



Zero Emissions Vehicle Awareness Initiative

Current state assessment

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This report is current as of **May 2024** and is intended to provide an accurate and up-to-date analysis of the subject matter at the time of writing. It is important to note that the information contained in this report is subject to change as new technology developments, policies, announcements, or circumstances arise in the future in the hydrogen value chain in Western Canada.

Executive summary



Actionable opportunities to scale the adoption of hydrogen as a transport fuel

Opportunities

What is the opportunity?

- Class 8 trucks and buses represent the biggest opportunity to build the hydrogen refueling corridor as those models are now commercially available for wide scale deployment.
- Supply and prioritization of Class 8 trucks by OEMs for the Alberta market is critical to ensure product availability from different OEMs.
- Total cost of ownership (TCO) is one of the key drivers for determining technology and fuel choice assuming the truck can perform the duty cycle.
- BEV will continue to dominate the short haul trucking sector for Class 3 through 8 as it has the lowest TCO and product availability, ease of use, and familiarity with charging.
- FCEV technology will lead in long-haul trucking where there is a need for range and to meet performance requirements for hauling heavy loads.
- Calgary to Edmonton corridor represents a significant opportunity to develop a viable and scalable hydrogen trucking corridor as this route has the highest HD truck traffic and potential hydrogen supply. Multiple refueling options need to be available on both ends of the journey to achieve scale.
- Bending the cost curve on the supply and refueling of hydrogen is critical to be competitive with other technologies. Large scale low carbon intensity hydrogen must be approximately \$5.35 per kg (from a current retail price range of \$14 - \$35 per kg for Alberta and British Columbia) to begin achieving TCO price parity with diesel trucks.
- Western Canadian corridor also needs to be prioritized from Edmonton to Prince George through Hinton to build out the refueling corridor.
- Critical to raise awareness with fleet operators on the need to decarbonize and democratize the information on pilots and learnings to achieve scale and not undertake another pilot.

Challenges

Financial:

- Limited and cost-prohibitive hydrogen supply for the transportation industry as the existing cost of hydrogen is significantly higher compared to traditional fossil fuels increasing operating expense for fleets.
- Capital investment required to purchase fuel cell trucks and buses can be 2-3x the price of traditional internal combustion vehicles.
- Lack of targeted incentives and policies for bat the provincial level which can reduce the CAPEX and OPEX improving the business case for zero-emission truck and bus adoption.

Operational:

- Hydrogen fueling infrastructure network needs to be established to support the widespread use of hydrogen trucks requiring investment and coordination between government, private sector, and other stakeholders.
- Lack of maintenance infrastructure and dealer support services for FCEV including spare parts inventory, certified repair facilities, and technician training.

Market and technology:

- Global FCEV supply is limited – Alberta competes with regions with strong policy incentives for MHDZEV adoption like California and British Columbia.
- Hydrogen internal combustion engines (HICE) have potential but are in early commercialization stage.

Ecosystem development and information access:

- Lack of knowledge on hydrogen value chain i.e., vehicle technology life cycles, greenhouse gas emissions, hydrogen standards, policies on building codes, and hydrogen ecosystem development through pilots. Information should be democratized so ecosystem stakeholders can learn from one another and prevent duplication of resources.

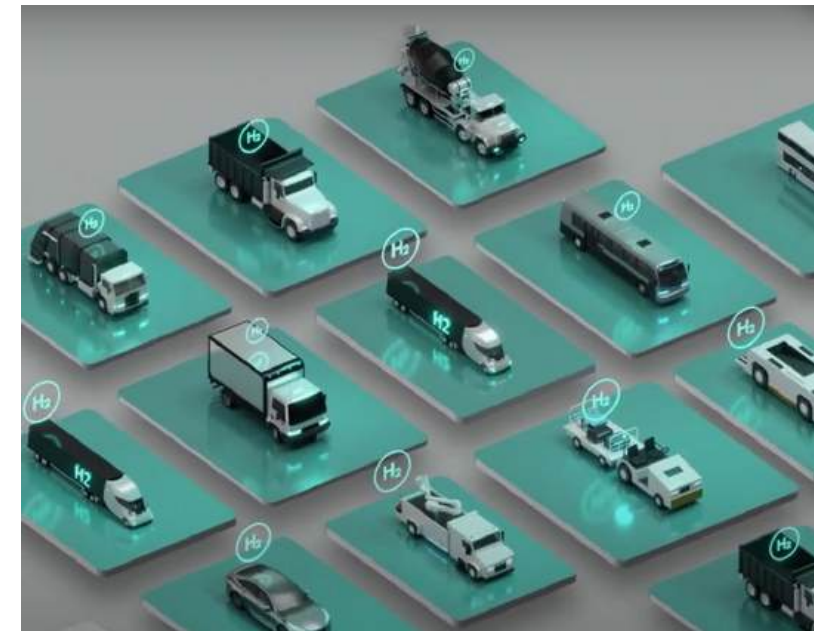
Available funding and investment

Available federal grants and incentives:

- Large scale investment (\$10M-500M)
- Build or expand production facilities (up to \$150M)
- Fleet assessments, retrofits or purchase (up to \$250k)
- Community investment (50% cost share)
- Vehicle purchase incentives (iMHZEV - \$10k-200k)
- Fueling station cost incentives (ZEVIP – 50% of cost up to \$10M)
- Refundable tax credits (up to 40%)
- Reduced fuels charge rate

Provincial sources available in Alberta:

- Alberta Innovates and Emissions Reduction Alberta (\$250k-\$7M)
- Alberta's Petrochemicals Incentive Program (12% of capital cost)



High impact strategic routes based on infrastructure analysis

Edmonton to Calgary is the highest impact strategic route based on traffic volume, supply, demand, and current infrastructure.

Is this a high traffic trucking route?

Higher number indicates higher traffic route

Is there hydrogen supply available for cities on route?

Higher number indicates higher supply

Is there hydrogen fuel demand in cities on this route from pilots?

Higher number indicates higher demand

Ranked strategic routes

Strategic route	Distance	Potential opportunity	Strategic route	Hydrogen supply	Hydrogen demand	Priority rating
Edmonton – Calgary	~ 300 km	- Investment in fueling stations in Edmonton and Calgary and along Highway 2 connecting both cities. - Red Deer could be an additional location for potential fueling station infrastructure investment due to its location between the major cities.	3	3	3	9
Edmonton – Prince George	~ 740 km	- Investment in a fueling station in Hinton, AB (which currently has over 3 cardlock stations) to connect both hydrogen hubs. - Another potential fueling site for infrastructure development is McBride, BC.	2	3	3	8
Edmonton – Fort McMurray	~ 450 km	- Investment near existing cardlock infrastructure in between Edmonton and Fort McMurray to prevent range anxiety for FCEV trucks hauling heavy loads. - Potential locations off Highway 63 include Boyle and Grassland, Alberta.	2	3	2	7
Calgary – Kamloops	~ 620 km	- In British Columbia, fueling station investments off Highway 1 in populated locations such as Sicamous, Revelstoke, or Golden should be explored. - In Alberta, fueling station infrastructure investment should be considered in Canmore or Banff.	3	1	2	6
Edmonton – Grande Prairie	~ 460 km	Fueling station infrastructure investments can be made on Highway 43 in areas like Whitecourt and Valleyview, Alberta to connect both cities.	2	2	2	6

Prioritizing trucking routes and strategic fueling infrastructure in the western corridor

Based on analysis of traffic data, the following routes and fueling station locations were identified as high-volume trucking routes.

High
↑
Priority
↓
Low

Edmonton to Calgary

- Strategic infrastructure locations:
 - Edmonton to Red Deer, ~150 km
 - Red Deer to Calgary, ~150 km

Edmonton to Prince Rupert

- Strategic infrastructure locations:
 - Edmonton to Hinton, ~290 km
 - Hinton to Prince George, ~450 km
 - Prince George to Terrace, ~580 km

Edmonton to Vancouver

- Strategic infrastructure locations:
 - Edmonton to Hinton, ~290 km
 - Hinton to Kamloops, ~520 km
 - Kamloops to Vancouver, ~350 km

Calgary to Vancouver

- Strategic infrastructure locations:
 - Calgary to Revelstoke, ~410 km
 - Revelstoke to Kamloops, ~220 km
 - Kamloops to Vancouver, ~350 km

Edmonton to Fort McMurray

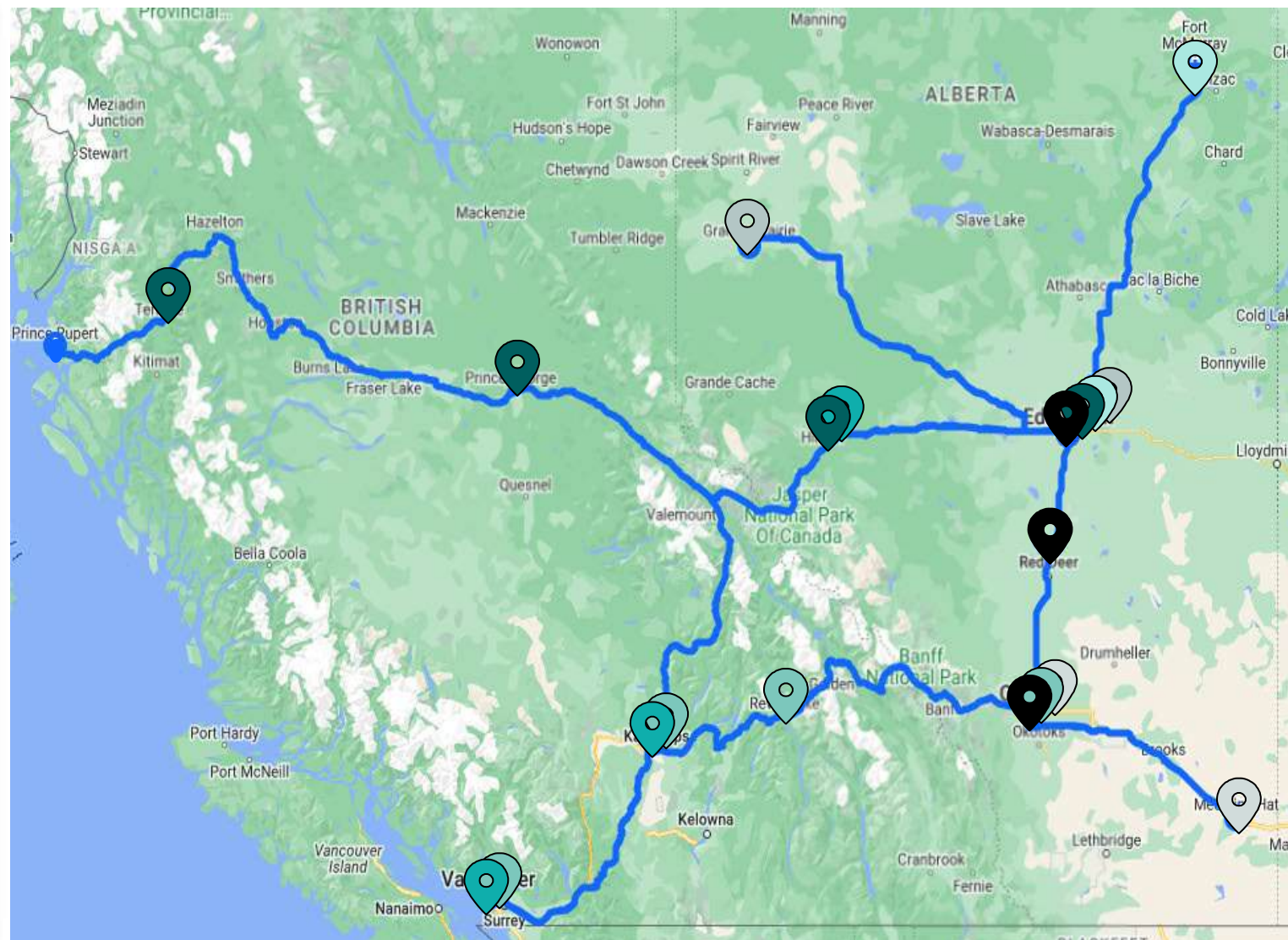
- Total distance: ~440 km on Highway 63

Edmonton to Grande Prairie

- Total distance: ~460 km on Highway 43

Calgary to Medicine Hat

- Total distance: ~290 km on Highway 1



Technology scan



Technology scan key findings

Key technological and commercial factors impact hydrogen vehicle adoption including cost of vehicles and fuel, commercial readiness of hydrogen propulsion technologies, supply of transportation grade fuel, enabling production, fueling and distribution infrastructure, and the availability of hydrogen fuel cell trucks.

1

Hydrogen propulsion technology overview

Provides an overview of the three hydrogen propulsion technologies including FCEV, internal combustion (HICE) and dual fuel technologies.

- FCEVs have no tailpipe emissions and are regulated as zero-emission. HICE vehicles have been classified as zero-emission vehicles in Europe, but it is unclear whether North America will follow suit.
- Dual fuel technology is considered a bridge technology where existing heavy-duty assets can be retrofitted to use both hydrogen and diesel; this can increase hydrogen demand while minimally affecting fleet operations, but criteria air pollutants and tail pipe emissions still exist.
- Hydrogen fuel cell technology requires the highest grade of hydrogen purity which increases the cost of fuel and limits availability.



Technology	Range (km)	Refueling Time (min)	Cost (\$/kg)	Availability
FCEV	~500	~5	~\$15	Low
HICE	~1000	~15	~\$15	High
Dual Fuel	~1000	~15	~\$15	Medium

2

Commercial readiness

Assesses the commercial readiness for adoption of hydrogen as a transport fuel for MHDV sector.

- Globally, fuel cell buses are the most commercially developed, followed by fuel cell trucks.
- In Alberta, fuel cell and dual fuel trucks and buses are in the pre-commercial demonstration stage due to limited product availability, shortage of fuel cell grade hydrogen, and limited infrastructure.
- The cost of hydrogen is a major adoption barrier for hydrogen vehicle technology.
- Enabling infrastructure, operating capabilities, and health and safety considerations are critical factors in assessing commercial readiness.



