# Case Study on the Role of Fiscal Policy in Hydrogen Development

## Economic Analysis

*May 10, 2004,*

***Pembina Institute and the Canadian Energy Research Institute***
*Contact Amy Taylor, 403-678-3355, amyt@pembina.org*

***Project Team:***
*George Backus, Abha Bhargava, Douglas Bruchet, Matt Horne,*
*Janna Poliakov, Jesse Row, Amy Taylor, Govinda Timilsina, Mark Winfield*

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# 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 modeling 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 modeling 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 modeling 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 modeling approach employed in this study. The Reference Case Results chapter, which presents the modeling 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 chapters summarize and interpret the results, and identify next steps in this study as well as key areas for future research.

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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 modeling analysis employed in this research is described in the flow chart below. The modeling began with the completion of a 'Reference Case' modeling 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 modeling 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.

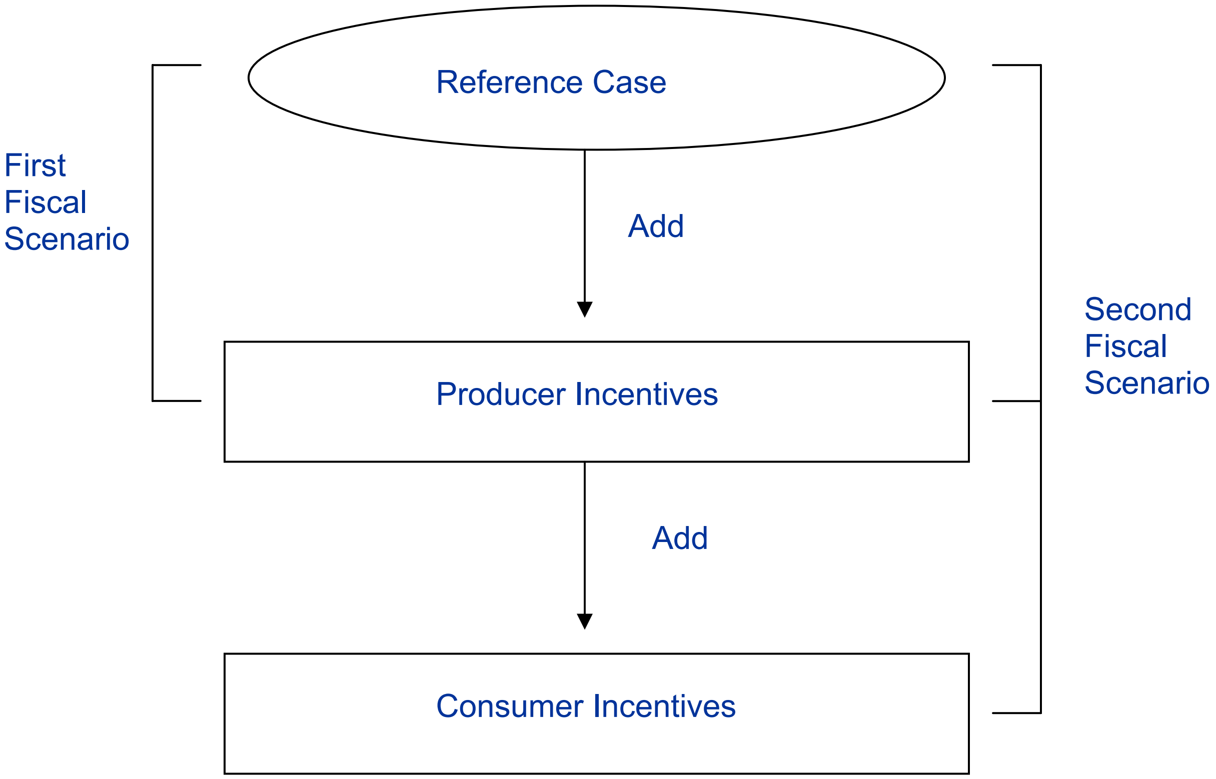

**Figure 1 General modeling framework**

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

Within the framework described in figure 1 above, 6 key scenarios were simulated using the Energy 2020 model[4]. Two scenarios are Reference Cases and 4 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 2 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 fueling 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 fueling stations | Fuel cell LDV or fuel cell transit bus or ICE LDV |

More specifically, the 6 modeling 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

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[4] For a detailed description of the Energy 2020 model, refer to Appendix A of 7the 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.

