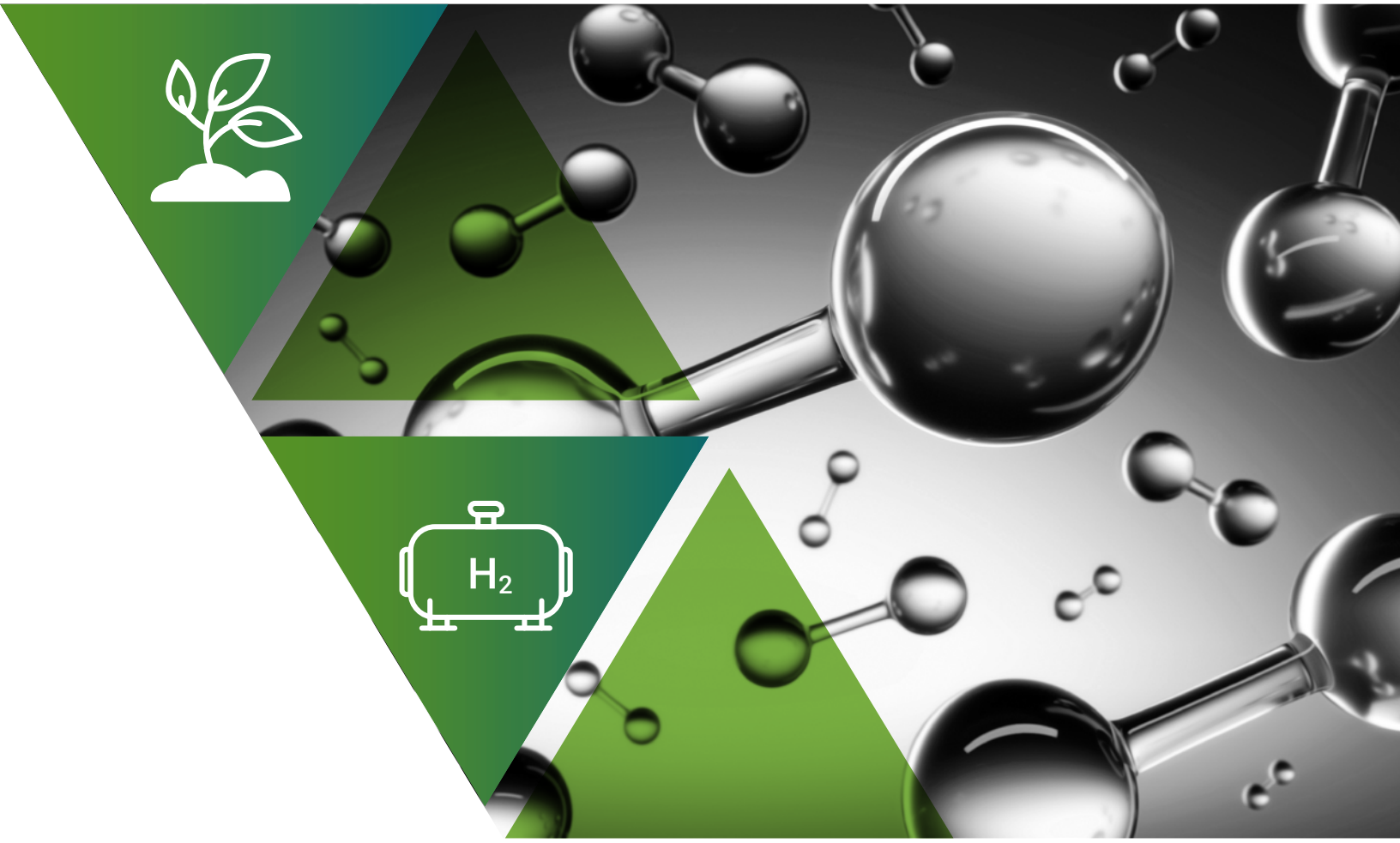
Reports of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada

Report 3

Hydrogen's Potential to Reduce Greenhouse Gas Emissions



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Introduction

Background

Potential benefits and uses of hydrogen

3.1 Hydrogen is the lightest and most abundant chemical element. It is a carbon-free energy carrier that produces no **greenhouse-gases**[1] or other pollutants, releasing only water and heat when it is burned. Burning 1 kilogram of hydrogen releases 3 times more energy than burning 1 kilogram of gasoline. All these characteristics make hydrogen an option for reducing Canada's and other countries' dependence on high-carbon fuels and for meeting net-zero greenhouse gas emission targets. Hydrogen can produce energy in 2 ways:

- by being combusted (for example, in an engine or a turbine)
- by being fed into a fuel cell to produce electricity

3.2 Hydrogen exists only in complex molecules, such as water or hydrocarbons. This means that for it to be used in its pure form, it first has to be produced and stored. Unlike the process of combusting hydrogen, producing hydrogen can take large quantities of energy and, depending on the energy source, can result in greenhouse gas emissions.

3.3 The potential role hydrogen could play in net-zero energy systems and **decarbonization**[2] is gaining significant global interest. Hydrogen can be used to drive down emissions where electrification is not technically or economically feasible, such as in energy-intensive industries. Examples include

- long-distance transportation that requires high-power generation (trains, ships, aircraft, long-haul trucking and buses)

[1] **Greenhouse gases**—Gases in the atmosphere that warm the earth by trapping infrared radiation. They include carbon dioxide, methane, and nitrous oxide.

[2] **Decarbonization**—The process of reducing and removing carbon dioxide output from a country's economy.

- mining vehicles
- small stationary power-grid systems
- power production and storage (storage and release of surplus renewable energy, commonly known as power-to-gas)
- heating fuel for industries that need high-grade heat (for example, in the oil and gas sector or in cement and steel manufacturing)
- fuel for space and water heating for buildings (as an alternative to natural gas)
- feedstock for industrial processes (petroleum refining, bitumen upgrading, ammonia production, methanol production, or steel production)

Methods to produce hydrogen

3.4 Hydrogen's potential for decarbonization depends on how the hydrogen is produced and used. In recent years, colours have been used to identify different methods of hydrogen production and the **carbon intensity**[3] of the process.

- Grey hydrogen is produced from natural gas through **steam methane reforming**[4] without capturing carbon dioxide emissions.
- Blue hydrogen is produced from fossil fuels with the use of **carbon capture and sequestration**[5] technologies to reduce carbon dioxide emissions.
- Green hydrogen is produced by **electrolysis**[6] using renewable electricity without releasing carbon dioxide into the atmosphere.

In 2018, grey hydrogen represented 99% of global hydrogen production, while the production of green and blue hydrogen was still emerging. It is important to highlight that beyond the colours,

[3] **Carbon intensity** of hydrogen production—A method for comparing the end-to-end life cycle of greenhouse gas emissions of hydrogen as it moves from a primary energy source to a delivered energy commodity.

