RAC Environment Committee Meeting

June 11, 2024

People. Goods.
Canada moves by rail.

Railway Association of Canada

Railway Association of Canada

Competition Law Compliance Policy

STATEMENT

The RAC is committed to compliance with all **competition laws** applicable in Canada, including Canada's *Competition Act*.
Under the leadership of its Board of Directors, the RAC carries out its activities in strict compliance with all **competition laws**, provides guidance to its committees and its employees on how to comply with these laws, and promotes with them the importance and value to the RAC of complying with them.
The RAC Corporate Secretary ensures that RAC, its committees and its staff are familiar and comply with this policy.

COMPETITION LAW

Competition laws are designed to maintain and encourage competition in the marketplace. Non-compliance with the **competition laws** relating to improper coordination among competitors could constitute a criminal offence to which significant fines and prison terms can be attached, and for which significant damages can be awarded in private lawsuits, including large class actions.
RAC is a forum for railway members to exchange information and views on the railway sector. Particularly because RAC is an association that represents most of the players in the rail sector in Canada, including many that compete with one another, any activity it conducts must be in strict accordance with the **competition laws**, and avoid even the perception of possible improper conduct.

PROHIBITED ACTIVITIES

Due to the presence of multiple competing entities in RAC, any activity, including discussions or agreements that relate, directly or indirectly, to the following "**Prohibited Topics**" are strictly prohibited:

- Prices (rates) charged to shippers for services provided by members of the RAC
- Prices (costs) paid to suppliers for services provided to members of the RAC
- Any other conditions associated with services provided to shippers or received from suppliers of RAC members, including discounts, rebates, etc. and level of service provisions
- Customer or territory allocation
- Limitation of supply of services provided by RAC members to their customers

GUIDANCE

Any activity, including discussions or agreements that could even remotely be construed as relating to the above Prohibited Topics, cannot take place at the RAC or any of its committees or any meeting organized or attended by RAC staff, or otherwise among RAC members.
To ensure compliance with these rules, when meeting, members of a RAC committee or of the Board of Directors must:

- Have a pre-set agenda and take minutes, recording resolutions adopted and summarizing the essentials of conversations that took place.
- Limit themselves to issues identified on the agenda, except if circumstances call for other issues to be addressed, in which case careful notes of the additional issues discussed must be recorded.
- If any participant believes that Prohibited Topics have been raised or discussed, they must advise all participants of their concern and any discussion relating to that issue be ceased immediately pending legal advice.
- Require legal advice if any issue to be discussed might cause the members to believe that **competition laws** could be infringed.
- Suspend or even postpone to a later date discussions on such issues if legal advice cannot be sought in a timely manner.

Staff of the RAC shall in their duties ensure the confidentiality of information brought to their attention by members, avoid conflict of interest or situations that would discredit the RAC, unless doing so could violate the **competition laws**.

Updated May 3, 2021

Railway Association of Canada

RAC Environment Committee Meeting 02-2024

June 11, 2024

13:00 – 15:00 Eastern Time

Items	Lead	Time
Administrative Items		
1. Welcome & Call to order. a. RAC Competition Policy b. Approval of Meeting Minutes c. October Committee Meeting	Ben	13:00
RAC Updates		
2. RAC Public & Government Affairs Update	Lora	13:10
3. RAC Regulatory Affairs Update	Mike	13:20
4. RAC Dangerous Goods Update	Scott	13:30
Environment Committee Initiatives		
5. Federal Regulatory & Initiatives Updates a. Project Checklist Update b. Storage Tank Regulations c. Emissions Inquiries d. Bill C-59 e. Benchmarking Exercise f. Natural Environment Subcommittee g. Climate Resilience Subcommittee h. Navius Research Climate Modelling	Ken Ben>	13:40
6. Committee Members Roundtable a. How can we formalize this format to increase engagement? b. Wildfire communications c. Member issues	All	14:30
7. Written updates a. University of Lakehead b. VOC Consultation c. Right to a Healthy Environment d. Rail Electrification Coalition		14:50
8. Other business	All	14:55
9. Adjourn	15:00	

Railway Association of Canada

RAC Environment Committee Meeting 2024-01

Tuesday, March 19, 2024
Virtual

Meeting Minutes

Attendees:

Stella Karnis, CN (Chair)
Aaron Stadnyk, CN
Abbigail Shillinglaw, ONT
Arjun Kasturi, Metrolinx
Arnaud Lizet, GWRR
Ben Chursinoff, RAC
Emily Mak, SRY
Francois Belanger, CN
Françoise Granda-Desjardins, VIA Rail
Johanne Delaney, RAC
Ken Roberge, TRC Companies (Consultant)
Kevin Houle, CPKC
Kevin Mason, RAC
Lora Smith, RAC
Luanne Patterson, CN
Magdy Fahmy, RAC Consultant
Murray Macbeth, GWRR
Paul Michael Pilkington, ONT
Scott Croome, RAC
Ted Jones, CPKC
Vanessa Côté, VIA Rail

Absent:
Jonathan Thibault (RAC), David Huck (CPKC), Christian Belliveau (NBMR), Benoit Gringas (exo), Joe Van Humbeck (CPKC), André Lapalme (GWRR), Sylvain Rodrigue (exo), Thomas Rolland (exo), Joe Viscek (ONTC), Bruno Riendeau (VIA Rail), James Skuza (Metrolinx), Marta Swiercz (Metrolinx), Nirwair Bajwa (CPKC),

1. Call to Order & Opening Remarks
Stella Karnis called the meeting to order at 1 PM ET.

a) Competition Law Compliance Policy – Forward statement
The Competition Guidelines, as adopted by the RAC Board of Directors, were read to the committee participants. The Guidelines explain that the policy emphasizes our organization's compliance with Canadian Competition Laws in all our meetings and activities.

b) Meeting Minutes
The meeting minutes of October 25, 2023, were approved by Stella Karnis and Françoise Granda-Desjardins.

2. Committee Members Roundtable
The roundtable is an opportunity for the committee members to share any compliance issues, regulatory challenges and any research updates related to environmental matters.

VIA Rail is testing an AI application for equal driving for passenger locomotive engineers. They are at the end of the second phase, testing in real world, of the pilot and seeing positive results. They are aiming to extend through the innovative solutions. Testing is done on auto Toronto route and progressively on the Toronto-Montreal route for the past two months at a gradual phase. VIA Rail will update the committee at the next meeting in June.

CN continues to test high-level biofuels with Progress Rail and are seeing issues. The testing is done until the end of June when they will get a better assessment. CN also continues to test with Union Pacific (UP) and with Wabtec. Wabtec is looking to approve by this year.

Ontario Northland Transportation (ONT) continue to develop their GIS framework for hazards such as water or rock falls along their right of way and subdivisions. They've been working with TC for mapping some of their subdivisions as well. ONT will continue to update the committee.

3. Federal Regulatory Updates & Initiatives

a) Reduction in the Release of Volatile Organic Compounds

Ken Roberge from TRC Companies and RAC consultant delivered the update.

The storage and loading regulation for Volatile Organic Compounds (VOC) releases is something he is observing. It was created as a discussion document and has been reviewed and provided comments to attempt to eliminate smaller gasoline tanks. An exemption was provided for tanks less than 4,000 liters but we need an exemption for 4,000 liters and up. As well, with intent, they tried to capture larger terminals therefore, it seems to be a discrepancy in the language.

One of the issues to raise would be how they are determining what is excluded from these exemptions or not. There is also the concentration of Benzene that they are using that differs in various parts of the regulation and could inadvertently catch some of these gasoline tanks that might be at facilities. For that reason, proof of the concentration of the benzene in gasoline has to come from a specific analytical standard. Ken did look at the Safety Data Sheets (SDS) from common providers in Canada and unfortunately, the Benzene information is more of a range, and that range fails to include beyond or above and below their criteria. Ken suggests that comments should be provided to at least raise this challenge. They have since released a draft set of regulations and are looking for comments by April 24.

The environment committee unanimously agreed to have Ken draft the comments.

b) Environmental Legal Registry

At the last environment committee meeting, it was discussed to develop an environmental legal registry. However, it would be a challenge to understand who would need one because federally regulated railways would have a different registry than the provincially regulated railways.

The first step is to understand what the desire is and how we can create an approach. Emily Mak considers it as a practical tool; however, it could get quite complex in terms of a function to ensure regulatory compliance.

The committee members agreed to developing a draft environmental legal registry. Ken and Ben to discuss further.

c) Bill S-211

At the last environment committee meeting, this was a matter of interest, therefore the RAC asked Magdy Fahmy, RAC's consultant to deliver an update on Bill S-211, Fighting Against Forced Labour In Supply Chain Act.

The Supply Chain Act came into force on January 1, 2024, and was introduced by the Federal Government to fight against Forced Labour and Child Labour in Supply Chains. Canada already adopted the importation of goods produced in whole or in part by forced or compulsory labor, including forced or compulsory child labor.

The new law expands the existing import ban to specifically cover and define "child labor", whether coerced or not, and introduces a new definition of "forced labor." The Act aims to combat the prevalence of forced labor in global supply chains by requiring companies to disclose information on their efforts to address forced labor in their operations and supply chains. This includes information about the company's policies and due diligence processes, as well as the actions taken to address identified risks.

Under the Act, entities & government institutions are required to report annually on their efforts to prevent or mitigate the risk that forced labor or child labor exists in their supply chains. The annual reports are filed with the Federal Minister of Public Safety by May 31 of each year and will be published prominently on the entity's website. Entities for the Act include companies "*engaged in either producing, selling or distributing goods in Canada or elsewhere, importing into Canada goods produced outside Canada, or controlling an entity engaged in either of those activities*". The consensus is that railways are considered "entities" and therefore must meet annual reporting obligations if they meet certain criteria.

The term "entity" is defined in the Act as any organization that is listed on a Canadian stock exchange or an organization that has a connection to Canada (defined as having a place of business in Canada, doing business in Canada, or having assets in Canada) and also meets **at least two of the following three conditions** for a minimum of one of its two most recent financial years:

- $20 million or more in assets
- $40 million or more in revenue
- An average of 250 or more employees

Public Safety released guidance that provides specific recommendations on the composition of reports in compliance with the Act, detailing both format and content

d) Right to a Healthy Environment

Bill S-5 – Strengthening Environmental Protection for a Healthier Canada Act received royal assent in June 2023. The recognition for the first time in Federal law that every individual in Canada has a right to a healthy environment as provided under the Canadian Environmental Protection Act (CEPA). It creates the definition of vulnerable populations, and then requires the development of an implementation framework 2 years from coming into force. A discussion paper was included in the briefing package.

The purpose of this consultation is to develop an implementation framework of how we can incorporate these different principles of a right to healthy environment into CEPA. A timeline would be to provide a draft implementation framework for commenting in Fall 2024 and publication of the final framework in June of 2025.

One of the new principles that is being introduced is the Environmental Justice, which is the avoidance of adverse effects that disproportionately affect specific populations and environmental contexts. The discussion document identifies different opportunities that this could be implemented into CEPA. It could include different types of research activities, compliance activities and collecting site-specific data to get more understanding of impacts to vulnerable populations. It also introduces a principle of non-regression which is preventing reduced levels of environmental and health protection and may include continuous improvement of such protections. The opportunities identified in the discussion document could include the regulation making process such as gender-based analysis, cost benefit analysis and duty consult requirements with indigenous communities. It also introduces the principle of intergenerational equity that relates closely to sustainable development that is meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. Opportunities may include considering a substance's potential to persist in and impact the environment.

A healthy environment is defined as one that is clean, healthy, and sustainable. The implementation framework will elaborate on the relevant factors that are to be considered. These include the science and the evidence, social health, economic and indigenous knowledge. The document also touches on enhancing procedural duties such as access to information, the participation and decision making and access to effective remedies. It also addresses Indigenous rights, such as under considerations and requirements.

Ben attended the Chemical Industry Association (CIAC) call organized by Dow, Canada, where they discussed that CEPA already contains many opportunities to participate and object. Which should continue. There's a high participation nexus for CEPA instruments and effective remedies already exist. Section 22 of CEPA outlines when an individual may bring an environmental protection action. This has never been challenged in court before. Which means that this discussion document is presenting an untested assumption that the existing remedies are ineffective.

It was unanimously approved by the committee to move forward.

e) AAR Decarbonization Committee

François Belanger at CN delivered the updated on the AAR Decarbonization Committee.

The main items being discussed at the AAR are the situation in California regarding the Environmental Protection Agency (EPA) and the regulation for fleet. EPA is looking at basically expand that across other states. The public hearing is tomorrow, March 20. CN will provide written comments on the difficulty it will be to meet the proposed regulation in California and across the US should it go that way.

CN will be updating studies in the next few months that were made on real electrification and will decide what to do with those results.

4. Subcommittee Working Groups

At the last committee meeting in October, the group expressed interest in the creation of subcommittees to enable more meaningful engagement and specific areas relevant to the rail industry's needs under the environment umbrella. Based on the survey the RAC did last year, Climate Resilience and Natural Environment emerged as top 5 priorities. Through some discussions with the committee chair and some members, we've developed proposals for these two new subcommittees.

Climate Resilience Subcommittee would serve as an advisory group to RAC Environment Committee, identifying and coordinating on funding opportunities, knowledge sharing, development of guidance materials, and addressing concerns of governments.

Natural Environment Subcommittee would serve as the rail industry's focal point for natural environment issues. Facilitate issue filtration, expertise sharing, and development of industry responses. Develop guidance materials that support rail industry knowledge of challenges, opportunities, and best practices. Develop alignment in industry reporting.

Members approved these two subcommittees and will seek internally for volunteers to participate.

5. RAC Advocacy & Communications Update

Kevin Mason, RAC's Director of Policy, Advocacy, and External Relations, delivered an advocacy update.

At the last committee meeting the political landscape was starting to shift towards the Conservatives and it is still the case. The RAC is not expecting an election until Fall 2025 which means a lot of key decisions will be made with the current government including a Fall economic statement, the budget on April 16, but also a potential a 2025 budget as well. This gives the RAC more time to influence political party platforms. The RAC's lobby meetings increased 10 times in 2023, compared to the 2022, and since the last meeting the RAC has made several submissions, including prebudget submission and a submission with respect to the budget 2023 in September. Implementation of a consultation on tax items included a compilation of the work of this committee, the tax committee as well, and our government relations team.

The RAC made strong recommendations on accelerated depreciation supporting our shortline railways, expanding access to clean investment technology, tax credits and enabling Modal shift to rail among others. The RAC is proud of the submission to the Treasury Board on its Supply Chain Regulatory Review, which included a section on actions to support green innovation and modal shift as well and ensured to underline the MOU and the great work that's been done by this committee.

Last month, Marc Brazeau, RAC's President & CEO, appeared at the Senate Standing Committee on Transporting Communications on the topic of climate resiliency, highlighting the industry's environmental record, innovation and adaptation and mitigation efforts. Many thanks to Francois for helping with last minute requests in preparation for that. The RAC also met with the Finance Minister's office on extended interswitching recently and on shortline support and tax credit. Great discussions with the Conservative leadership policy team around the need for investments, and Pierre Pollièvre is a policy director told and the Conservatives are open to accelerated appreciation and other tax measures to increase investment.

The RAC had a Lobby Day at Queen's Park in December and had several meetings with ministers, deputy ministers, ministerial staff, and other key officials. The RAC continues to push to secure the tax credit.

Doing advocacy in the West on issues important to the Environment committee.

Lora Smith, RAC's Vice President of public and Government Affairs, delivered a comms update.

The RAC is implementing an advertising campaign on interswitching that is targeting decision-makers. The RAC is also actively promoting passenger rail and its advantages on several fronts, as well as labour and work rest regulations. It will be a digital campaign not fully fleshed out yet, and I'll be happy to share that with VIA Rail, Metrolinx, and others prior to the launch. Following their discussions with upper management at each of those organizations, Lora and Marc decided to increase their promotion and key message dissemination efforts regarding the advantages of passenger rail. VIA Rail thanked the RAC at the committee meeting for the campaign on passenger rail.

Another campaign the RAC is working on is railroading. Trying to share the passion and love of our industry with a Rail Proud campaign looking for video-based testimonials of railroaders from all of our companies.

The RAC has three events coming up. The Shortline Conference is scheduled for May 6 with a tour of the NRC's facility in Ottawa and the conference all day on May 7. Women In Rail is in the planning stages, and will be held virtually on June 12, in the afternoon. The plan is to continue with the scholarship. The Annual Conference is in the early stages of planning for the Fall and the intent is for the government and industry to have interchanges and connections together.

Lastly, the RAC published the Rail Trends 2023 and distributed to members, stakeholders etc., and the Rail Atlas in paper form will be shipping out in the coming weeks.

6. RAC Dangerous Goods Update

Scott Croome, RAC's Director Dangerous Goods, provided an update on DG Team activities.

The Dangerous Goods Team (DGT), CN and CPKC submitted comments on the buffer car requirements at Transport Canada. The comments suggested that it doesn't improve safety in fact, increases train handling costs and has negative environmental impacts adding more cars to a train for no proven reason.

The DGT have a new safety training car in production. It's set to be completed by the end of April. The RAC hopes to do a grand opening in the West and East.

RAC's Emergency Response (RER) Course in June is full and the September course is nearing full as well. Training events are coming up with CPKC and CN at their British Columbia, Winnipeg and Colorado. This will be RAC's first time attending. The RAC is tasked with helping forest fires and right-of-way.

The DGT is also working with members and TC for a site registration for dangerous goods. Ben and Scott to ensure that Emily gets notice of the site registration.

7. **Writing Updates**
   a. **BC Carbon Tax**
   b. **Rail Climate Action Plan**
   c. **Salmon in BC**
   d. **Benchmarking best practices**
   This is based on our last committee meeting with interest in doing benchmarking best practice exercises. This will be revisited at our next environment committee meeting, which is scheduled for June 11, so we will have the opportunity to further refine our thoughts. The new subcommittee could start this initiative, and then look at the benchmarking best practices. So maybe a little bit of a takeaway for the group is to consider what type of best practices we could discuss.

   e. **University of Lakehead**
   The University of Lakehead contacted the RAC looking for industry support to do research and develop a process that would extract creosote from scrap railway ties and other treated wood with the intent of developing a more circular economy and sustainability practices. Their proposal includes financial numbers. Ben asked the committee if they are interested in having a conversation with the person from the University of Lakehead. CPKC and ONT are interested in pursuing this further.

8. **Other Business**

Correction on the date for the next committee meeting. It is October 23 and not October 13, in person, Venue TBD.

9. **Adjournment**
The meeting adjourned at 2:55 PM

Action Items – March 19, 2024	Lead	Status
1. Minutes: The meeting minutes are to be circulated within 21 calendar days	Johanne	
2. Ken Roberge to provide comments on the VOC release.	Ken	
3. Schedule kick-off meetings of subcommittees	Ben	
4. Get in contact with University of Lakehead	Ben	
5.		

Canada Gazette, Part I, Volume 158, Number 23: Regulations Amending the Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations

60-day consultation (until August 7, 2024 11:59pm EST)

June 8, 2024

Statutory authority

Canadian Environmental Protection Act, 1999

Sponsoring department

Department of the Environment

REGULATORY IMPACT ANALYSIS STATEMENT

(*This statement is not part of the Regulations*.)

General Comment

▶ Add a comment for the General Comment section

Issues

The Department of the Environment (the Department) administers various regulations under the *Canadian Environmental Protection Act, 1999* (CEPA), including the *Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations* (the Regulations), which set requirements for petroleum and allied petroleum storage tank systems under federal jurisdiction. When the Regulations were made, they incorporated by reference the technical standards that were available to the storage tank industry at the time. Since then, these technical standards have been updated. Amendments to the Regulations are needed for regulated parties [1] to be able to acquire the latest storage tank equipment that meets these updated technical standards.

▶ **Add a comment for the Issues section**

Background

The Regulations, which came into effect in June 2008, set requirements for petroleum and allied petroleum storage tank systems under federal jurisdiction to prevent soil and groundwater contamination. The Regulations apply to storage tank systems located on Aboriginal land, including those owned or operated by band councils or private businesses like gas stations. They also cover storage tank systems situated on federal land, such as those in federal parks managed by private companies, as well as systems operated by, or belonging to, federal departments, boards, or agencies, regardless of their location. Additionally, the Regulations extend to storage systems that are part of, or provide services to, federal works or undertakings, including railways, port authorities and airports.

In terms of ownership and operation, 50% of these storage tank systems are managed by First Nations communities and small businesses on Aboriginal land; 15% are operated by third parties on federal land and are classified as small businesses; 5% are overseen by federal entities; and the remaining 30% are part of federal works or undertakings. [2] The Regulations specify which storage tanks and components can be installed. This storage tank system equipment must have a certification mark that shows it meets the technical standards prescribed in section 14 of the Regulations. Some standards are directly referred to in the Regulations and others refer to select parts of the Environmental Code of Practice for Aboveground and Underground Storage Tank Systems Containing Petroleum and Allied Petroleum Products (CCME Code). [3]

The Department conducts periodic reviews of industry technical standards to ensure that the Regulations align with the latest industry practices and remain up to date. The most recent review indicated that amendments to the Regulations are needed to align the existing technical standards currently referenced in the Regulations with their updated versions.

▶ **Add a comment for the Background section**

Objective

The objective of the proposed *Regulations Amending the Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations* (the proposed amendments) is to update the existing references to technical standards incorporated by reference in the Regulations, ensuring the inclusion of the most up-to-date technical standard titles. The proposed amendments are intended to facilitate compliance for regulated parties, enabling them to acquire equipment certified in accordance with the technical standards that are current at the time of manufacturing of the storage tanks or components.

▶ **Add a comment for the Objective section**

Description

The proposed amendments would modify the regulatory text in section 14 of the Regulations by updating references to 48 technical standards. This update would involve revising references to technical standards incorporated within the Regulations, ensuring that the most current titles of these technical standards are accurately reflected. The proposed amendments would update references to titles for 38 technical standards incorporated by reference in the CCME Code. For example, ORD-C58.15-1992, *Overfill Protection Devices for Flammable Liquid Storage Tanks* is currently incorporated by reference in the CCME Code, and ANSI/CAN/UL/ULC 2583 *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*, a harmonized standard, would be added as the most recent version of this standard. The proposed amendments would also update references to 10 standards incorporated by reference in the Regulations that are out of date. For example, CAN/ULC-S660, *Standard for Nonmetallic Underground Piping for Flammable and Combustible Liquids* is currently prescribed in the Regulations, and CAN/ULC-S679, *Standard for Metallic and Nonmetallic Underground Piping for Flammable and Combustible Liquids* would be added to reflect the most recent version. The proposed amendments would also remove the year of reference from all technical standards, retaining only the title.

▶ **Add a comment for the Description section**

Regulatory development

Consultation

In 2022, the Department conducted a planned review of the Regulations and engaged with Indigenous peoples, regulated parties, industry and other interested parties to gather input on the implementation of the Regulations. As part of this engagement, the Department received numerous comments expressing support for improving the Regulations. A comprehensive summary of these comments is available in the What we heard report.

One common suggestion was the need to update the technical standards referenced in the Regulations, including options to simplify the incorporations by reference. The focus of these comments was on ensuring that the most current and relevant technical standards for the design and installation of storage tank systems are included. Consequently, the proposed amendments aim to ensure that the technical standards referenced in the Regulations are current.

Modern treaty obligations and Indigenous engagement and consultation

This proposal is not expected to impact differently, directly or indirectly, the rights of Indigenous peoples. It would respect the federal government's obligations in relation to rights protected by section 35 of the *Constitution Act, 1982*, modern treaties, and international human rights obligations.

▶ **Add a comment for the Regulatory development section**

Regulatory analysis

Benefits and cost

A compliance gap currently exists for regulated parties installing new storage tank equipment that complies with updated technical standards that are not yet prescribed in the Regulations. The proposed amendments would address this compliance gap by updating the technical standards referenced in the Regulations to the latest industry technical standards. These amendments would facilitate the acquisition and installation of compliant storage tank system equipment without imposing additional costs or administrative burden on regulated parties. There would be no requirement for new or different specifications, so no additional costs would be carried by regulated parties.

The proposed amendments would bring the Regulations in line with current technical standards recognized in the industry without adding new compliance or administrative burdens.

Small business lens

Analysis under the small business lens concluded that the proposed amendments will not impact Canadian small businesses as the proposed amendments are not expected to result in incremental costs to businesses.

One-for-one rule

The one-for-one rule does not apply as there is no impact on business. The proposed amendments would neither introduce new administrative costs for businesses nor introduce or repeal existing regulatory titles.

Regulatory cooperation and alignment

The proposed amendments are not expected to have any impact on regulatory cooperation, agreements nor obligations. The 48 technical standards updates being proposed include four that would be harmonized with Canadian and American standards (ANSI/CAN/UL/ULC). These harmonized standards facilitate the certification of storage tank equipment across jurisdictions, which may make it easier for regulated entities to acquire storage tanks and components.

Strategic environmental assessment

The proposed amendments would not alter current regulatory obligations, nor change existing environmental protections. Therefore, no important positive or negative environmental effects are anticipated as a result of the proposed amendments. The proposal is therefore exempt from the strategic environmental assessment (SEA) process as per the Department's SEA policy and in accordance with the *Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals*.

Gender-based analysis plus

No gender-based analysis plus (GBA+) impacts have been identified for this proposal.

▶ **Add a comment for the Regulatory analysis section**

Implementation, compliance and enforcement, and service standards

The proposed amendments would come into force on the day on which they are registered. The proposed amendments would not necessitate any implementation plan, nor would they impose new compliance and enforcement requirements. Similarly, no new service standards are introduced as part of these amendments.

▶ **Add a comment for the Implementation, compliance and enforcement, and service standards section**

Contacts

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PROPOSED REGULATORY TEXT

Notice is given, under subsection 332(1) [a] of the *Canadian Environmental Protection Act, 1999* [b], that the Governor in Council proposes to make the annexed *Regulations Amending the Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations* under section 209 [c] of that Act.

Any person may, within 60 days after the date of publication of this notice, file with the Minister of the Environment comments with respect to the proposed Regulations or a notice of objection requesting that a board of review be established under section 333 [d] of that Act and stating the reasons for the objection. Persons filing comments are strongly encouraged to use the online commenting feature that is available on the *Canada Gazette* website. Persons filing comments by any other means, and persons filing a notice of objection, should cite the *Canada Gazette*, Part I, and the date of publication of this notice, and send the comments or notice of objection to Astrid Télasco, Director, Waste Reduction and Management Division, Environmental Protection Branch, Department of the Environment, 351 Saint-Joseph Blvd., Gatineau, Quebec K1A 0H3 (email: registrereservoir-tankregistry@ec.gc.ca).

A person who provides information to the Minister may submit with the information a request for confidentiality under section 313 [e] of that Act.

Ottawa, May 30, 2024

Wendy Nixon

Assistant Clerk of the Privy Council

▸ **Add a comment for the PROPOSED REGULATORY TEXT section**

Regulations Amending the Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations

Amendments

1 (1) The portion of subsection 14(1) of the *Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations* [4] before paragraph (d) is replaced by the following:

(1) The owner or operator of a storage tank system that installs the system or any component of the system on or after June 12, 2008 must ensure that the system or the component conforms to the applicable requirements set out in the following provisions of the CCME Code of Practice, subject to subsection (6.1) of this section:

> **(a)** Part 3, excluding Section 3.2, Clause 3.3.1(1)(c), Article 3.3.2, Clause 3.4.1(1)(c), Article 3.4.3, Clauses 3.5.1(1)(a) and 3.6.1(1)(l), Section 3.7, Clause 3.9.2(2)(a), Articles 3.9.4 and 3.10.1;
>
> **(b)** Part 4, subject to the following:
>
> > **(i)** excluding Articles 4.2.1 to 4.2.3, Clauses 4.2.4(1)(e) and 4.2.4(2)(h), Articles 4.2.5 and 4.2.6, Sentences 4.2.8(1) to 4.3.1(1) and 4.3.6(1) to 4.3.8(1), Section 4.4, Clauses 4.5.1(1)(a), (c) and (d) and Sentences 4.5.2(1) to (4) and 4.5.3(2), and
> >
> > **(ii)** in Clause 4.5.1(1)(b),

(A) the reference to “CAN/ULC-S603-1992, ‘Underground Steel Tanks’” must be read as a reference to “CAN/ULC-S603, *Standard for Steel Underground Tanks for Flammable and Combustible Liquids*”, and

(B) the reference to “CAN/ULC-S603.1-1992, ‘Galvanic Corrosion Protection Systems for Underground Steel Tanks’” must be read as a reference to “CAN/ULC-S603.1, *Standard for External Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids*”;

(c) Part 5, subject to the following:

(i) excluding Clauses 5.2.1(1)(d) to (f), Articles 5.2.4 to 5.2.6, Clause 5.4.2(1)(b), Sentence 5.4.3(1) and Section 5.5,

(ii) in Clause 5.4.2(1)(c),

(A) the reference to “API RP 1632-96, ‘Cathodic Protection of Underground Storage Tank and Piping Systems’” must be read as a reference to “API RP 1632, *Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems*”, and

(B) the reference to “API Std 2610-94, ‘Design, Construction, Operation, Maintenance and Inspection of Terminal and Tank Facilities’” must be read as a reference to “API Std 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities*”;

(iii) in Clauses 5.4.4(1)(a) to (c), the references to standards must be read as references to one of the following, whichever is in effect at the time the system or component is manufactured:

(A) ULC/ORD-C971, *Nonmetallic Underground Piping for Flammable and Combustible Liquids*,

(B) CAN/ULC-S660, *Standard for Nonmetallic Underground Piping for Flammable and Combustible Liquids*,

(C) CAN/ULC-S679, *Standard for Metallic and Nonmetallic Underground Piping for Flammable and Combustible Liquids*; and

(2) Subsection 14(2) of the Regulations is replaced by the following:

(2) The owner or operator of a storage tank system that has aboveground tanks that installs those tanks on or after June 12, 2008 must ensure that

(a) the spill containment device, whether installed on the tank at the fill opening or attached to the remote fill station, bears a certification mark certifying conformity with one of the following standards, whichever is in effect at the time the storage tank system is manufactured:

(i) ULC/ORD-C142.19, *Spill Containment Devices for Aboveground Flammable and Combustible Liquid Storage Tanks*,

(ii) CAN/ULC-S663, *Standard for Spill Containment Devices for Flammable and Combustible Liquid Aboveground Storage Tanks*,

(iii) ANSI/CAN/UL/ULC 2583, *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*; or

(b) the tank is equipped with a spill containment device and bears a certification mark certifying conformity with one of the following standards:

(i) CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*,

(ii) CAN/ULC-S653, *Standard for Aboveground Horizontal Steel Contained Tank Assemblies for Flammable and Combustible Liquids*,

(iii) ULC/ORD-C142.5, *Concrete Encased Steel Aboveground Tank Assemblies for Flammable and Combustible Liquids*, or CAN/ULC-S677, *Standard for Fire Tested Aboveground Tank Assemblies for Flammable and*

Combustible Liquids, whichever is in effect at the time the storage tank system is manufactured,

(iv) ULC/ORD-C142.18, *Rectangular Steel Above-ground Tanks for Flammable and Combustible Liquids*, or CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*, whichever is in effect at the time the storage tank system is manufactured,

(v) ULC/ORD-C142.21, *Aboveground Used Oil Systems*, or CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*, whichever is in effect at the time the storage tank system is manufactured,

(vi) ULC/ORD-C142.22, *Contained Vertical Steel Aboveground Tank Assemblies for Flammable and Combustible Liquids*, or CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*, whichever is in effect at the time the storage tank system is manufactured.

(3) Subparagraph 14(3)(a)(i) of the Regulations is replaced by the following:

(i) if used for storing used oil, CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*, and

(4) Clauses 14(3)(a)(ii)(A) and (B) of the Regulations are replaced by the following:

(A) CAN/ULC-S603, *Standard for Steel Underground Tanks for Flammable and Combustible Liquids*, or

(B) CAN/ULC-S603.1, *Standard for External Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids*;

(5) Subparagraphs 14(3)(b)(i) and (ii) of the Regulations are replaced by the following:

(i) if used for storing used oil, CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*, and

(ii) if used for storing other petroleum products or allied petroleum products, CAN/ULC-S615, *Standard for Fibre Reinforced Plastic Underground Tanks for Flammable and Combustible Liquids*, or ANSI/CAN/UL/ULC 1316, *Standard for Fibre Reinforced Underground Tanks for Flammable and Combustible Liquid*, whichever is in effect at the time the storage tank system is manufactured; and

(6) Paragraph 14(4)(a) of the Regulations is replaced by the following:

(a) those tanks must bear a certification mark certifying conformity with CAN/ULC-S603.1, *Standard for External Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids*; or

(7) Subparagraphs 14(5)(b)(i) and (ii) of the Regulations are replaced by the following:

(i) one of the standards referred to in Clauses 5.2.1(1)(a) to (c) and (g) of the CCME Code of Practice, subject to subsection (6.1) of this section, or

(ii) ULC/ORD-C971, *Nonmetallic Underground Piping for Flammable and Combustible Liquids*, CAN/ULC-S660, *Standard for Nonmetallic Underground Piping for Flammable and Combustible Liquids*, or CAN/ULC-S679, *Standard for Metallic and Nonmetallic Underground Piping for Flammable and Combustible Liquids*, whichever is in effect at the time the storage tank system is manufactured.

(8) Section 14 of the Regulations is amended by adding the following after subsection (6):

(6.1) For the purposes of subsections (1) and (5), any reference to a standard in the provisions of the CCME Code of Practice set out in column 1 of Schedule 4 must be read as a reference to

(a) if only one standard is set out in column 2, the standard that is set out in that column; or

(b) if more than one standard is set out in column 2, any one of those standards, whichever is in effect at the time the storage tank system's component is erected or manufactured.

2 The Regulations are amended by adding, after Schedule 3, the Schedule 4 set out in the schedule to these Regulations.

▶ **Add a comment for the Amendments section**

Coming into Force

3 These Regulations come into force on the day on which they are registered.

▶ **Add a comment for the Coming into Force section**

SCHEDULE

(Section 2)

▶ **Add a comment for the SCHEDULE section**

SCHEDULE 4

(Subsection 14(6.1))

Updated Standards of the CCME Code of Practice

Item	Column 1 Provision of the CCME Code of Practice	Column 2 Standard
1	3.3.1(1)(e)(iii)	ANSI/API Std 2350, *Overfill Prevention for Storage Tanks in Petroleum Facilities*
2	3.4.1(1)(e)(ii)	(a) CAN/ULC-S661, *Standard for Overfill Protection Devices for Flammable and Combustible Liquid Storage Tanks* (b) ANSI/CAN/UL/ULC 2583, *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*
3	3.5.1(1)(b)	CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*
4	3.5.1(2)	CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*
5	3.6.1(1)(a)	API Std 650, *Welded Tanks for Oil Storage*
6	3.6.1(1)(b)	CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*
7	3.6.1(1)(c)	CAN/ULC-S602, *Standard for Aboveground Steel Tanks for Fuel Oil and Lubricating Oil*
8	3.6.1(1)(d)	CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*
9	3.6.1(1)(e)	CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*

10	3.6.1(1)(f)	CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*
11	3.6.1(1)(g)	CAN/ULC-S653, *Standard for Aboveground Horizontal Steel Contained Tank Assemblies for Flammable and Combustible Liquids*
12	3.6.1(1)(h)	CAN/ULC-S677, *Standard for Fire Tested Aboveground Tank Assemblies for Flammable and Combustible Liquids*
13	3.6.1(1)(i)	CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*
14	3.6.1(1)(j)	CAN/ULC-S652, *Standard for Tank Assemblies for the Collection, Storage and Removal of Used Oil*
15	3.6.1(1)(k)	CAN/ULC-S601, *Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids*
16	3.6.2	(a) CAN/ULC-S661, *Standard for Overfill Protection Devices for Flammable and Combustible Liquid Storage Tanks* (b) ANSI/CAN/UL/ULC 2583, *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*
17	3.6.3	CAN/ULC-S664, *Standard for Containment Sumps, Sump Fittings, and Accessories for Flammable and Combustible Liquids*
18	3.6.4	CAN/ULC-S668, *Standard for Liners Used for Secondary Containment of Aboveground Flammable and Combustible Liquid Tanks*
19	3.6.6(1)(a)	API Spec 12B, *Specification for Bolted Tanks for Storage of Production Liquids*

20	3.6.6(1)(b)	API Spec 12D, *Specification for Field-welded Tanks for Storage of Production Liquids*
21	3.6.6(1)(c)	API Spec 12F, *Specification for Shop-welded Tanks for Storage of Production Liquids*
22	3.8.1(1)(a)	API RP 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks*
23	3.8.1(1)(b)	API Std 653, *Tank Inspection, Repair, Alteration, and Reconstruction*
24	3.8.1(1)(c)	NACE SP0193, *Application of Cathodic Protection to Control External Corrosion of Carbon Steel On-Grade Storage Tank Bottoms*
25	3.8.1(1)(d)	STI R893, *Recommended Practice for External Corrosion Protection of Shop Fabricated Aboveground Tank Floors*
26	3.8.2(1)(b)	API Std 653, *Tank Inspection, Repair, Alteration, and Reconstruction*
27	3.9.1(2)(a)	CAN/ULC-S653, *Standard for Aboveground Horizontal Steel Contained Tank Assemblies for Flammable and Combustible Liquids*
28	3.9.1(2)(b)	CAN/ULC-S655, *Standard for Aboveground Protected Tank Assemblies for Flammable and Combustible Liquids*
29	3.9.1(2)(c)	CAN/ULC-S677, *Standard for Fire Tested Aboveground Tank Assemblies for Flammable and Combustible Liquids*
30	3.9.2(1)(a)(i)	CAN/ULC-S668, *Standard for Liners Used for Secondary Containment of Aboveground Flammable and Combustible Liquid Tanks*
31	3.9.2(1)(a)(ii)	CAN/ULC-S653, *Standard for Aboveground Horizontal Steel Contained Tank Assemblies for Flammable and Combustible Liquids*
32	3.10.3(1)(a)	CAN/ULC-S656, *Standard for Oil-Water Separators*

33	4.3.2	(a) CAN/ULC-S661, *Standard for Overfill Protection Devices for Flammable and Combustible Liquid Storage Tanks* (b) ANSI/CAN/UL/ULC 2583, *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*
34	4.3.3	CAN/ULC-S664, *Standard for Containment Sumps, Sump Fittings, and Accessories for Flammable and Combustible Liquids*
35	4.3.4	CAN/ULC-S664, *Standard for Containment Sumps, Sump Fittings, and Accessories for Flammable and Combustible Liquids*
36	4.3.5	CAN/ULC-S668, *Standard for Liners Used for Secondary Containment of Aboveground Flammable and Combustible Liquid Tanks*
37	4.5.1(1)(b)(ii)	NACE SP0285, *External Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*
38	4.5.3(1)(a)	CAN/ULC-S603, *Standard for Steel Underground Tanks for Flammable and Combustible Liquids*
39	5.2.1(1)(a)	ASTM A53/A53M, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*
40	5.2.1(1)(b)	CSA Z245.1, *Steel pipe*
41	5.2.1(1)(c)	CAN/ULC-S633, *Standard for Flexible Connector Piping for Fuels*
42	5.2.1(1)(g)	ANSI/CAN/UL-536, *Standard for Safety Flexible Metallic Hose*
43	8.6.1(1)(a)	CAN/ULC-S603.1, *Standard for External Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids*

44	8.6.1(1)(b)	NACE SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
45	8.6.1(1)(c)	NACE SP0285, *External Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*
46	8.6.1(1)(d)	NACE SP0193, *Application of Cathodic Protection to Control External Corrosion of Carbon Steel On-Grade Storage Tank Bottoms*
47	8.6.1(1)(e)	NACE TM0101, *Measurement Techniques Related to Criteria for Cathodic Protection of Underground Storage Tank Systems*
48	8.6.1(1)(g)	API RP 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks*
49	8.7.2(a)	CAN/ULC-S664, *Standard for Containment Sumps, Sump Fittings, and Accessories for Flammable and Combustible Liquids*
50	8.7.2(b)	(a) CAN/ULC-S663, *Standard for Spill Containment Devices for Flammable and Combustible Liquid Aboveground Storage Tanks* (b) ANSI/CAN/UL/ULC 2583, *Standard for Fuel Tank Accessories for Flammable and Combustible Liquids*

▸ **Add a comment for the SCHEDULE 4 section**

Confidential Business Information (CBI)

▸ **Add a comment for the Confidential Business Information (CBI) section**

Comment(s) Submission

Please note that, in order to increase the transparency of the regulatory process, all comments submitted to Canada Gazette, Part I, will be posted online after the comment period closes. Those who post as individuals will be identified only as individuals, those who post anonymously will be identified as anonymous and organizations will be identified with their organization name.

