PEMBINA institute

Fuelling the Transition

Low-carbon fuel choices for road freight

Hongyu Xiao

April 2024

revised July 2024

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About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions and convene diverse sets of stakeholders to identify and move toward common solutions.

The Pembina Institute acknowledges that the work we steward and those we serve span across many Nations. We respectfully acknowledge the space our organization is headquartered in as the traditional and ancestral territories of the Blackfoot Confederacy, comprised of the bands Siksika, Piikani, and Kainai, the Îyârhe Nakoda Nations, including the bands of Goodstoney, Chiniki, and Bearspaw, and the Tsuut'ina Dené. These Lands are also home to the Métis Nation of Alberta — Region 3 whose Peoples have deep relationships with the Land.

These acknowledgements are some of the beginning steps on a journey of several generations. We share them in the spirit of truth, justice, reconciliation, and to contribute to a more equitable and inclusive future for all of society.

Disclaimer

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Executive summary

Fleet owners and operators are planning and making significant investments to decarbonize their fleets. The combination of pending regulations, total cost of operations, and environmental targets are causing operators to incorporate low- and zero-emission vehicles into their fleets. To support owners and operators in making sound investment decisions, the Pembina Institute engaged with stakeholders in the clean fuel and medium- and heavy-duty vehicle (MHDV) sectors to analyze the role of clean fuels in the transition away from fossil fuel powered vehicles.

We studied four fuels in particular: biodiesel, renewable diesel, renewable natural gas, and hydrogen.

Two questions dictated the terms of our analysis. The first question explored the role of clean fuels in decarbonizing fleets during the transition period prior to full zero-emission vehicle adoption. The second question concerned the long-term role of clean fuels for vehicle classes where electrification is not yet commercially viable and is expected to remain technically difficult beyond 2040.

The Pembina Institute examined the merits and challenges associated with each clean fuel, taking into consideration cost, availability, ease of use, scalability and decarbonization value. Our assessment shows that:

- The fastest and most cost-effective means of reducing emissions generated by the MHDV sector is through electrification, which can currently be applied to most vehicle classes. For last-mile delivery trucks and vans and regional-haul vehicles that travel relatively short distances and return to central distribution centres, switching to battery-electric is optimal.
- Clean fuels will play an important role across the MHDV sector during the transition to ZEVs. During this time, a significant number of MHDVs will continue to run on internal combustion engines. Consequently, biofuels, and other alternative fuels, can reduce emissions while enabling operators to continue driving vehicles to end of life.
- Long term, clean fuels enable at least partial decarbonization in applications where electrification is not viable.

It warrants emphasizing that although three alternative fuels (biodiesel, renewable diesel, renewable natural gas) can diminish the carbon impact of a medium- or heavy-duty trucks relative to gasoline or diesel, their use does not lead to a fully decarbonized commercial freight sector. And although hydrogen-powered vehicles produce zero tailpipe emissions, the benefits of eliminating tailpipe emissions are offset to some degree given that almost all hydrogen is currently produced using carbon-intensive methods.

In summary, our findings show that:

- **Biodiesel** can reduce the carbon intensity of diesel, but supply limitations and the use of agricultural crops for fuel production could potentially offset biodiesel's greenhouse gas advantage over gas and diesel. Through measures such as the Clean Fuel Regulations, policymakers can ensure that biodiesel production is sustainable, by mandating that biodiesel is made from sustainable feedstocks with minimal land-use impacts and offering incentives that encourage boosting supply. There is sector-wide skepticism concerning biodiesel due to perceived operational problems in cold weather and warranty issues, although both are being addressed as the technology develops.
- **Renewable diesel** has the advantages of being a drop-in fuel, having few operational problems, and possessing the capacity to reduce tailpipe emissions. As with biodiesel, good policy is essential to maintain the sustainability of renewable diesel production. Production capacity in Canada is currently low, although the situation is changing as incentives provided through the Clean Fuel Regulations produce heightened investment.
- MHDVs that run on natural gas have become increasingly popular in Canada as automakers produce more natural gas heavy-duty trucks that meet Canadian specifications. Natural gas can be switched out to allow the same vehicle to operate on **renewable natural gas** as a way of lowering emissions. Still, renewable natural gas trucks continue to emit tailpipe pollution, and supply is unlikely to come close to meeting demand.
- Post-2035, **hydrogen** may be a decarbonization solution for long-haul vehicles and heavy freight. However, low-carbon hydrogen, i.e. hydrogen produced using either electrolysis or fossil fuels in conjunction with carbon capture, will likely remain significantly more expensive than hydrogen made from fossil fuels. This means that hydrogen vehicles would probably have to rely on fossil-based hydrogen. Consequently, the carbon intensity of hydrogen fuel is high despite the absence of tailpipe pollutants. Nevertheless, should the federal government regulate a mandate that, by 2040, all sales of new MHDVs will be zero-emission

vehicles, hydrogen fuel will be deployed since hydrogen fuel cell and battery-electric vehicles are the only categories of vehicles defined as zero-emission.

The majority of MHDVs (buses, Class 2b-7 trucks) can and should transition to battery-electric versions. Where electrifying road freight is more challenging (such as Class 8 vehicles for long-haul transport), biofuels and renewable natural gas are options in the short to medium term. However, more work needs to be done to improve the supply of feedstock and fuelling infrastructure.

Due to supply limits in some cases and carbon intensive means of production in others, prioritization in the use of clean fuels should target long-haul freight or sectors where there are no other viable options, and not vehicles classes that can be charged overnight in a central location, and where electric versions are cost-effective and market ready.

The certainty of predictions and estimates for future trends decreases with time. While there is relatively high certainty for the technologies, fuels, and vehicles that are likely to be available by 2030, predicting the same in 2040, not to mention 2050, is far more difficult. Developments are highly contingent on factors such as technological innovation, government policies, and market forces. As such, for vehicles that will take a longer time to decarbonize (such as heavy-duty trucks), a technology-neutral approach (for example, between battery-electric and hydrogen vehicles) might be most appropriate. For vehicle classes that currently have zero-emission options, however, a strategic approach to the use of clean fuels is justifiable.

1. Introduction

The electrification of medium- and heavy-duty vehicles (MHDVs) is vital to replacing gas- and diesel-dependent road freight and integral to emission reduction plans. In addition to electrification, clean fuels will also play an important role in the transition to fully sustainable transportation. First, electrification will not be viable in every class of the medium- and heavy-duty sector. Second, even among the majority of trucks and buses that are electrifiable, there will be a period, over the next 20 to 25 years, during which conventional fleets remain on the road as internal combustion engine (ICE) vehicles gradually reach their natural end cycle. In both cases, decarbonizing the MHDV sector will entail the deployment of clean fuels as the means to lower transportation emissions. As Canada maps the most expedient pathway to low-carbon mobility, it has become increasingly important to examine the merits, drawbacks and applicability of the clean fuel options on the market.

The imperative to drive down greenhouse gases (GHGs) generated by transportation in general and MHDVs specifically is stark. The transportation sector accounts for nearly a quarter of Canada's total GHGs, and MHDVs produce 37% those emissions. Electrification, in combination with clean fuels where necessary, is essential to achieving Canada's national climate goals.

In its 2030 Emissions Reduction Plan, the federal government announced that 35% of all new truck and bus sales by automakers and importers should be emission-free models by 2030, climbing to 100% of sales by 2040 where feasible. Our modelling indicates that even with a sales mandate in place, nearly 70% of medium-duty vehicles and 95% of heavy-duty vehicles will still run on internal combustion engines in 2030 (see Figures 1 and 2).

To date, 32 countries (including Canada) have signed on to the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles, which commits countries to accelerate the deployment of zero-emission MHDVs. Canada, Quebec, and British Columbia are now considering or implementing zero-emission mandates. In the U.S., the California Air Resources Board has been mandated to develop and propose zero-emission mandates for MHDVs by 2045, where feasible.

This scenario prompts two key questions:

1. During the period prior to a completed turnover to zero-emission vehicles (ZEVs), what is the role of clean fuels in decarbonizing fleets?
2. What is the role of clean fuels for vehicle classes where electrification is not commercially viable and remains technically difficult?

