and the supporting infrastructure to enable its convenient operation. An acceptable level of support for the operation and maintenance of fuel cells will be needed to ensure successful adoption of the technology.

G There are many safety and basic operability requirements for any technology. Hydrogen technologies require that these requirements be developed and applied to the various new applications that are envisioned for these technologies through the standardization of codes of practice. The codes and standards of public safety, building construction and automobile manufacturing are quite extensive and well established. Without having codes and standards in place, it becomes extremely resource-intensive to meet established safety and design requirements on a unit-by-unit basis.

H Hydrogen technologies will need to be integrated with the existing infrastructure including buildings, cars, or refuelling stations. Extensive research and design is required to ensure that this is accomplished successfully.

A societal barrier to hydrogen development is awareness, familiarity and general acceptance of the technologies. The majority of consumers, as well as product developers, are cautious about adopting new technologies until they have proven to meet their needs. Overcoming this barrier would involve educating these groups about the capabilities and accomplishments of hydrogen technologies.

In order to achieve significant market penetration of hydrogen technologies, a number, if not all, of these barriers need to more or less be overcome. Governments can increase the speed by which these barriers are addressed by intervening in market developments through the implementation of policies targeted at these barriers. In many cases, fiscal policies, and hence ecological fiscal reform, can minimize or reduce an existing barrier. In the section that follows, we identify a comprehensive list of fiscal policies and evaluate these policies according to their ability to address a barrier identified above, among other factors.

Fiscal Policies for Addressing Barriers

To the extent that the market penetration of hydrogen technologies is limited by the set of barriers described in the preceding section, governments can implement fiscal policies targeted at those barriers and facilitate market penetration. There are a host of policies available to governments in this regard, including:

- Greenhouse Gas Emissions Cap and Trade Program
- Eco Labelling
- Renewable Portfolio Standards
- Investment Tax Credits
- Producer Tax Credits
- Accelerated Capital Cost Allowances
- Research and Development
- Procurement
- Information and Education Programs
- Grants
- Carbon Taxation
- Reduction or Elimination of the Capital Tax
- Consumer Tax Credit
- Pilot or Demonstration Project

Not all of these policies will be equally suited for addressing the specific barriers associated with hydrogen technologies. Indeed, some policies may be too general to explicitly address hydrogen barriers, other policies may be politically unfeasible, and still other policies may not provide sufficient incentive to increase market penetration. To identify the most promising set of fiscal policies for facilitating hydrogen technology market penetration, the above list of policies was evaluated according to the following set of criteria:

1. **Administrative Requirements** – We provide a brief description of what would be required from an administrative perspective to implement the particular policy. We consider whether it would simply be an extension of an existing program, whether the systems needed to support the policy are already in place (for example in the case of eco-logos), or whether the policy would require monitoring and reporting that are not currently established.

2. **Incentive Effect** – Policies are evaluated according to whether they provide a direct incentive to hydrogen technologies or whether they apply more broadly, for example to any capital investments or all energy-efficient technologies. In the case of the latter, the incentive effect would be indirect as opposed to direct. Policies are also evaluated according to their ability to provide an ongoing incentive to invest in hydrogen technologies, as opposed to a one-time investment.

3. **Ability to Address Hydrogen/Fuel Cell Barrier** – Here we consider whether the policy is explicitly targeted at a known barrier associated with hydrogen (and fuel cell) technologies or whether it applies more broadly to various technologies.

4. **Likely Environmental Effectiveness** – Some policies will have a greater impact on environmental conditions than others. To evaluate the environmental effectiveness of particular

policies, we provide a brief description of the potential scale of impact the policy could have on environmental conditions.

5. **Cost Effectiveness** – Here we provide a brief description of the potential cost of the policy from a government and/or industry perspective. We identify cases where costs may be prohibitive or where they may be justifiable.
6. **Political Feasibility** – The objective for this criterion is to provide a sense of the federal government's stance on the particular policy. We note cases where precedents exist, where the type of policy is under consideration, or where the government has stated that it will not be pursuing the particular policy.[15]

The details of this policy evaluation are presented in the table below (in no particular order), and the results of this analysis are summarized in a table at the end of this section (Table 7).

Table 6: Fiscal Policy Evaluation

POLICY OPTION: Greenhouse Gas Cap and Trade
Description: This measure would establish an overall cap on greenhouse gas emissions and allocate emission allowances among emitting entities. The allowances could then be traded such that the total emissions remain at or below the specified cap. Entities would be encouraged to invest in emission reducing activities and technologies to the extent that such investments are more economical than the value of the emission allowances.
Administrative Requirements: The administrative requirements depend on the scope of the trading scheme – i.e., just large industrial emitters or all emitters, and could be substantial.
Incentive Effect: Depending on design, this type of policy can provide incentive to invest in energy-efficient and renewable energy technologies. Such a system will not guarantee investment in hydrogen technologies as emission reductions can be achieved in a number of different ways, some of which will certainly be cheaper than hydrogen and fuel cell investments.
Addresses Hydrogen/Fuel Cell Barrier: While this type of policy will encourage investments in technologies and processes that reduce greenhouse gas emissions, it will not explicitly address an existing barrier associated with hydrogen fuel or fuel cell technologies.
Likely Environmental Effectiveness: The environmental effectiveness of this policy depends on the scope of the program as well as the level at which the total greenhouse gas emissions for those participating in the trading program are capped. The impact on emissions could be significant.
Cost Effectiveness: Cap and trade programs are considered to be cost effective in that only those emission reductions that are most cost effective (i.e., cheaper than the cost of buying an allowance) are realized.
Political Feasibility: The federal government in Canada is currently considering a cap and trade program as a means to reduce greenhouse gas emissions. The political feasibility of such a program depends largely on the design and scope of the program.

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[15] Note that to limit uncertainty and increase simplicity of analysis, in the case of this criterion we focus on the current stance of government with respect to each policy. However, because the modelling for this analysis is over a 30-year period, it is possible that over time the political feasibility of any one of these policies could increase or decrease.

POLICY OPTION: Eco Labelling
Description: Eco labels identify or specify environmental attributes for goods and services. Such labels are intended to provide guidance to consumers so that they can make more informed investment decisions.
Administrative Requirements: To be truly legitimate, eco labels should be verified for compliance with strict ecological and performance criteria by independent, registered bodies. Third-party verification is already required for the Energy Star energy efficiency label in Canada, so extending such a program to other goods should be administratively straightforward.
Incentive Effect: While an eco labelling program does not provide an ongoing incentive to purchase or invest in hydrogen technologies, this type of program does provide the opportunity to distinguish these technologies from their competition.
Addresses Hydrogen/Fuel Cell Barrier: This program would not explicitly address any of the barriers identified above.
Likely Environmental Effectiveness: Unless a program such as this is used in combination with other programs that reinforce environmental objectives, it is unlikely that such a program would have a significant effect on environmental conditions.
Cost Effectiveness: The costs associated with such a program should not be prohibitive, although third-party verification will increase costs.
Political Feasibility: Based on experience with existing eco-logo programs in Canada (e.g., the Environmental Choice EcoLogo, the Green Leaf program and the Energy Star label), assigning such a rating to hydrogen technologies should be politically feasible.

POLICY OPTION: Renewable Portfolio Standard
Description: A renewable portfolio standard (RPS) ensures that a minimum amount of renewable energy is included in the portfolio of electricity resources serving a region.
Administrative Requirements: An RPS requires that compliance be tracked and verified. This entails the use of certification to demonstrate correspondence between sales and renewable energy generation.
Incentive Effect: An RPS would not provide a direct or ongoing incentive to invest in hydrogen technologies because the standard would specify production of energy from renewable sources, not the use of particular technologies (i.e., hydrogen technologies). Furthermore, energy from hydrogen would only be covered by an RPS to the extent that the hydrogen came from a renewable source (i.e., wind power).
Addresses Hydrogen/Fuel Cell Barrier: This policy would not explicitly address a barrier associated with hydrogen fuel and fuel cell technologies.
Likely Environmental Effectiveness: The impact on environmental conditions will depend on whether the renewable energy is displacing energy that is associated with high environmental impacts. It will also be directly correlated with the level of standard (i.e., the amount of energy that must come from renewable sources) established by the RPS.
Cost Effectiveness: Because an RPS forces the use of renewable technologies, which may be relatively more expensive than conventional technologies, it can be costly. The extent of the cost will depend on the level of the standard.
Political Feasibility: Renewable Portfolio Standards have not been implemented in Canada on a significant scale, but momentum is gaining and they are becoming more politically feasible. RPSs are under consideration in Nova Scotia and British Columbia. BC Hydro has committed to supply 10% of new demand from green electricity sources, targeting 800 GWh of electricity supply in 2003. Ontario recently announced that it will introduce an RPS to require generators in Ontario to secure an additional 1% of their electricity needs for eight years from wind, solar, hydro and biomass energy sources, starting in 2006.

POLICY OPTION: Investment Tax Credit
Description: Investment tax credits (ITC) are awarded for a portion of eligible costs associated with investments in specified technologies and/or activities. Such credits usually amount to 20% to 40% of eligible investment costs.[16]
Administrative Requirements: Because such policies are already in place in Canada (e.g., the Canadian Renewable Conservation Expenses program), implementing complementary policies, targeted at hydrogen technologies, should not result in significant administrative requirements.
Incentive Effect: Investment tax credits provide an ongoing and direct incentive to invest in eligible technologies. To the extent that hydrogen technologies qualified for such an incentive, an increase in the use of such technologies would be likely.
Addresses Hydrogen/Fuel Cell Barrier: Such a policy could be designed to explicitly address cost barriers associated with hydrogen and fuel cells.
Likely Environmental Effectiveness: To the extent that the investment tax credit is sufficiently large and market penetration of hydrogen and fuel cells ensues, environmental improvements would likely be realized.
Cost Effectiveness: The cost of the program would depend on the size of the credit required to overcome existing barriers and facilitate market penetration and could be substantial.
Political Feasibility: Because such policies already exist in Canada (e.g., the Canadian Renewable and Conservation Expenses program and the Renewable Energy Deployment Initiative), implementing such a policy targeted at hydrogen technologies should be politically feasible.

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16 A flow-through share tax credit is an investment tax credit for shareholders who purchase eligible flow-through shares. A portion of the investment in shares is then claimable as a refundable tax credit against taxes due. For the purposes of this analysis, the model that will be employed to simulate the effect of fiscal policies on hydrogen development will not include macroeconomic feedbacks and we will thus not be able to simulate the effect of a tax credit for shareholders within this particular analysis. This should be a topic of future research and consideration.

POLICY OPTION: Producer Tax Credit
Description: Producer tax credits (PTC) are awarded to energy producers according to the amount of energy produced. Such credits are usually based on the number of kilowatt-hours (kWh) of electricity produced from renewable sources (e.g., 1.5 cents/kWh of electricity from wind power).
Administrative Requirements: A precedent has been set with the introduction of the Wind Power Production Incentive. This initiative can inform production incentives for additional energy sources and can form the basis for expanding the incentive program.
Incentive Effect: Producer tax credits provide an ongoing and direct incentive to invest in the production of certain types of energy. By linking a producer tax credit to energy produced from hydrogen, such a policy would provide a direct and ongoing incentive to invest in hydrogen technologies.
Addresses Hydrogen/Fuel Cell Barrier: Such a policy could be targeted specifically at cost barriers associated site using hydrogen technologies (fuel cells) to create energy.
Likely Environmental Effectiveness: The environmental effectiveness will depend on the relative reduction in emissions from conventional technologies as the market penetration of hydrogen technologies increases as a result of this policy. In the case where fuel cells are used to generate electricity from natural gas, the increased efficiency of the fuel cell will lead to improved environmental conditions.[17]
Cost Effectiveness: The cost of this program will be determined by the gap between conventional fuels and hydrogen and therefore the magnitude of the credit that is needed to overcome this barrier.
Political Feasibility: Due to the precedent set with the Wind Power Production Incentive (WPPI), implementing a hydrogen or energy from hydrogen production incentive may be politically feasible.

