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DECARBONIZING LONG-HAUL TRUCKING IN EASTERN CANADA

PART 1 | Summary of a workshop held on April 25, 26 and 27, 2023

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Québec

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NOTE

The observations and conclusions put forward by the authors of this report are based on the highlights of discussions among participants during roundtables and do not necessarily reflect the opinions of the Québec Government.

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Executive summary

Reducing greenhouse gas (GHG) emissions from long-haul road freight is one of the greatest challenges for reaching climate objectives given the recent trends, the complexity of the sector and the need for interoperability across borders. The freight sector accounts for 9% of Québec's and Ontario's total emissions. However, the challenge is compounded by the fast-growing emissions of heavy duty trucks: 67% in Québec and 61% in Ontario between 1990 and 2019.[1] Furthermore, a lack of interregional comparative studies of different net zero technologies in key corridors limits the effectiveness of government and private actions. As a result, there is an urgent need to review options to reverse these trends.

Achieving net zero goals by 2050 imposes decisive concerted action, considering that globalization and increased trade flows, accelerated by e-commerce, will continue to increase demand for goods – and consequently GHG emissions. The Chair in Energy Sector Management at HEC Montréal and CPCS are carrying out, in collaboration with the Government of Québec, a techno-economic assessment comparing Class 8 technologies (weighing more than 27,215 kg) to decarbonize long-haul trucking, with a focus on the Autoroute 20 and Highway 401 corridor between Québec City and Windsor. The four technologies include:

1) Electric road system with overhead conductive transmission (ERS-OCT)
2) Battery electric trucks
3) Hydrogen fuel cell electric trucks
4) Renewable natural gas trucks

This report summarizes the main recommendations from the workshop *Decarbonizing Long-Haul Trucking in Eastern Canada: A Comparison of Technologies on the A20-H401 Highway Corridor Between Québec and Windsor* held on April 25, 26, and 27, 2023, as the first part of the study. The second part consists of a report presenting the results of a cost comparison analysis of the net zero technologies on the A20-H401 highway corridor between Québec City and Windsor.[2] The purpose of the event was to explore and validate with experts from industry, government, academic and professional both the larger decarbonization context for the trucking sector in Eastern Canada and the key techno-economic parameters and assumptions to consider in the analysis.

The workshop, which brought together about 60 experts from various sectors and decision-making levels and regions, including Ontario, Québec, US and the European Union (see list in Appendix 1), was an opportunity to (1) transparently improve the proposed methodology; (2) identify key factors that can impacts the technologies in Eastern Canadian context; (3) define assumptions on costs trends; (4) address issues with current government actions to accelerate the decarbonization of long-haul road freight; (5) identify additional support to accelerate the transition to net zero options; and (6) identify priority needs to support fleets and business owners in the early phase to reach net zero transition by 2050. Considerations on how to improve efficiency, modal shift and logistics in freight to support net zero long-haul freight technologies were discussed, as well as options for improving cooperation and involvement of stakeholders.

[1] ECCC, 2023. *National Inventory Report 1990–2021: Greenhouse Gas Sources and Sinks in Canada*. Annex 12 - Provincial and Territorial Greenhouse Gas Emission Tables by Canadian Economic Sector, 1990–2021, Environment and Climate Change Canada

[2] Roberts, N., Cyr, M., Whitmore, J., P.-O. Pineau, P.-O., 2023. *Decarbonizing Long-Haul Trucking in Eastern Canada: Part 2 - A cost comparison analysis of net zero technologies on the A20-H401 Corridor Between Québec and Windsor*, prepared by CPCS and the Chair in Energy Sector Management - HEC Montréal for the Government of Québec, https://energie.hec.ca/decabonizing-long-haul-trucking-in-eastern-canada .

While a wide variety of opinions were expressed during the round tables, there was a convergence of views on the need for greater access to data sharing and interregional collaboration for accelerating deployment of innovative solution for decarbonizing long-haul road freight transportation. The main findings presented below reflect key findings, challenges and opportunities raised in the four virtual round tables.

Considerations for improving modelling methodology

After reviewing the proposed modelling approach and techno-economic parameters considered for the simulation, participants provided detailed comments and recommendations to improve the methodology (see Appendix 2). Many recommendations were outside the scope of analysis of the current study (given the resource and time constraints) but could be mentioned for consideration in future work. There were four main findings:

1. **An open and collaborative methodological approach in evaluating the feasibility of different technologies is needed to clearly understand the limitations of the results,** as well as to avoid introducing biases. The current study is a first step towards an open approach.
2. **Future studies building on this one should broaden the scope of analysis.** Additional techno-economic modelling parameters should be included to better account for the complexity of net zero truck technologies, infrastructures, highway utilization and cross border markets.
3. **Measuring uncertainty and key trends using sensitivity analysis is needed to understand the limitations of results.** Given that the proposed study is a first step towards an open approach, results need to be presented with caveats to clearly account for limitations.
4. **Coordinated data collection, access and transparency between Québec, Ontario and neighboring US states is needed** to develop reliable and credible hypotheses in models and scenarios, and for the evaluation of the techno-economic potential of the different technologies on shared highway corridors.

Technological challenges, maturity and availability

Participants provided perspectives on gaps that need to be filled to reduce uncertainty, hedge risk and support large-scale deployment of net zero long-haul truck technologies. From the discussions, tow main findings were identified:

5. **Defining a time horizon for large-scale commercialization and deployment of net zero technologies is challenging due to uncertainties.** Many factors contribute to this uncertainty, but the difficulty to access information from manufacturers and fleet owners, low net zero truck supply in Canada and the lack of refueling or recharging infrastructure were seen as key factors.
6. **Technological challenges in the context of cold climates were generally viewed as manageable when planned into logistic operations.** Fleet owners favor technologies with simpler components, which are easier to maintain. Cold weather operations were seen as less of a concern.

Perspectives on government actions for the decarbonization of long-haul trucking

Most participants expressed a medium level of satisfaction with the current state of government actions for the decarbonization of long-haul trucking. Two main findings emerged:

7. **The lack of coordination between and within governments on measures and data-sharing** is recognized as the main source of dissatisfaction with the current state of government actions to decarbonize long-haul trucking.

8. **The trucking sector is hesitant to adopt new technology without a viable business case or regulatory policies to push adoption.** The "wait-and-see" attitude of the market leads to a **"race for second place"**– a trend to be the second to adopt a new technology to reduce risk and learn from the early adopters.

Options for improving government actions

Given that each technology presents different potential and risks, participants were asked what additional actions governments could take to support them. Four courses of actions were identified:

9. **Maintaining a technology neutral approach to policy development based on measures of emissions reduction outcomes** (i.e., performance-based metrics) **preserves flexibility** to address the best path towards reaching net zero goals while ensuring a leveled playing field in the market. However, **the approach could present a challenge for supporting significant infrastructure investment and deployment.**
10. **To accelerate the deployment of net zero truck technologies and their infrastructure, governments should adopt a common timetable with deadlines leading to a decision.** Germany's framework was provided as an example of a timeline that defines a scaled trial period of multiple technologies but sets a near-term window for making key decision on optimal technological pathways[3].
11. **The federal government should implement a comprehensive approach for improving cross-border coordination of collaborative trial projects** to evaluate on a common basis the performance of net zero technologies and to promote investment and risk sharing associated with the demonstration and full-scale implementation of new technologies.
12. **Government should make data transparency and dissemination of trial and pilot results a conditionality for receiving public funding.** This would foster collective learning, knowledge transfer and data sharing for further studies.

Priorities to support fleet owners in the early phase

Because the trucking industry is reluctant to change, there is a need for additional capacity to support an economic business case for shifting to new technologies. Participants were asked to define key priorities that could provide additional support to fleets owners and businesses in the early phase of transitioning towards net zero technologies. Two courses of action were identified:

13. **Improve data access and transparency to ensure a wide range of stakeholders can benefit from the knowledge gained from trials and pilot projects.** Increase data sharing on performance, markets and financials of new technologies would improve fleet owners' decision-making process for transitioning towards a net zero business model.
14. **Increase capacity for the training of fleet maintenance technicians, accessing service stations and improving awareness at the operation levels to support new technologies**.

Leveraging improved logistics to support net zero long-haul truck technologies

Participants were asked how improving efficiency, modal shift and logistics in freight could be a leverage for supporting net zero long-haul freight technologies. Fewer answers were provided as the question was optional.

[3] BMDV, 2020. *Overall Approach of climate-friendly commercial vehicles*, Government of Germany, https://bmdv.bund.de/SharedDocs/EN/publications/overall-approach-climate-friendly-commercial-vehicles.pdf

However, two perspectives could be noted.

15. **A systemic approach to intervention should be applied for the sector to successfully and structurally transition**. This implies looking at multi-modal solutions for the Québec-Windsor corridor (e.g., shifting road freight to rail or maritime), measures to optimize truck loads and implementing circular economy strategies.
16. **Shifting road freight to rail as a lower carbon mode and cheaper option of freight transportation should be part of government policies.** There is a gap to fill in terms of long-term rail infrastructure investment and policy development in the context of its role in decarbonizing freight transportation.

Options for improving stakeholder collaboration and engagement

In terms of stakeholder collaboration to accelerate reaching net zero goals for long-haul road freight, many participants stated that processes should be more inclusive, transparent and structured to take into account various expertise. Collaborative initiatives can build on existing initiatives. Cross-border dimensions should be accounted for, as well as results from international modelling initiatives (e.g., US National Renewable Energy Laboratory, OECD's International Transportation Forum). Two main courses of actions were identified:

17. **Make existing processes more transparent and inclusive by creating working groups** that include stakeholders from the business, academic and government sectors. The governance structure of the working groups could draw from existing initiatives (e.g., Québec's *Groupe de travail sur la décarbonation de l'industrie maritime*[4]).
18. **Hold periodic consultations to provide updates on progress and identify common data needed for accelerating the deployment of net zero truck technologies and infrastructure on key corridors[5].** To do this, the governments could mandate a review and stakeholder consultation cycle in its decision-making process. *The Great Lakes St. Lawrence Governors & Premiers* coordination on maritime decarbonization[6] was put forward as an example of an existing model to follow.

In our opinion, these findings and actions were the most significant. Nuances and clarifications are provided in the rest of the report.

[4] MEIE, 2023. *Groupe de travail sur la décarbonation de l'industrie maritime*, web page accessed on July 24, 2023, www.transports.gouv.qc.ca/fr/ministere/role_ministere/colloques-congres-conferences/forum-concertation-transport-maritime/Pages/decarbonation-industrie-maritime.aspx

[5] [Authors' note] Since the workshop, the Canadian Minister of Transport and the US Secretary of Transportation announced on May 16 2023, the first *Canada and United States Alternative Fuel Corridor* between Québec City and Detroit, www.canada.ca/en/transport-canada/news/2023/05/canadas-minister-of-transport-and-us-secretary-of-transportation-announce-the-first-canada-and-united-states-alternative-fuel-corridor.html

[6] GSGP, 2023. *Great Lakes St. Lawrence Governors & Premiers*, web page accessed on July 24, 2023, https://gsgp.org

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Introduction

A workshop entitled *Decarbonizing Long-Haul Trucking in Eastern Canada: A Comparison of Technologies on the A20-H401 Highway Corridor Between Québec and Windsor* was held on April 25, 26, and 27, 2023 as part of a techno-economic assessment study comparing Class 8 technologies to decarbonize long-haul trucking. It was organized by HEC Montréal's Chair in Energy Sector Management, in collaboration with CPCS and the Government of Québec.[7] The workshop aimed to explore and validate with experts both the larger decarbonization context and the important parameters to consider in a techno-economic study comparing four Class 8 technologies to decarbonize long-haul trucking, with a focus on the highway corridor between Québec City and Windsor.

Stakeholders from different regions (Ontario, Québec, USA and the European Union) and decision-making levels from the academic, government (federal, provincial and municipal), professional sectors were brought together. In total, approximately 60 participants contributed (see list in Appendix 1). The workshop, was an opportunity to develop potential actions to:

1. transparently improve the proposed methodology;
2. identify key factors that can impact the technologies in Eastern Canadian context;
3. define assumptions on costs trends;
4. address issues with current government actions to accelerate the decarbonization of long-haul road freight;
5. identify additional support opportunities to accelerate the transition to net zero options;
6. identify priority needs to support fleets and business owners in the early phase to reach net zero by 2050.

Considerations on how improving efficiency, intramodality and logistics in freight can support net zero long-haul freight technologies were discussed, as well as options for improving cooperation and involvement of stakeholders.