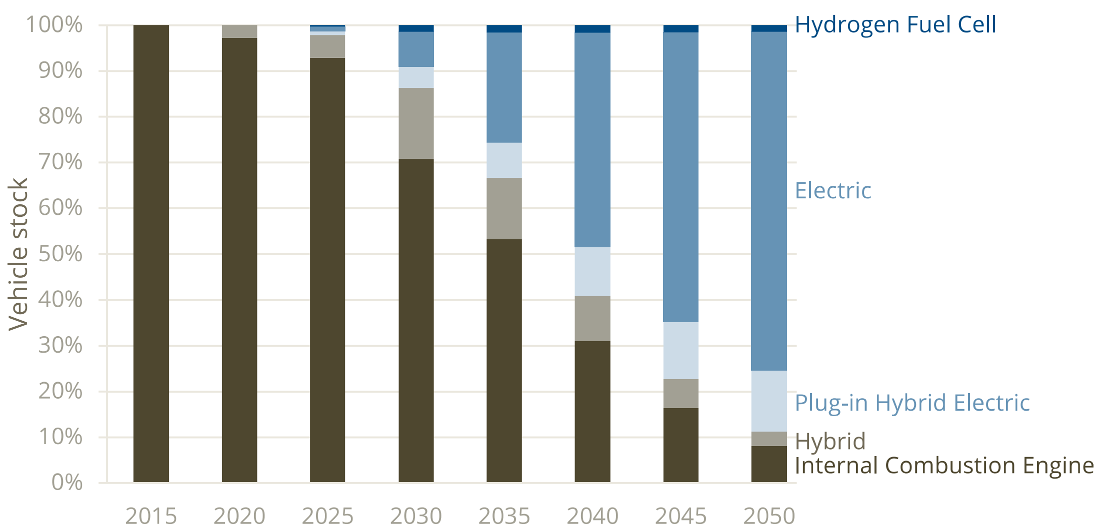

Figure 1. Medium-duty vehicle stock (with sales mandate)

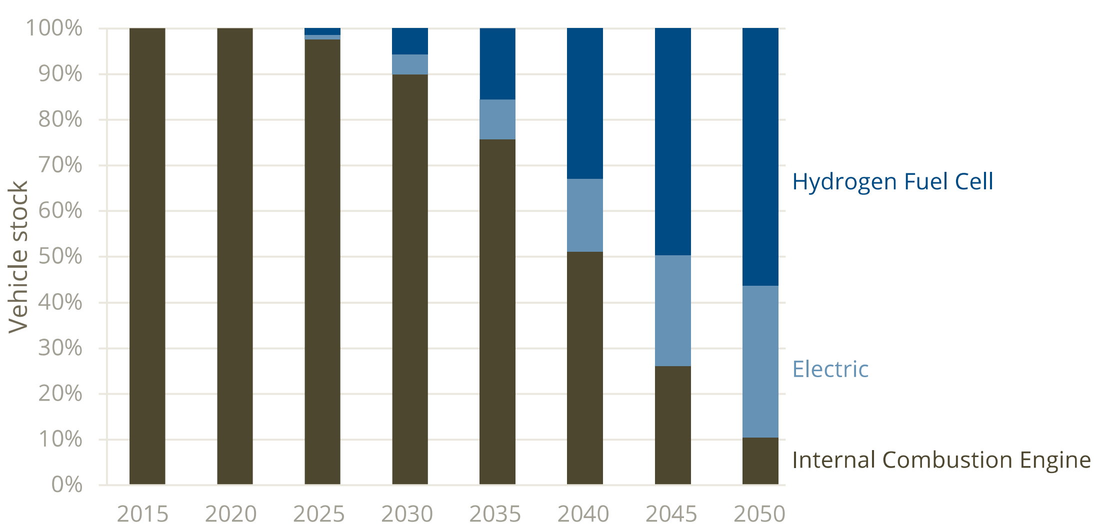

Figure 2. Heavy-duty vehicle stock (with sales mandate)

Our assessment used the following criteria:

- **Cost:** Is the market price of the fuel under consideration competitive with other fuel options, factoring in tax and subsidies?

- **Availability:** Is the fuel readily available in places where fleets will most likely require re-fuelling?
- **Ease of use:** Can the fuel be used in internal combustion road freight yet still offer greenhouse gas advantages over gas and diesel, allowing fleet operators to maximize the use of their existing fleet and avoid the additional expense of infrastructure investments?
- **Scalability:** Are infrastructure, feedstocks, and production capacity scalable so that the supply of the fuel can be deployed at volumes sufficient to lower emissions significantly rather than marginally?
- **Role in decarbonization pathway:** Under current production methods, are the emissions generated over the life cycle of the fuel significantly lower than those generated by fossil fuels? Relatedly, is there risk of locking in fossil fuel dependency or creating other secondary negative impacts such as diverting prime agricultural land from food to biofuel production?

Our analysis considers the viability of four clean fuels in achieving GHG reductions within the MHDV sector: biodiesel, renewable diesel, renewable natural gas, and hydrogen.

- Biodiesel and renewable diesel are options for road freight operating on diesel-fuelled engines. Both biofuels are less carbon intense than diesel and can contribute to decarbonization during the transition period, especially for vehicles that are hard to electrify. Good policy will be critical to fostering sustainable supply and accounting for land use impacts. While scalability is a concern, that could be addressed with increased crushing capacity, feedstock innovation, and higher yields.
- Renewable natural gas (RNG) can be deployed in trucks operating on natural gas although there are uncertainties related to adequate supply. Should RNG supply increase, significant investments will need to be made in infrastructure and adoption of trucks that operate on natural gas. Substantial government support will be required to foster production growth. If the supply of renewable natural gas fails to meet demand, commercial vehicles that use natural gas as the power source will continue to do so, locking in fossil fuel dependency and the associated infrastructure.
- Hydrogen fuel is the one fuel under consideration that does not generate tailpipe emissions. To date, however, the means of production is carbon-intensive; low-carbon hydrogen can only be produced at a very high cost.

The above criteria established the framework for the following case studies and our assessments of each of the alternative fuels under study.

2. Biodiesel

Summary

Biodiesel can contribute to decarbonization efforts during the transition period to zero-emission MHDVs as it has a lower carbon intensity than fossil fuels and can be used in internal combustion vehicles. Federal and provincial mandates that require renewable fuels (which are not limited to biodiesel) to be blended with diesel fuel ensure that biodiesel will remain part of the fuel mix over this period, where fossil-fuel powered MHDVs will continue to make up a significant proportion of Canada's road freight.

A cautionary note regarding the possible widespread use of biodiesel is that, while lowering the carbon intensity of fuel is a desirable outcome, diesel blended with biodiesel will still emit tailpipe emissions overall. Its most important role will therefore be as a transitional fuel while the sector switches over to ZEVs. Widespread use of biodiesel will require scaling up supply from sustainable feedstocks.

Background

A relatively low-carbon fuel, biodiesel is produced from organic matter. Approximately 85% of the biodiesel produced is made from canola or soybeans grown for this purpose while the remaining 15% is made from grease, tallow, or other feedstocks. Biodiesel is usually blended with fossil diesel in average concentrations of about 4% of the mix when sold commercially. The Clean Fuel Regulations require that biofuels should constitute 2% of diesel fuels (by volume), while provincial requirements range from 2% (Alberta and Saskatchewan) to 5% in Manitoba. The only province that has implemented a policy to increase the volumetric proportion of biofuel in the diesel pool over time is Quebec, where there is a requirement to increase the blend from its current 3% to 10% in 2030, modified by the fuel's carbon intensity.[1]

Biofuels made up 3.5% of the diesel pool in Canada in 2021. Of those, biodiesel constituted approximately 1.5% (445 million litres/year) of the total; renewable diesel fuel about 2% (540 million litres).[2]

Use projections

The International Energy Agency (IEA) report, *Net Zero Roadmap: A Global Pathway to Keep the 1.5 ° C Goal in Reach – 2023 Update*[3] includes modelling showing that to achieve a net-zero 2050, biofuels must constitute 12% of total fuel demand for all vehicles by 2035, before falling to approximately 3% by 2050 as demand for fuel in general diminishes. In the same report, biofuels are projected to make up approximately 7% of fuel use in heavy-duty trucks by 2035, a doubling from current levels. To align with a net-zero scenario, the IEA notes that, by 2030, at least 40% of the biofuel produced must be made using either municipal solid waste, forest residue or dedicated crops.[4]

The IEA's Renewables Report projects that, by 2028, global demand for biodiesel will increase to 52.9 billion litres annually. Should policies that require greater usage of biofuels be strengthened, demand could increase to 68.1 billion litres annually.

The Canada Energy Regulator likewise projects steady growth in the use of biofuels for road freight, particularly the use of renewable diesel.[5]

Biodiesel: Key characteristics and net-zero viability

Description	Biodiesel is made when organic matter such animal fats or canola are converted to a liquid biofuel that can be blended with diesel fuel. The replacement of petroleum diesel with biodiesel makes the resulting fuel mix less carbon-intensive.
Availability	Biodiesel in Canada is made commercially available through a combination of imports and domestic production. There are 11 biodiesel facilities in Canada with a combined capacity to produce 913 million litres of biodiesel annually; however, only 420 million litres were produced in 2023.[6] As much as 99% of the biodiesel produced in Canada is exported; virtually all the biodiesel that is used in Canada as a fuel or as a proportion of a fuel is imported from the United States. In 2022, Canada imported approximately 400 million litres of biodiesel from the U.S.[7] or 2% of the total amount of diesel (18.3 billion litres) consumed nationwide.[8]
Cost	Navius, a consultancy that specializes in quantitative modelling, estimates that a typical diesel consumer (such as a long-distance truck operator) will spend an additional $343/year, equivalent to a 0.9% increase, on blended fuels.[9] In general, biodiesel blends do not result in higher operating costs. These cost estimates are based on cheap first-generation biofuel production. Prices could rise as production becomes more sophisticated and increasingly reliant on non-agricultural feedstocks.
Ease of use	Most vehicles can use lower blends of diesel mixed with biodiesel. High blends usually require fuel filter maintenance and updated rubber seals. Some stakeholders expressed concern that use of higher blends would void the warranties provided by engine manufacturers, and they were also skeptical of the operational qualities of mid-level biodiesel blends (i.e. 5% to 20%). Against this, advocacy groups such as Advanced Biofuels Canada report that mid-level biodiesel blends are treated the same as all other fuels, and that a lack of