To submit your comment(s) follow these three steps:

1. Review your comment(s)
2. Complete your contact information
3. Submit your comment(s)

Step 1: Review your comment(s)

Footnotes

a S.C. 2023, c. 12, s. 55

b S.C. 1999, c. 33

c S.C. 2023, c. 12, s. 46

d S.C. 2023, c. 12, s. 56

e S.C. 2023, c. 12, s. 50

1 For the purposes of the Regulations, *regulated parties* refers to owners and operators of petroleum and allied petroleum storage tank systems under federal jurisdiction.

2 These percentages indicate the types of owners and operators, not the total amount of storage tank systems managed.

3 Established by the Canadian Council of Ministers of the Environment.

4 SOR/2008-197

(iii) either with or without a jury, as determined by the Attorney General of Canada for each corporation, if some but not all of the individuals elect or re-elect to be tried without a jury.

(i) sans jury, dans le cas où toutes les personnes physiques choisissent, lors d'un premier ou nouveau choix, d'être jugées sans jury,

(ii) devant jury, dans le cas où toutes les personnes physiques choisissent, lors d'un premier ou nouveau choix, d'être jugées devant jury,

(iii) devant jury ou sans jury, selon ce que décide le procureur général du Canada pour chaque personne morale, dans le cas où seules certaines des personnes physiques choisissent, lors d'un premier ou nouveau choix, d'être jugées sans jury.

236 (1) Subsection 74.01(1) of the Act is amended by striking out "or" at the end of paragraph (b) and by adding the following after that paragraph:

(b.1) makes a representation to the public in the form of a statement, warranty or guarantee of a product's benefits for protecting or restoring the environment or mitigating the environmental, social and ecological causes or effects of climate change that is not based on an adequate and proper test, the proof of which lies on the person making the representation;

(b.2) makes a representation to the public with respect to the benefits of a business or business activity for protecting or restoring the environment or mitigating the environmental and ecological causes or effects of climate change that is not based on adequate and proper substantiation in accordance with internationally recognized methodology, the proof of which lies on the person making the representation; or

236 (1) Le paragraphe 74.01(1) de la même loi est modifié par adjonction, après l'alinéa b), de ce qui suit :

b.1) ou bien, sous la forme d'une déclaration ou d'une garantie visant les avantages d'un produit pour la protection ou la restauration de l'environnement ou l'atténuation des causes ou des effets environnementaux, sociaux et écologiques des changements climatiques, des indications qui ne se fondent pas sur une épreuve suffisante et appropriée, dont la preuve incombe à la personne qui donne les indications;

b.2) ou bien des indications sur les avantages d'une entreprise ou de l'activité d'une entreprise pour la protection ou la restauration de l'environnement ou l'atténuation des causes ou des effets environnementaux et écologiques des changements climatiques si les indications ne se fondent pas sur des éléments corroboratifs suffisants et appropriés obtenus au moyen d'une méthode reconnue à l'échelle internationale, dont la preuve incombe à la personne qui donne les indications;

(1.1) Subsection 74.01(1.1) of the Act is replaced by the following:

Drip pricing

(1.1) For greater certainty, the making of a representation of a price that is not attainable due to fixed obligatory charges or fees constitutes a false or misleading representation, unless the obligatory charges or fees represent only an amount imposed on a purchaser of the product referred to in subsection (1) by or under an Act of Parliament or the legislature of a province.

(1.1) Le paragraphe 74.01(1.1) de la même loi est remplacé par ce qui suit :

Indication de prix partiel

(1.1) Il est entendu que l'indication d'un prix qui n'est pas atteignable en raison de frais obligatoires fixes qui s'y ajoutent constitue une indication fausse ou trompeuse, sauf si les frais obligatoires ne représentent que le montant imposé sous le régime d'une loi fédérale ou provinciale à l'acquéreur du produit visé au paragraphe (1).

(2) Subsection 74.01(3) of the Act is replaced by the following:

Ordinary price: supplier's own

(3) A person engages in reviewable conduct who, for the purpose of promoting, directly or indirectly, the supply

(2) Le paragraphe 74.01(3) de la même loi est remplacé par ce qui suit :

Prix habituel : fournisseur particulier

(3) Est susceptible d'examen le comportement de quiconque donne, de quelque manière que ce soit, aux

Forecasting the GHG Emissions of Canada's Rail Sector

Final Report

SUBMITTED TO

Jacob McBane and Christian Michaud
Transport Canada

May 23rd, 2024

SUBMITTED BY

Michael Wolinetz
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Navius Research Inc.

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Summary

Introduction

This study is designed to support Transport Canada, Environment and Climate Change Canada, and the Canadian rail industry with their planning to significantly reduce greenhouse gas (GHG) emissions within the rail sector. This study focuses on how policies can reduce the rail sector's GHG emissions to a level that is consistent with national GHG targets by transitioning to low-carbon fuels, such as renewable diesel, and the adoption of zero-emission locomotives (ZELs), including battery-electric and fuel-cell locomotives. Through enhanced modeling, the study offers a detailed understanding of potential policy impacts, facilitating informed decision-making in the pursuit of GHG reduction targets. Although the focus of this project is on GHG mitigation, the policies explored in this analysis would all have a significant impact on criteria air contaminant (CAC) emissions, which is an important consideration for the rail sector.

Modeling Methodology and Rail Sector Representation

The study uses the gTech model, which provides both comprehensive economic and technological insights, to simulate the Canadian rail sector's response to various policy scenarios. The model's representation of the rail sector has been refined for this study:

- **Segmentation and detail**: The rail sector is segmented into Class I railways and shortline & regional railways (SL&R), each further divided into line-haul and switcher services, allowing for detailed analysis of policy impacts.
- **Locomotive stock:** The model differentiates locomotive stock by Tier ratings, reflecting the diversity in emission standards and technological capabilities. It also includes a range of ZEL archetypes, characterized for each segment (e.g. Class I vs. SL&R, line-haul vs. switcher). This granularity enables the examination of how different segments might respond to policies aimed at accelerating the adoption of cleaner technologies.
- **Technology and Fuel Use:** The gTech model simulates technology adoption, energy consumption and GHG emissions within the rail sector as a function of policy influences, technological advancements, and economic behaviours. This approach provides a comprehensive view of potential emission trajectories under various policy scenarios.

Scenario Design

The scenarios tested in this analysis encompass a broad range of policies, categorized into three groups, all of which are compared against a Current Policy scenario:

- **GHG Pathways:** These scenarios explore the rail sector's response to varying GHG emission constraints, simulating the impact of stringent carbon pricing and sector-specific caps aimed at achieving net-zero emissions by 2050.
- **Fleet Renewal:** This group of policies tests the impact of regulations aimed at accelerating the renewal of the locomotive fleet, either through mandates for cleaner conventional locomotives (e.g., Tier 4) or through a shift to ZELs.
- **Funding Scenarios:** These scenarios examine the potential impact of direct funding incentives on ZEL adoption, particularly within the SL&R segment, simulating various levels of government support for the purchase of ZELs and related infrastructure.

Key Conclusions

The study demonstrates that while existing policies will not produce deep GHG reductions in the rail sector, strategic policy interventions, particularly in fleet renewal and targeted funding, hold significant potential to alter the sector's emissions trajectory. The conclusions of this study are summarized by each policy group below.

GHG Pathway Scenarios

- **Low-carbon fuels and ZEL adoption:** By 2050 and with strong policies, low-carbon fuels could constitute over 80% of the sector's liquid fuel consumption. ZEL adoption, particularly in Class I line-haul services, is expected to start significantly post-2035, impacting GHG emissions due to their substantial contribution to rail tonne-kilometers (RTKs). While the capital investment for ZELs is large, the high utilization of line-haul locomotives makes them attractive investments in a net-zero future.
- **Limited ZEL adoption in switchers:** Lower utilization discourages ZEL adoption in switcher locomotives, suggesting that GHG caps or carbon pricing might not be sufficient incentives to drive the adoption of ZELs for yard work.
- **Technological uncertainty:** The role of battery electric and fuel-cell locomotives is significant, but technological uncertainties concerning ZEL commercial availability and infrastructure development persist.

- **Fleet renewal rates:** Achieving the projected ZEL adoption requires a fleet renewal rate considerably higher than the current rates, influenced by climate policies.
- **Cost implications:** Levelized rail transportation costs ($/RTK) will increase in a net-zero future relative to what they would have been in the Current Policy scenario. To achieve deep GHG reductions, the rail sector will need to use higher-cost low-carbon fuels and may be subject to greater carbon costs. The sector will also need to make larger capital investments in ZELs. While ZELs generally have lower energy costs than conventional locomotives, they are not enough to offset other cost increases in the GHG pathways scenarios.

Fleet Renewal Scenarios

- **GHG benefits from renewal to Tier 4 locomotives:** Policies requiring fleet renewal to Tier 4 locomotives also accelerate ZEL adoption and the retirement of older locomotives. Consequently, they also offer modest GHG reductions, even if their intent is to reduce CAC emissions.
- **Substantial GHG with renewal to ZELs:** Policies accelerating ZEL adoption in line-haul service significantly lower GHG emissions, with only somewhat fewer GHG reductions if SL&R railways are excluded or have delayed requirements. ZEL requirements for switchers have small GHG impacts, though the impact on CAC emissions from rail yards near population centres could be more important.
- **Fleet renewal rates:** Fleet Renewal Policies increase locomotive renewal rates beyond what they would be in the Current Policy scenario. Peak renewal rates may start before the policies' enforcement if railways acquire new conventional locomotives to defer their investments in ZELs.
- **Cost implications:** Despite higher capital costs due to early retirements and ZEL investments, overall rail transportation costs remain similar to the Current Policy scenario due to lower energy costs from increased ZEL adoption.

Incentive Scenarios

- **Significant SL&R emission reductions:** Sufficient funding can lead to substantial ZEL adoption and GHG emission reductions within the SL&R segment.
- **Limited sector-wide impact:** Deep GHG reductions from SL&R railways have a modest impact on the rail sector's GHG emissions due to their small share of emissions.

- **Uncertain Investment Behavior:** The actual impact of funding is uncertain due to unknown investment behaviours and capacities of SL&R railways.

Limitations and Future Work

Key limitations of this study include:

- **Mode shifting and international competition:** The current model does not simulate shifts in transportation demand between rail and truck or between US and Canadian railways. Therefore this study does not how GHG policy will affect the competitiveness of the rail sector.
- **Technological Uncertainty:** The evolving landscape of ZELs and other technologies creates ongoing challenges to forecasting.
- **Representation of Passenger Rail:** The lack of a distinct representation for passenger rail overlooks unique opportunities for GHG reduction.

Further developing the model to simulate modal shifts and competition between Canadian and US railways is identified as a critical area for future work. This development would enable a more nuanced understanding of policy impacts on the rail sector's competitive dynamics and GHG emissions reduction capabilities. Future work should also include ongoing technology and fuel assessments to ensure the results are based on the latest information. Finally, explicitly representing passenger rail would allow the model to represent the unique characteristics and opportunities of that segment of the rail sector.

Table of Contents

1. Introduction

Transport Canada (TC) is working with Environment and Climate Change Canada (ECCC) and the rail sector to develop a pathway for sectoral greenhouse gas (GHG) reductions that will contribute to national GHG targets: 40 to 45% below 2005 levels by 2030, leading to net-zero emissions by 2050. Decarbonizing the rail sector will involve some combination of switching to low-carbon biofuels, such as biodiesel and renewable diesel, and adoption of zero-emission locomotives (ZELs), which may include battery-electric locomotives (BELs), fuel-cell locomotives (FLCs) or other zero-emissions propulsion systems where applicable (e.g. catenary electric).

TC has contracted Navius to use its proprietary energy-economy model, gTech, to forecast the impact of a range of policies and regulations that could affect the GHG emissions of the Canadian rail sector. This project leverages Navius' previous modeling of the rail sector for ECCC to accomplish two goals:

- To increase the level of detail with which the rail sector is represented in the model.
- To use the improved model to produce a more extensive policy analysis.

As such, this project contains a more granular representation of the Canadian rail sector. In previous work, the entire sector was represented as a single freight rail sector. However, in this project, the sector is split into multiple railway types and rail services. The improved model distinguishes between rail activity carried out by Class I and shortline & regional railways (SL&R). Class I refers to railways with revenues greater than $250 million over the past two years, which includes the Canadian National Railway (CN) and Canadian Pacific Kansas City (CPKC) Railway (formerly CPR) in Canada.[1] Railways with lower revenues are less formally categorized as shortline and regional railways.

Furthermore, activity within these railway types is also split into switcher and line-haul service (i.e., activity in the rail yards and other non-freight work versus freight movements). In total, the model now represents four rail "segments":

1. Class I line-haul
2. Class I switcher
3. SL&R line-haul

[1] Government of Canada. (n.d.) *Rail Transportation*.

4. SL&R switcher

Furthermore, the existing rolling stock within the rail sector is now broken down by locomotive Tier ratings (i.e., regulated air emissions ratings). This additional detail allows this analysis to represent the technologies and investment behaviours relevant to each segment.

This detailed representation of the rail sector allows for an analysis of policies and regulations whose requirements can be differentiated by rail segment and Tier. Specifically, this analysis forecasts the impact of a wide range of policies categorized as:

- GHG Pathways Scenarios, which explore how the rail sector would respond to varying GHG constraints.
- Fleet Renewal Scenarios, which test the impact of accelerated locomotive renewal, either to cleaner conventional locomotives (e.g., Tier 4) or ZELs.
- Incentive Scenarios, which forecast the impact of funding that incentivizes ZEL adoption.

Although the focus of this project is on GHG mitigation, the policies explored in this analysis would all have a significant impact on criteria air contaminant (CAC) emissions, which is an important consideration for the rail sector.

The following report summarizes the analysis and is structured as follows:

- Section 2 summarizes the modeling methodology
- Section 3 outlines key assumptions and scenario design
- Section 4 discusses the results of the project
- Section 5 summarizes and concludes the analysis

The appendices provide additional details on assumptions and a detailed description of the gTech model.

2. Summary of the Modeling Methodology

2.1. Summary of the gTech Model

This analysis uses Navius' **gTech** model to forecast the Canadian rail sector's GHG emissions to 2050. This model is well suited for this task because:

- **It is the most widely used energy-economy model in Canada**. gTech is used to advise most governments in Canada on the impacts of climate mitigation policy. The results of our work feed into GHG policy development for the governments of British Columbia, Alberta, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, PEI, Yukon, Northwest Territories and Nunavut, as well as federal government agencies including Natural Resources Canada and Environment and Climate Change Canada. Furthermore, this model has been used to produce analyses for a wide range of energy utilities, industry organizations, non-governmental organizations, and private companies.
- **It is a full economic model**. gTech is a computable general equilibrium (CGE) model that represents transactions between all sectors of the economy as measured by Statistics Canada national accounts.[2] Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and the transactions that occur between households, firms, and the government. As such, the model provides a forecast of how government policy affects many different economic indicators, including sector activity (notably transportation sectors such as rail), provincial and national gross domestic product, investment, household income and jobs. The model includes more than 100 sectors across all separate Canadian provinces, the territories (in aggregate) and the United States (in aggregate).
- **It is technologically explicit.** gTech explicitly simulates how households and firms adopt technologies and use fuels to meet their demand for energy services (e.g., transportation, heating, etc.). These choices are sensitive to energy prices, technology costs, and policy incentives or constraints. gTech includes 350 different archetypal technologies and fuels that define energy consumption and emissions within more than 80 different energy end-uses and emissions sources (e.g., different technologies for light-duty vehicle travel, residential space heating, industrial process heat, management of methane leaks, etc.). Specific to the rail sector, gTech includes six locomotive archetypes that are defined for each of the

[2] Statistics Canada. Supply and Use Tables.

four rail segments in this analysis. These represent a range of new and old diesel locomotives as well as ZELs. These archetypes may consume a range of fuels that include, fossil diesel, biodiesel, renewable diesel, hydrogen and electricity (described in more detail in section 3.3 and Appendix A).

- **It tracks technology vintage and stocks.** In addition to simulating technology and fuel choice, gTech also tracks technology vintage and stocks. Vintage refers to when a specific unit of technology was manufactured and stock is the quantity, by vintage, of a given technology. In most situations, technologies are used for the duration of their useful life. This slows down the rate of technological change and contributes to “inertia” in GHG emissions, where GHG reductions may be constrained by the rate of “stock turnover”, i.e., the rate at which older technology vintages are retired and new ones are acquired. For example, we estimate that on average, locomotives in Canada are retired after 44 years of use[3], with significant variation among the four rail segments represented in the model. Without policy, some of these locomotives may be retired sooner or later than this average retirement age. Note that the rate of retirement can be impacted/set by policies in the model.

- **It is behaviourally realistic.** Technological choice is strongly influenced by behaviour. In some cases, behaviour has as much influence on a technology acquisition decision as simple financial costs. gTech includes three behavioural dynamics designed to realistically describe how policies will influence technology choice: non-financial preferences, time preference (e.g., people prefer saving money in the present rather than the future) and market heterogeneity (e.g., different people will make different choices, all else held equal). Time preference for money is the most relevant to industrial sectors and is represented by using “revealed” discount rates for the evaluation of investments, which is typically much higher than a discount rate based on the cost of borrowing money. The revealed discount rate captures factors such as the uncertainty of the future costs and revenues related to a prospective investment and capital constraints (i.e., having a limited amount of capital to invest at a given time regardless of how many good investments are available).

- **It explicitly represents a wide range of GHG and energy policies.** gTech accounts for all major energy and GHG policies implemented or under consideration in Canada. A non-exhaustive list includes carbon pricing (taxes, cap-and-trade, output-based allocations and/or tradeable performance standards, and virtually any method for

[3] We calculated this based on the original manufacture date of all locomotives in the Canadian fleet using data supplied by the Railway Association of Canada. See “Energy Intensity, Average Life, and Utilization” starting on page 43 in the appendix for more details.

carbon revenue recycling), market-based regulations (such as low-carbon fuel standards, vehicle emissions standards, and federal clean fuel standards), and technology-specific regulations or incentives. Where policies create markets for compliance credits, gTech explicitly simulates the supply and demand of these credits. Finally, gTech fully accounts for policy interaction, whether that be policy overlap, where the impact of several policies is not additive, or policy synergy, where several policies may produce an outcome that is greater than the sum of their individual impacts.

The following section qualitatively describes how gTech forecasts energy consumption, technology adoption and GHG emissions in the rail sector. Appendix C: Detailed Description of the gTech Model, contains more information about the model.

2.2. Simulating rail transportation in gTech

Rail transportation activity in gTech is a function of demand from other sectors (e.g., demand from the wheat or oil production sectors for transportation of the goods they produce). Activity is measured in economic terms, real Canadian dollars, but this is converted to revenue tonne kilometer (RTK) travelled per year based on estimates of energy intensity in past years (e.g., in the data from Statistics Canada, the Railway Association of Canada (RAC) and the in NRCan Comprehensive Energy Use Database). Note that we split the rail sector into four segments:

- Class I line-haul
- Class I switcher
- SL&R line-haul
- SL&R switcher

Activity for switcher locomotives is measured using RTK/year, but this is truly "RTK equivalents", where the equivalent activity expressed as MWh or bhp*h (brake horsepower hours) is based on past annual energy consumption by switcher locomotives (e.g. from RAC data) and typical energy intensity for switcher locomotives relative to line-haul locomotives (e.g., from U.S. Environmental Protection Agency estimates).

The energy and emissions intensity of rail travel is a function of the technology and fuel archetypes used to provide this activity. Rail travel can be provided by archetypal representations of freight locomotives. gTech currently includes several locomotive archetypes:

- A representation of existing locomotive stock. We have split the model's "base" stock (what existed in 2015) into three groups representing different Tiers: Tier 0 and untiered, Tier 1, and Tier 2 & 3.[4].
- New diesel locomotives brought into service since 2015, which include some Tier 3 locomotives, but over the time horizon of the analysis (i.e., to 2050), are almost entirely Tier 4 locomotives.
- New hydrogen fuel cell locomotives (FCLs) capable of switcher and line-haul services.
- New battery-electric locomotives (BELs) capable of switcher and line-haul services.

Locomotives are modelled as units within an aggregate fleet. As such, the model does not represent nor prescribe how they may be used together as a consist to pull a train. This is a suitable methodology for this analysis since the policies that were modeled affect the composition of the fleet with constraints on locomotive retirement and renewal, but do not define how locomotives within that fleet may or may not be used.

The acquisition, use, and retirement or repowering of archetypal locomotives is simulated by the model for each vintage of the archetypes (e.g., existing locomotives vs. those acquired in 2020, 2025 etc.). When stock is retired or if demand for rail transport grows, additional "new" locomotives are added. The "new" locomotives include:

- Newly manufactured locomotives
- Used locomotives (i.e. lower Tier) newly added to a fleet. For switcher locomotives in both Class I and SL&R segments, we assume any Tier of locomotive may be added, with an associated repowering cost. For SL&R line-haul, we assume any Tier of locomotive may be added with an associated "used" purchase cost. Finally, very few Tier 0 locomotives have been added to the Class I line-haul fleet since 2015.[5] Therefore, we assume that Tier 1 or higher locomotives may be added, again with an associated "used" locomotive cost (see section 3.3 and "Locomotive Capital Costs by Segment" in the appendix).

In addition to retirement, locomotives of one archetype may also be repowered to become another archetype, subject to economics or policy requirements. In the

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[4] The Tier 2 and 3 group contains the handful of Tier 4 locomotives that were present in the Canadian fleet in 2015.

[5] Railway Association of Canada (2023). Locomotive Emissions Monitoring Report 2021.

context of this study repowering (or remanufacturing) represents a capital expenditure that either changes a locomotive to another archetype, extending its operating life, or simply extends its operating life (without becoming another archetype). The model does not represent a situation where a locomotive is repowered to become more energy efficient, but without improving its Tier rating.

The simulated technology choices are driven by economics and behaviour, which can affected by policies, whether that be when acquiring a new locomotive or choosing to repower an existing locomotive. The choices are affected by technology capital costs, operating costs and the “behavioural” factors described earlier (e.g., a preference for current savings over future savings). Climate policy can influence technology choice by changing these costs or by setting constraints on when and what technologies may be used (e.g., incentives, regulations, or carbon prices).

We’ve characterized a unique set of technologies for each rail segment, and the segments have differentiated investment behaviour:

- We assume Class I will generally make investments in locomotives that yield a 5-to-6-year payback (20% revealed discount rate).
- SL&R railways are known to operate with much tighter margins than Class I railways, which may restrict their capacity to invest regardless of the profitability of those investments. We represent this constraint by assuming they are unable to support investments unless they can get a 2-to-2.5-year payback (40% revealed discount rate).

Note this investment behaviour is based on anecdotal information and it is uncertain. If there is more/less capacity for investment, then there would be more/less adoption of ZELs because they generally have large upfront costs but lower operating costs.

Locomotives demand fuel, which can come from a range of sources, each of which is supplied by an archetypal fuel production sector. For example, a diesel locomotive could use fossil diesel, biodiesel, or renewable diesel. Renewable diesel may be produced from vegetable oils or biomass. As with the technology choice, the fuel choice is defined by fuel prices and any relevant constraints (e.g., typical blending rates for biodiesel), both of which may be affected by policies. Similarly, the FCL could use hydrogen produced via a range of pathways (e.g., conventional “grey” hydrogen or lower carbon “blue” or “green” hydrogen), and the BEL archetype uses electricity produced by a model of each provincial electricity system (which also change over time, subject to technology and fuel costs, as well as climate policies).

This modeling approach has some limitations. First, it does not represent passenger rail as a separate segment within the rail sector. However, the associated energy consumption and GHG emissions are included within the SL&R line-haul segment and they are affected by the policies and GHG reduction opportunities within that segment. Second, this model does not simulate the potential mode switch between rail and truck transportation, nor does it simulate the potential for Canadian rail transportation demand to be lost or gained from U.S. railways. Total rail activity will vary throughout the forecasts, but only as a function of overall economic activity within the other sectors that require rail transportation services. It will not be affected by climate policies that create differential costs between rail and truck transportation, or between Canadian and U.S. rail transportation. These limitations could be addressed with additional model development, but this was not within the scope of the project.

3. Scenario Design and Assumptions

3.1. Scenario Summary

The scenarios in this analysis focus on the following four policy variables:

- Effective (i.e., starting) date of a policy and the percentage of the fleet to be renewed by a given date
- The locomotive Tiers or ages affected by a policy
- The locomotive Tiers or propulsion systems required by a policy (e.g., ZELs)
- The scope of a policy (e.g., affects Class I freight vs. regional and shortline)

Each scenario will include a unique combination of these variables, which are described below and organized by policy groups. The groups include past trends and current policies, GHG pathways, fleet renewal, and incentives. The scenarios are summarized in Table 1 in section 3.2.

This analysis does not test the impact of uncertainty in future ZEL costs or low-carbon fuel costs. Previous work for ECCC demonstrated that the impact of this uncertainty on the technology adoption, fuel consumption and GHG emissions of the rail sector is limited when strong climate-specific climate policies are implemented. Nonetheless, other aspects of technology uncertainty may be important, such as when ZELs are commercially available or how carbon dioxide removals (e.g., direct air capture) affect the GHG abatement required to achieve net-zero. However, these uncertainties are outside the scope of this analysis.

3.1.1. Past trends and current policies

Current policy scenario: This scenario includes all currently legislated policies in Canada. Notably for the rail sector, the federal carbon pricing backstop rises to $170/tCO_2$ by 2030 and the *Clean Fuels Regulations* (CFR) apply as legislated. All legislated provincial policies also apply, notably the application of carbon pricing by province and the BC Low Carbon Fuel Standard (LCFS). As a baseline technology requirement, new locomotives must be Tier 4 compliant. These current policies are included in all other scenarios.

3.1.2. GHG Pathways

The GHG pathways scenarios all include a constraint on rail sector GHG emissions that varies by timing and scope. Because the sectoral GHG cap can drive substantial low-carbon fuel consumption in the rail sector, any rail-sector GHG cap must occur within the context of a net-zero requirement throughout the model. Consequently, all GHG pathway scenarios include national net-zero GHG caps for Canada and the United States. This scenario design ensures that the total demand for low-carbon fuels and their resulting price is reasonable and consistent with a net-zero future where there is substantial demand for a scarce supply of low-carbon fuels.

SBTi pathway scenario. This scenario includes a sector-wide GHG constraint based on the Science Based Targets initiative (SBTi) targets from Canadian National (CN) and Canadian Pacific (CP, which since merged with Kansas City Southern to become CPKC), which are used to approximate the SBTi pathway in the railway sector. The intensity targets validated by SBTi for these two Class I freight railways are the equivalent of reducing their combined emissions by 23.8% in 2030, relative to 2019, and achieving net-zero by 2050. We define net-zero as an 87% reduction in Class I railway GHG emissions relative to 2005, consistent with the percent GHG reduction we currently equate with net-zero emissions nationally.[6]

The value of the GHG cap is defined by Class I rail emissions, but because of how the model is structured, the cap is applied across the rail sector. Implicitly, this represents a situation where the Class I railways are obligated to reduce their GHG emissions, but voluntary GHG abatement from non-Class I railways could be traded to Class I railways and count towards their compliance obligation. This methodology also applies to the years where no GHG cap applies to SL&R railways in the “Staggered Rail Sector Net-Zero” scenario (see two paragraphs down).

Full rail sector net-zero scenario. This scenario has a GHG cap that requires the entire rail sector’s GHG emissions to be 40% below 2005 levels by 2030, consistent with the Canadian national target, and to reach net-zero by 2050. Net-zero is modeled as equivalent to at least an 87% reduction in emissions relative to 2005 levels.

Staggered rail sector net-zero scenario. This scenario has a GHG cap that requires Class I railway emissions to be 40% below 2005 levels by 2030 and to reach net-zero by 2050 (equivalent to 87% below 2005). SL&R railways are subject to the same cap

[6] We define net-zero emissions for Canada as a residual of 100 $MtCO_2e$ that are emitted and offset by additional carbon dioxide removals from land-use and land-use changes. This change equivalent to an 87% reduction in GHG emissions relative to 2005 and we apply this same proportional GHG reduction requirement to the rail sector.

but with a 10-year delay, which means 40% below 2005 levels by 2040, and a 64% reduction by 2050 (a linear interpolation to -87% by 2060). Although the GHG cap is defined by the timing and GHG reduction required from the rail segments included in the cap, it is applied across the entire sector. As described above, this implicitly means that SL&R railways could over-comply with their GHG reduction obligation, trading it to count towards the obligations of Class I railways.

DOE rail milestones scenario. This scenario uses the rail milestones proposed by the U.S. Department of Energy (DOE) as binding targets. Specifically, there is a GHG constraint combined with fleet renewal targets that require:

- Freight rail sector GHG emissions to be 30% lower than 2019 levels in 2030
- Zero emissions sector-wide by 2050 (approximating the DOE’s net-zero requirement that includes construction and maintenance as well as embodied carbon)
- 50% of switchers locomotive operations are to be done with ZELs by 2035, and 100% by 2040
- 40% of line-haul locomotives to be ZELs by 2040

3.1.3. Fleet Renewal

California-style fleet renewal scenario. This scenario is based on the California In-Use Locomotive Regulation[7], which requires all locomotives to retire 23 years after their original manufacture date as of 2030. However, if locomotives are repowered to be Tier 4 compliant before 2030, they may be used for another 23 years. Also, all new switcher locomotives must be zero-emissions locomotives (ZELs) starting in 2030 and all new locomotives must be ZELs starting in 2035. The California In-Use Locomotive Regulation is summarized in Appendix B: Additional Policy Details

California-style Class I fleet renewal scenario. This scenario is identical to the previous scenario, except that it only applies to Class I railways.

Class I renewal to Tier 4 scenario. This scenario has a fleet renewal regulation that requires Class I railways to retire their locomotives after 30 years in operation as of 2030 unless they are repowered to be Tier 4 compliant.

[7] See Appendix B: Additional Policy Details for more information on this policy

Staggered renewal to Tier 4 scenario. This scenario is like the previous scenario, except that the fleet renewal requirement is staggered by railway type. Class I railways must retire their locomotives after 30 years in operation as of 2030 unless they are repowered to be Tier 4 compliant. This requirement is delayed by 10 years (to 2040) for SL&R railways.

Ambitious fleet renewal to ZEL scenario. This scenario has a fleet renewal regulation that requires all locomotives to retire after 25 years of operation starting in 2035 unless they are repowered to be ZELs. New locomotives must be ZELs as of 2035.

Ambitious fleet renewal to ZEL and Tier 4 scenario. Starting in 2035, line-haul locomotives that are 25 years and older must be retired or repowered to be Tier 4 compliant. Likewise, as of 2035, switcher locomotives that are 25 years and older must be retired or repowered to be ZELs, and new switcher locomotives must be ZELs.

Fleet renewal to ZEL and Tier 4. The fleet renewal requirements in this scenario are staggered and differentiated according to the railway type and the service provided by the locomotives. For Class I railways:

- Line-haul locomotives that are 25 years and older must be retired or repowered to be Tier 4 compliant starting in 2030.
- Switcher locomotives that are 25 years and older must be retired or repowered to be ZELs starting in 2035 and new switcher locomotives must be ZELs after that date.

For SL&R railways:

- Line-haul locomotives that are 35 years and older must be retired or repowered to be Tier 4 compliant starting in 2030.
- Switcher locomotives that are 35 years and older must be retired or repowered to be ZELs starting in 2035 and new switcher locomotives must be ZELs after that date.

3.1.4. Incentives

CRISI scenario. This scenario will pair current policies with the equivalent Canadian level of investment as the U.S. CRISI[8] program in 2022. CRISI provided USD 96.8M of

[8] See U.S. Department of Transportation, Federal Railroad Administration Consolidated Rail Infrastructure and Safety Improvements (CRISI) Program

funding for locomotive renewals, equivalent to about CAD 130.7M (with a 1.35 CAD/USD exchange rate). The Canadian locomotive fleet is about 16% the size of the U.S. fleet, so a proportional level of annual funding would be about CAD 21M/yr. The funding is available starting in 2026 to non-Class I railways (i.e., applied to SL&R railways in this analysis) to acquire a ZEL, repower to a ZEL, or build ZEL charging and refuelling infrastructure.

Enhanced CRISI scenario. This scenario is the same as above, except the annual funding amount is doubled to CAD 42M/yr.

Net-zero funding scenario. The purpose of this scenario is to define an upper bookend on the annual funding required to drive a level of ZEL adoption in non-Class I railways that is "consistent with net-zero" GHG emissions. We define "consistent with net-zero" as having ZELs account for 80 to 90% of locomotives in use by SL&R railways in 2050. We iteratively determined a value of $275 million available from 2026 to 2050 with the same eligibility as in the previous two scenarios (for ZEL adoption by SL&R railways).

3.2. Policy Scenario Inputs

Table 1 summarizes the policy scenarios that were modeled for this analysis.

Table 1: Policy Scenario Summary

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
Policy Group: Past trends and current policies					
Current Policy	Business as usual	N/A	N/A	N/A	N/A
Policy Group: GHG Pathways					
SBTi pathway	SBTi GHG targets for Class I: -23.8% by 2030 from 2019 levels, net-zero by 2050 (-87% from 2005)	Class I only	Flexible	All tiers	2030 and 2050 GHG targets met by Class I locomotives, with linearly interpolated targets in between
Full rail sector net-zero	GHG cap on entire rail sector: -40% by 2030 from 2005 levels, net-zero by 2050 (-87% from 2005)	All locomotives	Flexible	All tiers	2030 and 2050 GHG targets met by all locomotives, with linearly interpolated targets in between

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
Staggered rail sector net-zero	Class I must reduce GHG by 40% from 2005 levels in 2030, reaching net-zero (-87% from 2005) by 2050. SL&R have a 10-year delay.	All locomotives (different timing)	Flexible	All tiers	2030 and 2050 targets to be met by Class I railways, SL&R railways must meet those same targets in 2040 and 2060.
DOE rail milestones	A GHG pathway combined with technology requirements	All locomotives	ZEL	50% of switchers to be ZELs, rising to 100% 40% of line-haul locomotives to be ZELs	In 2030: -30% freight rail GHG from 2019 levels In 2035: 50% switcher ZEL requirement 2040: 40% ZEL requirement for line-haul locomotives, 100% ZEL requirement for switchers In 2050: Sector-wide net-zero GHG accounting for construction, maintenance embodied carbon
Policy Group: Fleet Renewal					
California-style	Based on California In-use Locomotive Regulation: Age limits and powertrain requirements for locomotives	All locomotives (to a different degree)	Tier 4 and then ZELs are required	All Tiers must retire 23 years after manufacture (or repowering to Tier 4). New locomotives must be ZELs.	The 23-year age limit and ZEL requirement for new switchers come into force in 2030. The ZEL requirement for all locomotives is in force by 2035.

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
California-style Class I	Same as above, but applied to Class I only	Class I locomotives only	Tier 4 and then ZELs are required	All Tiers must retire 23 years after manufacture (or repowering to Tier 4). New locomotives must be ZELs.	The 23-year age limit and ZEL requirement for new switchers come into force in 2030. The ZEL requirement for all locomotives is in force by 2035.
Class I renewal to Tier 4	Older Class I locomotives must be retired or become Tier 4	Class I locomotives only	Tier 4	Locomotives 30 years and older must be retired or repowered.	The Tier 4 requirement for 30-year-old locomotives comes into force in 2030.
Staggered renewal to Tier 4	Older locomotives must be retired or become Tier 4	All locomotives (staggered)	Tier 4	Locomotives 30 years and older must be retired or repowered to be Tier 4.	The Tier 4 requirement begins in 2030 for Class I and in 2040 for SL&R.
Ambitious fleet renewal to ZEL	Older locomotives must be retired or become ZEL	All locomotives	ZEL	Locomotives 25 years and older must be retired or repowered to be ZEL.	The ZEL requirement begins in 2035. All new locomotives must be ZELs as of 2035.
Ambitious fleet renewal to ZEL and Tier 4	Older locomotives must be retired or become ZEL and Tier 4	All locomotives	ZEL (switchers) Tier 4 (Line-haul)	Locomotives 25 years and older must be retired or repowered to be ZEL (switchers) or Tier 4 (line-haul).	The requirement begins in 2035.
Fleet renewal to ZEL and Tier 4	Older locomotives must be retired or become ZEL and Tier 4	All locomotives (staggered)	ZEL (switchers) Tier 4 (Line-haul)	Locomotives must be retired or repowered to be compliant after: • 25 years (Class I) • 35 years (SL&R)	The requirement begins in 2030 for line-haul locomotives and 2035 for switchers. New switchers must be ZELs starting in 2035.