[4] **Steam methane reforming**—A process in which methane from natural gas is heated using steam, usually with a catalyst, to produce a mixture of carbon monoxide and hydrogen.

[5] **Carbon capture and sequestration**—The process of capturing carbon dioxide from facilities (including industrial or power applications), compressing it, and transporting it to be permanently stored in geological formations underground (for example, saline aquifers or oil reservoirs).

[6] **Electrolysis**—The process of using electricity to decompose water into hydrogen and oxygen gas.

what matters in assessing the decarbonization potential of hydrogen are the net carbon emissions in the energy system.

3.5 The differences in hydrogen colours reflect the source of energy used to produce it (Exhibit 3.1). For example, a comparison of the costs and emissions of hydrogen in 2020 with those of natural gas, a widely used energy source in Canada, reveals the scale and range of variation:

- In terms of cost, grey hydrogen was the cheapest hydrogen to produce and 4.4 times the price of natural gas. Blue hydrogen and green hydrogen from hydroelectricity were in the middle range. Green hydrogen from solar and wind was much more expensive, at about 16 times the price of natural gas.
- In terms of emissions, on the low end, green hydrogen has no emissions, and on the high end, grey hydrogen emits 2.2 times what natural gas does.
- As the price on carbon pollution increases, the relative price of the different types of hydrogen could change, depending on their carbon intensity and capture rate. This is because the market price reflects some of the costs attached to the emissions.

Exhibit 3.1— Hydrogen types by production costs and carbon intensity compared to natural gas, 2020

Type of gas	Production process (and % of carbon capture and sequestration)	Production costs (per gigajoule)	Emissions (carbon intensity)
Natural gas*		$3.79	60 kg carbon dioxide equivalent per gigajoule
Grey hydrogen	Steam methane reforming (0%)	$16.70	2.2 times the natural gas emissions
Dark blue hydrogen	Steam methane reforming (53%)	$19.60	1.1 times the natural gas emissions
Light blue hydrogen	Steam methane reforming (89%)	$23.90	0.25 times the natural gas emissions

Type of gas	Production process (and % of carbon capture and sequestration)	Production costs (per gigajoule)	Emissions (carbon intensity)
Green hydrogen	Electrolysis* (solar)	$62.60	No emissions
	Electrolysis* (wind)	$63.80	No emissions
	Electrolysis* (hydro)	$22.00	No emissions

* Carbon capture and sequestration[5] does not apply

Notes: Natural gas costs include capital, labour, and fuel for natural gas processes. Natural gas emissions are the sum of emissions from combustion and production.

Source: Adapted from information provided by Environment and Climate Change Canada

Hydrogen Strategy for Canada

3.6 Over the last few years, several countries and jurisdictions have developed strategies to tap the potential of hydrogen. In December 2020, Natural Resources Canada published the Hydrogen Strategy for Canada. The strategy is also mentioned in Canada's strengthened climate plan—A Healthy Environment and a Healthy Economy—which was released the same month. Canadian provinces have also taken actions in recent years to create frameworks for the development of hydrogen, notably Alberta, British Columbia, Ontario, and Quebec.

3.7 According to Natural Resources Canada, the Hydrogen Strategy for Canada was a call to action, intended to show hydrogen's full potential (economic, environmental, and social) in modernizing Canada's energy systems in the context of the commitment to be net zero by 2050.The strategy

- estimates that hydrogen could reduce Canada's annual greenhouse gas emissions by between 22 and 45 **megatonnes of carbon dioxide equivalent**[7] by 2030, and as much as 190 megatonnes by 2050, depending on actions taken and investments made across the economy
- estimates that the opportunity presented by hydrogen could lead to more than 350,000 sector jobs and direct annual revenues of over $50 billion by 2050

[7] **Megatonne of carbon dioxide equivalent**—The amount of a greenhouse gas that has the same warming potential as a million tonnes (a megatonne) of carbon dioxide over a specified period.

- envisions that hydrogen could represent up to 15% of all emission reductions by 2030 and up to 26% of the reductions by 2050
- foresees Canada as a world-leading exporter of hydrogen by 2050

3.8 According to the Hydrogen Strategy for Canada, the actual annual production of hydrogen in Canada is 3 megatonnes, almost all of it being grey hydrogen. The strategy envisions that in 2030, 4 megatonnes of hydrogen could be produced, representing 6% of energy demand in Canada. The strategy also projects the potential hydrogen demand to be 20.5 megatonnes in 2050, representing 30% of energy delivered.

3.9 The Hydrogen Strategy for Canada sets out near-, mid-, and long-term phases for its implementation (Exhibit 3.2). The strategy also, through collaboration with public and private sector stakeholders, sets out hydrogen's long-term projected contribution to greenhouse gas reductions in key areas of the economy (Exhibit 3.3).

Exhibit 3.2—Phases of the Hydrogen Strategy for Canada

Phase	Theme	Period	Goals/expectations
Near-term	Laying the foundation	2020–25	Development of new hydrogen supply and distribution infrastructure and mature market applications Launching of pilot projects in regional hubs (including pre-commercial applications for heavy-duty trucks, transport equipment for seaport goods, power generation, heat for buildings, and industrial feedstock) Development and implementation of additional policy and regulatory measures needed to reach net-zero carbon emissions by 2050
Mid-term	Growth and diversification	2025–30	Addition of new regional hubs Rapid expansion of adoption of fuel cell electric vehicles and transit buses Increase in new and large-scale hydrogen production, to be commercialized in regional hubs, to enable hydrogen and natural gas blending for industry and as feedstock for chemical production

Phase	Theme	Period	Goals/expectations
			Deployment of hydrogen in mining operations Pilot project testing of hydrogen as a way to store energy
Long-term	Rapid market expansion	2030–50	An increase of new commercial applications supported by supply and distribution infrastructure Commercial launch and rapid expansion of new ways to use hydrogen in transportation Building of more dedicated hydrogen pipelines An increase in the supply of low-carbon intensity hydrogen throughout Canada, allowing heavy-emitting industries to adapt operations to decrease carbon emissions Increased production of hydrogen, which could also position Canada as a large-scale exporter of hydrogen

Exhibit 3.3—Potential long-term emission reductions in key areas of the economy identified by the Hydrogen Strategy for Canada

Sector of the economy using hydrogen	Reduction in greenhouse gases in 2030 (megatonnes of carbon dioxide equivalent per year)	Reduction in greenhouse gases in 2050 (megatonnes of carbon dioxide equivalent per year)
Blending with natural gas	1.7	57.4
Oil and gas	25.0	22.3
Industrial processes	3.3	24.4
Transportation	14.8	61.5
Low-carbon fuels	0.2	24.4
Total	**45.0**	**190.0**

Source: Natural Resources Canada

Roles and responsibilities

3.10 Environment and Climate Change Canada. The department is responsible for supporting and coordinating the development and implementation of Canada's climate change policies, programs, regulations, and plans to reduce greenhouse gas emissions to achieve Canada's 2030 and 2050 climate targets. The department does this work by engaging with other federal government departments, Indigenous partners, provinces and territories, and other interested parties. These activities include

- developing credible science-based emission-reduction plans—also known as pathways—to achieve each target announced by the government
- supporting and coordinating the implementation of Canada's climate plan; working to reduce Canadian greenhouse gas emissions; driving clean growth; developing regulatory instruments; helping businesses and Canadians to adapt and become more resilient to climate change; and contributing to international climate change actions to increase global benefits
- designing and implementing Canada's approach to pricing carbon pollution

3.11 Natural Resources Canada. The department is the lead for the development and implementation of the Hydrogen Strategy for Canada. This includes providing analysis and modelling results and advice to the Minister of Natural Resources and the Government of Canada on hydrogen in Canada's energy system.