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[17] In the case where electricity from the grid rather than natural gas is used in a fuel cell, and even in the case where the electricity is from a renewable source (i.e., wind power), any improvements in environmental conditions will be difficult to estimate. This fact is due to the integrated nature of the North American energy market. Rather than displace electricity from the Canadian grid, the use of hydrogen technologies is apt to add to total national electricity generation as the electricity that would have been displaced is instead exported to the United States.

POLICY OPTION: Accelerated Capital Cost Allowance
Description: Certain investments qualify for accelerated capital cost allowances (ACCA). These allowances specify the rate at which the cost of the investment can be claimed as a deduction for tax purposes over time. Investments in hydrogen technologies currently qualify for a capital cost allowance of 30%. Increasing this allowance rate would provide additional incentive to invest in hydrogen technologies.
Administrative Requirements: Because these technologies already receive an allowance of 30%, the administrative requirements extending the rate would not be significant.
Incentive Effect: An increased capital cost allowance for hydrogen technologies would provide a direct and ongoing incentive to invest in these technologies.
Addresses Hydrogen/Fuel Cell Barrier: An increased ACCA would help address cost barriers associated with hydrogen technologies.
Likely Environmental Effectiveness: To have a significant effect on environmental conditions, the ACCA for hydrogen technologies would have to increase substantially. Otherwise, hydrogen technologies would not gain a competitive edge on competing technologies and market penetration of these technologies would not be enough to impact environmental conditions.
Cost Effectiveness: Increasing the ACCA for hydrogen technologies should not result in significantly increased costs.
Political Feasibility: Precedents have been set with increasing the ACCA in Canada. For example, the December 2001 budget increased the upper limit on the size of small hydroelectric projects that qualify for a 30% capital cost allowance to a maximum annual rated generating capacity of 50 MW from the previous limit of 15 MW. Given precedents such as this, increasing the ACCA for hydrogen technologies should be politically feasible.

POLICY OPTION: Research and Development
Description: Governments make funds available to support research and development of new and innovative technologies. The purpose of such programs is often to gain technological experience and to drive down often high, prohibitive, initial costs of relatively new technologies.
Administrative Requirements: Research and development programs are very common in Canada and relatively easy to administer.
Incentive Effect: A research and development program that was designed to explicitly target hydrogen technologies would help to reduce costs and provide an incentive to invest in such technologies.
Addresses Hydrogen/Fuel Cell Barrier: Such a program could be designed to target specific barriers currently preventing market penetration of hydrogen technologies.
Likely Environmental Effectiveness: Research and development programs do not result in immediate improvements in environmental conditions. Rather, over-time, as costs are reduced and market penetration increases, environmental improvements ensue.
Cost Effectiveness: Depending on the scale of such programs, costs can be substantial.
Political Feasibility: There are numerous examples of the federal government dedicating funds to support research and development related to hydrogen technologies in Canada. Specific examples include support for the National Research Center's Fuel Cell Program and the Transportation Energy Technology Program. Given this experience, it appears that supporting hydrogen technologies through research and development programs is politically feasible.

POLICY OPTION: Procurement
Description: Procurement policies secure support for a set of technologies or goods in the form of guaranteed purchases of those goods or technologies. In many cases, government entities will secure the particular goods for their own use or consumption, often at a premium price. In doing so, they increase commercialization of new and innovative technologies and prices decline over time.
Administrative Requirements: Administrative requirements related to procurement programs are relatively minor.
Incentive Effect: While procurement programs do not provide an ongoing incentive to invest in particular technologies, they do guarantee a specified level of investment and, in doing so, provide security to manufacturers that a portion of their goods will be supported.
Addressed Existing Barrier: A procurement program would help overcome existing barriers by providing opportunities for fuel cell and hydrogen technologies to be used in "real life" settings. Lessons learned through such a program can help overcome technological barriers while at the same time lead to a reduction in costs.
Likely Environmental Effectiveness: The environmental impact of a procurement program focused on hydrogen technologies depends on the level of commitment towards the goods and is likely to be minimal in the short term.
Cost Effectiveness: Such policies can be costly depending on the level of commitment that is made towards the technologies.
Political Feasibility: Procurement programs are politically feasible and provide opportunities for governments to take on leadership roles in facilitating market penetration of new and innovative technologies. Procurement policies in Canada currently support a number of renewable energy initiatives. For example, the Government of Canada Action Plan 2000 on Climate Change announced a commitment to purchase 20% of federal electricity requirements from emerging renewable energy sources.

POLICY OPTION: Information and Education
Description: Information and education programs are often introduced to overcome barriers related to public confidence and understanding. Such policies are needed to increase knowledge and awareness of new and cutting-edge technologies and to provide consumers with the tools they need to make informed investment decisions.
Administrative Requirements: Administrative requirements related to information and education programs depend largely on the design and scope of the particular program. Implementing a program that is targeted at a particular group (e.g., energy producers) will be much less administratively onerous than implementing a program that is targeted more broadly at all industrial users, for example.
Incentive Effect: Information and education programs would not provide an ongoing incentive to invest in hydrogen technologies. However, by increasing understanding and awareness of such technologies, they can lead, indirectly, to increased market penetration of the target technologies.
Addresses Hydrogen/Fuel Cell Barrier: An information and education program related to hydrogen technologies targeted at financial institutions or potential investors could help to overcome barriers associated with accessing financing and capital investments.
Likely Environmental Effectiveness: Without the support of complementary policies targeted at hydrogen technologies, an information and education program is unlikely on its own to have a significant impact on environmental conditions.
Cost Effectiveness: Depending on the scope of such policies, they can be relatively inexpensive to administer.
Political Feasibility: Information and education programs are considered low risk and tend to be politically feasible.

POLICY OPTION: Grants
Description: Grants can be awarded for investments in particular technologies and can help overcome competitiveness gaps between new and innovative technologies and less expensive conventional technologies.
Administrative Requirements: Depending on the scope of a grant program, such an initiative can be relatively easy to administer. A grant program targeted at a particular set of technologies (e.g., hydrogen technologies) would not be excessively onerous.
Incentive Effect: Grant programs can provide direct and ongoing incentives to invest in particular technologies.
Addresses Hydrogen/Fuel Cell Barrier: Such policies can be designed to explicitly address barriers associated with hydrogen technologies.
Likely Environmental Effectiveness: To the extent that the use of the technologies that receive the grants results in emission reductions, improvements in environmental conditions can be expected.
Cost Effectiveness: Grant programs can be costly depending on the magnitude of the barrier that needs to be overcome in order to achieve market penetration.
Political Feasibility: The federal government has used grant programs to encourage hydrogen and fuel cell developments in Canada in the past. For example, Fuel Cells Canada received $980,000 in 2000 to identify, coordinate and present fuel cell demonstration projects for further consideration and funding. Given this and other examples, additional grants to support hydrogen technologies seem politically feasible.

POLICY OPTION: Carbon Tax
Description: A carbon tax is levied on fossil fuels according to their relative carbon content (in the form of $/tonne of CO_2 equivalent). In this way, fuels with relatively higher carbon content become relatively more expensive and their consumption is thus discouraged.
Administrative Requirements: The administrative requirements for implementing a carbon tax in Canada could be substantial. To minimize costs, it would be useful to use a tax framework already in place in Canada, such as that which exists for excise fuel taxes.
Incentive Effect: Such a policy would provide a direct and ongoing incentive to purchase low-carbon fuel but would not provide a direct incentive to invest in hydrogen technologies. Such technologies would likely benefit indirectly from a carbon tax.
Addresses Hydrogen/Fuel Cell Barrier: This policy would not explicitly address a barrier associated with hydrogen technologies but would indirectly make hydrogen technologies more competitive with conventional technologies.
Likely Environmental Effectiveness: The impact on greenhouse gas emissions could be substantial and will be driven by the level of the tax that is imposed.
Cost Effectiveness: Environmental taxes, such as carbon taxes, are seen as being cost effective in that investments in emission reductions will be realized only to the extent that they are cheaper than the carbon tax itself. Thus, only the most economical emission reduction investments occur.
Political Feasibility: A carbon tax is currently not politically feasible in Canada, although several European countries have implemented carbon taxes as a means to reduce emissions and strive towards commitments established in the Kyoto Protocol.

POLICY OPTION: Reduction or Elimination of Capital Taxes
Description: The federal government as well as most provincial governments levy capital taxes on investments in capital goods. Such taxes could be reduced or eliminated at the federal level.
Administrative Requirements: Reducing or eliminating this tax would not be administratively difficult. However, if it were only capital investments in fuel cell and hydrogen technologies that were eligible for the reduced or eliminated capital tax, the administrative requirements would become much more onerous.
Incentive Effect: Reducing or eliminating the federal capital tax would encourage investment in capital goods in general. It would not be explicitly targeted at hydrogen technologies and would thus not provide a strong incentive to invest in these technologies relative to other competing technologies. A reduced or eliminated capital tax for which only investments in fuel cell and hydrogen technologies were eligible, would provide a direct incentive to hydrogen investments.
Addresses Hydrogen/Fuel Cell Barrier: This policy would help to overcome some of the financial barriers associated with investments in hydrogen technologies.
Likely Environmental Effectiveness: Because such a policy would not target capital investments in renewable or energy-efficient technologies in particular, it would not lead to improved environmental conditions. Indeed, the removal or elimination of the capital tax is likely to prompt investments in conventional technologies as well and could therefore result in an increase in greenhouse gas emissions and a decline in environmental conditions. A reduction in the tax for only hydrogen or renewable investments would have a positive impact on environmental conditions.
Cost Effectiveness: Reducing or eliminating the federal capital tax would mean a reduction or the elimination of a stable source of funds for the federal government.
Political Feasibility: While some provinces have reduced or eliminated their capital taxes (Alberta and British Columbia) there are not any indications that the federal government plans to do the same. There are no precedents in Canada of a reduced capital tax for particular types of investments; such reductions have only occurred for all investments. To target particular types of capital investments, an accelerated capital cost allowance is the more common fiscal policy tool.

POLICY OPTION: Consumer Tax Credit
Description: Consumer tax credits are offered to individuals that undertake investments in certain goods or activities. In the context of hydrogen technologies, consumer tax credits could be offered for investments in fuel cell vehicles or fuel cells for residences or commercial establishments.
Administrative Requirements: Examples of such credits already exist in Canada and such a policy would be relatively easy to administer.
Incentive Effect: The policy would provide a direct and ongoing incentive to invest in eligible technologies.
Addresses Hydrogen/Fuel Cell Barrier: This policy would explicitly address economic barriers associated with investing in hydrogen technologies (fuel cells).
Likely Environmental Effectiveness: To the extent that this policy is successful in addressing economic barriers, investments in hydrogen technologies would be realized and environmental improvements achieved.
Cost Effectiveness: Costs associated with this policy should be justifiable for a period of time until hydrogen technologies achieve minimum levels of production and the costs of these new and innovative technologies decline.
Political Feasibility: A consumer tax credit can come in several forms including an exemption from sales tax, a credit against income tax or a rebate on taxes paid. Precedents of such taxes in Canada are numerous. For example, in British Columbia, the purchase of materials and equipment used to conserve energy is exempt from the sales tax. Alternatively fuelled vehicles, including fuel cell vehicles, in British Columbia and Ontario currently qualify for tax concessions.