The workshop is part of Québec's *Energy Transition, Innovation and Efficiency Master Plan*, which recognizes that adopting a more transparent, collaborative and open approach to accessing energy data is essential to achieving the government targets outlined in the *2030 Plan for a Green Economy*,[8] including a 40% reduction in the consumption of petroleum products below 2013 levels. [9] The Master Plan's roadmap calls for stakeholder participation to guide the directions and actions that will help achieve Québec's energy and climate targets. By 2030, the vision of the Master Plan is to ensure that knowledge and data sharing "guide the government's priorities and actions to meet its targets," emphasize collaborative process and foster market innovation. [10]

[7] See the workshop program: https://energie.hec.ca/events/25apr2023/

[8] Government of Quebec, 2020. *2030 Plan for a Green Economy – Electrification and climate change policy framework*, https://www.quebec.ca/en/government/policies-orientations/plan-green-economy

[9] Government of Quebec, 2022. *Plan directeur en transition, innovation et efficacité énergétique – mise à niveau 2026,* https://transitionenergetique.gouv.qc.ca/fileadmin/medias/pdf/plan-directeur/MERN-Mise-niveau-2026-plan-directeur-transition-energetique.pdf

[10] Energy Transition Quebec, 2018. *Joining Forces For a Sustainable Energy Future – 2018–2023 Energy Transition, Innovation and Efficiency Master Plan*, p. 140–142, https://transitionenergetique.gouv.qc.ca/en/energy-transition-master-plan

Background and issues

Compared to passenger transport, initiatives to decarbonize freight are more limited due to the complexity of the sector. A lack of access to transparent data makes things even harder. The challenge is compounded by the fact that its emissions are growing rapidly relative to all personal vehicles. Between 1990 and 2019, heavy duty trucks for freight transport emissions increased by 67% in Québec and 61% in Ontario, compared to 30% and 24%, respectively, for personal transportation. The freight sector alone emits 7.8 Mt CO_2e in Québec and 14 Mt in Ontario, or about 9% of Québec's and Ontario's emissions. Semi-trailers (Class 8b) account for the largest share (78%) of kilometers travelled by Class 8 heavy vehicles in Canada. Industry reform, both technological and logistical, is needed to reverse these major trends.

The impact of initiatives to decarbonize long-haul road freight have been limited due to their shyness (no major initiative was undertaken), the complexity of the sector, lack of transparency, collaboration and independency in analysis used for decision making. Given the large value of the market and investments required to decarbonize the sector, initiatives are often politicized or led by special interest. These conditions can lead to incoherences and inefficiencies in efforts within and between governments and industry.

To date, few studies have assessed the feasibility associated with the potential of decarbonization technologies in long-haul trucking in Canada along the prominent trade corridor through Ontario, Québec and into the Northeastern United States (US). In addition, net zero technologies in this sector often require long-term planning due to infrastructure that goes beyond provincial and national borders. Therefore, it is relevant to explore net zero options in a broader context, including Québec, Ontario and US stakeholders, to encourage further collaboration and use of common analytical tools and data to make informed decision and take relevant actions in this sub-sector towards achieving net zero goals by 2050.

The lack of transparent, rigorous comparative studies of different decarbonization technologies for Class 8 freight transport in Québec and Ontario, and more broadly in the North American context, limits the effectiveness of government and private actions in this sector. This project aims to contribute to filling part of this gap and reduce some of the risks associated with technological and logistical choices by providing more complete information based on a review of the costs and associated technological issues. The study also aims to provides transparent data and assumptions on the technologies, with full references, to allow others to use and update the data, and the simulation model for further studies in the future.

Results of this study can be used in future work, including a review of the technologies within a more systemic approach for decarbonizing long-haul freight (e.g., optimized freight logistics, intermodality and business models) and to assess the impacts of different technological choices on overall electricity and energy demand for reaching GHG reduction targets based on different pathway scenarios (e.g., University of Windsor's Carbon Free Corridor Initiative from Montréal to Chicago; calibrating E3 model, such as NATEM implemented by ESMIA, with the data from the simulation; contribution to the Energy Modelling Hub Common and Open Platform).

The workshop – A step towards an open modelling approach

Models are simplified mathematical representations of the real world. Decision makers consult them to obtain information on the possible consequences of their decisions. However, models are only as good as the extent to which we understand their limitations.[11,12]

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[11] Bonnery, C., 2017. « La vision de... Christophe Bonnery », In Ancel, F. (Ed.), *Perspectives Energies 2050, Connaissance des énergies*, p.24 www.connaissancedesenergies.org/perspectives-energies-2050/christophe-bonner

[12] Hassenfeld, S., 2022. The Truth about Scientific Models, *Scientific America*n, June 15 2020, www.scientificamerican.com/article/the-truth-about-scientific-models

To make sense of results, it is critical to have access to transparent methodology, data and assumptions used as inputs to models. When these limitations are not well understood and accounted for, results can introduce biases in the decision process and hinder the ability to plan out the best path forward.

The modeled simulations to be examined in the proposed study will examine the potential deployment of technologies at scale to decarbonize Class 8 long-haul heavy-duty trucks that are compatible with net zero by 2050. To support the model development, close to 60 experts were gathered for an online workshop (see the list in Appendix 1) to validate the modelling approach and key parameters considered in the study.

The workshop was divided into three steps:

- **(i) Sharing of a backgrounder.** To prepare for the workshop, a review of the proposed modelling approach and of techno-economic parameters considered for the simulation was shared with the participants.
- **(ii) A scoping conference** on April 25, 2023, by webinar, to prepare participants for their contribution to one of the four round tables.
- **(iii) Virtual round tables** held on April 26 and 27, 2023 where participants had three hours to answer eight questions, prepared by the research team, with the last two being optional if time allowed. Each round table included about 10-12 participants.

This document summarizes the highlights from the round tables and the presentations given during the scoping conference. To facilitate the practical use of the recommendations from this report, the main recommendations from the round tables have been structured to further highlight the areas in which the group agreed or disagreed. The second part of the study consists of a report presenting the results of a cost comparison analysis of the net zero technologies on the A20-H401 highway corridor between Québec City and Windsor.[13]

Since decarbonizing long-haul road freight is a broad theme, the authors recognize that the recommendations are not exhaustive and reflect the expertise of the invited participants around table.

[13] Roberts, N., Cyr, M., Whitmore, J., P.-O. Pineau, P.-O., 2023. *Decarbonizing Long-Haul Trucking in Eastern Canada: Part 2 - A cost comparison analysis of net zero technologies on the A20-H401 Corridor Between Québec and Windsor*, prepared by CPCS and the Chair in Energy Sector Management - HEC Montréal for the Government of Québec https://energie.hec.ca/decabonizing-long-haul-trucking-in-eastern-canada

Scoping conference

The scoping conference provided participants with an overview of the state of long-haul road transportation in Eastern Canada, presented key considerations on the net zero technologies to be included in the study, as well as lessons learned from international experiences on decarbonizing the sector. This information sharing, based on perspectives of government, academia, and industry, enabled participants to have a common set of information for the round table discussions.

The scoping conference was broadcast via videoconference. Thirteen lectures were presented to participants on April 25, 2023. The following section summarizes the key ideas presented by the speakers. The presentations and recordings from these panels are available online.[14]

Part 1 | General overview – state of long-haul freight transportation

For the opening remarks, members of the research team, **Johanne Whitmore, Senior Researcher at the Chair in Energy Sector Management of HEC Montréal** and **Nick Roberts, Senior Consultant in transportation at CPCS**, presented the scope of the project and the proposed modelling approach. The study focusses on the 1,300 km highway corridor between Québec City and Windsor. This corridor is one of Canada's busiest long-haul trucking routes which connects the largest population centres (Toronto and Montréal), hubs for intermodal facilities and cross-border links with the US. The scope of the study encompasses five steps: 1) identify the vehicle technologies to assess; 2) undertake a literature review of the techno-economic parameters; 3) validate the data with experts through a workshop; 4) define operating parameters for simulation; and 5) conduct a cost-benefit and sensitivity analysis. Data transparency and defining limitations will be important to nuance results, build credibility and manage expectations from stakeholders.

Pierre-Olivier Pineau, Professor and Chairholder, Research Chair in Energy Sector Management at HEC Montréal provided an overview of key trends in energy consumption and emissions growth related to heavy duty freight trucks in Québec and Ontario. Heavy-duty freight trucks are among the fastest growing sector when it comes to GHG emissions. While overall GHG emissions have decreased in Québec and Ontario, they have grown by more than 50% since 1990. Canada is one of the OECD countries where freight transport emissions have increased the most. This is not surprizing since the number of heavy-duty trucks used for freight transport have grown more quickly than other modes (rail and marine), and road freight is about 10 times more energy intensive per tonne-kilometer than rail and marine freight transport.

Michael Roeth, Executive Director of the North American Council for Freight Efficiency, presented an overview on fleet decision-making process and key factors driving fleets to decarbonize, including current and future fuel prices, regulations, and sustainability goals. Main actions considered include burning less diesel through improved efficiency and opting for net zero technologies (fuel cell, electric battery trucks) and alternative fuels. He reminded participants that the average annual sales of Canada and US Class 8 trucks were 234,000 per year, of which 45% were sleeper tractors used for long-haul, while 40% of Class 8 tractors (of which 19% from Canada) were day cabs mainly used for regional haul driving long distances (approx. 480 km per day) before returning to base. E-commerce is driving the growth of this segment, which better lends itself to electrification and employment attraction and retention.

[14] HEC Montréal, 2023. *HEC WORKSHOP | Decarbonizing long-haul trucking in Eastern Canada*, web page, https://energie.hec.ca/events/25apr2023/

The next three speakers provided federal, Québec and Ontario government perspectives on decarbonizing heavy-duty vehicles. **Jordan Wolfe, Deputy Director, Zero Emission Trucking Program at Transport Canada**, presented the Government of Canada's key policies for decarbonizing the sector, including Zero Emission Vehicle Sales (ZEV) Mandates, Zero Emission Trucking Program (ZETP) and the On-Road Decarbonization Programs. In the 2022 Emissions Reduction Plan, the federal government set a target to achieve 100% overall medium- and heavy-duty vehicle (MHDV) sales being ZEV by 2040, where feasible, with an interim sales target reaching approximately 35% by 2030. Key challenges for heavy-duty ZEVs include the high purchase price of vehicles, vehicle availability, infrastructure readiness, Canadian conditions (e.g., range, climate, weights, dimensions), intensive duty cycles and grid readiness. Despite these challenges, the industry seems keen to adopt net zero solutions. A suite of subsidies, research programs and tax credits support the transition, as well as intergovernmental collaborations (e.g., industry workshops, CAN-US ZEV Summit).

Perspectives on Québec government initiatives for decarbonizing road freight was presented by **Alain Lemieux, Economist at the ministère des Transports et de la Mobilité durable** (MTMD) of Québec. Different policies for decarbonizing the sector are part of the government 2030 Plan for a Green Economy, which includes $331 million planned until 2027 to increase the use of renewable energies and efficiency in the freight transport sector. Two programs are key: *Écocamionnage* and *Transportez vert*. The *Écocamionnage* program aims to reduce GHG emissions in the road freight transport industry and service vehicles through the implementation of measures to improve energy efficiency or the use of alternative energies. It finances up to $175,000 for battery electric trucks and provides funding for fuel cell electric vehicles and other energy-efficiesnt technologies. *Transportez vert* supports the acquisition of charging stations up to $60,000, with a charging power of at least 50 kW. The government also has regulation and other initiatives to support alternative fuels, including the Clean Fuel Regulation setting GHG standards and Québec's Green Hydrogen and Bioenergy Strategy. Québec's competitive renewable electricity prices is seen as an opportunity. Challenges for large scale deployment of net zero heavy trucks in the long-haul sector include limited vehicle autonomy and lack of a dedicated charging station infrastructure. For green hydrogen and biofuels, the challenges are closing the current price gap, supply and improving their competitiveness with fossil fuels.

The last panelist, **Carolyn Kim, Senior Director, Communities & Decarbonization Group at the Pembina Institute,** offered perspectives on decarbonizing long-haul trucking in Ontario.[15] She first emphasized the importance of the Québec-Ontario corridor which carries up to 44% of Ontario's interprovincial trade by road and accounted for about 3,000 long-distance heavy trucks border crossing between Ontario and Québec. In 2019, the corridor accounted for about 62,000 for-hire trucking companies in Ontario, with a combined operating revenue of over $24 billion. Ontario freight emissions grew by 99% between 1990 and 2021. Similarly to Mike Roeth, she positioned that near-term opportunities to reduced emissions included lowering fuel use through greater efficiency and exploring the use of alternative fuels (e.g., natural gas, sustainably produced biofuels) while transformative technology is developed. Finally, compared to Québec and British Columbia, Ontario has fewer policies in place to effectively decarbonize heavy trucking. In addition, other supportive actions can include pilot and demonstration programs, preferential electricity rates, incentives for supporting vehicle purchase and charging infrastructure, as well as for fleet electrification assessments.

The optimum technology for decarbonizing a long-haul trucking duty cycle must strike a balance between freight payload (lb) and range autonomy (km). Currently, most technologies are nascent and present multiple uncertainties and challenges. Before achieving ideal conditions for large-scale deployment of net zero technologies by 2050 (e.g., widespread fast charging facilities and hydrogen refuelling stations, long-life and low-cost batteries, acceptable weights and costs), the sector will first undergo a « messy middle » phase. This near-term period will need to deploy hybrid solutions as new infrastructure is built out, competing alternative fuels are marketed and more pilot projects enable replacing estimates with facts to accelerate the learning curve and certainty. Finally, the speaker presented a summarized framework for powertrain decision-making during this intermediate phase.

[15] Representatives of the Government of Ontario were invited to present their perspectives at the conference but declined and instead opted to only participate in the round table sessions.