Technology	Commercial Readiness	Key Challenges
FCEV	Low	High cost, limited infrastructure
HICE	High	Low cost, established infrastructure
Dual Fuel	Medium	Intermediate cost, emerging infrastructure

3

Hydrogen MHDV catalogue

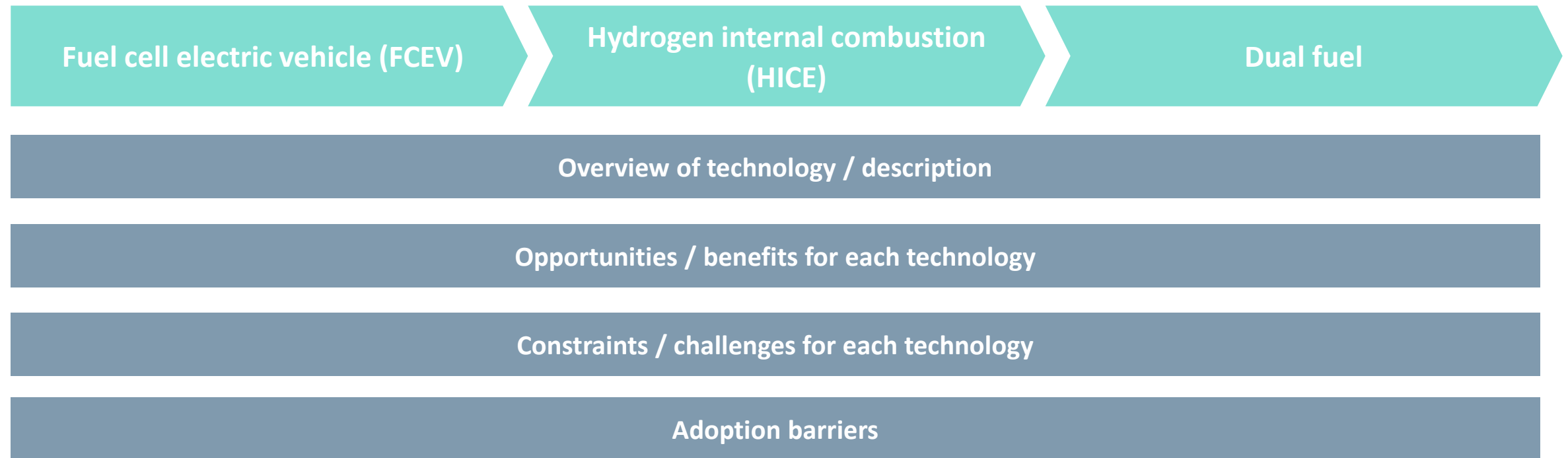
Highlights various MHDV hydrogen vehicle models with key specifications and model availability.

- All commercially available models are in the Class 8 truck and bus segment.
- 19 fuel cell, 3 hydrogen combustion, and 3 dual fuel retrofit providers were identified globally at various stages of commercialization.
- Fuel cell trucks and buses accounted for majority of vehicles available for purchase.
- 14 models are available in Canada.



Hydrogen propulsion technology overview

Three main hydrogen propulsion technologies will be assessed including FCEV, dual fuel, and HICE. A technology description will be provided for each along with opportunities, constraints, and adoption barriers.



FCEV opportunities, constraints, and adoption barriers

FCEV technology is the most commercially mature hydrogen propulsion technology with on-going pilots in Alberta, and globally across various vehicle classes.

FCEV technology overview

- Most fuel cell trucks are considered load followers, where most of the power to the electric motor is provided by a large fuel cell stack, supplemented by a smaller battery providing extra electricity if needed.
- The propulsion system, powered by a fuel cell system and electric motor, generates electricity using hydrogen stored in pressurized tanks in the vehicle.
- Compressed hydrogen in the pressurized tanks can be stored at 350 or 700-bar, with 700-bar pressurized tanks providing higher driving range due to higher volumetric density per liter of hydrogen system storage.
- FCEVs have a small battery relative to battery electric trucks and primarily rely on these batteries to smooth fuel cell power fluctuations absorbing and releasing electricity as needed rather than powering the vehicle.
- Hydrogen fuel cell trucks are considered *zero-emissions vehicles* with water vapour (H₂O) as the only byproduct released from their tailpipes.

Opportunities

- Similar fueling time, range, hauling capabilities and performance to internal combustion engine vehicles making FCEV technologies preferential for long-haul trucking compared to battery electric technologies.
- High energy efficiency from fuel cell technology resulting in significantly lower fuel consumption compared to a comparable conventional internal combustion engine.
- Considered zero-emission technology, as a result this technology falls within government's ZEV sales mandate.
- Applicable for various provincial and federal grants and incentives like [iMHZEV](#) which can reduce capital and operating costs for FCEV trucks and buses improving TCO.
- Wide variety of models available particularly in Class 8 truck and bus categories.

Technology constraints

- Fuel cells require high purity (minimum of 99.97%) grade hydrogen to operate efficiently to prevent fuel cell degradation thus increasing cost and limiting supply. Hydrogen production methods have a significant effect on purity levels, with green hydrogen production being the purest but generally the most expensive production method.
- Fuel cell trucks are largely in piloting phases so operators are learning how they will perform under various conditions.

Adoption barriers

- Capital costs can be 2-3x the cost of an equivalent diesel vehicle.
- Robust fueling network required to maintain operations.
- Low supply of fuel cell grade hydrogen and high cost associated with accessible supply.
- Limited supply availability of MHDV vehicles.
- Safety concerns and myths on hydrogen as a fuel.
- Cost of producing, storing, and distributing low-carbon fuel cell grade hydrogen is significantly higher than diesel leading to high operating costs for truck and bus owners.

Source 1: <https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf> Source 2: <https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-1-jul22.pdf> Source 3: <https://hyfindr.com/hydrogen-purification/> Source 4: <https://commercialfuelsolutions.co.uk/hydrogen/grade-D-gaseous-hydrogen/> Source 5: <https://www.energy.gov/eere/fuelcells/articles/fuel-cells-fact-sheet#:~:text=Fuel%20cell%20vehicles%2C%20which%20use,a%20gasoline%20internal%20combustion%20engine>

HICE opportunities, constraints, and adoption barriers

Hydrogen combustion engines are currently being prototyped and have the potential to be used in heavy-duty applications which have severe duty cycles requiring large energy demands and long operational hours.

HICE technology overview

- Hydrogen combustion engines require a combustion process like spark-ignition or compression ignition engines to generate power in the vehicle.
 - Hydrogen is stored in high pressure tanks on a truck and is fed into the combustion chamber where it is mixed with oxygen and ignited.
 - The pressure from the ignition moves the engine pistons, driving the crankshaft, and creating a rotating motion.

Opportunities

- As combustion engines become more efficient at higher loads, HICE has potential to be used in heavy-duty applications which require large energy demands and long operational hours, like mining trucks and other off-road heavy-duty applications.
- No CO₂ is produced while operating a hydrogen combustion engine.
- Engines operate very similar to internal combustion engines not requiring significant upskilling from mechanics.
- Existing supply chains are already in place for key inputs required for HICE engines and servicing.
- Hydrogen engines are more tolerant to impurities than a fuel cell and can operate on lower grade hydrogen (98% purity) compared to FCEV (99.97% purity) increasing likelihood of securing supply at a lower cost.

Technology constraints

- Emit nitrogen oxides (NOx) from the tailpipe which may require aftertreatment technologies such as Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) to reduce emissions.
- In general, less efficient than FCEV because of energy lost during the combustion process, however, efficiency improves under certain heavy-duty applications.

Adoption barriers

- Robust fueling infrastructure required to maintain operations.
- High R&D cost required to develop HICE engines.
- No commercial models currently available to pilot.
- Regulated zero-emission technology in the European Union, however, it is unclear whether the United States and Canada will follow suit.

Source 1: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-hydrogen-combustion-engines-can-contribute-to-zero-emissions> Source 2: <https://www.cummins.com/news/2022/01/26/how-do-hydrogen-engines-work> Source 3: <https://www.cummins.com/news/2022/10/21/lets-do-fuel-comparison-natural-gas-vs-hydrogen> Source 4: <https://www.energy.gov/sites/default/files/2023-03/h2iqhour-02222023.pdf> Source 5: <https://commercialfuelsolutions.co.uk/hydrogen/grade-A-hydrogen/>

Dual fuel opportunities, constraints, and adoption barriers

Hydrogen dual fuel technology can be an important bridge technology allowing diesel truck and bus operators to reduce emissions while maintaining existing assets and operations.

Dual fuel technology overview

- Existing internal combustion trucks or buses can be retrofitted by dual fuel companies* adding components like hydrogen storage tanks, hardware to deliver hydrogen into an engine cylinder, and control software, hardware, and sensors to monitor and regulate fuel injection, combustion, and performance.
- Dual fuel technology specifics often vary based on the retrofitter's proprietary technology.

Opportunities

- Truck retrofits are lower cost relative to FCEVs and can be installed immediately as existing assets can be retrofitted rather than replaced.
- Retrofitted vehicles can have a GHG emission reduction of up to 80% while maintaining high uptime and having a minimal impact on operations.
- Considered a bridge technology creating a demand for hydrogen while FCEV technology matures.
- Lower grade of hydrogen is required to operate dual fuel trucks compared to FCEV trucks.

Technology constraints

- Retrofitting is only available for diesel powered trucks and buses.
- While dual fuel reduces GHG emissions, it is not considered a zero-emission technology and can still produce common diesel pollutants like NOx, particulate matter, carbon monoxide, etc.

Adoption barriers

- Extensive fueling network is required for dual fuel vehicles to operate on hydrogen.
- Retrofit kits may risk voiding some OEM warranties
- Dealerships and OEMs may be hesitant to service vehicles which have been retrofitted.
- Technology does not qualify as zero-emission.

Note: Dual fuel retrofitter technologies often varies based on technology provider.

Source 1: <https://www.volvopenta.com/about-us/news-page/2023/sep/exploring-hydrogen-engine-advantages-volvo-penta-insights/> Source 2: <https://transitionaccelerator.ca/wp-content/uploads/2020/11/Building-a-Transition-Pathway-to-a-Vibrant-Hydrogen-Economy-in-the-Alberta-Industrial-Heartland-November-2020-5.pdf> Source 3: <https://albertainnovates.ca/wp-content/uploads/2023/07/202102028-UofA-Public-Final-Report.pdf> Source 4: <https://www.hydraenergy.com/fag>

Hydrogen propulsion technology side-by-side comparison

FCEV technology is the only zero-emission hydrogen propulsion technology available for purchase in Canada. Dual fuel vehicles can be used as a bridge solution to significantly reduce fleet emissions while minimally affecting operations. While still in early development, HICE* technology has strong potential for the heavy-duty segment.

Propulsion type	Technology opportunities	Technology barriers	Adoption constraints
Fuel cell electric vehicle (FCEV)	- Similar fueling time, range, and performance to ICE vehicles. - Regulated as zero-emissions. - Grants and incentives available to help lower capital costs of vehicles and enabling infrastructure. - High energy efficiency compared to HICE. - Models available for both light and heavy-duty vehicle classes.	- High CAPEX requirements for the heavy-duty segment with certain models costing 2-3x their diesel counterparts. - Low supply of high-grade hydrogen required for FCEVs as the fuel must be purified to fuel cell grade with a minimum of 99.97% purity.	- Requires a robust hydrogen fueling network to maintain operations. - Vehicles are largely still in the piloting phase in Canada but are widely commercially available in Europe, Asia, and California. - Low supply of fuel cell grade hydrogen.
Hydrogen internal combustion engine (HICE)	- High potential for heavy-duty application which have high energy demands and long duty cycles like mining trucks. - Negligible tailpipe GHG emissions. - Robust engine which can operate with lower grade hydrogen potentially making it easier to source supply at a lower cost. - Comparable operations to combustion engines, resulting in more transferable skills for mechanics relative to FCEVs.	- Trace amounts of criteria air pollutant emissions such as NO_x therefore it is unclear whether it will fit zero-emission vehicle mandates and be eligible for incentives in North America. - Lower energy efficiency compared to FCEV under most duty cycles.	- Technology is in the prototyping and testing phase and not currently available. - Requires robust hydrogen fueling network to maintain operations. - Expected to require high CAPEX to purchase a HICE truck due to large amounts of capital invested into R&D by OEMs.
Dual fuel combustion engine	- Requires lowest CAPEX compared to FCEV and HICE trucks - can retrofit existing assets rather than purchase new ones. - Can significantly reduce GHG emissions (not to zero-emissions). - Variable fuel mix can help extend the range and load capacity ensuring existing operations are not disrupted. - A potential bridge solution as diesel fueling infrastructure can be used if hydrogen fueling is not available on route. - Technology is currently available to convert certain Class 8 heavy-duty trucks. - Lower grade of hydrogen required than FCEV.	- GHG emissions can be reduced up to 80% depending on retrofit technology and carbon intensity of hydrogen. - Emit trace amounts of criteria air pollutants such as NO_x and particulate matter. - Considered a temporary solution for heavy-duty vehicles until FCEV prices decline and mobility grade hydrogen becomes widely available at a competitive price.	- Conversions are currently limited to Class 8 trucks and buses. - As vehicles are not considered zero-emission, this technology is a temporary solution which will not meet the government's zero-emission guidelines. - Retrofit kits create risk voiding OEM warranties.

Note: Currently, HICE vehicles have only been classified as zero-emission vehicles in Europe.

Approach for assessing commercial readiness of hydrogen technology

Our methodology to determine the commercial readiness of FCEV, dual fuel, and HICE trucks and buses, in Alberta and globally.

1

Global technology readiness levels

- Used the IEA ETP Clean Energy Technology Guide¹, which provides technology readiness levels (TRL) of over 550 energy-related technologies from a global perspective, to determine technology readiness level ratings for fuel cell, dual fuel, and hydrogen combustion technologies for all MDHV.

2

Commercial readiness considerations

- Commercial readiness is a function of technology readiness levels and market conditions which support the deployment of the technology like product availability, fuel supply and infrastructure, successful pilots, and customer familiarity. Enabling infrastructure, workforce capabilities, and health & safety considerations in Alberta were examined.

3

Alberta commercial readiness levels

- The TRL from the IEA Clean Energy guide was supplemented with the hydrogen MHDV catalogue from Appendix A, and the commercial readiness considerations from step 2, to determine commercial readiness for hydrogen vehicle technologies in Alberta.