POLICY OPTION: Pilot or Demonstration Projects
Description: Through pilot or demonstration projects, governments ensure that certain technologies are developed and tested in real-world circumstances by assuming a portion of the costs and risks associated with the development and implementation of particular technologies.
Administrative Requirements: The administrative requirements of such a program are not onerous, although governments do have to decide what technologies are most worthy of investment.
Incentive Effect: Such programs provide incentive for developers to invest in those technologies that are targeted by pilot or demonstration projects. The scope of the project may be narrow or broad and will have a direct impact on the level of incentive provided.
Addresses Hydrogen/Fuel Cell Barrier: Such programs help address cost barriers for the particular technologies that are chosen as worthy of investment. The information gained through pilot projects can help to reduce costs and make technological improvements.
Likely Environmental Effectiveness: Because only a limited number of technologies are covered by pilot or demonstration projects, they do not generally have a significant effect on environmental conditions.
Cost Effectiveness: Because pilot programs focus on getting particular technologies to an implementation stage, they do not generally require ongoing, long-term funding and are thus not cost prohibitive.
Political Feasibility: Examples of such projects are numerous in Canada, including government support for Vancouver's fuel cell transit bus demonstration project.

The National Round Table on the Environment and the Economy is particularly interested in how barriers that limit (1) demand for hydrogen technologies and (2) infrastructure for hydrogen technologies can be addressed using fiscal policy. At the same time, the NRTEE's ultimate objective is to develop recommendations on fiscal instruments that can be presented to the Government of Canada. Given these considerations and to refine the substantial set of policies presented above, weight was given to three key evaluative criteria. Specifically, taking into account the incentive effect of the particular policy (i.e., does the policy provide a direct incentive to hydrogen technologies specifically), the ability of the policy to explicitly address a barrier that currently restricts hydrogen development, and political feasibility, the comprehensive list of policies was scoped to a manageable set of policies that will be considered further. This exercise was undertaken recognizing that all of the policies that were chosen for additional consideration met the environmental effectiveness criterion and would thus lead to a reduction in greenhouse gas emissions should technology penetration occur.

Note that this policy evaluation is focused on the barriers that currently exist and the ability of particular policies to address those barriers immediately and facilitate hydrogen development over the study period. The evaluation does not try to account for or anticipate the various barriers that may or may not arise over the next 20 years.

Table 7: Policy Evaluation Summary

POLICY	INCENTIVE EFFECT FOR HYDROGEN AND FUEL CELLS	HYDROGEN AND/OR FUEL CELL BARRIER ADDRESSED	POLITICAL FEASIBILITY
GHG Cap and Trade	Indirect	Not explicitly	Under consideration
Eco Label	Indirect	Not explicitly	Existing precedents
RPS	Indirect and limited	Not explicitly	Under consideration
ITC	Direct	Explicitly	Existing precedents
PTC	Direct	Explicitly	Existing precedents
ACCA	Direct	Explicitly	Existing precedents
R and D	Direct	Explicitly	Existing precedents
Procurement	Indirect	Explicitly	Existing precedents
Info and Education	Indirect	Explicitly	Existing precedents
Grants	Direct	Explicitly	Existing precedents
Carbon Tax	Indirect	Not explicitly	Not currently
Red./Elim. Capital Tax[18]	Indirect	Explicitly	Existing precedents
Consumer Tax Credit	Direct	Explicitly	Existing precedents
Pilot Projects	Direct	Explicitly	Existing precedents

The summary table above demonstrates that of the list of policies that can be used to facilitate market penetration of hydrogen technologies, seven of these policies (shaded) can be designed to provide a direct incentive to hydrogen technologies, while at the same time explicitly address an existing barrier. In addition, for each of these seven policies, precedents have already been set with similar policies in Canada – an indication that such policies, targeted at hydrogen technologies, may be politically feasible.

These seven policies[19] will guide the economic analysis modelling exercise. Specifically, we will employ the Energy 2020 model to simulate a set of fiscal policy scenarios that will represent some combination of the above policies and evaluate the impact of those scenarios on carbon emissions among other factors. The outcome of this modelling exercise will give us a sense of the level of technology penetration that occurs under specific levels of government support both targeted at the production of hydrogen and the purchase of hydrogen technologies. In the section below, we provide a brief description of the Energy 2020 model.

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[18] Assuming we are considering an across-the-board reduction rather than a targeted reduction, there are no precedents for such a targeted reduction. Instead, an accelerated capital cost allowance is used to target particular capital investments.

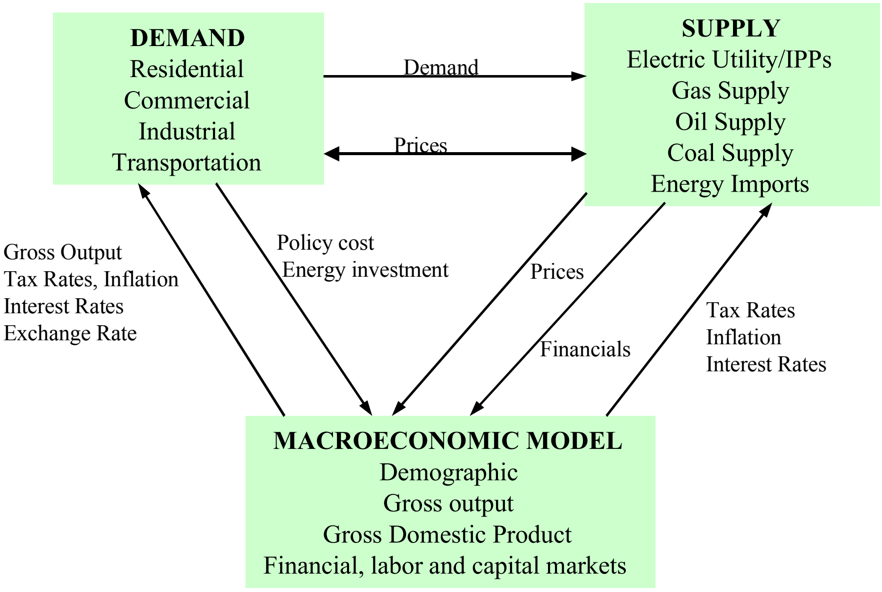
[19] The focus on these seven policies does not preclude the use of other fiscal policies to facilitate hydrogen technology penetration in Canada.

Energy 2020

The Canadian Energy Research Institute's model, Energy 2020, will be used to evaluate the impact of key fiscal policy scenarios on hydrogen development in Canada. Energy 2020 is an integrated multi-region, multi-sector model that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. The basic foundations of Energy 2020 are: (i) "Stocks and Flow" simulation that captures the physical aspects of the processes utilizing energy and (ii) the Qualitative Choice Theory (QCT) capturing human behavioural aspects. In contrast to the many existing policy analysis models, Energy 2020 has a database containing 20 years of time-series on all economic, environmental, and energy variables. The database enables the model to derive most parameters endogenously through econometric estimations. Energy 2020 is equally capable of producing long-term energy market forecasts as well as analyzing impacts of any policy shock in the markets. The most notable use of Energy 2020 in recent years in Canada is the analysis of Kyoto options.

The basic structure of Energy 2020 is provided in Figure 2. Like other energy models, the energy demand sector affects with the energy supply sector to determine energy prices in the equilibrium. The economic sector is the driving agent for energy demands, which in turn provides inputs to the economy sector in terms of investments in energy using equipment and processes and energy prices. The stand-alone model does have a simplified economy sector to capture the linkages between the energy system and the macro-economy. However, the model is best run in full integration with a macroeconomic model. For more information on the Energy 2020 model, please refer to Appendix A.

Figure 2 Overall Structure of Energy 2020



Energy 2020 will first be used to establish a business as usual (BAU) scenario. This scenario will describe Canada's energy pathway without the addition of new fiscal policies targeted at hydrogen technologies. The model outputs associated with the business as usual will provide the basis for evaluating the impact of the various fiscal policy scenarios. Using the BAU as a benchmark from which to measure change, we will be able to estimate the greenhouse gas emission reductions that occur as a result of the fiscal policy scenarios. We will also be able to quantify the cost of the various fiscal scenarios. The business as usual scenario will be calibrated to *Canada's Emissions Outlook, An Update* to allow for comparison with the NRTEE's case study research on fiscal policies for renewable energy and energy efficiency.

Once the business as usual is defined, we will introduce hydrogen technologies into Energy 2020 based on the technology parameters associated with each of the chosen hydrogen pathways. Specific technology parameters for each of the pathways are presented in Appendix B. The hydrogen technologies will then be made to compete with conventional energy technologies. Finally, we will simulate the fiscal policy scenarios and evaluate their effectiveness in facilitating market penetration of hydrogen technologies.

Summary and Next Steps

The purpose of this research project is to examine the role that fiscal policy can play in promoting hydrogen-based energy systems in Canada. The basic methodology employed in this analysis involves the use of microeconomic modelling to evaluate the impact of a set of fiscal policy scenarios on key hydrogen pathways (and associated technologies). This draft baseline report is the first stage in this analysis. Through this baseline report we have:

- Provided an overview of the state of hydrogen development in Canada and globally
- Identified key hydrogen pathways for further consideration and analysis
- Presented the current policy framework governing hydrogen development in Canada
- Discussed factors which presently limit market penetration of hydrogen technologies
- Evaluated an extensive list of fiscal policies for addressing those barriers

Following this baseline report, the next major component of this research project is to complete an economic analysis of key fiscal policy scenarios. Using the Energy 2020 model, fiscal policy scenarios will be evaluated according to their ability to facilitate market penetration of hydrogen technologies, reduce greenhouse gas emissions and minimize costs.

Appendix A: The Energy 2020 Model

Summary. A large number of modelling tools have been used to analyze economic and energy sector impacts of the Kyoto Protocol. The models range from large, long-term general equilibrium to detailed econometric models. The representation of energy sectors in these models ranges from very aggregated single commodity specification to the very detailed technology, fuel and end-use disaggregation. In Canada, a model called Energy2020 (hereafter "E2020") has been widely used by the federal and provincial governments to analyze sectoral and provincial impacts of implementing the Kyoto Protocol. The basic foundations of E2020 are: (i) "Stocks and Flow" simulation that captures the physical aspects of the processes utilizing energy and (ii) the Qualitative Choice Theory (QCT) capturing human behavioural aspects. In contrast to the many existing policy analysis models, E2020 has a database containing 20 years of time-series on all economic, environmental and energy variables. The database enables the model to derive most parameters endogenously through econometric estimations. E2020 is equally capable of producing long-term energy market forecasts as well as analyzing impacts of any policy shock in the markets. The most notable use of E2020 in recent years in Canada is the analysis of Kyoto options. The paper discusses the structure and capability of E2020 and the modelling of various climate change policies using this model.

1. Introduction

After the Kyoto agreement in 1997, researchers and policy makers focused on analyzing economic impacts of the Kyoto Protocol at national, regional and global levels. The analyses are based on numerical models integrating energy, environment and the economy. The models ranged from partial equilibrium types (e.g., PRIME, POLES) to complex multi-sector general equilibrium models (e.g., EPPA, GTEM, G-CUBED, MS-MRT, SGM).[20] While these models are best suited to analyze economic effects such as the impacts on economic welfare, employment, gross domestic product (GDP), sectoral outputs and international trade, most of these models represent the energy sector (i.e., activities related to production, conversion and utilization of energy) at an aggregate level. This limits the ability of the models to reflect details of the sectors primarily responsible for greenhouse gas (GHG) and criteria air contaminants (CAC) emissions. On the other hand, energy models such as the U.S. DOE's NEMS and the Stockholm Environmental Institute's LEAP model represent the energy sector in detail; accounting for energy demand at the end-use level. While these models are more appropriate in analyzing and forecasting of energy markets (i.e., energy supply, demand and price), they are incapable of incorporating macroeconomic feedbacks and, hence, are inappropriate for analyzing economic impacts of energy-environmental policies. Such models, however, could be linked with other macroeconomic models to analyze economic impacts of energy-environmental policies. Energy 2020 is an example of this category of energy-environment model.