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
Policy Group: Incentives					
CRISI funding scenario	An incentive-based policy modelled on the U.S. CRISI program. We assume CAD 21M/yr in funding.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available in 2026 through the end of the forecast.
Enhanced CRISI funding scenario	An incentive-based policy modelled on the U.S. CRISI program. We assume CAD 42M/yr in funding.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available starting in 2026 through to the end of the forecast.
Funding to achieve net-zero	An incentive-based policy where the annual funding is enough to result in 80-90% ZELs in non-Class I railways.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available starting in 2026 through to the end of the forecast.

3.3. Technology and Fuel Cost Assumptions

3.3.1. Assumptions

Table 2 summarizes key assumptions used in this analysis. The resulting locomotive costs and parameters are explained in more detail following the table. As well, the appendix contains further characterization of the archetypal locomotives and low-carbon fuels included in this analysis.

Table 2: Growth, technology and fuel cost assumptions by scenario ($ are 2020 CAD)

	Assumptions
Population and economic growth	Population growth and GDP in the Current Policy scenario are calibrated to the 2021 Canada Energy Outlook. The population will grow at an average of 0.8%/yr from now (2023) to 2050, while GDP will grow by 1.3%.[9] GDP growth may vary from this rate in other scenarios in response to policy costs.
The Price of crude oil and liquid fuel prices in the rail sector	Fossil fuel prices are based on a global oil price of $75/bbl from 2025 onward (USD, equivalent to about $95/bbl or $0.6/L, expressed in 2020 CAD). Purchaser prices in the rail sector include GST/HST/QST, the federal excise tax of 4 cent/L on diesel fuel consumed in the rail sector and provincial excise taxes ranging from about 3 to 16 cent/L. Including refining and distribution margins, the average price of diesel fuel for the rail sector in Canada is about $1.20/L (again in 2020 CAD). With the carbon price reaching $170/tCO2e in 2030, the all-in price would be in the range of $1.60/L. Note that biodiesel and renewable diesel prices include similar distribution margins and are also subject to sales and excise taxes.
Lowest possible vehicle battery cost[10]	$84/kWh for battery manufacturing cost, plus an additional 40% cost for battery integration and retail margins. It declines as a function of deployment with moderate sensitivity to adoption: Every doubling of stock reduces battery cost by 25% and reduces other vehicle component cost by 7%

[9] Canada Energy Regulator. (2023). *Canada's Energy Future 2023*

[10] Battery electric vehicle component cost assumptions are based on:

Bloomberg. (2020). Electric Vehicle Outlook

NREL. (2019). Market segmentation analysis of medium and heavy-duty trucks with a fuel cell emphasis.

ICCT. (2019). Estimating the infrastructure needs and costs for the launch of zero-emission trucks.

ICCT. (2017). Transitioning to zero-emission heavy-duty freight vehicles.

Fries et al. (2017). An Overview of Costs for Vehicle Components, Fuels, Greenhouse Gas Emissions and Total Cost of Ownership Update 2017

	Assumptions
H_2 fuel cell vehicle component minimum costs[11]	Fuel cell stacks and H2 tank costs may decline to $74/kW and $11/kWh (about $370/kg H2), respectively. Fuel cell costs are increased by an additional 40% to cover component integration and retail margin. The cost reductions are a function of deployment: Every doubling of stock reduces fuel cell costs by 13% and tank costs by 8%.
Low-carbon H_2 supply costs[12]	H_2 production and transmission costs are $5-6/kg, plus another $2/kg for liquefaction and dispensing.
Electricity supply and costs	The cost and GHG intensity of electricity generation in each Canadian province are represented using archetypal thermal generation technologies and renewable electricity supply curves that are in turn calibrated to Navius' hourly electricity system model. Electricity supply options and costs are based on province-specific sources as well as assumptions from the National Renewable Energy Laboratories Annual Technology Baseline.[13]
Blending limits for low-carbon fuels	Biodiesel may be at most $5\%_{vol}$ on average within diesel, rising to $10\%_{vol}$ on average in 2030 and thereafter (i.e., it could be as high as $20\%_{vol}$ seasonally). Post-2025, there is no blending constraint on renewable diesel. I.e., 100% of diesel could be renewable rather than fossil diesel.
Renewable diesel from biomass [14]	~$1.9/L (wholesale, pre-tax production cost), post 2030 with biomass feedstock at $60/dry tonne
Renewable diesel (and biodiesel) from vegetable oil	This fuel is represented by a canola-to-diesel pathway. The price of canola varies within the model as a function of its demand and a constrained representation of available agricultural land. Production costs are in the range of $1.65/L when canola seed costs about $900/tonne (typical of 2021/2022). Production costs may rise to $2-3/L when demand is high (e.g., in 2045 or 2050 within a net-zero scenario). Biodiesel follows a similar price trajectory.

[11] Fuel cell component cost assumptions are based on:

SA Consultants. (2016). Final Report: Hydrogen Storage System Cost Analysis

SA Consultants. (2017). Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update.

SA Consultants. (2019). 2019 DOE Hydrogen and Fuel Cells Program Review Presentation.

[12] See "Hydrogen Supply" in the appendix

[13] National Renewable Energy Laboratory (2022). 2022 Electricity ATB Technologies and Data Overview

[14] See "Low-Carbon Fuel Supply" in the appendix

3.3.2. Locomotive Assumptions

Rail transportation demand within each of the four segments is satisfied by a fleet of archetypal locomotives. The technology archetypes are differentiated by segment, with different availabilities, utilization, costs and energy/GHG intensity for Class I line-haul, SL&R line-haul, and Class I and SL&R switchers (switcher technology assumptions are the same for both railway types).

At the start of the forecast, each segment has a fleet of conventional diesel locomotives within three archetypes representing Tier 0/untiered, Tier 1, and Tier 2 & 3 (together) locomotives. "New" locomotives (i.e., new stock) are added to each of the segment fleets as old locomotives are retired, or as additional locomotives are required. New stock refers to all locomotives added to a given fleet. For Class I line-haul, this includes:

- Newly manufactured locomotives (Tier 4), used locomotives purchased from outside the fleet (Tier 1 or Tier 2&3), lower-tier locomotives repowered to Tier 4, and BELs or FCLs. Fleet composition data from the Railway Association of Canada (RAC)[15] indicates that Tier 0 and untiered locomotives have generally not been added to the Class I line-haul fleet since 2015. Therefore, they can not be added as "new" locomotives to the Class I fleet in this analysis.

For SL&R line-haul, new locomotive stock includes:

- Newly manufactured locomotives (Tier 4), used locomotives purchased from outside the fleet (Tier 0/untiered, Tier 1 or Tier 2&3), lower-tier locomotives repowered to Tier 4, and BELs or FCLs.

For Class I and SL&R switchers, new locomotive stock includes:

- Newly manufactured locomotives (Tier 4), repowered locomotives coming from line-haul fleets (Tier 0/untiered, Tier 1 or Tier 2&3), lower-tier locomotives repowered to Tier 4, and BELs or FCLs.

Note that the model does not explicitly track the movement of locomotives from one fleet to another. The purchase of used locomotives is reflected only by the capital cost. Likewise, the movement of repowered lower-tier locomotives from line-haul fleets to switcher fleets is only reflected by the associated capital cost. These costs, as well

[15] Railway Association of Canada (2023). Locomotive Emissions Monitoring Report 2021

as assumptions for locomotive life, utilization and energy intensity, are described in detail in "Locomotive Capital Costs by Segment" in the appendix.

The characteristics of the ZELs available to each segment are described in Table 3 and Table 4 below. The ranges (or operating times) are based on:

- Typical daily utilization of switcher locomotives inferred from RAC data[16] and assumed by the California Air Resources Board (2022), ranging from 0.8 to 2.3 MWh/day.[17]
- Over 80% of SL&R freight requires a 500+km roundtrip.[18]
- For Class I line-haul BELs: Average rail speeds of roughly 36 km/yr,[19] allowing almost 830 km travel over a 23 hr. period.
- For Class I line-haul FCLs: California Air Resources Board (2022) assumptions.[20]

The resulting locomotive capital costs in 2020 and the lowest possible capital costs for each of these ZELs, by segment, are shown in Figure 1 through Figure 6. More detail on the ZEL assumptions is provided in "Locomotive Capital Costs by Segment" in the appendix. BEL charging infrastructure costs are described in section 3.3.3 and FCL refuelling costs associated with hydrogen liquefaction and dispensing are explained in the appendix in "Distribution and Refueling".

[16] Railway Association of Canada (2023). Locomotive Emissions Monitoring Report 2021

[17] California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

[18] Personal communication with the Railway Association of Canada

[19] Statistics Canada. Table 23-10-0276-01 Weekly rail system performance indicators, by commodities, Transport Canada DOI: https://doi.org/10.25318/2310027601-eng

[20] California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

Table 3: BEL archetype characteristics

	Switcher	SL&R line-haul	Class I line-haul
kW, max traction power	1,500	3,200	3,200
kWh battery storage	3,000	35,700	51,000
Battery tenders, per locomotive	0	2	3
Capital cost multiplier, accounts for lower productivity due to tenders*	n/a	1.08	1.14
Approximate range, or days of operation per charge**	1 to 3 days of operation	500 km	830 km

*The capital cost multiplier accounts for the reduction in RTK when replacing revenue-generating cars with battery tender cars. The factor is based on the assumption that a single diesel locomotive will pull 25 revenue-generating cars, while a BEL will put just 22 (Class I line-haul) or 23 (SL&R line) haul.

** The range for line-haul archetypes is based on the energy intensity assumption for each archetype, 80% battery depth of discharge, and a consist of four locomotives pulling 6155 revenue tonnes.

Table 4: FCL archetype characteristics

	Switcher	SL&R line-haul	Class I line-haul
kW, max traction power	1,500	3,200	3,200
kg hydrogen storage per locomotive	58 (compressed)	988 (liquid)	4,000 (liquid)
Hydrogen tenders, per locomotive	0	0	1/2
Approximate range, or days of operation per refuelling**	1 to 3 days of operation	515 km	2,400 km

Figure 1: Class I line-haul fuel-cell locomotive (FCL) cost assumptions

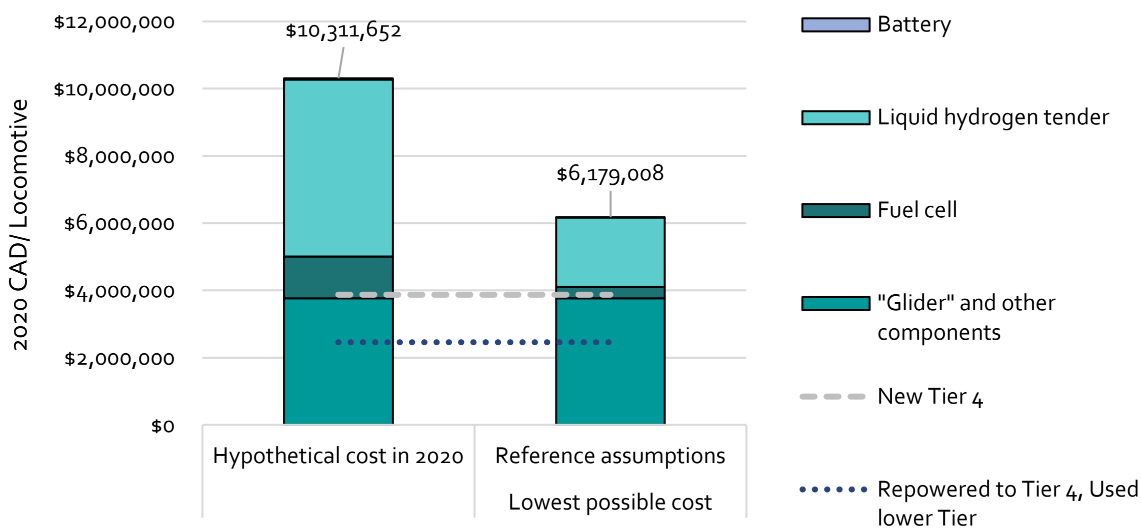


Figure 2: Class I line-haul battery-electric locomotive (BEL) cost assumptions

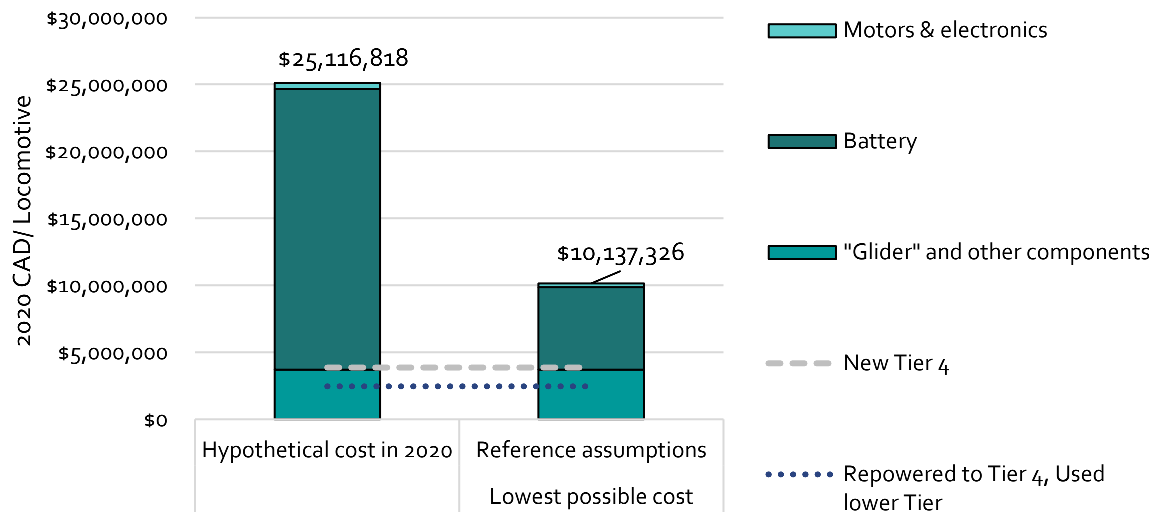


Figure 3: SL&R line-haul fuel-cell locomotive (FCL) cost assumptions

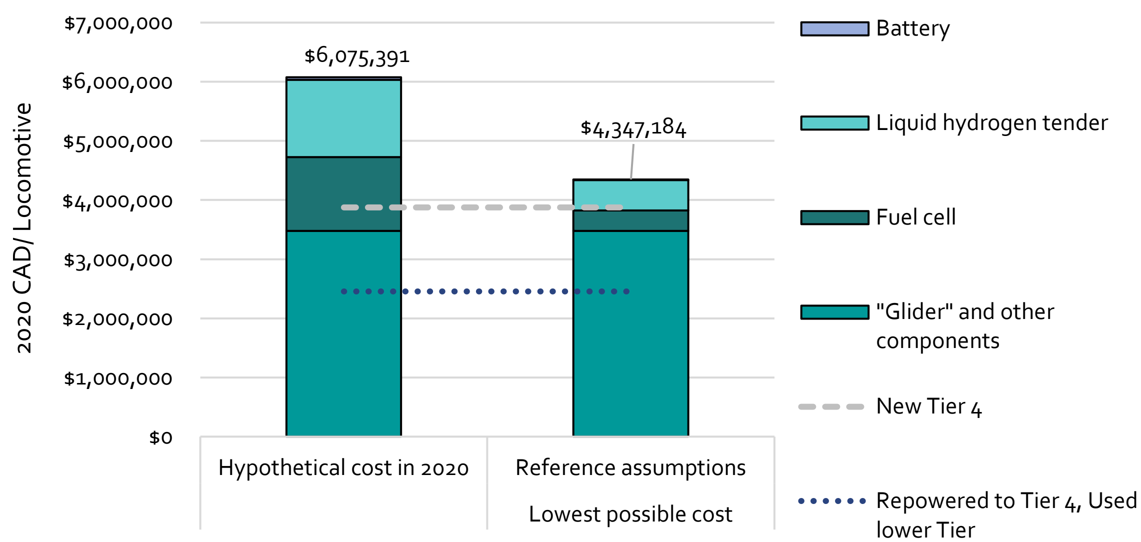


Figure 4: SL&R line-haul battery-electric locomotive (BEL) cost assumptions

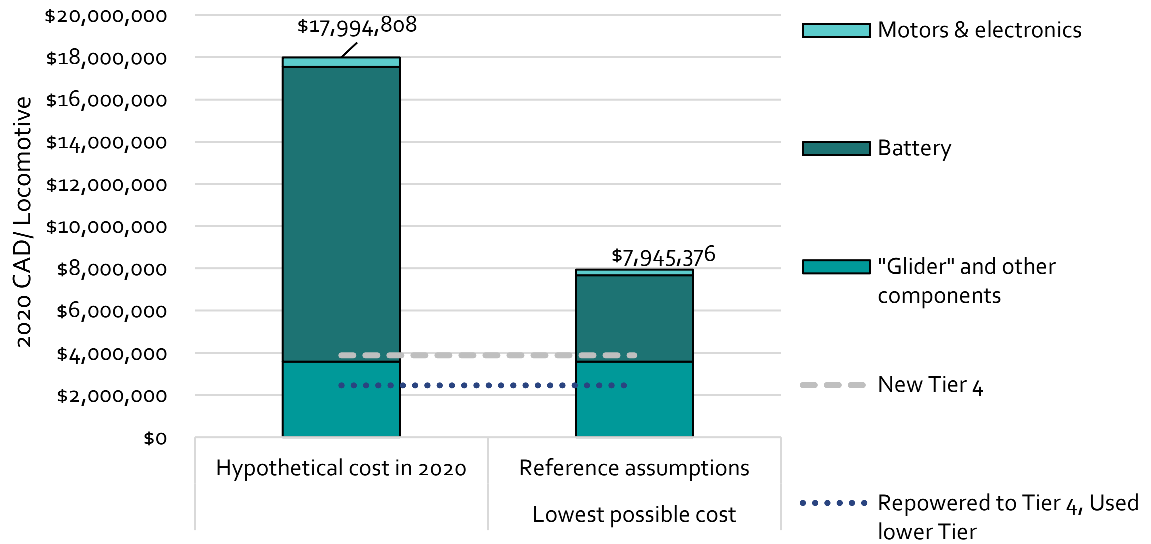


Figure 5: Class I and SL&R switcher fuel-cell locomotive (FCL) cost assumptions

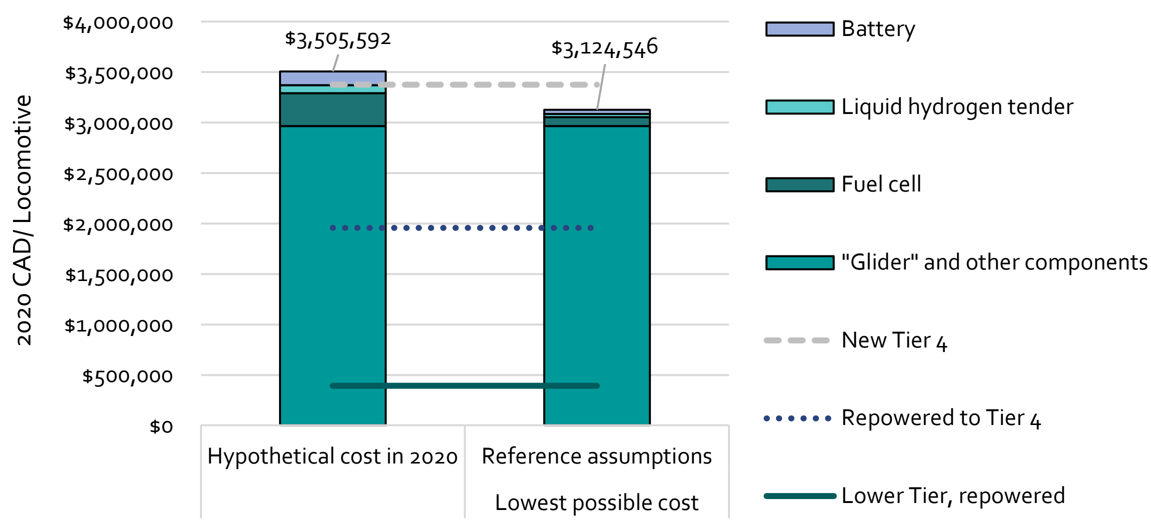
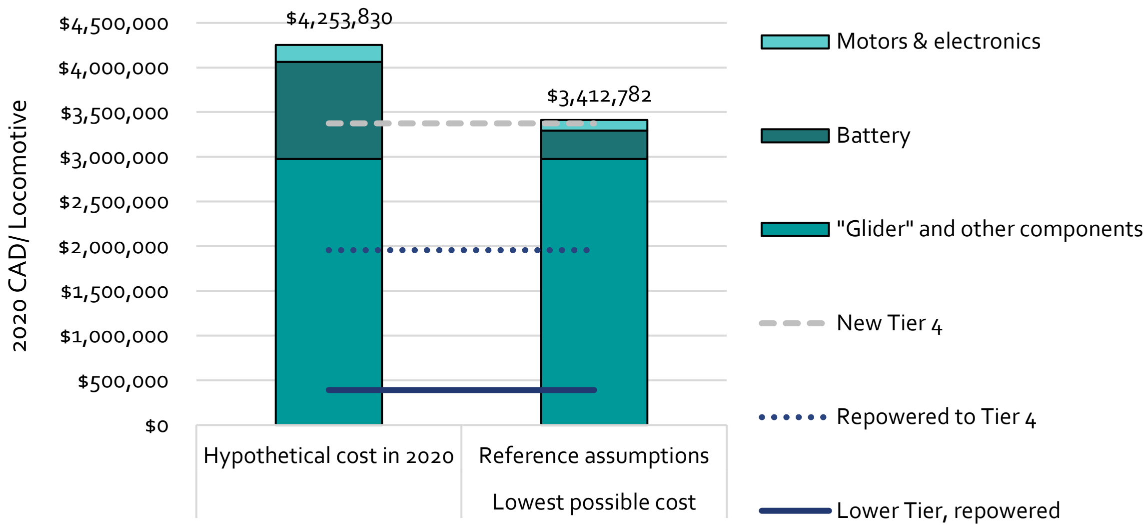


Figure 6: Class I and SL&R switcher battery-electric locomotive (BEL) cost assumptions



3.3.3. BEL Charging Infrastructure Assumptions and Costs

Table 5 shows the assumptions used to characterize BEL charging infrastructure costs. Key assumptions include:

- The maximum depth of discharge of a BEL battery that must be replenished (80% which is typical of vehicle batteries)
- The time available to do this (ranging from 1 hour for Class I line-haul to 8 hours for a switcher locomotive), our assumption)
- The capital cost per MW of charging power (based on Popovich et al. 2021[21])
- The charger utilization (i.e. % of hours in use each year, based on the baseline assumption used by Popovich et al. 2021.)

These assumptions lead to a levelized cost of charging in the range of $62/MWh, which in many regions would be similar to the cost of the electricity itself.

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[21] Natalie D. Popovich, Deepak Rajagopal, Elif Tasar, and Amol Phadke (2021). Economic, environmental and grid-resilience benefits of converting diesel trains to battery-electric. Nature Energy, VOL 6, November 2021, 1017–1025. https://doi.org/10.1038/s41560-021-00915-5

Table 5: BEL charger assumptions and costs

	Switcher	SL&R line-haul	Class I line-haul
Assumed depth of discharge	80%	80%	80%
Maximum to be charged, MWh	2	29	41
Time for charging, hrs	8	4	1
MW charging power needed	0.300	7	41
$/ MW charger Capital Cost (2020 CAD)	$ 1,533,383	$ 1,533,980	$ 1,533,906
Charger cost (2020 CAD)	$ 460,015	$ 10,952,620	$ 62,583,354
Charger utilization assumption	30%	30%	30%
Full charging sessions per day	0.9	1.8	7.2
$/MWh levelized cost of the charger (amortized at 10% over 30 years)	$ 61.895	$ 61.919	$ 61.916

4. Results and Discussion

This section presents key scenario results by each policy group. Section 4.1 outlines results from the GHG pathways scenarios, section 4.2 presents the fleet renewal policy results, and section 4.3 provides results from the ZELs incentives scenarios. The impact of these policies on rail transportation costs, expressed as levelized dollars per RTK ($/RTK) is discussed in section 4.4. Section 4.5 discusses the limitations of this analysis and avenues for future work.

Note that we focus the discussion on key features of each policy group using examples from specific scenarios, comparing contrasting outcomes within and across policy groups. This means the section does not include an exhaustive discussion of each policy option. Additionally, while we provide some discussion of sub-sector results, the discussion is focused on the rail sector as a whole.

4.1. GHG Pathway Scenarios

As outlined in section 3, the first policy group simulated for this analysis includes a constraint on rail sector GHG emissions that varies by timing and scope. As a reminder, these are the GHG pathways scenarios tested for this analysis:

- **SBTi pathway scenario.** A target based on Class I railway GHG commitments, set at a reduction in Class I emissions of 23.8% in 2030, relative to 2019, trending to net-zero by 2050 (we assume -87% relative to 2005).
- **Full rail sector net-zero scenario.** The entire rail sector's GHG emissions to be 40% below 2005 levels by 2030, and net-zero by 2050 (-87% relative to 2005).
- **Staggered rail sector net-zero scenario.** The same as above, but a 10-year delay in the requirement is applied to SL&R railways.
- **DOE rail milestones scenario.** GHG emissions are 30% lower than 2019 levels in 2030, and zero-emissions sector-wide by 2050. 50% ZELs are required among switchers by 2035, and 100% by 2040. 40% ZELs are required among line-haul locomotives by 2040.

The rail sector will not hit any of these proposed GHG targets in the Current Policy scenario (Figure 7 and Table 6). Rail sector emissions in the Current Policy scenario decrease from 7.3 $MtCO_2e$/yr in 2020 to 6.5 Mt in 2030, primarily because of additional renewable fuel blending driven by the *Clean Fuel Regulations.* However, because we do not assume that this policy will become more stringent after 2030, and by 2050, emissions increase to 9.2 $MtCO_2e$/yr.

By definition, each of the four GHG Pathways scenarios hits their respective targets. In 2030, the Full Rail Sector Net-Zero and Staggered Rail Sector Scenarios achieve a similar impact, though the Staggered scenario tends to have somewhat higher emissions for the rest of the forecast.

The SBTi Pathway scenario is the least ambitious pathway, given that it is only based on Class I GHG emissions. However, by 2050 the SBTi, Full Net-Zero, and Staggered Net-Zero are very similar. This means that excluding or delaying GHG targets on SL&R has a relatively muted impact on sector-wide GHG emissions.

The DOE Rail Milestones scenario produces the greatest GHG abatement after 2040, a result of its ZEL adoption requirements and its wider scope for GHG reduction (i.e. net-zero including construction and embodied GHG emissions).

Figure 7: Canadian rail sector GHG emissions in the GHG Pathways Scenarios

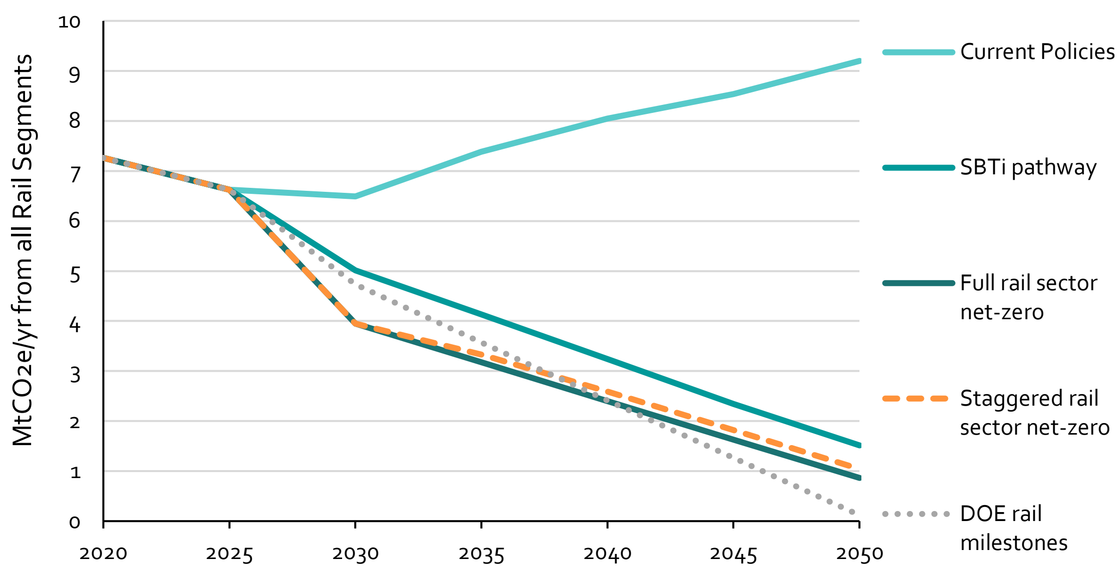


Table 6: Canadian rail sector GHG emissions in the GHG Pathways Scenarios ($MtCO_2$)

	2020	2025	2030	2035	2040	2045	2050
Current Policies	7.3	6.6	6.5	7.4	8.0	8.5	9.2
SBTi pathway	7.3	6.6	5.0	4.1	3.2	2.3	1.5
Full rail sector net-zero	7.3	6.6	4.0	3.2	2.4	1.6	0.9
Staggered rail sector net-zero	7.3	6.6	4.0	3.3	2.6	1.8	1.0
DOE rail milestones	7.3	6.6	4.7	3.6	2.4	1.3	0.1

The rail sector uses both low-carbon fuels (i.e., biodiesel and renewable diesel) as well as ZELs to achieve the targets set out in the GHG Pathways scenarios. By 2030, low-carbon fuel content in the diesel pool (i.e. the sum of diesel-compatible fuels) in the pathways scenarios ranges from 30-45%, and by 2050 it is 80-95%. The range in low-carbon fuel content is driven by the stringency of the sector target, as a stronger target requires more biofuels.

The adoption of ZELs drives down total liquid fuel demand over time and tempers demand for low-carbon fuels in a net-zero future. This is illustrated in Figure 8 below, which shows energy consumption by locomotives in the Full Rail Sector Net-Zero scenario as an example. The low-carbon fuel blend rate grows by a factor of 1.8 between 2030 and 2050 (45% to 83%). During the same period, low-carbon fuel consumption only grows by a factor of 1.2 (45 to 52 PJ/yr).

Figure 8: Locomotive energy consumption for all segments in the Full Rail Net-Zero scenario by fuel (bars), and percentage of liquid fuel that is renewable (line). Data labels show PJ/yr renewable liquid fuel.

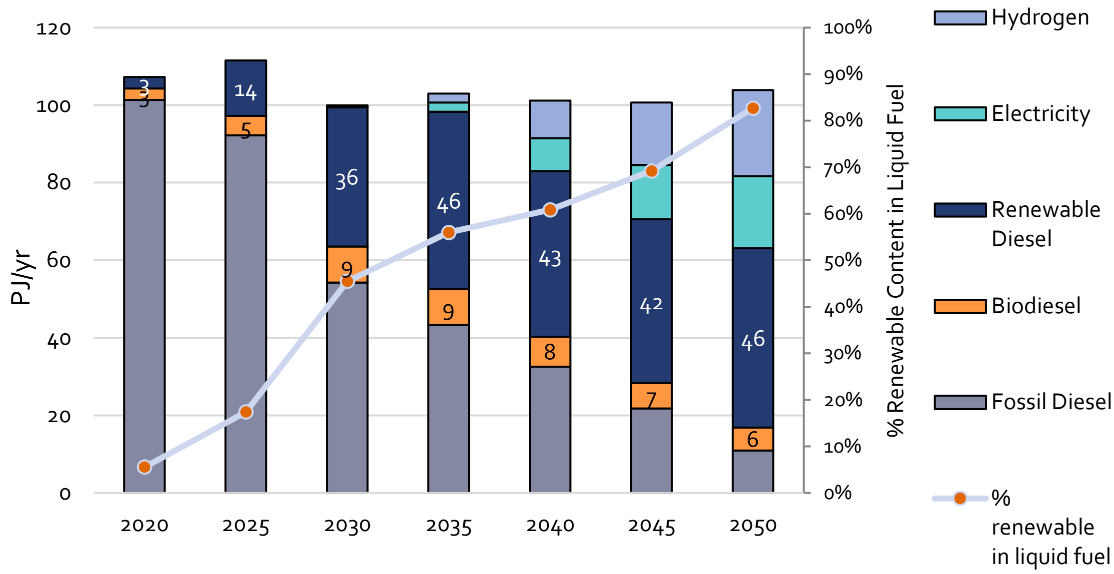
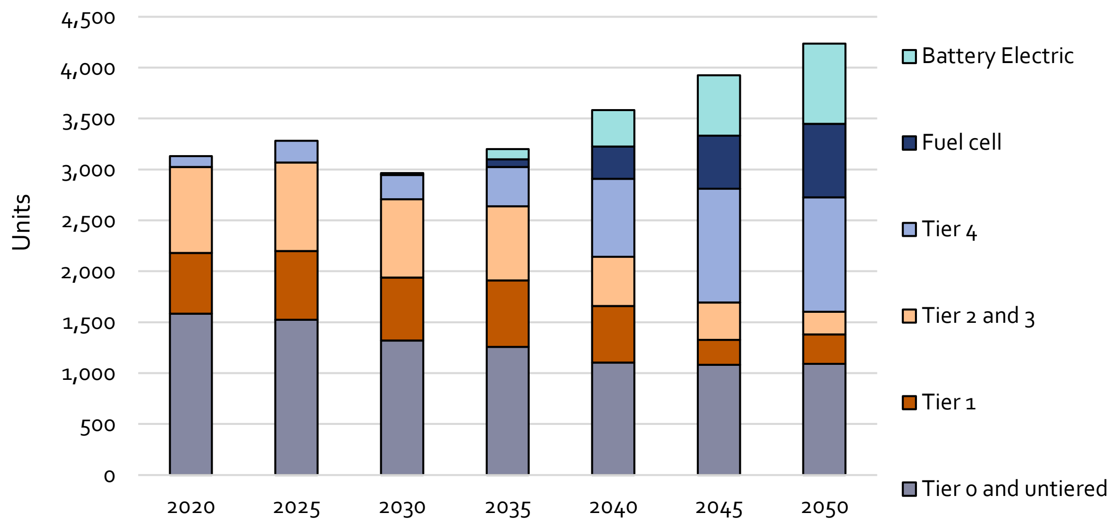


Figure 9 below shows locomotives in use, by archetype, in the Full Rail Net-Zero scenario, as an example. **ZEL adoption starts in earnest after 2035 and is concentrated in Class I line-haul, increasing to 30% in 2040 and 55% in 2050**, as highlighted in Figure 10 below. ZEL adoption is concentrated in the Class I line-haul segment because these locomotives are highly utilized, allowing them to offset their higher capital costs sooner. Furthermore, Class I railways have a greater capacity to make long-term investments that may reduce their lifetime costs. In contrast, very few ZELs are adopted in SL&R line-haul (only 3% by 2050 as shown in Figure 10). This is due to the lower utilization of locomotives in this sector, and less capacity for the sector to invest in new locomotives.

Likewise, **there are almost no ZELs adopted in switchers in the GHG Pathways scenarios** (aside from the DOE Milestones scenarios which requires this). While the incremental capital cost for ZELs capable of yard work is much lower than for line-haul (both for the locomotive and charging/refuelling infrastructure), their low utilization makes it harder to recuperate this investment. This means that **a GHG cap or carbon pricing is not enough to drive ZEL adoption in switchers and may have little impact on the CAC emissions produced in rail yards.**

Figure 9: Locomotives by type across all rail sector segments in the Full Rail Net-Zero scenario



The number of locomotives is approximated from activity based on typical utilization by segment. The number in 2020 may differ from the historical fleet due to differences in typical utilization and utilization in that year.

Across all rail segments, **the ZELs account for roughly one-third of locomotives in 2050 in the GHG Pathways scenario** (again, excluding the DOE Milestones scenario, which requires some fleet renewable to ZELs). **However, because ZELs are concentrated in line-haul service, they carry proportionally more RTKs and have a proportionally larger impact on GHG emissions**. For example, in the Full Rail Net-Zero scenario, 36% of locomotives are ZELs in 2050, but 51% of rail activity is carried out by ZELs (see Table 7 below). Roughly speaking, this level of ZEL adoption would reduce GHG emissions, and other air emissions by half (e.g., NOx and PM) relative to what they would be in a given year in the current policy scenario.

There is a role for both electric and fuel-cell line-haul locomotives in a net-zero future. Note that the technology archetypes are specific to each rail segment. For example, the cost of the battery electric locomotive (BEL) archetype covers a locomotive with tender cars capable of 23 hours of travel at Canadian railway average speeds and its electricity price includes the cost of a high-power charger (one hour charge time), with relatively low utilization (30%). Likewise, the fuel cell locomotive (FCL) archetype has a similar range to a diesel locomotive and its fuel cost includes the additional cost of hydrogen liquefaction. Nonetheless, these results do not eliminate significant technological uncertainty related to when ZELs will be commercially available or how their charging or fuelling network might evolve. Nor do these results prove that other ZEL archetypes not included in this analysis, such as hydrogen combustion or catenary-electric, will not play a role.