Source: <https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide>

Global technology readiness levels of hydrogen trucks and buses

Hydrogen fuel cell EV trucks and buses have the highest technology readiness levels (TRL) according to the International Energy Agencies (IEA) Clean Energy Guide.

	 Concept 1 - 3	 Early prototype 4	 Late-stage prototype 5 - 6	 Pre-commercial 7 - 8	 Market uptake 9 - 10	 Mature product 11
Technology	Description			Global technology readiness level*		
				Bus	Truck	
FCEV	A fuel cell produces electric power when fed with oxygen and hydrogen fuel, which propels the vehicle via an electric motor. The compressed hydrogen fuel is stored in tanks in the vehicle and refueled at refueling stations similarly to gasoline or diesel vehicles. Depending on hydrogen emission intensity, fuel cell electric vehicles reduce direct and indirect emissions by up to 100% relative to ICE vehicles.			 9	 8	
Dual Fuel	Hydrogen co-combustion or dual fuel combustion technology blends hydrogen fuel into the combustion chamber of a diesel vehicle to offset 40 - 80% of diesel. The technology can be installed on existing vehicles via a retrofit that makes minor modifications to the engine and that adds hydrogen tanks behind the cabin of a Class 8 truck. This technology can reduce direct and indirect greenhouse gas emissions by up to 80% relative to baseline ICE vehicles, depending on retrofit technology and carbon intensity of hydrogen.			 7	 7	
HICE	A hydrogen combustion engine operates by initiating a combustion process of hydrogen fuel to generate mechanical power. The engine works similarly to traditional internal combustion engines, but instead of gasoline or diesel, it uses compressed hydrogen fuel. This hydrogen fuel is stored in high-pressure tanks within the vehicle, ready for combustion. The combustion process's byproduct is water vapor, making the operation virtually emission-free. The potential for emissions reduction is significant, with hydrogen combustion engines potentially reducing direct and indirect emissions by up to 100% compared to traditional ICE vehicles, depending on the hydrogen fuel source.			 4-5	 4-5	

Note: Technology readiness levels (TRL) were assessed using IEA Clean Energy Guide (2023).

Additional considerations to assess commercial readiness

Enabling hydrogen infrastructure and supply, operating capabilities of the workforce in Alberta, and adequate health and safety regulations are additional considerations required to assess and scale Alberta’s commercial readiness for hydrogen vehicle adoption.

	Enabling infrastructure	Enabling capabilities	Health and safety
Definition	Access to infrastructure required for operations such as hydrogen production, distribution, and fueling.	Skill level of the workforce to operate and maintain the vehicle to the required standard, or the option to up-skill if capability gaps exist. Additionally, service locations and dealer support are required to support hydrogen vehicles.	Extent to which the safeguards and mechanisms are in place to ensure safe operation of hydrogen technology within the vehicle value chain.
Current status for Alberta	- There are two temporary fueling stations currently set up in Alberta which are servicing pilot programs and one permanent station which opened in 2024 by HYL A. - One temporary station is located at Edmonton International Airport. It is used to fuel the seven Toyota Mirai’s currently operating in their fleet. - One temporary station is located at Sherwood Park where the hydrogen is supplied by Suncor and the station operated by HTEC. It is used to fuel the AZETEC and AZEHT pilots. - First commercial fueling station opened in Alberta by HYL A in Leduc County off Highway 2 at Blackjacks in Nisku. - In 2024, there may be an additional temporary fueling station in Calgary for the AZETEC and AZEHT pilots. - In 2025, Air Product’s Net Zero Hydrogen Energy Complex will open producing 30 tonnes per day of hydrogen as well as a commercial fueling station with capacity of 6 tonnes per day. - Fueling stations are proposed across Alberta, potentially reaching the double digits by 2030, starting with the Edmonton region. Fueling stations will have a focus on the heavy-duty segment but may be able to fuel light-duty vehicles. Source: Interviews with HTEC, Air Products, Diesel Tech, City of Edmonton	- Through the NAIT and SAIT, there exists efforts to develop training programs to upskill existing operations and maintenance staff for vehicles for hydrogen technology. - Private companies have taken their own initiative for their technology. Hydra and Diesel Tech both have developed multi-day training courses to perform work and operate their dual fuel technology and retro-fit kit. - Though training programs either exist or are in development, they are not at the same level of certification as will be required in the future and therefore work is still needed to develop robust training programs and to enroll participants to upskill the workforce. Source: Interviews with NAIT and SAIT	- Across the hydrogen value chain, technology has been adapted to be fit for purpose for hydrogen. The result is new systems being designed to sets of standards that are either not Canadian made or developed for other products. - Swift innovation creates uncertainty in the project reliability, from permits being approved, to the safety of fueling stations. - From interviews with groups across the value chain, gaps still exist, however, both private and public organizations are developing hydrogen specific codes and standards for vehicle transport. Source: Interview with Air Products and HTEC

Alberta commercial readiness levels (CRL) of hydrogen buses and trucks

Commercial readiness is a function of technology readiness level (TRL) and market conditions supporting deployment such as product availability, fuel supply and infrastructure, successful pilots, and customer familiarity. Using the TRL from the IEA Clean Energy Guide (2023), the hydrogen MHDV catalogue in Appendix A, interviews with hydrogen ecosystem stakeholders, and desktop research into infrastructure and capabilities in Alberta, we were able to assess commercial readiness.

 Concept 1 - 3		 Early prototype 4	 Late-stage prototype 5 - 6	 Pre-commercial 7 - 8	 Market uptake 9 - 10	 Mature product 11
Technology		TRL in Alberta*	CRL explanation	Commercial example		
Trucks	FCEV	 7	FCEV trucks in Alberta are in the commercial demonstration stage, where vehicles are operating in expected conditions and demanding duty cycles.	- Trials underway with Alberta Motor Transport Association (AMTA) trialing truck routes between Edmonton and Calgary and validating the operation and fueling of two long-range FCEV trucks. - Four long-haul truck models and one waste refuse truck model are available for purchase in Canada (Reference: OEM Catalogue).		
	Dual fuel	 7	Dual fuel trucks have working prototypes with plans for full-scale deployment.	- City of Edmonton is converting two waste refuse trucks to dual fuel technology with Diesel Tech Industries. - Trials underway with AMTA trialing truck routes between Edmonton and Calgary and validating the operation and fueling of Hydra Energy’s dual fuel long-range truck.		
	HICE	 3	Hydrogen combustion trucks in Alberta are currently being conceptualized and require a proven prototype to validate the concept.	- In Canada, FEV is developing a hydrogen converted combustion engine, while Volvo and Westport Fuel Systems have established a joint venture to develop a HICE truck and begin customer tests in 2026. - HICE is still in early concept development at universities.		
Buses	FCEV	 3	FCEV buses have commercial demonstrations in final conditions underway in Alberta.	- Current trial involving two new FCEV buses, one in the Edmonton transit fleet and another in Strathcona County under the Alberta Zero Emission Hydrogen Transit (AZEHT) (source: Hydrogen and Electric Buses City of Edmonton). - Currently two models (40 ft and 60 ft) of New Flyer and 40 ft ENC Axxess are available for order in Canada (Reference OEM Catalogue).		
	Dual fuel	 6	Established plans to demonstrate dual fuel technology in buses.	City of Edmonton is converting two buses to dual fuel technology with Diesel Tech Industries.		
	HICE	 3	Hydrogen combustion buses in Alberta have only been conceptualized with no established plans of a prototype.	Through interviews with funding organizations in Alberta (i.e., Alberta Innovates), HICE buses were found to still be in early concept development at universities.		

Key findings from the hydrogen MHDV catalogue

The hydrogen MHDV catalogue in Appendix A documents hydrogen MHDV models and their commercial availability*. All available models are Class 8 truck or buses.

Vehicle breakdown

- 100% of the vehicles catalogued are within the Class 8 truck and bus segment.
- 21 trucks, 3 buses, and 1 waste-collection vehicle identified globally.
- FCEVs were the most commercially available hydrogen propulsion technology with 19 models identified globally.



Availability in Canada

- 14 vehicle technologies (models and retrofit kits) have stated commitments to sell in Canada.
- 3 buses, 4 trucks, 1 waste-collection vehicle, and 3 dual fuel truck retrofits are available for order today.



Hydrogen storage pressure

- 14 vehicles are designed with 350-bar hydrogen storage pressure.
- 3 vehicles are designed with 700-bar hydrogen storage pressure.



Vehicle range

- Trucks can expect ranges between 400 – 800 km.
- Buses can expect ranges between 300 – 600 km.



Refueling time

- Refueling time for trucks range from 8 – 20 minutes.
- Refueling time for buses range from 6 – 20 minutes.



Note: Snapshot as of May 2024; information may change at future dates.

Class 6, 7, and 8, medium- and heavy-duty hydrogen vehicles available in Canada

14 technologies are projected to be available in Canada by 2030*. Five FCEV models are expected to be released in 2024, and two dual fuel retrofitting options are currently available.

	Product name	Description	Projected availability
	Nikola Tre	Class 8 Trucks	2024
 Mercedes-Benz	Mercedes-Benz GenH2	Class 8 Trucks	TBD
 HYUNDAI	Hyundai Xcient	Class 8 Trucks	2025
 KENWORTH	Kenworth T680	Class 8 Trucks	2024
 HYZON	HYZON HYHD8-110 & HYHD8-200	Class 8 Trucks	2024
	HYZON REFUSE	Waste-collection trucks	2025
 NEW FLYER	New Flyer Xcelsior Charge FC	40-foot & 60-foot Buses	2024
 ENC	ENC Axxess EVO-FC	40-foot Buses	2024
 Cummins	Cummins H2-ICE 6.7-litre in a Freightliner Cascadia	Class 8 Trucks	2027
 Westport Fuel Systems	Westport H2 HPDI fuel system	Class 8 Trucks	TBD
 INNOVATIVE Fuel Systems	Innovative Fuel Systems Multi Fuel Technology Platform	Class 8 Trucks	TBD
 DTI DIESEL TECH INDUSTRIES	DTI Guardian Hydrogen Diesel System (Retrofit)	HD Trucks and Buses	Available Now
 hydra	Hydra Energy	Class 8 Trucks and Buses	Available Now

Note: Snapshot as of May 2024; information may change at future dates.



Techno-economic analysis



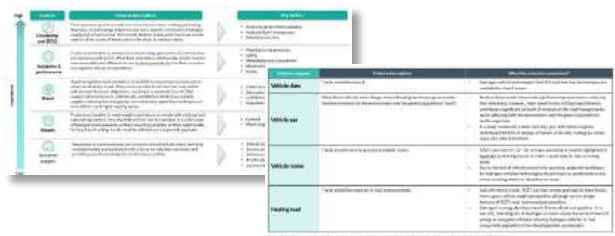
Techno-economic analysis key findings

The techno-economic analysis may be used to educate fleet owners and assist stakeholders with the evaluation of low-carbon and zero-emission technologies.

1 Truck purchasing decisions

When purchasing a truck, a fleet owner/operator considers a variety of factors including total cost of ownership (TCO), reliability and performance, brand, potential payload capacity, and customer support.

- TCO is prioritized by fleet owners when making purchasing decisions followed by reliability and performance of the truck.
- Trucks must be able to perform a similar duty cycle to their ICE counterparts and have accessible energy supply and refueling services including maintenance when needed.
- Due to limitations in battery electric truck technology, Class 8 trucks hauling heavy loads over long and predictable routes should be prioritized to transition hydrogen vehicle technologies.



2 TCO for regional and long-haul trucking

TCO was examined for regional trucking (50,000 km per year) and long-haul trucking (100,000) for FCEV and dual fuel hydrogen technologies compared to other propulsion technologies.

- For the regional trucking segment, BEV technology had the lowest TCO when compared with FCEV and dual fuel technologies.
- In the long-haul trucking segment, FCEV had the highest TCO followed by dual fuel trucks. Utilizing grants and incentives and lower hydrogen fuel costs are key factors in reducing TCO for FCEV and dual fuel technologies and achieving parity with diesel.
- Hydrogen fuel cost would need to decline to \$5.35 per kg (from a current retail price range of \$14 - \$35 per kg for Alberta and British Columbia) to begin achieving price parity with diesel.



3 Sensitivity analysis and grants and incentives

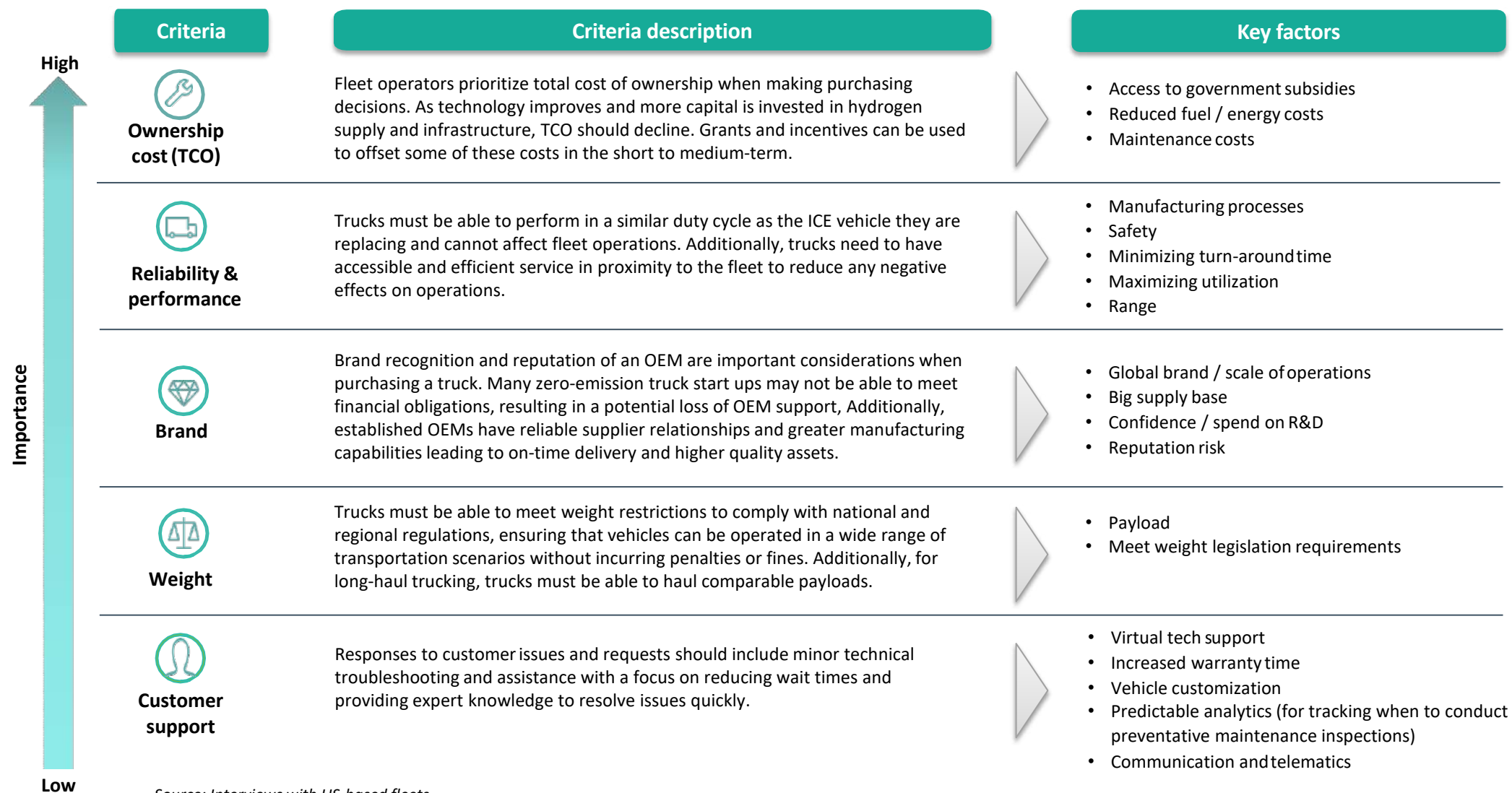
Sensitivity analyses were done to examine the impacts in TCO for varying inputs including grants and incentives.