E2020 is an integrated multi-region, multi-sector model that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. It is an outgrowth of the FOSSIL2/IDEAS model

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[20] Weyant and Hill (1999) present a number of general equilibrium models analyzing economic impacts of the Kyoto Protocol at national and global levels.

developed for the U.S. Department of Energy (DOE) and used for national energy policy analysis since the Carter administration.[21] E2020 is flexible and could define as many geopolitical regions as required by users. Currently, it defines 13 Canadian regions and 50 U.S. States. On the U.S. side, the 50 states were regrouped for the Canadian climate change work into five regions for ease of computation and presentation.[22] It is historically parameterized and can simulate any groupings of the 3500 interacting energy suppliers in North America. It can also be linked with macroeconomic models to determine the economic impacts of energy/environmental policies. Currently, it has been linked with a dynamic input-output approach based macroeconomic model developed by Informetrica for economic analysis in Canada and with the REMI[23] macroeconomic model in the U.S. One of the attractive features of E2020 is that, unlike most energy models, it houses an enormous historical database to econometrically estimate all model parameters (e.g., price response of demand, price response of supply).

The model has been used extensively by several state departments and electric utilities in the U.S. In Canada, Natural Resources Canada was instrumental in the construction of the national model in the early 90s. The model was used within the department for technology assessments. The Department of Energy & Mines in Saskatchewan has used the model since 1993. The Canadian Energy Research Institute (CERI) is an important Canadian participant in the building of the current North American version of E2020. Since E2020 is capable of producing long-term energy market forecasts and analyzing impacts of policy changes to the markets, its use would continue in future for a range of studies starting from energy market forecasting to specific policy issues such as energy sector restructuring, and promotion of clean energy technologies. There is also a possibility of using it for developing countries and economies in transition in analyzing impacts of GHG mitigation options under the Clean Development Mechanism and Joint Implementation.

The application of energy-environmental models in analyzing national climate change policies in Canada started with the establishment of the Analysis and Modelling Group (AMG).[24] AMG has conducted an integrated assessment of economic and environmental implications for Canada of implementing the Kyoto Protocol using various models. During the first phase of the analysis, the AMG used two Canadian energy-technology models (hereafter “micro” models), an optimizing model, MARKAL operated by McGill University, and a behavioural model, Canadian Integrated Modelling System (CIMS), developed by the Energy Research Group at Simon Fraser University.[25] The analyses provided estimates of the energy savings and emissions reduction required in achieving

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[21] FOSSIL2 was the original version but was renamed IDEAS later to reflect its evolutionary development since its original construction. The early version of the E2020 model was developed in 1978 at Dartmouth College for the DOE’s Office of Policy Planning and Analysis.

[22] Several stand-alone versions focusing on individual jurisdictions also exist for E2020. For Canada, one such version is the E2020 model for Saskatchewan.

[23] Regional Economic Models, Inc., Amherst, Massachusetts.

[24] Analysis and Modelling Group (AMG) is one of the 16 working groups established by the Joint Ministers of Energy and Environment Meeting (JMM) to manage the National Climate Change Process in 1998. It is mandated to address issues related to data, analytical and modelling needs in developing a national climate change implementation strategy. The objectives of AMG included (i) ensure baseline data coherency in evaluating various climate change mitigation measures/options, (ii) provide a consistent and comparable analytical framework to evaluate the mitigation measures/options, and (iii) direct analysis and modelling of various implementation scenarios.

[25] For more information on Canada’s National Climate Change Process and Analytical and Modelling Group, interested readers may want to visit http://www.nccp.ca/NCCP/national_process/issues/analysis_e.html.

the Kyoto target (ERG and MKGA, 2000; Loulou et al. 2000). Since the micro models are incapable of analyzing economic impacts of climate change policies, the AMG also used two economic models (hereafter "macro" models) for this purpose: the Informetrica Model developed by Ottawa-based Informetrica Ltd. and the Canadian Sectoral General Equilibrium Model (CaSGEM) developed by the Department of Finance. Taking results from the micro models as inputs, the Informetrica model simulated economic impacts (e.g., impacts on GDP, employment, international trade, etc.) of climate change mitigation policies (Cebryk et al. 2000). The CaSGEM model further complemented the Informetrica model by focusing on the long-term effects of the climate change policies (Iorwerth et al. 2000).

In the second phase of AMG (hereafter "AMG2"), E2020 and MARKAL (instead of CIMS and the MARKAL in AMG1), were used as micro models and the Informetrica model (TIM) as macro model to analyze a number of policy options for the federal and provincial governments in meeting Canada's Kyoto commitments. Under the AMG2, three working groups, namely, Domestic Emissions Trading Working Group (DETWG), Targeted Measures Working Group (TMWG), and Emissions Allocation Burden Sharing Working Group (EABSWG) provided necessary data and assumptions to E2020 to examine micro impacts (e.g., impacts on energy demand, prices and investments and GHG emissions) and to the Informetrica model to analyze macro impacts (e.g., GDP, employment, trade and investment).

Since E2020 is one of the main tools in analyzing GHG mitigating options, programs and plans in Canada, the model methodology and capabilities are of interest to researchers, policy makers, academia and other stakeholders. This paper presents the overall structure of E2020 and a brief overview of how key climate change policies are analyzed using this model.

2. The Structure of E2020

The basic structure of Energy 2020 is provided in Figure 2 (page 37). Like other energy models, the energy demand sector affects with the energy supply sector to determine energy prices in the equilibrium. The economic sector is the driving agent for energy demands, which in turn provides inputs to the economy sector in terms of investments in energy using equipment and processes and energy prices. The stand-alone model does have a simplified economy sector to capture the linkages between the energy system and the macro-economy. However, the model is best run in full integration with a macroeconomic model such as REMI. Given the modular nature of Energy 2020, additional sectors or modules from other models (macroeconomic, supply such as oil, gas, renewables etc.) can be incorporated directly into the E2020 framework.

2.1 Energy Demand

Sectors, end-uses and fuels: The demand sector of the model represents the interacting geographic areas to be simulated, disaggregated into four major economic sectors and their sub-sector detail, based on energy services. The sectors and end-uses considered in E2020 are presented in the table below. As can be seen from the table, the residential sector is divided into 3 sub-sectors with 7 end-uses, the commercial sector into 14 sub-sectors with 7 end-uses, the industrial sector into 28 sub-sectors with 4 end-uses, and the transportation sector into 3 sub-sectors with 6 modes. The oil mining is further divided into five types: heavy, light, frontier, oil sands, bitumen mining. For each of the end-uses, up to six fuels are modelled, for example, the residential space heating has the choice of a gas, oil, coal, electric, solar and biomass space heating technologies. The model has the flexibility to include additional economic categories, end-uses, technologies, fuels and modes to accommodate the needs of particular projects. In most cases, data availability is the limiting factor to detailed specifications. For all end-uses and fuels, the model is parameterized based on historical locale-specific data. Each demand sector is identical in equation and structure to all the other demand sectors.[26] The sector considers the demand for energy or transportation services as the driving consideration. Thus, the energy demands to satisfy those energy or transportation services are derived demands.

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[26] The demand sectors are by end-use, fuel, mode, and province for residential (single-family, multi-family, rural) commercial (14 economic categories), industrial (28 economic categories) and transportation (3 categories).

Economic Sectors and End-Uses in E2020

Sector →	**Residential**	**Commercial**	**Industrial**	**Transportation**
Sub-sector →	1. Single family 2. Multifamily 3. Rural/agricultural	1. SIC 45 transportation 2. Pipelines 3. Communication 4. Electric utilities 5. Gas utilities 6. Water & other utilities 7. Wholesale 8. Retail 9. FIRE 10. Offices/business services 11. Education 12. Health 13. Food, lodging, recreation 14. Government	1. Food, beverage & tobacco 2. Textiles 3. Apparel 4. Lumber 5. Furniture 6. Paper 7. Printing 8. Chemicals 9. Petroleum products 10. Rubber 11. Leather 12. Non-metallic minerals 13. Iron & steel 14. Nonferrous metal 15. Fabricated metals 16. Machinery 17. Electrical equipment 18. Electronic & computers 19. Transport equipment 20. Other manufacturing 21. Metal mining 22. Non-metal mining 23. Oil mining 24. Gas mining 25. Coal mining 26. Construction 27. Forestry 28. Agriculture	1. Residential transportation 2. Commercial transportation 3. Industrial transportation
End-use → or Modes	1. Space heating 2. Water heating 3. Lighting 4. Air conditioning 5. Refrigeration 6. Other substitutable[a] 7. Other non-substitutable[b]	1. Space heating 2. Water heating 3. Cooling 4. Refrigeration 5. Lighting 6. Other substitutable[a] 7. Other non-substitutable[b]	1. Process heat 2. Electric motors 3. Other substitutables[c] 4. Miscellaneous[d]	1. Highway (automobiles & trucks) 2. Buses 3. Trains 4. Planes 5. Marine 6. Others (electric vehicles, fuel cells and ethanol)

[a] *an aggregate category to include cooking and drying end-use services*

[b] *represents miscellaneous electric appliances*

[c] *hot water or drying that is not part of the primary-process heat*

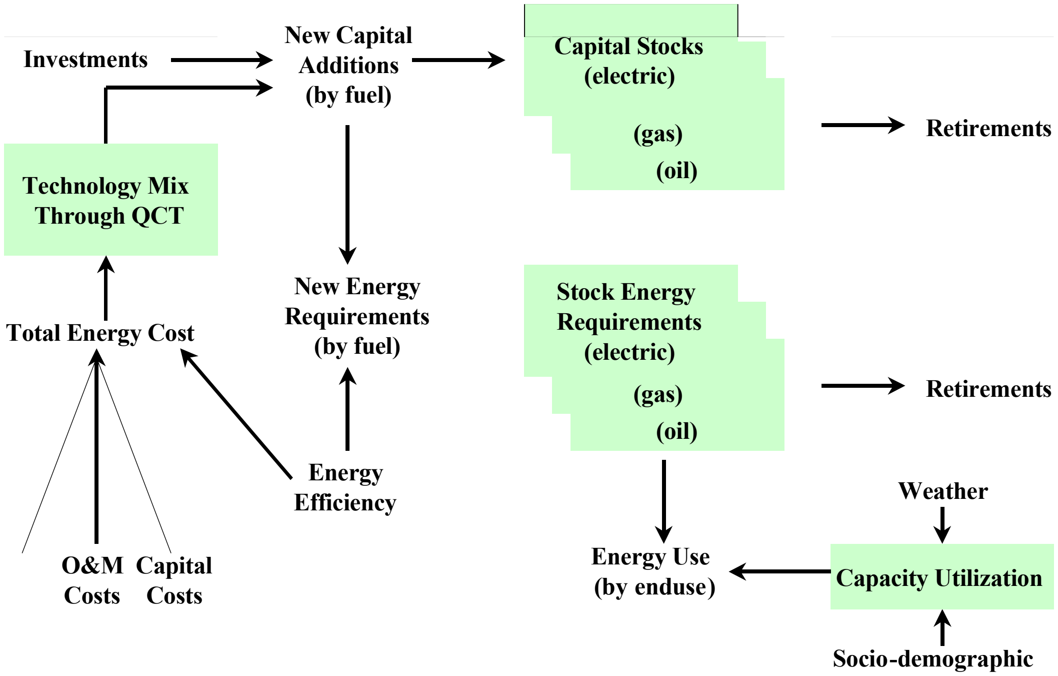
[d] *lighting and electrochemical process*

The modelling approach: E2020 falls in the league of "hybrid" models. Following are the two conceptual linchpins that form the theoretical perspective used in the model to determine energy demand:

- First, a "Stocks and Flow" simulation captures the physical aspects of the process, specifically the physical flow of entities within a system. For example, new investments increase the number of energy using devices, and retirements reduce the number of energy using devices. This function is similar to many other end-use accounting type models, which keep track of the energy using stock.
- Second, the Qualitative Choice Theory (QCT) as put forth by the Nobel Laureate Daniel McFadden determines how consumers make their energy decisions. All consumer decisions affecting the flow part of the stock are simulated with QCT.[27]

Determining energy demand is a four-step process: (i) new capital formation and corresponding stock energy demand due to economic growth, (ii) determining technology and fuel mixes to meet the energy demand, (iii) stock and flow accounting and (iv) converting energy requirement to annual energy demand. The figure below presents the mechanisms to derive energy demand in E2020.