Figure 10: % of Locomotives that are ZELs by segment in the Full Rail Net-Zero scenario

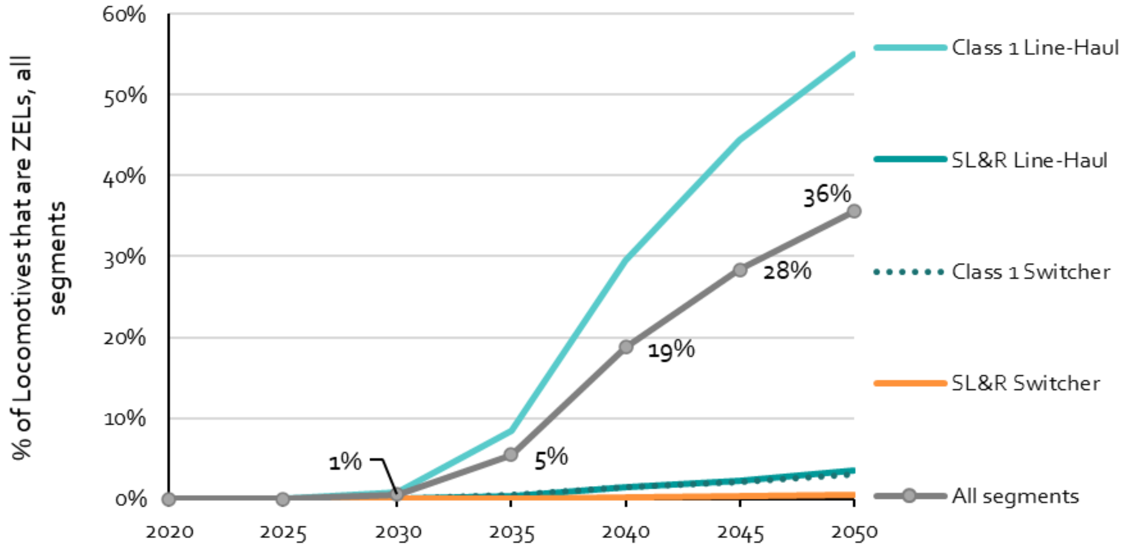


Table 7: % of locomotives that are ZELs vs. % of rail sector activity using ZELs, all segments in the Full Rail Net-Zero scenario

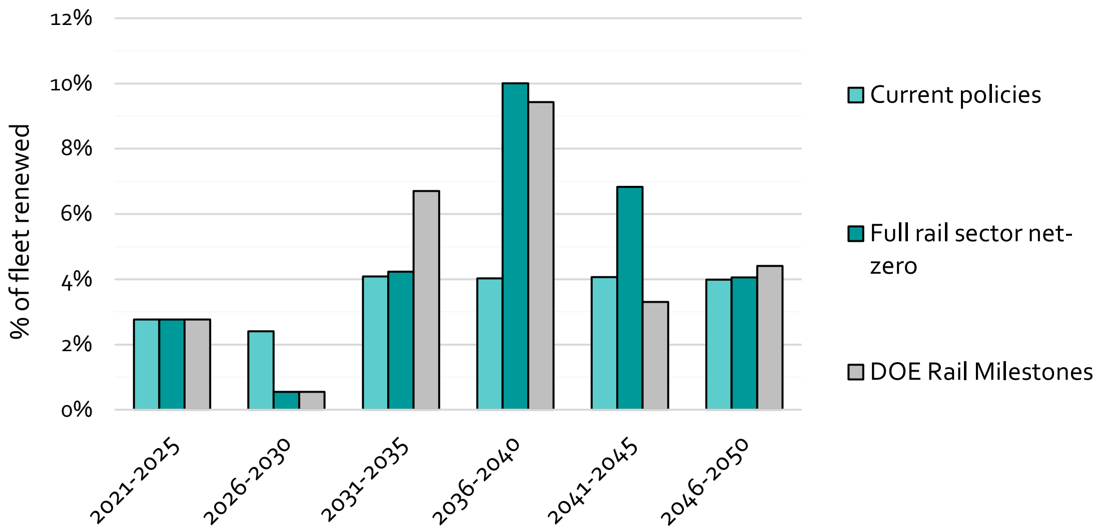
	2030	2035	2040	2045	2050
% of locomotives that ZEL	1%	5%	19%	28%	36%
% of rail activity using ZELs	1%	8%	27%	41%	51%

Figure 11 below shows the fleet renewal rate to achieve the ZELs in Figure 10. This renewal rate includes replacing retired locomotives, or adding additional locomotives to satisfy a growing demand for rail transportation, with:

- Used/old locomotives that are newly added to the fleet within each rail sector segment (e.g. an older Tier 0 that joins the SL&R switcher fleet)
- Newly manufactured locomotives that are added to the fleet
- Existing locomotives within the fleet that are repowered

The fleet renewal rate required to achieve the amount of ZEL adoption seen in the GHG Pathways scenarios is significantly higher than under current policies. For example, between 2035 and 2045, the fleet renewal rate in the Full Rail Sector Net-Zero scenario is about 1.7 to 2.8 times higher than in the Current Policy scenario. Adding fleet renewal requirements, may both advance and increase the periods of peak fleet renewal (e.g. in the DOE Rail Milestones scenario, Figure 11)

Figure 11: Percent per year of new*, replaced, and repowered locomotives (annual average over five years)



* "New" means new additions to the fleet, which may include older locomotives

4.2. Fleet Renewal Scenarios

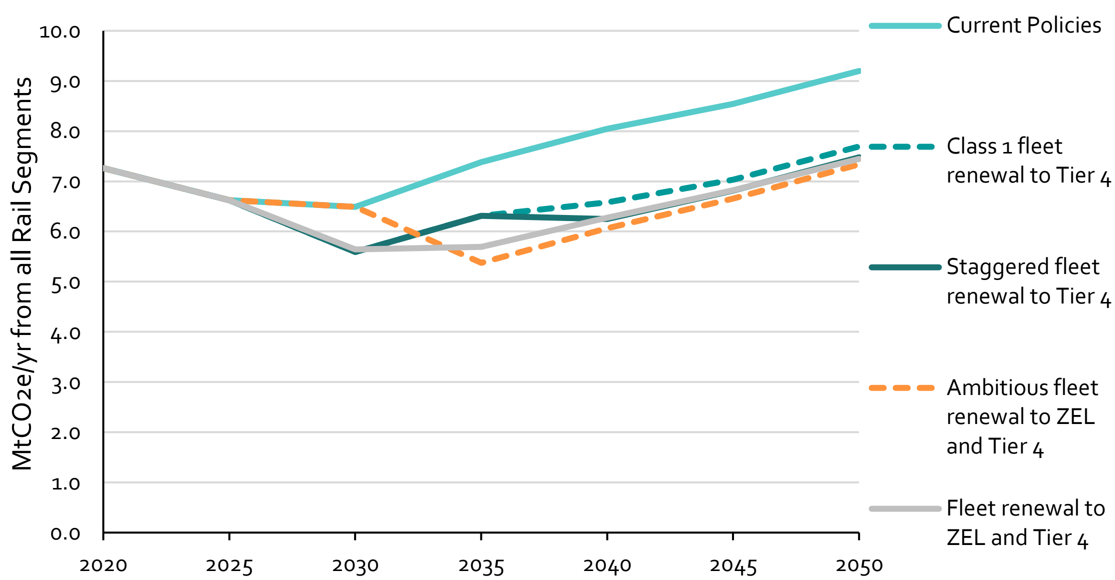
This section presents results for the Fleet Renewal policy group. The GHG and technology impact of the Fleet Renewal Policies depends on their intent. For example. some of these policies are designed to accelerate the adoption of ZELs and drive the associated reduction in sector GHG emissions, while others drive greater adoption of Tier 4 locomotives. In these instances, the adoption of ZELs occurs within a subset of the rail sector, such as switchers, and is ancillary to the policy intent. While air quality is not the focus of this analysis, it is important to note that these policies would have an important impact on CAC emissions, even if their impact on GHG emissions is modest.

The scenarios that focus on renewal to Tier 4 for line-haul service reduce GHG emissions relative to the Current Policy Scenario (Figure 12). For example, in the Staggered Fleet Renewal to Tier 4 scenario, total annual rail sector GHG emissions are about 1.8 $MtCO_2e$. This means emissions are around 20% lower in 2050 than they would be with only current policies in place. The GHG reductions are a result of ZEL adoption amongst switchers combined with the increased energy efficiency of newly manufactured locomotives (compared to the fleet average). The extent to which this latter outcome is realized in the real world depends on whether the efficiency of older locomotives is improved upon repowering, independently of changes in Tier (e.g. upgrading a Tier 0 locomotive from DC to AC motor). This dynamic is not represented in the model. Because we do not model the opportunity to increase the energy efficiency of locomotives without raising them to Tier 4, the results may somewhat overstate GHG emissions in the Current Policy Scenario, thus overstating the impact of new locomotives on fleet energy efficiency. This error would be minor. Because the efficiency gains for upgraded or new locomotives are in the range of 10-20%, and repowering to improve efficiency only (no Tier rating change) would occur only for a subset of locomotives, we expect we are overstating this impact by 5 to 10%.

Delayed application of Tier 4 fleet renewal policies to SL&R railways may result in modest additional GHG abatement, relative to a scenario where they are exempted from the policy. For example, annual GHG emissions in the Staggered Fleet Renewal to Tier 4 scenario are about 0.2 $MtCO_2e$ (3%) lower in 2050 than if SL&R were exempt from such as policy, as in the Class I Fleet Renewal to Tier 4 (see Figure 12).

Requiring switcher fleets to be renewed to ZELs yields a modest additional GHG reduction. These reductions are also in the range of 0.2 $MtCO_2e$ (3%) in 2050. This can be seen if the Staggered Fleet Renewal to Tier 4 scenario is compared to the Ambitious Fleet Renewal to ZEL and Tier 4 scenario (see Figure 12).

Figure 12: Canadian rail sector GHG emissions in the Fleet Renewal Scenarios that require Tier 4 for line-haul service

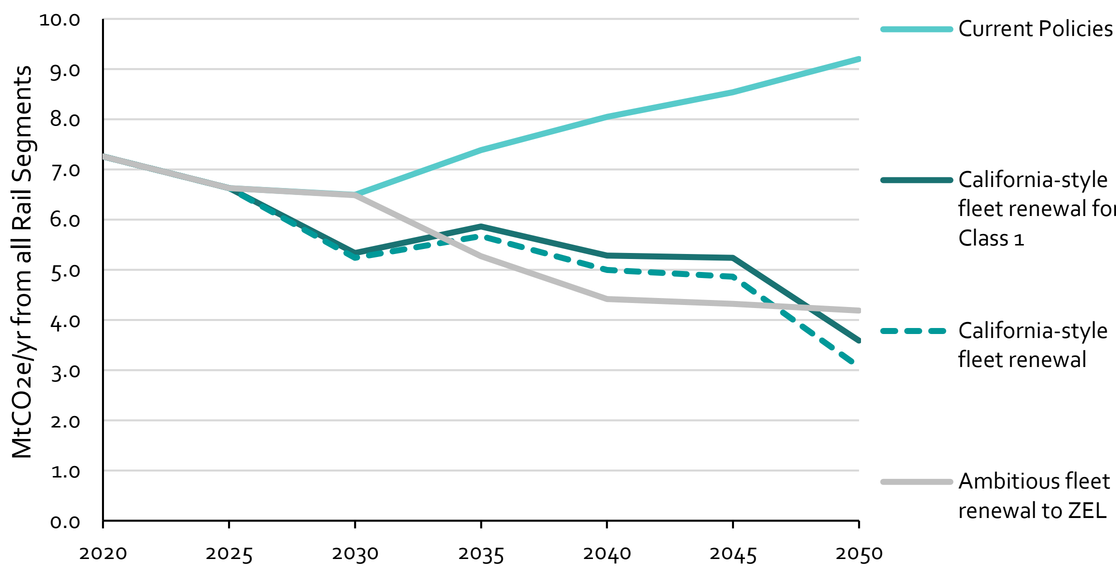


The Fleet Renewal policies that require ZEL adoption for line-haul service result in substantial GHG reductions relative to the Current Policy scenario. This abatement is about 1 to 2 $MtCO_2e$ in 2030 and 2035 rising to 5 to 6 $MtCO_2e$ in 2050 (see Figure 13).

Omitting SL&R railways from the Fleet Renewal policies has a modest impact on total sector GHG emissions. For example, GHG emissions in 2050 with the California-Style Fleet Renewal scenario are about 0.5 $MtCO_2e$ (15%) less than in the variant of that policy that applies only to Class I railways (see Figure 13).

Delaying the fleet renewal requirements by five years results in a similar delay in the GHG impact of the policy. In 2030, GHG emissions in the Ambitious Fleet Renewal to ZEL scenario are substantially higher than in the California-Style Fleet Renewal Scenario. The renewal requirements in the latter scenario start five years sooner for switchers, and there is also an incentive to repower to Tier 4 (i.e., resetting the original manufacturing date). However, the impact of these two policies is very similar by 2035 (Figure 13). We would expect a similar policy impact in 2055 if that year were within the time horizon of this analysis.

Figure 13: Canadian rail sector GHG emissions in the Fleet Renewal Scenarios that require ZELs for line-haul service

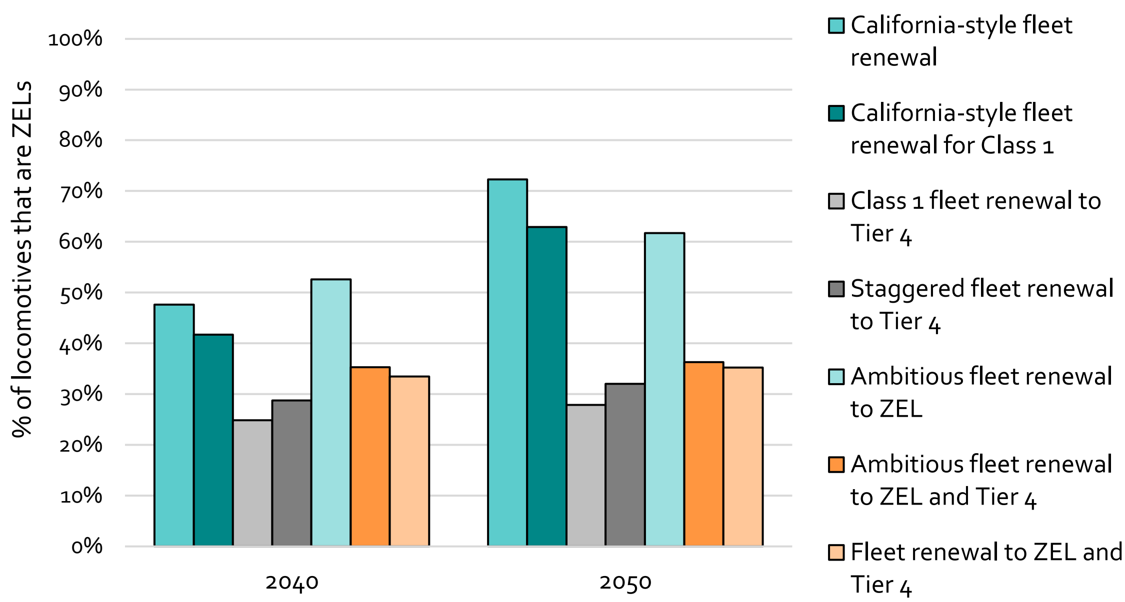


ZEL adoption is greater in the Fleet Renewal Scenarios with ZEL sales requirements, where ZELs account for 45 to 55% of all locomotives in 2040 and 60 to 70% of locomotives in 2050 (the bars shaded with teal/turquoise in Figure 14). Nonetheless, **the other fleet renewal scenarios still have a substantial amount of ZEL adoption**, ranging from 25 to 35% of locomotives from 2040 onward (the bars shaded with grey/orange in Figure 14). **However, the GHG impact of ZEL adoption is muted in the scenarios that primarily require fleet renewal to Tier 4**. In these scenarios, ZEL adoption is concentrated among Class I railway switchers, and the limited utilization of these locomotives limits the associated reduction in sector-wide GHG emissions.

Requiring fleet renewal amongst switchers may result in substantial ZEL adoption within Class I railways, even if ZELs are not specifically required. The reason is that the switcher fleet is composed of older repowered locomotives. Requiring that these be replaced or repowered to be Tier 4 compliant significantly reduces the incremental cost between a diesel-fueled locomotive and a ZEL.

Note that the fraction of locomotives in all Fleet Renewal Scenarios that are Tier 4 *and* ZEL is between 80% and 100% by 2050.

Figure 14: % of Locomotives that are ZELs in a subset of the Fleet Renewal Scenarios



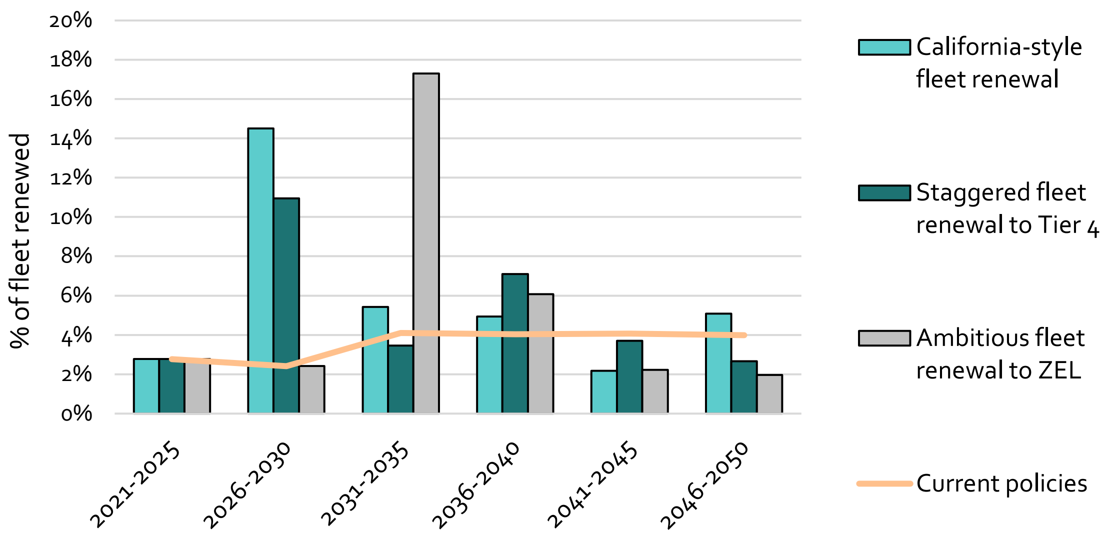
All Fleet Renewal Policies produce peaks in the "locomotive renewal rate" that are well above the Current Policy Scenario (see Figure 15). As previously discussed, the renewal rate includes replacing retired locomotives, or adding additional locomotives to satisfy the growing demand for rail transportation with:

- Used/old locomotives that are newly added to the fleet within each rail sector segment (e.g. an older Tier 0 that joins the SL&R switcher fleet)
- Newly manufactured locomotives that are added to the fleet

- Existing locomotives within the fleet that are repowered

The fleet renewal rate in the Current Policy Scenario ranges from about 2 to 4% per year. The Fleet Renewal Policies could cause this rate to intermittently spike to between 14 and 20% per year. For example, the California-Style Fleet Renewal scenario results in a renewal rate of just under 15% per year during the 2026 to 2030 period. The renewal requirements of The Ambitious Fleet Renewal to ZEL Scenario are delayed by about five years, resulting in the peak renewal rate (about 17% per year) occurring five years later (between 2031 and 2035). Staggering when the renewal requirements are imposed on Class I versus SL&R railways mitigates the magnitude of these peaks (e.g., see the Staggered Fleet Renewal to Tier 4 in Figure 15). However, the rates expressed as a percentage of the affected rail segments are almost as large (e.g. renewal rates expressed as a percentage of the SL&R fleet).

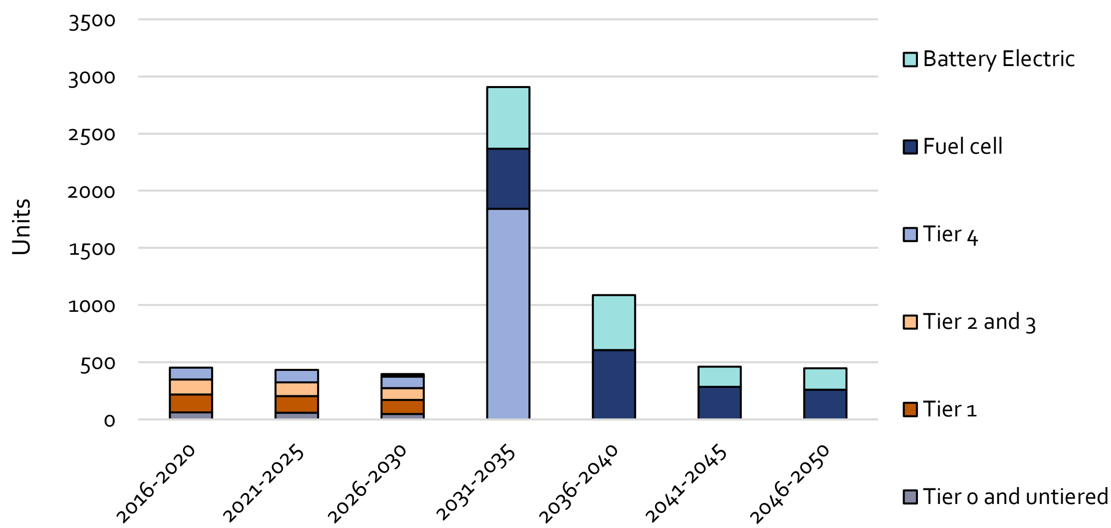
Figure 15: Percentage per year of new, replaced, and repowered locomotives (5-year annual average in a subset of the Fleet Renewal Scenarios)



* "New" locomotives may include old or used locomotives that are added to the fleet of a given segment.

These peaks in renewal rate will likely begin in advance of the policy in-force date as railways may seek to mitigate their initial investment in ZELs. For example, in the Ambitious Fleet Renewal to ZEL scenario, locomotives older than 25 years must retire, and all new locomotives must be ZELs by 2035. Consequently, a railway is unlikely to add an older locomotive to the fleet in the years leading up to the policy in-force date because it would need to be retired soon thereafter. Likewise, the railways have an incentive to add new locomotives to their fleets, deferring the need to buy additional ZELs for a further 20 to 25 years. In the results, this shows up as a substantial addition of new Tier 4 locomotives in the years before a fleet renewal requirement begins (e.g., in the 2031-2035 period in the Ambitious Fleet Renewal to ZEL scenario as shown in Figure 16)

Figure 16: New, replaced, and repowered locomotives by 5-year period across all rail sector segments in the Ambitious Fleet Renewal to ZEL scenario



The Fleet Renewal Policies cause peaks in the renewal rate because they impose a maximum age for in-use locomotives, many of which are already over this age when the policies come into force. Even if this maximum age and in-force date vary by railway type (Class I vs. SL&R) and service type (line-haul vs. switcher), it still causes a significant wave of retirement because the locomotive fleet is old. The Canadian locomotive fleet was on average 26 years old in 2021, with 34% of locomotives being older than 35 years.[22] Consequently, mitigating the peaks in the renewal rate caused by Fleet Renewal Policies might also require differentiating maximum ages and policy in-force dates by Tier or vintage as well as by railway type and service type.

4.3. Incentive Scenarios

The Incentive scenarios include various iterations of funding to support ZEL adoption within SL&R railways. As a reminder, these scenarios include:

[22] Railway Association of Canada (2023). Locomotive Emissions Monitoring Report 2021.

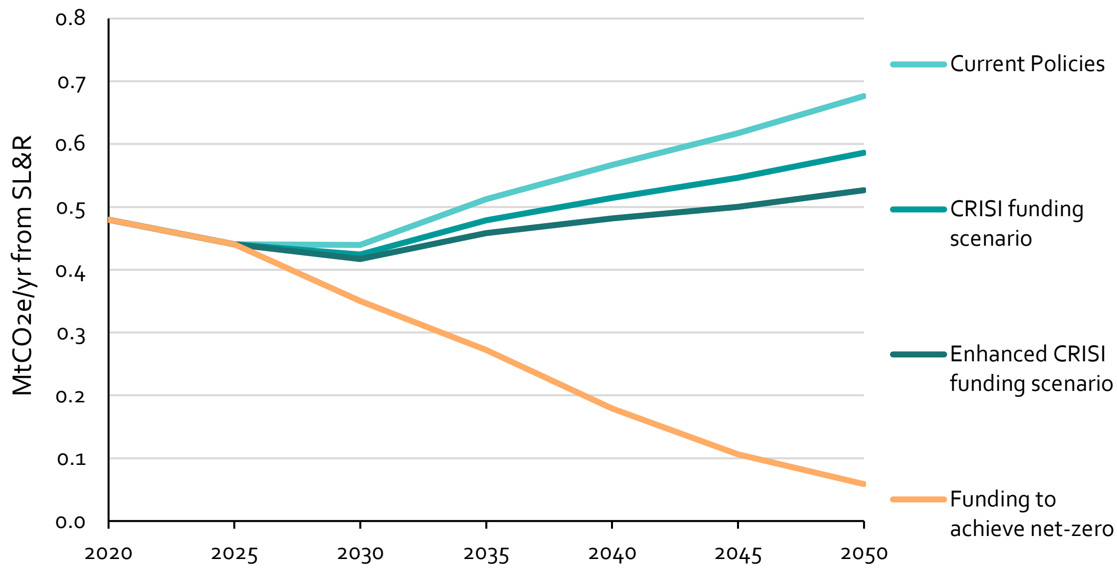
- The CRISI Funding Scenario, with $21 million (CAD) available per year from 2026 through 2050 for SL&R railways to purchase ZELs and associated infrastructure.
- The Enhanced CRISI Scenario, where the incentive is doubled to $42 million (CAD) per year.
- The Funding to Achieve Net-Zero scenario, where the incentive is increased to $275 million (CAD) per year. This amount is enough to make the SL&R railway rolling stock consistent with net-zero, meaning there is 80-90% of locomotives are ZELs by 2050. Again, the purpose of this scenario is to define an upper limit on the amount of support required to decarbonize SL&R railways using only an incentive-based policy approach.

Incentivizing ZEL adoption amongst SL&R railways has a limited impact on sector-wide GHG emissions, though they may have a large impact on SL&R segment emissions (Figure 17). SL&R railways produce a minority of rail sector GHG emissions in all future scenarios (roughly 6-7% of the total). By 2050:

- The CRISI Funding achieves a reduction of about 90 ktCO_2e per year (about 1% of total rail sector GHG emissions, or 13% of SL&R emissions)
- The Enhanced CRISI Funding achieves a reduction of about 150 ktCO_2e per year (about 2% of total rail sector GHG emissions, or 22% of SL&R emissions)
- The Funding to Achieve Net-Zero achieves a reduction of about 620 ktCO_2e per year (about 7% of total rail sector GHG emissions, or 91% of SL&R emissions)

Recall that the SL&R segment includes passenger rail in this analysis, so the impact of this funding is somewhat larger than if it were only applied to SL&R freight railways.

Figure 17: SL&R GHG emissions in the Incentives Scenarios



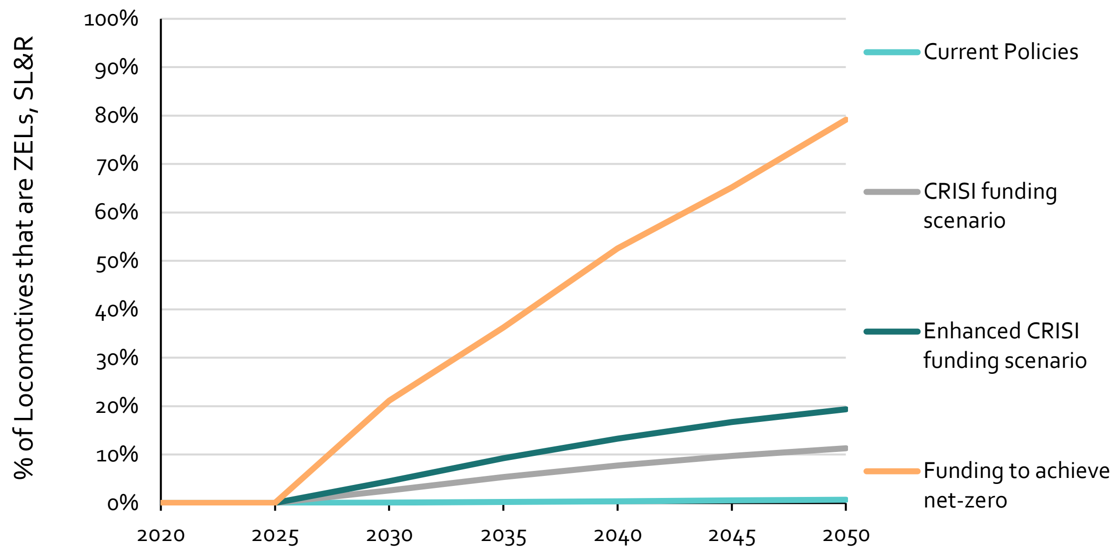
The GHG impacts are the result of ZEL adoption, which by 2050 will reach:

- 11% of SL&R locomotives with the CRISI Funding
- 19% of SL&R locomotives with the Enhanced CRISI Funding
- 83% of SL&R locomotives with the Funding to Achieve Net-Zero

This is highlighted in Figure 18 below. Note that ZELs reach just 1% in the Current Policy scenario.

The GHG impacts of the Incentive Scenarios are not proportional to ZEL adoption since the funding applies to both switcher and line-haul locomotives. Because line-haul locomotives generate more GHG emissions on a per-unit basis, a given rate of line-haul ZEL adoption will produce a proportionally greater GHG reduction than the same rate of ZEL adoption amongst switcher locomotives.

Figure 18: Percentage of SL&R Locomotives that are ZELs by segment



The impacts of the Incentive Scenarios are uncertain because the investment behaviour and capacity of SL&R railways is uncertain. As discussed previously, based on anecdotal information we assume the SL&R segment can make investments with a 2-to-2.5-year payback period. However, the acceptable payback period could be more or less than we have assumed, which will influence the results discussed here.

4.4. Impact of Policies on Rail Transportation Costs

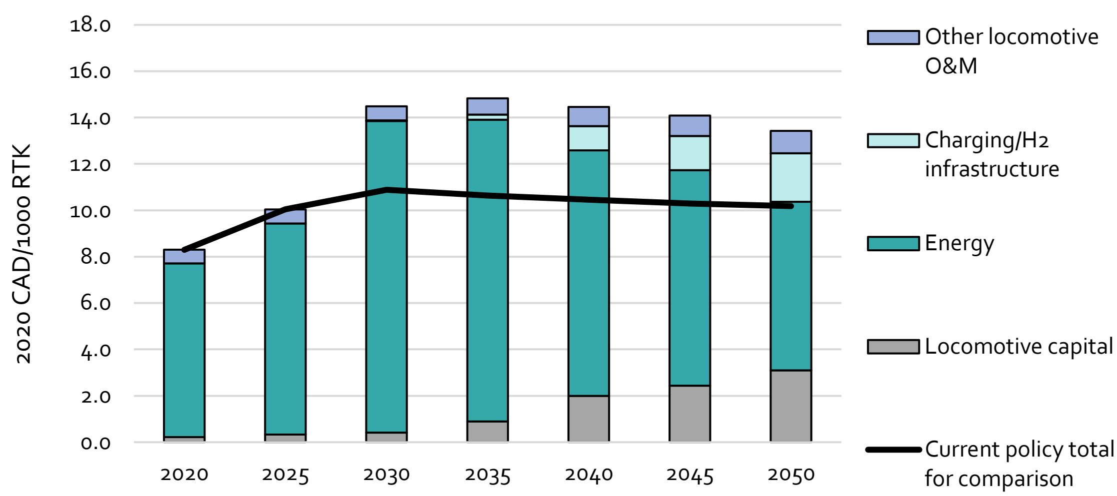
The results also include levelized rail transportation costs. Levelized costs show capital costs, energy costs (including the levelized cost of electric charging or hydrogen refuelling), and other operating and maintenance costs expressed on a per-activity basis ($/1000 RTK). This metric allows a consistent basis of comparison across all years and scenarios, even if rail transportation activity differs. To properly interpret the "Locomotive capital" portion of these costs, not that:

- "Locomotive capital" represents capital annuities, i.e. annual payments on capital, for locomotives acquired during the forecast (i.e. from 2016 to 2050). It does not account for capital acquired before the forecast, so it is not a full accounting of levelized locomotive capital costs. Nonetheless, when "existing" capital (acquired before the forecast) is retired, this analysis will show the additional capital cost to replace it. Therefore, the difference between scenarios is the most meaningful result since it will show how different policy paths change the magnitude and timing of capital costs.

- Capital expenditures are amortized over 30 years at a 7% discount rate.[23] These expenditures persist over the amortization period whether the capital stock is still in use or retired, so the analysis will account for how early retirement of locomotives will increase capital costs.
- Capital expenditures are not net of the CRISI funding or other incentives. Therefore, they show the full cost to the rail sector and government, not just the cost to the rail sector.

Compared to the Current Policy scenario, The GHG Pathway scenarios (e.g., DOE Milestones, shown in Figure 19) have higher capital costs and higher charging/hydrogen fueling infrastructure costs since there is a switch to ZELs. These scenarios result in higher energy costs since the sectoral and national net-zero requirements result in a rising cost of carbon on fossil diesel fuel. Furthermore, these scenarios also drive significant demand for low-carbon fuels such as renewable diesel, which in turn drives up their price as well. The cost difference in a GHG pathways scenario tends to remain stable or even decline over time as ZEL adoption reduces energy costs (Figure 19).

Figure 19: Rail sector levelized costs in the DOE Milestones Scenario (columns) vs. the Current Policy Scenario (black line)

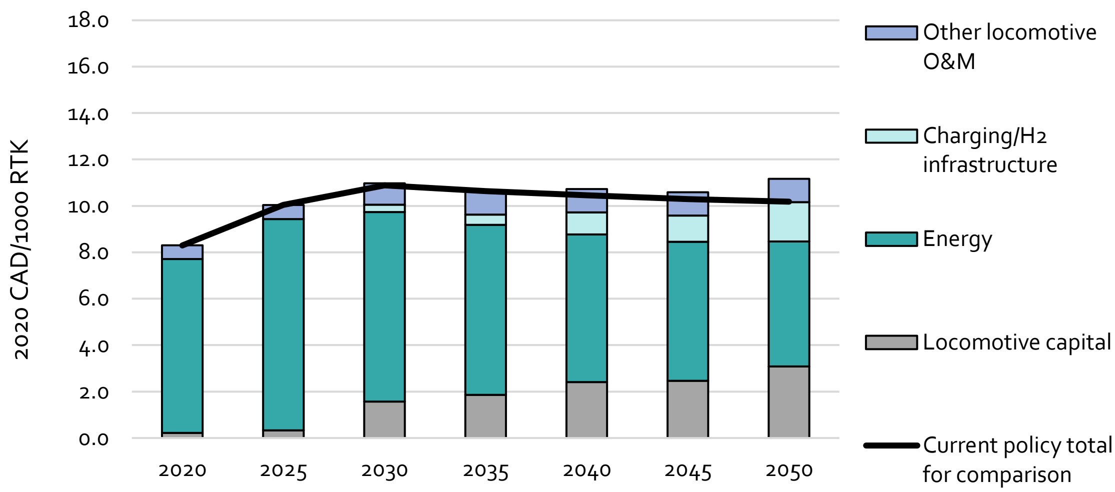


Fleet renewal scenarios (e.g. California-style, shown in Figure 20) also have higher capital costs and charging/hydrogen refueling infrastructure costs than in the Current

[23] 7% is the opportunity cost of capital prescribed by Treasury Board of Canada Secretariate for federal cost benefit analyses: Treasury Board of Canada Secretariate, Canada's Cost-Benefit Analysis Guide for Regulatory Proposals

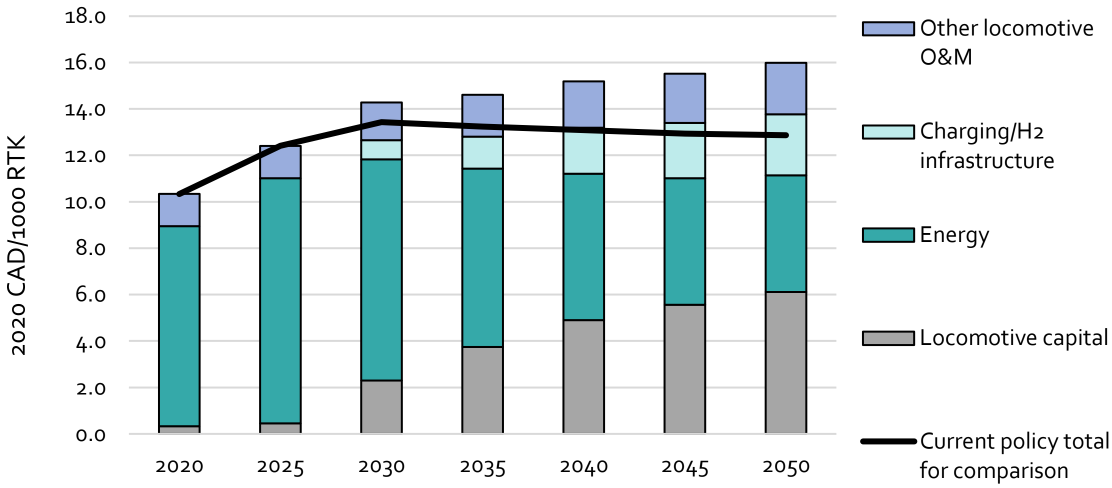
Policy scenario since there is a switch to ZELs. However, this additional cost tends to be cancelled out by lower energy costs since ZEL adoption results in less energy consumption. Furthermore, both the price of fossil diesel and low-carbon alternatives tend to be stable after 2030 because these scenarios do not have a net-zero requirement (the carbon price does not rise, nor does demand for low-carbon fuel).

Figure 20: Rail sector levelized costs in the California-Style Fleet Renewal Scenario (columns) vs. the Current Policy Scenario (black line)



The scenarios that include funding for SL&R railways also have higher costs than in the Current Policy scenario (e.g., in the Funding to Net-Zero scenario in Figure 21). However, in those scenarios, the government bears the additional cost rather than the railways. In the Current Policy scenario, the levelized costs of SL&R railways are dominated by energy costs. In contrast, the proportion of levelized costs from energy declines in the funding scenario, while the proportion from capital increases.

Figure 21: SL&R levelized costs in the Funding to Net-Zero Scenario (columns) vs. the Current Policy Scenario (black line)



4.5. Limitations and Opportunities for Future Work

Table 8 summarizes the limitations of this analysis that exist due to the current capacities of Navius' energy-economy model, gTech, and the time and budget available for this study. These limitations could be addressed with additional model development and analysis. Therefore, each of them is paired with a brief explanation of how this methodology could be improved in a future project.