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).

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 modeling 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 modeling outputs for the residential, commercial, and transportation sectors.

## Fiscal Scenarios

Of the modeling scenarios described above, 4 of them represent the fiscal scenarios simulated in this analysis. The table below identifies the 4 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 modeling 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%

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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 Modeling work related to climate change.

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%. 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 modeling 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 Energy2020 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 in the 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

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

2030 for both Reference Cases. The change in demand associated with fuel cell buses and conventional buses is less significant.

**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 Modeling 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 | 14 | 18 | 22 |

## Greenhouse Gas Emission

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 |

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 |

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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.

[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.

Table 14 shows total greenhouse gas emissions for the sectors of relevance to the 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 |

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.

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

## 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 |
| Northwest Territory | 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 for 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% |
| Northwest Territory | 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 that 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% |
| Northwest Territory | 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 14 above, but also the change in the physical stock of fuel cell vehicles as a result of the Fiscal Scenario. Table 22 shows 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 for 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 |
| Northwest Territory | 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 |
| Northwest Territory | 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 |
| Northwest Territory | 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 electrolysers is consistent with work completed in the United States. See for example, the May 2004 issue of Scientific America, 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, 2030-Consumption only**

| 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 increase.

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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 is 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 electolyzer 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 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.

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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.

## 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. These 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. The 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 electrolysers (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 respectfully. 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 lead to electricity imports into BC that 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 inter-provincial 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 overtime, 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 | 1171.93 |
| 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 | 1216.35 | 1670.50 |
| **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 higher for technologies dominated by capital costs. Ultimately, reducing the capital costs for hydrogen related vehicles as well as hydrogen production costs, lead 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 cells 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 lead to an increase of 47,312 fuel cell vehicles, 33,371 hydrogen ICE vehicles and 218 fuel cells buses in the case of hydrogen production from SMR. Similar results were realized for hydrogen production using electolyzers. 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 |
| Northwest Territory | 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 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

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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.

province, more so than any other region, the 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 equaled 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 lead 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 modeling 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

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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.

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:

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 kilometer 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 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, fueling 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 fueling network.

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 historic 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 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 fueling 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 modeling undertaken in 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

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

30% and 140% higher in 2000 respectfully 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, amoung 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 modeling exercise), and the price of natural gas is over priced, 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 modeling 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 modeling 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 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 |
| Northwest Territory | 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 | 2002.17 | 2118.21 |

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 |
| Northwest Territory | 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 | 2001.38 | 2117.75 |

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** | **2016** | **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** | **2016** | **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 | 1996.91 | 2112.00 |

## 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 | 1995.40 | 2110.70 |

## 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 Modeled

Several hydrogen transportation pathways were identified as being commercially advanced and capable of reducing greenhouse gas emissions yet due to do the need to prioritize the number of runs that could actually be modeled, these hydrogen transportation pathways were deemed outside the scope of this modeling 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 fueling 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 fueling stations | Fuel cell LDV or fuel cell transit bus or ICE LDV |
| 3. Methanol from off-shore natural gas | Decentralized methanol reformer | | | Compressor and tanks at fueling stations | Fuel cell LDV or fuel cell transit bus or ICE LDV |
| 4. Gasoline | Decentralized gasoline reformer | | | Compressor and tanks at fueling stations | Fuel cell LDV or fuel cell transit bus or ICE LDV |
| 5. Methanol from off-shore natural gas | | | | | Methanol fuel cell LDV |
| 6. Gasoline | | | | | Gasoline fuel cell LDV |

The role 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 (pathways 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

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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.

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 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 demand, 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 incent 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 |