- Changes in fuel/electricity caused the greatest fluctuation in TCO, followed by ownership period, and mileage.
- Further federal and provincial grants and incentives have the potential to substantially lower both CAPEX and OPEX for hydrogen vehicles and infrastructure reducing the TCO for fleet operators.
- Two high value federal incentive programs that reduce the TCO include the Incentives for Medium-Heavy duty Zero Emission Vehicle Program (iMHZEV) and the Zero-Emission Vehicle Infrastructure Program (ZEVIP).



How truck purchasing decisions are made

To spur hydrogen truck adoption, it is important to understand key inputs driving purchase decisions. While TCO is the most important factor, it is one of many criteria.



Source: Interviews with US-based fleets

Operational considerations when transitioning to hydrogen trucks

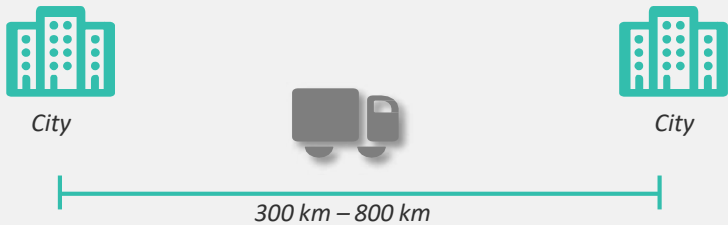
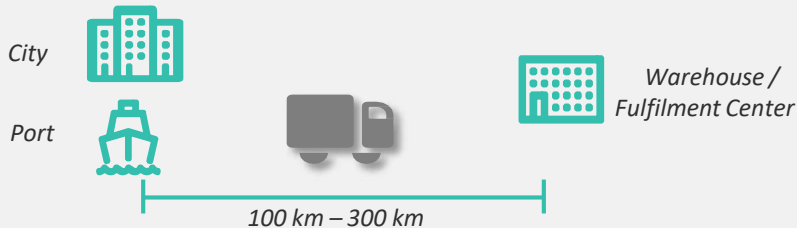
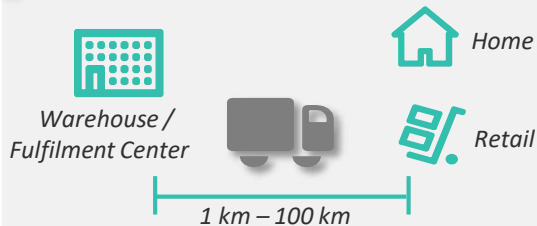
Aside from TCO, fleet owners and operators must take operational considerations to ensure the right type of vehicle is transitioning to hydrogen.

Criteria category	Criteria description	Why this criteria is important?
Vehicle class	Trucks should be Class 8.	Hydrogen vehicle technologies like FCEV and dual fuel technologies are available for Class 8 assets.
Vehicle age	Older diesel vehicles emit a larger share of total greenhouse gas and criteria air pollutants with impact on public health.	- Modern diesel trucks have made significant improvements in reducing their emissions; however, older diesel trucks still disproportionately contribute a significant amount of emission in the road-transportation sector affecting both the environment, air quality, and public health - In a study conducted in New York City, pre- 2007 diesel engines contributed 64-83% of tailpipe emissions while only making up a total share of 6-10% of the fleet.¹
Vehicle routes	Trucks should travel long and predictable routes.	- FCEVs can refuel in 10 – 20 minutes according to models highlighted in Appendix A allowing a truck to make a quick fuel stop on a long route. - Due to the lack of infrastructure in the province, potential candidates for hydrogen vehicles should travel on predictable routes where a fueling station is identified.
Hauling load	Trucks should be required to haul heavy payloads.	- Fuel cell electric trucks (FCET) can haul similar payloads to diesel from a gross vehicle weight perspective, although certain design features of FCET's may lower payload capacities. - Hydrogen's energy density is nearly three times diesel and gasoline. In a fuel cell, one kilogram of hydrogen contains nearly the same amount of energy as one gallon of diesel allowing hydrogen vehicles to haul comparable payloads to their diesel/gasoline counterparts.

¹Source: <https://theicct.org/publication/true-diesel-trucks-nyc-apr22/#:~:text=Older%20diesel%20trucks%20are%20responsible,truck%20tailpipe%20PM2.5%20emissions>

Allocating trucking technologies to different responsibilities

FCEV trucks are preferred for long-haul routes relative to BEV trucks due to greater range. BEV trucks are limited by current battery technology and charging speeds.

Trucking routes	Preferred technology	Reasoning
1 Line Haul – Long haul routes between cities. 	Hydrogen fuel cell vehicles	FCEV trucks have longer range capabilities and quicker refueling times compared to BEV trucks, enabling more continuous operations.
2 Regional – Medium haul routes between Ports / Cities and regional distribution centers or fulfilment centers. 	Hydrogen fuel cell / electric vehicles	FCEVs offer quick refueling that is suitable for regional distribution, while BEVs can still complete a route on one charge and has ample charging infrastructure availability.
3 Last Mile – Movement of goods from a transport hub to the final destination. 	Electric vehicles	Electric vehicles can handle frequent stops and short distances between a transport hub and the final destination, benefiting from lower operating and fuel costs.

Limitations of the TCO tool

Limitations in the tool exist to reduce the number of assumptions and avoid complexity that may cause the calculator to be less user-friendly.

What the tool does account for:

1. TCO of FCEV, dual fuel, BEV, CNG, and diesel trucks with separate inputs depending on leasing or purchasing decisions.
2. TCO in \$, \$/year, and \$/km-travelled units.
3. Comparative bar chart that allows the evaluation of two technologies at the same time.
4. Option for charging or fueling infrastructure costs to be included in the TCO calculation.

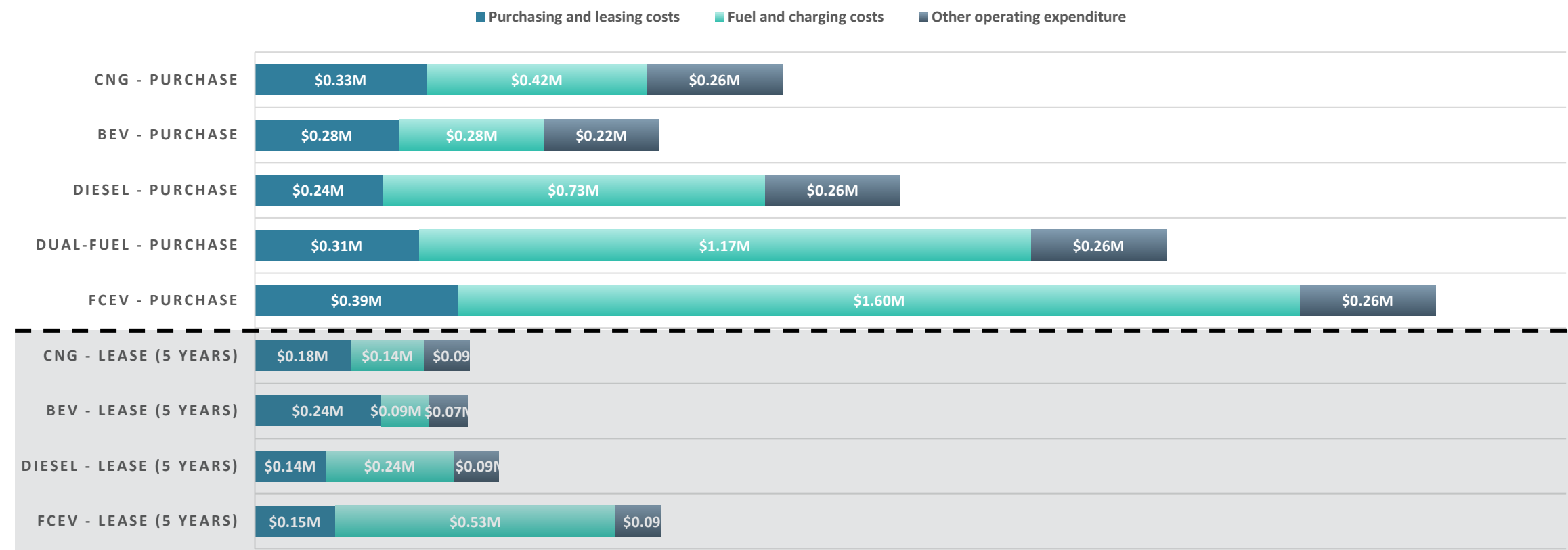
What the tool does not account for:

1. Forecasted future input values (although, this can be inputted by the user).
2. Infrastructure availability (i.e., refueling stations, charging network, pipe networks, etc.).
3. Supply of the vehicle type.
4. Payload's impact on fuel or electricity usage.
5. Opportunity cost of time spent at the pump or charger.
6. Range constraints that may make the annual mileage inputted difficult to achieve.
7. Discount rates on future cash flows.
8. Differences in the cost of insurance across vehicle technologies.

TCO for regional trucking (50,000 km-travelled/year)

For regional trucking classified as 100 – 300 km routes, BEV trucks were found to have the lowest TCO for MHDV trucks over the life of the vehicle due to relatively low infrastructure, energy supply, and charging costs. FCEV trucks had the highest TCO followed by dual fuel trucks.

Fuel costs make up a large share of the total cost of ownership for FCEV and dual fuel trucks. A high federal purchase grant and a decrease in hydrogen fuel price are key to reducing FCEV TCO. Decreasing the hydrogen fuel cost to **\$4.00 per kg** would bring FCEV to parity with diesel.

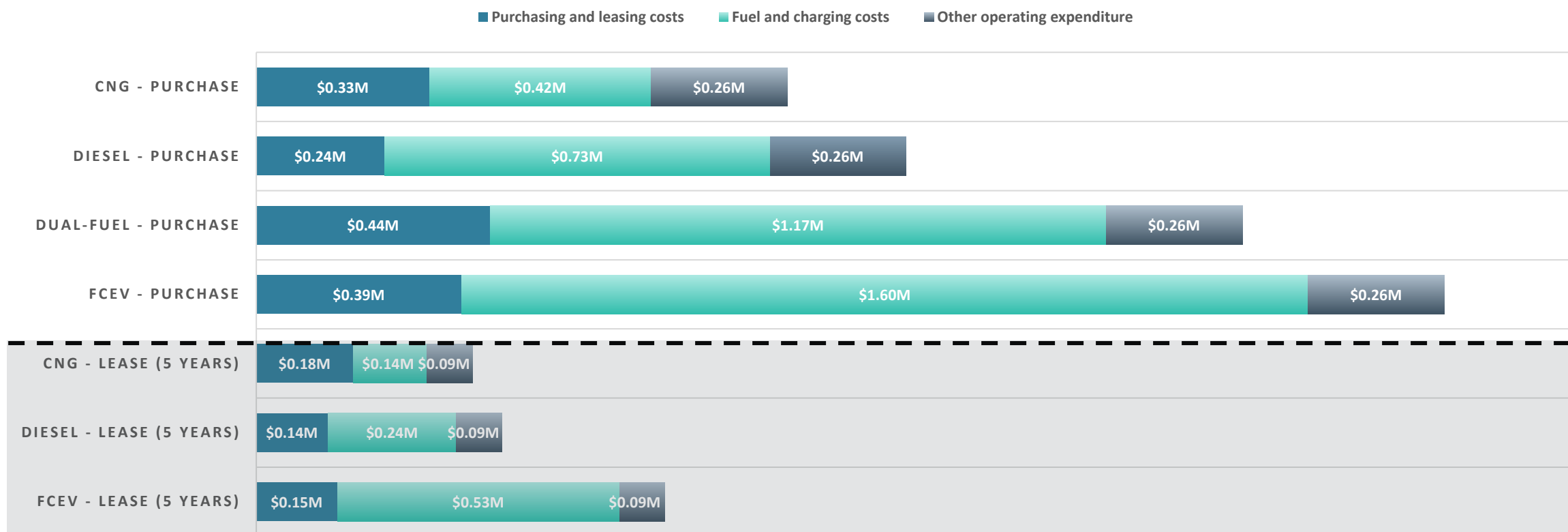


Note: Analysis assumes the truck can perform the duty cycle and includes \$200,000 iMHZEV federal grant in the purchase price for zero-emission trucks.

TCO for long-haul trucking (100,000 km-travelled/year)

FCEV trucks are currently the only zero-emission technology suitable for long-haul trucking due to the limitations of BEV technology. Grants and incentives, and a decrease in hydrogen fuel costs are key factors to reducing TCO for FCEV and dual fuel technologies.