Table 8: Limitations of this analysis and opportunities for future work

Limitation	Opportunities for Future Work
Technological uncertainty related to availability of ZELs and other technological pathways is not included in the analysis.	Ongoing technology research and updates, integrated with engagement with stakeholders and other researchers. Testing the sensitivity of the results to varying dates for commercial availability.
Lack of quantification of CACs/Air Pollution and testing of CAC policies.	Add CAC emissions factors to each technology archetype and test the impact of policies on CAC emissions. Add the capability to price CAC emissions with different methods for revenue recycling.
Passenger rail is not represented as its own segment.	Build this out as a sector in the model, complete with technology archetypes. This allows for exploration of policies and opportunities specific to passenger rail.
Mode shift between rail and truck and carbon leakage to the U.S. is not represented.	Add a representation of competition between truck and rail transport, as well as competition between Canadian and U.S. rail carriers in the gTech model. Test how asymmetric or symmetric climate policies impact rail and truck transport within Canada and the U.S.
The investment behaviour of railways is uncertain.	Use survey work and "choice modeling" to systematically define the range of investment behaviours and capacities amongst railways. Could conduct a sensitivity analysis examining how sensitive the results are to different discount rates.
Depth of cost analyses	Do further analysis of how policies affect rail sector levelized costs and connect this with changes in sector GDP, investment, fuel and operating costs, and national GDP.
Additional policy and sensitivity scenarios could be tested.	Test additional variations on fleet renewal (perhaps differentiating by rail segment and Tier). Test the interaction of fleet renewal policies with carbon pricing and the Clean Fuel Regulations. Test different definitions of "net-zero" and how the rail sector might interact with offset opportunities, i.e. opportunities for carbon dioxide removal in the rest of the economy.

5. Summary and Conclusion

This section summarizes the key insights and conclusions provided in this analysis, organized by the policy scenario groups.

GHG Pathway Scenarios

- With current policies, the rail sector will not achieve a level of GHG emissions that is consistent with current Canadian GHG targets and commitments.
- However, with strong climate policies constraining the rail sector's GHG emissions, the rail sector can achieve deep emissions reductions and transition towards net-zero. This will likely be achieved using a combination of low-carbon fuels (i.e., biodiesel and renewable diesel) and ZELs.
- The adoption of ZELs drives down total liquid fuel demand in the rail sector over time and tempers demand for low-carbon fuels in a net-zero future. By 2050, low-carbon fuels in the GHG Pathways scenarios may account for over 80% of liquid fuel consumption in the sector (up from 40 to 50% in 2030). While the percentage of low-carbon fuel within total liquid fuel doubles over that period, the absolute quantity (PJ per year) of that fuel may only grow by 20%.
- ZEL adoption starts in earnest after 2035 and is concentrated in Class I line-haul, increasing to 30% in 2040 and 55% in 2050. ZELs account for roughly one-third of locomotives in 2050 in the GHG Pathways scenario. However, because ZELs are concentrated in line-haul service, they carry proportionally more RTKs and have a proportionally larger impact on GHG emissions.
- There are almost no ZELs adopted in switchers in the GHG Pathways scenarios. This is a simulated economic decision that is a consequence of their relatively low utilization, compared to a line-haul locomotive. Therefore, it is likely that a GHG cap or carbon pricing is not enough to drive ZEL adoption in switchers and may have little impact on the CAC emissions produced in rail yards.
- There is a role for both electric and fuel-cell line-haul locomotives in a net-zero future, as they account for a significant portion of locomotives in many of the scenarios. Note that there is significant technological uncertainty related to when ZELs will be commercially available and how their charging or fuelling network might evolve. Furthermore, other ZEL archetypes not included in this analysis, such as hydrogen combustion or catenary-electric, could also play a role in the rail sector.

- The fleet renewal rate required to achieve the amount of ZEL adoption seen in the GHG Pathways scenarios is significantly higher than under current policies (e.g. from 2035 to 2045, the rate of renewal may be 1.7 to 2.8x higher than it would be with current policies). Adding fleet renewal requirements, as in the DOE Rail Milestone scenario, may both advance and increase the periods of peak fleet renewal.
- In the GHG Pathways scenarios, the cost of rail transportation is higher compared to the Current Policy scenario. This is because the sector experiences high energy costs, which occur due to increasing carbon costs on diesel fuel and the increased use of low-carbon fuels. Additionally, the sector incurs higher capital costs since it is investing in ZELs in response to stronger climate policy.

Fleet Renewal Scenarios

- Fleet Renewal policies that require Tier 4 locomotives yield modest GHG benefits (emissions are around 20% lower than under current policies), even if the design of these policies is geared towards reducing air pollution. This GHG impact occurs because they accelerate the adoption of ZELs (in switchers) while also accelerating the rate at which older and less efficient locomotives are retired.
- The delayed application of Tier 4 fleet renewal policies to SL&R railways may result in modest additional GHG abatement, relative to a scenario where these railways are exempted from new policies.
- In contrast, the Fleet Renewal policies that require ZEL adoption for line-haul service result in substantial GHG reductions relative to the Current Policy scenario. Omitting SL&R railways from these policies has a modest impact on total sector GHG emissions (GHG impact is about 15% less than it would be if SL&R were included). Delaying the fleet renewal ZEL requirements by five years results in a similar delay in the GHG impact of the policy throughout the forecast.
- Requiring fleet renewal amongst switchers may result in substantial ZEL adoption within Class I railways, even if ZELs are not specifically required. This is because requiring older locomotives to be replaced with Tier 4 compliant units (either new or repowered) raises the cost of diesel locomotives and significantly reduces the incremental cost of zero-emissions switcher locomotives.
- All Fleet Renewal Policies produce peaks in the “locomotive renewal rate” that are well above what occurs in the current policy scenario. These peaks in renewal rate will likely begin in advance of the policy in-force date as railways may seek to mitigate their initial investment in ZELs. For example, there can be significant

adoption of new Tier 4 locomotives in the years before a fleet renewal requirement begins. This wave of renewal before the policy in-force date adds a group of diesel locomotives to the fleet that will not need to be replaced for the next 25-35 years (policy dependent), deferring the near-term need to buy ZELs.

- The Fleet Renewal Policies cause peaks in the renewal rate because they impose a maximum age for in-use locomotives, many of which are already over this age when the policies come into force. Even if the maximum age and in-force date vary by railway type (Class I vs. SL&R) and service type (line-haul vs. switcher), it still causes a significant wave of retirement because locomotive fleets are generally old. Mitigating the peaks in the renewal rate caused by Fleet Renewal Policies might also require differentiating maximum ages and policy in-force dates by Tier or vintage as well as by railway type and service type.
- In the Fleet Renewal scenarios, the cost of rail transportation is similar to the Current Policy scenario. Because the Fleet Renewal scenarios require earlier locomotive retirement and greater investment in ZELs, the sector's capital costs are higher than in the Current Policy scenario. However, this additional capital cost is offset by lower energy costs resulting from increased ZEL adoption.

Incentive Scenarios

Because SL&R railways emit only 6-7% of total rail sector GHG emissions, incentives for these railways to acquire ZELs have a limited impact on total rail sector GHG emissions (1-7% by 2050). However, the impact on SL&R emissions can be substantial. By 2050:

- The CRISI funding ($21 million per year after 2026) results in 11% ZEL adoption, and reduces SL&R GHG emissions by about 13% relative to current policies.
- The Enhanced CRISI funding ($42 million per year after 2026) results in 19% ZEL adoption and reduces SL&R GHG emissions by about 24% relative to current policies.
- The Funding to Achieve Net-Zero ($275 million per year after 2026) results in 83% ZEL adoption and reduces SL&R GHG emissions by about 91% relative to current policies.
- However, the impact of this funding is uncertain because the investment behaviour and capacity of SL&R railways is uncertain.

- The levelized cost of SL&R rail transportation is higher in the Funding Scenario than in the Current Policy scenario, though the government bears the additional cost rather than the railways. Because the funding drives additional ZEL adoption, capital becomes a proportionally larger part of the levelized cost structure, while energy costs become proportionally smaller.

Appendix A: Additional Assumption Detail

Detailed Locomotive Technology Assumptions

Energy Intensity, Average Life, and Utilization

Table 9: Locomotive technology archetype energy intensity, GJ/1000 RTK

	Class 1 line-haul , GJ/1000 RTK	SL&R line haul, GJ/1000 RTK	Switcher, GJ/MWh	Notes and sources
Existing locomotive stock in the model base year (2015): Tier 0 and untiered, Tier 1, Tier 2 &3	0.24	0.27	0.079	Fuel may be a blend of fossil diesel, biodiesel and renewable diesel. The energy intensity of the base year stock is calibrated to freight rail activity and total emissions from all rail segments (i.e., passenger rail emissions are captured within an archetypal representation of freight rail). We assume new and repowered Tier 4 locomotives have a 17% reduction in energy intensity relative to average existing stock based on notional improvements in combustion engines, switch from DC to AC traction motors, and control systems. The difference between Class I line-haul, SL&R line-haul and switcher energy intensity is based on US EPA (2009).[24]
New or repowered to Tier 4 diesel	0.20	0.23	0.065	
Fuel cell electric	0.12	0.13	0.025	Based on an energy efficiency ratio (EER) of 1.3 for line-haul used by CARB (2013)[25] and an EER of 1.55 for switchers (Argonne, 2019)[26]
Battery electric	0.15	0.17	0.013	Based on an EER of 2.2 for switchers used by CARB (2013) and 1.7 for line-haul used by Popovich et al. (2021)[27]

[24] US Environmental Protection Agency (2009) Office of Transportation and Air Quality EPA-420-F-09-025, Emission Factors for Locomotives

[25] California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

[26] Argonne National Laboratory (2019). Total Cost of Ownership for Line Haul, Yard Switchers and Regional Passenger Locomotives - Preliminary Results

[27] Natalie D. Popovich, Deepak Rajagopal, Elif Tasar, and Amol Phadke (2021). Economic, environmental and grid-resilience benefits of converting diesel trains to battery-electric. Nature Energy, VOL 6, November 2021, 1017–1025. https://doi.org/10.1038/s41560-021-00915-5

Average locomotive lifespan and utilization are based on data from the Railway Association of Canada (RAC).[28] Specifically, we used the year of manufacture listed for each locomotive by segment in the Canada fleet noted in appendices B1 through B3 in the Locomotive Emissions Monitoring Report. That year is given as a range for each locomotive, so we used an average of that range. We then defined the age profile of the fleet in 10-year intervals and calibrated our model's retirement function to match that profile (minimizing the sum of squared differences) (see Figure 22: Fitting our model to locomotive age data, Class I line-haul).

The resulting average lifespan for Class I line-haul locomotives is 30 years, meaning about half of locomotives leave this fleet 30 years after their date of first manufacture (some will leave sooner and some later, e.g., 10% of locomotives retire after 25 years, while another 10% retire after 35 years). In this case, leaving the fleet could be being retired, sold to another fleet (e.g., SL&R) or put into switcher duty. Note that the model is not specific about why a locomotive leaves a fleet, nor does it explicitly track the movement of locomotives from between different segments.

The average lifespan assumptions for other segments are:

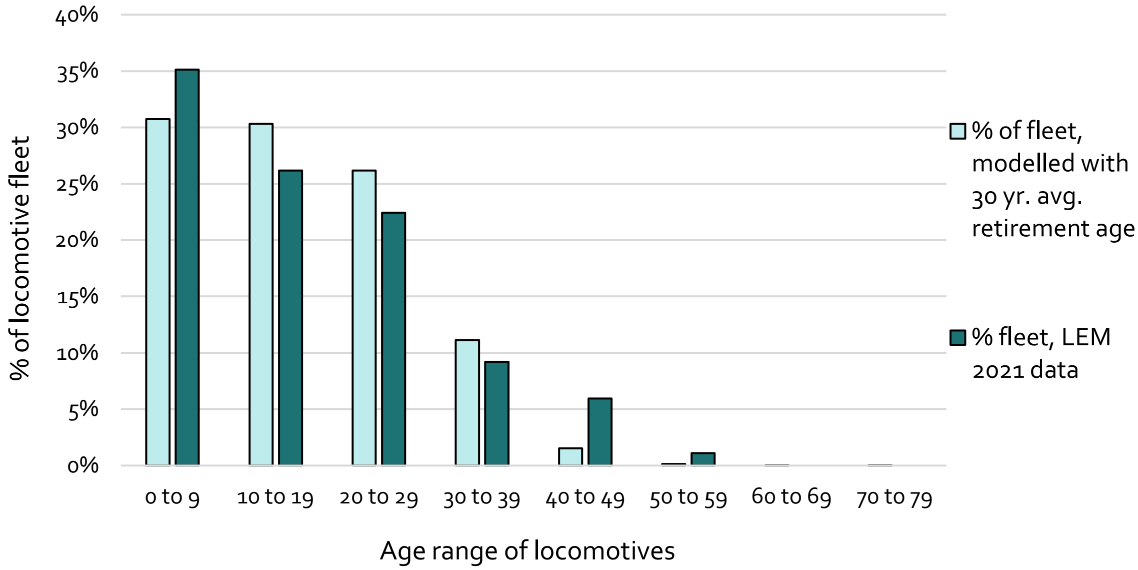
- 65 yrs, SL&R line-haul
- 80 yrs, Class I and SL&R switchers

Average locomotive utilization is defined by freight activity in each segment divided by the population of locomotives over the past decade (2012 to 2021). Average utilization is:

- 209,000 million RTK/yr for Class I line-haul
- 79,000 million RTK/yr for SL&R line-haul
- 300 MWh/yr for switchers (or averaging about 200 kW over 18% of annual hours, energy equivalent to 12,100 million RTK/yr)

[28] Railway Association of Canada (2023). Locomotive Emissions Monitoring Report 2021

Figure 22: Fitting our model to locomotive age data, Class I line-haul



Locomotive Capital Costs by Segment

Table 10: Class I Line-haul locomotive technology archetype capital costs, 2020 CAD, (note, only reference costs are used in this analysis)

	Cost in 2020	Lowest possible cost in:			Notes and sources
		High cost-assumptions	Reference assumptions	Low-cost assumptions	
Used Tier 0 or less	n/a	n/a			Tier 0 and untiered generally have not been added to the Class I line-haul fleet since 2015
Used Tier 1	$2,771,243	Same			Discount of roughly 1,000,000 for like-new used locomotives, based on CARB (2016)[29]
Used Tier 2 or 3	$2,771,243	Same			
New Tier 4 diesel	$3,875,324	Same			Based on CARB (2023)[30]
Repowered to Tier 4 diesel	$2,457,684	Same			
Fuel cell electric	$10,311,652	$9,560,965	$6,179,008	$5,797,689	
"Glider" & other components	$3,766,910	$3,766,910	$3,766,910	$3,766,910	3,200 kW fuel cell, with current and lowest costs based on Argonne (2019)[31]
Battery	$40,217	$16,265	$11,777	$9,705	
Fuel cell	$1,240,034	$586,820	$343,462	$196,404	
Liquid hydrogen tender	$5,264,490	$5,190,970	$2,056,859	$1,824,669	Current and lowest tank costs based on Argonne (2019). Assuming 8000 kg liquid H_2 in one tender for every two locomotives.
Battery electric	$25,116,818	$12,547,924	$10,137,326	$9,029,778	Capital includes a 1.14 factor to account for lost RTK when hauling battery tenders
"Glider" and other components	$3,721,833	$3,721,833	$3,721,833	$3,721,833	Based on new diesel net of engine cost from Argonne (2019)
Battery	$20,930,059	$8,464,684	$6,128,790	$5,050,951	51,000 kWh battery in three tenders per locomotive, with a 40% component integration and sales margin added to the cost
Motors, electronics	$464,925	$361,406	$286,703	$256,994	3,200 kW locomotive, with a 40% component integration and sales margin added to the cost

Note that repowering an existing locomotive to be a fuel cell or battery electric locomotive is possible within the model. The same cost savings that occurs for repowering to Tier 4 diesel also applies (about $1.4 million in 2020 CAD).

29 California Air Resources Board (2016). Technology Assessment: Freight Locomotives

30 California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

31 Argonne National Laboratory (2019). Total Cost of Ownership for Line Haul, Yard Switchers and Regional Passenger Locomotives - Preliminary Results

Table 11: SL&R Line-haul locomotive technology archetype capital costs, 2020 CAD, (note, only reference costs are used in this analysis)

	Cost in 2020	Lowest possible cost in:			Notes and sources
		High cost-assumptions	Reference assumptions	Low-cost assumptions	
Used Tier 0 or less	$2,771,243	Same			Discount of roughly 1,000,000 for like-new used locomotives, based on CARB (2016)[32]
Used Tier 1	$2,771,243	Same			
Used Tier 2 or 3	$2,771,243	Same			
New Tier 4 diesel	$3,875,324	Same			Based on CARB (2023)[33]
Repower to Tier 4 diesel	$2,457,684	Same			
Fuel cell electric	$6,075,391	$5,375,586	$4,347,184	$4,139,384	
"Glider" & other components	$3,478,440	$3,478,440	$3,478,440	$3,478,440	3,200 kW fuel cell, with current and lowest costs based on Argonne (2019)[34]
Battery	$40,477	$16,370	$11,852	$9,768	
Fuel cell	$1,248,029	$590,604	$345,676	$197,670	
Liquid hydrogen storage	$1,308,445	$1,290,172	$511,215	$453,506	Current and lowest tank costs based on Argonne (2019). Assuming 988 kg liquid H_2.
Battery electric	$17,994,808	$9,575,762	$7,945,376	$7,197,616	Capital includes a 1.08 factor to account for lost RTK when hauling battery tenders
"Glider" and other components	$3,581,175	$3,581,175	$3,581,175	$3,581,175	Based on new diesel net of engine cost from Argonne (2019)
Battery	$13,970,310	$5,649,973	$4,090,820	$3,371,388	35,700 kWh battery in two tenders per locomotive, with a 40% component integration and sales margin added to the cost
Motors, electronics	$443,324	$344,614	$273,382	$245,053	3,200 kW locomotive, with a 40% component integration and sales margin added to the cost

Note that repowering an existing locomotive to be a fuel cell or battery electric locomotive is possible within the model. The same cost savings that occurs for repowering to Tier 4 diesel also applies (about $1.4 million in 2020 CAD).

32 California Air Resources Board (2016). Technology Assessment: Freight Locomotives

33 California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

34 Argonne National Laboratory (2019). Total Cost of Ownership for Line Haul, Yard Switchers and Regional Passenger Locomotives - Preliminary Results

Table 12: Class I and SL&R switcher locomotive technology archetype capital costs, 2020 CAD, (note, only reference costs are used in this analysis)

	Cost in 2020	Lowest possible cost in:			Notes and sources
		High cost-assumptions	Reference assumptions	Low-cost assumptions	
Repowered Tier 0 or less	$240,690	Same			We assume lower-tier locomotives may join the switcher fleets from line-haul fleets. Cost is set based on lower-tier repowering from CARB (2023)[35]
Repowered Tier 1	$391,397	Same			
Repowered Tier 2 or 3	$542,104	Same			
New Tier 4 diesel	$3,375,175	Same			Based on CARB (2023)[36]
Repower to Tier 4 diesel	$1,957,535	Same			
Fuel cell electric	$3,505,592	$3,250,383	$3,124,546	$3,075,206	
"Glider" & other components	$2,963,358	$2,963,358	$2,963,358	$2,963,358	1,500 kW fuel cell with a similarly sized battery, with current and lowest costs based on Argonne (2019)[37]
Battery	$136,792	$55,322	$40,056	$33,011	
Fuel cell	$327,759	$155,105	$90,782	$51,912	
Compressed hydrogen storage	$77,683	$76,598	$30,351	$26,925	Current and lowest tank costs based on Argonne (2019). Assuming 58 kg compressed H_2.
Battery electric	$4,253,830	$3,564,758	$3,412,782	$3,344,624	
"Glider" and other components	$2,976,563	$2,976,563	$2,976,563	$2,976,563	Based on new diesel net of engine cost from Argonne (2019)
Battery	$1,085,178	$438,876	$317,764	$261,881	3,000 kWh battery, with a 40% component integration and sales margin added to the cost
Motors, electronics	$192,090	$149,319	$118,455	$106,180	1,500 kW locomotive, with a 40% component integration and sales margin added to the cost

Note that repowering an existing locomotive to be a fuel cell or battery electric locomotive is possible within the model. The same cost savings that occurs for repowering to Tier 4 diesel also applies (about $1.4 million in 2020 CAD).

Hydrogen Supply

Hydrogen supply costs are the total of the production, transportation and distribution/refuelling costs. These costs vary by hydrogen supply pathway.

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35 California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

36 Ibid.

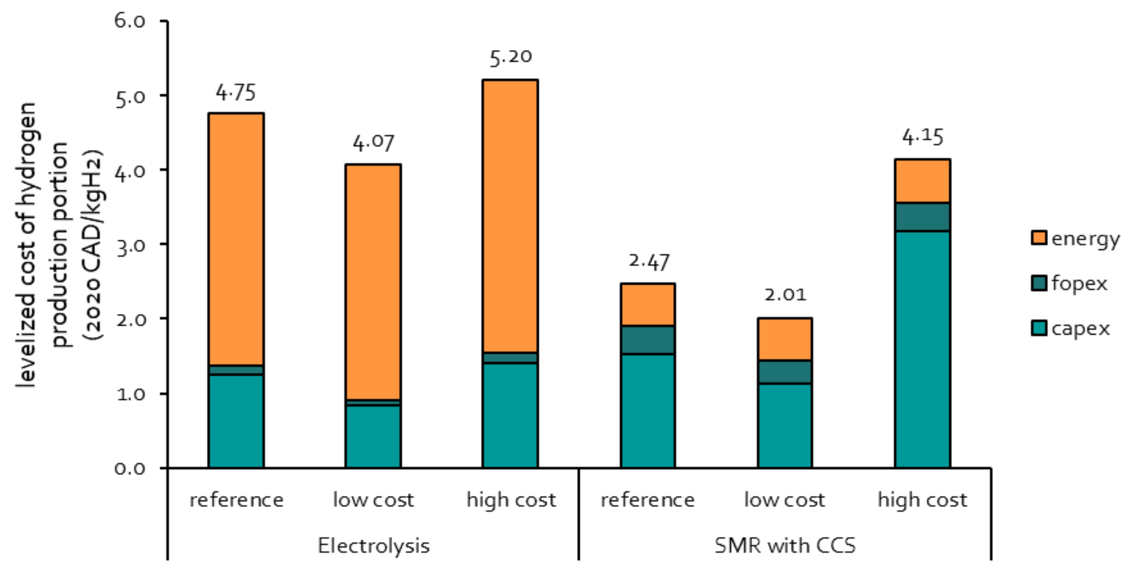
37 Argonne National Laboratory (2019). Total Cost of Ownership for Line Haul, Yard Switchers and Regional Passenger Locomotives - Preliminary Results

Production

gTech represents two low-carbon hydrogen production pathways - electrolysis and steam methane reforming with carbon capture and storage (SMR with CCS). The electrolysis technology parameters are based on IEA's "The Future of Hydrogen" report[38] and NREL's H2A Hydrogen Analysis Production Models[39]. The SMR with CCS technology parameters are based on the same reports as well as the GCCSI "Global Costs of Carbon Capture and Storage: 2017 Update" report[40].

provides the levelized cost of existing hydrogen production methods in gTech under reference, low, and high-cost assumptions. Costs are presented using a plant life of 30 years and a discount rate of 15%. Levelized costs depend significantly on energy costs which vary over time and from province to province. For this specific example, the natural gas price is assumed to be $3.0/GJ, electricity price $110/MWh, and electrolysis production electricity rate $70/MWh[41]. Note that energy costs are endogenous to the model and will change depending on the scenario.

Figure 23: Levelized hydrogen production costs for electrolysis and steam methane reformation (2020 CAD/kg H_2) **(note: reference costs are used in this analysis)**



[38] IEA. (2019). *The Future of Hydrogen*. Available from: https://www.iea.org/reports/the-future-of-hydrogen

[39] NREL. (2019). *H2A: Hydrogen Analysis Production Models*

[40] GCCSI. (2017). *Global Costs of Carbon Capture and Storage: 2017 Update.*

[41] 2020 CAD.

Transportation

We assume hydrogen produced via electrolysis occurs at the point of supply and requires no transportation via pipeline. In contrast, we assume hydrogen produced via SMR with CCS is a centralized process that also requires access to carbon storage, either directly or with a pipeline. Consequently, a pipeline is required to move the hydrogen from where there is access to carbon storage to its point of distribution. The cost the pipeline transportation is a function of distance and throughput based on IEA (2019) and Beaufume et al. (2012).[42]

The cost is relatively low in provinces with carbon storage (e.g., Alberta or Saskatchewan), on the order of $1 to 2/kg even with relatively low throughput. For other provinces, such as BC or Ontario, the cost of this transport is higher. At lower volumes of throughput (e.g., 5 to 10 PJ/yr), the cost is 3 to 5 $/kg of hydrogen (2020 CAD) but could fall to as low as 1 $/kg at higher volumes (e.g., 40-50 PJ/yr).

In practice, the forecasts generally show that hydrogen via electrolysis is the predominant supply pathway given the lower transportation costs at lower volumes. However, regions with good access to geological CO_2 storage, such as Alberta, may have hydrogen produced from natural gas with CCS.

Distribution and Refueling

The rail sector consumes liquid hydrogen. The capital cost for hydrogen liquefaction and dispensing is about $1/kg H_2.[43] This cost is based on a large-scale liquefaction plant, producing about 375,000 kg H_2 annually. This size of a plant could fuel about 100 locomotives and is consistent with the California Air Resource Board's assumption for the scale hydrogen refuelling infrastructure in the rail sector.[44]

Hydrogen liquefaction is an energy-intensive process. We assume it requires 0.28 GJ_{elec}/GJ_{H2} based on the 2020 energy intensity target for this process set by the US

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[42] IEA. (2019). The Future of Hydrogen

And

Beaufume S. et al. (2012). GIS-based scenario calculations for a nationwide German hydrogen pipeline infrastructure

[43] R. K. Ahluwalia, D. Papadias, and X. Wang (2020). U.S. DOE Hydrogen and Fuel Cells Program, Argonne National Laboratory: Rail and Maritime Metrics.

[44] California Air Resources Board (2022). Proposed In-Use Locomotive Regulation, Standardized Regulatory Impact Assessment (SRIA)

Department of Energy.[45] If electricity costs 9 cent/kWh, this adds about another $1/kg H_2 to the liquefaction cost of hydrogen. Therefore, total distribution and refuelling costs are about $2/kg H_2 in addition to the production and transmission costs.

Low-Carbon Fuel Supply

Table 13 contains examples of the production costs for the archetypal low-carbon renewable fuel pathways included in gTech, derived from model inputs. Biodiesel, renewable diesel from canola seed and renewable diesel from biomass are the three fuels that are most relevant to this analysis of the rail sector.

The capital cost portion of the fuel production costs is calculated using a 15% annuity (i.e., a 15% discount rate with a 30-year project life). Operating costs include labour, natural gas, electricity, maintenance and operation costs. These costs are examples based on gTech inputs using feedstock prices typical of 2022/2023. Because feedstock costs may vary during a simulation, these costs are not necessarily the costs that result in the forecast in any given year.

Note that gTech is a long-term model and fuel production costs will not capture the volatility that may be present in fuel costs over the short-term, due to supply and demand imbalances for the fuel or feedstocks. For example, short-term renewable diesel supply constraints have likely driven up the price of that fuel between 2021 and 2023. However, high prices are encouraging more investment in production capacity which will in turn put downward pressure on the price.

Feedstock quantities are constrained because they are outputs of other sectors: Agricultural feedstocks are produced by the agriculture sectors and fuel producers will compete with other uses for these commodities, which are produced from a finite amount of land. Lignocellulosic feedstocks (wood and grassy material) in gTech are agriculture residue and forestry residue and their supply is constrained by activity in the agriculture and forestry sectors. Note that the renewable gasoline and diesel fuel archetypes serve as a placeholder for the thermochemical conversion of biomass to fuels, either in standalone processes or through the co-production of gasoline and diesel from crude and biocrude.

[45] US Office of Energy Efficiency and Renewable Energy, DOE Technical Targets for Hydrogen Delivery

Table 13: Examples of typical gTech liquid bio-energy production costs, based on modeling assumptions (2020 CAD)

	Ethanol from corn	Biodiesel from canola	Renewable diesel from canola seed	Ethanol from biomass (cellulosic)	Renewable gasoline and diesel from biomass
Feedstock, $/t	325*	919*	919*	84*	84*
Co-product $/t	306	554	554	n/a	n/a
Capital, $/GJ	4.4	2.5	4.8	22.8†	37.0†
Operating, $/GJ	4.5	4.6	3.1	9.0	10.9
Feedstock, $/GJ	34.9	54.6	56.5	8.8	6.1
Co-product, $/GJ	-9.5	-18.8	-19.5	-2.7**	0.0
Total, $/GJ	**34.4**	**42.9**	**44.9**	**37.9**	**53.9**
MJ/L	23.6	35.4	36.5	23.6	35.6
Total, $/L	**0.81**	**1.52**	**1.64**	**0.90**	**1.92**

* Feedstock costs are an example similar to 2022 prices. However, feedstock costs are simulated and may vary from the values shown here.

** The co-product of cellulosic ethanol is electricity, produced from combustion of by-product lignin, calculated based on an electricity price of $85/MWh.

†These capital costs use the reference assumptions. Across the scenarios in this analysis, these capital costs may vary by +/- 25% (+/- 0.13 $/L for cellulosic ethanol; +/- 0.33 $/L for renewable gasoline and diesel from)

Capital and operating costs are based on APEC (2010), IRENA (2013), and Jones et al. (2013).[46,47,48]. Energy inputs, feedstock inputs and yields are based on inputs to the GHGenius model. V4.03a.[49,50]

The availability of lignocellulosic feedstock, as a function of the residue produced from agriculture and forest harvest, is based on Agriculture and Agri-Food Canada. (2017), Statistics Canada, Yemshanov et al. (2014) and the National Forestry Database.

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[46] Asia Pacific Economic Cooperation (2010). Biofuel Costs, Technologies and Economics in APEC Economies, APEC Energy Working Group.

[47] International Renewable Energy Agency (IRENA) (2013). Road Transport: The Cost of Renewable Solutions.

[48] Jones, S., Meyer, P., Snowden-Swan, L., Padmaperuma, A., Tan, E., Dutta, A., Jacobson, J., Cafferty, K., 2013, Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels Fast Pyrolysis and Hydrotreating Bio-oil Pathway, National Renewable Energy Laboratory

[49] GHGenius 4.03a lifecycle analysis model, (S&T)² Consultants, www.ghgenius.ca

[50] (S&T)² Consultants Inc. (2012). Update of Advanced Biofuels Pathways in GHGenius.

[51,52,53,54] The resulting quantity of feedstock available on a per $ of agricultural or forestry output basis is also applied to the US region of the model. Thus, both Canada and the US may produce these feedstocks (as well as agricultural feedstocks like soy or canola oil) and low-carbon fuels for trade or domestic consumption.

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[51] Agriculture and Agri-Food Canada. (2017*). Biomass Agriculture Inventory Median Values*. Available from: www.open.canada.ca

[52] Statistics Canada, CANSIM 001-0017.

[53] Yemshanov et al. (2014). Cost estimates of post harvest forest biomass supply for Canada*, Biomass and Bioenergy, 69, 80-94.*

[54] Government of Canada, National Forestry Database, accessed May 28, 2018.

Appendix B: Additional Policy Details

This summary of the California In-use Locomotive Regulation highlights the aspects of this policy that are most relevant to this analysis. The final proposed regulation is available from the California Air Resources Board here. As well, the International Council on Clean Transportation published a policy summary available here.

The regulation applies to all locomotive operators that operate locomotives in California. It distinguishes between several different types of locomotives including freight line-haul locomotives, switch locomotives, industrial locomotives, passenger locomotives, and historic locomotives.

The regulation applies several operational requirements to these locomotives that are highly relevant to this analysis:

- As of January 1st, 2030, locomotives with an original build date 23+ years earlier may not operate in California unless they can operate in zero-emissions configuration at all times. However, if a locomotive is repowered to be compliant with the most stringent air emissions regulations (i.e., is Tier 4 compliant), the date of that repowering becomes its effective build date.
  - This part of the policy creates a 23-year retirement requirement for conventional diesel-fuelled locomotives unless they are repowered to be Tier 4 compliant. This repowering essentially “resets” the age of a locomotive and it could operate for another 23 years.
- As of January 1st, 2030, any switch, passenger, or industrial locomotives with a build date of 2030 or newer must be able to operate in zero-emissions configuration in California at all times.
  - This clause effectively creates a ZEL sales requirement for a segment of the rail sector. Starting in 2030, all new switch, passenger, or industrial locomotives must be ZELs.
- That requirement is extended to line-haul locomotives starting January 1st, 2035.
- Alternatively, locomotive operators may follow a compliance plan where they achieve specified targets for the proportion of their fleet operating in California that are Tier 4 compliant and operate in ZEL configurations.

The regulation also creates:

- A registration requirement for locomotive operators and each of their locomotives.
- A 30-minute limit on locomotive idling, unless required for safety or to prevent damage to equipment.

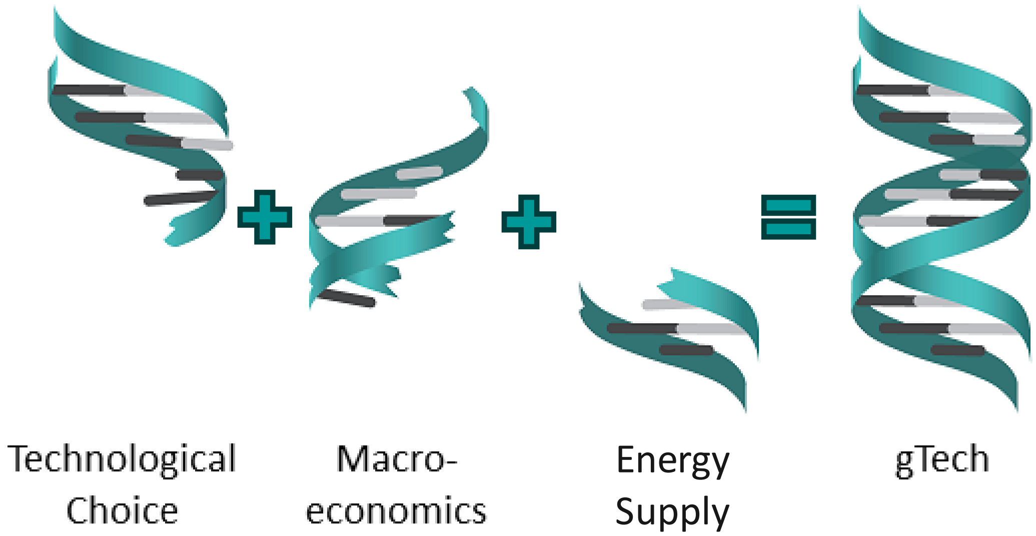
A spending account, funded by each locomotive operator and to be used to purchase ZELs or ZEL infrastructure. The funding requirement for an operator's spending account is a function of the NOx and PM emissions of that operator's locomotives, starting on July 1st, 2026.

Appendix C: Detailed Description of the gTech Model

Overview

Navius maintains and operates an in-house computable general equilibrium (CGE) model of Canada and the United States called gTech. By being an energy-economy model that treats all actions as happening simultaneously, gTech performs well at capturing policy interactions. However, unlike other energy-economy models, gTech incorporates a sophisticated representation of technological change and technological choice (see “Technological Change”) within a full economic equilibrium framework that represents all key economic transactions and feedbacks (see “Macroeconomic feedbacks”). gTech was developed from three earlier models used by Navius, combining their best elements into a comprehensive, integrated framework. The representation of technological choice in gTech came from the CIMS model, macroeconomic feedbacks from the GEEM model, and energy supply from OILTRANS. The three key elements that were brought together to create gTech are illustrated in Figure 24.

Figure 24: Origin of the gTech model



Model Calibration

To characterize the energy-economy of Canada and the United States, gTech is calibrated to a variety of data sources, including:

- Environment and Climate Change Canada's National Inventory Report[55]
- Statistics Canada's Supply-Use Tables[56]
- Natural Resources Canada's Comprehensive Energy Use Database[57]
- Statistics Canada's Annual Industrial Consumption of Energy Survey[58]
- Statistics Canada's Report on Energy Supply and Demand[59]
- Navius' technology database
- Canada's Energy Future 2021[60]

55 Environment and Climate Change Canada. National Inventory Report.
56 Statistics Canada. Supply and Use Tables.
57 Natural Resources Canada. Comprehensive Energy Use Database.
58 Statistics Canada. Annual Industrial Consumption of Energy Survey.
59 Statistics Canada. Report on Energy Supply and Demand in Canada.
60 Canada Energy Regulator. (2021). *Canada's Energy Future 2021*.

- Statistics Canada datasets on the electricity sector[61]

Each data source is generated using different methods; therefore, the sources are not necessarily consistent with one another. For example, expenditures on gasoline by households in Statistics Canada's Supply-Use tables may not be consistent with fuel consumption reported by Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

gTech's calibration routine places greater emphasis on some data sources relative to others. This approach means that gTech achieves near perfect alignment with data sources receiving the highest priority weight, but alignment starts to diverge from data sources that receive a lower weight.

For this project, the datasets that received the highest weight are:

- Revised Environment and Climate Change Canada's National Inventory Report
- Natural Resources Canada's Comprehensive Energy Use Database
- Navius' technology database
- Canada's Energy Future 2021

GHG emissions are calibrated in the model base year (currently 2015) to align with historical emissions. Between the base year and the most recent year for which data are available (2020 at the time of model calibration), modeled emissions are also calibrated to align with historical trends. The ability of gTech to replicate these trends improves confidence in its projections.

Questions gTech Can Answer

By incorporating an explicit and realistic representation of technological change into an equilibrium framework that links all the major macroeconomic feedbacks, gTech can provide extensive insight into the effects of climate and energy policy.

Because gTech explicitly represents technological change, the model can respond to questions such as:

[61] Statistics Canada. (n.d.). Electricity and Renewable Energy.

- What is the impact of a technology-focused policy, such as a vehicle emissions standard?
- How do policies affect the adoption of a particular technology?
- How does adoption of a technology affect GHG emissions and energy consumption?

In addition to being a technologically explicit model, gTech considers important non-financial influences on the technological choices of consumers and businesses. Therefore, it provides realistic insights, rather than insights into illustrative, hypothetical, or optimal situations.

Because gTech captures macroeconomic feedbacks in a CGE framework, the model can respond to questions such as:

- What is the impact of an economy-wide policy, such as a carbon price at the federal or provincial level?
- How do policies affect national and/or provincial gross domestic product (GDP)?
- How do policies affect individual sectors of the economy?
- How are households affected by policies?
- Do policies affect energy prices or any other price in the model, such as food prices?

Because gTech combines these features – incorporating an explicit representation of technological change within a CGE model – it can respond to questions such as:

- What are the effects of investing carbon tax revenue into low- and zero-carbon technologies?
- What are the macroeconomic impacts of technology-focused policies?

Macroeconomic feedbacks

CGE models are widely used by economists investigating the impact of GHG policy. Therefore, a general description of the GCE approach, its strengths, and its limitations is provided in “Introduction to CGE Models” below. The specific attributes of gTech as a CGE model are documented after that introduction.