Presentations

Pierre-Olivier Pineau. *State of Long-Haul Freight Transportation in Ontario and Québec,* https://energie.hec.ca/wp-content/uploads/2023/04/1-PINEAU_PPT.pdf

Michael Roeth. *Decarbonizing Long-Haul Trucking – North America,* https://energie.hec.ca/wp-content/uploads/2023/04/2-ROETH_PPT_v2.pdf

Jordan Wolfe. *Decarbonization of Long-Haul Trucking in Canada*, https://energie.hec.ca/wp-content/uploads/2023/04/3-WOLF-TC_PPT.pdf

Alain Lemieux. *Québec Perspectives and Initiatives on Road Freight Transport Decarbonization,* https://energie.hec.ca/wp-content/uploads/2023/04/4-LEMIEUX-MTMD_PPT.pdf

Carolyn Kim. *Perspectives on Decarbonizing Long-Haul Trucking in Ontario*, https://energie.hec.ca/wp-content/uploads/2023/04/5-KIM-PEMBINA_PPT.pdf

Recording of the conference (part 1): https://youtu.be/1-44JrPHglY

Part 2 | Techno-economic overview – trucks and infrastructure

For the second session of the conference, experts were invited to present a techno-economic overview of the four net zero technologies considered for the study.

Rymal Smith, Owner of Change Energy Services, presented the pros and cons of hydrogen fuel cell technology (see Table 1), pointing out that the net benefit depends on the value of the investors or end-users. Currently, few Class 8 fuel cell trucks are commercially available. In addition, existing vehicle retrofits and hydrogen internal combustion engines may be limited in certain markets. Hydrogen storage volume onboard vehicles is 2 to 6 times higher than for diesel depending on whether it is liquefied (LH2) or compressed (CH2). For return-to-base fleets, slow fill CH2 cycle stations are well understood and allow for better optimization of capital expenditure, LH2 systems present advantages: they operate at lower pressures and hold 3 times the energy in the same volume as hydrogen compressed to 350 bar. Refueling stations can cost less in a scaled-up fleet scenario and LH2 tend to require lighter tanks. Uncertainties regarding the supply chain must be addressed, including improving the capacity of decarbonized hydrogen supply, ensuring safety and reliability, and considering regional differences, such as distribution versus on-site production, regulatory landscape and integration with other infrastructure.

In closing, Mr. Smith noted that choosing the best net zero solution for a particular fleet depends on many factors, including the specific application, range and duty cycle; availability of the technology; local fuel supply infrastructure; capital and operating costs; end user values and goals (e.g., cost, GHG emissions, energy security, air pollution, jobs). In the decision process, he recommended that both "market-ready" and "emerging" technologies be considered, as well as the need to define goals and performance indicators. Funding strategies must evolve given that government funding skews the playing field and often produce inefficient markets. Finally, governments must proactively address market barriers (e.g., safety norms, regulations, and end-user understanding), and ensure hydrogen adoption and infrastructure development be viewed within the larger energy system framework, rather than within a "silo" approach.

TABLE 1. KEY ADVANTAGES AND DISADVANTAGES OF HYDROGEN FUEL CELL TRUCKING TECHNOLOGIES

Advantages	Disadvantages
· Potential for greater EV driving range	· Cost (technology dependent)
· Quicker refuelling than BEV	· Hydrogen Fuel Cost
· Efficiency (vs diesel)	· Lack of refuelling facilities
· Emissions reductions	· Range (vs diesel)
· Noise reduction	· Efficiency (vs BEV)
· Lighter weight energy storage	· Complex Hydrogen Supply chain
· Permits large payloads	

Francisco Doyon, Advisor development Natural Gas for Vehicles at Energir, presented an overview of the use of renewable natural gas (RNG) for decarbonizing long-haul trucking. RNG is produced by converting the biogenic GHG emissions from organic waste generated from existing activities (e.g., landfills, agriculture waste) into value-added inputs for the biomethanation process. RNG does not contribute to additional GHG emissions when it is derived from residual organic matter. Furthermore, RNG is interchangeable with fossil-based natural gas. RNG is already part of federal and provincial GHG reduction strategies (e.g., Québec's 2030 target is a minimum of 10% of the province's gas system distribution to be comprised of RNG. In 2023, RNG represented around 2% of Québec's gas network). There are 281 RNG production sites in North America, with 180 under construction and 296 being planned. Today's RNG supply is low compared to conventional gas but will increase with new production sites as they become operational.

Natural gas can either be stored compressed or liquefied, but compressed gas (CNG) has been heavily adopted for convenience, cost, and supply reasons. The supply infrastructure between Québec and Windsor includes 13 public access CNG stations with a maximum distance between stations of 250 km. Currently, six of those public access CNG stations advertise a R-CNG offering but potentially all could offer the purchase of R-CNG supported by a demand from their fleet customers. Average truck autonomy is set around 900 km and the average incremental cost compared to diesel is $90,000 depending on the tank size. To help advance the technology, Mr. Doyon recommends that ZEV mandates include a full lifecycle approach; increasing financial incentives for the purchase of a CNG truck using RNG; continuing support for the deployment of public R-CNG stations, as well as transformation of maintenance infrastructure to increase and improve the service offering.

TABLE 2. KEY ADVANTAGES AND DISADVANTAGES OF RNG TRUCKING TECHNOLOGIES

Advantages	Disadvantages
· Availability of public infrastructure is increasing to deliver R-CNG to HD trucks · Refueling is easy and fast · RNG is available now and production is expanding · Most Original equipment manufacturers (OEMs) already offer Cummins NG engines · Minimal impact on total payload carried compared to other ALT-fuels · Existing CSA codes for infrastructure and tanks · Clean Fuel Regulation (CFR) offers credit opportunities for RNG · RNG is available and production is increasing	· Cost of CNG truck and RNG compared to diesel · More maintenance facilities required · Rental companies slow to incorporate ALT-fuel · Small number of technicians trained to maintain CNG trucks · OEMs all have their powertrain solution for diesel, offering NG engines impacts profitability · ZEV focus not encompassing a lifecycle approach

David Cebon, Professor of mechanical engineering at the University of Cambridge and Director of the Centre for Sustainable Road Freight presented an overview of electric trucks with dynamic charging via overhead contact lines. These supply electricity directly to trucks equipped with deployable pantographs that engage and disengage automatically. Outside of the electrified road systems (ERS), trucks use (small) batteries to reach their destination. They can also use biofuel or diesel range extenders for longer journeys off the ERS. The ERS dramatically reduces battery size, weight, cost and recharging time compared to vehicles with big batteries. ERS also avoids energy lost in the charge/discharge of the battery and reduces the need and impacts associated with the mining of critical metals.

ERS is an efficient option for decarbonizing long-haul as vehicles require less energy per km than alternative propulsion systems. For example, electrifying all UK road freight using ERS would require 11 GW of renewable electricity compared to 36 GW for powering trucks using green hydrogen. A green hydrogen solution would require at least 3.3 times as much energy and incur 2 times the vehicle capital cost compared to ERS trucks. Dr. Cebon underlined that electrification of heavy vehicles is all about fitting the battery charging into the logistics day. Future vehicle automation may reduce the times available for battery charging as trucks could continue to operate without mandated rest stops for drivers. This could make larger battery electric vehicles even more challenging to schedule for optimal recharging times. ERS eliminates the need to stop and charge, as well as for fast charging in warehouses that require large power connections. The total cost of ownership (TCO) of ERS vehicles (on a 6-year basis) is predicted to be less than for diesel vehicles by 2034 or earlier. This would enable governments to generate revenue from taxation to replace diesel excise duty. Conversely, hydrogen propulsion would require substantial subsidies to reach parity with diesel.

TABLE 3. KEY ADVANTAGES AND DISADVANTAGES OF ERS DYNAMIC CHARGING TRUCKING TECHNOLOGIES

Advantages	Disadvantages
· Low-cost vehicles, high payload, good for mass-limited loads	· Upfront infrastructure cost requires government investments to support business case (but not subsidies)
· Reduced energy consumption due to smaller batteries on-board and lighter vehicle weight	· Requires highway authorities to learn about managing electric systems
· Highly efficient compared to H2 trucks	· Aesthetic concerns related to catenary infrastructure
· No need to stop vehicles for battery charging	
· Benefits enhanced by automation and autonomy	
· Much reduced need for high power charging and grid connections in warehouses	
· Privately financeable	
· Can generate tax revenue to replace diesel tax	

The final panellist, **Charles Trudel, Technological Application Group Manager, Innovative Vehicle Institute**, provided an overview of the state of electric battery trucks. As of December 2022, 70 battery trucks were registered in Québec, mostly for less than truckload (LTL) and regional haul. Most major legacy truck manufacturers offer electric trucks. In Québec, the early adopters have been operating 1 or 2 electric trucks for about a year, which represents a 3-year lag behind California in terms of project size and involvement. BEV trucks are roughly 10 years behind light-duty EVs. Long-haul is not here yet, however it is expected that in the next decade, it will be made possible without much more effort as the technologies are already available on the market and continue to improve. Class 8 trucks are currently delivered with 350-600 kWh batteries requiring 150-250 kWh/100 km, which can yield a 250-450 km range. Currently, the maximum charging power for these trucks is approximately 150 kW (up to 250 kW for some), with charging times for 80% state-of-charge (SOC) taking about 60-120 minutes. Payload and elevation gain have had a major impact on the range. Preliminary data shows that winter does not affect range nearly as much as in light-duty EVs

Battery energy density (kWh / kg) is progressing fast and a Megawatt Charging System (MCS) is being discussed. Compared to diesel trucks, there are BEV parameters that have already reached parity (e.g., typical weight, safety, remote diagnostics), while most are expected to be reached by 2025-2030. Initial cost, maximum life before obsolescence, fuelling and overall maturity are on a longer horizon. Fleet-operated charges represent a high cost but offer better EV operation management opportunities for charging. Start-ups, pilot projects and shared station hubs are increasingly being deployed. In closing, Mr. Trudel emphasized the need for more purpose-built public charging hubs at already existing truck stops along the main corridors; to maintain subsidies year-round with no dead zone between program editions; and to bring more dedicated electric battery trucks maintenance and repair programs to HD truck mechanics.

TABLE 4. KEY ADVANTAGES AND DISADVANTAGES OF BATTERY ELECTRIC TRUCKING TECHNOLOGIES

Advantages	Disadvantages
· BEV trucks are already on the road · Long-haul trucks will come to market following battery development · Upfront costs are manageable · Subsidies cover most of the cost difference, pilot projects and internal hours, private charging station · Charging is easy · Simple vehicle architecture compared to hydrogen or hybrid · Opportunity for shared charging stations in North America · Battery density (kWh/kg) is improving · Battery prices are lowering every year	· Charging time: most operators expect the same refueling time as conventional trucks, no matter the ROI as a whole · Payload « penalty » around 4 000 lbs · Chargers are new assets to manage and maintain · Demand charges ($/kW) considerable for larger charging stalls · Steep learning curve for managing large EV fleets and chargers · Dependent on the battery supply chain · BEV in long haul is not the "Low-hanging fruit" for OEMs

Presentations

Rymal Smith. *An Overview of Hydrogen Trucking Technology and Techno-economic Factors,* https://energie.hec.ca/wp-content/uploads/2023/04/6-SMITH_PPT_v2.pdf

Francisco Doyon. *Renewable natural gas (RNG) Decarbonize long-haul trucking today,* https://energie.hec.ca/wp-content/uploads/2023/04/7-DOYON-ENERGIR_PPT.pdf

David Cebon. *Overhead Conductive Transmission Trucks with dynamic charging*, https://energie.hec.ca/wp-content/uploads/2023/04/8-CEBON_PPT.pdf

Charles Trudel., 2021. *Battery-Electric Trucks as an Options to Decarbonize Long-Haul Trucking in Eastern Canada*, https://energie.hec.ca/wp-content/uploads/2023/04/9-TRUDEL_PPT.pdf

Recording of the conference (Part 2): https://youtu.be/5Y2FB7J92no

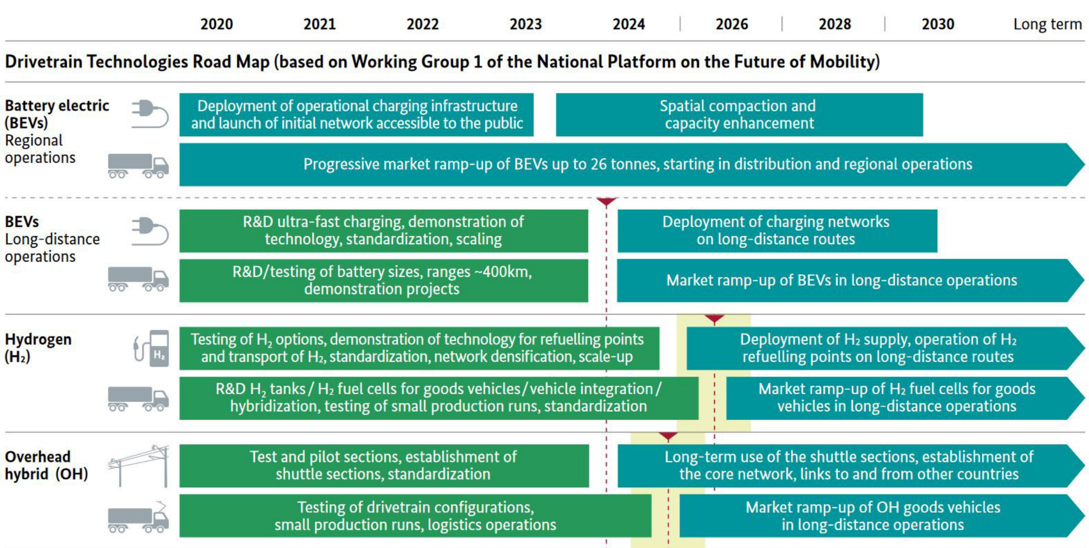
Part 3 | International perspectives and lessons

Matteo Craglia, Transport Analyst and Modeller at the International Transport Forum – OECD, presented findings from an analysis looking at how to minimize cost uncertainties associated with decarbonizing road freight in Europe. The economic feasibility of three net zero technologies, compared to diesel trucks, were considered: battery electric vehicles (BEV), hydrogen fuel cell electric vehicles (FECV) and catenary electric road systems (ERSV). Scenarios of future strategies are useful to evaluate policy decisions but are sensitive to assumptions which can lead to unintentional biases. The study explored a range of futures (optimistic versus conservative cases) to better understand uncertainties related to different technologies based on multiple techno-economic parameters.