Mechanism to Derive Energy Demand in E2020



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[27] A key feature of the QCT is the inclusion of a number of factors in addition to price in making decisions. The factors represent tastes and preferences that the decision-makers use to determine the best (utility maximization) choice for them. Because the information on the factors is uncertain, QCT uses a distribution to determine the probability of a choice being made. On average, the choices that are made correspond to this probability. The data needed to parameterize the distribution are readily obtained from historical time-series. Because the uncertainty has more to do with the decision-maker than the object (technology) of the decision, the parameterization is applicable to new technologies and conditions not experienced historically.

The starting point in the model is to establish a relationship between energy demand and capital stock in the production of goods and services. For example, the industrial sector produces goods in factories, which require energy for production; the commercial sector requires buildings to provide services; and the residential sector needs housing to provide sustained labour services. The occupants of these buildings require energy for heating, cooling, lighting and electromechanical appliances. Thus any new capital formation is the starting point for any new energy demand. The estimate of capital formation is an exogenous variable in the model derived either from the interactions with the macroeconomic model or other exogenous sources.

The second step is the choice of fuel (technologies) and the corresponding efficiencies. For each demand sector, the consumer has a choice what fuel (technology) should be used in meeting the energy service (e.g., space heating in the residential sector). QCT is used here to make the decision. The model considers price factors (e.g., marginal cost of technology use) and non-price factors (e.g., tastes, income-adjusted preferences, technology availability) to decide the selection of fuels (technologies) in meeting the need for energy service.[28] Both price and non-price factors enter directly into the QCT equations and, thereby, the distribution that determines market shares. QCT is used to both determine market shares for modes or fuels as well as to determine the efficiency of particular technologies utilized. The choice of the efficiency is based on the price of the fuel and the perceived trade-off between efficiency and capital plus O&M costs.[29]

The model, in the third step, calculates energy using capital stocks in terms of energy requirements (e.g., space heating requirements) based on the additions to the stock of energy using processes determined in Step 1 and the additions to the stock of energy using devices determined in Step 2. Both retirement and loss (e.g., due to fire or other disasters) of processes and devices are accounted in the model. The retired and lost stock is replaced by the new stock subject to the demand for energy service. Thus new stock is introduced for two purposes: (i) to replace the retired stock, which satisfies the existing demand for energy service, and (ii) to meet the new demand for energy service associated with economic growth. Note that for any given year, the model keeps track of energy using stock in terms of its energy requirements (e.g., space heating requirements) rather than the number of physical units (e.g., number of furnaces).

Finally, the application of capacity utilization factor to the stock of energy requirements determines the actual demand for energy. The stock energy requirements are calculated on the assumption that the stock is fully utilized. However, the reality is that the stock may not be fully utilized depending upon such factors as weather, socio-economics, current economic conditions, exogenous policies, and others. Utilization of capital stock can also change due to new requirements on operation of the devices. For example, a reduced speed limit reduces the energy use per kilometre for an automobile or truck because it has to use less energy to counter the created air-pressure.

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[28] In the case of the transportation sector, the consumer decides between the various transportation modes to satisfy the need for transportation services.

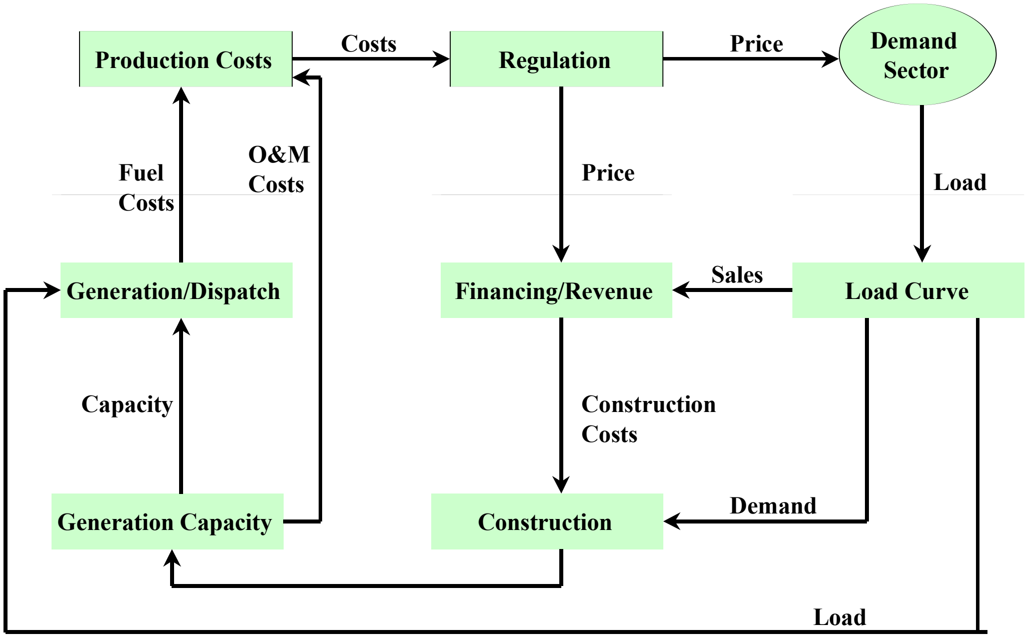
[29] O&M costs are considered a function of capital costs. Therefore, the QCT derived the trade-off explicitly between efficiency and capital costs.

2.2 Energy Supply

On the energy supply side, E2020 models electricity, oil, gas and coal. Electric supply is modelled extensively for more than 60 nodal levels with details in load dispatching, capacity expansion, regulation and financing. On the other hand, the supply for oil and gas is represented through incorporation of supply elasticities derived through consensus discussions with the Canadian Association of Petroleum Producers (CAPP) and Natural Resource Canada (NRCan).

Electricity: The electricity supply module of E2020 endogenously simulates capacity expansion including planning, construction, operation and retirement of generating plants and transmission facilities. Each step is financed in the model by revenues, debt, and the sale of stock. The regulator, where applicable, sets the allowed rate of return, divides revenue responsibility among customer classes, approves rate base, revenues and expenses, and sets fuel adjustment charges. The following figure presents an overview of the electricity supply module.

An Overview of the Electricity Supply Module in E2020



End-use electricity demand is endogenously forecasted based on stock of end-use appliances, their load curves and utilization rates.[30] Electricity load thus forecasted would serve as the basis for the capacity expansion plan. The expansion plan takes into account plants already under construction. Capacity expansions are differentiated for meeting peak and base loads. The model allows the minimum reserve margin to be temporarily violated at the peak if new base load capacity is scheduled to be available within the year. Minimum plant size is exogenous to the model. The mix of new base load plants (i.e., alternative coal technologies, hydro, or nuclear) is user specified in the

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[30] Each end-use in E2020 has a related set of load shape factors. Typically, these factors define the relationship between peak, minimum and average load for each season. These factors when combined with the weather-adjusted energy demand by end-use and corrected for co-generation, resale, and load management programs, form the basis of the approximated system load duration curve. Alternatively, representative hours over each season are used.

standard E2020 configuration. The model also evaluates the financial implications of new construction, including total construction costs, cost schedules and AFUDC/CWIP. It can also be configured to consider intermediate load units, firm purchase contracts, external sales, independent power producers, and demand side management.

Financial requirements/performance of utilities can also be simulated in E2020. The model forecasts funding requirements and follows corporate policies for obtaining new funds. It simulates the borrowing and issuing of stock, repurchase of stock or making investments in the situation of excess cash. Cash flows are explicitly modelled, as are any decisions that affect them. Coverage ratios, intermediate and long-term debt limits, capitalization, rates of return, new stock issues, bond financing, and short-term investments are endogenously calculated. The model keeps track of gross, net, and tax assets. It also calculates the depreciation values used for the income statement and tax obligations. E2020 produces a complete set of utility financial reports.

The model is equipped to deal with both regulated and unregulated markets. Where electric utilities are regulated, it follows the allowed rates-of-return regulation. The utility rate base is calculated according to a detailed conventional rate making formula. The model allows the user to adjust allowable costs, and has been used extensively to evaluate alternative rate base scenarios for individual plants. The regulatory sub-module of E2020 automatically factors in a wide variety of regulatory policies and options. More importantly, the model can be readily modified to consider a wide spectrum of scenarios. Environmental constraints, such as air pollution restrictions, can also be included in the model. When E2020 is configured as a regional or statewide system, municipal utilities, with their unique tax and rate structures, are also incorporated. Similarly, regional or power pool interchange is also recognised.

Oil, gas and coal: Oil and gas production in E2020 is based solely on a supply price-response determined through discussions with CAPP and NRCan. Production has process (type) detail (tar sand, bitumen, frontier, light, and heavy) by province. Production is broken out by province based upon the provincial share in each type of oil production. Each type of oil responds to the world price of oil, which is exogenous to the model. The production response (supply elasticity) varies by type of oil to capture the variations in costs, maturity of oil basins, resource potential, and the overall ability to respond to changes in price.

Coal production is by type and province. Its production can be price sensitive, but is determined through supply demand balancing (i.e., production and import are equal to demand and export). Imports and exports are exogenous to the model.

2.3 Emissions Estimation

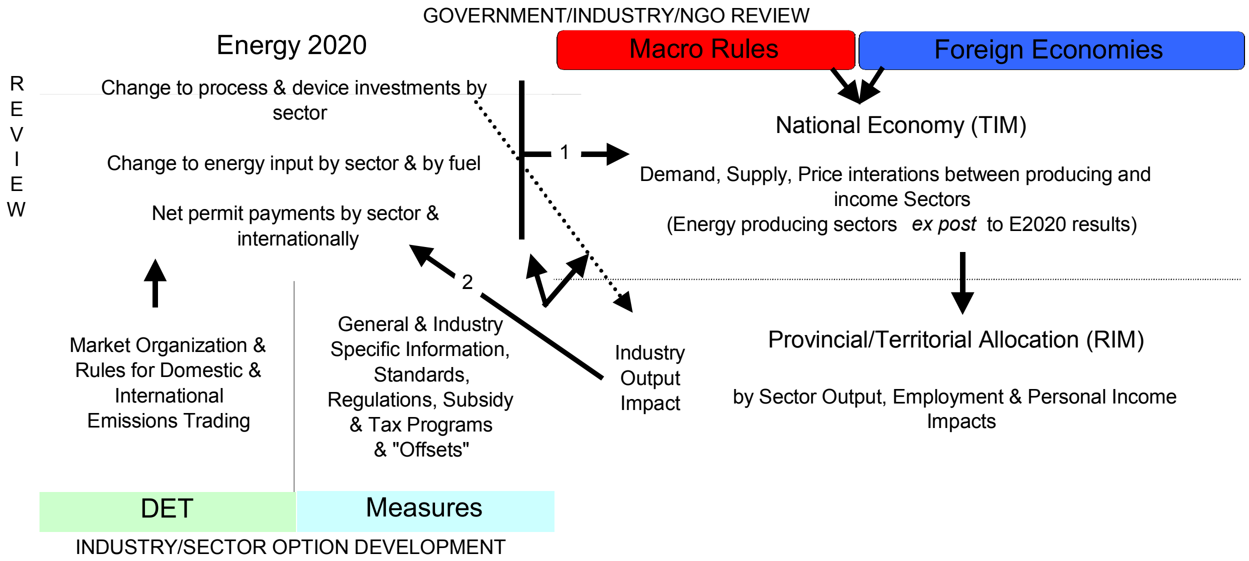
Greenhouse gases (GHGs) and the criteria air contaminants (CACs) are the main emissions related to the combustion of energy. Using emission coefficients for each of these pollutants, the model tracks emissions for these pollutants by fuel, sector and jurisdiction. In addition, the model also tracks non-combustion and non-energy/fugitive emissions. These are emissions associated with processes not directly associated with the use of energy. For example, CO_2 released from chemical processes in cement manufacturing, leakage of hydrofluorocarbons (HFCs) from air-conditioning, and methane emission from gas production can lead to the venting of methane into the atmosphere.