	warranty approval for some biodiesel blends does not mean that using those blends will void a warranty. [10] All major automakers approve blends with up to 5% biodiesel with appropriate standards. One large manufacturer has approved 7% biodiesel blends. Some manufacturers require further accreditation to approve the blend. OEMs have also participated in development of quality standards that run mid-level blends (B6 – B20), with widespread use across the United States and Canada. That said, some operators expressed concerns that the biodiesel quality blends were insufficiently regulated and that standards were not clear. Training with proper fuel management, storage and transportation help with ensuring that biodiesel is used effectively. Regulatory standards and testing have also helped improve the quality of biodiesel. For example, best practices include storage under cool, clean and dry conditions, with usage of dessicant filters and stability additives.[11] There are operational limitations in very cold weather due to biodiesel's higher congealing point relative to fossil diesel. Gelling occurs when fuel solidifies into a waxy gel-like substance that can render a fuel supply or engine unusable, although this risk can be mitigated with proper handling techniques.
Role in decarbonization pathway	Looking at life-cycle GHG emissions, Navius estimates that replacing diesel with biodiesel represents an approximately 90% reduction in carbon intensity.[12] The Clean Fuel Regulations will further support the use of biodiesel in fuels, with requirements to reduce the carbon intensity of fuels by 15% below 2016 levels by 2030. Under B.C.'s Clean Fuel Standard, the carbon intensity of biodiesel in B.C. is now negative. Well-designed policy is essential to reduce or prevent the unintended consequences of an increase in feedstock supply for biodiesel. One such consequence is the repurposing of agricultural lands to grow fuel crops.[13] Boosting crop yields and greater refining capacity within Canada is one way to ensure that feedstocks are sustainable. Another policy is the Clean Fuel Regulations, which include land-use impacts when calculating carbon intensity. While the calculations do not include emissions generated from indirect land-use change (where increased demand for feedstocks incentivizes conversion of land into agriculture), the Regulations expect fuel producers to mitigate that risk.[14] The Energy Transitions Commission, a U.K.-based think tank, has concluded that, because feedstocks for sustainable biofuels will be limited, biofuel should be restricted to hard-to-decarbonize sectors such as aviation. They also note that while biofuels may be cost-competitive for long distance trucking in a transition period, this advantage will diminish over time. Consequently, fleet operators and policymakers should not rely on biodiesel playing a major long-term role in decarbonizing long-haul trucks.[15]
Scalability	Made from commonly grown crops, first-generation biodiesel production is scalable whereas the production of biodiesel using non-food biomass is not, and only small-scale projects are currently active. EU-based studies find that scaling up biofuel supply to provide more than 10% of final energy to vehicles would be infeasible, because proposed additional feedstocks that do not compete with global food supply would increase costs significantly.[16] However, the situation

	may be different in North America as processing capacity in Canada and the U.S. increases, along with rising investments in feedstock innovation and crop yields. Renewable and low-carbon fuel policies could also create demand for wastes that are currently underutilized, such as chicken and poultry fats. Rising prices for biofuel could spur development of new supplies and industry innovation, although this has not yet occurred at scale.[17]
Appropriate use cases in a net-zero transition	There will likely be broad use of biodiesel at low-blend levels as long as road freight continues to run on diesel fuel. However, biodiesel usage will decrease as electric and hydrogen-fuelled heavy-duty vehicles replace internal combustion ones. Biodiesel will continue to be used in aging HDVs that run on diesel and which have few, if any, alternative options. Given the difficulties in sustainably scaling up biodiesel and the potential climate impacts in land use, the deployment of biodiesel should be targeted towards vehicles that have not yet electrified, or in areas where there is inadequate charging infrastructure. However, operational challenges in cold weather mean that, even in the case of road freight, the utility of biodiesel will be limited.

[1] Navius Research, *Biofuels in Canada* (2023), 3. https://www.naviusresearch.com/wp-content/uploads/2023/11/Biofuels-in-Canada-2023-2023-11-01-1.pdf

[2] *Biofuels in Canada,* ii.

[3] Araceli Fernandez and Thomas Spencer, *Net Zero Roadmap: A Global Pathway to Keep the 15 ° C Goal in Reach – 2023 Update* (International Energy Agency, 2023), 93. https://iea.blob.core.windows.net/assets/6d4dda5b-be1b-4011-9dad-49c56cdf69d1/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf

[4] International Energy Agency, *Biofuels* (2023). https://www.iea.org/reports/biofuels

[5] Canada Energy Regulator, *Canada's Energy Future* (2023), 59. https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/canada-energy-futures-2023.pdf

[6] Erin Voegele, "Report: Canadian Consumption of Biobased Diesel to Grow in 2023," *Biodiesel Magazine*, August 23, 2023. https://biomassmagazine.com/articles/report-canadian-consumption-of-biobased-diesel-to-grow-in-2023-20326

[7] Erin Danielson, *Biofuels Annual* (U.S. Department of Agriculture, 2023), 16-17. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Ottawa_Canada_CA2023-0030.pdf

[8] Statistics Canada, *Motor vehicle fuel sales* (2022). https://www150.statcan.gc.ca/n1/daily-quotidien/230919/dq230919d-eng.htm

[9] *Biofuels in Canada,* vi.

[10] Advanced Biofuels Canada, "Biodiesel." https://advancedbiofuels.ca/fuels-and-tech/biodiesel/

[11] *Biodiesel*

[12] *Biofuels in Canada,* 50.

[13] *Biofuels in Canada,* 50.

[14] Environment and Climate Change Canada, *Clean Fuel Standard regulatory design*. https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-regulations/regulatory-design.html#toc2

[15] Energy Transitions Commission, *Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible* (2021), 12. https://www.energy-transitions.org/wp-content/uploads/2022/07/ETC-Bioresources-Report-Final.pdf

[16] Jakob Rogastadius et al., *2035 Joint Impact Assessment of Greenhouse Gas Reducing Pathways for EU Road Transport* (2024), 38. https://ri.diva-portal.org/smash/get/diva2:1846969/FULLTEXT02.pdf

[17] International Energy Agency, "Is the biofuel industry approaching a feedstock crunch?" *Renewables 2022,* (2022). https://www.iea.org/reports/is-the-biofuel-industry-approaching-a-feedstock-crunch

3. Renewable diesel

Summary

As a near-term action, renewable diesel fuel is being used as transition fuel so that emissions from medium- and heavy-duty vehicles start to decline prior to the commercial viability of zero-emission vehicles in this sector. Renewable diesel has the advantage of being a drop-in fuel, in that it is chemically identical to petroleum diesel and can therefore replace it without vehicle modifications.

For renewable diesel to make a significant contribution to decarbonization, it will have to become more widely available commercially. Stakeholders were of the view that British Columbia and Quebec are the only two provinces where renewable diesel is a viable option, due to favourable policy. Canada has recently started producing relatively small quantities of renewable diesel through facilities in Prince George, British Columbia and Come-By-Chance in Newfoundland, although not yet at the volume required to meet demand. Policy also needs to support production of renewable diesel from sustainable sources, which should include feedstocks beyond vegetable oils.

Given the supply challenges, renewable diesel is unlikely to play a significant role in the decarbonization pathway for medium-duty vehicles or short-haul/last mile delivery vehicles. In these classes, electrification is more viable and cost-effective than switching to low-carbon fuels where diesel is still used.

Background

Renewable diesel is a synthetic fuel that is produced using organic matter such as animal fats and vegetable oils. It is a “drop-in fuel” with the same chemical composition as petroleum diesel (unlike biodiesel, which is chemically similar, not identical, to petroleum diesel). Using renewable diesel does not require retrofitting vehicles or investing in fuelling infrastructure. Nor does renewable diesel present the operational challenges associated with biodiesel, which include concerns about performance in cold weather (see Section 2 Biodiesel).

Use projections

According to the International Energy Agency, to achieve carbon neutrality by 2050, biofuels (including biodiesel and renewable diesel) should constitute approximately 7%

of total fuel demand for heavy-duty vehicles (HDVs) by 2030.[18] In Canada, modelling suggests that biofuels will similarly constitute about 5% of MHDV fuel demand by 2030 in a net-zero scenario. Currently, renewable diesel constitutes approximately 2% of total diesel demand in Canada.[19] The Canada Energy Regulator projects that in a net-zero scenario, renewable diesel will reach 7% of the diesel fuel supply by 2030, increasing to 35% by 2050.[20]

Renewable diesel consumption in Canada reached approximately 1.43 million liters per day in 2021, or 1.6% of all diesel demand nationwide.[21] While Canada has been co-processing biogenic diesel with fossil diesel for several years, the first stand-alone facility began commercial operations only in June 2023 at Tidewater Midstream's facility in Prince George, British Columbia. The facility has a capacity of 465,000 litres of renewable diesel per day and is expected to produce at an average 75% capacity. Braya also started producing renewable diesel at its facility in Newfoundland in February 2024, with an estimated capacity of about 2.9 million liters per day.[22] Before the facility opened, most renewable diesel in Canada was imported from the United States and Singapore.[23]

As with the production of biodiesel, a scalable supply of renewable diesel is also problematic due to a possible feedstock crunch. Globally, the consumption of vegetable oils is expected to soar by 46% to 54 million tonnes by 2027, which includes increasing the share of vegetable oil dedicated to biofuels from 17% to 23%. At this rate, demand will reach the supply limits of used cooking oil and animal fats — which are in high demand because they are less emissions-intensive and meet EU feedstock requirements — by around 2027.[24] The IEA projects that even if other wastes (such as palm oil effluent, tall oil, and other agribusiness waste oils) are considered, overall demand for biofuels would still consume about 65% of global supply. Nevertheless, high prices could be a signal for markets to innovate and seek out new supplies in order to avoid the crunch.