When evaluating the share of the heavy-duty vehicle market that each technology could theoretically attain by having the lowest TCO, BEVs have the potential to outcompete ICEV and FCEV options, even without incentives. ERSVs could be cost competitive, but their utilization and speed of deployment are uncertain. Policy support of various kinds (e.g., zero-interest loans, purchase subsidies, carbon tax) can shift the range of uncertainty, unlocking high ambition possibilities. Although travel distances in North America are longer compared to Europe, most journeys are less than 1,000 km and 10% of the busiest roads account for around 63% of all road freight travel. The findings are therefore relevant to the North American context.

Germany's policy framework for decarbonizing road freight provides a useful example of an approach for dealing with uncertainties associated with different technologies[16]. The first phase is a scaled trial period of multiple technologies but sets a window of opportunity by mid-2020 for making key decision on optimal pathways to follow for achieving 70% GHG reduction in road freight by 2030 (see figure 1). Government funding is reserved for the highest performing technologies and for scaling up as quickly as possible. In closing, Dr. Craglia recommends that governments introduce policies that accelerate the deployment of net zero vehicles and their infrastructure (learning by doing); ensure that policies to promote direct electrification of trucks remain technology-neutral; launch targeted studies and pilot projects to assess the merits of electric road systems for road freight decarbonization; and further investigate decarbonization technologies for particularly challenging road freight applications.

FIGURE 1. GERMANY'S NET ZERO DRIVETRAIN TECHNOLOGIES ROAD MAP



Source: BMDV, 2020.

16 BMDV, 2020. *Overall Approach of climate-friendly commercial vehicles*, Government of Germany, https://bmdv.bund.de/SharedDocs/EN/publications/overall-approach-climate-friendly-commercial-vehicles.pdf

Maja Piecyk, Professor of logistics at the University of Westminster, discussed the important role of improved logistics and modal shift for optimizing the efficiency of decarbonizing road freight with the broader freight system. By 2050, the volume of freight traffic is expected to more than double, which underlines the magnitude of the challenge of decarbonizing the sector. Decarbonizing long-haul road freight must be planned within an optimized logistics framework to minimize energy use, regardless of the source, as well as other negative externalities (e.g., GHGs, noise, accidents, air pollution). Logistics measures can cost effectively and significantly reduce GHGs from diesel trucks in the short- and medium terms (34% by 2035 below 2015 levels). If we change to a road pricing structure this could help shift towards more sustainable modes, such as rail and maritime, but we need to ensure continued work to decarbonize all modes. Improved modal shift between freight transportation modes is needed to address congestion and other externalities. Improving vehicle utilization (loads) is important for optimizing and reducing overall energy use and GHG reductions.

In conclusion, Dr. Piecyk notes that although net zero technologies are important for decarbonizing road freight, we need to address the growth of freight traffic and other externalities. Even with net zero options we still need to minimize energy use. Significant GHG reduction opportunities in current fleets exist through improved logistics and should be deployed as a priority in the short- and medium terms. Understanding the implication of logistics is important to evaluate the feasibility and wider impacts of net zero technologies. Better logistics data is needed to provide for a whole system analysis of decarbonizing road freight.

Georgiana Vani, Research associate with the Cross-Border Institute at the University of Windsor, presented an overview of modelling work undertaken under the Carbon Free Corridor initiative to measure the grid impact of long-haul electric vehicles (LHEVs) in Ontario. The Carbon Free Corridor is a multidisciplinary working group looking at the feasibility, opportunities and risks associated with the development of a decarbonized corridor between Montréal and Chicago. The LHEV study aims to develop models that help improve the understanding of the challenges and opportunities for Ontario grid operators on the pathway to the long-haul truck decarbonization. Three objectives are pursued: 1) establish a representative Archetypal Routing Network (ARN) to assess long-haul transport loading of support infrastructure; 2) develop a parameterized charging/fuelling load model to characterize energy grid loads; and 3) build out an industry-specific case study to examine detailed economics and distributed energy resource opportunities.

Overlaying ARN maps of hourly truck flow at secondary stations over distribution of energy loads and the electric grid networks enables to identify the potential location for charging stations for long-haul electric vehicles. From this analysis, daily traffic at those stations is derived to estimate the energy demands from charging activities. The modelling allows for an optimization of the locations of charging stops and is based on an electric Tesla Class 8 truck model (800 km range, 80% charge of 1,000 kWh battery, with typical semi-truck stop counts). Given the economic activities related to freight movements between Canada and the US, strategies need to be developed to reflect transborder realities. In closing, Dr. Vani mentioned that ongoing work included collaborating closely with strategic utility partners to align transport loading functions to the grid, and continued development of business cases and dynamic electricity pricing strategies to attract border charging.

For the last presentation, **Arthur Yip, Researcher, National Renewable Energy Laboratory (NREL)** summarized key findings from NREL's 2022 Medium and Heavy Duty (MHD) Zero Emission Vehicles (ZEV) cost analysis for the US. Based on central assumptions in the study, both Class 8 BEVs and FCVs are projected to achieve total cost parity with ICEVs by 2035. However, results are highly sensitive to fuel prices, as well as battery and fuel cell costs. If these costs do not fall as expected, total cost parity would be pushed closer to 2050. Results are also affected by the payback period of the incremental cost associated with ZEVs (2 versus 10 years), applications (e.g., day cab versus sleepers) and different scenarios. To accelerate the transition to clean technologies, the US federal government is moving ahead with substantial funding for MHD ZEVs (Inflation Reduction Act) and proposals for stringent MHD fuel economy and GHG emissions regulations, while some US states led by California have enacted ambitious MHD ZEV regulations.

In closing, Dr. Yip mentioned that similarities between the US and Canada freight market structure mean that ZEV feasibility and adoption opportunities may be similar. Because light and medium duty vehicles and short-haul tractors are likely to transition towards BEVs earlier, this could provide a significant advantage for the heavy BEV pathways. Certain technologies and pathways can be deployed in a more scalable, distributed, capital-friendly manner, while others (e.g., FCV, catenary) rely on larger-scale network investments in fuel supply and infrastructure. Intermediate options (liquid and gaseous biofuels, hybrid technologies) could be helpful in bridging gaps, but are unlikely to be dominant. More detailed analysis is needed for the cost of fuel and infrastructure in various use cases, as well as economic and risk profiles of private versus public fuelling/charging infrastructures. Transparency in hydrogen costs and forecasts, and data from real-world utilization cases are needed.

Presentations

Matteo Craglia. *Decarbonising Europe's Trucks How to Minimise Cost Uncertainty,* https://energie.hec.ca/wp-content/uploads/2023/04/10-CRAGLIA-ITF_PPT.pdf

Maja Piecyk. *Decarbonizing logistics, intermodality and efficiency*, https://energie.hec.ca/wp-content/uploads/2023/04/11-PIECYK_PPT.pdf

Georgiana Vani. *Carbon Free Corridor - Modeling the Grid Impact of Long-Haul Electric Vehicles (LHEVs) in Ontario*, https://energie.hec.ca/wp-content/uploads/2023/04/12-VANI-UW_PPT.pdf

Arthur Yip., *Decarbonizing Heavy-Duty Vehicles in the U.S.*, https://energie.hec.ca/wp-content/uploads/2023/04/13-YIP-NREL_PPT_v2.pdf

Recording of the conference (Part 3): https://youtu.be/jCXoivd3aNE

Outcomes of the round tables

The purpose of the round tables was two-fold: (1) collect information to improve the proposed methodology of the study, including identifying key factors that can impacts the technologies in the Eastern Canadian context and defining assumptions on costs trends; (2) address issues with current government actions to accelerate the decarbonization of long-haul road freight and identify priority measures needed to support fleets owners in the early phase of transitioning towards net zero technologies. Participants were also invited to share their perspectives on the role of improving efficiency, modal shift and logistics in freight as a leverage to support net zero technologies, as well as options for improving stakeholder engagement, collaboration and data sharing.

There was a total of four virtual round tables, each with a dozen people (see Appendix 1). The research team facilitated the discussions and took notes (see Appendix 2). Based on those notes, the authors identified findings and options shared by the participants within a group, as well as converging perspectives between tables.

To ensure that the makeup of the different round tables met the criteria of representativeness and diversity of profiles and organizations, the research team ensured that different sensitivities, points of view and preferences in relation to the various aspects of assessing the decarbonization of long-haul trucking were represented. Therefore, each table included people from various institutional backgrounds (e.g., academic, government, private and associations) and decision-making levels. To ensure the consistency of points of view shared in this final report, a preliminary copy was forwarded to participants for comment.

Considerations for improving modelling methodology

To prepare participants for the workshop, a backgrounder presenting the modelling approach and the techno-economic parameters considered for the simulation was shared. Detailed concerns and recommendations to improve the methodology were proposed (see Appendix 2). Although most were outside the scope of the study (given the resource and time constraints), the **considerations put forward confirm the need for an open and collaborative methodological approach in evaluating the feasibility of different technologies to clearly understand the limits of the results**, as well as to avoid introducing biases. It was understood that the proposed study is a first step towards an open approach. Results will need to be presented with caveats to clearly account for limitations.

There was a consensus that a **wider scope of modelling parameters and analysis should be included in future work building on this study.** This includes enlarging the network to cover more roads (within Eastern Canada and the US) and classes of trucks, as well as different highway utilization scenarios. Many additional modelling parameters should be included in future analysis to better account for the complexity of the technologies and markets, including impact of vehicle weight on road maintenance, different battery seizes, end-of-life costs, well-to-wheel (total lifecycle perspective) on emissions from electricity, fuels (hydrogen and biofuels), critical minerals, land use for infrastructure (charging / refueling stations), and the impact of air quality on health of the general population.

Participants agreed that **measuring uncertainty and key trends using sensitivity analysis is needed to better understand study limitations.** Given the early-stage maturity of the net zero technologies being assessed and the high-level cost-benefit analysis being conducted, there is a wide range of cost and performance parameters available in the research and literature. This can give rise to conflicting assumptions or discrepancies of key parameters. Clear documentation of sources and the sensitivity analysis should help to mitigate these concerns. In addition, consideration should be given to modelling the trends on a couple of key parameters to support the validity of the modelling exercise (namely the declining cost of batteries, for its impact on BEV and OCT truck prices, and the price of green hydrogen).

Data access is viewed as key to developing reliable, credible and transparent hypotheses in models and scenarios, and for the evaluation of the techno-economic potential of the different technologies. **There is a need for improved data collection, consistency and accessibility of data to better understand the trucking market in Ontario and Québec**. This will enable a more tailored assessment of which technologies could offer the best cost-benefit solution to decarbonization based on unique segments of the market (e.g., understanding origin-destination pairings of trips, commodities and goods transported, ways to optimize routings and optimize the load factor of trucks). Conducting analyses based on transparent data is also needed to evaluate and better understand the uncertainties and limitations of the results.

Finally, other parameters to consider in future work include accounting for economies of scale with other markets scaling-up adoption of new technologies (e.g., US); technological and cost improvement over time (e.g., truck efficiency and cost, battery energy density, longevity and cost, higher charging rates, fuel supply and production cost).

KEY FINDINGS

1. **An open and collaborative methodological approach in evaluating the feasibility of different technologies** is needed to clearly understand the limitations of the results, as well as avoid introducing biases. The current study undertaken is a first step towards an open approach.
2. **Future studies building on this one should broaden the scope of analysis.** Additional modelling parameters should be included in future analysis to better account for the complexity of the net zero truck technologies, infrastructures, highway utilization and cross border markets.
3. **Measuring uncertainty and key trends using sensitivity analysis is needed to understand study limitations.** Given that the proposed study is a first step towards an open approach, results need to be presented with caveats to clearly account for limitations.
4. **Coordinated data collection, access and transparency between Québec, Ontario and the US is needed** to better represent the long-haul trucking market and develop reliable and credible hypotheses in models and scenarios, and for the evaluation of the techno-economic potential of the different technologies on shared highway corridors.