Introduction to CGE Models

CGE models represent the economy through a series of simultaneous equations linking economic inputs with outputs. Their parameters capture aggregate relationships between the relative costs and market shares of energy and other inputs to the economy and may be estimated econometrically from time-series data. CGE models represent all economic activity and capture all the major macroeconomic feedbacks that balance supply and demand through price signals. They do so in a full equilibrium framework, solving for a set of prices that results in supply being equal to demand in every market.

In addition to parameter values, CGE models require data in the form of a social accounting matrix (SAM). The SAM describes all income and spending in an economy over a specified period, typically one year. It includes income and spending by households, firms, and governments. The matrix also records savings and investment spending and international trade. The SAM is normally based on information from official national accounts. Researchers must decide to what degree data are aggregated within the SAM, trading off the benefits of disaggregation for analysis of specific industries, for example, against the benefits of an aggregated database, which include ease of use and understanding[62].

CGE models are used to simulate the economy's response to a financial signal or "shock." When these models are applied to the problem of GHG emissions abatement, this signal would normally be in the form of an emissions tax or an emissions permit price that increases the relative cost of emissions-intensive technologies and energy forms. The magnitude of the financial signal necessary to achieve a given emissions reduction target indicates its implicit cost.

When an external shock such as a carbon tax is simulated, the model describes changes in the prices of and demand for different energy forms, impacts on prices and demand for other goods and services, and effects on employment and wages. CGE models can address not only demand from producers and households but also from government, investors, and foreign markets. These models are used to calculate macroeconomic indicators such as gross domestic product (GDP), aggregate savings

[62] Loschel, A. (2002). Technological change in economic models of environmental policy: A survey. Ecological Economics, 43, 105-126. https://doi.org/10.1016/S0921-8009(02)00209-4

and investment, the balance of trade, and (in some cases) the fiscal position of government[63].

CGE models generally lack an explicit representation of technologies, including those that can potentially improve energy efficiency and/or reduce GHG emissions. Technological change tends to be represented as an abstract, aggregate phenomenon. Conventional CGE models are therefore only able to help policy makers assess economy-wide policy instruments, such as taxes and tradable permits. Likewise, these models are unable to identify the specific changes that comprise the response of the economy to a shock.

When the parameters of a CGE model are based on historical data, the model can be said to provide a realistic representation of technological choice because it captures how people have responded to price changes in the past. This is the case even though the technologies themselves are not explicit. However, there is no guarantee that the values of the statistically estimated parameters will remain valid into the future under substantially different policies, energy prices, and technological options for GHG abatement[64,65,66].

These challenges in the field of CGE modeling motivated the developers of gTech to incorporate an explicit representation of technological change into the model. The treatment of technology stock turnover and technology choice in gTech is described in a following section, “Technological Change”.

Specific Attributes of gTech

gTech accounts for all economic activity in Canada and the United States, as measured by national accounts. Specifically, it captures all sector activity, all GDP, all trade of goods and services, and the transactions that occur among households, firms, and government. As such, the model provides a forecast of how government policy affects many different economic indicators including GDP, investment, trade,

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63 Burfisher, M. (2021). Introduction to computable general equilibrium models. In *Introduction to computable general equilibrium models* (pp. 9-24). Cambridge University Press. https://doi.org/doi:10.1017/9781108780063.002

64 DeCanio, S. J. (2003). *Economic models of climate change: A critique.* Palgrave Macmillan.

65 Grubb, M., Kohler, J., & Anderson, D. (2002). Induced technical change in energy and environmental modeling: Analytic approaches and policy implications. *Annual Review of Energy and the Environment, 27*, 271-308. https://doi.org/10.1146/annurev.energy.27.122001.083408

66 Laitner, J. A., DeCanio, S. J., Koomey, J. G., & Sanstad, A.H. (2003). Room for improvement: Increasing the value of energy modeling for policy analysis. *Utilities Policy, 11*, 87-94. https://doi.org/10.1016/S0957-1787(03)00020-1

household income, and employment. The key macroeconomic feedbacks captured by gTech are summarised in Table 14.

The key macroeconomic inputs to gTech are: (1) a social accounting matrix (SAM) used to characterize the structure of the economy in the model base year (currently 2015) and (2) forecasts of growth in labour supply and productivity. The SAM is based on Statistics Canada supply and use tables[67] and IMPLAN supply and use tables[68] for the United States. The expected rates of growth in labour supply and labour productivity are based on the Parliamentary Budget Office's Fiscal Sustainability Report[69] for Canada and the U.S. Energy Information Administration's Annual Energy Outlook[70]. gTech generates an internal forecast of economic growth from these growth rates, subject to policy and other conditions, such as the price of oil.

gTech is customizable in terms of the way North America is divided into regions. The version used for this analysis represents all the Canadian provinces separately, except for the Maritimes, which are aggregated together with the territories as a single region. In the United States, California is represented separately, and the rest of the country is modeled as a single region.

The model has a high degree of sectoral disaggregation, representing over 89 economic sectors. Each sector represented by gTech produces a unique good or service (e.g., the mining sector produces ore, while the trucking sector produces transportation services) and requires specific inputs to production. Of these inputs, some are not directly related to energy consumption or GHG emissions (e.g., the demand by a sector for services or labour), while other inputs are classified as "energy end-uses". The sectors, fuels, and energy end-uses covered by gTech in this analysis are listed in the final section of this appendix.

gTech normally solves in 5-year increments. While Navius has developed versions that solve in smaller time increments, 5-years is the default because the model simulates full equilibrium in all markets and is intended to capture long-term trends, as opposed to the short-term effects of business-cycles in which markets may be out of equilibrium. Solving in 5-year increments also reduces the amount of time required to complete analyses (relative to annual or biannual increments).

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[67] Statistics Canada (annual). *Supply and Use Tables.*

[68] IMPLAN, 2021, Customized supply-use tables.

[69] E.g., Parliamentary Budget Office, 2020 Fiscal Sustainability Report.

[70] U.S. Energy Information Administration, 2021, Annual Energy Outlook 2021.

Table 14: Macroeconomic feedbacks captured by gTech

Model feature	Description
Full equilibrium	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply of each good or service is equal to its demand). This means a shift that occurs in one sector is likely to have ripple effects throughout the entire economy. For example, greater demand for electricity due to GHG policy initiatives will require greater electricity production. In turn, greater production is expected to necessitate greater investment in and consumption of goods and services by the electricity sector. An increase in demand for labour in construction services could ultimately lead to higher wages. The model also accounts for price responses. In the above example, the price of electricity may increase, as more expensive generation resources are brought online to meet the increased demand. Households can adjust to this price increase by making changes that reduce their electricity consumption, such as switching to technologies that are more energy efficient, switching to technologies that use alternative forms of energy, and reducing their consumption of services that use electricity. They may even reduce their demand for unrelated goods and services.
Energy supply markets	gTech accounts for all the major energy supply markets, such as electricity, refined petroleum products, and natural gas. Each market is characterized by resource availability and production costs by region, as well as costs and constraints related to transporting energy between regions (e.g., pipeline capacity). Low carbon energy sources can be introduced within each market in response to policy, including renewable electricity and bioenergy. The model accounts for the availability and cost of bioenergy feedstocks, allowing it to provide insight about the economic effects of emissions reduction policy, biofuels policy, and the approval of pipelines. Oil price is an exogenous input to the model (i.e., based on an assumed global price). The price for other energy commodities is determined by the model based on demand and the cost of production.
Labour and capital markets	Like other markets, labour and capital markets must achieve equilibrium in the model. The availability of labour can change with the real wage rate (i.e., the wage rate relative to the price for consumption). If the real wage increases, the availability of labour increases. The model also accounts for "equilibrium unemployment".
Interactions between regions	Economic activity in each region represented in gTech is highly influenced by interactions with other modeled regions. These interactions are based on: (1) the trade of goods and services, (2) capital movements, (3) government taxation, and (4) various types of "transfers" between regions (e.g., the federal government provides transfers to provincial and territorial governments).

Model feature	Description
Representation of households	Households receive income from businesses in exchange for their labour and investment of savings. They use this income to consume various goods and services. gTech accounts for these interactions. Households are disaggregated into 5 different income groups within the model to provide greater insight into how policies might affect different households.

Technological Change

gTech contains detailed information describing the key technologies and processes that influence energy consumption and GHG emissions. The model currently includes almost 350 archetypal technologies across more than 60 energy end-uses and emissions sources (e.g., LDV travel, residential space heating, industrial process heat, management of agricultural manure). The energy end-uses covered by gTech in this analysis are listed in the final section of this appendix, "Covered Sectors, Fuels, Energy End-Uses and Sources of Emissions in gTech".

gTech keeps track of how stocks of technologies change over time. As older technologies reach the end of their lifespans, they are retired, and when new technologies are needed, gTech simulates how households and businesses choose between the available options (see "Technology Choice" below). The explicit representation of stock turnover in gTech allows technology stocks to improve in terms of their energy and emissions performance over time. If an emerging technology is included in the model database that is more energy efficient and/or uses an energy source with lower emissions than the conventional existing technology, and if this technology is attractive to households and businesses, then it will gain market share as stocks of the conventional technology retire. However, stock turnover is also a source of inertia with respect to meeting emissions targets, both in gTech and in the real world, because some technologies, such as electric power plants and pipelines, have long lifespans, and a cost is incurred when a technology is retired before the end of its economic life.

Technology Choice

If demand for an energy end-use is constant or increasing, the natural process of stock turnover creates a demand for new technologies to provide that service. The process of technological choice, whereby households and businesses select the technologies that best meet their needs, has a profound influence on energy consumption and GHG emissions in a market economy. Table 15 summarizes key factors that influence technological choice and describes how each of these are addressed in gTech.

The factors addressed in Table 15 include financial costs, non-financial influences, and policy. Accounting for non-financial influences such as time preference, technology-specific preferences, and diversity of choice allows gTech to represent human behavior in a realistic way. Policies can influence technological choice indirectly by affecting the other factors (e.g., a subsidy that reduces the capital cost of a technology) or by directly imposing requirements or restrictions on the technological options available to households and businesses through regulation (e.g., a standard that requires a minimum level of energy efficiency). Additional factors (not addressed in Table 15) that influence technological choice in gTech include technology operating costs, technology lifespans, and constraints on technology adoption.

Several of the technology cost components represented by gTech are dynamically represented, meaning they can change over time based on the model simulation. gTech includes functions that allow capital costs, as well as the non-financial (intangible) costs representing technology-specific preferences, to decline over the course of a simulation. Energy costs are dynamic in gTech because they are influenced by energy prices, which are determined by the model (except for the global price of oil). Finally, the impact of policies on technology costs can vary during the course of a gTech simulation, following either a fixed trajectory (e.g., a 10% reduction every five years until a defined lowest cost) or as a function of adoption (e.g., a 10% reduction for every doubling of cumulative production of a given class of technologies such as vehicle batteries or DAC)

Table 15: Key factors that influence technological choice in gTech

Influencing factor	Description
Capital cost	The capital cost is simply the upfront cost of purchasing a technology. For emerging technologies, the capital cost can decline as more units are produced, reflecting economies of scale and economies of learning (as manufacturers gain experience). The literature confirms that this dynamic is important[71]. It has been observed in a wide variety of contexts, such as aircraft manufacturing, chemical processing, agricultural technology, shipbuilding, and automobile manufacturing[72]. The cost of electric vehicles has come down significantly in recent years and this trend is expected to continue[73]. A declining capital cost function has been incorporated into gTech to allow costs to decline over time as a function of cumulative production, until a technology reaches maturity (defined by a prespecified minimum cost). Capital costs can be broken down into components in gTech, with the declining capital cost function applied to each one independently. Therefore, increased adoption of one technology can affect the cost of another technology that uses similar components. For example, increased battery electric vehicle adoption reduces battery, motor and electronics costs for fuel cell vehicles.
Energy cost	The energy cost associated with a technology is a function of: (1) the price of energy (e.g., cents per litre of gasoline) and (2) its energy requirements (e.g., a vehicle's fuel economy, measured in litres per 100 km). In gTech, the energy requirements of a given technology are fixed, but the price of energy is determined by the model.

[71] Löschel, A. (2002). "Technological Change in Economic Models of Environmental Policy: A Survey". *Ecological Economics*, 43 (2-3), 105-126.

[72] Bollinger, B., & Gillingham, K. (2014). Learning-by-doing in solar photovoltaic installations. Available at SSRN 2342406.

[73] Nykvist, B., Sprei, F., & Nilsson, M. (2019). "Assessing the Progress Toward Lower Priced Long-Range Battery-Electric Vehicles". *Energy Policy*, 124, 144-155.

Influencing factor	Description
Time preference	Some technologies offer energy cost savings in exchange for a higher capital cost, relative to the conventional option. Because households and businesses generally incur the capital cost of a technology before they incur its energy costs, a trade-off exists between the higher upfront costs and future energy savings in these cases. Energy-economy modelers represent the higher priority placed by households and businesses on upfront costs using a "discount rate" (analogous to the interest rate applied to a loan). Many energy modelers employ a "financial" discount rate (commonly between 5% and 10%) to represent time preference. However, research has consistently shown that the decisions of households and firms indicate rates significantly higher than a financial discount rate[74]. This implies that using a financial discount rate would overvalue future savings relative to revealed behavior and provide a poor forecast of household and firm decisions. Given the objective of forecasting how households and firms are likely to respond to GHG policy, gTech employs behaviorally realistic discount rates of between 8% and 25%[75] to simulate technological choice.
Technology-specific preferences	Households and businesses also exhibit preferences for specific technologies and technology attributes. For example, when it comes to electric passenger vehicles, some potential buyers may be concerned about driving range and available charging infrastructure or the risk associated with an emerging technology, while others may see a zero-emission vehicle as a status symbol[76]. Technology-specific preferences can be quantified as non-financial or "intangible" costs, which are included in the technology choice algorithm of gTech. As emerging technologies penetrate the market, improved availability of information and decreased perceptions of risk can make people even more likely to buy them[77]. The literature indicates that this dynamic is important[78]. To represent it in gTech, a function is available that allows the intangible cost of an emerging technology to decline as its share of the market for new purchases increases.

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74 Rivers, N., & Jaccard, M. (2006). "Useful Models for Simulating Policies to Induce Technological Change". *Energy Policy*, 34 (15), 2038-2047.

75 Axsen, J., Mountain, D.C., Jaccard, M. (2009). "Combining Stated and Revealed Choice Research to Simulate the Neighbor Effect: The Case of Hybrid-Electric Vehicles". *Resource and Energy Economics*, 31, 221-238.

76 Kormos, C., Axsen, J., Long, Z., Goldberg, S., 2019. Latent demand for zero-emissions vehicles in Canada (Part 2): Insights from a stated choice experiment. Transportation Research Part D: Transport and Environment 67, 685-702.

77 Mau, P., Eyzaguirre, J., Jaccard, M., Collins-Dodd, C., & Tiedemann, K. (2008). "The Neighbour Effect: Simulating Dynamics in Consumer Preferences for New Vehicle Technologies". *Ecological Economics*, 68, 504–516.

78 Axsen, J., Mountain, D. C., & Jaccard, M. (2009).

Influencing factor	Description
Diversity of choice	As suggested by the example regarding electric vehicle preferences above, individuals are unique and may weigh factors differently when choosing what type of technology to purchase. Different people may come to different decisions, even when faced with the same financial costs. Financial costs and the availability of technologies and fuels can also vary across individuals within a given region. According to the gTech market share equation, the technology with the lowest net cost (including all the cost factors described above) will capture the greatest market share, but technologies with higher net costs may still capture some market share[79]. The more costly a technology is relative to its alternatives, the less market share it will earn.
Policy	One of the most important drivers of technological choice is government policy. Governments have a variety of policy options available to influence technological choice in order to mitigate GHG emissions: (1) subsidy or incentive programs, which pay for a portion of the capital cost of a preferred technology or technologies; (2) regulations, which impose requirements or restrictions on the technological options available to households and businesses; (3) carbon pricing, which increases energy prices in proportion to their carbon content; (4) adjustments to other taxes (e.g., not charging GST on a preferred technology); and (5) flexible regulations, like the federal *Clean Fuel Regulations*, which create a market for compliance credits. gTech can be used to simulate the impact of virtually any substantive GHG abatement policy on technological choice, as well as the combined impact of multiple policies implemented together.

Covered Sectors, Fuels, Energy End-Uses and Sources of Emissions in gTech

Table 16: Covered sectors

Sector name
Soybean farming
Oilseed (except soybean) farming
Wheat farming
Corn farming
Recovery of agricultural residue
Other farming

79 Rivers, N., & Jaccard, M. (2006). "Useful Models for Simulating Policies to Induce Technological Change". *Energy Policy*, 34 (15), 2038-2047.

Sector name
Animal production and aquaculture
Forestry and logging
Recovery of logging residue
Fishing, hunting and trapping
Agriculture services
Natural gas extraction (conventional)
Natural gas extraction (tight)
Natural gas extraction (shale)
Light oil extraction
Heavy oil extraction
Oil sands in-situ
Oil sands mining
Bitumen upgrading (integrated)
Bitumen upgrading (merchant)
Coal mining
Metal mining
Non-metallic mineral mining and quarrying
Oil and gas services
Mining services
Fossil-fuel electric power generation
Hydro-electric and other renewable electric power generation
Nuclear electric power generation
Electric power transmission, control and distribution
Liquefied Natural Gas
Natural gas distribution
Construction
Food manufacturing
Beverage and tobacco manufacturing
Textile and product mills, clothing manufacturing and leather and allied product manufacturing
Wood product manufacturing
Paper manufacturing
Petroleum refining
Coal products manufacturing
Petrochemical manufacturing
Industrial gas manufacturing
Other basic inorganic chemicals manufacturing
Other basic organic chemicals manufacturing

Sector name
Biodiesel production from canola seed feedstock
Biodiesel production from soybean feedstock
Ethanol production from corn feedstock
Ethanol production from wheat feedstock
HDRD (or HRD) production from canola seed feedstock
Renewable gasoline and diesel production from biomass
Renewable natural gas production
Cellulosic ethanol production
Resin and synthetic rubber manufacturing
Fertilizer manufacturing
Other chemicals manufacturing
Plastics manufacturing
Cement manufacturing
Lime and gypsum manufacturing
Other non-metallic mineral products
Iron and steel mills and ferro-alloy manufacturing
Electric-arc steel manufacturing
Steel product manufacturing from purchased steel
Alumina and aluminum production and processing
Other primary metals manufacturing
Foundries
Fabricated metal product manufacturing
Machinery manufacturing
Computer, electronic product and equipment, appliance and component manufacturing
Transportation equipment manufacturing
Other manufacturing
Wholesale and retail trade
Air transportation
Rail transportation
Water transportation
Truck transportation
Transit and ground passenger transportation
Pipeline transportation of crude oil
Pipeline transportation of natural gas
Other transportation, excluding warehousing and storage
Landfills
Services

Sector name
CO_2 pipeline transportation
CO_2 storage
Direct air capture of CO_2
Enhanced oil recovery with CO_2
Hydrogen production from methane
Hydrogen production via electrolysis
Hydrogen pipeline transportation

Table 17: Covered fuels

Fuel
Fossil fuels
Coal
Coke oven gas
Coke
Natural gas
Natural gas liquids
Gasoline
Diesel
Heavy fuel oil
Still gas
Electricity
Electricity (no specific fuel by generation pathway)
Hydrogen
Via steam methane reformation
Via steam methane reformation with carbon capture
Via electrolysis
Renewable fuels (non-transportation)
Spent pulping liquor
Wood
Wood waste (in industry)
Renewable natural gas
Renewable fuels (transportation)
Ethanol produced from corn
Ethanol produced from wheat
Cellulosic ethanol
Biodiesel produced from canola
Biodiesel produced from soy
Hydrogenated renewable diesel (HDRD) from canola
Renewable gasoline and diesel from pyrolysis of biomass
Renewable natural gas

Table 18: Covered energy end-uses and emissions sources

End-use
Stationary industrial energy/emissions sources
Fossil-fuel electricity generation
Process heat for industry
Process heat for cement and lime manufacturing

End-use
Heat (in remote areas without access to natural gas)
Cogeneration
Compression for natural gas production and pipelines
Large compression for LNG production
Electric motors (in industry)
Other electricity consumption
Transportation
Air travel
Buses
Rail transport
Light rail for personal transport
Marine transport
Light-duty vehicles
Medium-duty vehicles
Heavy-duty vehicles
Other off-road vehicles (what is not included heavy-duty)
Oil and gas fugitives
Formation CO2 removal from natural gas processing
Flaring in areas close to natural gas pipelines
Flaring in areas far from natural gas pipelines
Methane vents
Methane leaks
Surface casing vent flows
Industrial process
Mineral product GHG emissions
Aluminum electrolysis
Metallurgical coke consumption in steel production
Hydrogen production for petroleum refining and chemicals manufacturing
Non-fuel consumption of energy in chemicals manufacturing
Nitric acid production
Agriculture
Enteric fermentation
Manure management
Agricultural soils
Waste
Landfill gas management

End-use
Residential buildings
Single family detached shells (defining heating and cooling load)
Single family attached shells (defining heating and cooling load)
Apartment shells (defining heating and cooling load)
Space heating
Air conditioning
Lighting
Dishwashers
Clothes washers
Clothes dryers
Ranges
Faucet use of hot water
Refrigerators
Freezers
Hot water
Other appliances
Commercial buildings
Food retail shells (defining heating and cooling load)
Office building shells (defining heating and cooling load)
Non-food retail shells (defining heating and cooling load)
Educational shells (defining heating and cooling load)
Warehouses (shells) (defining heating and cooling load)
Other commercial shells (defining heating and cooling load)
Commercial heat load
Commercial hot water
Commercial lighting
Commercial air conditioning
Auxiliary equipment
Auxiliary motors (in commercial buildings)

Final Results: Rail Sector GHG Modelling Analysis

Navius Research

May 27th, 2024

Michael Wolinetz
Michael@NaviusResearch.com

Outline

- Introduction:
  - Context and research goals
- Methodology:
  - The “gTech” model and the representation of the rail sector in this model
  - Policy Scenarios: Summary of the future scenarios tested
  - Assumptions: Focus on locomotive costs
- Results:
  - Discussion
  - key insights
  - Opportunities for future work

Introduction

- An energy-economic modelling study.
- Support planning by TC, ECCC, and industry to reduce rail sector GHG emissions.
- Forecasts how a range of hypothetical policy approaches can reduce rail GHG emissions in Canada from the present to 2050.
- Considers the impact of carbon pricing, fleet renewal and funding policies on zero-emissions locomotive (ZEL) and low-carbon fuel adoption.

The model, scenarios, and assumptions

Methodology

gTech: Navius' Energy Economy Model

- We use gTech to forecast climate and energy policy impact on technologies, fuels, sectors, and the economy in general from the present to 2050
- gTech:
  - Is the most widely used energy-economy model in Canada
  - Is a full economic model (computable general equilibrium)
  - Has significant fuel and technology detail
  - Simulates technology and fuel adoption
  - Tracks technology stock and vintages
  - Explicitly simulates a wide range of energy and GHG policy

Scope of the gTech Model

Regions
- Covers North America
- Individual provinces and territories plus US region

Economic sectors
- 90+ sectors
- They interact in terms of supply/demand of commodities (goods & services), energy, labour, capital

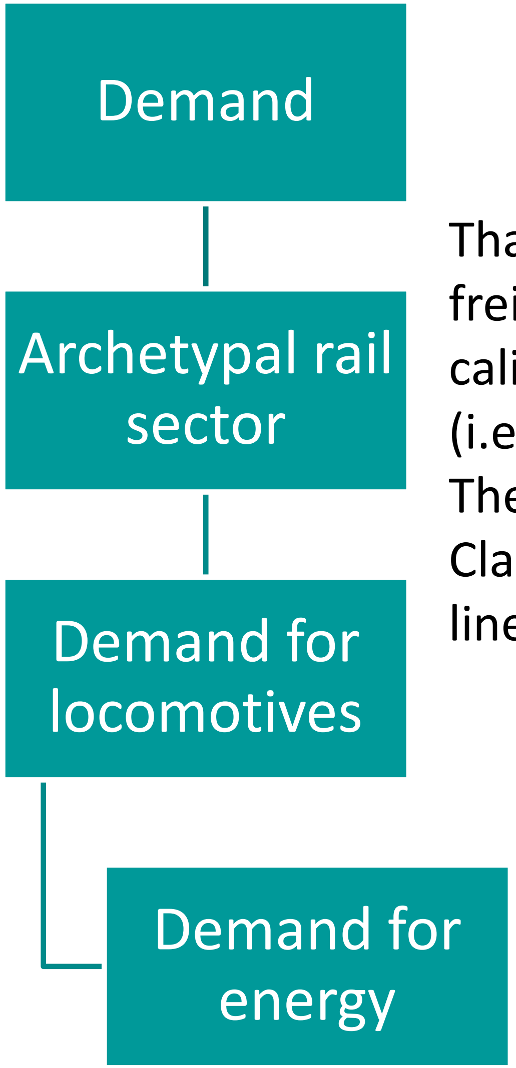
Energy "end-uses"
- What energy is used for, or activities that produce GHG emissions
- E.g., Space heating, transportation, process heat, motive power, lights
- 60+ end-uses

Technologies
- Equipment that satisfies demand for energy end-uses (e.g., different furnaces/heat pumps, vehicles, power plants etc.)
- 350+ archetypal technologies

Energy and fuels
- Energy consumed by technologies, resulting in GHG emissions
- E.g., liquid, gaseous and solid fossil fuels and renewable fuels, electricity and hydrogen from a range of sources

Structure of the Rail Sector in gTech

Demand is a function of activity in other sectors that require rail transport per unit of production (based on StatsCan input/output data). Activity is expressed in $, then converted to revenue tonne km (RTK = 0.62 * RTM)



That demand is satisfied by an archetypal freight rail sector. Energy and GHG are calibrated to represent all rail in Canada (i.e., passenger is aggregated with freight). The rail sector activity is broken down into Class I vs. shortline & regional (SL&R) and line-haul vs. switcher activity

A “fleet” of locomotives provide this rail activity. Locomotive retirement and repowering is modelled as is technology choice when acquiring new locomotives.

The type and quantity of energy demanded is a function of locomotives. For substitutable fuels (e.g., diesel vs. renewable diesel), demand is simulated.

Policy Scenarios

This analysis include 15 scenarios, categorized into three groups, all of which are compared against a Current Policy scenario:

- **GHG Pathways**: These scenarios explore the rail sector's response to varying GHG emission constraints, simulating the impact of stringent carbon pricing and sector-specific caps aimed at achieving net-zero emissions by 2050.
- **Fleet Renewal**: This group of policies tests the impact of regulations aimed at accelerating the renewal of the locomotive fleet, either through mandates for cleaner conventional locomotives (e.g., Tier 4) or through a shift to ZELs.
- **Incentive Scenarios**: These scenarios examine the impact of incentives for ZEL adoption within the SL&R segment, simulating various levels of government support for the purchase of ZELs and related infrastructure.

Assumptions

- Drivers of economic growth:
  - GDP and economic structure
- Determinants of energy prices:
  - Crude oil and natural prices, inputs to production of low-carbon fuels, electricity, hydrogen (e.g., capital, labour, feedstock)
- Determinants of technology costs:
  - Locomotive cost by component and potential for cost reductions (e.g., due to cheaper batteries, fuel cells etc.)
  - Cost of charging and H_2 refueling infrastructure

Technology Simulation

- Rail transportation demand within the four segments is satisfied by a fleet of archetypal locomotives (Class I vs. SL&R, line-haul vs. switcher)
- Locomotives are differentiated by segment: availability, utilization, costs energy/GHG intensity,
- Investment behaviour is differentiated by Class I and SL&R segments
- Additional locomotives are added to each of the segment fleets as old locomotives are retired and/or as activity grows
  - Includes newly manufactured and/or an implicit representation of used locomotives from other fleets
  - Opportunities for repowering are represented by locomotive life, operating cost or capital cost (depending on the context).

Battery Electric Locomotive (BEL) Assumptions

	Switcher	SL&R line-haul	Class I line-haul
kW, max traction power	1,500	3,200	3,200
kWh battery storage	3,000	35,700	51,000
Battery tenders, per locomotive	0	2	3
Capital cost multiplier, accounts for lower productivity due to tenders*	n/a	1.08	1.14
Approximate range, or days of operation per charge**	1 to 3 days of operation	500 km	830 km

*The capital cost multiplier accounts for the reduction in RTK when replacing revenue-generating cars with battery tender cars. The factor is based on the assumption that a single diesel locomotive will pull 25 revenue-generating cars, while a BEL will put just 22 (Class I line-haul) or 23 (SL&R line) haul.

** The range for line-haul archetypes is based on the energy intensity assumption for each archetype, 80% battery depth of discharge, and a consist of four locomotives pulling 6,155 revenue tonnes.

BEL Charger Cost Assumptions

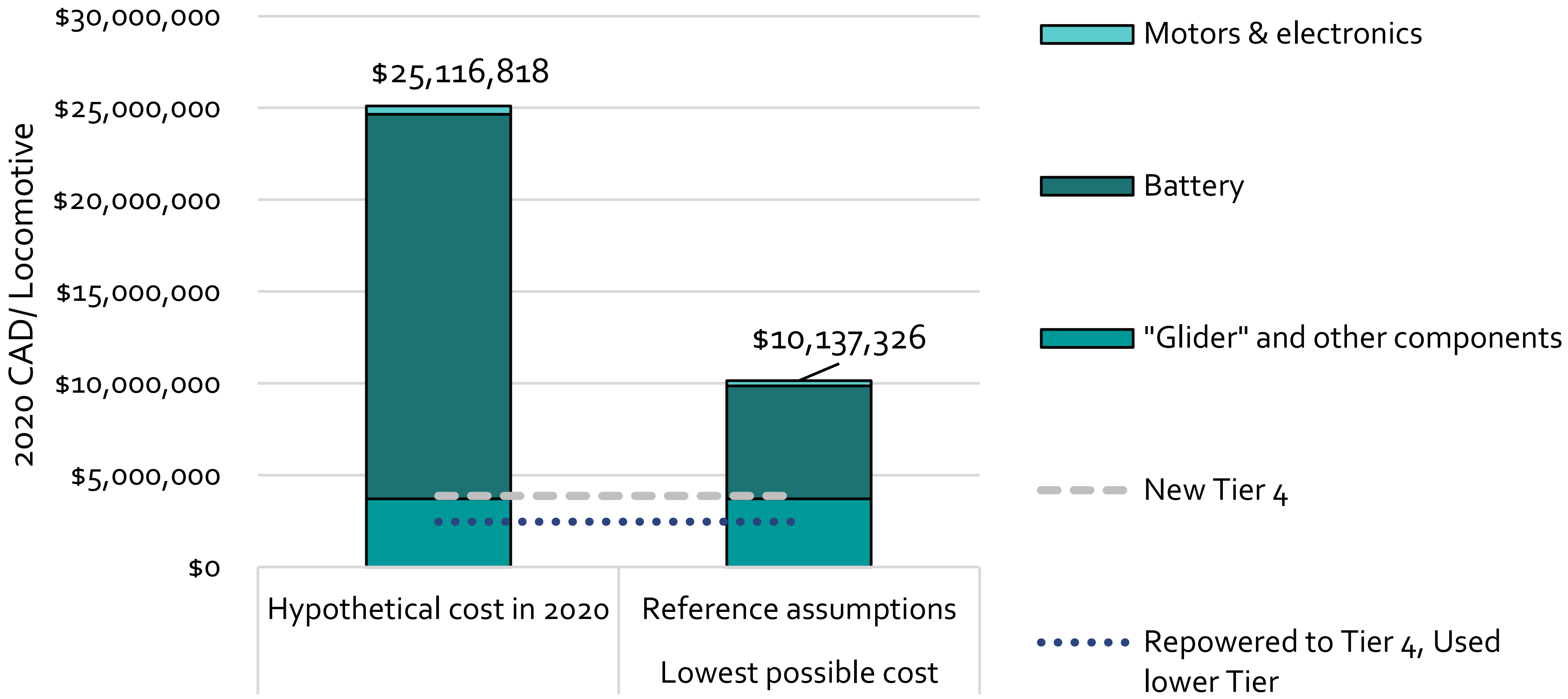
	Switcher	SL&R line-haul	Class I line-haul
Assumed depth of discharge	80%	80%	80%
Maximum to be charged, MWh	2	29	41
Time for charging, hrs	8	4	1
MW charging power needed	0.300	7	41
$/ MW charger Capital Cost (2020 CAD)	$ 1,533,383	$ 1,533,980	$ 1,533,906
Charger cost (2020 CAD)	$ 460,015	$ 10,952,620	$ 62,583,354
Charger utilization assumption	30%	30%	30%
Full charging sessions per day	0.9	1.8	7.2
$/MWh levelized cost of the charger (amortized at 10% over 30 years)	$ 61.90	$ 61.92	$ 61.92

H_2 Fuel Cell Locomotive (FCL) Assumptions

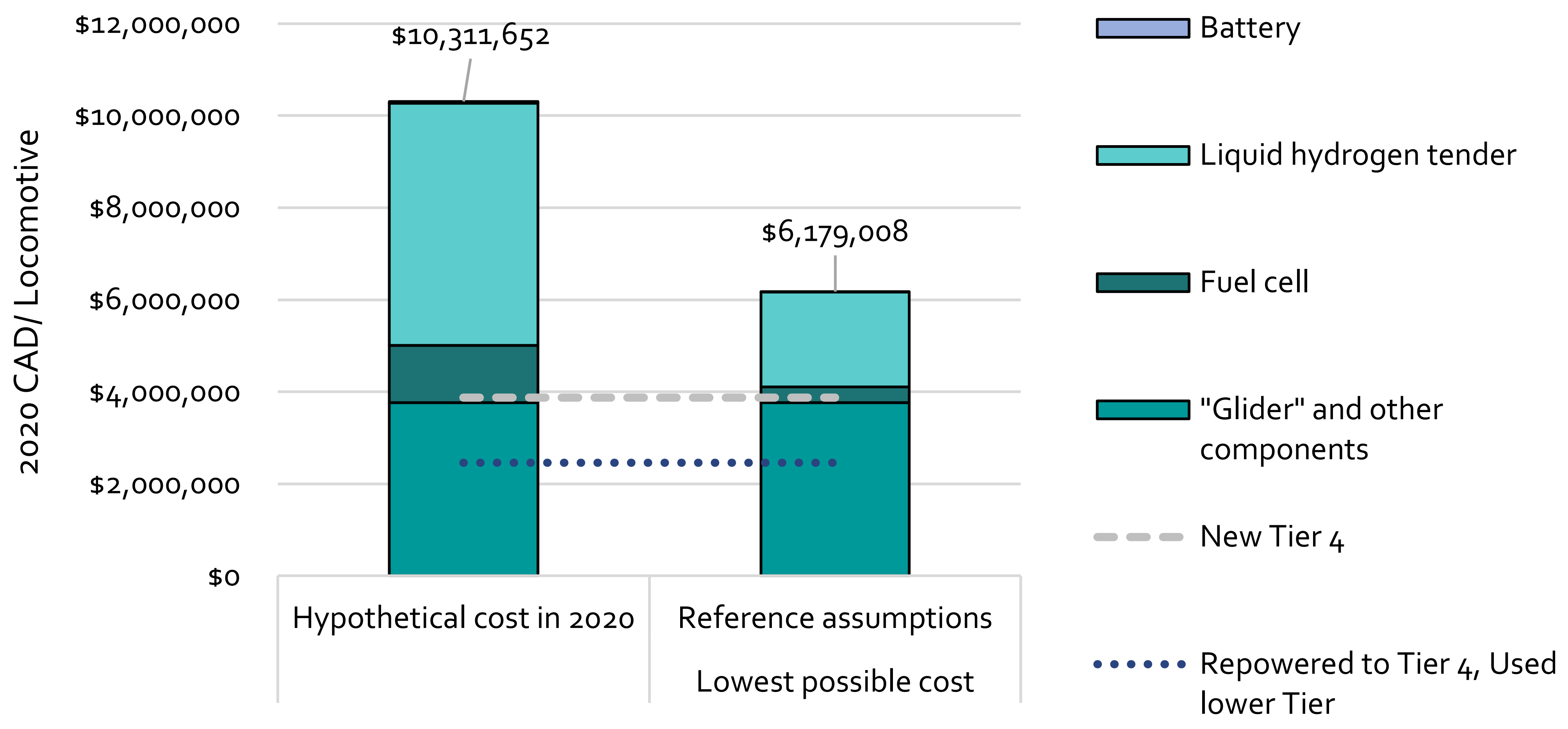
	Switcher	SL&R line-haul	Class I line-haul
kW, max traction power	1,500	3,200	3,200
kg hydrogen storage per locomotive	58 (compressed)	988 (liquid)	4,000 (liquid)
Hydrogen tenders, per locomotive	0	0	1/2

Hydrogen transportation, distribution and refueling is modelled as part of the hydrogen supply price. It adds another \$2-\$3 / kg H_2 (about an additional 30 to 50% of the fuel price).

Class I Line-Haul BEL Costs



Class I Line-Haul FCL Costs



Circling Back: Why study the rail sector with an economy-wide model?

- To show impacts of economy-wide policy, e.g., simulating:
  - Clean Fuel Regulations compliance market
  - The carbon price needed to get to net-zero
  - Spillover technology cost reductions from other sectors (e.g., batteries, fuel cells)
- To model the context of net-zero:
  - Some sectors may have positive or negative emissions
  - What is the GHG abatement required from the rail sector in net-zero?
- To show the integration with energy supply and simulate reasonable energy prices, e.g.:
  - How feedstock constraints may affect renewable fuel prices
  - GHG constraints on electricity and hydrogen production affect energy prices
- Ideally, to be able to study mode shifting to/from rail and impact on CAC emissions
  - However, this is currently not a capability of gTech but it could be added.