One concern with biofuels (both biodiesel and renewable diesel) is with the use of agricultural land for fuel crops. Unsustainable production could result in an increase in net emissions, due to the emissions generated by crop cultivation, as well as emissions produced by diverting land from its prior use to grow crops for both biofuel and/or food. To safeguard against this risk, good policy is essential. Current models that calculate the life-cycle emissions of biofuels incorporate emissions from cultivation and land use change, while the Clean Fuel Regulations contains safeguards against agricultural expansion.

Stakeholders in the biofuel industry expressed confidence that they could scale up renewable diesel production without adversely affecting food supply, arguing that the current bottleneck slowing supply is refining capacity, not feedstock availability. Agricultural producers in Canada currently prioritize food production, with fuel being a secondary market for excess supply or waste material. However, there is limited control over the sustainability of imported renewable diesel.

Renewable diesel: Key characteristics and net-zero viability

Description	Renewable diesel is a synthetic fuel that is produced using organic matter and vegetable oils. It is chemically indistinguishable from fossil-based diesel and can therefore be used as a "drop-in" fuel.
Availability	To date, renewable diesel is only widely available in British Columbia due to supportive provincial policies such as the Low Carbon Fuel Standard. Outside of British Columbia, access to renewable diesel is more limited, although facilities are expanding in Quebec and there are some fuelling stations in Ontario. [25] As North American production is expected to increase significantly over the next few years, availability across Canada could improve if policies continue to encourage renewable fuel adoption. California currently absorbs almost all renewable diesel production in the United States, such that more than half of diesel consumed in California is now derived from organic sources.[26] Renewable diesel is also nearly 15% of diesel content in British Columbia, due to its favourable regulatory regime including the Low Carbon Fuel Standard. The IEA has warned that with increased demand for renewable diesel, nearly 100% of estimated supplies of used oil and animal fats are likely to be exhausted by 2027. If demand continues to rise to levels greater than anticipated, global feedstocks as they stand are unlikely to be sufficient.[27] Further innovations in feedstock and processing could address these supply changes and provide viable pathways for increased supply.
Cost	Navius estimates that a typical heavy-duty consumer spent an additional $345 per year (or 0.9% of overall fuel costs) because of biodiesel and renewable diesel blending.[28] The best estimates for a credible price for renewable diesel would be from California, where the average price of renewable diesel was approximately $5.33/gallon as of April 2023, while the average diesel price was $5.24/gallon (i.e. a price premium of about $0.03/L)[29] In Ontario and British Columbia, recent spot prices suggest that consumers can expect to pay a minimum of $0.33/L more for renewable diesel than for fossil diesel, with conservative estimates anticipating that the price premium will be around $0.39/L.[30] A 2021 study on the use of renewable diesel in the Northwest Territories showed that replacing 5% of transport diesel would cost $1.7 million/year after accounting for carbon tax savings (savings are realized as renewable diesel does not incur a carbon tax whereas conventional diesel does).[31]

Ease of use	As already noted, renewable diesel can be used as a "drop-in fuel" in MHDVs that already run on diesel power. However, the only commercially available renewable diesel in Canada has a cloud point of about -20°C (where crystals form in fuel to create a cloudy suspension), so it would not be usable in the winter months in more remote areas of Canada. Renewable diesel with cloud points of -40°C are being developed and produced for the Canadian market.[32]
Role in decarbonization pathway	Renewable diesel can contribute to the decarbonization pathway as a transition fuel in the short- to medium-term (up until 2035 to 2040). The degree to which renewable diesel can lower life-cycle emissions depends largely on how it is produced, whether from spent vegetable oils or from crops grown specifically for the purpose of being turned into a fuel source. Some studies report that renewable diesel delivers a reduction of only 4.2% in tailpipe emissions relative to fossil diesel.[33] On the other hand, Navius reports that renewable diesel is up to 90% less carbon intensive than diesel,[34] and that overall use of biofuels in Canada avoided 7.3 MT of CO_2 in 2021.[35] Tailpipe pollution is still emitted when using renewable diesel, and limited feedstock for sustainable production (i.e. production with minimal land-use impacts) that means that the use of renewable diesel should be targeted to areas or sectors where electrification is not viable, such as remote provinces or long-haul trucking and aviation. Given that sustainable feedstocks exist in limited quantities, coupled with the persistence of tailpipe emissions, policymakers and operators should be restrained in their use or allowance of renewable diesel and aware that its usefulness has an end point.
Scalability	Renewable diesel production in the U.S. and Canada has increased substantially and has the potential to increase further. U.S. production has increased from about 427 million litres per year in 2013, to approximately 6.5 billion litres in 2021, and could increase further to some 22 billion litres by 2025[36], while Canadian facilities could produce about 4.07 billion litres a year by 2027.[37] Stakeholders in the biofuel industry indicated that renewable diesel production could be scaled up without adverse effects on land use. If refining capacity is expanded, more waste material from agriculture crops could be processed without affecting food supply, noting that the fuel market is a secondary market that can be used as a hedge against price fluctuations. As with biodiesel, the Clean Fuel Regulations account for land use impacts when calculating the carbon intensity of renewable diesel, while imposing requirements to manage the risk of indirect land use changes. A review of the Clean Fuel Regulations, slated to occur in 2025, could assess the impact of an increase in production for renewable diesel.[38]
Appropriate use cases in a net-zero transition	Given the limited availability of renewable diesel, it is likely to find the best use cases for vehicles that have not yet transitioned to ZEVs, or in areas with harder-to-access alternatives such as long-haul trucking or in remote areas. For example, Navius, a consultancy with expertise in modelling energy use, has estimated that to reach net-zero in 2050 in the Northwest Territories, biofuels would have to account for the entire diesel pool not only for transportation but also electricity generation and heating.[39],[40]

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[27] "Is the biofuel industry approaching a feedstock crunch?"

[28] *Biofuels in Canada,* 65.

[29] U.S. Department of Energy, *Clean Cities Alternative Fuel Price Report* (2023), 18. https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_april_2023.pdf

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[31] *Assessing the Use of Liquid Biofuels in the Northwest Territories,* 34.

[32] *Assessing the Use of Liquid Biofuels in the Northwest Territories,* 34.

[33] Kenneth Kelly and Adam Ragatz, *Economy and Emissions Impacts from Solazyme Fuel in UPS Delivery Vehicles* (National Renewable Energy Laboratory, 2018), 9. https://www.nrel.gov/transportation/fleettest-fuels-diesel.html

[34] *Biofuels in Canada*, 51.

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[36] Maria Gerveni, Scott Irwin, Todd Hubbs, "Overview of the Production Capacity of U.S. Renewable Diesel Plants for 2023 and Beyond," *farmdoc daily* (13):57, March 29, 2023. https://farmdocdaily.illinois.edu/2023/03/overview-of-the-production-capacity-of-u-s-renewable-diesel-plants-for-2023-and-beyond.html

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4. Renewable natural gas

Summary

Renewable natural gas (RNG), made from the biogas emitted by natural waste products found in biomass such as landfills and agricultural waste, will be of limited value during the transition period to zero-emitting medium- and heavy-duty vehicles.

Supply is one concern. Canada's renewable natural gas production capacity is currently about 7 petajoules (PJ), enough to power approximately 3,200 MHDVs a year. By 2030, production capacity is estimated to increase to approximately 69.7 PJ a year, enough to power roughly 32,000 MHDVs, assuming that all the RNG produced is dedicated to transport.[41] Contingent on the implementation of policies that encourage RNG production, modelling shows that as much as 231 PJ of RNG could theoretically be produced,[42] enough to meet the energy demands of 106,000 MHDVs. Even so, with 2.6 million MHDVs on the road — and given that RNG is mixed into the natural gas supply — it is unlikely that RNG will power more than a fraction of Canada's MHDV fleets.

Although supply may be relatively small for the foreseeable future, RNG could be a viable means of decarbonizing specific classes of MHDVs during the period prior to a full transition to zero-emission vehicles. Because existing gas pipelines can be used for distribution, RNG requires no new specialized infrastructure, although an increase in RNG volume may require new investments in fuelling stations and pipelines. For heavy-duty vehicles (HDVs) that travel long distances, using RNG can potentially lower life-cycle emissions substantially. RNG may also be an optimal choice for garbage trucks powered by natural gas, which have access to a ready supply of RNG sourced from landfills as part of a "closed loop" system. Some municipalities across Canada have already constructed RNG processing plants next to waste management facilities for electricity generation and to power fleets.[43]

Nevertheless, investing in RNG should be approached with caution. RNG may result in reduced or even negative emissions on a life-cycle basis (once the avoided emissions from methane capture are accounted for), but there are still associated tailpipe emissions. Furthermore, fugitive upstream emissions are associated with the storage and transportation of RNG fuel. Because RNG requires no operational or infrastructure changes, fleet operators could purchase gas-powered MHDVs with the expectation that the natural gas supply would contain substantial quantities of RNG. Doing so would lock in natural gas infrastructure while the supply of RNG at the levels required may fail to materialize.