Technological challenges, maturity and availability

Providing answers on the time horizon for large-scale commercialization and deployment of net zero technologies is challenging due to uncertainties. Many factors contribute to this uncertainty, but the difficulty to access information from manufacturers and fleet owners (due to intense competition), low net zero truck supply in Canada and the lack of refueling or recharging infrastructure were seen as key factors. Given the uncertainties, some suggested that infrastructure build-up could start by collaborative trials or a phase-in approach (e.g., catenary-diesel hybrid trucks, blended fuels) before scale-up of net zero options.

Other factors influencing the time horizon and pace of change include the lifecycle of truck acquisition and replacement, truck delivery and training period, limited supply of energy for producing alternative fuels (e.g., RNG, green hydrogen) and delays related to administrative procedures (e.g., permits, compliance with load limits, safety). Regional differences in lead times for network upgrades to electrical system will affect the timeline of technology deployment, as well as logistics related to supply chains of alternative fuels (e.g., hauling gaseous hydrogen requires six times more trucks to haul supply to refueling station than diesel). Table 5 provides perspectives on the maturity and timeline of different net zero technologies shared by some participants.

TABLE 5. PERSPECTIVES ON MATURITY AND TIMELINE OF NET ZERO TRUCKING TECHNOLOGIES

Electric road system with overhead conductive transmission (ERS-OCT) trucks
· Catenary technology is a mature technology in streetcar, light rail and trolley buses in North America. · On-going freight trials in Europe since 2016 (Germany, Sweden). Expected to be more widely available and deployed by 2025-2030. · Timeline issues mainly related to implementation, not technological feasibility. Lack of political leadership hinders its implementation.
Hydrogen fuel cell electric trucks (FCEV)
· By 2024/2025 some fuel cell vehicles starting to come to market, similar timeline for green hydrogen. · FCEV trucks on pilot in Edmonton have accumulated nearly 4,000 km with Alberta Motor Transport Association (AMTA) project. AZETEC (Alberta Zero Emissions Trucks Electrification Collaboration) looking to replicate trials in Eastern Canada.
Battery electric trucks
· Battery electric Class 8 trucks are already available in Canada, but they may not be ready for long-haul trips as they have a limited range and face weight limit issues. · Trials ongoing with several fleets (e.g., Kruger, Simard Transport) · It is important to define what is considered as long haul, such as whether it is over 500 miles and whether it can be done on one charge.
RNG trucks
· Class 8 trucks using conventional compressed natural gas are already available and have years of operations, with the latest technology being released (Cummins 15 L engine). · The use of RNG is developing and a larger engine size is expected to be on the market by 2024 · Issue of supply availability remains as RNG uses will be in competition with other uses (e.g., heating, industry, maritime, aviation). In Québec, RNG is prioritized for heating new buildings.

Technological challenges in the context of cold climates were generally viewed as manageable (at temperature warmer than –20°C). **It was pointed out that fleet owners are looking at technologies with less components, which are easier to maintain**. Cold weather operations are less of a concern.

However, **very cold winter condition implies higher energy consumptions** (about 20%) due to higher resistance and cab heating. A relatively high energy consumption is needed to reach a comfortable temperature in the cabin (17°C and above). For battery electric trucks, technical issues can be limited if the vehicle is plugged into charger at depot to maintain battery temperature. However, range is compromised to heat the cabin. Several companies adopting electric trucks have developed business cases under cold winter conditions by planning for reduction in operating range into logistic operations. Options to pre-heat trucks and powertrain systems can help mitigate cold start issues and improve range (e.g., radiant heat and heat pumps).

In Spring, trucks face load limitations to reduce road deterioration. Differences in load limits between jurisdictions can impact load factor optimization and net zero technology deployment. There is no leeway in both Québec and Ontario to increase weight limits.

Experiences in Europe given trials electric trucks (ERS-OCT, BEV) operating in winter conditions (i.e., Sweden, Germany) show no major concerns. Ice on catenary wires can cause some arcing (electricity jump between pantograph and catenary), but de-icing measures are mature given the technology has over a century of use and experience in cold climates.

KEY FINDINGS

5. **Defining time horizon for large-scale commercialization and deployment of net zero technologies is challenging due to uncertainties.** Many factors contribute to this uncertainty, but the difficulty to access information from manufacturers and fleet owners, low net zero truck supply in Canada and the lack of refueling or recharging infrastructure were seen as key factors.
6. **Technological challenges in the context of cold climates were generally viewed as manageable when planned into logistic operations.** Fleet owners favor technologies with simpler components, which are easier to maintain. Cold weather operations were seen as less of a concern.

Satisfaction with the state of government actions to decarbonize long-haul trucking

Except for some participants, most expressed medium level of satisfaction with the current state of provincial and federal level actions on the decarbonization of long-haul trucking. Satisfaction varied by stakeholder, namely, whether they were fleet owners or technology providers, or stakeholders inside or outside the public service.

More widespread dissatisfaction stemmed from a perceived **incoherence in provincial and federal government measures and data-sharing**. The lack of coordination is not only between governments, but also within government (e.g., the government promotes the use of net zero trucks, but there is no mandate for ministries to evaluate potential issues with using such vehicles, including extra weight and loss of payload).

Some suggested that the failure of government measures to account for the variability of impacts based on fleet composition and fuel switching strategy hindered progress. Current policies (e.g., Écocamionnage) tend to favor larger fleet owners than at the expense of smaller fleet owners facing greater financial and risk barriers. Current policies do not adequately account for competitive and fairness issues, including challenges in managing differentiated effects of profitability in a market with multiple concurrent technologies. The lack of clarity in targets and guidance on how to adapt business models to new technologies was also viewed as a limit to the effectiveness of public policies.

The trucking sector is hesitant to adopt new technology without a viable business case or regulatory policies to push adoption (e.g., ZEV sales mandates). There is a « wait-and-see » attitude in the market while waiting for risk and technological cost to come down, as well as technology performance to improve (hesitation of first mover advantage). Given the intense competition and slim profit margins in the sector, **there a risk aversion to new technologies which leads to a "race for second place" – a trend to be the second to adopt a new technology to mitigate risk and learn from the early adopters.**

Incentives and funding options are generally seen as very supportive for electric trucks. The recommended next step should be to increase measures for increasing the availability of trucks on the market in line with ZEV sale mandates (e.g., support manufacturing capacity). Finally, it was recommended that public funding supporting new technologies be tied to data sharing and accessibility (e.g., make publicly available data from pilot programs).

KEY FINDINGS

7. **The lack of coordination between and within governments on measures and data-sharing** is recognized as the main source of dissatisfaction with the current state of government actions to decarbonize long-haul trucking
8. **The trucking sector is hesitant to adopt new technology without a viable business case or regulatory policies to push adoption.** The « wait-and-see » attitude of the market leads to a **"race for second place"**– a trend to be the second to adopt a new technology to reduce risk and learn from the early adopters.

Options for improving government actions

Given that each technology presents different potential and risks, participants were asked what additional actions governments could take to support them. There was general agreement that **government should maintain a technology neutral approach to policy development based on measures of emissions reduction outcomes** (i.e., performance-based metrics), as different technologies may be better suited to decarbonizing different segments of the long-haul trucking market. Under a neutral scheme, measures would apply indiscriminately to all types of vehicles and would rely on policies to price carbon and road usage. Subsidies could be based on a dollar per tonne of emission reduced ($/tonne CO_2e), rather than a specific technology, while a mileage tax could ensure the financing of road infrastructure and incentivize load and/or route optimization.

While a **technology agnostic approach** preserves flexibility to address the best path towards reaching net zero goals while ensuring a leveled playing field in the market, some argued that it **would represent a challenge to support significant infrastructure investment for all net zero technologies**. The government might not fund all technologies equally given the time constraints and should establish a prioritization of taxpayer money on the most promising technologies on a performance-based evaluation. To evaluate technologies, government could post a Request for Proposals (RFPs) of targeted studies and pilot projects to assess the merits of different net zero technologies based on use cases.

Participants pointed the need for a **coordinated approach to roadmap and plan for zero emission trucking infrastructure.** A coordinated plan to decarbonize long-haul trucking between Ontario, Québec, Canada and US governments, along with a long-term plan on investment in infrastructure (charging / refueling) would provide the trucking industry with a clearer path forward on planning for technology adoption, fleet investments, adjustments to logistics, routing, etc. Similar infrastructure would be needed along the inter-provincial corridor and match with infrastructure in the US, due to the large amount of cross-border truck traffic.

Germany's framework for decarbonizing road freight was provided as an example of a timeline that defines a scaled trial period of multiple technologies but sets a near-term window for making key decision on optimal technological pathways[17]. Government funding would then target the highest performing technologies for scaling up as quickly as possible.

Greater coherence and coordination of cross-border regulation on long-haul technologies and infrastructure was viewed as a priority. Regulations can vary across jurisdictions (e.g., permissible vehicle and axles weights in Ontario, Québec, and the US), which can impact the viability of technology adoption, such as being able to operate heavier battery electric trucks in Ontario but not in Québec or the US. Sales mandates should also be set at the federal level to avoid policy gap, leakage of purchasing and vehicles sales in other jurisdictions with less restrictions.

There was general agreement that the **federal government should implement a comprehensive approach for improving cross-border coordination of collaborative trial projects** to evaluate on a common basis the performance of net zero technologies and to promote investment and risk sharing associated with the deployment of new net zero technologies. It was recommended that the governments adopt a similar approach in technology development as in Europe, based on sharing and collaboration amongst industry, energy distributors, universities, and government actors in field trials of different technologies under identical settings (e.g., ELISA project which involves a multi-phase field trial of different technologies on the same corridor stretch[18]).

[17] BMDV, 2020. *Overall Approach of climate-friendly commercial vehicles*, Government of Germany, https://bmdv.bund.de/SharedDocs/EN/publications/overall-approach-climate-friendly-commercial-vehicles.pdf

[18] "The first phase of the research project "ELISA – Electrified, Innovative Heavy Traffic on Motorways" was successfully completed in December 2018 with the completion of the first (of three nationwide) public eHighway test sections on the A5 freeway with a 5 km overhead line between Frankfurt and Darmstadt. This was followed in January 2019 by the second phase of the project, which will involve extensive field testing of the new technology in its system environment until the end of 2022". www.iwar.tu-darmstadt.de/sur/forschung_sur/projekte_sur/elisa/index.en.jsp

Finally, transparency within freight carriers and industry was viewed as limited, notably on test trials and pilot results of new truck technologies. To foster collective learning and knowledge transfer, **governments should make data transparency and dissemination of trial and pilot results a conditionality for receiving public funding.** Public funding is also needed to support risk analysis for each technology, including the availability of energy supply in the case of new fuels (e.g., hydrogen and RNG). Additional industry support aiming to reduce competitive risk associated with the adoption of new technologies is also needed.

COURSES OF ACTION

9. **Maintaining a technology neutral approach to policy development based on measures of emissions reduction outcomes** (i.e., performance-based metrics), **preserves flexibility** to address the best path towards reaching net zero goals while ensuring a leveled playing field in the market. However, **the approach could represent a challenge for supporting significant infrastructure investment and deployment.**
10. **To accelerate the deployment of net zero truck technologies and their infrastructure, governments should adopt a common timetable with deadlines leading to a decision.** Germany's framework was provided as an example of a timeline that defines a scaled trial period of multiple technologies but sets a near-term window for making key decision on optimal technological pathways.
11. **The federal government should implement a comprehensive approach for improving cross-border coordination of collaborative trial projects** to evaluate on a common basis the performance of net zero technologies and to promote investment and risk sharing associated with the **full-scale implementation** of new technologies.
12. **Governments should make data transparency and dissemination of trial and pilot results a conditionality for receiving public funding.** This would better foster collective learning, knowledge transfer and data sharing for further studies.

Priorities to support fleet owners in the early phase

There is a need for a regulatory push or economic business case to transition to new technologies as the trucking industry is reluctant to change. Participants were asked to define key priorities that could provide additional support to fleets owners and businesses in the early phase of transitioning towards zero emissions technologies.

There was a common agreement that **improved data access and transparency was needed so a wide range of stakeholders can benefit from the knowledge gained from trials and pilot projects**. It was not viewed as useful to have multiple companies all trialing the same technologies or use cases in isolation. Data sharing on performance and financials of new technologies, as well as better market monitoring by governments, would provide additional guidance on cost-effective actions by fleet owners to plan out transition to a net zero business model. **More training and awareness at the operation and fleet maintenance levels was also considered a top priority**.

In keeping with a technology neutral approach, it was mentioned that rewarding the performance of GHG reductions, rather than setting a preferred technological pathway could provide more flexibility for achieving net zero goals. Clean fuel standard, carbon tax, ZEV sales mandates, and tax on vehicle or axle weight were seen as performance-based metrics moving in this direction. A near term hybrid approach was also seen by some as preserving flexibility for operators.