For long-haul trucking routes, **BEV trucks** are generally limited by their range, refueling times, significant weight of the battery reducing payload, weather, and energy supply availability. Currently available battery electric trucks have ranges of 500 km or less without accounting for payload.



Notes: 1. More detailed breakdown of long-haul trucking costs in [Appendix B](#). 2. BEV trucks were only included in the appendix for long-haul trucking due to limitations in their specifications. 3. Analysis assumes the truck can perform the duty cycle and includes \$200,000 iMHZEV federal grant in the purchase price for zero-emission trucks.

Sensitivity of TCO to fluctuations in input values

Total cost of ownership values were most sensitive to changes in a vehicle's ownership period, mileage, and fuel cost. These input costs should be monitored due to their ability to change ownership costs drastically.



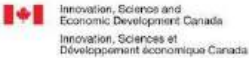
TCO sensitivity is a measurement of how much the total cost of ownership value changes with a variation in an input value that may occur. The sensitivity values were measured by changing specific input values to a value that may occur in the future and measuring the impact the change has on the vehicle's total cost of ownership. The change in input values is illustrated in [Appendix C](#).

< 10%
 10% - 20%
 > 20%

Truck type	Sensitivity to change in Ownership period	Sensitivity to change in Mileage	Sensitivity to change in Fuel/electricity prices	Sensitivity to a change in Loan term	Sensitivity to change in Vehicle price	Sensitivity to change in APR
Fuel cell	+/- 22%	+/- 21%	+/- 24%	+/- 1.3%	+/- 11%	+/- 1.3%
Dual fuel	+/- 19%	+/- 19%	+/- 15%	+/- 1.0%	+/- 5.4%	+/- 0.9%
Battery Electric	+/- 16%	+/- 11%	+/- 17%	+/- 4.2%	+/- 24%	+/- 4.0%
CNG	+/- 17%	+/- 13%	+/- 18%	+/- 2.5%	+/- 9.1%	+/- 2.4%
Diesel	+/- 20%	+/- 18%	+/- 10%	+/- 1.5%	+/- 7.4%	+/- 1.4%

Reducing TCO with government grants and incentives (1/2)

Grants and incentives can reduce TCO and improve the business case for ZEV vehicle technologies.

Providers	Program name	Description	Funding
	 Strategic Innovation Fund (SIF) - Net Zero Accelerator (NZA)¹	Funding for large scale investment in clean fuels and clean technology.	\$10 - \$500 Million (\$8 Billion)
	 Federal Clean Fuels Fund²	Funding to build new or expand existing clean fuel production facilities.	Up to \$150 Million (\$1.5 Billion)
	 Green Freight Program³	Fleet energy assessments, retrofits, repowers, purchase low-carbon vehicles, etc.	Up to \$250 Thousand (\$200 Million)
	 Zero-Emission Vehicle Infrastructure Program (ZEVIP) – Owner-Operator Stream⁴	Development of EV chargers and hydrogen refueling stations.	50% cost share up to \$10 Million (\$680 Million)
	 Zero Emission Transit Fund⁵	Funding for communities to invest in zero emission transit and school transportation.	50% cost share (\$2.75 Billion)
	 Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program (iMHZEV)⁶	Purchase incentive for eligible medium- and heavy-duty vehicles.	\$10 - \$200 Thousand (\$548 Million)
	 The Clean Hydrogen Investment Tax Credit⁷	Refundable tax credit of investment projects that produce hydrogen before 2034.	Tax credit of up to 40%
	 Innovative Clean Energy Fund⁸	Funding for pre-commercial clean technology projects, clean energy vehicles, and energy efficiency programs.	\$110 million
	 Hydrogen Innovation Fund⁹	Funding used to develop opportunities for hydrogen to be integrated into Ontario's electricity system.	Up to 50% cost share (\$15 Million)
	 Accelerating Hydrogen Fund: Alberta Innovates (AI) funds stage 1; Emissions Reduction Alberta (ERA) funds stage 2¹⁰	Stream 1: Early-stage Hydrogen technology innovation Stream 2: Later-stage Hydrogen technology innovation	\$250 Thousand - \$7 Million (\$20 Million from Alberta Innovates, \$5 Million from NRCAN, \$25 Million from Emission reduction Alberta)
 Federal  Provincial  Currently unavailable			

*This list is non-exhaustive

¹Source: [Innovation, Science and Economic Development Canada: SIF](#); ²Source: [NRCAN – Clean Fuels Fund](#); ³Source: [NRCAN – Green Freight Program](#); ⁴Source: [NRCAN – ZEVIP](#); ⁵Source: [Infrastructure Canada – Zero Emission Transit Fund](#); ⁶Source: [Transport Canada - MHZEVs](#); ⁷Source: [Government of Canada – Clean Hydrogen ITC](#); ⁸Source: [British Columbia – Innovative Clean Energy Fund](#); ⁹Source: [Ontario – Hydrogen Innovation Fund](#); ¹⁰Source: [ERA – Accelerating Hydrogen Fund](#);

Reducing TCO with government grants and incentives (2/2)

Grants and incentives can reduce TCO and improve the business case for ZEV vehicle technologies.

Providers	Program name	Description	Funding
	 Go Electric Program ¹	Rebates available for individuals and organizations on the purchase of EVs, including FCEVs.	\$1,500 - \$3,000 per vehicle for up to 10 vehicles
	 Go Electric Hydrogen Fleet Program ²	Rebates available for organizations qualified as fleets on FCEV purchases.	Up to \$8,000 or 35% off selling price
	 CleanBC Heavy-Duty Vehicle Efficiency Program ³	Funding for the purchase and installation of fuel-efficient vehicles and equipment.	\$20 - \$150 Thousand (\$1.4 Million per year)
	 Go Electric Hydrogen Fueling Infrastructure Program ⁴	Funding for the construction of hydrogen fueling stations.	Up to 1/3 of total eligible costs to a maximum of \$8.5 Million
	 Programme Technoclimat ⁵	Funding for technologic projects in Quebec in terms of GHG reduction, including hydrogen innovation.	Up to 50% or \$3 Million per project
	 Roulez Vert Program ⁶	Funding for individuals and organizations on the purchase of low-emission vehicles, including FCEVs.	Up to \$8,000 per vehicle
	 Alberta Petrochemicals Incentive Program ¹¹	Funding to incentivize large-scale investment in Alberta's petrochemicals sector	12% of the capital cost of a project that has a minimum investment in capital dollars of \$50 million
	 Green Commercial Vehicle Funding Program ⁷	Funding to encourage Ontario businesses to switch to GHG emission reducing vehicles.	Up to 33% or \$2.500 of the incrementall cost of a vehicle equipped with H ₂ injection technology
Regulatory			
	 Federal Fuels Charge Rate ⁸	Charge rates for various fuel types and combustible waste. The rates are based on global warming potential factors and emission factors used by Environment and Climate Change Canada.	
	 Clean Fuel Regulation ⁹	Incentives for the development and adoption of clean fuels, technologies and processes that require liquid fossil fuel suppliers to gradually reduce the carbon intensity from the fuels they produce and sell for use in Canada.	
	 British Columbia's Low Carbon Fuel Standard ¹⁰	The LCFS sets carbon intensity (CI) targets that decline each year. Fuel suppliers generate credits for supplying fuels with a CI below the targets and receive debits for supplying fuels with a CI above the targets.	
	 Federal  Provincial  Currently unavailable		

**This list is non-exhaustive*

¹Source: [CleanBC - Go Electric Program](#); ²Source: [CleanBC - Go Electric Hydrogen Fleet Program](#); ³Source: [CleanBC - Heavy Duty Vehicle Efficiency Program](#); ⁴Source: [CleanBC - Go Electric Hydrogen Fueling Infrastructure Program](#); ⁵Source: [Government of Quebec - Programme Technoclimat](#); ⁶Source: [Government of Quebec - Roulez Vert Program](#); ⁷Source: [Government of Ontario - Green Vehicle Funding Program](#); ⁸Source: [Government of Canada - Fuel Charge Rates](#); ⁹Source: [Government of Canada - Clean Fuel Regulations](#); ¹⁰Source: [Government of British Columbia: Low Carbon Fuel Standard](#) ¹¹Source: <https://www.alberta.ca/alberta-petrochemicals-incentive-program>

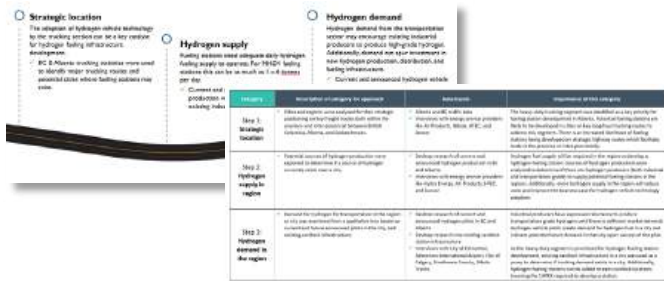
Fueling infrastructure review



Identifies strategic trucking corridors which have potential for fuel station development based on location, access to fuel, and potential for hydrogen vehicle pilots.

1 Fueling infrastructure methodology

- Key inputs include location of a city on a major freight route, current and proposed hydrogen supply in and around a city/region, hydrogen demand in the region from the transportation sector, and existing cardlock infrastructure.
- Inputs for analysis came from publicly available data, interviews with hydrogen ecosystems stakeholders, desktop research, and subject matter experts.



2 Identifying potential fueling stations in British Columbia

- Vancouver currently has two tonnes per day of low-carbon transportation fuel grade supply produced by HTEC with another 15 tonnes per day coming online in 2026.
- Prince George to Edmonton was identified as one of the highest priority routes with the potential to develop into a hydrogen trucking corridor. Hydra Energy will be opening the first commercial fueling station in Prince George with on-site transportation grade hydrogen production.
- Prince Rupert had low truck traffic volume indicating rail as the preferential mode of transportation.



3 Identifying potential fueling station in Alberta

- Industrial producers in Alberta may produce transportation grade hydrogen if demand for fuel increases.
- Highway 2 between Edmonton to Calgary was ranked as the highest priority route for potential station development and has some of the highest truck traffic in the province.
- Edmonton to Prince George via Highway 16 is another key route with potential opportunity for a fueling station in Hinton Alberta.



Methodology overview for identifying strategic fueling station locations

Key determinants of strategic fueling locations include trucking route statistics, transportation-grade hydrogen, and demand from the sector.

Strategic location

The adoption of hydrogen vehicle technology by the trucking sector can be a key catalyst for hydrogen fueling infrastructure development.

- ✓ Trucking statistics for both British Columbia and Alberta were used to identify major trucking routes and potential cities for new stations.



Hydrogen supply

Fueling stations need adequate daily supply to operate. For MHDV fueling stations this can be as much as 1 – 6 tonnes per day.

- ✓ Current and announced hydrogen production including existing industrial supply were identified.



Hydrogen demand

Hydrogen demand from the transportation sector may encourage existing industrial producers to produce high-grade fuel. Additionally, demand can spur investment in new hydrogen production, distribution, and fueling infrastructure.

- ✓ Mapped current and announced hydrogen vehicle pilots in British Columbia and Alberta.
- ✓ Analyzed whether existing cardlock infrastructure are in cities identified as proposed fueling station locations.

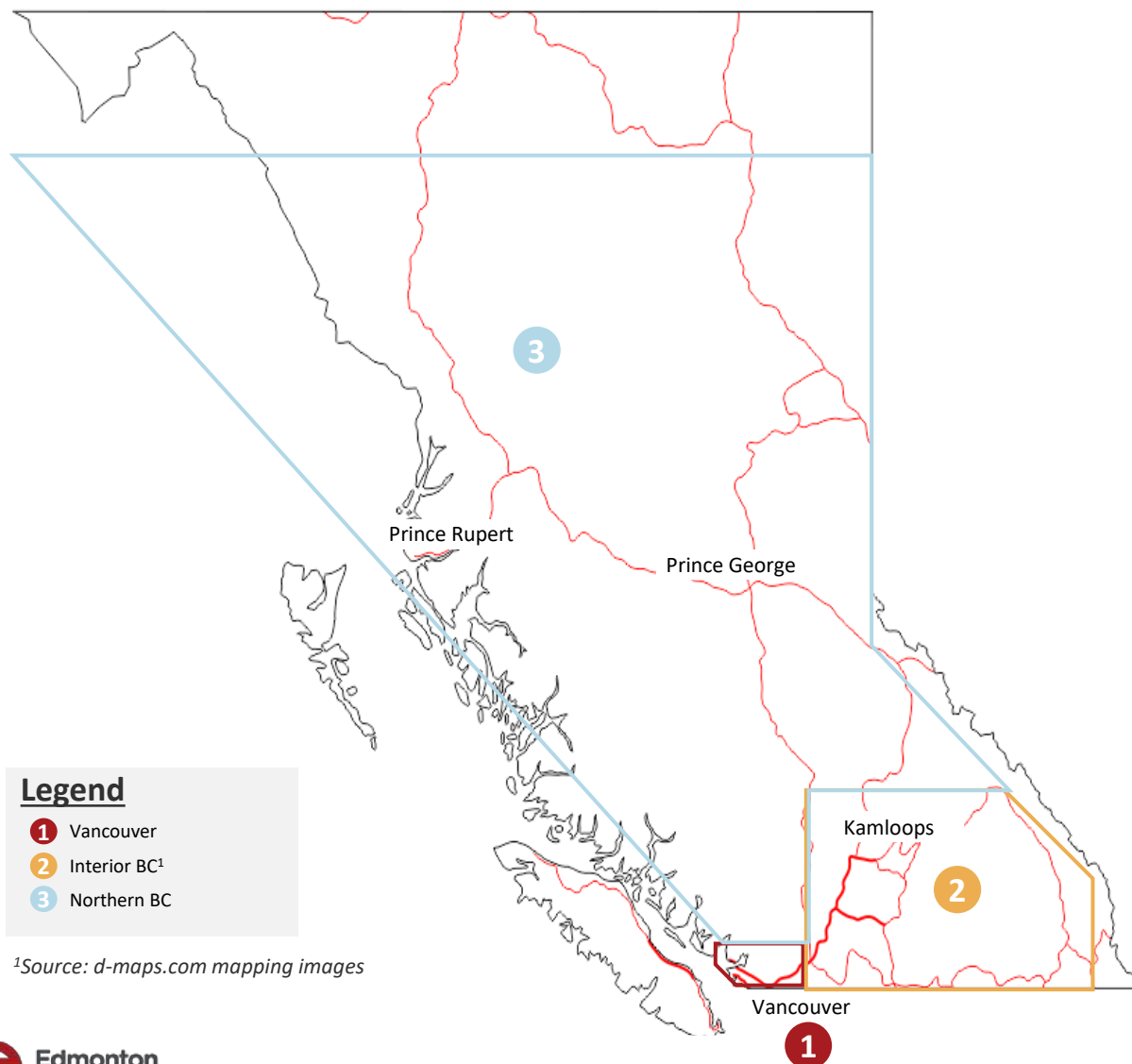
Approach for anticipating future hydrogen fueling locations in Alberta

To determine strategic locations for hydrogen infrastructure in Alberta, traffic data, locations of cities, and hydrogen supply and demand sources were determined to be predictive inputs into anticipating future station development.