As RNG will be available only in limited quantities, its use should be prioritized for heavy road freight and certain industrial uses. Electric vehicles are cleaner and commercially viable for most medium-duty (Class 2b to 6) vehicles, including buses and urban delivery vehicles, and therefore are a far preferable option over vehicles using RNG.

Background

Biogas, primarily made up of methane, carbon dioxide and water, is emitted from landfills, farmland, food processing and wood waste. The biogas generated by these sources can be captured and processed to remove carbon dioxide and impurities, turning it into renewable natural gas, which is indistinguishable from natural gas in terms of its use and chemical make-up.

Both Quebec and British Columbia have mandated the inclusion of RNG in the supply of natural gas (which, in addition to transportation, will be used for home heating and gas stoves). In Quebec, distributers were first required to blend in RNG as 1% of the total amount of natural gas distributed by 2020, increasing the proportion of RNG to 5% by 2025 and 10% by 2030. British Columbia has committed to a minimum of 15% renewable content in the natural gas stream by 2030, which includes but is not limited to RNG.[44] Distribution companies such as British Columbia's FortisBC and Enbridge in Ontario have launched opt-in programs where customers can choose to make financial contributions that are directed towards purchasing RNG to blend with the natural gas distributed throughout the network. Enbridge estimates that some 1,000 customers have contributed to the program to date.[45]

Use projections

RNG will likely have the greatest applicability in the short term to meet federal requirements under the Clean Fuel Regulations. The Clean Fuel Regulations aim to reduce the life-cycle carbon intensity of liquid fuels used in Canada. To incentivize production of clean fuels, credits are issued to producers of renewable fuels such as biogas and RNG. It is therefore quite likely that RNG production will scale up, although it is too early to predict the impact of the regulations on future volumes.

Renewable natural gas: Key characteristics and net-zero viability

Description	Renewable natural gas is produced using the biogas emitted from agricultural waste, landfills, sewage treatment plants, and other biomass. RNG can be blended with liquid natural gas or compressed natural gas to reduce the carbon intensity of pure natural gas; some provincial governments, such as Ontario, are considering the construction of fuelling stations for trucks that only offer RNG.
Availability	Natural gas vehicles and associated fuelling infrastructure have not penetrated widely across Canada. In 2019, there were only 41 operational public compressed natural gas refuelling stations, down from 72 in 2010.[46] Canada's RNG capacity is expected to increase to 17.1 PJ in 2025 (enough to power about 7,700 MHDVs) from approximately 7 PJ in 2021. For reference, in 2007 total fuel used for natural gas vehicles in Canada was 1.9 PJ, which powered about 12,000 vehicles (less than 1% of total MHDVs). This figure included 150 urban buses, 45 school buses, 9,450 light-duty cars and trucks, and 2,400 forklifts and ice-resurfacers.[47] In Ontario, Enbridge operates four RNG production facilities, producing approximately 11.6 million m^3 of RNG (or about 0.43 PJ, enough to power about 196 MHDVs).[48] Because Ontario has not mandated blending RNG into the gas supply as B.C. and Quebec have, RNG in Ontario could be entirely directed toward transportation usage. Doing so would be optimal given that RNG output is a fraction of the levels of natural gas that are produced: Ontario produces about 71.315 million m^3 of natural gas annually, which is approximately 0.1% of total natural gas production in Canada.[49]
Cost	The cost to add RNG to the natural gas distribution system ranges between $10 and $25/GJ. By way of comparison, Ontario utilities have contracted with solar power producers at price points between $19 and $44/GJ.[50] RNG costing is largely determined by source. RNG production from landfills is the most affordable; RNG from forest and agricultural waste the most expensive. In British Columbia, FortisBC offers a program where RNG is purchased at a cost of ~$15/GJ.[51] One important caveat is that costs are based on existing supply and demand; prices could rise if demand increases and more expensive supply sources need to be tapped. HEC Montreal conducted a recent study of decarbonization technologies along Canada's Eastern Corridor and found that of the options under consideration for long-haul vehicles (including battery-electric, fuel cell, and RNG), vehicles that ran on RNG were the most cost-efficient. This is due to the low incremental costs of purchasing an RNG truck, the maturity of RNG technology, and the operational cost savings of RNG fuel over diesel.[52] They also found that over the lifetime of the vehicle, the savings realized on trucks that run on RNG instead of diesel fuel offset the higher purchase price. However, these findings are contingent on widespread availability of RNG, which is a key concern.
Ease of use	RNG is easily integrated into existing fuelling facilities and used in gas-powered vehicles. Until recently, one barrier to the widespread adoption of gas-fuelled long-haul trucks was that ones suitable for the Canadian trucking industry, which pulls heavier weights than American trucks (about 125,000 lbs versus 80,000 lbs), were not commercially available. However, Cummins, an American-

	based engine manufacturer, has recently introduced a 15-litre engine capable of supporting Canadian payloads, which could make natural gas for long-haul trucking a viable option and therefore straightforward to refuel using RNG.
Role in decarbonization pathway	Heavy-duty trucks powered by gas are marginally less carbon-intensive than ones that run on diesel fuel. Over the lifetime of a gas-fuelled truck, emissions are anywhere from 4% to 18% lower than those generated by diesel-fuelled trucks. However, these savings are lost when upstream methane emissions from leakage during production and transportation are taken into account. Furthermore, methane, a potent GHG, has more than 80 times the warming power of CO_2 over the first 20 years of reaching the atmosphere. A recent study found that compressed natural gas and liquid natural gas have greater climate impact than diesel-fuelled HDVs, after accounting for the greater warming potential of methane over carbon dioxide.[53] To decarbonize MHDVs fuelled by gas, RNG must be a substantial part of the fuel mix. In a scenario where Class 8 long-haul trucks run entirely on RNG, GHG emissions over the lifetime of the vehicle could drop by as much as 55%.[54] However, as most current approaches favour mixing RNG with the gas supply, it is unlikely that the average operator could see such substantial reductions. Moreover, the carbon intensity of RNG depends on the production method, the scope of fugitive methane capture, and calculating the emissions avoided by replacing fossil natural gas with renewables. One of the arguments in favour of RNG is that by capturing methane, the production process reduces the methane that would otherwise be emitted into the atmosphere. Fuel producers are therefore keen on accounting methods that would include life-cycle and avoided emissions as part of the analysis for whether a vehicle is “zero-emission”. Analysis from the International Council on Clean Transportation found that cost-effective outputs of RNG (e.g. RNG produced from landfill or wastewater) can displace, at most, 8.9% of the total volume of natural gas anticipated to be consumed by heavy-duty trucks in California in 2030. This assumes that the RNG produced is used solely for transport. In a life-cycle comparison, a truck fuelled by the average mix of RNG plus natural gas would see only about 11% GHG emission reductions compared to a conventional truck.[55] Should fleet operators transition to gas vehicles with the expectation of a steady supply of RNG, there is a real risk of natural gas infrastructure lock-in, which would be especially problematic if the supply of RNG does not materialize. Fleet operators should be careful not to rely on a large-scale conversion from diesel to natural gas vehicles in their plans to decarbonize operations.
Scalability	Whether there will be an adequate supply of RNG to substantially decarbonize medium- and heavy-duty trucks is an open question. Currently, Canadian RNG production capacity is approximately 7 PJ, a mere 0.18% of the total demand for natural gas.[56] Active policies could unlock higher supply, up to 261PJ.[57] Still, for RNG to be a viable fuel alternative for big rigs, most — if not all — production of RNG would need to be directed to transportation uses instead of home heating or industrial use. Longer-term planning must account for the very real possibility that increasing the production of RNG will require increasingly expensive methods of

	production as feedstocks become harder to source. Landfills and waste facilities are finite; the RNG produced from these sources would probably be used to power garbage trucks. Animal waste and forest residue can also be used to produce RNG, although collection of feedstock from farms is more expensive.[58] One possible solution is to concentrate facilities near farms and with access to gas pipelines. This would theoretically be a more efficient and cost-effective way for farmers to supply feedstock.[59] However, this may be more difficult to achieve in practice. In Quebec, studies show that potential RNG feedstock is already used in more profitable and/or environmentally friendly avenues such as forest preservation. The same studies also note that where biomass has not been used, that is because it has often been left in place to preserve ecosystem integrity. Extracting forest biomass for RNG therefore risks damaging the local ecosystem and releasing carbon stored in the soil.[60] More realistically, FortisBC has analyzed the price points at which RNG production from various feedstocks becomes viable for the producer. [61] At lower price points (about $18/GJ), only about 28 PJ per year of production of RNG is viable. To reach the goal of 69 PJ production in 2030, production costs would have to rise to approximately $50/PJ, which could make RNG too expensive for the market. British Columbia's Greenhouse Gas Reduction Regulation requires gas utilities to ensure that RNG makes up to 15% of their total gas purchases at a maximum price of $30 per GJ. At that price, about 60 PJ of production will become viable in 2030.
Appropriate use cases in a net-zero transition	RNG has been most widely used for garbage trucks that can be easily refuelled at production facilities sited at landfills and waste treatment facilities. Other potential use cases include tractor-trailers, vehicles used by the forestry industry in B.C., and long-distance trucks operating in provinces with strong RNG mandates (B.C. and Quebec).