KEY FINDINGS

13. **Improved data access and transparency needed to ensure a wide range of stakeholders can benefit from the knowledge gained from trials and pilot projects.** Increase data sharing on

performance, markets and financials of new technologies would improve fleet owners' decision-making process and planning towards a net zero business model.

14. **Need additional capacity for the training of fleet maintenance technicians, accessing service stations and increasing awareness at the operation levels to support new technologies**.

Leveraging improved logistics to support net zero long-haul truck technologies

Participants were asked how improving efficiency, modal shift and logistics in freight could be a leverage for supporting net zero long-haul freight technologies. Less answers were provided as the question was optional. Therefore, the following findings are based on fewer perspectives.

It was recognized that a systemic approach to intervention (i.e., accounting for GHG across the value and logistic chains) would need to be applied for the sector to successfully and structurally transition. This implies looking at multi-modal solutions for the Québec-Windsor corridor (e.g., shifting freight to rail), measures to optimize truck loads and implementing circular economy strategies.

There is a gap to fill in terms of long-term rail infrastructure investment and policy development in the context of its role in decarbonizing freight transportation**. Shifting freight to rail as a lower carbon mode and cheaper option of freight transportation should be part of government policies**. Private ownership of rail infrastructure in North America is however a challenge for increasing modal shift in comparison with Europe where there are different ownership models. Another limitation is the difficulty for private owner-operators of rail infrastructure (e.g., CN and CP) to make large CAPEX investments with long payback periods.

There is a need for greater data visibility. Governments have a central role in collecting, anonymizing and sharing data to help stakeholders understand decarbonization opportunities in the freight sector at a broader system level (e.g., shift transport of select goods from truck to rail or other modes). More data on daily-duty cycles (routes / trips) from trucking companies (anonymized for privacy) and more visibility on commodities carried would unlock studies on how to optimize trips to reduce empty truck hauls.

Future analysis should go beyond the scope of Class 8 long-haul trucks and the H401-A20 corridor, to understand how opportunities for charging / refueling zero emission trucks outside of the corridor (e.g., at return-to-base locations or along feeder routes) may impact the energy demand for charging / refueling infrastructure along the corridor itself. Furthermore, there should be an assessment on intermodal opportunities (shift of trucking to rail and/or marine as lower carbon modes of freight transportation).

KEY FINDINGS

15. **A systemic approach to intervention should be applied for the sector to successfully and structurally transition**. This implies looking at multi-modal solutions for the Québec-Windsor corridor (e.g., shifting freight to rail), measures to optimize truck loads and implementing circular economy strategies.
16. **Shifting freight to rail as a lower carbon mode and cheaper option of freight transportation should be part of government policies.** There is a gap to fill in terms of long-term rail infrastructure investment and policy development in the context of its role in decarbonizing freight transportation.

Options for improving stakeholder collaboration and engagement

In terms of stakeholder cooperation and engagement to accelerate reaching net zero goals in long-haul freight, many participants noted that processes should be more inclusive, transparent and structured to take into account various expert opinions and needs.

In the short term, it was suggested that **transparency and the functioning of existing mechanisms be improved, and that working groups on the decarbonization of the trucking industry be created**. Working groups should build on existing freight hubs or associations, and its structure could draw inspiration from the working group on the decarbonization of the maritime industry in Québec[19]. There is a need for cross-border collaboration under the leadership of governments (Canada and the United States).

Given the extensive modelling work on net zero freight technologies undertaken in Europe and the US, it was recommended that the federal government establish a dialogue between research groups in Canada (e.g., Natural Resources Canada, Transport Canada), the US (e.g., National Renewable Energy Laboratory) and Europe (e.g., International Transportation Forum - OECD).

There was also agreement on the need to hold **periodic consultations to follow state of progress and data needs for accelerating the energy transition of the trucking sector on key corridors** (e.g., 6-month check-ins to foster collaboration between academics, governments and industry). To do so, it was proposed governments launch a collaborative initiative for the trucking sector like the *Great Lakes St. Lawrence Governors & Premiers*[20] coordination on maritime decarbonization – as a joint effort between Canadian provinces and US states.

Collaborative planning between different jurisdictions can help achieve economies of scale, benefiting all stakeholders. While the demand for speed and convenience in e-commerce is increasing, it is important to differentiate between the needs of industrial goods and final consumers. Speed may be less critical for industrial goods, but for final consumers, the need for quick delivery is significant.

COURSES OF ACTION

17. **Make existing processes more transparent and inclusive by creating working groups** that include stakeholders from the business, academic and government sectors. Its structure could draw inspiration from the working group on the decarbonization of the maritime industry in Québec (*Groupe de travail sur la décarbonation de l'industrie maritime*).
18. **Hold periodic consultations to provide update on progress and data needed for accelerating the deployment of net zero truck technologies and infrastructures on key corridors.** To do this, the governments could mandate a review and stakeholder consultation cycle in its decision-making process. *The Great Lakes St. Lawrence Governors & Premiers* coordination on maritime decarbonization was put forwards as an example of an existing model to follow.

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[19] MEIE, 2023. *Groupe de travail sur la décarbonation de l'industrie maritime*, web page accessed on July 24 2023, https://www.transports.gouv.qc.ca/fr/ministere/role_ministere/colloques-congres-conferences/forum-concertation-transport-maritime/Pages/decarbonation-industrie-maritime.aspx

[20] GSGP, 2023. https://gsgp.org/: "The Great Lakes St. Lawrence Governors & Premiers unites the chief executives from Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Ontario, Pennsylvania, Québec and Wisconsin. The Governors and Premiers work as equal partners to grow the region's $6 trillion economy and protect the world's largest system of surface fresh water".

Conclusion

The objective of the workshop was to foster exchanges between experts to validate data and assumptions to be used in the simulations to compare the techno-economic potential of four identified net zero technologies for long-haul trucking, as well as exploring the challenges and best practices associated with the different technologies in the context of the highway corridor between Québec City and Windsor.[21] The net zero propulsion types considered included battery electric, catenary electric (with battery), hydrogen fuel cell and renewable natural gas Class 8 trucks.

After reviewing the proposed modelling approach and techno-economic parameters considered for the simulation, participants provided detailed comments and recommendations to improve the methodology. Many recommendations were outside the scope of analysis of the current study (given the resource and time constraints) but could be mentioned for consideration in future work.

While a wide variety of opinions were expressed, there was convergence on the need for greater access to data sharing and cross border collaboration to clearly understand uncertainties and study limitations. Conversely, when limitations are not well defined, understood and accounted for, results can introduce biases in the decision process and hinder the ability to plan out the best path forward for decarbonizing long-haul freight.

In a policy perspective, it is worth stressing that some participants raised the need of having a broader view of decarbonization, beyond road freight. Including other options like multi-modal, logistics solutions and modal shifts to train, can be a promising start for a successfully transition to net zero.

The proposed study is a first step towards an open approach. Additional techno-economic parameters should be included in future analysis to better account for the complexity of net zero truck technologies, infrastructures, highway utilization and cross border markets.

[21] Results of the simulation are availble in: Roberts, N., Cyr, M., Whitmore, J., P.-O. Pineau, P.-O., 2023. *Decarbonizing Long-Haul Trucking in Eastern Canada: Part 2 - A cost comparison analysis of net zero technologies on the A20-H401 Corridor Between Québec and Windsor*, prepared by CPCS and the Chair in Energy Sector Management - HEC Montréal for the Government of Québec, https://energie.hec.ca/decabonizing-long-haul-trucking-in-eastern-canada/

Appendix 1 | List of round table participants

In alphabetical order

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Appendix 2 | Compilation of detailed round table responses

In the virtual round tables, each table (10-12 participants) had to answer eight questions predefined by the organizers. The first three question were more specific to a backgrounder document sent to participants that laid out the scope of the project and a review of techno-economic parameters considered for the broader simulation study, while the next three focused on better understanding perspectives on current government actions on decarbonizing long-haul freight and to support fleet owners. The last two questions, which looked at how logistics consideration can support net zero long-haul freight technologies, as well as options for improving stakeholder cooperation and engagement, were optional.

Considerations for improving modelling methodology

Question 1. *After reviewing the Backgrounder, what are your top 3 comments or recommendations to improve our study methodology?*

TABLE 1

- **Broaden scope of study beyond corridor.** Enlarge network to cover more roads, include other types / classes of trucks (e.g., class 7) rather than on only a single corridor and Class 8 long-haul trucks.
- **Need origin-destination and load data**. Knowledge of origin-destination of truck trips helps identify where charging stations should optimally be located. However, there is a challenge in Canada, both at federal and provincial levels, with data availability.
- **Need to account for data discrepancies between sources**. BEV truck with large battery cost like catenary truck with small battery pack – discrepancies between different studies: should ensure consistent hypotheses (e.g., battery price assumptions, time interval between acquisition decision and actual use).
- **Sensitivity analysis is key**. Add sensitivity analysis on number of trucks adopting the new net zero technology (e.g., market penetration of new technology) – takes around 10-years for new infrastructure technology to be implemented.
- **Need coherent and consistent terminology and accounting**.
    - Cannot call "total life-cycle cost" if not including "end-of-life"
    - Private and for-hire carriers typically operate 6 – 8 years, average lifecycle for Class 8 long-haul 10 years (based on registration data – provincial trucking associations)
- **Zero-emissions fuels and renewable natural gas (RNG) considerations**.
    - RNG translate into 70% reduction (not 100%) on a LCA (well-to-wheel) basis.
    - Need to consider leaks and fugitive emissions across the supply chain (extraction, transportation, storage, truck slippage). ¸
    - RNG is severely limited in supply – should be used for high priority sectors which cannot be electrified (e.g., maritime, aviation, heavy industry)

TABLE 2

- **Broaden the scope of the analysis.** Include charging and recharging scenarios, where electricity could be a source of revenue.
- **Issues with the significant range of electricity rates.** Electricity rates are highly dependent on use case (e.g., time of day and peak demand) – currently modelling inputs are based on Hydro Québec rates. [The scope of the study will use a representative average annual electricity rate ($/kWh) and sensitivity analysis. We will not be able to dive into the details on specific rate structures.]
- **Analysis on V2G and power supply.** Distributed energy resources may become more common for depots, and vehicle-to-grid could offer opportunities for revenue generation – some long-haul trucks sit idle over weekend, could use (vehicle-to-grid) V2G in power outage situations. Commercial use of trucks as assets for revenue generation (transportation of goods) likely to outweigh potential benefit of having truck sit idle and deliver V2G power supply.
- **Need to include GHG on a life cycle basis**. The study is only considering direct avoided emissions compared to diesel, and not the indirect emissions associated with the production of electricity or fuel.
- **Land-use cost**. The study is not considering the land use cost associated with charging infrastructure, such as the space needed for parking and charging.

TABLE 3

- **Technological improvement over time**. The methodology doesn't include an analysis of technology development over time (e.g., battery energy density and cost decreasing). Should consider an exogenous forecast of how key parameters are evolving over time (e.g., longer lasting batteries, ability to charge at higher rates, lower cost of production).
- **Broaden the scope of study.** Concern of only looking at a single highway corridor and knowledge of utilization (e.g., how much the infrastructure is going to be used along the corridor, versus charging or refueling off-corridor on adjacent routes).
- Should account for the **load factor** of trucks (proportion running empty) **and resiliency of infrastructure** (e.g., planning for power outages, etc.).
- **Broaden the range of result indicators** (e.g., levelized costs, air quality benefits, end of life costs
- **Need sensitivity analysis.** NREL presentation showed large sensitivity analysis on variety of modelling parameters.
- **Evolving costs change over time**. Need to consider how costs change over time – hydrogen costs and battery costs (pack, efficiency) are the two most prominent.
- **Inductive charging**. Could consider inductive charging on the ERS because the technology is being explored by Detroit. [The technology is out of scope and has limited data availability.]
- **Need origin-destination data**. Origin-destination data from MTO or MTMDQ is needed to size battery packs for trucks and to know distances to determine appropriate battery pack size (this approach faces data limitations)
- **Include other environmental benefits**. To include air pollution benefits, number of reduced deaths, health illnesses etc. (lack of data make it challenging to quantify these indirect benefits).
- **A technology-neutral approach** could be the most applicable as data limitations currently hinder a more in-depth analysis, which could yield more specific recommendations (e.g., analysis of routes, commodities transported, with origin-destination and selection of most appropriate technology for this trucking market segmentation)
    - The lack of data and input illustrates the need for better access to data and transparent evaluation of different technologies

- **Modelling should consider different battery sizes**. Should disclose battery size (range of size) for long-haul trucks in consideration as this parameter greatly affects results.

TABLE 4

- **Broaden the scope of analysis of the study, including international dimension with the US**. Consider the practicalities of technologies.
    - Ease of use and flexibility of trucks, with preference for technical simplicity by fleet owners
    - Timeline and delay of regulatory approvals for infrastructure
    - Competitiveness issues (e.g., imperfect substitutes, competition of energy uses)
- **Account for economies of scale beyond scope.** Model-in economies of scale with other markets scaling-up adoption (e.g., in United States). Should also mention the strategic technology direction of passenger transport and its influence on freight vehicles (e.g., large battery manufacturing plants).
    - Identify the location and quantities of energy needs by overlaying the geographical configuration of goods flow with electricity grid
    - Limited access to ON and US data may limit opportunities to validate this information
- **Include cost projections.** Should project cost of vehicles and costs of fuel until 2030 as there are significant changes underway. For example, California cost of hydrogen $15 - $20 per kg future price could be $5 - $10 per kg (can get below $10/kg green hydrogen).
- **Consider environmental impacts on a life cycle basis**. Should consider well-to-wheel emissions, energy losses, fugitive emissions, impact of mining critical minerals for total lifecycle approach to assessing technologies – roll into next step recommendations following this study.