Focus of the audit

Build resilient infrastructure, promote sustainable industrialization and foster innovation

Source: United Nations

3.12 This audit focused on whether Environment and Climate Change Canada and Natural Resources Canada comprehensively assessed the role that hydrogen should play as a pathway to reach Canada's climate commitments. The audit scope considered the 2030 emission reduction target—to reduce greenhouse gas emissions by 30% below 2005 levels—that was in effect at the time of the development of the Hydrogen Strategy for Canada.

Take urgent action to combat climate change and its impacts

Source: United Nations

3.13 This audit is important because of the potential significant contribution of hydrogen to meeting Canada's emission reduction goals. In addition, it relates to Goal 9 (Industry, Innovation and Infrastructure) and Goal 13 (Climate Action) of the United Nations' Sustainable Development Goals. If the 2 departments do not appropriately project hydrogen's impact on reducing emissions, then there is a risk that Canada will not achieve its emissions reduction targets.

3.14 More details about the audit objective, scope, approach, and criteria are in **About the Audit** at the end of this report.

Findings, Recommendations, and Responses

Overall message

3.15 Overall, we found that Environment and Climate Change Canada and Natural Resources Canada had different approaches to assessing the role hydrogen should play in reducing greenhouse gas emissions. Environment and Climate Change Canada expected to achieve 15 megatonnes of carbon dioxide equivalent emission reduction in 2030, whereas the Hydrogen Strategy for Canada, published by Natural Resources Canada, projected up to 45 megatonnes. In our view, Environment and Climate Change Canada should have exercised stronger coordination to estimate the role hydrogen should play to meet Canada's emission reduction targets.

3.16 We found the 2 departments used unrealistic assumptions for modelling the potential of hydrogen to reduce greenhouse gas emissions. Based on our findings, we are concerned that A Healthy Environment and a Healthy Economy was not aligned with Canada's climate commitment of 30% emissions reduction in 2030, which was in effect at the time of the development of that plan.

3.17 In our view, this plan is not fully transparent because it includes assumptions that are not clear and relies on some policies that are not announced or in effect. This compromises the credibility of the expected emission reductions. This is also concerning because Canada's greenhouse gas emissions have increased significantly since the United Nations Framework Convention on Climate Change was signed in 1992, making it the worst performer of all G7 nations since that time.

Pathways to inform options for policy on greenhouse gas emission reduction

Context

3.18 Natural Resources Canada used a fuel pathway to inform policy options. A fuel pathway is the journey taken by energy where it begins as a raw natural resource and ends as a refined fuel. The carbon intensity of hydrogen depends on the way it is produced, transported, and used. Hydrogen releases almost zero greenhouse gas when produced with renewable electricity, compared with more than 100 grams of carbon dioxide equivalent per megajoule for gasoline and diesel.

Natural Resources Canada overestimated hydrogen's potential to reduce greenhouse gas emissions

What we found

3.19 We found that when estimating the potential of hydrogen to reduce greenhouse gas emissions of Canada's energy system, Natural Resources Canada prioritized a transformative approach. This approach assumed the adoption of aggressive and sometimes nonexistent policies. The department also assumed ambitious technology uptake in its modelling. In our view, these assumptions are overly optimistic and could jeopardize the achievement of the objectives of the Hydrogen Strategy for Canada. Finally, departmental officials told us that policy makers did not use the hydrogen strategy to inform policy decisions.

3.20 The analysis supporting this finding discusses the following topics:

- Transformative scenario favoured
- Unfounded assumptions of policy implementation across jurisdictions
- Unrealistically low production cost assumptions
- Supporting infrastructure costs not considered
- Overly ambitious assumptions of technology uptake

Why this finding matters

3.21 This finding matters because Canada's greenhouse gas emissions have increased significantly since the United Nations Framework Convention on Climate Change was signed in 1992, making it the worst performer of all G7 nations since that time. Sound modelling is needed to change the trajectory of Canada's greenhouse gas emissions. Such modelling is critical for good decision making on policies and programs that assess how hydrogen could help Canada meets its targets to reduce emissions for 2030 and 2050.

Context

3.22 Natural Resources Canada conducted modelling exercises to obtain insight about the role hydrogen could play in the decarbonization of Canada's energy system, as well as about the potential size of hydrogen demand. Models help to

- understand how complex systems work and behave when they are subject to policy intervention
- explore options and isolate the best ones when assessing the impacts of policies or forecasting future uptake for a technology or fuel
- identify opportunities and inform public debate

3.23 The department's modelling exercises explored 2 scenarios:

- **The incremental scenario:** This is a bottom-up, aggregated demand modelling based on a business-as-usual approach. That is, it uses known regulations and technologies and light policy measures, representing a slower adoption and the lower-end demand for hydrogen.
- **The transformative scenario:** This is an aggressive modelling that assumes the most favourable future regulations, technological developments, and adoption growth rates will be in place to achieve net-zero emissions by 2050.

Recommendation

3.24 Our recommendations in this area of examination appear at paragraphs 3.34 and 3.35.

Analysis to support this finding

Transformative scenario favoured

3.25 We found that when estimating the potential benefits of hydrogen, Natural Resources Canada favoured a transformative scenario to show the potential offered by hydrogen. However, the transformative scenario did not consider some of its associated costs. In the Hydrogen Strategy for Canada, Natural Resources Canada modelled hydrogen as the solution to fill the gap in energy demand not met by other decarbonization means (such as electrification, biofuel, and emissions offset for fossil fuels). The modelling assumed that Canada's net-zero climate objectives were the end goal but did not propose distinct individual policies or programs on which the government was expected to make decisions.

3.26 The Hydrogen Strategy for Canada stated that the transformative scenario should be viewed as the potential size of the hydrogen opportunity and should not be used as a forecast for future hydrogen demand. Despite this, we found that the department used the transformative scenario as a projected demand of hydrogen to quantify the associated emission reductions. Instead of relying on a bottom-up scenario, which would have modelled the potential outcome of policies leading to the expansion of hydrogen end-uses, the projection assumed Canada's carbon neutral objective without knowing how to get there. According to Natural Resources Canada officials, the projections and the specific actions in the strategy have not been considered in any policy decisions.