[41] Assuming annual energy consumption of 2,200 GJ per truck.

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5. Hydrogen

Summary

Zero-emission vehicles — those that produce no tailpipe emissions — can be powered by either hydrogen fuel cells or batteries. Hydrogen fuel cells are significantly lighter than batteries and can refuel quickly — but there are drawbacks, too. Because the production of hydrogen is generally carbon-intensive, the climate benefits of eliminating tailpipe emissions are diluted. Cleaner means of production are in development, but we have yet to see evidence that clean methodologies can operate at scale. Currently, fuel cell trucks are limited in supply and considerably more expensive to purchase relative to conventional trucks; publicly accessible hydrogen fuelling stations are nearly non-existent.

Nevertheless, the potential for hydrogen is sufficiently compelling that their use warrants close consideration especially for long-haul trucks and vehicle classes where battery electrification presents technological and design challenges. The option of using hydrogen fuel cells may well be a solution in the long term, if not in the short term, for hard-to-decarbonize vehicle classes.

Background

Hydrogen fuel cell vehicles operate on the same propulsion system as battery-electric vehicles. Pure hydrogen gas is stored in the vehicle's tank, not unlike conventional gasoline. The hydrogen undergoes a chemical reaction with oxygen to produce electricity, which powers an electric motor. The tailpipe simply emits water vapour.

Many fleet operators and stakeholders see hydrogen fuel as the most viable alternative to using diesel or gas to power long-haul Class 8 trucks. Being comparatively light and able to charge quickly means that fuel cells offer attributes that are essential for heavy-duty trucks driving long distances where weight is a high-priority consideration, and drivers do not return to a central base for trucks to be charged overnight. Hydrogen fuel cells can be refueled in eight to 60 minutes depending on how much fuel is needed.[62] Moreover, fuel cell operated trucks are twice as energy efficient as ones operated by a combustion engine.[63]

Use projections

The International Energy Agency's (IEA) *Net Zero Roadmap: A Global Pathway to Keep the 1.5 ° C Goal in Reach – 2023 Update* posits that, to realize a carbon-neutral economy in 2050, hydrogen would need to contribute approximately 16% of the total amount of fuel consumed by vehicles of all classes. Should Canada implement regulations that require all new medium- and heavy-duty vehicles sold in 2040 be zero-emission vehicles, unpublished modelling undertaken by the Pembina Institute shows that hydrogen will need to increase from an anticipated 1% of MHDV fuel consumption in 2035 to approximately 50% in 2050.

The Canada Energy Regulator anticipates that the use of hydrogen in freight will increase to 0.5 Mt in 2030 and to nearly 5 Mt in 2050.[64] In this scenario, 5 Mt would meet almost half of total hydrogen demand,[65] enough to power approximately 190,000 long-haul trucks a year.[66]

There are, however, some significant drawbacks to relying on hydrogen to help decarbonize the MHDV sector, with a primary concern being the carbon intensity of the production process. Less than 1% of the world's hydrogen is produced using methods that employ carbon capture or electrolysis, which substantially lower emission levels. Secondly, because hydrogen contains less energy per unit volume than other fuels, transporting, storing and delivering it to multiple fuelling stations is more costly on a per-gasoline-gallon equivalent. Hydrogen also presents challenges to pipeline construction and storage design. Hydrogen degrades the quality of commonly used pipeline and storage materials and is more prone to leakage than natural gas[67] — all of which makes construction of a resilient and reliable network of fuelling stations difficult.[68]

In the immediate future, most hydrogen will continue to be produced using processes that have a large carbon footprint.[69] Production of unabated hydrogen where processing is powered by fossil fuels could produce up to 50% more warming than simply burning fossil fuels, whereas hydrogen produced using electrolysis powered by a renewable energy source does not generate any emissions.[70] Estimates of emission levels are highly variable and depend on the fuel and technology employed, as well as the rate at which carbon capture is applied. Consequently, hydrogen fuel should be selectively targeted to use in heavy-duty, long-haul trucks where battery electrification is less viable.

Hydrogen: Key characteristics and net-zero viability

Description	Hydrogen is a gas that can be combined with oxygen in a fuel cell to produce electricity. Fuel cells are lighter than batteries and can be charged quickly.
Availability	As a fuel source for MHDVs, hydrogen is available in extremely limited quantities in Canada. Only five retail hydrogen stations exist in the country: four in British Columbia and one in Quebec.[71] The governments of Alberta and Ontario are planning to construct a small number of stations in their respective provinces. There are also some private hydrogen refuelling stations for corporate use. Canada currently produces approximately 3 million tonnes of hydrogen annually through steam methane reformation of natural gas, most of which is designated for industrial purposes.[72] The infrastructure for supplying hydrogen to refuelling stations is still rudimentary. In the long run, hydrogen production is expected to increase. However, governments have yet to figure out a cost-effective means of transporting and distributing hydrogen at levels that will meet the potential demand. Nor is there a clear roadmap to guide where hydrogen stations should be located along major traffic corridors. Another area of uncertainty is whether increased hydrogen production can or will be directed to transportation or other hard-to-decarbonize sectors like industrial production, where it may achieve more cost-effective reductions in overall emissions. There is also limited availability of commercial fuel cell Class 7 or 8 vehicles. Currently, most trials in North America are focused on regional haul with a quasi return-to-base model. Long-haul trucks with hydrogen fuel cells are not yet available on a commercial basis that is viable without extensive subsidies.
Cost	The cost to refuel at a hydrogen fuelling station in British Columbia can run as high as $12.75 per kilogram.[73] Assuming a tractor-trailer requires 9 kg of hydrogen fuel per 100 km, a 100 km drive will cost approximately $114.75. According to a 2020 study, hydrogen prices need to fall below US$5/kg for hydrogen fuel-cell vehicles to be economical.[74] ICCT projects that by 2030, diesel fuel will be priced at approximately US$1.27 per kg, hydrogen produced using natural gas will cost US$4.39 per kg, and hydrogen produced using renewable energy will cost US$6.97 per kg.[75] A hydrogen fuel-cell vehicle is anywhere from 8% to 33% more expensive than an internal combustion engine vehicle, and hydrogen fuel is more expensive than gas or diesel.[76] Estimates as to when hydrogen-fuelled trucks will be cost-competitive vary. ICCT estimates that in the United States, the total cost of ownership for hydrogen fuel cell vehicles will be 5% to 30% cheaper than diesel vehicles by 2030, depending on the source of hydrogen.[77] The US National Renewable Energy Laboratory (NREL) estimates that hydrogen fuel-cell long-haul heavy trucks can become cost-competitive by 2035, at which time technological advances and policy development should enable the creation of a competitive hydrogen refuelling market.[78]On the other hand, EU-based studies suggest that FCEVs using low-carbon hydrogen are unlikely to be

	competitive with battery-electric vehicles or ICE vehicles in most vehicle classes, even by 2050.[79] If low-carbon hydrogen is used, the Swedish Research Institute estimates that the total costs for FCEVs in 2035 will be double those of battery-electric vehicles, entirely due to the high cost of producing and distributing the hydrogen to trucks.[80] The high degree of uncertainty exists because the total cost of ownership of FCEVs is dominated by the cost of hydrogen fuel, particularly in the first few years. Predicting costs (especially in 2040 or 2050) is subject to a high degree of uncertainty, which substantially affects the estimated cost of FCEVs because FCEVs are less energy efficient than battery-electric vehicles, and consequently more vulnerable to energy price fluctuations.[81] There is an important variation between the Canadian and American heavy-duty trucking market. Canadian trucks pull heavier loads than American ones, so trucks designed for the American marketplace won't find market share in Canada. This limits the options available to Canadian fleet operators, as most manufacturers design and build trucks for the (larger and more profitable) American market. Absent the availability of low or zero-emission long-haul truck models in the Canadian market, we cannot accurately project the total ownership costs of an HDV that is powered by a fuel cell.
Ease of use	In a scenario where hydrogen fuel-cell vehicles are commercially viable and the cost of hydrogen fuel is on par with the cost of gasoline and/or diesel, this type of vehicle is best suited for long-haul transport and is preferable to battery-electric given the high energy density of fuel cells and the fast fill characteristics. A promising area of research and development now underway is the integration of hydrogen with internal combustion engines. Hydrogen combustion functions much the same way as diesel engines, meaning that they can be manufactured using current engineering know-how and drawing on existing supply chains and production capacities.[82] The purchase price would likewise be comparable to that of a conventional vehicle. An additional benefit is that clean transportation policies can target improvements in the hydrogen fuel supply without needing to encourage market growth at the same time.
Role in decarbonization pathway	Post-2035, hydrogen is the most viable pathway for reducing tailpipe emissions from long-haul trucks. With the implementation of a sales standard for medium- and heavy-duty vehicles, as much as 25% of new sales of heavy-duty vehicles by 2030 and 42% by 2050 could be powered by hydrogen fuel-cell, with battery-electric constituting 53% of new MHDV sales.[83] The decarbonization potential of hydrogen is maximized when clean energy is used for its production — so-called "green hydrogen". Compared to diesel-fuelled vehicles, fuel cell tractor-trailers that use fossil-based hydrogen emit 15% less greenhouse gases (GHGs) over the life cycle of the vehicle. Hydrogen fuel cell urban buses emit 33% fewer GHG emissions. If green hydrogen is used, emissions are reduced by 84% in tractor-trailers and 89% in urban buses. Essentially, the emissions savings when using green hydrogen are comparable to the savings realized by battery-electric vehicles.[84] If liquefied hydrogen is used, emissions are increased because of higher energy and storage requirements. A hydrogen vehicle that uses liquefied fossil hydrogen produces similar emissions to those of diesel vehicles. The ICCT has also estimated that fuel cell vehicles powered by a mix of 50% renewable and