Other considerations specific to parameters presented in backgrounder document:

- Cost of overhead catenary electric trucks is near high end of battery electric price range (should be much lower) – should also disclose power transfer rate for catenary system.
- Clarify at what point in the supply chain hydrogen and natural gas prices are specified (should be at dispenser) – ensure not double counting costs.
- Cost for maintenance on diesel trucks appears to be understated compared to operator experience.
- Revise energy consumption levels. In backgrounder, energy consumption for hydrogen trucks is currently listed higher than diesel (seems incorrect). Hydrogen is more efficient should have a lower consumption when evaluated on a consistent energy unit basis (J/km). Natural gas energy consumption seems low compared to diesel.
- For ERS, include the costs of projects in Germany as a reference point, or the cost of the tramway project in Québec City?

Technological challenges, maturity and widespread availability

Question 2. *What is the timeline for technological (trucks and infrastructure) maturity and widespread commercial availability of different new zero emission Class 8 trucks coming to market in Eastern Canada?*

TABLE 1

- **Challenging to provide answer on the time horizon for large-scale commercialization of zero-emissions trucks**, as it is difficult to access information from manufacturer due to intense competition, and lack of net zero recharging/refuelling infrastructures
- **Influences on time horizon and pace of change** of trucking compagnies:
  - Acquisition of trucks done on a cycle of about 10 years
  - Need a period of 2-3 years for truck delivery and training.
  - Delays often related to administrative procedures (e.g., permits, compliance with load limits, safety)
- BEV – about 10-years away from widespread adoption – some trucking associations in conversation with OEMs to help guide members, however there is an element of secrecy on developments. Today, need to wait 1-2 years to order an electric truck and still need to adapt operations with current technology, phase-in needs to align with average lifecycle of 10-years.
- **Two scenarios are required to accelerate the uptake of long-haul net zero technologies in the marker:** 1) cost effectiveness compared to diesel trucks, or 2) regulations requirements (e.g., ZEV or CAFÉ standards) with penalties for noncompliance. Currently, there is no effective scenario in either case, only some pilot deployments on short-haul routes – need BEV capable of 1,000 km/day to be on par with diesel truck autonomy.
- Coming 2024, Cummins is launching a new Westport engine up to 15L (500 hp) to help address the power deficiency (compared to diesel) of 12L natural gas CNG engine.
- In Québec, there are a lot of local issues to get permits to install new infrastructure (notably natural gas and hydrogen refuelling).

What are the main technological challenges in the context of cold climates (–25^{o}C)?

- **Higher air density and energy consumption in winter**. Implies higher resistance and increase in energy consumption (20% or more) for cab heating
- **Catenary de-icing concepts very mature** – over 100-years experience in cold climates such as Sweden
- **Trucks face load limitations during the spring** (due to road wear concerns which could accelerate road degradation.
  - Road deterioration is a nonlinear (exponential) function of truck mass
  - Diversity of load limits between jurisdictions: impact on logistics. (e.g., trailer separation)
  - No leeway in both Québec and Ontario to increase road weight limits as already high
  - Impact on load factor optimization.
  - Implications for infrastructure life cycle and supply chain (e.g., steel industry)

What external conditions can promote or hinder the adoption of one technology over another?

- High level of integration in trucking sector Canada-US, which will influence the technology choice and direction of Canada's trucking sector.
- Challenge with lack of service available – maintenance and repair of natural gas trucks in Québec (qualified technicians and maintenance facilities meeting appropriate standards, e.g., fire safety and ventilation for maintenance of natural gas vehicles)
- Truck OEMs currently sell trucks with their preferred in-house engine / transmission model. If electric powertrain is supplied by another company, then this could influence the profitability of the OEMs
- Ontario – can accommodate higher weight limits due to Canadian shield – US has more restrictive weight restrictions 80,000 lbs. Some trucks need to reconfigure and split their load onto two vehicles at borders (Canada-US or Ontario-Québec) due to different weight regulations for trucking on roads.
- Vehicle weight increases impacts to road / infrastructure by exponential factor (x4) unlikely to accommodate increase in weight restrictions for EVs or other heavier vehicle types.
- Constraints related to the limit of driving time
- US market integration and dependence: Canada, being a smaller market, is often forced to be a follower of US trends in the trucking industry rather than a leader

TABLE 2

- **Hydrogen:** By 2024/2025 some fuel cell vehicles starting to come to market, similar timeline for green hydrogen. FCEV trucks on pilot in Edmonton have accumulated nearly 4,000 km with Alberta Motor Transport Association (AMTA) project - AZETEC, looking to replicate in Eastern Canada (FCEVs are lighter than BEVs and operate within US standard on road weight of 82,000 lbs per vehicle).
- **Electric:** Battery electric Class 8 trucks are already available in Canada, but they may not be ready for long-haul trips as they have a limited range and may face weight limit issues. It is important to define the scope of the study and what is considered as long haul, such as whether it is over 500 miles and whether it can be done on one charge.
- **Catenary:** Catenary technology is mature technology with use in Europe (trucks), streetcar, LRT and trolley buses in North America, but the lack of real political will is hindering its implementation. Most of the questions remaining are related to implementation and not technological issues. It is expected to be available by 2025-2030.
- **Natural gas:** trucks are already on the road and have years of operations. The technology for renewable natural gas is developing and is expected to be available on the market by 2024 (latest Cummins 15L engine), with compressed natural gas already available and liquefied natural gas in development. However, the question of supply availability remains as renewable natural gas uses will be in competition with heating and other transport uses. (RNG tends to be prioritized for heating new buildings.)

What are the main technological challenges in the context of cold climates (–25°C)?

- Maintaining battery temperatures, auxiliary power draw, can be less impactful if vehicles remain plugged-in at the depot.
- No technical challenge if warner that –20°C to heat the cabin and the auxiliary battery (battery supplement)
- Relatively high energy consumption needed to reach a normal temperature in the cabin (e.g., 17°C)

What external conditions can promote or hinder the adoption of one technology over another?

- The current measurement of the number of new decarbonized vehicles is not enough. The goal should be to reduce GHG emissions, so avoided GHG emissions should be measured instead of just the number of vehicles hitting the road.
- Diesel surcharge applied by trucking companies to accommodate higher diesel fuel prices is passed along directly to customers so increased fuel prices do not impact their revenue. Could there be policy to address this gap and incentivize trucking companies to switch from diesel?
- Challenge with complex, multi-jurisdictional permitting and construction projects for linear infrastructure (e.g., overhead catenary).
- Pathways and scaling: Different technologies require different pathways at different stages of development. The ability to scale is the main difference between technologies. Catenary systems need to be built along long distances, while the main advantage of EV charging is that it is distributed and any company can buy their own EV charging infrastructure. The ability to scale hydrogen technology will depend on the supply chain.

TABLE 3

- **Infrastructure** is the key limitation on getting electric trucks (e.g., number of charging stations available, and upstream T&D upgrades)
- Could start to build up infrastructure by phase-in (e.g., diesel-hydrogen blended engines) to enable infrastructure to scale – return-to-base (RTB) and blended fuels can be a way to start developing – fuel cells still being built by hand whereas battery packs are gaining economies of scale.
- Québec climate strategy only accounts for green hydrogen, does not consider blue or other types.
- Vehicle supply is an issue in Canada (Class 8 trucks are typically on a 2-year wait) a majority of trucks coming available are going to US (California)
- Potentially not enough renewable energy for producing enough green hydrogen

What are the main technological challenges in the context of cold climates (–25°C)?

- Experience in Sweden, no major concerns of electric vehicles operating in winter
- Radiant heat and heat pumps are the best way to reduce impact in range
- Ice on catenary wires does cause some arcing (electricity jump between pantograph and catenary, which produces a loud bang)
- No issue starting electric truck in minus 18°C if vehicle is plugged into charger, range is compromised to heat cabin
- Several companies adopting electric trucks have already done business case with cold winter conditions so that reduction in operating range is already planned for – more concern with type of loads in the truck (payload) than winter conditions
- Technical conversations with (few) vehicle OEM experts point to that heavy commercial vehicles are much less affected by range degradation in winter than passenger cars

What external conditions can promote or hinder the adoption of one technology over another?

- Availability of maintenance and repair service
- Complexity in assessing the cost-effectiveness of technologies (e.g., logistics, return to the loading center (return-to-base))

- Truck deployment and charging challenges:
- Additional cost of the zero-emission truck
- Behavioral: adjusting usage compared to diesel trucks (e.g., preheating and maintaining charging)
- Obstacles to cost pooling of public infrastructure: need oversight by regulatory bodies
- Limited supply of input to produce large scale alternative fuels (e.g., green hydrogen, RNG)

TABLE 4

- 7 to 10 years lead time in the United States for network upgrades to the electrical system (should be factored into adoption timeline)
- Hauling gaseous hydrogen would require ~6x more fuel trucks to haul supply of fuel to refueling stations, compared to current diesel fuel trucks
- RNG seems more promising on compressed gas side (not liquified gas) – significant fugitive emissions for RNG

What are the main technological challenges in the context of cold climates (–25ºC)?

- Trucking companies are looking at technologies with less components, which are easier to maintain. Cold weather operations are less of a concern.
- There are options to pre-heat truck / powertrain systems, which can help mitigate cold start issues (e.g., use of heat pumps)
- The effect of cold weather on battery electric trucks is less of an impact than on passenger EVs

What external conditions can promote or hinder the adoption of one technology over another?

- Lagging behind in heavy-duty vehicle engineering compared to the light-duty vehicle segment (e.g., requires manual operation of the preheating)

Perspectives on cost trends

Question 3. *What are your perspectives on the costs and expected trends of: 1) Infrastructure costs for RNG and hydrogen fueling stations, infrastructure maintenance per year; 2) BEV, OCT and FCEV trucks price ranges; and 3) RNG costs ($/GJ) in Ontario and Québec*

TABLE 1

Infrastructure costs

- $3 million per fast refueling RNG station.
- Hydrogen fueling station estimate 3% per year for maintenance costs.
- Consider dynamic catenary charging – 75% of total route covered as trucks do have battery packs on-board which provide a level of autonomy and they do not need the catenary 100% of the route.

Trucks price ranges

- N/A

RNG costs ($/GJ) in Ontario and Québec

- Clean fuel regulation to impact RNG prices

TABLE 2

Infrastructure costs

- Values in the backgrounder are on the high side.
- Hydrogen fuel station costs are dependent on the type of station (total cost of refueling), centralized production delivery dispatching vs production dispatching on site, and whether to have a normalized price per output (per kg of H2).
- Should have scenarios for different sized battery-powered trucks

Trucks price ranges

- FCEV price range seems high $1 – 1.5 million (ICCT source)

RNG costs ($/GJ) in Ontario and Québec

- N/A

TABLE 3

Infrastructure costs

- Should confirm assumptions on electricity prices in Ontario, and state charging profile assumed for all technologies.
- Utilization rate of chargers 80 – 90%
- Each location of charging / refueling infrastructure has different challenges, more accurate costing would require a detailed look at each site (e.g., electrical feed capacity, underground or overhead feeder lines, etc.) [outside the scope of the study]
- Need to account for disparity of costs and challenges by province and location

Trucks price ranges

- Need to account for declining battery pack price trends (gaining economies of scale).

RNG costs ($/GJ) in Ontario and Québec

- Assume $20 to $30 GJ, how much RNG is available for trucks? Check with Enbridge, Canadian Biogas Association or Storm Fisher.

TABLE 4

Infrastructure costs

- Fuel stations cost do not scale linearly as size increases.
- Apply context to cost estimates (e.g., first infrastructure project to build catenary system would be significantly higher than subsequent projects)
- UC Davis newly published report on FCEVs on how vehicle and infrastructure costs likely to scale over coming years.
- For ERS: opportunity to draw from cases in the US and Europe as a benchmark for cost development.