3.27 The transformative scenario developed by Natural Resources Canada projected that hydrogen could represent up to 15% of the emission reductions needed to meet the 2030 target. In contrast to this, we found that one of Natural Resources Canada's incremental demand reports projected that in 2030, hydrogen will contribute only 0.5% of the 2030 target and 5.5% of the 2040 target. The department did not find this estimation compelling and chose to use more aspirational numbers in the Hydrogen Strategy for Canada modelling.

3.28 Finally, we found that the transformative scenario did not systematically assess the cost effectiveness of different alternatives or evaluate whether technologies would be ready or deployable. This approach did not fully consider supporting infrastructures or the risk of retiring assets before their full life span. These shortcomings limited the department's ability to have a clear and complete picture of the best uses for hydrogen.

Unfounded assumptions of policy implementation across jurisdictions

3.29 We found that the Hydrogen Strategy for Canada assumed that several provincial measures and policies would need to be in place in all provinces. For example, the department extended the idea of blended natural gas to apply it to hydrogen and to all provinces. However, if the proposed Clean Fuel Standard were to be adopted as is, its exclusion of gaseous fuel would not support this expansion of a blending mandate to other provinces. The proposed Clean Fuel Standard would promote blending for liquids, but not blending of hydrogen in natural gas. Other examples of generalizations include the following:

- The strategy assumed that zero-emission vehicle mandates that apply only in British Columbia and Quebec would be adopted in all provinces in a similar way.
- The strategy assumed the federal government would implement a zero-emission buses mandate similar to the one in California.

These assumptions were unfounded because they were not backed up by either provincial or federal policies.

3.30 We found that the department assumed uniform measures and policies across all provinces. However, even in cases where such polices and measures were uniform, they could yield different levels of emission reductions. This is mainly because of variation in the distribution of natural resources and economic networks. According to best practices, for demand modelling to be sound, it should be built on provincial hydrogen demand driven by both provincial and federal regulations and then aggregated to get Canada's total demand.

Unrealistically low production cost assumptions

3.31 We found that when assessing opportunities to generate hydrogen using electrolysis, Natural Resources Canada assumed

a very low price of electricity across all provinces. For example, it assumed an electricity price of $40 per megawatt hour across all provinces. This was well below the recent prices observed in Canadian provinces in 2020, which ranged from $52 to $124 per megawatt hour for large-power customers. This meant that the department overestimated the opportunity of electrolysis to produce hydrogen at a low cost.

Supporting infrastructure costs not considered

3.32 We found that Natural Resources Canada's modelling did not factor in how the supply of hydrogen and associated costs would be deployed to meet the projected demand. We also found that the department did not factor in how the existing grid and infrastructure could accommodate electrification ambitions, as well as hydrogen production from renewable generation. For example, the modelling did not consider the following elements:

- the required size of the grid to support the level of hydrogen deployment and long-term contracts for electricity supply to the United States
- the real rate of capture for **carbon capture, utilization, and storage,**[8] which is currently less than the 89% that is required to make blue hydrogen emission reduction competitive against natural gas (Exhibit 3.1)
- the pipeline and storage infrastructure needs
- the time needed to build supporting infrastructure

Overly ambitious assumptions of technology uptake

3.33 We found that Natural Resources Canada's modelling approach included ambitious assumptions about uptake and deployment of technologies:

- It estimated that annual sequestration of carbon dioxide equivalent by 2050 would increase by 34 times, from 4 megatonnes at the time of the audit to 135 megatonnes.
- It included direct air capture, which is a new technology that needs further research and development to get to maturity.

[8] **Carbon capture, utilization, and storage**—The process of carbon capture and sequestration when the captured carbon dioxide is used to create products (for example, concrete and low-carbon synthetic fuels) or is stored underground in geological formations.

3.34 **Recommendation.** Natural Resources Canada should perform a comprehensive bottom-up modelling for the use of hydrogen. This modelling should account for the following:

- emission reduction efficiencies by sector (cost of emission reductions per megatonne of carbon dioxide equivalent)
- substitutional fuels (for example, biofuel, electrification, credit systems)
- feasible deployment of technologies and supporting infrastructure

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

3.35 **Recommendation.** Based on the updated modelling, Natural Resources Canada, in partnership with interested stakeholders, should publish a hydrogen market development roadmap to track progress and outcomes of the deployment of the hydrogen in Canada.

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

Environment and Climate Change Canada used an inadequate approximation to model hydrogen's potential

What we found

3.36 We found that Environment and Climate Change Canada used an inadequate approximation, called a proxy, in modelling the potential demand for hydrogen in A Healthy Environment and a Healthy Economy and used this estimate to comment on the Hydrogen Strategy for Canada. The proxy—a hydrogen–natural gas blending obligation—was not based on any existing policy at the provincial or federal level. In addition, it was uneconomical based on the current trend of carbon pricing. This weakness in the proxy called into question whether the emission reduction pathway was realistic and achievable.

3.37 The analysis supporting this finding discusses the following topics:

- Distorting effect of hydrogen–natural gas blending proxy
- Questionable economic feasibility

Why this finding matters

3.38 This finding matters because rigorous modelling is an important component in developing credible, science-based emission reductions plans to help Canada meet its greenhouse gas emission targets.

Context

3.39 In modelling, hydrogen production is brought into the energy mix through 2 primary mechanisms:

- **A competitive approach based on market dynamics.** This is when the lowest cost production technology meets the demand for hydrogen or when direct subsidies to hydrogen are sufficient to render the hydrogen technology efficient. The constraint in this approach is that the modeller needs to specify assumptions on production cost and rate of subsidies and how they could affect hydrogen supply and demand.
- **A regulatory approach.** This is when, for example, a blending mandate of hydrogen in natural gas assumes that hydrogen will be used, at least partially, in place of natural gas. In that case, modelling helps determine the lowest cost technologies to produce the hydrogen needed to fulfill the mandate.

In cases where the cost of hydrogen per energy unit (for example, gigajoule) is relatively higher than other energies, a blending mandate, rather than market dynamics, is required as an incentive for hydrogen uptake.

3.40 Canada is the world's fourth-largest producer of natural gas, generating 16.6 billion cubic feet per day. It is the sixth-largest exporter of natural gas. Natural gas plays a pivotal role in Canada's energy system, providing 35.7% of energy demand. It is used to generate electricity and to heat space and water in buildings and in industrial processes.

3.41 To blend hydrogen with natural gas, natural gas providers face many technical hurdles, such as the weakening of pipes, the lack of measurement standards, and the lack of end-use equipment. The blending rate will be determined primarily by supply and the technical limits of the network and end-use equipment.