Gas, oil and coal are also used for feedstock in the production of goods such as fertilizers, paints and solvents. Emissions in such cases are not produced from combustion but from the decay or evaporation of these goods. The emissions that come from the use of a fuel for the purposes other than combustion are designated as non-combustion emissions. In both the cases of non-combustion and non-energy use, emissions coefficients are expressed in terms of per unit of sectoral output.

2.4 Linkage of E2020 with Macroeconomic Model

E2020 is linked with a macroeconomic model developed by Ottawa-based Informetrica Ltd.[31] to capture the interactions between the energy sector and the economy. For example, a change in price affects demand that then affects future supply and price. These energy market dynamics are captured within E2020. But energy demand also changes due to increased economic activity and in turn a higher demand increases the investment in new supplies. The new investment affects the economy and energy prices. The energy prices also affect the economy. These (indirect) impacts are captured through interactions with the macroeconomic model. The linkage between E2020 and the Informetrica model (i.e., TIM/RIM) is presented in the figure below.

Linkage Between E2020 and the Informetrica Macroeconomic Model[32]



E2020 and TIM/RIM models are simulated as two separate models; however, they are soft-linked with input and output flows. Simulation begins with E2020 estimating the direct impacts of climate change policies. Three outputs from E2020 are submitted to TIM/RIM to be included as model inputs. They are: (i) changes to investments in energy using equipment and structures by sector and industry; (ii) changes to energy intensity (energy input per unit of output) by sector, industry and fuel; and (iii) net emissions permit purchases/sales by industry and government for

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[31] There are two models owned and operated by Informetrica, TIM (The Informetrica Model capturing the interactions of the economy nationally) and RIM (a Regional-Industrial Model estimating the impacts on production and incomes at the provincial/territorial levels).

[32] Source: Sonnen and Saunders (2002).

sectors covered under domestic emission trading systems. Incorporating the E2020 output, TIM/RIM are then simulated to generate the output, employment and personal income impacts by industry and jurisdiction. Three outputs from TIM/RIM are used as inputs to E2020. They are: (i) gross output by industry and jurisdiction; (ii) personal income by jurisdiction; and (iii) inflation, interest rates, tax rates and exchange rates. The preceding figure shows information/data flows between the two models. The data input-output flows are iterated twice and the final results from E2020 reflect the inclusion of the second-pass results from TIM/RIM. This in essence is the third iteration and completes the process.

3. Modelling Climate Change Policies in E2020

E2020 has an immense capacity to analyze consumer and business responses over a wide range of policy initiatives. An illustrative subset includes tax initiatives or disincentives, energy taxes, regulatory standards for buildings, equipment and motor vehicles, grants, rebates and subsidy initiatives, consumer awareness initiatives (education and awareness), technology improvements (R&D), moratoriums and mandated cut-backs, and emissions permit trading. In this section, we focus largely on the type of policies modelled as part of AMG 2. The AMG 2 policies can be divided into three broad categories.

- Market instruments: carbon tax[33] and emissions permit trading.
- Targeted measures: a wide range of initiatives (or programs) comprising those that enhance consumer understanding of available technologies and options (education and awareness) to building and device standards.
- Exogenous supply cost curves and reduction measures: This corresponds to supply cost curves for the oil and gas sector initiatives; landfill gas supply curve; forestry and agricultural sector carbon sinks and offsets.

3.1 Market Instruments

Market-based policies (instruments) send a signal to the market to change behaviour. The most common and widely used market instruments are energy and emission taxes, which by increasing end-use price, result in a lower energy demand. In the context of climate change, there are two widely used market instruments, namely a carbon tax and an emissions permit. Under both these policy mechanisms, the price of energy rises to encourage investments in more efficient energy using processes and devices to reduce energy demand and consequently energy-related emissions.

Under a carbon tax, a tax is imposed on all fuels in proportion to their carbon content. The cleaner the fuel (lower the carbon content), the lower the tax rate. This type of tax has three effects. First is a temporary budget response, or an income effect that decreases the disposable income due to the higher price and therefore leads to lower demand for all energy fuels. Second is a fuel switching effect caused by changes to the relative prices of energy fuels. Thus the demand for lower taxed (cleaner) fuels increases and the demand for higher taxed (dirtier) fuels decreases. Third, the increase in energy prices causes the consumer to move to more efficient use of energy. This may result in the same level of energy service demand but at the cost of lower fuel consumption.

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[33] Although carbon tax was not included as part of the AMG 2 policies, it is discussed briefly here to explain the difference between a carbon tax and permit trading in terms of modelling within E2020.

Emission permits are generally considered a more politically acceptable approach to reducing GHG emissions. Policy makers have seen the use of permits as a means to avoid many of the revenue collection and recycling problems of carbon tax. The requirement of an emissions permit works in much the same way as the carbon tax. A non-zero cost of the permit results in an increase in the price of energy fuels based on the carbon content. This again sends the signal to the energy consumer to change behaviour (reduce demand and emissions, and the need for buying emissions permits). However, the permits have much different dynamics than does a carbon tax. Permits represent a market and possibly one with a rigid supply. There is a demand for permits (the emissions) and there is a supply for permits (the compliance level). Based on the demand and supply, there is an equilibrium price at which the demand for permits equals the supply. Contrary to emission permits, there is no equilibrium carbon tax that is determined in a market although there may be an "optimum" level of carbon tax, which leads to a "desired" level of reductions. In terms of the treatment of these two alternative market instruments from the perspective of modelling, the level of carbon tax is an input to the model, as opposed to the price of permit, which can be an output of the model dynamics or determined exogenously.

Under AMG2, a domestic emissions trading (DET) scheme was considered, the modelling of which is different from that normally used for carbon tax and emission permit systems, in three ways. First, part of the permit requirement is distributed by the government gratis, and although the threat of having to pay for added permits provides an incentive to reduce emissions, the price signal is much weaker than a policy case where permits are fully auctioned. Second, the permit trading is not economy wide and is limited to the large final emitters (LFE) including the electricity sector. The residential, commercial and transportation sectors are exempt from domestic emissions trading. Third, two alternative price scenarios are examined for DET. The US$6 and US$30 per tonne of CO_2 are assumed as alternative prices for permits in the international market. Indirectly, these permit price levels assume that a significant portion of Canada's Kyoto obligation will be met through permit purchases in the international market. The LFE sector will make reductions domestically up to the amount of the international permit price (US$6 or US$30). The last feature implies that the DET scheme is modelled as a carbon tax, at alternative tax levels of US$6 and US$30.

3.2 Targeted Measures

Targeted measures (TM)[34] can be defined as a set of targeted initiatives to reduce energy demand and or shift it to cleaner fuels, thus reducing emissions. A subset of these TMs is akin to regulatory standards such as building codes or automobile standards targeted largely to increasing efficiency of marginal (new) stock of energy using devices and processes. As stock turnover takes place with old stock being retired and replaced by new stock, the efficiency of the entire stock increases. Approximately 75 TMs were included in AMG2 as direct initiatives to reduce emissions. The list of TMs considered is presented in the table below. Most of these measures relate directly to those described in the Issue Tables.

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[34] The origins of the TMs can be traced back to the establishment of the 16 Issue Tables/Working Groups, comprising 450 experts from government, industry, academia and non-governmental organizations following the April 1998 JMM meeting to manage the National Climate Change Process. The overall mandate of the Issue Tables was to estimate the cost and amount of GHG emissions that could be achieved in individual sectors.

Name of measure modelled	Description
Residential Sector	
RES_AE-1	National Standards Program for Equipment & Appliances
RES_AE-5	Energy Star Labeling/Premium Energy Performance Labeling Program
RES-C8-A	Multi-Residential Retrofit Program
RES_R3	National Energy Efficient Housing Renovation & Retrofit Program
RES-R-4A	Adoption of More Stringent MNECH by Provinces
RES-R-5A	Strengthened R2000 Program
RES_R6B	R-2000 for Existing Dwellings Renovation Program
RES_R-7V	EnerGuide for Houses – Voluntary
RES-R10	Residential Retrofit Guidelines and Installation Standards
Commercial Sector	
COM_AE-1	National Standards Program for Equipment & Appliances
COM _AE-5	Energy Star Labeling/Premium Energy Performance Labeling Program
COM _C2B	Improved MNECB
COM _C7	Public Building Initiative
COM _NewC8	Additional Commercial Building Retrofit Program
COM_CHP	Commercial Cogeneration
Municipal Sector	
COM _MUN22	Develop and Finance Viable CES Projects
ELEC_MUN009	Capital Infrastructure Funding Program
IND_ MUN16	Municipal Green Fund Incentives for Integrated Waste Management
IND_ MUN2425	Revolving Fund for Energy Efficiency Retrofits
Industrial Sector	
IND_ Aluminum	Aluminum Recycle
IND_ Audits	Audit Identified
IND_ Capture	CO2 Capture
IND_ CIPEC	Expanded CIPEC
IND_ ENERGUIDE	Industry EnerGuide
IND_ FUND	Facilitation Fund
IND_ Minerals	Concrete Fly Ash
IND_ LfgOffsets	Capital Infrastructure Funding Program for Landfill Gas
IND_ Steel	Steel Recycle
Transport Sector	
TRAN_A-1	Enhancements to the Pedestrian and Bicycle Environment
TRAN_A3H	Transit Service Improvements (Includes A2H)
TRAN_A-5	Telecommuting
TRAN_A-7	Car Sharing
TRAN_A-14	Accelerated Light Duty Vehicle Scrappage
TRAN_A-15	Syncronized Traffic Signals
TRAN_A-16L	Driver Education and Awareness Program
TRAN_B-7	Rigid Pavements (Cement)
TRAN_B-16	Advanced vehicle Control Systems (AVCS)
TRAN_D-1	Short-term Aviation Measures
TRAN_F-3	Trucking Load Matching
TRAN_F-5A	Truck Central Tire Inflation
TRAN_F-6	Truck Lubricants
TRAN_F-10H	Driver Education Program
TRAN_G-6	Marine Code of Practice I
TRAN_G-7	Marine Code of Practice II
TRAN_H-1BL	Fleet Average Fuel Consumption Target Harmonized
TRAN_H-2A	AFV Fleet Purchase
TRAN_TRA-101	50% Ethanol
TRAN_TRA-115	Biodiesel from waste greases, stressed Canola
TRAN_TRA-117	Freight inter-modal system improvements (High Scenario)
TRAN_TRA-119	Off-road Efficiency Improvements
TRAN_TRA-120	Anti-idling Technology for Heavy Truck Fleets
TRAN_TRA-121	Light Duty Vehicle Tire Pressure Warning System
Electricity Sector	
ELEC_CHPMIP	Combined Heat and Power
ELEC_WPPI	Wind Power Generation
ELEC_Capture	CO_2 Capture
Oil & Gas Sector	
Gas_AcidCapture	CO_2 Capture
Oil_InfraCapture	CO_2 Capture

Source: http://db.nccp.ca/cfmsite/nmd/cfmlpriv/

To describe how each of these measures is modelled within E2020, the discussion below is categorized by the type of measure. The measures are implemented at the point where they affect the decision process. The primary measure categories and their associated decision points for the demand sectors are shown in the figure below. Wherever possible, the measures are implemented in their logic rather than in their impact. Thus, most measures are implemented as "Measures" and not as "Actions[35]". The AMG2 targeted measures can be grouped into the following six categories based on how they are modelled and the decision points they impact.