Category	Description of category for approach	Data inputs	Importance of this category
Step 1: Strategic location	Cities and regions were analyzed for their strategic positioning on key freight routes both within the province and inter-provincial between British Columbia, Alberta, and Saskatchewan.	✓ Alberta and British Columbia traffic data. ✓ Interviews with energy service providers like Air Products, Nikola, HTEC, and Suncor.	The heavy-duty trucking segment was identified as a key priority for fueling station development. Fueling stations are likely to be developed in cities on key long-haul trucking routes. There is an increased likelihood of fueling stations being developed on strategic highway routes which facilitate trade in the province or inter-provincially.
Step 2: Hydrogen supply in region	Potential sources of hydrogen production were explored to determine if a source of hydrogen currently exists near a city.	✓ Desktop research of current and announced hydrogen production in British Columbia and Alberta. ✓ Interviews with energy service providers like Hydra Energy, Air Products, HTEC, and Suncor.	Hydrogen supply is required for the build-out of hydrogen fueling stations. Sources of hydrogen production were analyzed to determine if there are hydrogen producers (both industrial and transportation grade) to supply potential fueling stations. Additionally, more supply in the region will reduce costs and improve the business case for hydrogen vehicle technology adoption.
Step 3: Hydrogen demand in region	Demand for hydrogen for transportation in the region or city was examined from a qualitative lens based on current and future announced pilots in the city and existing cardlock infrastructure.	✓ Desktop research of current and announced hydrogen pilots in British Columbia and Alberta. ✓ Desktop research into existing cardlock station infrastructure. ✓ Interviews with City of Edmonton, Edmonton International Airport, City of Calgary, Strathcona County, Nikola Trucks.	- Industrial producers have expressed reluctance to produce transportation grade hydrogen until there is sufficient market demand. Hydrogen vehicle pilots create demand for hydrogen fuel in a city and indicate potential future demand in that city upon success of the pilot. - As the heavy-duty segment is prioritized for hydrogen fueling station development, existing cardlock infrastructure in a city was used as a proxy to determine if trucking demand exists in a city. Additionally, hydrogen fueling stations can be added to exist cardlock locations lowering the CAPEX required to develop a station.

Understanding strategic locations based on British Columbia traffic data

British Columbia trucking traffic volume was analyzed to determine high traffic trucking routes in Vancouver, Interior British Columbia, and Northern British Columbia.



Objective of British Columbia traffic analysis:

1. To gain a present-day snapshot of high truck-traffic areas in particular inter-provincial routes between British Columbia and Alberta.
2. Provide insights on which routes and locations major fueling stations may be developed.

Methodology:



1. ADVC

Retrieve *average daily vehicle count (ADVC)* from the traffic count station in the latest available year (each count represents a vehicle passing the sensor).



2. Truck %

Retrieve the *vehicle length* breakdown from the traffic count station to identify percentage of vehicles that are trucks (assume a truck is greater than 6m in length).



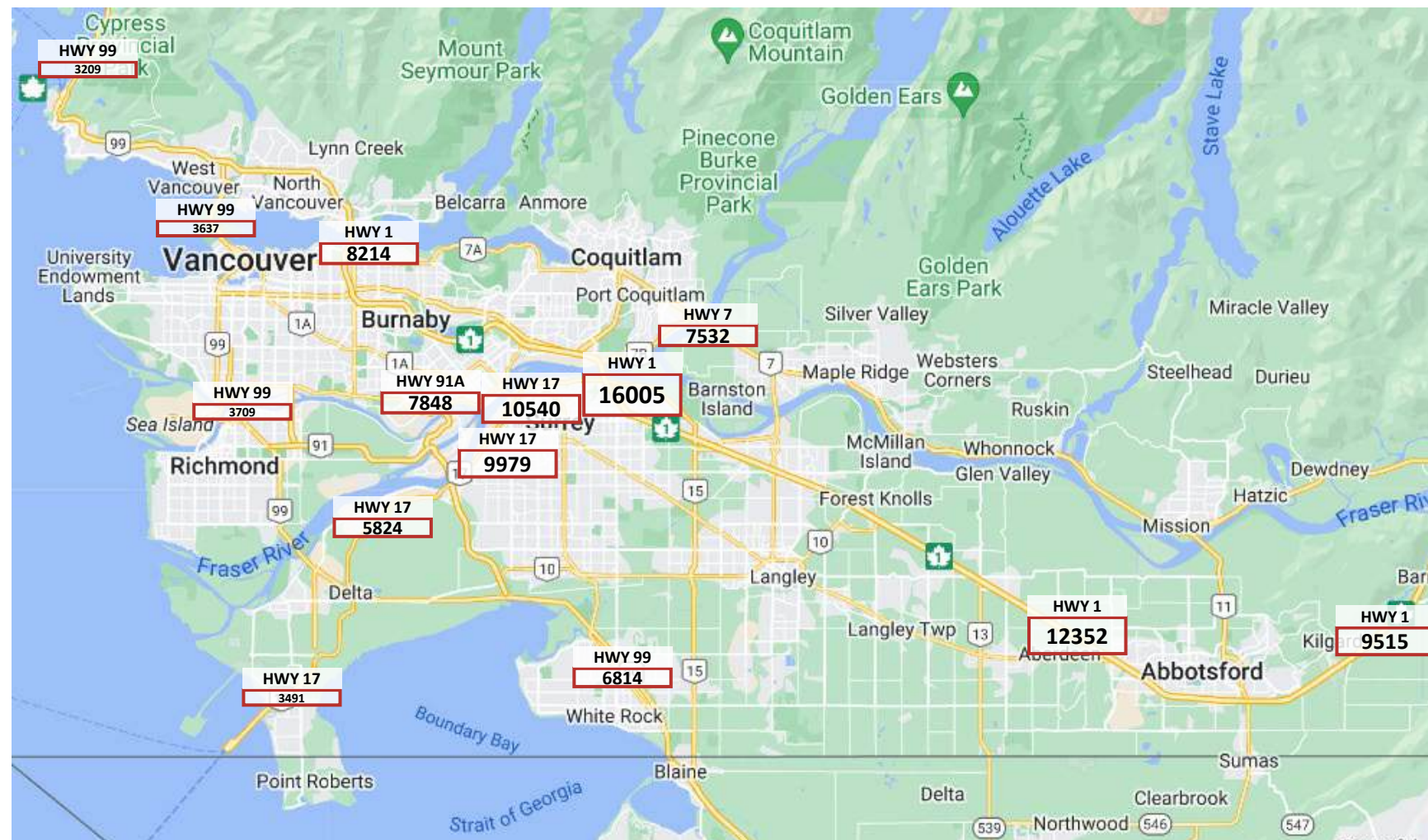
3. Trucks per day

Multiply ADVC by *truck %* to obtain the **non-unique daily truck traffic**.

British Columbia Zone 1 – Vancouver MHDV traffic volumes

Highway 1 from Vancouver moving east to Abbotsford and beyond had the highest volume of daily traffic flow.

Daily sensor volume



Legend

- Truck sensor volume
- Road affected

Significant traffic flows

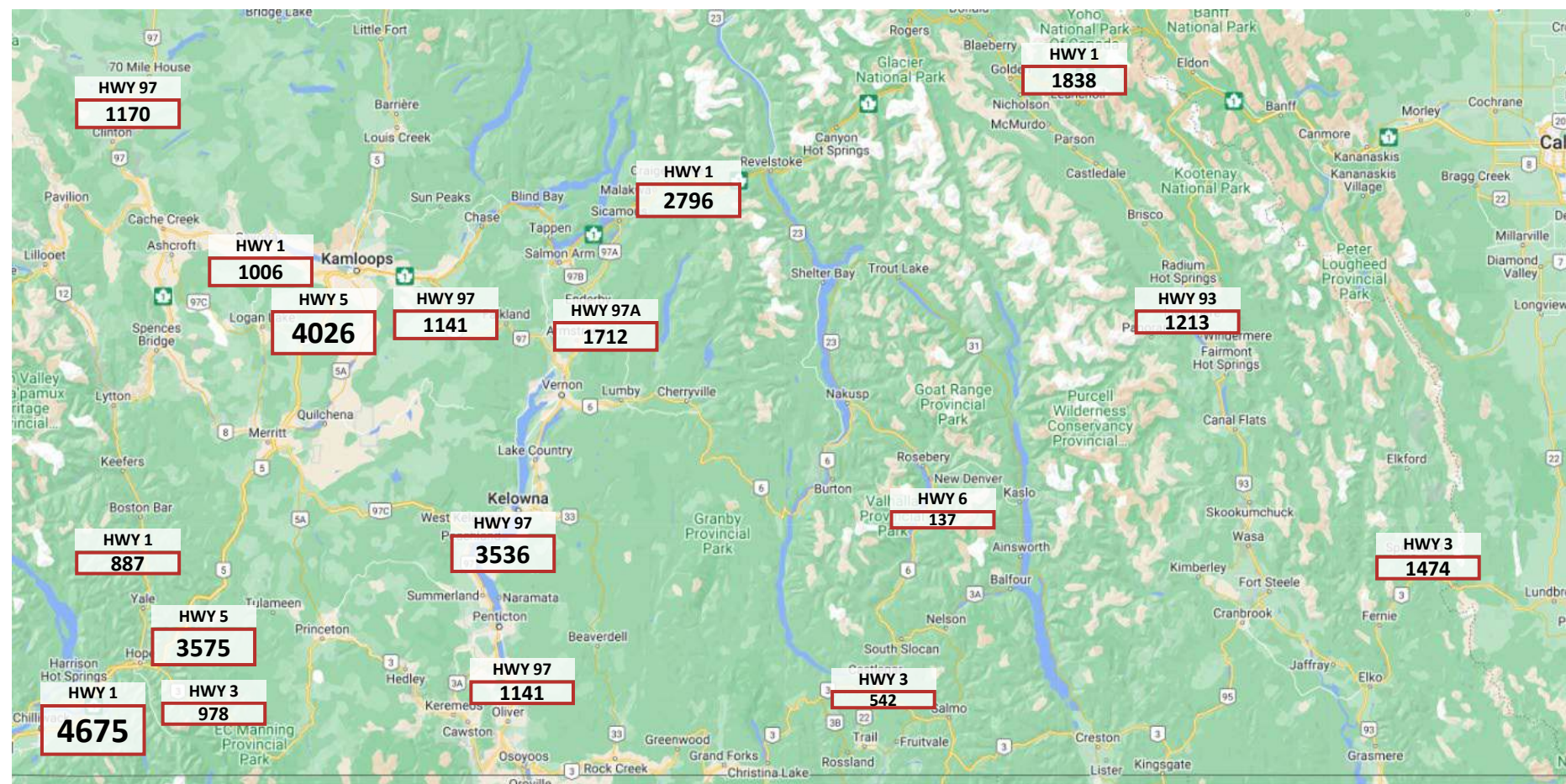
- Highway 1 between Burnaby and Abbotsford.
- Highway 17 along the South Fraser Perimeter Road.
- Highway 1 across Second Narrows bridge.

Source: Government of BC Traffic Data Program (2021, 2022)

British Columbia Zone 2 – Interior British Columbia MHDV traffic volumes

Highway 5 between Hope and Kamloops had the highest amount of MHDV traffic volume.

Daily sensor volume



Source: Government of BC Traffic Data Program (2021, 2022)

Legend

- Truck sensor volume
- Road affected

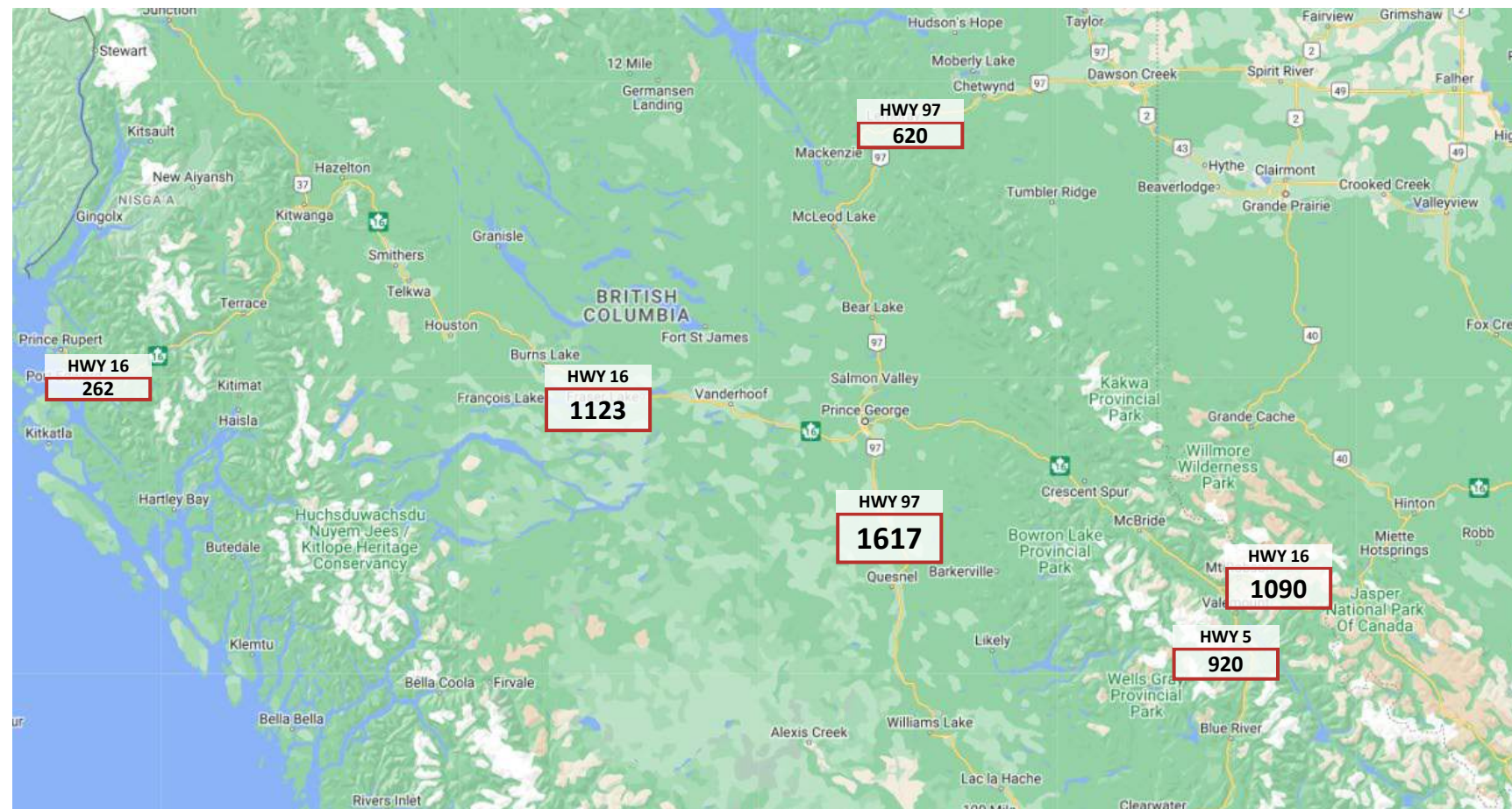
Significant traffic flows

- Coquihalla Highway between Hope and Kamloops.
- Highway 97 between 97C and Kelowna.
- Highway 1 between Kamloops and Revelstoke.