	50% fossil hydrogen (with carbon capture) emits 75% to 83% fewer emissions over the life cycle of the vehicle relative to diesel powered.[85] While the carbon intensity associated with production methods is problematic, there is an argument to be made in investing in increased supply and distribution networks. Doing so could increase uptake of fuel-cell HDVs while building out re-fuelling infrastructure. As the methodologies used to produce green hydrogen become cost competitive, its deployment then becomes straightforward. This approach is not without risk. Encouraging dependence on methane-based hydrogen could lock-in natural gas, delaying the transition away from fossil fuels while accomplishing little in the way of GHG reductions. One way to mitigate the risk is through policies like the Clean Fuel Standard, which supports the development of hydrogen and low-intensity ways to produce it. One possible pathway to build out hydrogen production and fuelling infrastructure is to use hydrogen for relatively niche classes of vehicles, where battery electrification is less viable and the capital requirements for infrastructure are less onerous, such as forklifts, port drayage, and yard rail. Buses in larger cities that travel longer routes, over hilly terrain, may also be better suited for hydrogen than electrification. As demand for hydrogen grows, investing in building out a refuelling network becomes increasingly attractive.
Scalability	To ensure there is an adequate and cost-effective supply of hydrogen fuel, most hydrogen production will likely use natural gas and other light hydrocarbons, with carbon capture technology to minimize emissions. So far, it has not been possible to produce hydrogen cost-effectively using electrolysis. One reason for this is that seven times more energy is needed to produce hydrogen with electrolysis as opposed to methane reforming.[86] Currently, low-emission hydrogen production (i.e. employing either electrolysis or steam reforming with carbon capture) represents less than 1% of total hydrogen production. Even in the IEA's net-zero scenario, by 2030, green hydrogen will meet approximately one-third, or 50 Mt, of the total amount of hydrogen needed. Hydrogen produced from fossil fuels using processes that include carbon capture will yield about 30 Mt. Another 70 Mt of hydrogen will be generated from fossil fuels using fossil fuel as the power source without carbon capture.[87] According to the Canada Energy Regulator, hydrogen production in 2050 could range from 5 Mt in a "current measures" scenario to 22 Mt in a "net-zero" scenario. In the net-zero scenario, the Regulator anticipates that 32% of hydrogen production will be from natural gas, 58% from electrolysis and 10% from biomass.[88]
Appropriate use cases in a net-zero transition	Hydrogen is a viable option in the long term for most long-haul and heavy-duty trucks, once sufficient refuelling infrastructure is in place, hydrogen trucks are commercially viable, and a supportive transport ecosystem (truck maintenance and repair) has been established.

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6. Clean fuels and fleets in Canada

Our engagement with fleet operators revealed considerable uncertainty within the sector concerning which decarbonization option is best suited for their fleet while also being fiscally prudent.

Our assessments are based on several key assumptions. One is that the federal government is considering a progressive sales standard where 35% of all new truck and bus sales are emission-free models by 2030, climbing to 100% by 2040 where feasible. B.C. and Quebec are considering similar standards. Because most vehicles must eventually be replaced with either battery-electric or fuel cell hydrogen ones, investments in models that run on clean fuel, and in the associated infrastructure, must be made with that timeline in mind. The second assumption is that heavy-duty trucks (Class 7-8) will remain difficult to electrify for the long term.

Given the above assumptions, our assessment is that the clean fuels under consideration are most environmentally and fiscally effective as either a transition fuel as the adoption of electric MHDVs gathers momentum, or as part of a long-term solution for discrete MHDV classes where no other viable option is available.

Clean fuels as transition fuels

Transit and school buses, Class 2b-3 cargo vans and step vans for last-mile delivery applications, and some specific Class 3-6 use cases (e.g., short haul, urban freight) are all highly amenable to electrification. Their well-defined, predictable routes, duty-cycles with range requirements that can be met with current battery technology, and long overnight dwell times for depot charging are factors that make these vehicle classes and use cases ideal for battery-electric powertrains.

As such, deployments of EVs at scale are underway globally and throughout Canada. Given that global trends will affect the availability of vehicles for the Canadian market, fleet operators are well advised to keep close watch on how these classes are performing and growth forecasts. Many jurisdictions are or will soon be passing regulations that will prioritize early electrification targets for specific MHDV categories. For example:

- California's Advanced Clean Truck Rule (ACT) applies a requirement for 55% of new Class 2b-3 and 75% of Class 4-8 truck sold to be emission-free models by 2035. The ACT Rule has since been adopted in 11 other states. Additionally, by 2029, all purchases of new buses in California must be zero-emission.
- British Columbia's provincial government is holding consultations on a sales standard that would require 55% of Class 3 truck sales to be zero-emission by 2035, reaching 100% by 2036 — with similar targets for Class 4-8 trucks.
- Across the EU, regulations are in place that mandate an almost complete phase-out (90%) of sales of fossil-fuel powered trucks by 2040; by 2035, all sales of urban buses will be non-emitting vehicles.

Transit and school buses

Transit and school buses represent an almost ideal case for electrification. Buses follow predictable routes and scheduling overnight charging at a centralized depot is generally straightforward. Electric buses also offer immediate fuel and maintenance cost savings relative to diesel buses, making them cost-competitive.[89] Zero-emission transit buses in Canada are predicted to reach total cost of ownership (TCO) parity with internal-combustion engine equivalents sometime between 2022 and 2025.

Supportive funding and policy efforts in Canada have already begun to accelerate the pathway to bus electrification. Through the Zero Emission Transit Fund, the Zero-Emission Buses Initiative, and the Zero-Emission Vehicle Infrastructure Program, funding streams to support the transition have been established. Many municipal transit agencies are in the process of acquiring electric buses, and several jurisdictions are advancing the electrification of school buses. Battery-electric and hydrogen fuel cell buses are now located in eight out of 10 provinces in Canada — with nearly 976 deployments as of 2023.

During the course of our stakeholder outreach, some industry representatives advocated for RNG as a complementary option to decarbonize urban transit buses, noting the cheaper purchase price and longer range compared to the battery-electric counterpart.[90] Buses operating on RNG are said to be more reliable in cold weather and refuel times are shorter than charging times. Some municipalities, such as the Hamilton Street Railway, are piloting buses that run on RNG.[91]

However, it is unlikely that RNG buses will be carbon-neutral on a life-cycle or tailpipe basis given the challenges of scaling up RNG production and the relatively low percentage of RNG in a typical gas fuel mix. Investing in RNG buses and infrastructure will require substantial resources that are unlikely to deliver substantial decarbonization.

Other stakeholders advanced hydrogen buses as a potential decarbonization pathway. Municipalities including Edmonton[92] and Mississauga[93] are running pilot programs using hydrogen buses. As noted earlier in this report, hydrogen buses may well be the solution for discrete MHDV classes that are exceptionally difficult to electrify — with the caveat that hydrogen production remains carbon intensive. Currently, there is little in the way of existing hydrogen fuel infrastructure in Canada, and the few hydrogen buses that are on the market are considerably more expensive than battery-electric ones.

The Government of Canada recently launched consultations on a progressive sales standard that would increase sales of emission-free buses to replace fossil-fuel models. Given the likelihood of near-future electrification, any investments in clean fuels should be directed only to ICE fleets that are not yet close to the end of their natural life cycle. In this scenario, biodiesel and renewable diesel could be deployed where a) there is an existing supply chain of biofuels and b) with built-in time limits predicated on limited supply and need.

Light and medium-duty vehicles

Class 2b-3 cargo vans and step vans for last-mile delivery applications and some specific Class 3-6 use cases (e.g., short haul, urban freight) are also good fits for electrification. Typically, such vans and trucks travel less than 160 km a day, and in some cases less than 80 km, meaning that distances travelled can be met with current battery technology. Zero-emission options are plentiful and commercially viable. Of the 73 models now on the market, the GM EV600, Ford E-Transit, and Lion Electric 6 have ranges of 125 to 400 km. Long overnight dwell times in these vehicle categories allow operators to take advantage of low-cost charging (e.g., smart charging).[94] As much as 65% of the medium-duty trucks on the market are electrifiable.

We are already seeing electric MDVs that are cost competitive on a TCO basis with the diesel and gas equivalents. In B.C. and Quebec, the TCO of a battery-electric Class 6 box truck is $243,403 to $258,535 compared to $297,963 for the diesel equivalent.[95] The TCO of an electric Class 2 truck in Canada has been assessed at $1.87 per km in 2022 compared to $1.99 per km for the ICE counterpart.[96] Demand for zero-emitting vans is increasing quickly, and large fleet owners continue to add battery-electric trucks to their urban delivery services.