Informetrica transferred measures: These measures are modelled through the macroeconomic impacts captured in Informetrica's TIM & RIM. Examples of such measures are agriculture related (AE001 to AE009), where costs are captured through factor-input changes on the macro side. Other examples include the enforcement of speed limits where the fuel cost savings are measured on the micro side, but the added costs from law enforcement activities are included on the macro side.

Regulatory standards: Standards affect the minimum efficiency decision of investments (for marginal or retrofits) for energy using devices and processes. Device standards are defined in terms of GJ-out/GJ-in and process standards as $ of output/GJ. As a result of these standards, consumers are forced to choose a higher level of efficiency, assuming of course that the standards are set at a level above the marginal efficiency. Thus both process and device efficiency decisions are impacted. Good examples of this category of measure are AE-1, R10 and C2-B.

Financial measures: In this category fall the various cost support measures as well as the financial incentive measures. Cost support measures reduce the cost of the desired device and process, and therefore encourage the consumer decision to invest in the desired technology. Examples of this measure include C8-A, R3 and R6B. The financial incentive measures work in much the same way as the cost support measures through reduction in costs of the devices and processes. Low-interest loans are good examples of this measure. These loans reduce capital payments.

Operational efficiency measures: Some measures reduce the utilization (or energy use) of a device or process without changing its intrinsic mechanical efficiency. The use of synchronized traffic lights would be an example that reduces highway vehicle energy use and emissions but not the design of the car engine. These reductions require external engineering analysis. Many of the transportation measures fall in this category. For this type of measure, the Issue Table information is used to derive the reductions in utilization. These types of measures affect the operational efficiency decisions, which impact the energy-use emissions.

Information measures: The information measures result in consumers making better-informed decisions. Information programs affect the uncertainty relative to efficiency versus fuel trade-off choices. For devices, this uncertainty parameter is Device Fuel Trade-off Coefficient and for process, it is the Process Fuel Trade-off Coefficient. AE-5 and R5-A are again good examples of this category of measures. Although generally a reduction in uncertainty would lead to more efficient decisions, in some cases, due to preferences, the decrease in uncertainty may not necessarily move the consumer towards greater energy efficiency.

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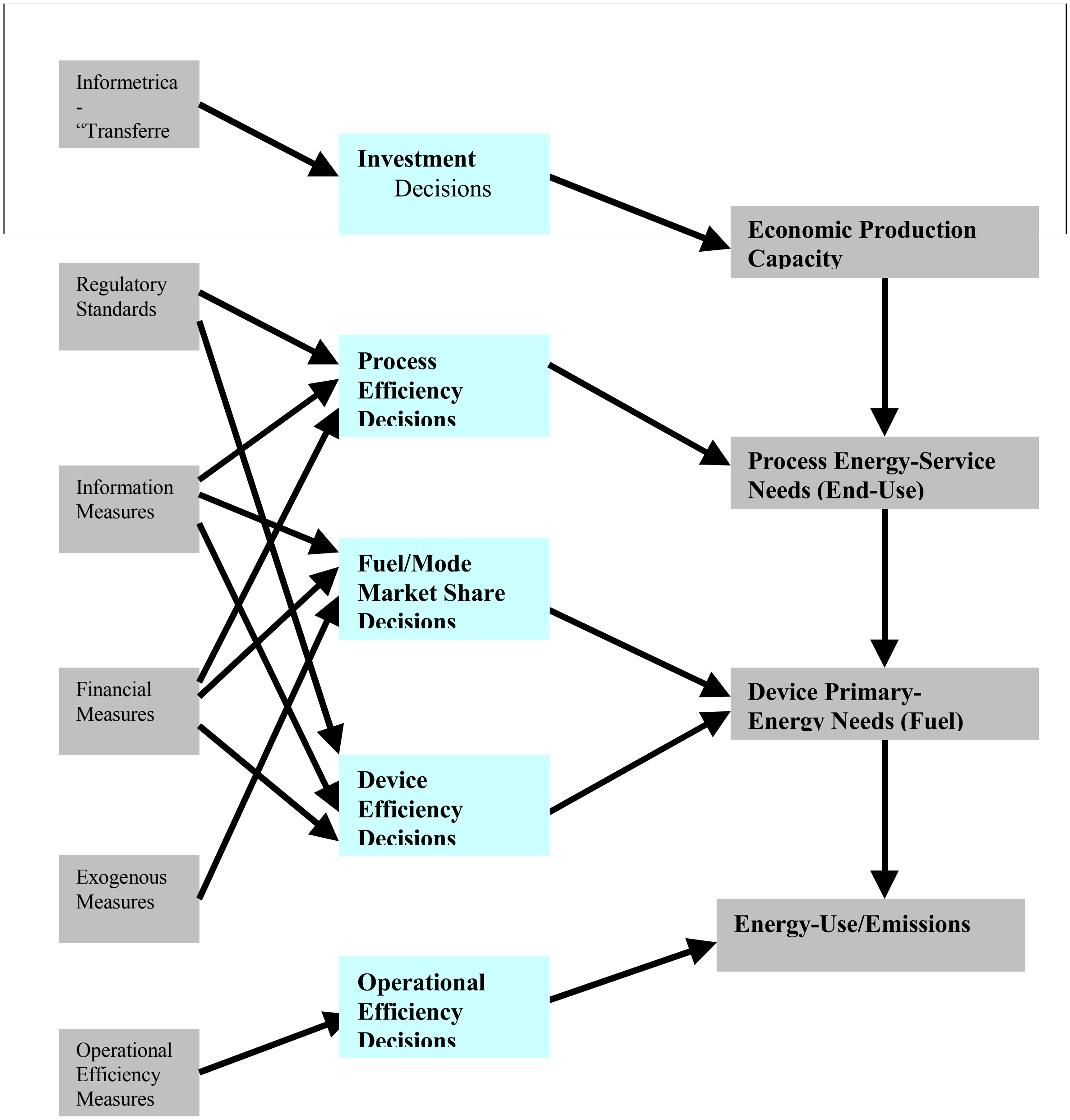
[35] This is a change from the micro modelling of AMG1, where the impact information from the Issue Tables was incorporated in its entirety as "Actions."

Targeted Measure Categories & Model Decision Points



3.3 Exogenous Supply cost Curves and Reduction Measures

Exogenous measures: Finally, there is a range of measures that have been included as exogenous measures. The effect of these measures has been incorporated as an exogenous impact taken either from the Issue Tables or described by the experts within the government departments. An example is the forced use of ethanol, where a percent of market share is allocated to ethanol vehicles (TRA-101).

Finally, it should be noted that AMG measures have "penetration levels" (PL). This does not really reflect penetration per se but rather how intensely the measure is pursued compared to what is specified in the Issue Tables. For example, if an efficiency standard was to improve furnace efficiency by 10%, a 50% PL would imply a 5% efficiency improvement. If strict enforcing of the speed limit caused a 3% reduction of motor vehicle emissions, then a 200% PL would cause a 6% reduction.

In cases of "overlapping" measures, such as the efficiency standards being applied multiple times to the same end-use, fuel and sector, the final effective standard is the maximum of all the imposed standards. Whenever there are multiple overlapping measures, the model acts to logically/physically reflect the combined impacts rather than naively adding measures as if they were independent.

Several CO_2 abatement cost curves to account for sectoral initiatives on reducing GHGs are incorporated in E2020 under AMG2 analysis. These curves include the oil & gas cost curves based on the Issue Table information; a CO_2 sequestering cost curve was developed by the Canadian Energy Research Institute and the landfill gas cost curve provided by Environment Canada. Based on these curves, the model endogenously generates the amount of CO_2 reduction at a given permit price.

While the model does have the dynamics and cost curves for measures associated with the agriculture and forestry sectors, the AMG decided to exogenously specify the CO_2 sequestration through carbon sinks associated with agriculture and forestry. Forestry cost-free sinks are set to 20 MT per year for all years. Agriculture cost-free sinks are set to 4 MT/year. Combined agricultural measures produce 10.1 MT/year. by 2010 and 10.3/year by 2020. There are no endogenous dynamics. These are "forced-in" exogenous values specified by the AMG.

4. Conclusions

E2020 is one of the key tools used in analyzing federal and provincial governments' plans in meeting Canada's GHG mitigation commitments under the Kyoto Protocol. It is an integrated multi-region, multi-sector model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. Stocks and flow simulation and the Qualitative Choice Theory are the two basic foundations of E2020. It is flexible to define the geopolitical region, number of economic sector, fuel and end-use as required by users. The most important feature of E2020 is that, unlike most energy models, it houses an enormous historical database to econometrically estimate all model parameters. For the purpose of capturing macroeconomic impacts of a policy change, it has been linked with a dynamic input-output model developed by Informetrica for Canada and with the REMI model in the case of the U.S. In Canada, E2020 was used mainly to analyze various climate change options of federal and provincial governments under the framework of the Analysis and Modelling Group established by the Joint Ministers of Energy and Environment Meeting (JMM) to manage the National Climate Change Process.

E2020 has an immense capacity to analyze consumer and business responses over a wide range of policy initiatives such as energy-environmental taxes, regulatory standards for buildings, equipment and motor vehicles, grants, rebates and subsidy initiatives, consumer awareness initiatives (education and awareness), technology improvements (R&D), moratoriums and mandated cut-backs, and emissions permit trading. Under AMG study series, it was used to model particularly three types of GHG mitigation measures. These were (i) market instruments, such as carbon tax and emissions permit trading; (ii) a wide range of initiatives (or programs) comprising those that enhance consumer understanding of available technologies and options (education and awareness) to building and device standards; and (iii) exogenous supply cost curves and reduction measures.

Since E2020 is equally capable of producing long-term energy market forecasts as well as analyzing impacts of any policy shock in the market, its application will serve as a useful analytical tool for a range of issues. These may span from general energy supply-demand forecasting at provincial and federal levels to modelling of specific issues such as restructuring of the electricity sector, and impacts of clean energy technologies (e.g., renewable energy technologies). There is also a possibility of using it for developing countries and economies in transition in the analysis of impacts of GHG mitigation options under the Clean Development Mechanism and Joint Implementation.

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Appendix B: Technology Parameters

The following parameters have been assembled from various sources including previous studies and publicly available literature, data directly from technology developers, and general rule-of-thumb assumptions. The references from which the assumptions originated are presented in the table below. Technology parameter details are presented in the set of tables beginning on the next page.