British Columbia Zone 3 – Northern British Columbia MHDV traffic volumes

Low daily MHDV traffic in Prince Rupert indicates that the preferred mode of transportation for goods shipped into the Port of Prince Rupert is via rail.

Daily sensor volume



Legend

-  Truck sensor volume
-  Road affected

Significant traffic flows

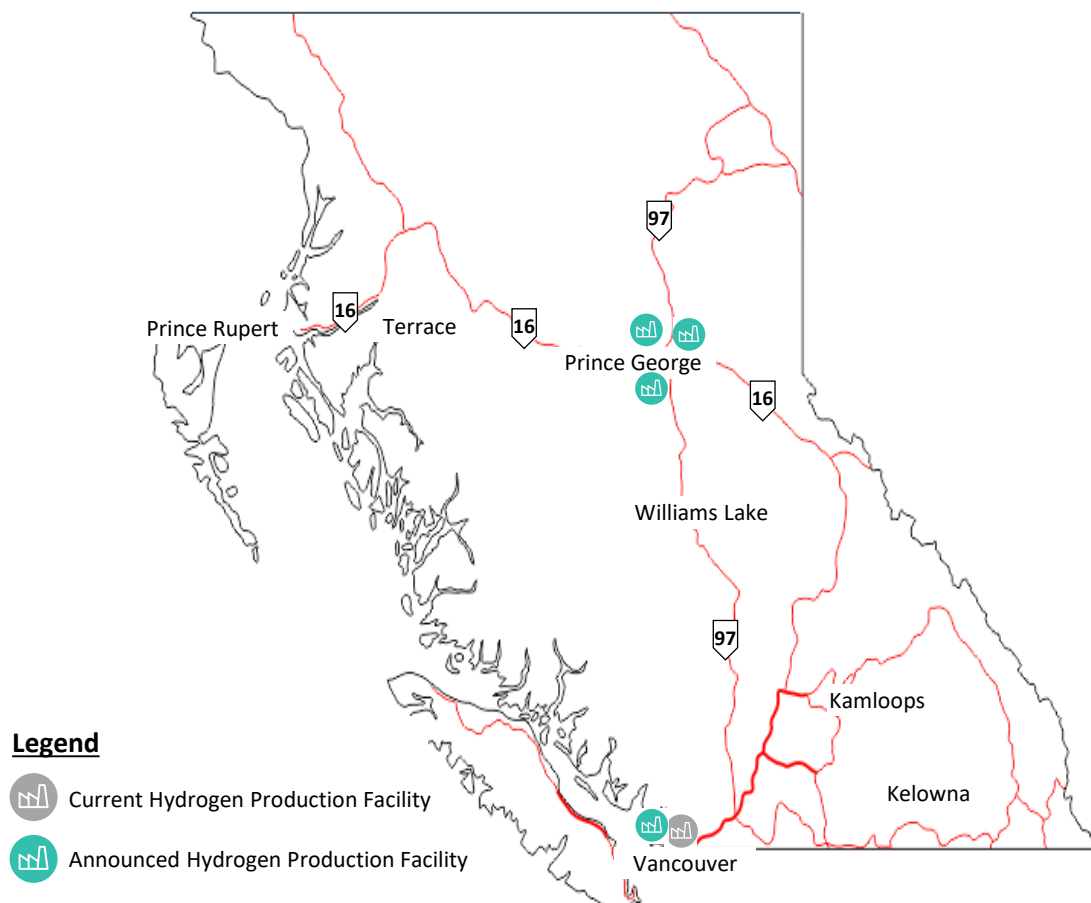
- Highway 16 either side of Prince George.
- Highway 97 south of Prince George.

Note: Truck % not available, assumed to be 75%.

Source: Government of BC Traffic Data Program (2021, 2022)

Current and proposed hydrogen supply in British Columbia

Vancouver and Prince George are developing hydrogen production hubs and have ambitions to collectively produce approximately 400 tonnes per day for various end uses in both regions. This could spur investment into hydrogen fueling infrastructure.



Region	Company and project name	Hydrogen production volume *	Expected operational date
Lower Mainland Burnaby	HTEC, Low-carbon production facility	2 tonnes / day ¹	Currently operating
Lower Mainland North Vancouver	HTEC, ERCO off-take	15 tonnes / day ²	Operational by 2026
Interior British Columbia Prince George	Hydra Energy	3.25 tonnes / day ³	Operational in 18 – 24 months
Interior British Columbia Prince George	Fortescue, Coyote Project	385** tonnes / day ⁴	Operational by 2029
Interior British Columbia Prince George	Mitsubishi Power & McLeod Lake Indian Band	TBD	TBD

* Hydrogen production volume is not guaranteed to be used for the transportation sector and may be used for industrial purposes or exported.

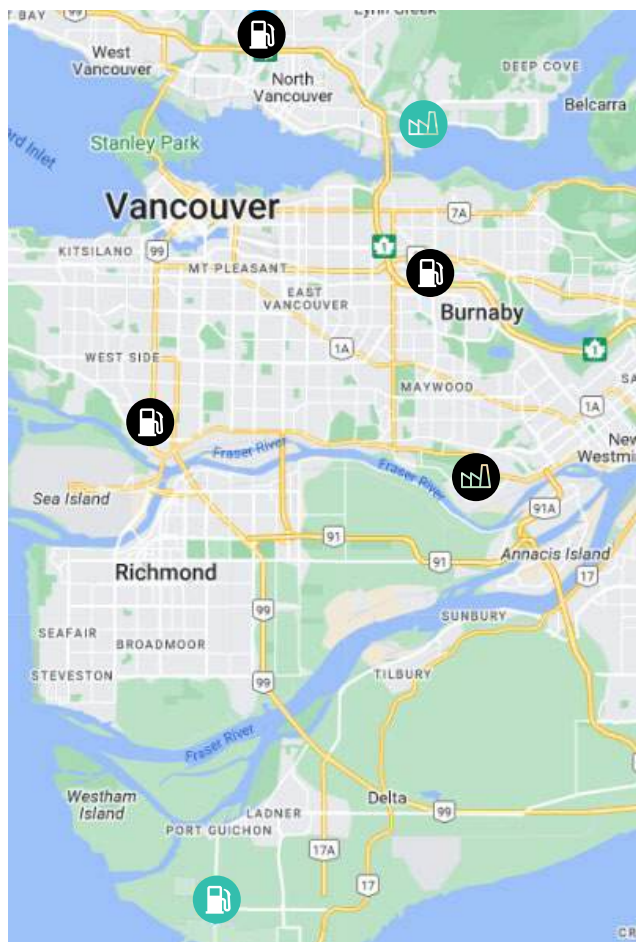
** Assuming production is 24/7 – 140,000 tonnes per year was announced.

¹Source: <https://www.htec.ca/htec-hosts-ground-breaking-ceremony-for-its-low-carbon-hydrogen-production-facility-in-burnaby/> ²Source: <https://www.dnv.org/sites/default/files/edocs/CAP-presentation-20230223.pdf> ³Source: <https://www.hydraenergy.com/news/groundbreaking> ⁴Source: <https://www.projects.eao.gov.bc.ca/p/650b5adc5d77c20022fb59fc/project-details>

Snapshot of hydrogen demand and infrastructure in British Columbia (1/2)

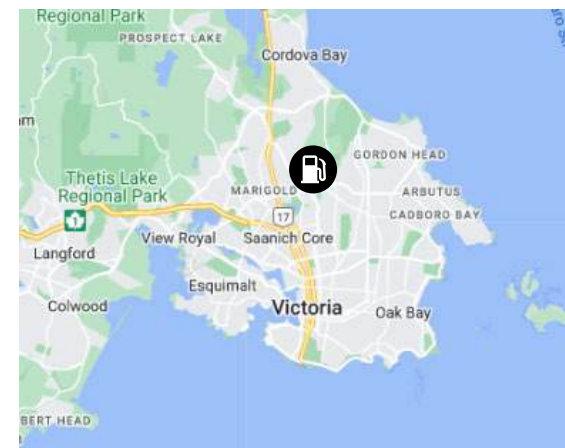
As of May 2024, there are approximately 200, light-duty hydrogen fuel cell vehicles operating in British Columbia¹. Most fueling infrastructure is dedicated for light-duty vehicles with the first heavy-duty pilot announced by HTEC.

LOWER MAINLAND



- Currently there are **three, operational, 700-bar hydrogen fueling stations** located in Vancouver, North Vancouver, and Burnaby servicing **light-duty vehicles**
- HTEC is **leading a consortium of organizations to open a heavy-duty, higher capacity, fueling station** located at a Parkland cardlock station on Tsawwassen First Nation land.
- This fueling station will service **four fuel-cell electric yard trucks, and two Class 8 drayage trucks** that HTEC will lease to fleet operators.
- HTEC's Burnaby site can produce 1-tonne of low carbon hydrogen per day.
- HTEC has a proposed clean hydrogen facility which is expected to **support the deployment of up to 30,000 fuel cell vehicles** by producing 15 tonnes of hydrogen per day.³

VANCOUVER ISLAND



- There is **one, 700-bar, hydrogen fueling station** operated by HTEC on Vancouver Island.
- This station is located at an Esso gas station and resulted in a partnership between HTEC and 7-Eleven.

Legend

- | | | | |
|---|--|---|----------------------------------|
|  | Current public hydrogen station |  | Future hydrogen fueling station |
|  | Operational hydrogen production facility |  | Future hydrogen production plant |

¹Source: <https://vancouvernews.com/news/local-news/hydrogen-highway-still-more-of-an-island-in-b-c> ²Source: <https://www.htec.ca/hydrogen-will-fuel-clean-transportation-at-b-c-ports/> ³Source: <https://sustainablebiz.ca/htec-announces-construction-of-green-hydrogen-plant-in-vancouver>

Snapshot of hydrogen demand and infrastructure in British Columbia (2/2)

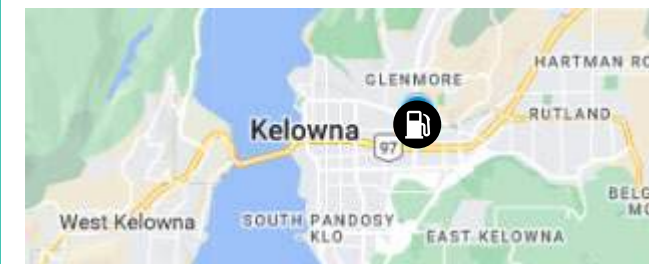
As of May 2024, Hydra Energy is in the process of constructing a hydrogen fueling and production facility for up to 24, Hydra converted, dual fuel trucks. HTEC currently operates one light-duty fueling station in Kelowna.

NORTHERN BC



- Hydra Energy is developing a low-carbon hydrogen production facility and **3.25 tonne per day hydrogen commercial fueling station** on the same site near Prince George, BC which is expected to be operational in 2024.
- The low-carbon hydrogen will be produced **from two, on-site, electrolyzers** with electricity provided by BC Hydro.
- The station will be able **to fuel up to 24**, Hydra converted, dual fuel trucks across four bays.
- Hydra has ambitions to set up a **hydrogen corridor between Prince Rupert and Edmonton** with additional fueling stations.
- Fortescue Future Industries has proposed a large hydrogen production facility, the Coyote Project, approximately 12.5 KMs away from Prince George which may be **able to produce up to 140,000 tonnes of hydrogen** per year.
- The Coyote Project is currently in **the early engagement stage** of an environmental assessment and the timelines unclear.