Recommendations

3.42 Our recommendation in this area of examination appears at paragraph 3.50.

Analysis to support this finding

Distorting effect of hydrogen–natural gas blending proxy

3.43 We found that in A Healthy Environment and a Healthy Economy, Environment and Climate Change Canada used a proxy of 7.3% blending of hydrogen in the natural gas network to simulate the demand for hydrogen. This modelling assumption was to guide possible future work on policy drivers. However, a 7.3% blend was not supported by any blending regulation at the provincial or federal level. We noted that the department was not comfortable moving to a higher blending model assumption until the results from pilot projects and the codes and standards results were available.

3.44 In its pathway modelling, the department assumed that all existing buyers of natural gas must switch to a 7.3% hydrogen–natural gas blend. We found that this mandatory unique uptake for hydrogen misrepresented the share of other blending options (for example, a blend of renewable natural gas and natural gas). This imposes a *de facto* substitution towards a hydrogen–natural gas blend even though other types of blending and energy could be more economically effective. Furthermore, we found that A Healthy Environment and a Healthy Economy attributed only limited hydrogen demand to the transportation sector given that the transportation sector used little natural gas. This did not align with the Hydrogen Strategy for Canada, released by Natural Resources Canada, which noted that hydrogen can be used in transportation. As a result, modelling hydrogen with a proxy of a 7.3% hydrogen–natural gas blend could distort the projected choices of businesses and consumers between existing fuels, hydrogen and other low-carbon fuels, and the respective share of each fuel in the energy system.

3.45 The Canada Energy Regulator conducted various analyses on the energy supply and demand in Canada. In its report Canada's Energy Future 2021, the regulator assumed hydrogen blending in natural gas at 1% by 2030. This was because of the physical limits on how much hydrogen can be blended into existing natural gas pipelines and how much can be used in conventional end-use devices. We found that this blend was much lower than the 7.3% hydrogen blending into natural gas assumed by Environment and Climate Change Canada in 2030. The Canada Energy Regulator assumed a 7% hydrogen blending into natural gas only by 2050.

3.46 As Canada works toward decarbonizing its economy, many utility providers are exploring mixing natural gas with hydrogen to reduce emissions. Utility providers in Alberta and Ontario have been awarded funds to pilot projects on hydrogen blending. We found that Natural Resources Canada conducted a survey of utility providers during the preparation of the Hydrogen Strategy for Canada. The survey showed that most utility providers agreed on hydrogen's important role in the future of the natural gas industry. However, most respondents believed this would only happen with more stringent Clean Fuel Standard regulations or targets. Furthermore, utility providers stressed that consumers were not asking for cleaner natural gas and that blending natural gas with hydrogen would require a break-even price of less than $15 per gigajoule to make it competitive. Currently, as Exhibit 3.1 shows, producing the hydrogen that could lower emissions through blending in the natural gas network costs at least $23.90 per gigajoule (blue hydrogen) and $22 per gigajoule (green hydrogen with hydroelectricity).

3.47 Environment and Climate Change Canada expected that the 7.3% blending assumption would achieve15 megatonnes of carbon dioxide equivalent emission reduction in 2030. We found that this projection for 2030 did not align with the projection published by Natural Resources Canada in the Hydrogen Strategy for Canada, which was of up to 45 megatonnes of carbon dioxide equivalent. This shows a clear difference in the projected size of the possibility of decarbonization by hydrogen. This also shows the absence of standardized methods across government departments to estimate potential emission reductions.

3.48 Furthermore, Environment and Climate Change Canada's 7.3% blending modelling assumption required additional carbon capture utilization and storage capacity given that the natural gas blending would be made up primarily of blue hydrogen. We found that, in A Healthy Environment and a Healthy Economy, the department projected the total annual Canada carbon capture utilization and storage capacity in 2030 to be 57 megatonnes,

compared with the current capacity of 4 megatonnes. Meeting this projection would require a significant increase in the adoption and use of carbon capture utilization and storage within the decade. According to Environment and Climate Change Canada, 30 megatonnes out of the 57 megatonnes would support the production of hydrogen needed to obtain the 7.3% natural gas blending obligation.

Questionable economic feasibility

3.49 We found that even though a 7.3% blending of hydrogen in natural gas might be technically feasible for some gas networks, it was not justified economically. According to analysis provided to Natural Resources Canada, a more stringent carbon price of at least $500 per tonne would be needed to encourage businesses to adopt blending at this level. Also, at the time of the audit, natural gas, as a gaseous fuel, was excluded from Environment and Climate Change Canada's recently proposed Clean Fuel Standard. It was contradictory to assume that utility providers would adopt blending given that it was currently uneconomical for them do so, and would be so even when the carbon price reached $170 per tonne of carbon dioxide equivalent in 2030.

3.50 Recommendation. To improve consistency across departments, Environment and Climate Change Canada and other federal departments should adopt a standard framework to estimate emission impacts of proposed policies, clean technologies, and fuels.

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

Environment and Climate Change Canada relied on policies not yet announced to justify that its plan was sufficient to meet the original 2030 target

What we found

3.51 While auditing the modelling for hydrogen performed by Environment and Climate Change Canada, we found that the achievement of the original 2030 target in A Healthy Environment and a Healthy Economy relied on some policies not yet announced or used, and in some cases modelling was based on overly confident assumptions. In addition, we found its models

underwent limited quality assurance control and review from peers and stakeholders. Finally, departmental officials told us it is not in the purview of Environment and Climate Change Canada's modelling group to develop cost-effective decarbonization pathways. According to the department, this responsibility is disseminated across several federal organizations.

3.52 The analysis supporting this finding discusses the following topics:

- Lack of transparency and overly confident assumptions in the model
- Limited quality control and review from peers and stakeholders

Why this finding matters

3.53 This finding matters because if models are not based on realistic assumptions, they cannot identify the most cost-effective pathway for Canada to achieve targets for emission reductions. A lack of solid assumptions can also jeopardize the reliability of the plans and the ability of Canada to achieve its emission reduction target.

Context

3.54 In December 2020, after a series of plans and commitments, the Government of Canada released a strengthened climate plan—A Healthy Environment and a Healthy Economy (Exhibit 3.4). The new plan builds on the efforts that are currently underway through the Pan-Canadian Framework on Clean Growth and Climate Change to cut more pollution. A Healthy Environment and a Healthy Economy provides details of initiatives that aim to reduce emissions by at least 30% below 2005 levels by 2030. It includes measures such as

- more stringent carbon pricing
- energy conservation and efficiencies for buildings
- clean transportation and zero-emission vehicles
- technologies that remove carbon (for example, carbon capture, utilization, and storage)
- clean fuel and technologies (for example, hydrogen)