Results, discussion, key conclusions and opportunities for future work

Results

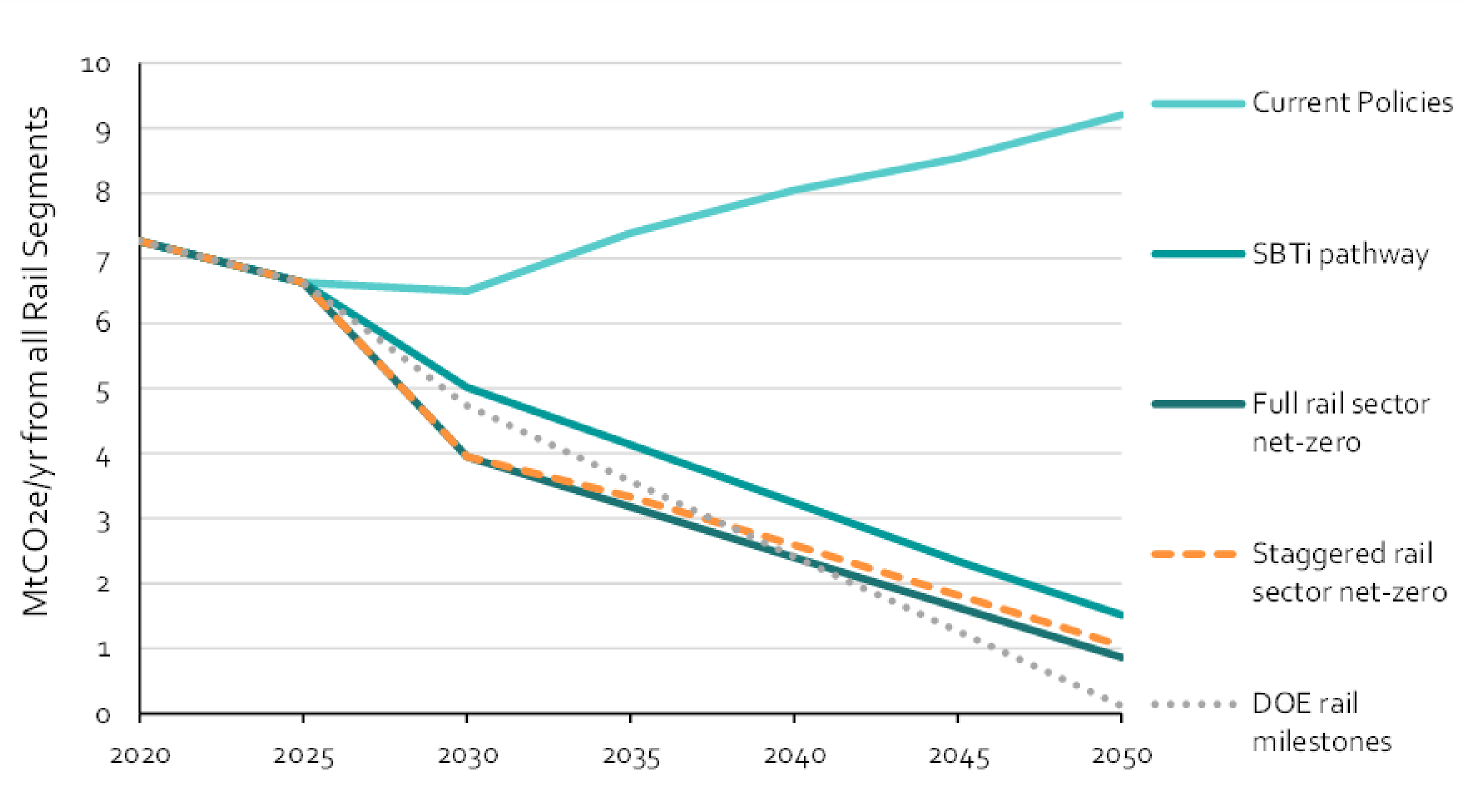
GHG Pathway Scenarios

- **SBTi pathway scenario:** A target based on Class I railway GHG commitments, set at a reduction in Class I emissions of 23.8% in 2030, relative to 2019, trending to net-zero by 2050 (we assume -87% relative to 2005).
- **Full rail sector net-zero scenario:** The entire rail sector's GHG emissions to be 40% below 2005 levels by 2030, and net-zero by 2050 (-87% relative to 2005).
- **Staggered rail sector net-zero scenario:** The same as above, but a 10-year delay in the requirement is applied to SL&R railways.
- **DOE rail milestones scenario:** GHG emissions are 30% lower than 2019 levels in 2030, and *zero-emissions** sector-wide by 2050. 50% ZELs are required among switchers by 2035, and 100% by 2040. 40% ZELs are required among line-haul locomotives by 2040.

* The DOE target is net-zero emissions including GHGs embodied in equipment and infrastructure. We represent this as a zero-emissions requirement (rather than a net-zero requirement for the sector)

Rail sector GHG emissions in the GHG Pathway Scenarios

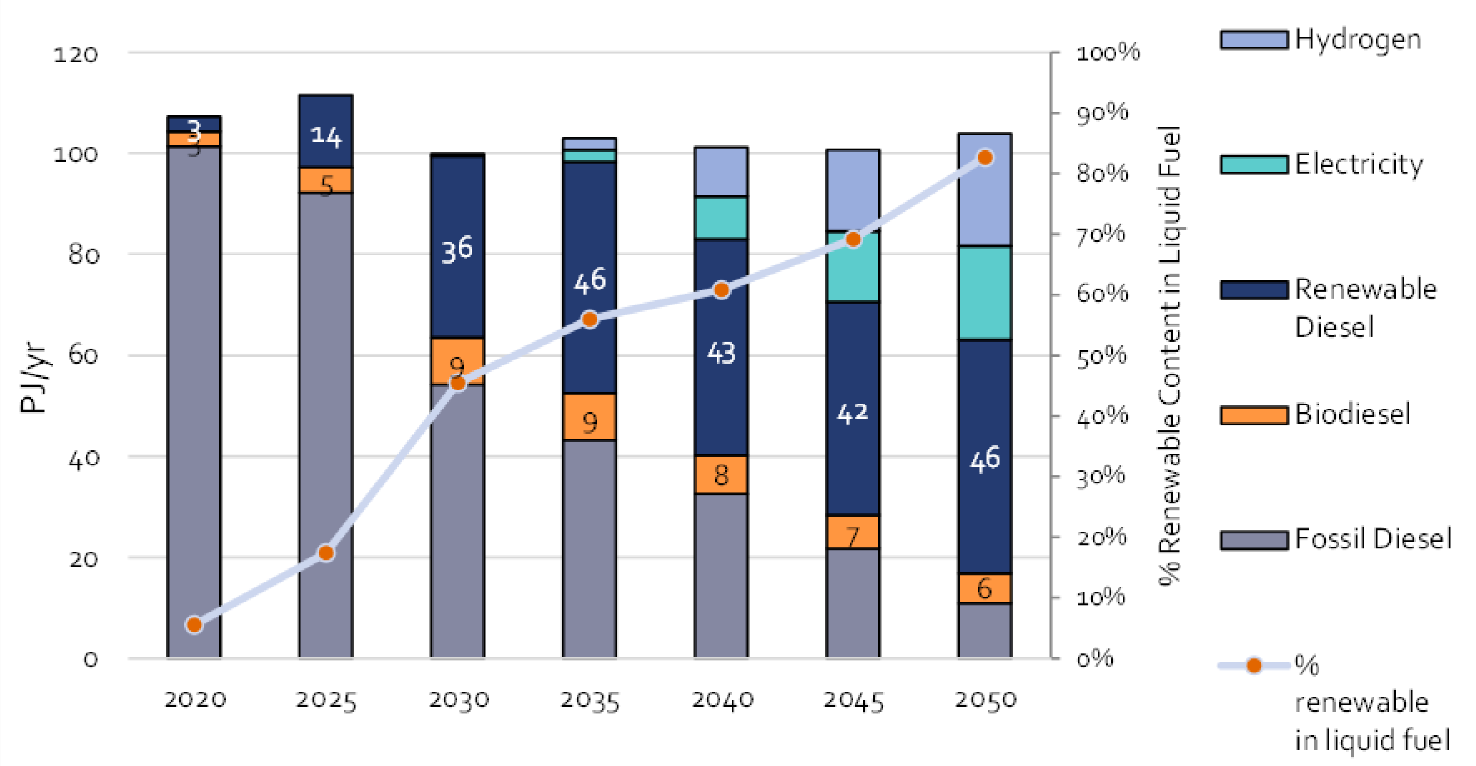
- The rail sector will not hit any of the proposed sector GHG targets in the Current Policy scenario
- Each of the four GHG Pathways scenarios hits their targets (by scenario definition)
- Excluding or delaying GHG targets on SL&R has a relatively muted impact on sector-wide GHG emissions by 2050
- The DOE Rail Milestones scenario produces the greatest GHG abatement after 2040, due greater requirement for GHG reduction



Locomotive energy consumption for all segments in the Full Rail Net-Zero scenario: 1) by fuel (bars), and 2) percentage of liquid fuel that is renewable (line).

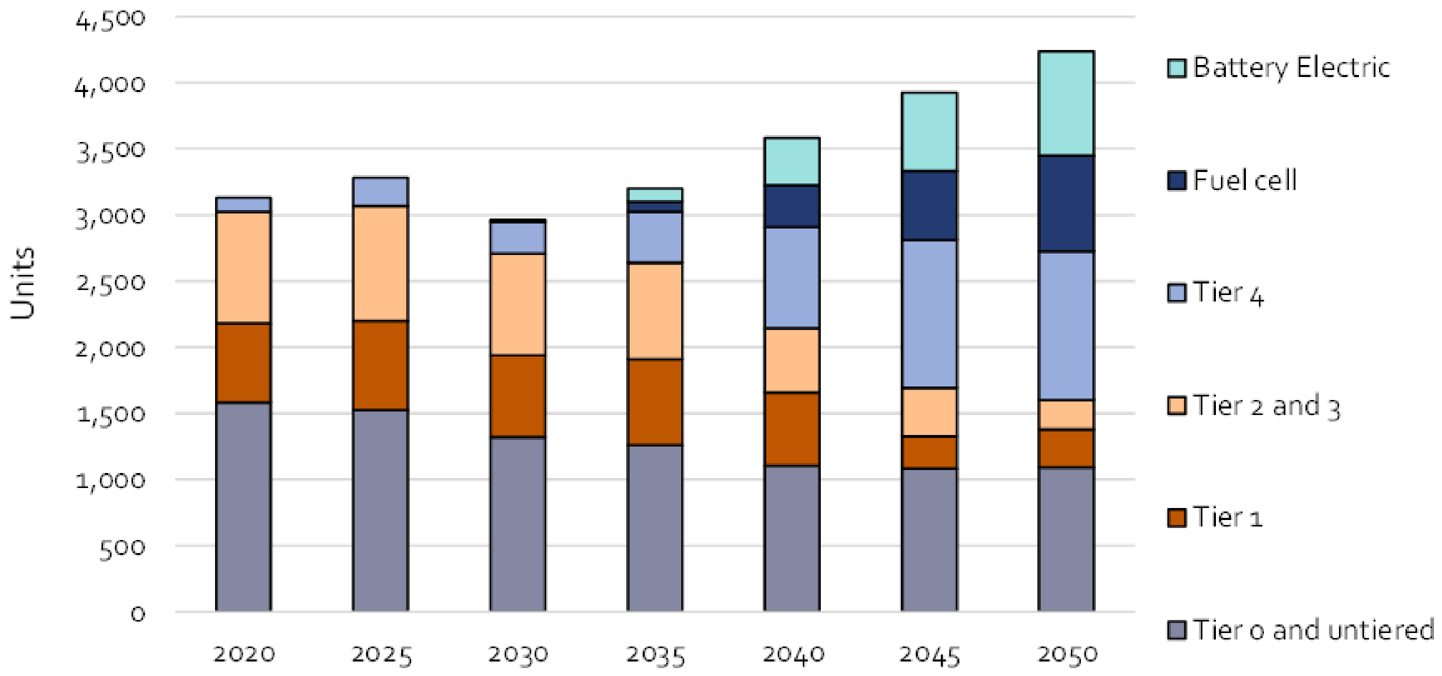
Data labels show PJ/yr renewable liquid fuel.

- The rail sector uses both low-carbon fuels (i.e., biodiesel and renewable diesel) as well as ZELs to achieve the targets set out in the GHG Pathways scenarios.
- The adoption of ZELs drives down total liquid fuel demand over time and tempers demand for low-carbon fuels in a net-zero future.



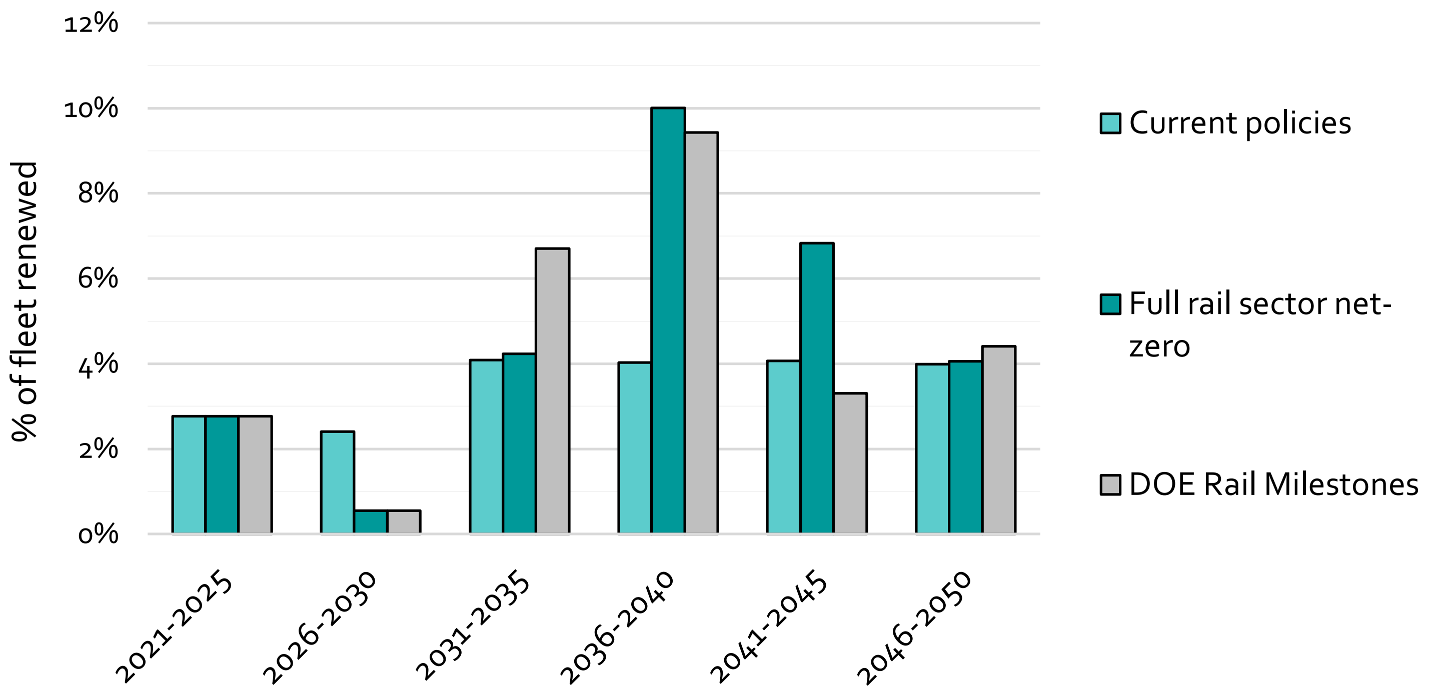
Locomotives by type across all rail sector segments in the Full Rail Net-Zero scenario

- ZEL adoption starts in earnest after 2035 and is concentrated in Class I line-haul, increasing to 30% of these locomotives in 2040 and 55% in 2050.
- There is a role for both electric and fuel-cell line-haul locomotives in a net-zero future
    - Still significant uncertainty related to when ZELs will be commercially available or how their charging or fuelling network might evolve
- There are almost no ZELs adopted in switchers in the GHG Pathways scenarios (unless required, as in DOE Milestones scenario)
    - ZEL switchers cost less, but lower utilization makes them less attractive than low-carbon fuel
- A GHG cap or carbon pricing is not enough to drive ZEL adoption in switchers, which lessens its impact on the CAC emissions produced in rail yards.



Percent per year of new*, replaced, and repowered locomotives (avg.%/yr over each five-year period)

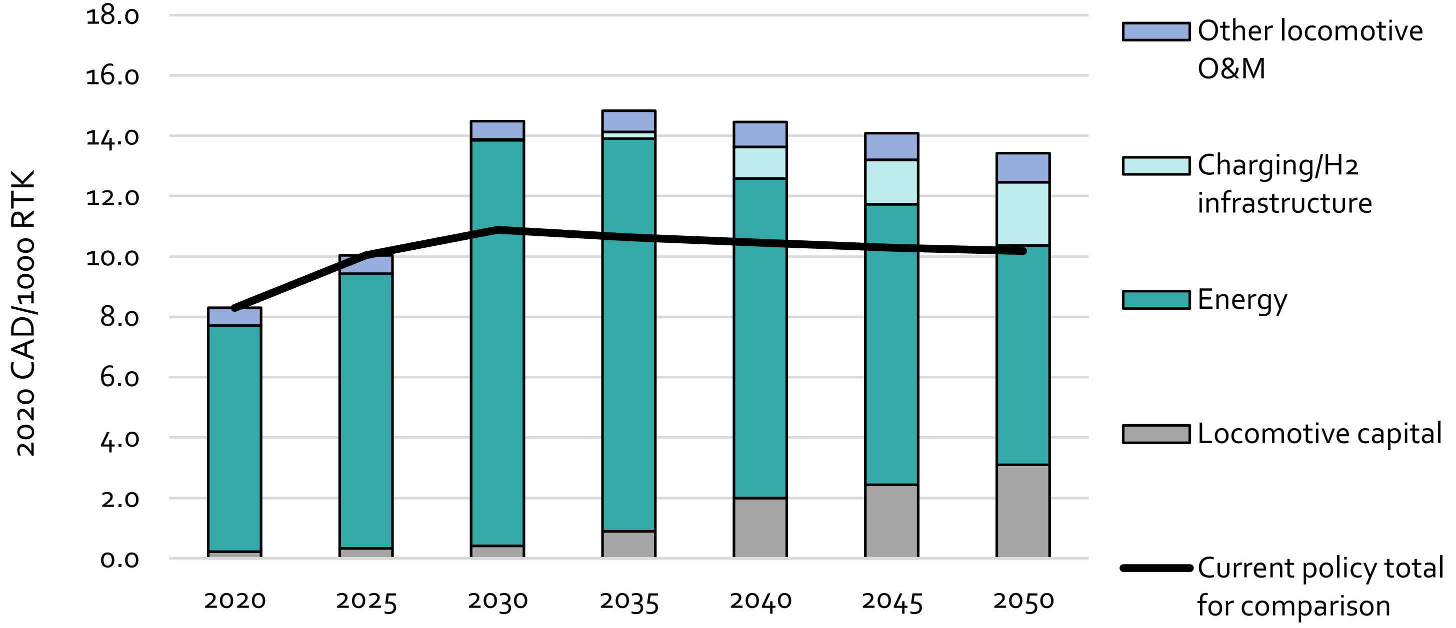
- The fleet renewal rate required to achieve the level of ZEL adoption seen in the GHG Pathways scenarios is significantly higher than under current policies
- From 2035 and 2045, the fleet renewal rate in the Full Rail Sector Net-Zero scenario is about 2-3 times higher than in the Current Policy scenario
- Adding fleet renewal requirements may both advance and increase the periods of peak fleet renewal (e.g., in the DOE Rail Milestones scenario)



* "New" means new additions to the fleet, which may include older used locomotives

Rail sector levelized costs, GHG Pathway Scenarios

- In the figure: the DOE Milestones Scenario (columns) vs. the Current Policy Scenario (black line)
- Higher energy costs since the sectoral and national net-zero requirements result in a rising cost of carbon on fossil diesel and more consumption of renewable diesel.
- Costs decline over time with greater ZEL adoption which also leads to a more capital-intensive cost structure.



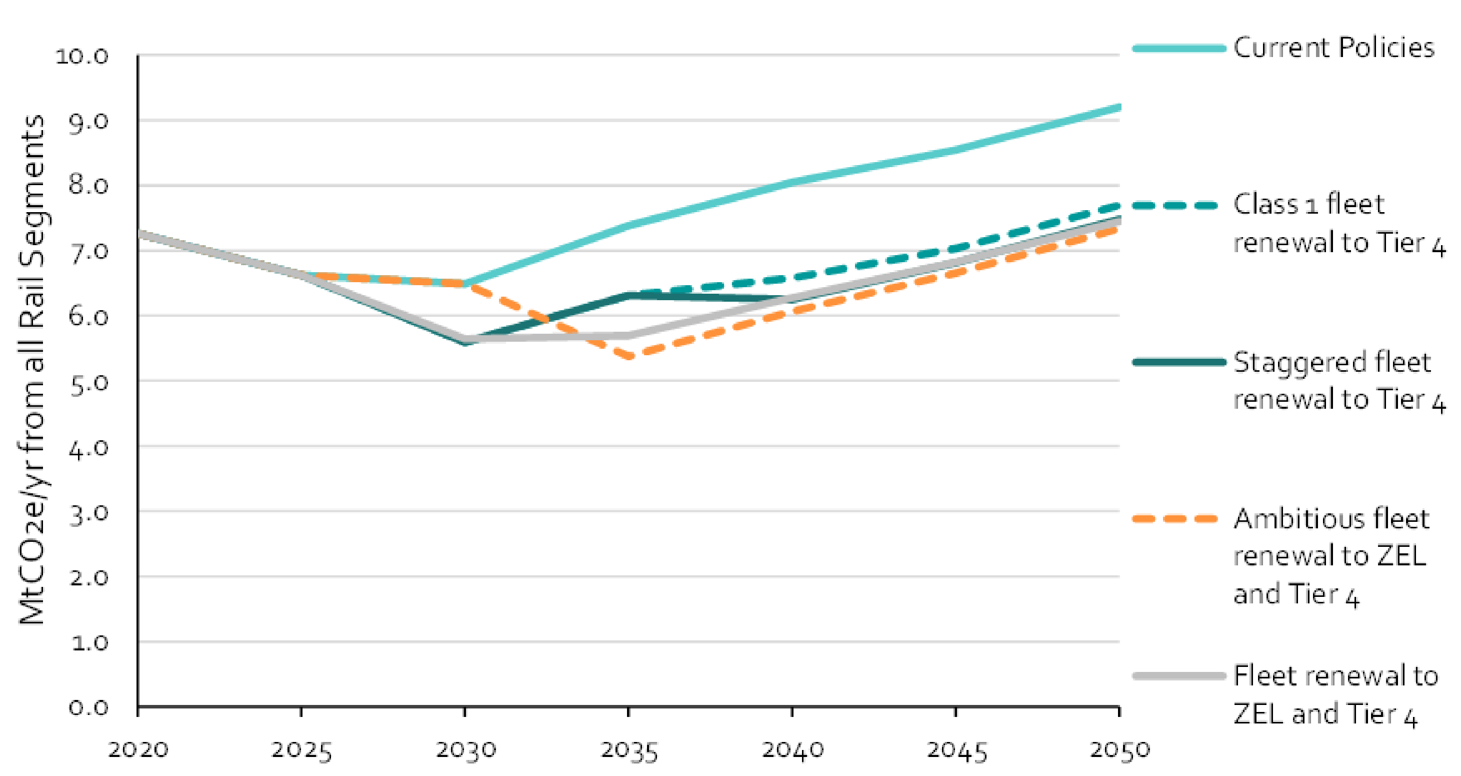
Capital is capital annuities amortized over 30 years at a 7% discount rate (opportunity cost of capital)

Fleet Renewal Scenarios: Tier 4 for line-haul

- **Class I renewal to Tier 4:** Requires Class I railways to retire their locomotives after 30 years in operation as of 2030 unless they are repowered to be Tier 4 compliant.
- **Staggered renewal to Tier 4:** This scenario is like the previous scenario, except that the fleet renewal requirement is delayed by 10 years for SL&R railways.
- **Ambitious fleet renewal to ZEL and Tier 4 scenario:** Starting in 2035, line-haul locomotives that are 25 years and older must be retired or repowered to be Tier 4 compliant. Likewise, as of 2035, switcher locomotives that are 25 years and older must be retired or repowered to be ZELs, and new switcher locomotives must be ZELs.
- **Fleet renewal to ZEL and Tier 4:** As above, but the retirement age is extended to 35 years for SL&R railways.

Rail sector GHG emissions in the Fleet Renewal Scenarios that require Tier 4 for line-haul service

- Renewal to Tier 4 for line-haul also reduces GHG emissions relative to the Current Policy Scenario
  - But not consistent with net-zero
  - Air quality impact would be more significant
- Including SL&R railways in Tier 4 renewal requirement may result in modest additional GHG abatement
- Requiring switcher fleets to be renewed to ZELs yields a modest additional GHG reduction.

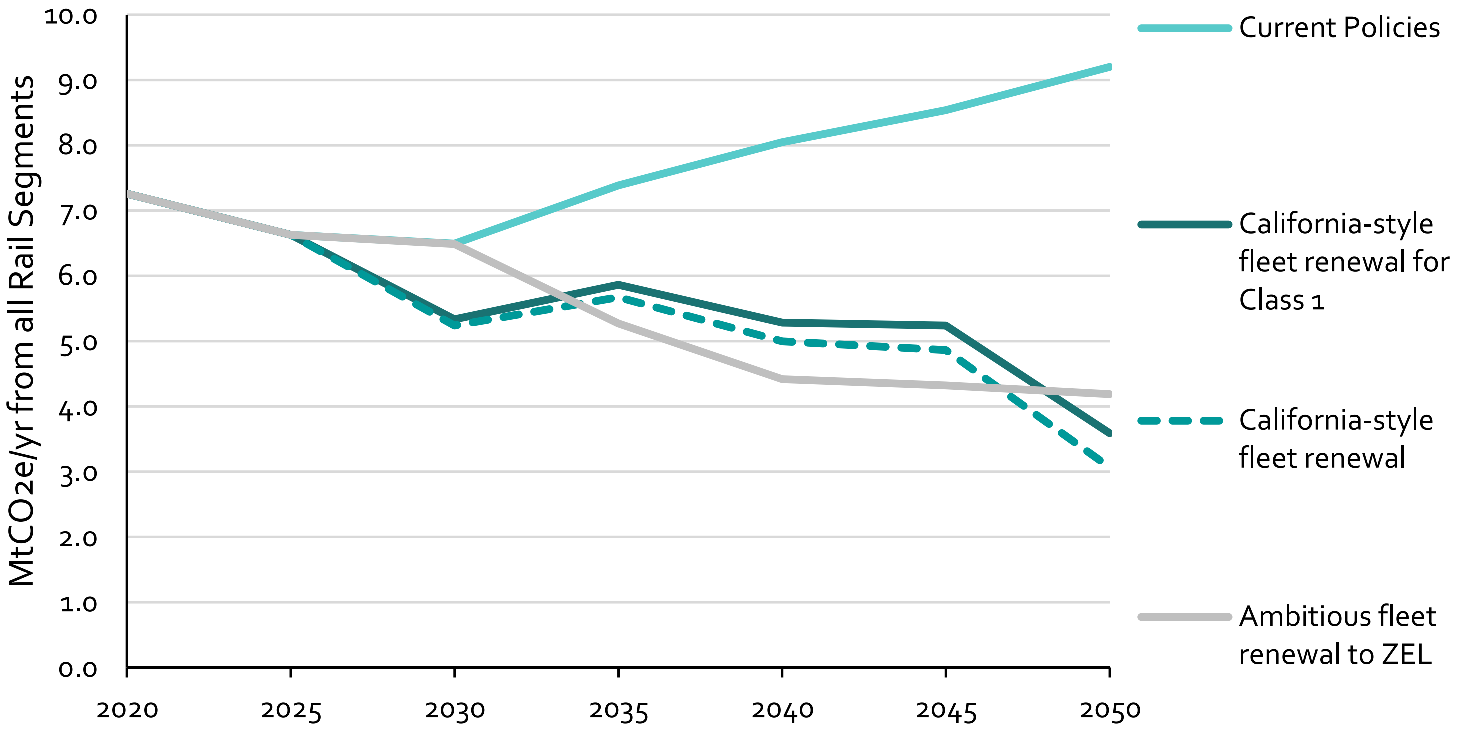


Fleet Renewal Scenarios: ZEL for line-haul

- **California-style fleet renewal scenario:** Based on the California In-Use Locomotive Regulation. As of 2030, locomotives must retire 23 years after original manufacture date. Repowering to Tier 4 resets that date. Requirement for new locomotives to be ZELs is phased-in from 2030 to 2035.
- **California-style Class I fleet renewal scenario:** Identical to the previous scenario, except that it only applies to Class I railways.
- **Ambitious fleet renewal to ZEL scenario:** All locomotives to retire after 25 years of operation starting in 2035 unless they are repowered to be ZELs. New locomotives must be ZELs as of 2035.

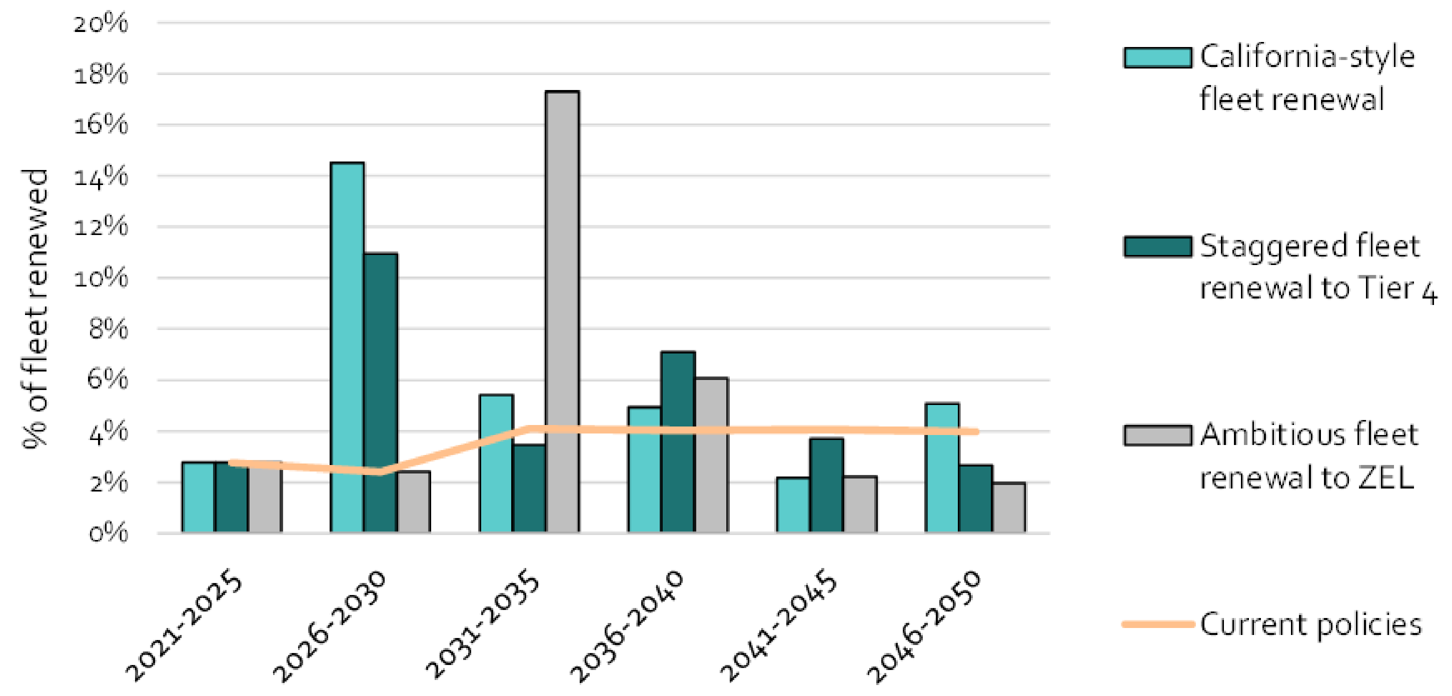
Rail sector GHG emissions in the Fleet Renewal Scenarios that require ZELs for line-haul service

- Fleet Renewal to ZELs for line-haul service result in substantial GHG reductions relative to the Current Policy scenario.
  - But still not consistent with net-zero
- Omitting SL&R railways from the Fleet Renewal policies has a modest impact on total sector GHG emissions
- Delaying the fleet renewal requirements by five years results in a similar delay in the GHG impact of the policy.
  - E.g., GHG impact in 2030/2035 of “Ambitious fleet renewal to ZEL” vs. “California-style fleet renewal”



Percent per year of new*, replaced, and repowered locomotives (avg.%/yr over each five-year period)

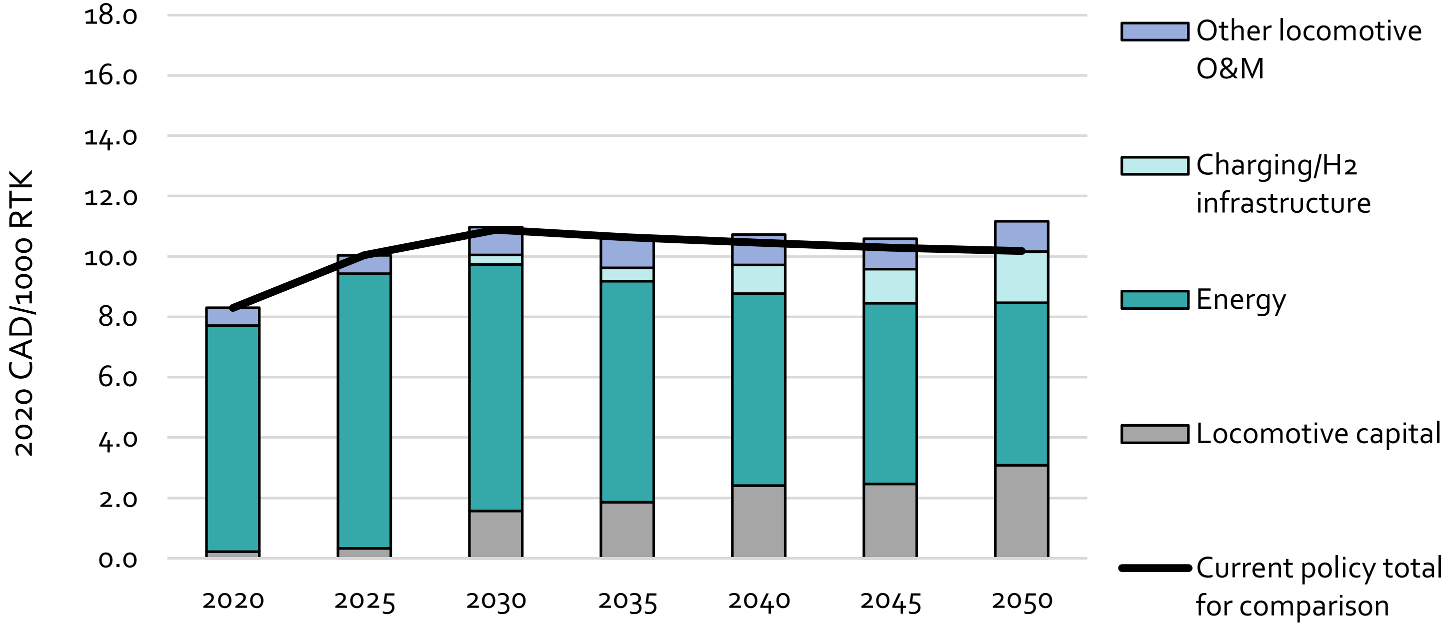
- Fleet Renewal Policies produce peaks in the "locomotive renewal rate"
- These peaks in renewal will begin before the policy in-force date if railways seek to mitigate their initial investment in ZELs with "early purchases" of diesel locomotives
- Peak renewal rates occur because many locomotives will be over the age limit when policies come into force
    - Mitigate peaks by differentiating maximum ages and policy in-force dates by Tier or vintage as well as by railway type (Class I vs. SL&R) and service type (line-haul vs. switcher)



* "New" means new additions to the fleet, which may include older used locomotives

Rail sector levelized costs, Fleet Renewal Scenarios

- In the figure: the California-Style Fleet Renewal Scenario (columns) vs. the Current Policy Scenario (black line)
- A shift in cost structure from energy to capital for locomotives and charging/refuelling infrastructure
- Lower energy costs generally cancel out greater capital costs



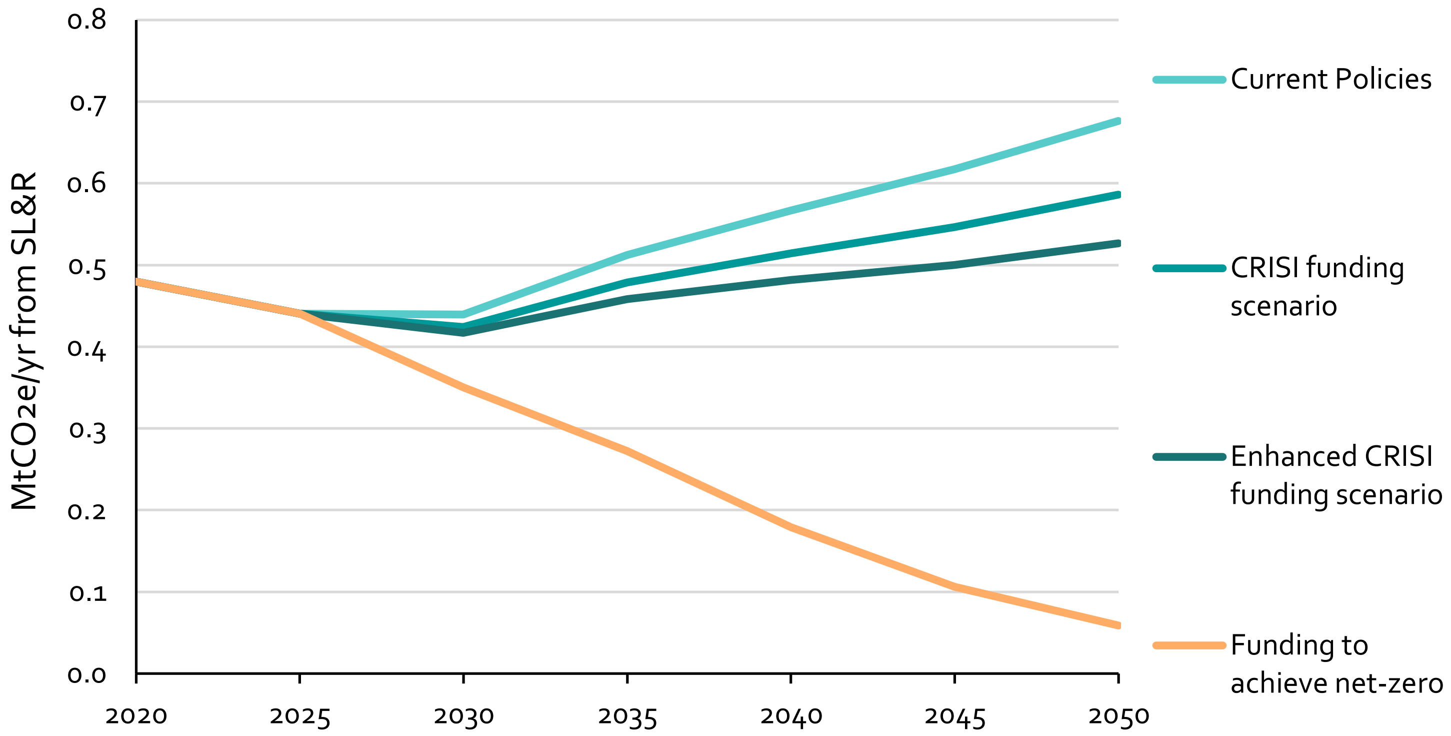
Capital is capital annuities amortized over 30 years at a 7% discount rate (opportunity cost of capital)

Incentive Scenarios

- **The CRISI Funding Scenario:** $21 million (CAD) available per year from 2026 through 2050 for SL&R railways to purchase ZELs and associated infrastructure (Based on US Federal Rail Admin. program, scaled to Canada)
- **The Enhanced CRISI Scenario:** The incentive is doubled to $42 million (CAD) per year.
- **The Funding to Achieve Net-Zero scenario:** The incentive is increased to $275 million (CAD) per year. This amount is enough to make the SL&R railway rolling stock consistent with net-zero (i.e., 80-90% of locomotives are ZELs by 2050). The purpose is to define an upper limit on the amount of support required to decarbonize SL&R railways using only an incentive-based policy approach.