Trucks price ranges

- Pick midpoint of price range and adjust in the sensitivity analysis – FCEVs are in such an early stage of development – big difference between prototype demonstrator units and commercialized production (could account for the cost discrepancy in sources $400k versus $1M to $1.5M)

- Consider an option to apply a deflationary factor over a time horizon on truck prices (e.g., FCEVs) following a similar curve as other emerging technologies, BEV prices could be influenced by decreasing battery pack prices

RNG costs ($/GJ) in Ontario and Québec

- N/A

Perspectives on current state of government actions to accelerate the decarbonization of long-haul trucking

Question 4. *Are you satisfied with the current state of government policies and actions (federal, provincial, cross-border) to accelerate the decarbonization of long-haul road freight at the Eastern Canadian and provincial levels? What are top 3 key issues that explain your answer?*

TABLE 1

Incoherence and gaps in provincial/federal government policies and programs

- Government push to use clean trucks, however other ministries not following up on practicality of using such vehicles (e.g., 4,000 kg extra weight on vehicle, loss of payload and issue with road weight regulations)
- Infrastructure gap, coordinated roadmap needed between Ontario and Québec – would provide industry a path forward on planning technology investments, logistics, routing, etc.
- Ontario regulations permit higher weight on steer axles, however this is not the case in Québec. Regulations can impact truck design and selection – will hydrogen technology allow same payloads and operating range.
- Policy gap for smaller owner-operators to adapt to new technologies – financial barriers, risk of reduced revenue. Often, only the largest fleets owners have the capacity to acquire new technologies (e.g., Ecocamionnage)
- Need to consider LCA requirements in long-term public investment decisions
- Gaps in innovation and policy adjustment in Canada (e.g., California ZEV mandate allows 20% of vehicles to be hybrid vehicles)

Weak information-sharing culture in the trucking sector

- Needs to be more coherence amongst government ministries, coordination on data sharing between ON, QC and US for roadmap for planning.
- Need data collection for longer term investment policy through a neutral entity for gathering and sharing data.

In the short term, need more focus "low-hanging fruit" **solutions** – to improve aerodynamics (fairings, sideskirts, etc.) any ways to optimize logistics and routing – however, there are some limitations on reducing empty trips (e.g., return trips from dangerous goods haul).

Charging penalty: ERS have the advantage of flexibility with a smaller electric battery

TABLE 2

Level of satisfaction: acceptable as long as there is a technology neutral approach

Limits in public policy.

- Lack of clarity in targets and definition of objectives for business model change. Need to consider the effect of inertia by imposing regulatory constraints (e.g., environmental performance in kg CO_2e/km)
- Failure to take into account the variability of impacts according to fleet composition and fuel switching strategy
- Insufficient incentives for fuel switching, even for the largest fleet owners. Additional costs of diesel trucks are passed on to users (e.g., pricing of transportation costs)
- Gaps in policies to support innovation and private R&D
- There is a need for policy to push the private sector to invest in net zero technologies.

Race to the second place.

- Given the intensity of technological competition in the trucking industry, there a risk aversion to new technologies.
- Companies operate with slim margins, so there is a « wait-and-see » attitude in the market while waiting for risk and technological cost to come down, as well as technology performance to improve (hesitation of first mover advantage).
- Trucking companies do not have an incentive to switch to zero emission models unless subsides and incentives provide a compelling business case – not in a hurry to switch, unclear which technologies are going to emerge as the favourite.
- Product availability is an issue (e.g., lead times on new trucks)

TABLE 3

Governance issue

- Insufficient cross-border regional collaboration. Need for regional coordination, including with US, ON and QC on infrastructure solutions (e.g., logistics hubs or shared charging infrastructure). Could look to Europe for examples on how to approach this issue (e.g., EU technical members from all member countries to coordinate and evaluate project proposals)
- Policy to remove bottlenecks, grid expansion (e.g., in Sweden cannot build T&D upgrades based on speculation of future demand), labour resources to execute construction projects is a concern and equity considerations (e.g., how to ensure infrastructure is not built to the benefit of just a few companies)
- Collaboration for coordinated financial support (both federal and provincial levels) to companies

Competitive and fairness issues

- Challenge in managing differentiated effects on profitability in a market with multiple concurrent technologies

TABLE 4

Good level of satisfaction with the government support.

- Incentives, subsidies and funding options are very supportive for electric trucks, with subsides a regional haul EV truck is only ~$40k more than a diesel truck
- The next step should be to push the supply of EVs (e.g., support manufacturing capacity) in line with sales mandate, supportive measures for number of trucks coming to market

- Historical funding stream for natural gas vehicles / infrastructure (1990s in Ontario) was more accessible to light-duty vehicles, not a successful market – ultimately market collapsed with absence of government funding
- The biggest issue is the infrastructure, is not ready yet and if its ready there is not enough power at least in Québec – not power to supply all the trucks at this moment.
- Non-recourse loan – a business case should accompany a loan agreement
- Should tie in grant funding to data accessibility (e.g., publicly available data from pilot programs),
- ZEV standards should align with those in the US (e.g., California)
- Target the right segments (fuels, link in the chain between production and use) to support in order to avoid distortion effects

Options for improving government actions

Question 5. *Given that each technology presents different potential and risks, what actions should governments take to support them (e.g., transparent test-pilot projects, policies, regulatory, financial)? Should the government have a technology-neutral approach? Do you have examples of best practices?*

TABLE 1

- Gov. should have a technology neutral approach – subsidies for $/tonne CO2 reduced rather than specific technologies. There are many different segments of trucking sector, a technology agnostic approach preserves flexibility to address the best path to net zero.
- Transparency within freight carriers and industry is very limited (even business case to test trial or pilot new vehicles) – gap from Ontario government providing support to industry to reduce risk of new technology trials, in comparison to Québec and BC.
- Upfront capital cost is a major barrier to smaller fleets, owner-operators, government support to help address this barrier.
- There has not been enough support to make a change. No one want to be the first to try something new, it is a race for second place. As an industry, it is placing the transport sector behind. If the government could help in testing the new technologies that would be great.

Importance of the role of government

- Support for industry
    - for financing test infrastructures
    - for supporting the acquisition of new equipment
- Contribution to risk reduction (technological, economic, etc.)
- Favor technological neutrality: more realistic insofar as there will not be one solution but a diversity of them responding to different needs.
- Considering the national security dimension related to technological choices in the trucking industry
    - Climate adaptation and resilience issues (e.g., transport of food and medical products in the case of catenaries)
- Need for analysis on a national scale
    - Cost of large-scale technology choice
    - Risk of choice with regret (e.g., Availability of energy supply on the territory in the case of hydrogen)
- Conduct risk analysis for each technology.

Adopt similar approach in technology development as European:

- More sharing and collaboration between actors and governments in trials and pilot projects
- Trials of different technologies on identical real-life settings and conditions (e.g., testing of different truck technologies on the same stretch.)

TABLE 2

- Maintain a technology neutral approach for different technologies each to play to their strengths.
- QC unlimited amount of ZEVs incentives apply for, at the federal level there are limitations on the number of vehicles per year eligible for incentives (could hold back advancement of net zero technology adoption for larger fleets)
- Incentives to maximize the loads in each truck, mileage tax to address maintenance impacts to road infrastructure (would be fair to all technologies – compared to EVs having exemptions under a fuel tax policy)
- Sales mandates need to be set at the federal level to avoid policy gap / leakage of purchasing / selling vehicles in other jurisdictions (with less restrictions)

Principles of a technology neutral approach

- Must be based on GHG reductions performance, not on a vehicle counts
- Focus on reaching GHG reduction goals, rather than technology by implementing measures that apply indiscriminately to all types of vehicles (e.g., mileage tax is fair to all technologies for financing road infrastructure and incentivizing load optimization.)
- Ensure a leveled playing field

Need for a comprehensive or systemic approach to government interventions

- For improving cross-border coordination
- To promote pilot projects to study technologies and business models, including intermodality.
- To promote risk sharing by the grouping of actors and stakeholders

TABLE 3

Technology neutral policies – performance-based metrics for target setting CO_2e reduced

- Government cannot fund all technologies equally – there should be a prioritization of taxpayer money on most promising technologies and a performance-based evaluation
- Government posted RFPs for pilot demonstrations of different technologies to understand pros/cons and use cases (to share knowledge and avoid multiple companies all trialing the same)
- Current conditions / regulations make it more challenging to scale existing pilot / operations than establish a new pilot – question of scaling rather than pilots
- Government coordination with regional utilities (to scale electrical capacity, fuel/gas feeds)

Actions and mechanisms to accelerate technology deployment

- Need for a timetable and deadlines leading to a decision (e.g., Germany's approach with 3 technologies identified)
- Conduct collaborative trial projects to understand net zero technologies, their limitations and mitigate barriers
    - Bring together ON, QC, federal governments, industry and university actors
    - Foster collective learning and knowledge transfer
    - Make data transparency a conditionality (dissemination of test bench results)
- Accelerate energy projects by establish collaboration between governments and energy distributors

TABLE 4

- **Technology neutral approach** would rely on policies to price carbon and road usage. Would be a challenge to support significant infrastructure investment for all four technologies
- Apply a holistic approach to intervention. Look at multi-modal solutions for the corridor (e.g., shifting freight to rail) and ways to optimize / maximize truck loads, implement circular economy strategies.

Government Action

- Policy and regulatory measures should be based on GHG and environmental performance outcomes and objectives rather than technological specific (e.g., axle weight tax)
- Create working groups on the subject (e.g., draw inspiration from the working group on the decarbonization of the maritime industry in Québec[22]). Foresee the cross-border dimension under the leadership of governments (Canada and the United States)
- The need for collective production and transfer of knowledge and data
    - Collaboration between industry and governments
    - Relaunch trucking surveys with the collaboration of various departments (TC, NRCan, ECCC)
    - Include systematic sharing of data and results as a condition for receiving government financial support

Priorities to support fleet owners in the early phase

Question 6. *What are the top 3 needs (e.g., data access and transparency, studies, pilots, measures for improved efficiency, learning, training, capacity-building), that are a priority to support fleets and business owners in the early phase to reach net zero transition by 2050?*

TABLE 1

- The trucking industry is reluctant to changes – need a regulatory push or economic business case to make a move to new technologies
- Training fleet maintenance technicians to support new technologies
- Data sharing on performance and financials of new technologies. Need for better market monitoring by governments.

[22] MTMD, 2023. *Groupe de travail sur la décarbonation de l'industrie maritime,* web page consulted on July 18, 2023, https://www.transports.gouv.qc.ca/fr/ministere/role_ministere/colloques-congres-conferences/forum-concertation-transport-maritime/Pages/decarbonation-industrie-maritime.aspx

TABLE 2

- More data on daily-duty cycles (routes / trips) from trucking companies (anonymized for privacy) and more visibility on goods / commodities carried. Could unlock studies on how to optimize trips to reduce empty truck hauls.

TABLE 3

- Data access – so a wide range of stakeholders can benefit from the knowledge gained from pilot programs/ projects – not useful having multiple companies all trialing the same technologies or use cases in isolation
- Need more training and awareness to the level of operation and maintenance
- Guidance on actions to be put in place to support the market (e.g., how to transition to business model in charging that favours private ownership and operation to achieve a level of maturity comparable to public service stations)

TABLE 4

- Data access and transparency
- Reward performance on reducing GHG emissions, rather than setting a preferred pathway and policies to support that path – clean fuel standard, carbon tax and ZEV sales mandates moving in this direction towards performance-based metrics
- Tax on vehicle or axle weight to be considered as a policy
- Hybrid catenary approach preserves flexibility for operators

Leveraging improved logistics to support net zero long-haul truck technologies

Question 7. [Optional] *How can improving efficiency, intramodality and logistics in freight be a leverage to support net zero long-haul freight technologies?*

TABLE 1

- N/A

TABLE 2

- Government policy for rail sector development, shift freight to rail as a lower carbon mode and cheaper option of freight transportation.
- Private ownership of rail infrastructure in North America is an obstacle for increasing modal shift compare with Europe where there is different ownership models
- There is a gap to fill in terms of long-term rail infrastructure investment, difficult for CN and CP and private owner-operators of rail infrastructure to make large CAPEX with long payback periods

TABLE 3

- A reference for an expert in transportation logistics and value chain optimization was recommended: Professor Benoît Montreuil at Georgia Tech University: https://www.isye.gatech.edu/users/benoit-montreuil

TABLE 4

- N/A

Options for improving stakeholder collaboration and engagement

Question 8. [Optional] *What type of interregional collaboration could help different stakeholders (industry, government, research) better work together to accelerate reaching net zero goals in long-haul freight (e.g., acceleration labs, expert committees, networks, forums, annual meeting, platform)?*

TABLE 1

- Possible 6-month check-in meetings to foster collaboration between academics and industry (following successful working group examples elsewhere, such as the UK)
    - Create broader working group on the decarbonization of the trucking industry that builds on existing freight hubs or associations (e.g., Québec's working group on the decarbonization of the maritime industry)
    - Consider a dialogue between Canada (RNCan), provinces, US (NREL) and Europe (ITF-OECD)
- Challenging to bring people together for data sharing – activities within federal government there is an ongoing effort to collect data on Canada's trucking sector and share (subject to resolving any privacy concerns)

TABLE 2

- Need greater data visibility – government in a central role, collecting, anonymizing, sharing to understand decarbonization opportunities in the freight sector at a broader system level (e.g., shift transport of select goods from truck to rail or other modes)
- Collaborative planning between different jurisdictions can help achieve economies of scale, benefiting all stakeholders. While the demand for speed and convenience in e-commerce is increasing, it is important to differentiate between the needs of industrial goods and final consumers. Speed may be less critical for industrial goods, but for final consumers, the need for quick delivery is significant. In this context, airplanes are gaining market share in various goods movement supply chains.

TABLE 3

- N/A

TABLE 4

- Take example of St. Lawrence Seaway coordination on maritime decarbonization – joint effort between Canadian provinces and US
- Include Environment Canada, Transport Canada and NRCan in conversation.