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Technology Parameter Details

Fuel Cells SOFC (5 kW – residential, small commercial)					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	5	Kw elec.	154	GJ elec. / year	Typical unit size under development
Utilization	0.95				Standard assumption
Incremental capital cost for heat exchanger	0	$			Assumes incremental cost for integrating with DHW and space heating is offset with savings on displaced equipment. Assumes that for a future new house (well insulated) the fuel cell will be able to meet total heat demands using a 9kW start-up burner.
Air contaminants					
CO_2 emissions	1.89	kg / m^3 natural gas	107	kg / GJ elec. (post 2010)	Environment Canada (2002)
No_x, CO and hydrocarbons	6	g/MWh	0.0017	kg/GJ elec	SiemensWestinghouse (2002)
So_x	0	g/MWh	0	kg/GJ elec	
Operating Method	100% of operating time, sell excess electricity to the grid (assume 70% of power) and uses 40% of heat for domestic hot water and space heating.				
Costs and fuel requirements - 2010 to 2030					
Lifetime (years)	10; half price for recharge				Broad assumptions made by manufacturer predictions.
Annual O & M Cost	2% of 2020 CC		1.36	2000$ / (GJ elec. /year)	Standard assumption
Natural Gas Required	45%	electrical efficiency	2.22	GJ NG / GJ electricity	Improved performance (45% elec. eff., 45% heat eff.)
Costs and fuel requirements - 2010 to 2030					
Capital Cost	3532	2000$ / kWe	112	2000$ / (GJ elec. /year)	USDOE (2003)
Costs and fuel requirements – 2015					
Capital Cost	2598	2000$ / kWe	82	2000$ / (GJ elec. /year)	USDOE (2003)

Fuel Cells SOFC (250 kW - large commercial, industrial)

Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	250	kW elec.	7,690	GJ elec. / year	Typical unit size under development
Utilization	0.95				Standard assumption
Incremental capital cost for heat recovery	0	$			Assumes incremental cost for integrating with DHW and space heating is offset by savings on displaced equipment.
Air contaminants					
CO_2 emissions	1.89	kg / m^3 natural gas	107	kg / GJ elec. (post 2010)	Environment Canada (2002)
No_x, CO and hydrocarbons	6	g/MWh	0.0017	kg/GJ elec	SiemensWestinghouse (2002)
So_x	0	g/MWh	0	kg/GJ elec	
Operating Method	100% of operating time, sell excess electricity to the grid (assume 10% of power) and uses 70% of heat for domestic hot water, space heating and absorption chilling. Actual amount of heat used is case specific. 70% is a conservative assumption considering the fact that this is a new technology.				
Costs and fuel requirements - 2010 to 2030					
Lifetime (years)	10; half price for recharge				Broad assumptions made by manufacturer predictions.
Annual O & M Cost	2% of 2020 CC		1.36	2000$ / GJ elec.	Standard assumption
Natural Gas Required	45%	electrical efficiency	2.22	GJ NG / GJ electricity	Improved performance (45% elec. eff., 45% heat eff.)
Costs and fuel requirements - 2010 to 2030					
Capital Cost	3532	2000$ / kWe	112	2000$ / (GJ elec. /year)	USDOE (2003)
Costs and fuel requirements - 2015					
Capital Cost	2598	2000$ / kWe	82	2000$ / (GJ elec. /year)	USDOE (2003)
Costs and fuel requirements - 2020					
Capital Cost	2143	2000$ / kWe	68	2000$ / (GJ elec. /year)	USDOE (2003)

Decentralized Electrolysers (to serve 2700 LDVs or 22 buses)					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	1	tonne/day	51,757	GJ / year	Estimates based on size and service from E&Y (2003) station.
Utilization	0.75				Operates on demand. Assumed to be 75% of the time.
Lifetime (years)	20				Standard assumed equipment economic lifetime.
Capital Cost - today	1700	2003$ / kW	50.9	2000$ / (GJ/year)	Average of highest literature estimate from E&Y (2003), and Stuart Energy (2001) estimate for small systems.
Capital Cost - 2015	388	2002$ / kW	11.8	2000$ / (GJ/year)	Decreasing to same price as large units in 2015 - Stuart Energy (2004)
Annual O & M Cost	15	2004$ / kW	0.44	2000$ / GJ	Stuart Energy (2004)
Electricity Required - Current	55	kWh / kg	1.40	GJ elec / GJ H2	E&Y (2003) - Obtained from NRCan
Electricity Required - 2010	50	kWh / kg	1.27	GJ elec / GJ H2	Stuart Energy (2004)
Water Required	1	L / Nm3	78.5	L H20 / GJ H2	E&Y (2003) - Obtained from Norsk Hydro
Air contaminants	none				
Operating Mode (options)	Operates based on hydrogen demand – assumed to be 75% utilization 1. grid average electricity supply (commercial electricity rates) - used in modelling 2. dedicated power plant (contract rate for specific plant plus transmission costs) 3. off-peak power = for defined periods of time at discounted rates				

Decentralized SMR (1tpd to serve 2700 LDVs or 22 buses)					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	1	tonne/day	51,757	GJ / year	Estimates based on size and service from E&Y (2003) station
Utilization	0.9				Allows for 5 week shutdown - NRTEE scoping group (similar to Amos, 1998)
Lifetime (years)	20				Standard assumed equipment economic lifetime
Capital Cost	1.38	2003$ / Nm^3/y	102	2000$ / (GJ/year)	E&Y (2003)
Annual O & M Cost	100	2001$ / kW	3.10	2000$ / GJ	Average of Air Products (2001), and Praxair (2001)
Electricity Required	0.28	kWh / Nm^3	0.08	GJ elc / GJ H2	E&Y (2003)
Water Required	0.55	L / Nm^3	43.2	L H20 / GJ H2	From Air Products (2001), and Praxair (2001)
Natural Gas Required	0.46	m^3 NG / Nm^3 H2	1.42	GJ ng / GJ H2	E&Y (2003)
Air contaminants					
CO_2	1.89	kg / m^3 natural gas	68	kg / GJ H2	Environment Canada (2002)
NO_x	0.898	g / kgH2	0.0063	kg / GJ H2	Spath (2001)
CO	0.0798	g / kgH2	0.0006	kg / GJ H2	
PM	0.022	g / kgH2	0.0002	kg / GJ H2	

Hydrogen Storage

Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	For every kg of hydrogen produced per day, 1 kg of storage capacity is required within the decentralized electrolysis system. This is similar to the storage requirements set out in Myers (2002). Decentralized SMR operation is assumed to require 2 kg of storage due to its reduced operating flexibility.				
Utilization	Matches the utilization of the system				
Lifetime (years)	20				Standard assumed equipment economic lifetime.
Hydrogen Required	0% permeation losses		1.000	GJ H2 in / GJ H2 out	Dynetec (2004). Assumes aluminum lined cylinders.
Air contaminants	none				
Decentralized electrolysis					
Capital Cost	596.75	2002$ / kg/day of production capacity	11	2000$/ (GJ/year) @ 100% utilization	Myers (2002). 634 kg storage cost of US$244,224
Annual O & M Cost	2% of CC		0.22	2000$/GJ @ 100% utilization	Standard assumption - comparable to Simbek and Chang (2002) for variable non-fuel O & M (0.5 to 1.5%)
Decentralized natural gas					
Capital Cost	1193.5	2002$ / kg/day of production capacity	22	2000$/ (GJ/year) @ 100% utilization	Myers (2002). 634 kg storage cost of US$244,224
Annual O & M Cost	2% of CC		0.44	2000$/GJ @ 100% utilization	Standard assumption - comparable to Simbek and Chang (2002) for variable non-fuel O & M (0.5 to 1.5%).

Dispensers

Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Utilization	Downtime assumed to not significantly affect station productivity				
Lifetime (years)	20				Standard assumed equipment economic lifetime.
Capital Cost	279	2002$ / kg/day	5	2000$ / (GJ/year)	Myers (2002). US$20,700 per dispenser for a 115 kg/day system.
Annual O & M Cost	2% of CC		0.10	2000$ / GJ	Standard assumption

Compressors					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	4.8	kg / hr outlet at 7000 psi	5,962	GJ / year	Myers (2002). 150 psi to 7000 psi compressor. Used as a proxy for the other sizes that are required in this study.
Utilization	Matches the utilization of the equipment supplying the compressor				
Lifetime (years)	20				Standard assumed equipment economic lifetime.
Capital Cost	6200	2002$ / kg/h	4.99	2000$ / (GJ/year)	Myers (2002). 150 psi to 7000 psi compressor. Used as a proxy for the other sizes that are required in this study.
Annual O & M Cost	2% of CC		0.10	2000$ / GJ	Standard assumption - comparable to Simbek and Chang (2002) for variable non-fuel O & M (0.5 to 1.5%).
Air contaminants	none				
From electrolyzer to refuelling station storage (5000 psi to 7,000 psi)					
Electricity Required	0.18	kWh / kg	0.0046	GJ elec / GJ H2	Zittel (1996). Assumes 65% isentropic efficiency.
From SMR to refuelling station storage (150 psi to 7,000 psi)					
Electricity Required	2.3	kWh / kg	0.06	GJ elec / GJ H2	Zittel (1996). Assumes 65% isentropic efficiency.

Hydrogen Light-Duty Fuel Cell Vehicles					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	Light-duty vehicles				
Lifetime (years)	14				Same as ICE LDV
Capital Cost	Assumed 50% greater than equivalent ICE LDV in 2015 and decreasing to 15% greater than equivalent ICE LDV in 2030 (expected eventual OEM price).				
Annual O & M Cost	Same as ICE LDV				Ballpark estimate
Hydrogen Required	1.4	kg / 100 km	0.20	GJ H2 / 100 km	E&Y (2003) - assumes comparable vehicle 11.2 L/100km (0.35 GJ gasoline/100km).
Air contaminants	none				

Fuel Cell Buses					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	Urban transit buses				
Lifetime (years)	18				Same as ICE buses.
Capital Cost	Assumed 50% greater than equivalent ICE LDV in 2015 and decreasing to 15% greater than equivalent ICE LDV in 2030 (expected eventual OEM price)				
Annual O & M Cost	Same as ICE bus				Ballpark estimate
Hydrogen Required	9	kg / 100 km	1.28	GJ H2 / 100 km	E&Y (2003) - assumes comparable vehicle 59 L/100km
Air contaminants	none				

Hydrogen ICE Vehicles					
Parameter	*Value*	*Unit*	*Value*	*Unit*	*Sources and Assumptions*
Description / Size	Light-duty vehicles				
Lifetime (years)	14				Same as ICE LDV
Capital Cost	50% higher than comparable gasoline ICE in 2010 (comparable to projections by Ari Swiller, Hydrogen Car Company) decreasing to 30% higher than comparable gasoline ICE in 2015 (comparable to price premium for an OEM natural gas vehicle)				
Annual O & M Cost	Same as ICE LDV				Ballpark estimate
Hydrogen Required	2.0	kg / 100 km	0.28	GJ H2 / 100 km	Assume 20% less than gasoline ICE (11.2 L/100km) - H2 Car Company (2004)
Air contaminants	Assume No_x 50% lower than gasoline ICEV. No other significant levels of emissions.				Auto Field Guide (2001)

Availability Assumptions

- The installation of stationary fuel cells was limited to new buildings in the residential sector and select commercial sub-sectors: Communications, Financial, Insurance, Real Estate, Business Services, Health and Social sectors and Government.
- Availability of hydrogen technologies in the transportation sector was limited to fleets. It is also assumed that fleets are responsible for no more than 10% of vehicle kilometres travelled for light-duty vehicles. 10% is the portion of vehicle kilometres travelled for work purposes in vehicles less than 4.5 tonnes compared with total vehicle km travelled in this vehicle class. The entire bus population is also considered to be part of the fleet group.