Exhibit 3.4—Canada's climate commitments and plans

Plans and commitments	High-level intentions
2015—Paris Agreement	Canada signs the Paris Agreement in 2016 and commits to reducing its greenhouse gas emissions by 30% below 2005 levels by 2030.
2016—Pan-Canadian Framework on Clean Growth and Climate Change	The government publishes the framework to meet the target to reduce emissions by 30% below 2005 levels by 2030.
2020—A Healthy Environment and a Healthy Economy	The plan builds on the efforts of the Pan-Canadian Framework on Clean Growth and Climate Change. It provides details of initiatives that aim to reduce emissions by at least 30% below 2005 levels by 2030.
2021—Canada's new greenhouse gas emission reduction target	Canada commits to a higher emission reduction target of 40% to 45% below 2005 levels by 2030. This means that Canada could emit a maximum of 401 to 438 megatonnes of carbon dioxide equivalent in 2030. (In 2019, Canada emitted 730 megatonnes of carbon dioxide equivalent.)
2021—Canadian Net-Zero Emissions Accountability Act	The act requires that the Minister of the Environment set national targets for reducing greenhouse gas emissions for 2030, 2035, 2040, and 2045, with the goal of net-zero emissions by 2050. It also requires that an emission reduction plan, a progress report, and an assessment report for each target be tabled in each House of Parliament.
2022—Emission Reduction Plan	The emission reduction plan outlines how Canada will achieve greenhouse gas emission reductions of 40% to 45% below 2005 levels by 2030. This plan also includes an interim greenhouse gas objective for 2026, which will act as a midpoint check-in between now and 2030.

3.55 In meeting its climate commitments, the Government of Canada can build awareness and trust with citizens through being transparent about its plans and progress. Transparency can also help to hold the government to account. As we noted in our 2021 report of the Commissioner of the Environment and Sustainable Development—Report 5: Lessons Learned from Canada's Record on Climate Change—many climate-related audits have examined transparency and have found persistent issues with how departments report on their emissions modelling.

In addition, our 2021 audit—Report 4: Emissions Reduction Fund: Natural Resources Canada—noted that the process for estimating expected reductions lacked transparency.

3.56 Environment and Climate Change Canada used a suite of models to analyze policy decisions regarding the energy sector and their impact on the economy and the environment.

Recommendations

3.57 Our recommendations in this area of examination appear at paragraphs 3.64, 3.65, and 3.73.

Analysis to support this finding

Lack of transparency and overly confident assumptions in the model

3.58 We found that Environment and Climate Change Canada modelled A Healthy Environment and a Healthy Economy based on measures that have not been implemented. It also relied on policies that did not have the necessary legislative and financial support as if they were already in place. The following are some examples:

- **A tax incentive similar to 45Q in the United States for carbon capture, utilization, and storage.** Such a tax incentive in Canada was not announced at the time of A Healthy Environment and a Healthy Economy and was still not finalized at the time of the audit.
- **A proxy of 7.3% blending of hydrogen in the natural gas to represent demand for hydrogen.** Such a proxy was not supported by any blending regulation at the provincial or federal level.
- **Clean Fuel Standard regulations.** These are forthcoming and not yet finalized. The scope of the standard has evolved over the past years and at the time of the audit recognized only liquid fuels.

3.59 We found that A Healthy Environment and a Healthy Economy presented a list of government policies, programs, and strategies that aimed to support the achievement of its emission reduction target. However, it did not distinguish existing policies and measures from those not yet announced or implemented. In

this regard, Environment and Climate Change Canada lacked transparency in the reporting of its modelling. Despite the fact that A Healthy Environment and a Healthy Economy presented a reference case and an updated case with announced initiatives, the document provided no clear and comprehensive public list of assumptions for each case. Instead, it presented only high-level and vague assumptions. In our view, this situation prevented an informed public debate about policy choices.

3.60 Environment and Climate Change Canada provided us with a comprehensive list of assumptions for both cases. We found that the department relied on some inflated and overly confident assumptions when modelling measures to reach the 30% emission reduction target for 2030 (Exhibit 3.5).

Exhibit 3.5—Environment and Climate Change Canada based its modelling on some unrealistic assumptions

Assumption	Facts
An increase, starting in 2022, in shell (elements of the building structure, such as the walls, windows, etc.) energy efficiency of all buildings by a target of 2% each year for residential and 2.5% for commercial	These levels of increase would require major retrofits in the industry. Between 1990 and 2017, overall energy efficiency (lighting, heating, shell, appliances) for the residential sector improved on average by 1.6% per year and for the commercial and institutional sectors by 0.7% per year.
Increased sales shares in line with the California policy on zero-emission heavy-duty vehicles	In Canada, no similar policy had been implemented or announced.
The building of new electricity transmission lines between provinces by 2028 and 2030 to provide clean electricity to provinces that rely on fossil fuel electricity generation	This would require billions of dollars of investment and agreement between various stakeholders (such as the provinces, First Nations, utility providers, and the federal government) to secure a right of way.

3.61 We found that Environment and Climate Change Canada did not model each initiative as a separate pathway. Instead, it modelled all the initiatives together with the goal of getting to the climate emission reduction target. Department officials told us their series of models could not attribute the impact of a specific policy initiative when modelled as a package. This meant that the department could not

- trace back the performance of a specific policy
- attribute an amount of emission reductions to a specific policy

- isolate interactions between policies or programs
- model the measures in any sequence since the sequence of adding a measure into the model affects the estimate of greenhouse gas emission reduction

3.62 In addition, we found that Environment and Climate Change Canada could not identify the most cost-effective pathway to achieve emission reduction targets. For example, when modelling hydrogen for A Healthy Environment and a Healthy Economy, the department did not demonstrate that it considered the costs of the hydrogen blending or of the strengthened climate plan. Instead, it focused solely on achieving the target for reducing emissions. Moreover, departmental officials told us it is not in the purview of Environment and Climate Change Canada's modelling group to develop cost-effective decarbonization pathways. According to the department, this responsibility is disseminated across several federal organizations

3.63 We found that Canada used targeted funds to support specific policies or sectors without making public its estimate of expected emission reductions. For example, the department had not yet performed modelling of the impact on emissions of the $5 billion for the Strategic Innovation Fund's Net Zero Accelerator initiative announced in Budget 2021.

3.64 **Recommendation. I**n order to increase transparency of its emission projections, Environment and Climate Change Canada should develop and publish results for scenarios

- that include a detailed list of measures and assumptions considered
- that show a clear distinction between (1) scenarios based on existing policies and measures and (2) exploratory scenarios that include proposed or aspirational policies and measures

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

3.65 **Recommendation. I**n order to better inform decision making, Environment and Climate Change Canada, in coordination with Natural Resources Canada, should improve its pathway modelling by using reasonable, cost-effective, and technically feasible assumptions.

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

Limited quality control and review from peers and stakeholders

3.66 We found that Environment and Climate Change Canada had a limited framework through which its most important models supporting decisions on decarbonization policies were subject to

- review from peers and stakeholders
- quality assurance control

3.67 In 2014, the Office of the Auditor General of Canada conducted an audit on the methods for estimating and reporting Canada's future greenhouse gas emissions. We recommended to Environment Canada that, in order to strengthen quality controls and increase transparency, the department should take steps to enhance external review of its climate change modelling framework. In our view, although there was progress made in a number of areas, this 2014 recommendation is still relevant.