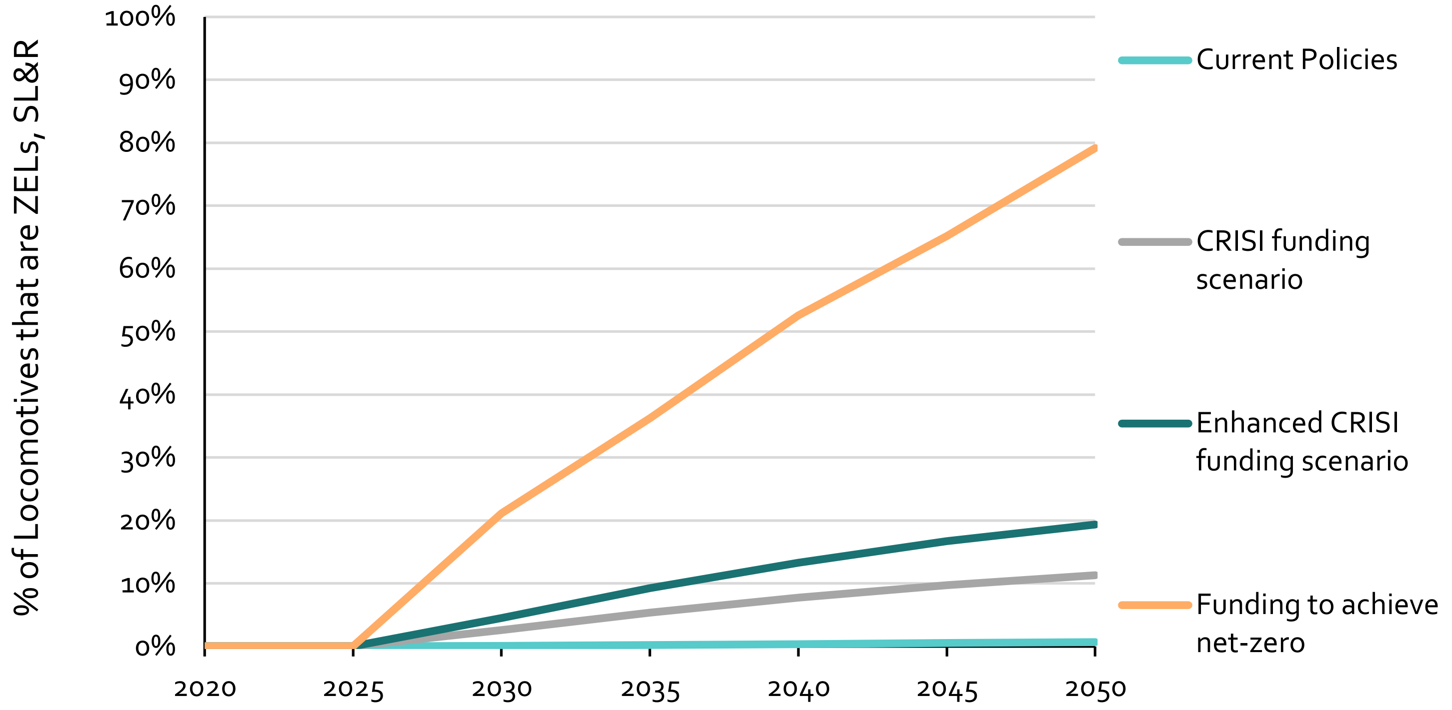
SL&R GHG emissions in the Incentives Scenarios

- Limited impact on sector-wide GHG emissions but potentially large impact on SL&R segment emissions
- GHG impact is due to increased ZEL adoption
- Funding to achieve net-zero: GHG impact in 2050 is ~ 620 kt CO_2. This is 91% of SL&R GHG emissions, equivalent to about 7% of rail sector GHG emissions



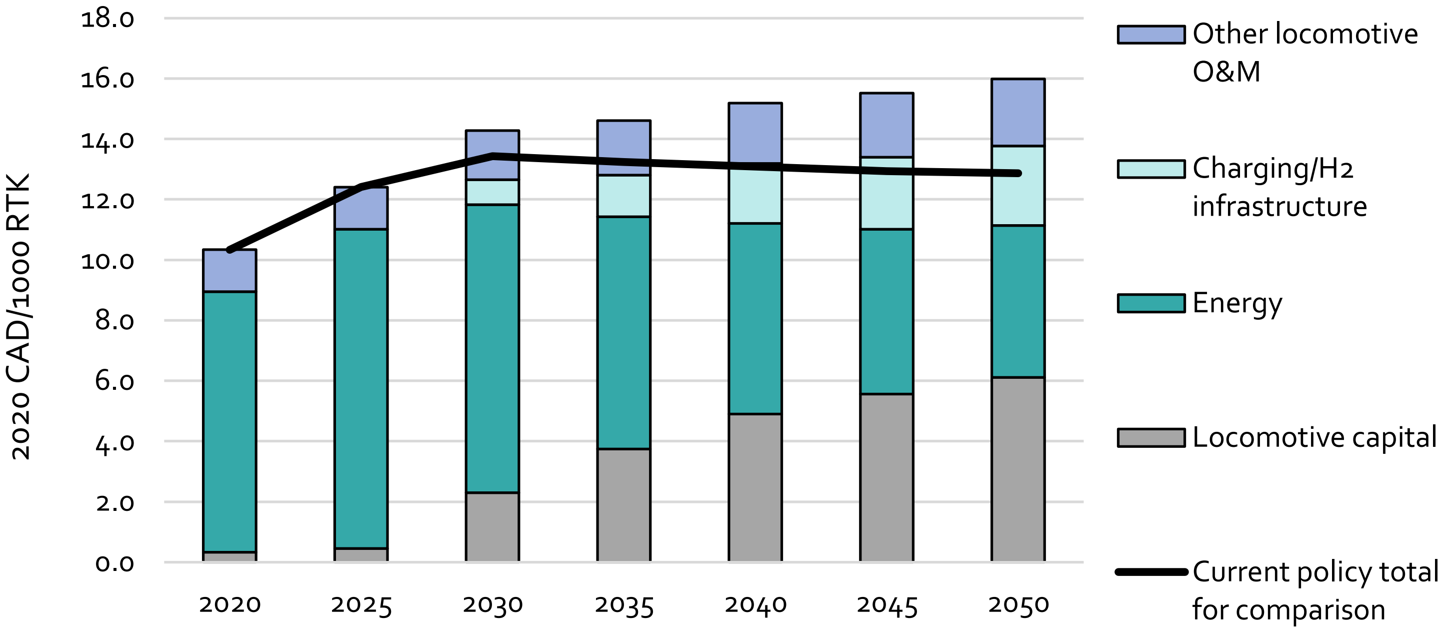
Percentage of SL&R Locomotives that are ZELs

- The GHG impacts of the Incentive Scenarios are not proportional to ZEL adoption since the funding applies to both switcher and line-haul locomotives.
- Adoption of line-haul ZEL results in more GHG abatement
- The impacts of the Incentive Scenarios are uncertain because the investment behaviour and capacity of SL&R railways is uncertain.
  - How capital constrained are they?
  - What payback periods can they sustain?



SL&R levelized costs, Incentive Scenarios

- In the figure: Funding to Net-Zero Scenario (columns) vs. the Current Policy Scenario (black line)
- The scenarios that include funding for SL&R railways have higher costs than in the Current Policy scenario
    - The government bears the additional cost in these scenarios
- A shift in cost structure from energy to capital for locomotives and charging/refuelling infrastructure



Capital is capital annuities amortized over 30 years at a 7% discount rate (opportunity cost of capital)

Opportunities for future work: Mode Shift

Limitation	Opportunity for Future Work
Mode shift between rail and truck and “carbon leakage” to the U.S. is not currently represented.	• Add a representation of competition between truck and rail transport, as well as competition between Canadian and U.S. rail carriers in the gTech model. • Test how “asymmetric” or “symmetric” climate policies impact rail and truck transport within Canada and the U.S. • Better understand the relative impact of greater rail costs resulting from GHG policy. Is the sector more or less competitive?

Opportunities for future work: CAC emissions

Limitation	Opportunity for Future Work
CAC emissions are not currently quantified, and we did not test CAC-focused policies.	• Add CAC emissions factors to each technology archetype and test the impact of policies on CAC emissions. • Add the capability to price CAC emissions with different methods for revenue recycling.

Opportunities for future work: Technologies

Limitation	Opportunity for Future Work
Representing emerging technologies is like trying to hit a moving target.	• Ongoing technology research and updates, integrated with engagement with stakeholders and other researchers. • Testing the sensitivity of the results to varying dates for commercial availability. • Test the impact of other ZEL types or different assumptions about charging/refueling infrastructure

Additional supporting information

Appendix

Current Policy and GHG Pathways Scenario Summary

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
Current Policy	Business as usual	N/A	N/A	N/A	N/A
SBTi pathway	SBTi GHG targets for Class I: -23.8% by 2030 from 2019 levels, net-zero by 2050 (-87% from 2005)	Class I only	Flexible	All tiers	2030 and 2050 GHG targets met by Class I locomotives, with linearly interpolated targets in between
Full rail sector net-zero	GHG cap on entire rail sector: -40% by 2030 from 2005 levels, net-zero by 2050 (-87% from 2005)	All locomotives	Flexible	All tiers	2030 and 2050 GHG targets met by all locomotives, with linearly interpolated targets in between
Staggered rail sector net-zero	Class I must reduce GHG by 40% from 2005 levels in 2030, reaching net-zero (-87% from 2005) by 2050. SL&R have a 10-year delay.	All locomotives (different timing)	Flexible	All tiers	2030 and 2050 targets to be met by Class I railways, SL&R railways must meet those same targets in 2040 and 2060.
DOE rail milestones	A GHG pathway combined with technology requirements	All locomotives	ZEL	50% of switchers to be ZELs, rising to 100% 40% of line-haul locomotives to be ZELs	In 2030: -30% freight rail GHG from 2019 levels In 2035: 50% switcher ZEL requirement 2040: 40% ZEL requirement for line-haul locomotives, 100% ZEL requirement for switchers In 2050: Sector-wide net-zero GHG accounting for construction, maintenance embodied carbon

Fleet Renewal Policy Scenario Summary

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
California-style	Based on California In-use Locomotive Regulation: Age limits and powertrain requirements for locomotives	All locomotives (to a different degree)	Tier 4 and then ZELs are required	All Tiers must retire 23 years after manufacture (or repowering to Tier 4). New locomotives must be ZELs.	The 23-year age limit and ZEL requirement for new switchers come into force in 2030. The ZEL requirement for all locomotives is in force by 2035.
California-style Class I	Same as above, but applied to Class I only	Class I locomotives only	Tier 4 and then ZELs are required	All Tiers must retire 23 years after manufacture (or repowering to Tier 4). New locomotives must be ZELs.	The 23-year age limit and ZEL requirement for new switchers come into force in 2030. The ZEL requirement for all locomotives is in force by 2035.
Class I renewal to Tier 4	Older Class I locomotives must be retired or become Tier 4	Class I locomotives only	Tier 4	Locomotives 30 years and older must be retired or repowered.	The Tier 4 requirement for 30-year-old locomotives comes into force in 2030.
Staggered renewal to Tier 4	Older locomotives must be retired or become Tier 4	All locomotives (staggered)	Tier 4	Locomotives 30 years and older must be retired or repowered to be Tier 4.	The Tier 4 requirement begins in 2030 for Class I and in 2040 for SL&R.
Ambitious fleet renewal to ZEL	Older locomotives must be retired or become ZEL	All locomotives	ZEL	Locomotives 25 years and older must be retired or repowered to be ZEL.	The ZEL requirement begins in 2035. All new locomotives must be ZELs as of 2035.
Ambitious fleet renewal to ZEL and Tier 4	Older locomotives must be retired or become ZEL and Tier 4	All locomotives	ZEL (switchers) Tier 4 (Line-haul)	Locomotives 25 years and older must be retired or repowered to be ZEL (switchers) or Tier 4 (line-haul).	The requirement begins in 2035.
Fleet renewal to ZEL and Tier 4	Older locomotives must be retired or become ZEL and Tier 4	All locomotives (staggered)	ZEL (switchers) Tier 4 (Line-haul)	Locomotives must be retired or repowered to be compliant after: • 25 years (Class I) • 35 years (SL&R)	The requirement begins in 2030 for line-haul locomotives and 2035 for switchers. New switchers must be ZELs starting in 2035.

Incentive Scenario Summary

Scenario Name	Scenario Description	Scope of the Policy	Tier or Propulsion System Required	Tier, Segment, or Age Affected	Effective Date
CRISI funding scenario	An incentive-based policy modelled on the U.S. CRISI program. We assume CAD 21M/yr in funding.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available in 2026 through the end of the forecast.
Enhanced CRISI funding scenario	An incentive-based policy modelled on the U.S. CRISI program. We assume CAD 42M/yr in funding.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available starting in 2026 through to the end of the forecast.
Funding to achieve net-zero	An incentive-based policy where the annual funding is enough to result in 80-90% ZELs in non-Class I railways.	SL&R only	Must be ZEL or ZEL infrastructure to be eligible for funding	N/A	Funding is available starting in 2026 through to the end of the forecast.

University of Lakehead

Dr. Seyedrahman Djafaripetroudy with the University of Lakehead reached out to the RAC in March with a research proposal titled *The Forgotten Waste to Sustainable Wealth: Unlocking the Magic of Underutilized Rail Wood Ties for Innovative Value-Added Products*. They are seeking partnerships to develop technology for the efficient removal of creosote from treated wood.

The research proposal was shared with the RAC Environment Committee for consideration. Ontario Northland Transportation Commission has offered to supply scrap rail ties for research purposes as an in-kind contribution.

Dr. Seyedrahman Djafaripetroudy will keep RAC apprised of the research.

Volatile Organic Compounds Consultation

Following the last Environment Committee (EC) meeting, Ken Roberge has conducted further analysis of the proposed Regulations. It has been identified that the discussed scenario of gasoline tanks at railway facilities used for fueling equipment would be exempt, even those with tanks over 4,000 litres in size.

The key section is s. 14 which states that for the purposes of these Regulations, all gasoline is considered to have a VOC concentration of 100% by weight, a TVP of 65 kPa and a benzene concentration of 1% by weight.

Given this, 2(f) would be the primary exemption to use:

These Regulations do not apply to the following facilities:

2(f) facilities where the following conditions are met:
i) The tanks at the facility never store and the loading racks at the facility never load volatile petroleum liquids with a TVP greater than 76 kPa or a benzene concentration greater than 1% by weight,
ii) The sum of the internal volume of all tanks at the facility used to store volatile petroleum liquids is less than 500 m3, and
iii) The total volume of volatile petroleum liquid loaded at the facility does not exceed 1000 standard m3 in a calendar year.

Since gasoline has a TVP of 65 kPa (i.e. not greater than 76 kPa) and a benzene concentration of 1% (i.e. not greater than 1% by weight) you would be exempt provided the sum of the internal volume of all gasoline tanks at the facility is less than 500,000 litres (500 cubic metres) and the total volume of gasoline loaded at the facility does not exceed

1M litres (1000 cubic metres) in a calendar year which should not be an issue for any railway facilities.

Given this, it has been determined there is no longer a need to file comments. This assumes that no railway members have any other facilities that would trigger the proposed Regulations that they want considered (none were raised during the last EC meeting).

Right to a Healthy Environment Consultation

Environment and Climate Change Canada issued a discussion document earlier this year to provide opportunity for stakeholders to share their views on matters of environmental justice, racism, and sustainability under the Canadian Environmental Protection Act (CEPA). Environment Committee members discussed opportunity to highlight the rail sector's existing contributions to these concepts (e.g., Proximity Initiative, MOU with Transport Canada to reduce locomotive emissions, TRANSCAER, and other member initiatives).

Comments were drafted for EC review. However, as the submission navigated the approvals process the ongoing labour challenges (i.e., threat of rail strikes) diverted available resources of government relations representatives involved in the review process. It was determined that not enough time was available to finalize comments and that industry should wait for the next commenting opportunity once the draft framework is published in fall 2024.

Rail Electrification Coalition

RAC attended a workshop hosted by the Rail Electrification Coalition with the intent of strictly observing the proceedings. Discussions included case studies of rail electrification (i.e., India), research, rail transportation for portable batteries, passenger rail perspectives, and co-location of transmission infrastructure on ROW. Summary notes from the workshop are available in the briefing booklet.

SUMMARY

The RAIL ELECTRIFICATION COALITION'S
April 30, 2024
ELECTRIFICATION WORKSHOP

During its second major Workshop, the REC continues its search for feasible pathways to railroad electrification in North America. We believe the interest in rail electrification is climbing the list of national priorities as other modes of transportation electrify, as the supply chains become more competitive, as the electric power business is transforming technologically and operationally, and as public and private infrastructure investment amps up. The coming changes in the energy and transportation economies stir new questions about the role of government in driving, guiding, or funding new developments, whether industries as critical as electric power and railroads can change, communicate, and collaborate to advance their respective economic interests and historical advantages, and how the timing and depth of electrification measures will impact regulation and system planning, manufacturing priorities and technological advances, investment patterns, and state and federal public policy, and consumer and community developments around the country.

The REC April 2024 WORKSHOP is focused on diverse case studies and new innovations principally in the railroad industry. The record of innovation and deployment of proven electric technologies is surprisingly robust. It presents new opportunities for both electric utilities and developers and the rail companies themselves, many times involving proven technologies and motive power approaches that were both proven and deployed more than a half century ago. That does not make today's business decisions facing Class I and other railroads any less complicated, but we believe that investing in these deliberations will help point companies, their suppliers, and customers in new directions. Recognizing that public policy is changing rapidly at FERC, DOE, DOT, on Capitol Hill and at the State level, our Coalition encourages exploration of new proposals, techniques, and projects which point the way toward electrification, digitalization, clean energy, and transportation efficiency.

Note: "This summary is not a transcript. It is based on notes taken in good faith, without identifying names or companies, to encourage open comment. We regret any errors."

THE WORKSHOP began at 9:00 a.m.

CASE STUDY 1: BRIEFING FROM INDIA ON ITS PATH TO NET ZERO

Representatives from USAID, New Delhi, and Indian Railways

India has committed to reaching net zero emissions by 2070 and has set targets to achieve 50% of its energy requirements from non-fossil fuel sources by 2030. The International Energy Agency stated in its Net Zero 2050 report that "more efforts are needed" by the world's rail systems. India has emerged as an unlikely hero. Consistent with its big commitment made at COP28 in Dubai, India's rail network is now 94% electrified – an achievement largely made in the past decade. Indian Railways had signed a Memorandum of Understanding with US AID to collaborate on investing in energy efficient buildings in close proximity to the railways, procurement of round the clock renewable energy power for traction loads, and the adoption of EV's across Indian Railways. Energy storage has been a key asset for peak load management as India's rail electrification progressed.

India Railways has electrified 40,000 km of track since 2014 at a cost of about $5.5 Billion, jumping in the ranks of the Climate Change Performance Index (CCPI) from 31st to 7th despite its massive population and being 139th in per capital GDP. Behind electrification is an effort to move up the development trajectory from dependence on its abundant coal supply for fuel (for steam), to petroleum, to investments in solar and other renewables, and digitalization. Indian Railways plans to be a net-zero emitter by 2030. The Modi Government drove electrification, despite India's significant coal and oil resources, because of its climate commitments and the central importance of railroads to the country's economy and supply chains. It's fair to say that the speed of the conversion to rail electrification in India is unprecedented.

Discussion included:

1. What lessons can be fairly drawn from India's drive for rail electrification? Is North America in a better or worse position to perform as well on the range of climate change metrics?
2. Is Indian Railways as strong a service provider to the Indian economy as North American Class1s? Are there technological differences that make changes to the rail system more possible (e.g., passenger service as a bigger share, lighter rail equipment, less difficult terrain, etc)?
3. The major shift in Indian railway electrification is in part the product of a government industrial policy. However, the investments are strongly supported by the private sector.
   For instance, the government has allocated $2.2B to develop 5 million metric tons of green hydrogen and 125 GW of renewable resources; another $200B is pledged by private capital in support of India's energy roadmap. Is the US infrastructure legislation in 2022 sufficient to match this performance?

INTRODUCTION OF RAIL ELECTRIFICATION STUDY [*IN PROGRESS*]: COST AND BENEFIT RISK FRAMEWORK FOR MODERN RAILWAY ELECTRIFICATION OPTIONS

Presenter: Rydell Walthall, Doctoral Student, University of Texas.

With funding by the Federal Railroad Administration, the University of Texas commenced research on a cost and benefit risk framework for assessing modern railway electrification options. The project will examine past electrification efforts to identify the organizational, technical, and economic reasons they were or were not implemented, and what conditions might make rail electrification feasible going forward. The project, which is planned for completion during the Fall of 2024, contains (3) tasks: a review of past/current railway electrification studies, a review of alternative technologies and strategic implementation approaches, and the development and demonstration of an updated risk-based electrification benefit-cost framework. The study will also look at electrification case studies from other countries Walthall pointed to a similar study in Scotland showing a 60% cost reduction from discontinuous electrification (i.e., a concept that reduces infrastructure clearance costs by leaving gaps in overhead line equipment where non-compliant structures exist and using on-board energy storage systems to power trains across those gaps). While there is no opportunity for public comment on the framework, an industry advisory panel is being created to provide input as it is developed.

CASE STUDY 2: WHAT ROLE WILL ENERGY STORAGE PLAY IN RAIL MODERNIZATION? This session explored new ideas about rail-based deployment of energy storage and dispatch. Rail transportation is emerging as a testbed for energy storage technologies (e.g., batteries) as an alternative to investment in electric transmission and another way to deliver clean electrical generation. The Workshop explores how near these exciting new undertakings are to actual deployment and the potential that battery technology has for transforming the electric power and transportation systems. Batteries could provide an economical means to capture regenerative power and a motive power resource that is mobile, unlike catenary.

Senior Executive, Global Strategy & Marketing, Locomotive Manufacturer
This manufacturer produces a 100% battery-electric, heavy-haul locomotive capable of a maximum battery capacity of 8MWh. It had worked with a Class I railroad on a heavy-haul battery locomotive project in California. Over a three-month pilot program, the battery-driven locomotive has delivered more than an 11 % average reduction in fuel consumption and greenhouse gas emissions for an entire train saving over 6,200 gallons of diesel fuel and approximately 69 tons of CO2 emissions reduced. Regenerative braking was able to capture up to 30% of the energy from the battery, allowing it to charge twice, thereby saving fuel in the process.

Researchers, Lawrence Berkley National Labs (LBNL)
The researchers discussed the LBNL study which finds that rail-based mobile energy storage is a feasible way to ensure reliability inn response to extreme weather events and other exigencies. Batteries aboard trains are a cost-effective option for backup power. The published analysis found that mobile energy storage could travel between major power markets along existing rail lines within a week without disrupting freight schedules. A good example of this would be the State of New York, its rail network could utilize rail-based mobile energy storage to overcome the current transmission constraint between upstate clean energy generation and downstate load centers.

CEO, entrepreneurial developer proposes to move energy via utility-scale battery facilities scaled up as part of unit trains.
The concept for this organization is based on using the rail network to supply massive amounts of mobile energy, even as baseload when the freight rail system is not utilized at capacity. Coal railway substations that have been decommissioned are/can be used as charging stations for these utility scale batteries. They are currently working with two Class I railroads and have determined that the pricing model for transporting these batteries is similar to deploying transmission technology; however, such rail-based storage can be deployed for similar purposes in 24 months, compared to 10-15 years to develop transmission solution to reliability challenges. Another use case for this

model would be temporary power for first responders in the aftermath of a natural disasters. It is argued that rail-based energy delivery has reliability advantages even over the use of rail for conventional supply chain deliveries. This model of rail-based energy delivery could create novel questions about whether FERC or the STB would have sole regulatory oversight of this model and which grid entity would manage the dispatch of this storage. The developer is already advancing a prototype and an interconnection application in the West.

Discussion questions included:

1. What is the feasible future role of battery technology in supporting expansion of the electric grid, either as a mobile resource, a resilience or reliability asset, a network real estate support, major load, or a combination?
2. How might the use of battery-powered locomotive propulsion impact the need for catenary, and vice versa? Is there a strategic case for deploying catenary and battery technology jointly as a major or intermediate step toward rail electrification?
3. As part of locomotive propulsion systems, does the use of batteries as either propulsion or as grid support necessarily require development of a network of external charging facilities?
4. Does current development of prototype battery-electric locomotives indicate there is a nascent movement in the industry to a move away from established (diesel) traction?
5. What are battery capabilities now and potentially in the future, especially for heavy freight transport? What are their best uses and major disadvantages?
6. What battery technologies are best suited to railroad use, both on-board and trackside, at the present time? What technological developments will enhance that suitability?
7. Does the potential for delivering electric power from mobile sources like a unit train represent potential alternative or complement to development of macrogrid facilities? Can such development become an alternative base load resource in some regions? What is the potential impact on grid resilience and reliability? What appetite do investors have for such long-term investment?
8. What differences, if any, from the international state-of-the-art catenary installation will North America require?
9. What companies can build the machines that build the catenary? Can the electrification process be "industrialized" to support rapid implementation?
10. How is the Benefit-Cost Analysis of the catenary and battery/hybrid balance determined?

CASE STUDY 3: TRANSMISSION CO-LOCATION WITH RAIL. The Workshop continued previous discussion of the opportunity to install HVDC, HVAC, or lower voltage electric facilities alongside existing rights-of-way (e.g., railroads or highways). At a moment when transmission expansion and upgrades are needed to address coming challenges from extreme weather, massive demand growth, snarled supply chains, and a need to access more non-fossil energy, transmission development has proven incredibly difficult, in part due to regulatory delay at the state level and outmoded methods of planning the grid regionally or inter-regionally. Using existing rights of way – including railroads, highways, existing transmission corridors, even pipeline routes – offers the prospect of reducing the need for massive environmental reviews of "greenfield" properties, eminent domain, and long delays. That opportunity has not been clearly recognized by DOE, FERC, or DOT except in passing, while some state governments have helped to encourage use of "brownfield" (i.e., industrial, or established rights-of-way) to minimize community impacts and help regulated utilities preserve local reliability. What's the experience so far and are railroads paying attention?

Director of Corridor Services, Class I Railroad

This Class I Railroad is working with a transmission developer and regulators in the Northeast as part of their project to bring wind and hydropower from Quebec to New York City. Railroad websites often have online tutorials and a portal through which property assets can be identified. The permitting process for a utility to use an existing railroad rights-of-way starts with an application on the electric power side, which then goes through quality control and engineering review before the agreement between the railroad and the developer is created and executed. There are several things to consider on 3rd party installations along rights-of-way, especially railroad operations, design, and construction. Inductive interference from parallel overhead lines (AC) can pose safety risks and the potential for disrupting railroad communications and signaling. Railroad rights-of -way are not universal in width so when burying HVDC it needs to be at the edge of the property line. Train operations need to be able to continue during construction so future interactions between the utility and the railroad are reduced. Access is critical both in construction as well as maintenance. That said, the rail network and its associated real property network may actually be a natural site for interregional electric transmission that may need to cross utility boundaries, market boundaries, and regional grid or state boundaries with differing environmental regulations and community interests. It can be a totally different conversation if an abandoned right-of-way is being considered. Class I railroads generally know what they own and whether their rights-of-way will support installation of lateral facilities for non-railroad purposes.

VP Development, Transmission Developer
Large renewable energy developers recognize the major need for more transmission investment. Several barriers can impede the timeliness and cost-effectiveness of transmission planning, design, and construction – not the least of which is permitting and siting which is typically managed by the states and increasingly subject to multiple stakeholder and community engagement requirements. Access to established rights-of way is an important option for overcoming those barriers. The transmission companies, especially those that seek to develop projects that would be built in more than one market or jurisdiction, need to plan for worst case scenarios with respect to transmission planning. Geospatial tools are used to identify potential areas of opportunity for best routes. Any transmission modeling needs to fully quantify all benefits. There are layers of factors to consider with respect to the location of a project and the impact on communities and landowners. Using railroad or other rights-of-way will be preceded by extensive commercial negotiations, just as might be the case for private "greenfield" property. The Class I railroad representative agreed with that observation.

Advisor, Department of Energy, Grid Deployment Office, and former RTO planner
Transmission is currently a hot topic, both at the DOE and at FERC. The DOE will soon be releasing updated guidance on National Interest Electric Transmission Corridors (NIETC). Acting through two of its national labs (National Renewable Energy Lab and Pacific Northwest National Lab) as well as GDO, DOE will issue this summer the National Transmission Planning Study, a multi-model framework for better understanding the role, value, and opportunities for US transmission development mapped out in over 100 future scenarios and solutions. There is a need for a shared vision of the "electric future" and greater collaboration between state and federal government and between government and industry. After DOE issues for comment its proposed designations of NIETC corridors (very soon), FERC will establish procedures for reviewing and authorizing projects proposed for location within such designated corridors. More importantly is FERC's forthcoming major Final Rule on transmission planning and cost allocation. [See below] Ten years after FERC's last major rulemaking on transmission planning, the agency and its constituents generally recognize that sufficient transmission, especially interregional transmission

projects that can bring renewables to market and enhance the system's reliability and resilience, are not being considered and built in time to meet the national need for such capacity arising from a surge in electric demand, increases in extreme weather that threaten reliability, and looming decarbonization goals.

Discussion questions:

Electric Grid Synergy

1. What are the needs of the electric industry for new transmission corridors?
2. Do railroad ROWs have particular advantages/disadvantages for transmission co-location? Do railroads view this as a legitimate long-term business opportunity? What practical questions must be answered to evaluate the co-location of new transmission lines along rail rights-of-way? Are priorities compatible between rail and utilities or developers?
3. What considerations impact the sharing of risks and economic benefits between railroad ROW owners and high voltage transmission developers? Can an electrified railroad serve both the needs of the larger grid and local needs for power and transportation?
4. Will rail electrification expand the market for the construction of new remote renewable power generation?
5. What is the value of grid-connected idle switching (and road) locomotives offering peak shaving, line conditioning, and backup electric power?
6. What potential benefits to trackside communities could be available as a result of installation of high voltage?
7. What other elements could use grid electric power, such as reefer units and crossing signals, charging stations?

Power Delivery

8. What are the cost and construction implications of each power delivery method (i.e., overhead wire, third rail, induction from buried cable, etc.?) Can a forensic and credible analysis demonstrate the variations, strengths, and weaknesses?
9. Installation of underground cable will entail disturbing a ROW; what issues does this raise for potential waste disposal, impacts on adjacent landowners, and reduction in permitting time and complexity compared to "greenfield" development.
10. What is the experience with overhead catenary suffering pole and wire damage from shifted loads and/or damaged railcars? How can this risk be minimized?
11. What are the lifecycle economics of using composite catenary poles versus steel poles?
12. What is the experience with catenary clearing double-stacked containers and other taller railcars?
13. Can power suitable for locomotives be drawn from very high-voltage transmission lines? How could this affect transmission development decision.

*[**NOTE**: Side conversations during lunch involved the planning and cost allocation reforms that the FERC will consider during its May 13 open meeting. The Coalition has commented multiple times on the need to explore the use of existing rights-of-way for the co-location of major transmission facilities. FERC Order No. 1920 (Docket Nos. RM21-17-000) and Order No. 1977 (Docket No. RM22-7-000); also, DOE has designated National Interest Electric Transmission Corridors under FPA §216, which is the predicate for transfer of some state siting authority to FERC. Docket DOE-HQ-2023-0039-0001.]*

CASE STUDY 4: A REPORT FROM THE PASSENGER SIDE. Because of North America's vast expanse and competition from highway transportation (in part supported by taxpayers), passenger rail is widely available only in metropolitan areas and in the Northeast US. Asian and European countries have invested more heavily in passenger service as a principal mode of moving people. The US has fewer miles of electrified rail than Uzbekistan, according to a recent Sierra Club report. Amtrak has received a recent infusion of funds, but much of it will be required for the improvement of existing railbed. Amtrak may consider electrifying more of its routes outside of the Northeast, but outcomes are not clear. The many individuals and organizations that are working to expand passenger rail services across the country also support greater investment in commuter services and in high-speed rail in North America between now and 2050.

Representatives, California High Speed Rail Authority
The California HSR Authority is a 494-mile electrified rail corridor that will connect San Francisco to Los Angeles/Anaheim in Phase 1 of the project. The subsequent Phase 2 will extend 300 miles to provide connections to Sacramento and San Diego. Trains will travel at approximately 220 mph. Currently 119 miles are under construction, approximately 422 miles have been environmentally cleared, and (4) Central Valley Stations are being designed. Since the start of the project, over 13,000 construction jobs have been created and 840 small businesses have been employed. There has been an overall push for interoperability throughout the project. Among the efficiency benefits of the electrified high-speed trains is its ability to supply regenerative power for up to 18% of the system's needs. Under the Infrastructure Investment and Jobs Act (IIJA), over $3.3Billion grant funds have been received to help fund this project. Coordination with the local utility suppliers will be achieved via traction power substations placed approximately every 30 miles along the corridor to provide load balancing and reliability services.

Director, Virginia Rail Policy Institute (VRPI)
VRPI's mission is to strengthen and improve public policy with respect to both freight and passenger rail in the Commonwealth of Virginia. VRPI's studies include truck diversion to rail; shared use, high performance infrastructure; optimal station design, autonomous rail vehicles; and public incentives for common carrier best practices. One potential concept for further exploration is the North American Steel Interstate System (SIS) which is a concept of a core national network of high-capacity, grade-separated, electrified railroad mainlines. SIS freight trains will operate on one track at truck-competitive speeds, while passenger trains will travel on the other track at auto-competitive speeds. This could be demonstrated in the Interstate-81 corridor. Virginia is well-suited to extend the Northeast Corridors (NEC) electrification to cover the reach of the NEC regionals into VA. VRPI promotes electrification of the Richmond-Washington corridor, with 20 stations and multiple round trips daily.

Chair, US Rail Passenger Association
The Rail Passenger Association is the largest advocacy organization for rail passengers in the United States. It is a transformational period for passenger rail transportation in America, case in point the State of Virginia which has made significant progress in improving transforming its rail network via a 10-year, $4 Billion program. Rail is the optimal solution to alleviate traffic congestion along the interstate 95 corridor between Richmond and Washington, DC. There are gaps in our current US passenger rail systems that can result in people not having easy access to essentials such as healthcare, particularly in rural locations. An enhanced electrified national passenger rail network can provide more trains for people in these areas allowing them to improve their economic and social well-being.

Discussion Questions

1. Is improvement of passenger rail service to communities, especially those in rural America and rural Canada or Mexico, a sufficiently high priority among state and federal transportation legislators and other policy makers?

2. Can electric power and transportation policy makers work collaboratively to make deployment of their network industry resources more efficient and environmentally positive using strategic electrification and decarbonization?
3. What are the expected levels of investment in (non-local transit) passenger rail in the US? In Canada? What have been the most helpful/strategic investments of public monies the last two years and going forward? Does Congress need to do more?
4. How would electrification strategies for (non-electric) passenger rail compare to those for Class I, II, or III freight rail in terms of tactical steps, timing, or the available technological alternatives?
5. What is the per gallon price of diesel that would make electrification an obvious economic choice? Is this the key metric or only part of a more complex analysis?
6. How can locomotives be designed to take advantage of regenerative braking, vibration harvesting, and other waste energy capture methods?
7. What portion of the North American rail network should be electrified?
8. How are target sections determined?
9. How should electrification be staged to secure maximum benefits?
10. How will electrification coexist with residual diesel-powered segments?
11. What models of locomotives are candidates for conversion in the relatively near-term? Is this the most cost-effective option or an incremental approach?
12. What companies can perform the conversions?
13. How many fewer all-electric locomotives can be employed for the same service(s), compared to the same train using diesel-electric power?
14. What concerns do railroad management have about a move away from established (diesel) traction? To what extent do investors, consumers, and policy makers share those How can their fears be addressed or balanced by anticipation of new economic opportunities or social gains?
15. What entities and resources can (or should) be mobilized to advance such an industry transformation carefully but deliberately and economically?

The Workshop concluded at 3:30, after brief announcement regarding the following planned events later this year: a Public and Private Investment conference in the Fall 2024, most likely combined with the REC Annual meeting, and a possible third workshop.

(All the slides from this workshop are available on the Coalitions Website)

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During all Coalition meetings, the central question we seek to answer is ----

Can we identify ways to ensure that technology developers, railroads, investors, and policymakers make the wisest energy and operational efficiency decisions so that North American railroads can (1) contribute o lowering the emissions and resource requirements of freight and passenger movement, (2) capitalize on their current and potential efficiencies to sustain and grow rail's market share, strengthen supply chains, enhance customer services, and participate in expansion and strengthening the electric system, and (3) attract private and public capital sufficient to support the transition to a cleaner energy economy?

If your company or organization desire to become an official member in the Coalition, you may apply via the following URL:
Rail Electrification Coalition Membership Application