For vehicle classes that travel longer distances, have irregular schedules, and unpredictable parking locations, RNG is an option to consider. There is a relatively established market for refitting diesel trucks with natural gas versions, which could be a cost-effective way for operators to reduce their emissions.

As with buses, biodiesel and renewable diesel could play a role in reducing the carbon intensity of last-mile delivery vehicles during the transition. With medium-duty vehicles, the transition is expected to be slower because of the larger diversity of vehicle classes and higher reliance on small operators. Therefore, reducing the emissions of existing internal combustion vehicles during this period will align with Canada's climate goals.

Heavy-duty vehicles

Heavy-duty (Class 7/8) long-haul and regional freight will be the last MHDV class to fully decarbonize, likely not until the mid 2030s and into the 2040s. They are therefore the best use case for clean fuels.

Operational and technological constraints limit the application of battery-electric powertrain technology. Very few commercially available models have ranges that can complete the distances and demanding utilization requirements of long-haul operations. A network of high-power charging stations along inter-provincial/ state corridors would need to be constructed for battery-electric applications to be feasible. Regional-haul freight vehicle, with routes that average 200 km and have predictable routes and return-to-base operations, may, however, be candidates for battery-electric applications. Moreover, nascent high-power charging technology is proving that regional-haul applications with distances beyond 200 km may soon be electrifiable with supportive infrastructure (i.e., regional hubs). Recent examples include PepsiCo using fast-charging (750 kW) infrastructure to power Class 8 electric trucks travelling more than 1,600 km.

Renewable diesel is an effective pathway to emission reduction for heavy-duty vehicles during the transition and allows operators to continue to deploy existing fleets. Supply is expected to increase across Canada, adding to its viability. While substantial investment would be required to build out a robust network of natural gas fuelling stations, RNG is also an option for reducing fleet emissions in the short to medium term. Arguably, operating RNG vehicles will train drivers on using gaseous fuels, skills that can be transferred to operating hydrogen trucks. That said, the risk of becoming over-reliant on substantial RNG supply to decarbonize operations remains.

Clean fuels and long-term solutions

As most fleet operators do not see battery-electric vehicles as viable options for regional or long-haul trucks, hydrogen fuel cell electric vehicles (FCEVs) are viewed as the most likely clean fuel for ZEVs in the long term. Relative to battery-electric, hydrogen FCEVs are lighter, have shorter refuelling times, and operate better in cold weather. Most projections of fuel usage in net-zero scenarios in 2040 or 2050 have hydrogen as the most viable alternative, and FCEVs, together with battery-electric vehicles, are the only "zero-emission" vehicles considered in sales mandates.

However, there is a high degree of uncertainty with these projections. Other estimates suggest that with the high cost of low-carbon hydrogen production, FCEVs are unlikely to attain more than 10% market share before 2050 for vehicle classes involved in road freight, outside of applications such as heavy-duty (more than 70 tons) freight in long-haul scenarios (over 1000 km).[97] There will also be a tension between supporting fossil-based hydrogen production (which expands the availability of fuel), and encouraging a transition away from fossil fuels generally (which will increase fuel cost).

The hydrogen industry for long-haul transport is still at a nascent stage. A few fuel-cell electric models are commercially available, but most are in use in pilot projects. Supply and distribution are patchy, and there is no national or provincial hydrogen fuelling network. Stakeholders report that they are aware of some private operators who source their own fuel supply, but this information is not publicly available.

Some stakeholders also advocate for RNG as part of a long-term solution and not just as a transition fuel. Contingent on substantial RNG supply that effectively decarbonizes natural gas, natural gas vehicles could be net-zero on a life-cycle basis and thus compatible with Canada's climate goals. The extraction of methane from waste also contributes to emission reductions, making them a possible part of the net-zero future.

Clean fuels are likely to be long-term solutions for vehicle classes and vocations where electrification is non-viable due to distance, weight or operational needs. This means that they will see the most use with some medium-duty box trucks and Class 7 / 8 vehicles involved in long- or regional-haul freight.

Table 1. Clean fuel applications for MHDVs

VEHICLE TYPE	Biodiesel	Renewable diesel	Renewable natural gas	Hydrogen	Electrification
BUSES					
Until 2030	Strong case →	Strong case →	Weak case	Weak case	Strong case
2030-2040			Weak case	Decent case *	Strong case
After 2040			Weak case	Decent case *	Strong case
CARGO VANS					
Until 2030	Strong case →	Strong case →	Weak case	Weak case	Strong case
2030-2040			Weak case	Weak case	Strong case
After 2040			Weak case	Weak case	Strong case
MEDIUM-DUTY VEHICLES					
Until 2030	Strong case →	Strong case →	Decent case * →	Decent case *	Strong case *
2030-2040	Strong case →	Strong case →	Decent case * →	Decent case *	Strong case *
After 2040				Decent case *	Strong case *
REGIONAL HAUL VEHICLES					
Until 2030	Strong case →	Strong case →	Decent case * →		Weak case
2030-2040	Strong case →	Strong case →	Decent case * →	Decent case *	Decent case *
After 2040	Strong case →	Strong case →	Decent case *	Strong case *	Decent case *
LONG-HAUL VEHICLES					
Until 2030	Strong case →	Strong case →	Decent case * →		Weak case
2030-2040	Strong case →	Strong case →	Decent case *	Decent case *	Weak case
After 2040	Strong case →	Strong case →	Decent case *	Strong case	Decent case *

LEGEND

Strong case (green) | Decent case (orange) | Weak case (red) | → Transition fuel | * only for certain regions, use cases or fuel availability

The path ahead: areas of concern

A thorough inquiry into the role of clean fuels in the decarbonization of the MHDV sector must incorporate the concerns of the end user. We undertook multiple outreach initiatives with industry representatives and other stakeholders and subsequently identified three main areas in which progress is necessary if clean fuels are to play a meaningful role in decarbonizing MHDVs:

- Scaling sustainable supply
- Using a "corridor" approach to locate fuelling stations
- Fostering a transportation ecosystem that can support clean fuel use in commercial freight

The first area of concern is the limited supply characterizing all four of the clean fuels under consideration. Moreover, resources in the form of either financing or capacity building to increase production and/or importing clean fuels are not currently in place. While policies such as the Clean Fuel Regulations and Low Carbon Fuel Standard (in B.C.) are having a positive impact in creating certainty and boosting supply, they need to be sustained and improved for their full potential to be realised.

Boosting supply is not without associated risk. Dedicating investments to increase supply may inadvertently result in unsustainable means of production, which would negate the original purpose to reduce carbon. A feature of limited supply is that it reinforces the need to deploy clean fuels only in vehicle classes where there are few if any alternatives. A mandate to phase in increased sales of ZEVs could accelerate the transition for vehicle classes where the transition is feasible, further encouraging this prioritization.

A second source of frustration expressed by stakeholders is the lack of clarity surrounding the cost, accessibility and volume of clean fuels. There is also a patchwork of available information on the locations of fuelling stations. Stakeholders recommended that maps and other resources providing up-to-the-minute information on stations and fuel availability be created. Information around the commercial availability of vehicles, including total cost of ownership, is also useful to help planning and investments. In focus groups, stakeholders noted that improving information availability and greater transparency were the most impactful interventions that could be made in the short term.

An additional recommendation was the implementation of a "corridor" approach along major freight highways as a way of prioritizing the construction of clean fuel stations.

Adequate fuelling infrastructure would eliminate much of the reluctance to invest in either fuel cell or natural gas HDVs.

Stakeholders also voiced concerns regarding the absence of a robust transport ecosystem for low- and zero-carbon MHDVs, including maintenance services and a resale market. Most small operators rely on the resale market to meet their bottom line, and they depend on maintenance and repair services to operate their fleets along the entire trucking route, which often falls outside urban centre boundaries.

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7. Conclusion

Two questions dictated the terms of our analysis of clean fuels and their role in the decarbonization of fleets and buses. The first question concerned the role of clean fuels in decarbonizing fleets during the interim period prior to full ZEV adoption. The second question asked what the role of clean fuels is for vehicle classes where electrification is not yet commercially viable and remains technically difficult.

Based on our analysis, clean fuels are a useful means of reducing emissions from MHDVs in specific classes and under discrete circumstances. There are also drawbacks associated with clean fuels, such as insufficient feedstock, carbon-intensive production processes, and adverse land impacts. Ultimately, clean fuel deployment, apart from hydrogen, runs the risk of prolonging the period of transition rather than hastening the switch to emission-free commercial vehicles.

To maximize the benefits of clean fuel deployment, their use must be targeted to specific areas and vehicle classes. Any decarbonization pathway that incorporates clean fuels must also factor in the duration of use. In many instances, low-carbon fuel is best thought of as a temporary measure until an ICE vehicle is replaced with an electric one. Within a discrete segment of vehicle categories, clean fuels, namely hydrogen, may be useful over the long term.

Cutting transportation emissions is critical to meeting Canada's 2030 target of emission reductions of 40% to 45% below 2005 levels and net-zero GHG emissions by 2050, given that transportation is the second largest source of planet-warming gases in the country. Other means of emission reductions, such as fuel efficiency, mode switching, and overall efforts to reduce vehicle kilometers travelled will also be essential.