3.68 We also found that Environment and Climate Change Canada annually consulted on projections with provinces, territories, and other federal departments. In this way, it shared data, information, assumptions, and modelling results to explain the results of the projections and to better understand and reflect all the provincial policies.

3.69 In addition, department officials told us that Canada's Emissions Trends reports and the academic papers written by officials at Environment and Climate Change Canada involving the models were reviewed by external peers. We found that of the 4 models the department used to estimate emissions, 1 underwent a peer review in 2018. We also found that the consultants reviewed a set of predetermined charge questions.

3.70 The department believed that these were sufficient to claim acceptable modelling. In our view, however, these reviews were insufficient in terms of rigour and transparency compared with practices of other jurisdictions. Those practices included asking another organization to choose the peer reviewers, having a framework to avoid conflicts of interests, and publishing the peer reviews of their modelling framework on the internet.

3.71 The United Kingdom, for example, established a quality control framework on both the process (guidance and documentation) and the modelling environment (culture, capacity and capability, and control) for its critical models. Given the models' usefulness and complexity, it was important to ensure that they were fit for intended purposes. Quality assurance control covered the following:

- model concept and design, including the rationale and scope
- model build and development, including the department's process for quality assurance
- model input data and assumptions
- testing of model sensitivity
- making use of the outputs

3.72 In 2010, the United Kingdom launched the 2050 Calculator, an online scenario testing tool that allows users to explore many different ways of reducing the United Kingdom's emissions by 2050. This tool gave experts and stakeholders the opportunity to provide inputs. Both the model and its assumptions were published on the Internet. When developing the 2050 Calculator, the UK Department for Business, Energy and Industrial Strategy published several "calls for evidence" and worked with hundreds of stakeholders to improve the model. Also, the department openly discussed uncertainties and the way it handled them. In this way, it improved trust in the model and its insights and achieved quality assurance control from experts all over the world.

3.73 **Recommendation.** To improve quality, transparency, and trust in climate change modelling, Environment and Climate Change Canada should develop a formal review framework where its modelling would be subject to

- enhanced peer review
- formal consultations with stakeholders
- formal periodic quality assurance control
- public scrutiny

The department's response. *Agreed.*

See the **List of Recommendations** at the end of this report for detailed responses.

Conclusion

3.74 We concluded that Environment and Climate Change Canada and Natural Resources Canada modelled the role that hydrogen could play as a pathway to reach Canada's climate commitments. However, Natural Resources Canada overestimated hydrogen's decarbonization potential, and Environment and Climate Change Canada used an inadequate proxy to model it. In addition, we were concerned that Environment and Climate Change Canada's modelling of A Healthy Environment and a Healthy Economy used policies that had not yet been implemented. Finally, the plan was based on some overly confident assumptions that called into question its credibility and its ability to achieve Canada's 2030 emission reduction target, which was in effect at the beginning of the audit. Environment and Climate Change Canada would benefit from a stronger framework for peer review, public scrutiny, and quality assurance and control in its modelling exercises.

Subsequent Event

3.75 On 29 March 2022, Environment and Climate Change Canada released the 2030 Emissions Reduction Plan—Canada's Next Steps for Clean Air and a Strong Economy to meet its new 40% target. Annex 5 of the Plan presents the most up-to-date assumptions and the key drivers that will influence Canada's overall greenhouse gas emissions. As such, it acknowledges the Hydrogen Strategy for Canada. The 2030 Emissions Reduction Plan uses the same approach as the strengthened climate plan—A Healthy Environment and a Healthy Economy—to reflect hydrogen's potential contribution to achieving Canada's target. The modelling included in the 2030 Emissions Reduction Plan assumes a 7.3% natural gas blending mandate as a proxy for potential future emission reductions.

About the Audit

This independent assurance report was prepared by the Office of the Auditor General of Canada on hydrogen as a pathway to reduce greenhouse gas emissions. Our responsibility was to provide objective information, advice, and assurance to assist Parliament in its scrutiny of the government's management of resources and programs, and to conclude on whether the modelling of the departments complied in all significant respects with the applicable criteria.

All work in this audit was performed to a reasonable level of assurance in accordance with the Canadian Standard on Assurance Engagements (CSAE) 3001—Direct Engagements, set out by the Chartered Professional Accountants of Canada (CPA Canada) in the CPA Canada Handbook—Assurance.

The Office of the Auditor General of Canada applies the Canadian Standard on Quality Control 1 and, accordingly, maintains a comprehensive system of quality control, including documented policies and procedures regarding compliance with ethical requirements, professional standards, and applicable legal and regulatory requirements.

In conducting the audit work, we complied with the independence and other ethical requirements of the relevant rules of professional conduct applicable to the practice of public accounting in Canada, which are founded on fundamental principles of integrity, objectivity, professional competence and due care, confidentiality, and professional behaviour.

In accordance with our regular audit process, we obtained the following from entity management:

- confirmation of management's responsibility for the subject under audit
- acknowledgement of the suitability of the criteria used in the audit
- confirmation that all known information that has been requested, or that could affect the findings or audit conclusion, has been provided
- confirmation that the audit report is factually accurate

Audit objective

The objective of this audit was to determine whether Environment and Climate Change Canada and Natural Resources Canada comprehensively assessed the role that hydrogen should play as a pathway to reach Canada's climate commitments.

Scope and approach

The audit on hydrogen and the pathways to reduce greenhouse gas emissions focused on Environment and Climate Change Canada and Natural Resources Canada.

During the audit, we interviewed representatives of the departments. We examined and analyzed documents provided by the departments, stakeholders, and international

organizations. We conducted interviews with stakeholders and experts in the field. We analyzed international good practices related to the topics we were auditing.

Criteria

Criteria	Sources
We used the following criterion to determine whether Environment and Climate Change Canada and Natural Resources Canada comprehensively assessed the role that hydrogen should play as a pathway to reach Canada's climate commitments:	
Environment and Climate Change Canada and Natural Resources Canada, according to their respective roles and responsibilities, conduct modelling exercises to assess the greenhouse gas reduction potential associated with the development of the hydrogen economy, provide technical advice, and perform comprehensive pathways analysis.	• A Healthy Environment and a Healthy Economy, Environment and Climate Change Canada • Pan-Canadian Framework on Clean Growth and Climate Change, Environment and Climate Change Canada • 2021–22 Departmental Plan, Environment and Climate Change Canada • Hydrogen Strategy for Canada, Natural Resources Canada • *Canadian Net-Zero Emissions Accountability Act*

Period covered by the audit

The audit covered the period from 1 December 2019 to 15 January 2022. This is the period to which the audit conclusion applies.

Date of the report

We obtained sufficient and appropriate audit evidence on which to base our conclusion on 17 February 2022, in Ottawa, Canada.

Audit team

This audit was completed by a multidisciplinary team from across the Office of the Auditor General of Canada led by Philippe Le Goff, Principal. The principal has overall responsibility for audit quality, including conducting the audit in accordance with professional standards, applicable legal and regulatory requirements, and the office's policies and system of quality management.

List of Recommendations

The following table lists the recommendations and responses found in this report. The paragraph number preceding the recommendation indicates the location of the recommendation in the report.

Recommendation	Response
3.34 Natural Resources Canada should perform a comprehensive bottom-up modelling for the use of hydrogen. This modelling should account for the following: • emission reduction efficiencies by sector (cost of emission reductions per megatonne of carbon dioxide equivalent) • substitutional fuels (for example, biofuel, electrification, credit systems) • feasible deployment of technologies and supporting infrastructure	Agreed. Natural Resources Canada agrees that it is important to model the potential role for hydrogen use across all sectors of the economy, including resulting emission reductions potential and cost. The modelling undertaken for the Hydrogen Strategy for Canada focused on the nearest term, most likely and economically viable end-uses—such as heavy-duty transportation, natural gas blending, cement and steel manufacturing, and low-carbon fuel production. This sector-by-sector analysis of hydrogen end-uses included aspects of technology readiness levels, economic competitiveness, adoption potential, and other factors, including supporting infrastructure. This analysis will be updated as new deployment activities occur and new technologies enter the market. Results of the energy use modelling can then be used by Environment and Climate Change Canada to inform their modelling of potential emissions reductions, while also contributing to Environment and Climate Change Canada's efforts to address the recommendation identified in paragraph 3.65. We acknowledge that the modelling undertaken did not include a specific cost per tonne, given the focus was on hydrogen's full potential for use across the economy, as opposed to focusing on the cost and impacts of a specific measure or combination of specific measures. Because costs per tonne are dependent on a number of variables, including production technologies (and feedstocks), distribution, type of investment, and specific end-use, the Government analyzes cost per tonne on a measure-by-measure basis when considering possible new regulatory, fiscal, or program measures, as opposed to economy-wide modelling.

Recommendation	Response
3.35 Based on the updated modelling, Natural Resources Canada, in partnership with interested stakeholders, should publish a hydrogen market development roadmap to track progress and outcomes of the deployment of the hydrogen in Canada.	Agreed. Natural Resources Canada agrees that it is important to explore specific market opportunities in greater detail and develop and release regional roadmaps, then track progress. This echoes a recommendation in the Hydrogen Strategy for Canada to develop regional blueprints that can go a level deeper in identifying regionally specific opportunities and potential challenges, as well as clear actions that must be taken to seize those opportunities. The Hydrogen Strategy for Canada also identified the need to establish a comprehensive reporting framework to track progress as being an essential early action for implementation. Natural Resources Canada is already advancing work on blueprints in partnership with provinces and territories and key stakeholders. Natural Resources Canada has provided technical and financial support to the development of several regional strategies that have been released or are currently under development, including those in British Columbia, Alberta, Ontario, Quebec, and the Atlantic region. Given the evolving nature of the hydrogen market, additional analysis will continue through the 16 thematic working groups that have been established to support the implementation of the Hydrogen Strategy for Canada. This analysis is focused on all aspects of the hydrogen value chain—from production to distribution and multiple end-use. Natural Resources Canada is also working on the development of the reporting framework for the biennial progress report, which will track progress on the recommendations outlined in the Hydrogen Strategy for Canada, as well as data and market analysis related to the expected growth in Canada and globally. The biennial report will be a single compendium of information and results on all hydrogen-related activities undertaken across the country, including activities directly receiving federal or provincial/territorial support, as well as those undertaken strictly through the private sector. It will include key metrics and data related to hydrogen production, end-uses, investments, jobs, and exports.

Recommendation	Response
3.50 To improve consistency across departments, Environment and Climate Change Canada and other federal departments should adopt a standard framework to estimate emission impacts of proposed policies, clean technologies, and fuels.	Agreed. It is agreed that consistent and reliable emission estimates of proposed policies are necessary to inform decision making. The recently established Integrated Climate Lens Centre of Expertise, located at Environment and Climate Change Canada, has a mandate to ensure that major government decisions, namely through budget and Cabinet processes, consider climate mitigation and adaptation in a rigorous, consistent and, where possible, measureable manner.
3.64 In order to increase transparency of its emission projections, Environment and Climate Change Canada should develop and publish results for scenarios • that include a detailed list of measures and assumptions considered • that show a clear distinction between (1) scenarios based on existing policies and measures and (2) exploratory scenarios that include proposed or aspirational policies and measures	Agreed. This recommendation aligns with current Environment and Climate Change Canada practice. Environment and Climate Change Canada's greenhouse gas emission projections are published in accordance with international standards that require a clear distinction between existing and planned initiatives. Environment and Climate Change Canada models and publishes 2 greenhouse gas cases: the "Reference" case, which includes federal, provincial and territorial policies and measures that are funded, legislated and implemented; and the "With Additional Measures" case, which builds on the "Reference" case by including planned policies. International guidelines for reporting from the United Nations Framework Convention on Climate Change (UNFCCC) are available online: • Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part II: UNFCCC reporting guidelines on national communications (Annex starts on page 29, Section VI; projections on page 35, para. 26) • UNFCCC biennial reporting guidelines for developed country Parties (Annex I, starts on page 31, Section V; projections on page 33) Canada’s reports to the UNFCCC include the detailed list of measures in both the "Reference" and "With Additional Measures" cases.
3.65 In order to better inform decision making, Environment and Climate Change Canada, in coordination with Natural Resources Canada, should improve its pathways modelling by using reasonable, cost-effective, and technically feasible assumptions.	Agreed. For purposes of modelling greenhouse gas projections in the context of Canada’s climate plan, Environment and Climate Change Canada publishes both a "Reference" case and a "With Additional Measures" case. Both use reasonable, cost-effective and technically

Recommendation	Response
	feasible assumptions. These assumptions are informed by the policy and program development work led by other government departments, including Natural Resources Canada, and include other considerations such as uncertainty in assumptions about future costs and technical parameters, particularly for rapidly evolving or emergent technologies. The assumptions are also informed by reviewing the latest academic literature.
3.73 To improve quality, transparency, and trust in climate change modelling, Environment and Climate Change Canada should develop a formal review framework where its modelling would be subject to • enhanced peer review • formal consultations with stakeholders • formal periodic quality assurance control • public scrutiny	Agreed. Environment and Climate Change Canada agrees with the importance of ensuring the ongoing suitability of the models themselves and shares the objective of maximizing the transparency of the inputs to those models. In addition to the existing consultation, review, and transparency measures, Environment and Climate Change Canada will consider what additional measures may be necessary to ensure that the modelling process remains suitable and reliable by reviewing international best practices and consulting with modelling experts. The details of the approach will be determined based on these consultations