INTERIOR BC



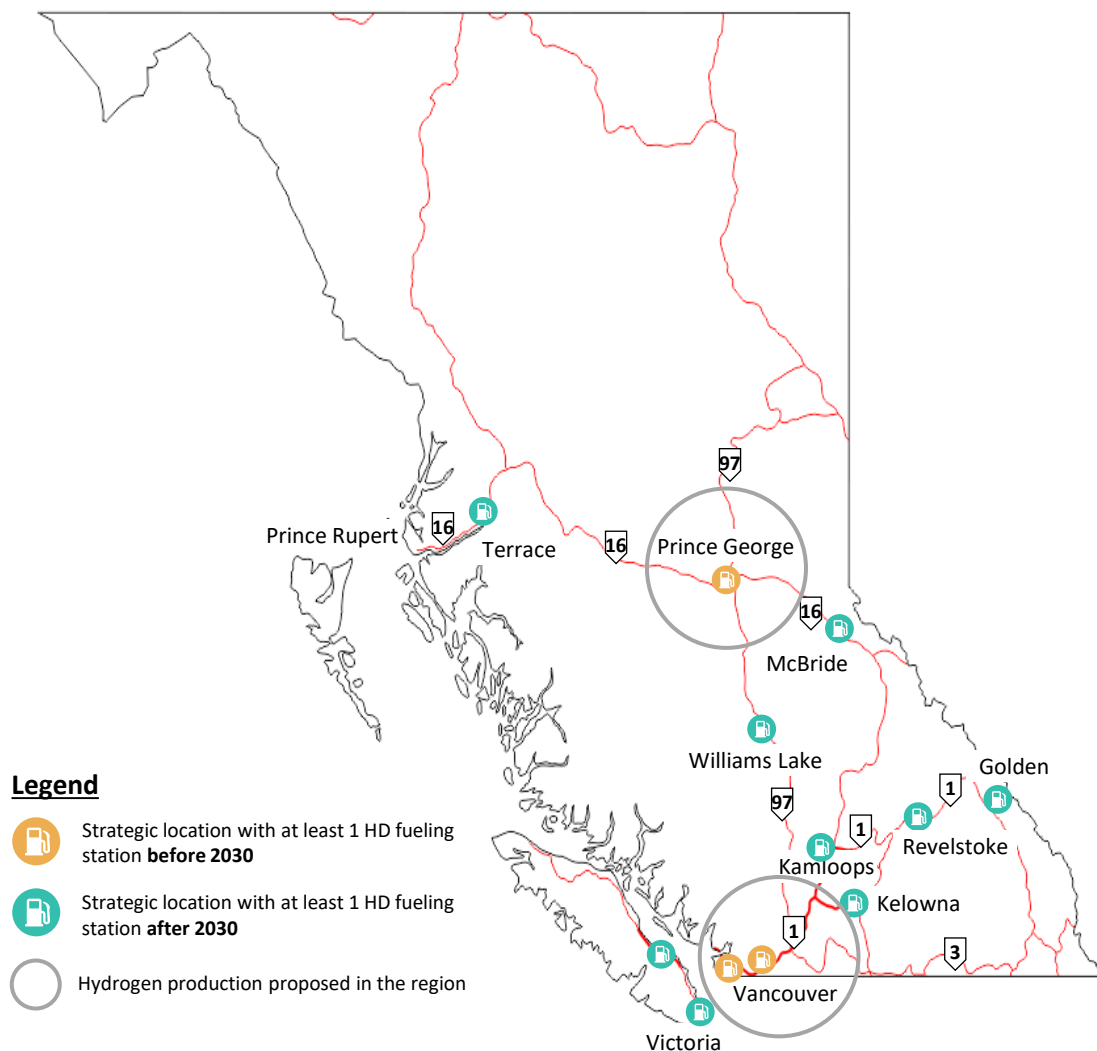
- HTEC currently operates a **700-bar hydrogen fueling station** at a 7-Eleven Canada site in the city of Kelowna.

Legend

-  Current public hydrogen station
-  Future hydrogen fueling station
-  Future hydrogen production plant

Identifying strategic HD hydrogen fueling stations in British Columbia

Vancouver and Prince George were identified as the cities most likely to have at least one fueling station before 2030 based on strategic location, access to hydrogen supply, and current demand from the transportation sector.

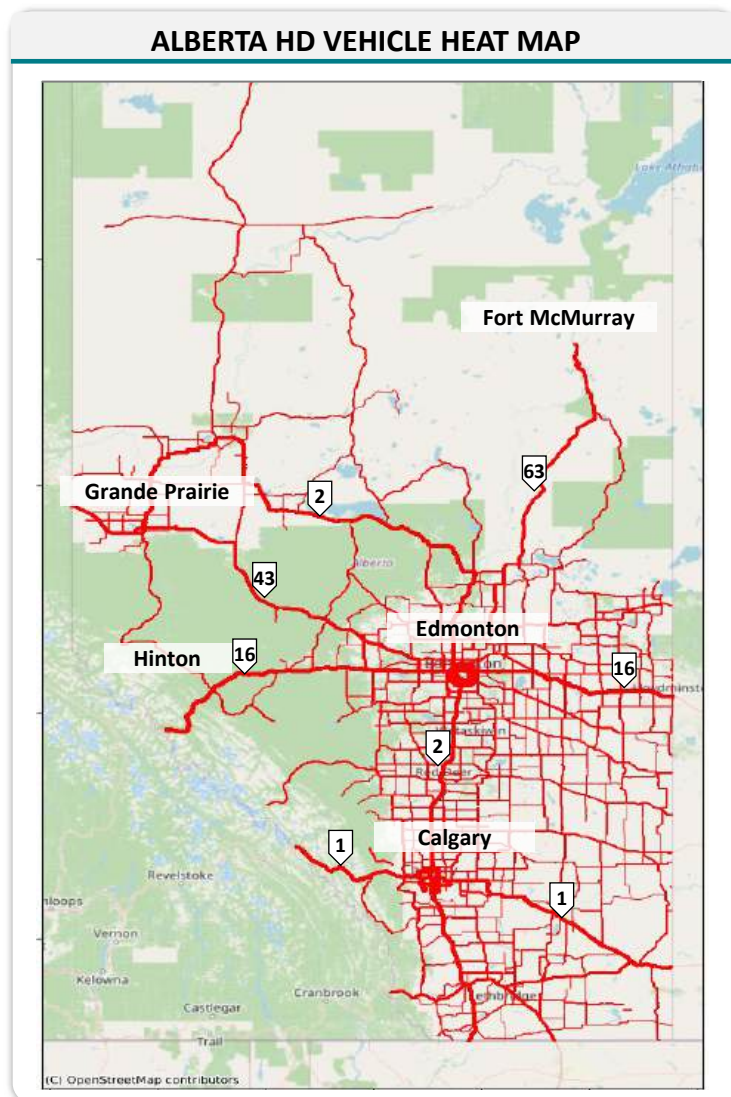


Timeframe	Region/city	BC traffic data (high, medium, low)	Strategic highway location	Current hydrogen producers in the region
Before 2030	Lower Mainland - Vancouver	High	Highway 1, 7, 17 & 99	HTEC Chemtrade Logistics
	Abbotsford	High	Highway 1 & 11	HTEC Chemtrade Logistics
	Prince George	Medium / Low	Highway 16 & 97	Hydra Energy Chemtrade Logistics Fortescue
After 2030	Kamloops	Medium	Highway 5, 1, & 97	N/A
	Kelowna	Medium	Highway 97	N/A
	Revelstoke	Medium	Highway 1	N/A
	Golden	Medium	Highway 1	N/A
	McBride	Medium / Low	Highway 16	N/A
	Williams Lake	Medium / Low	Highway 97	N/A
	Terrace	Low	Highway 16	N/A
	Victoria	Medium	Highway 17 & 1	N/A
	Nanaimo	Medium	Highway 19 & 1	N/A

Note: Each city currently has at least one operational cardlock station demonstrating trucking demand.

Understanding strategic locations based on Alberta trucking data

Heavy-duty vehicle traffic volumes indicate that there are multiple high volume trucking corridors in Alberta.



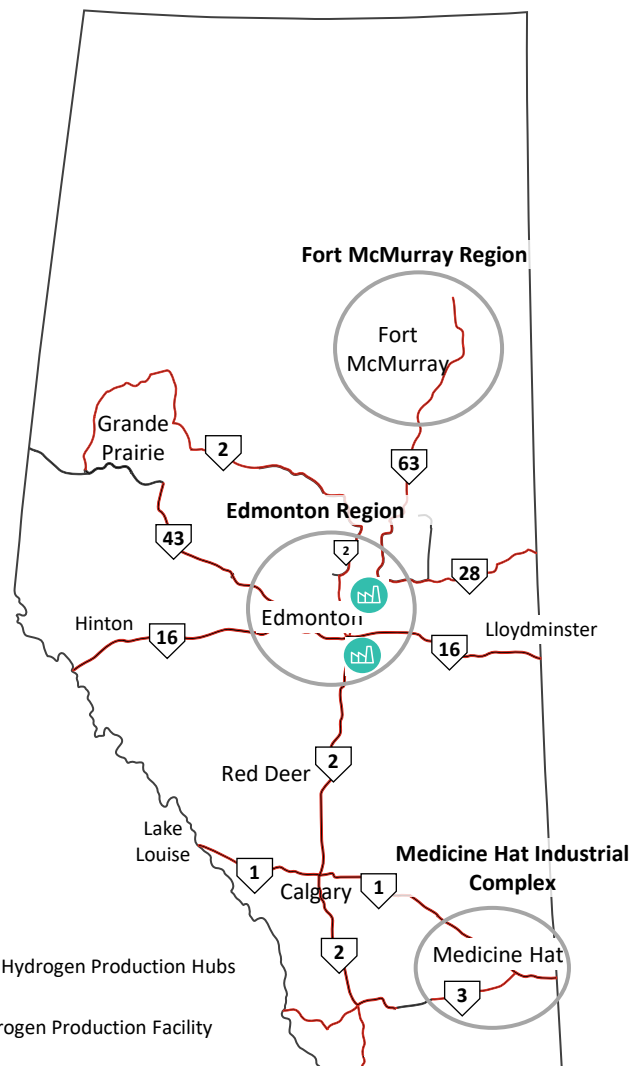
Key takeaways:

- 1 **Edmonton and Calgary may require multiple fueling stations**
 - ✓ Due to high volumes of trucking and transit buses in and around the cities, multiple fueling stations may be developed in Edmonton & Calgary. Currently, there is one commercial hydrogen fueling station open in Edmonton (by HYL A) with plans for an Air Products station to open in 2025.
- 2 **Hinton is a strategic location between Edmonton and Prince George**
 - ✓ Edmonton to Prince George is over 700 km. A fueling station in Hinton would reduce range anxiety and improve route feasibility for fuel cell trucks, especially while hauling heavy loads. Additionally, multi-modal fueling station could be developed in Hinton due to the high volume of visitors to the area.
- 3 **Fort McMurray and Grand Prairie may require fueling stations**
 - ✓ Significant trucking volume between Fort McMurray and Edmonton suggests a need for fueling station development in Fort McMurray. Due to the distance between the cities, it would be difficult for a fuel cell truck to complete the route without refueling in Fort McMurray.
 - ✓ Grand Prairie is a strategic fueling station location to enable trucking routes in Northwestern Alberta.

Note: Heavy-duty traffic volume assumes each highway has consistent traffic volume throughout.

Current and proposed hydrogen supply in Alberta

Alberta currently produces more than 5,000 tonnes of low-cost hydrogen per day of which a majority is used as industrial feedstock for the production of crude oil, fertilizers, fuels, and chemicals.¹



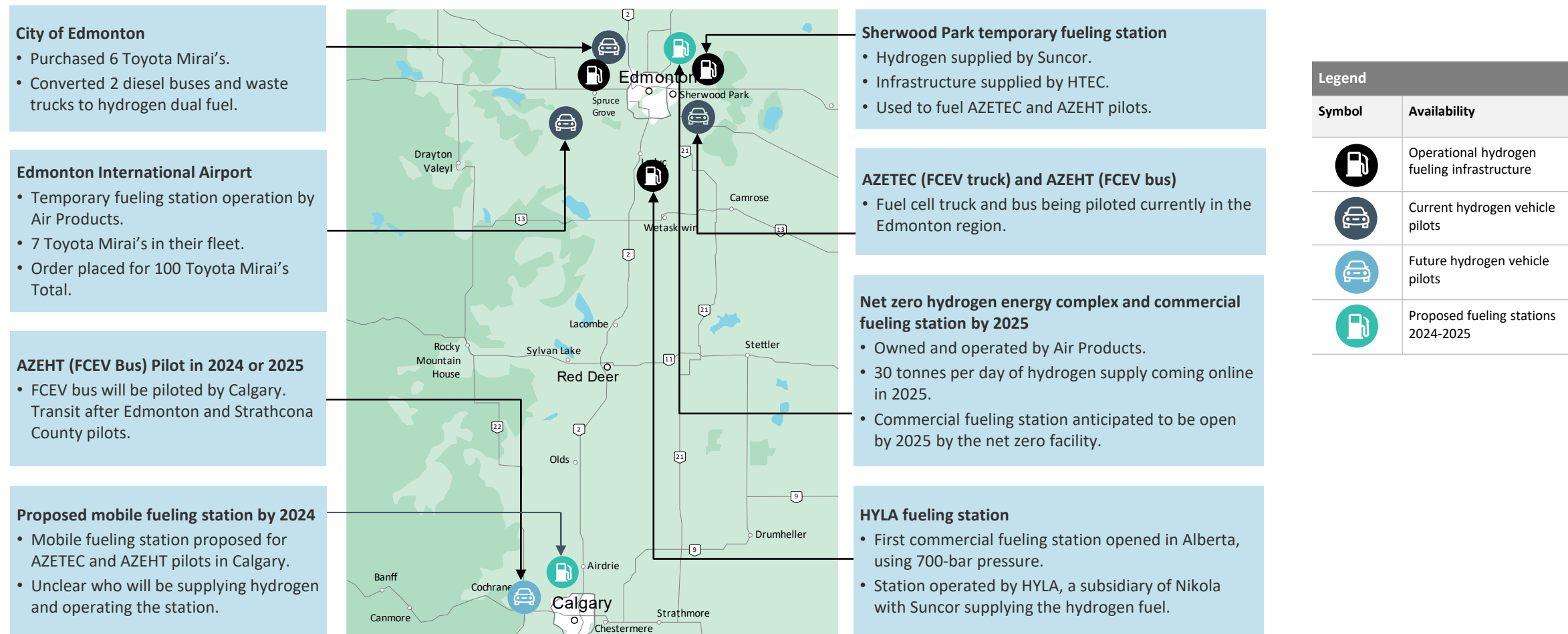
Region	Company and project name	Hydrogen production volume *	Carbon Intensity	Expected operational date
Edmonton Region	Air Products, Net Zero Hydrogen Complex	1,500 tonnes per day ²	Blue Hydrogen – Low carbon intensity	Operational by 2025
	Fort Saskatchewan Hydrogen Blending Project	TBD	Grey Hydrogen – High carbon intensity	Operational in 2024
	Producers include: NWR, Shell, Suncor, Nutrien, Sherritt, & Air Products	~ 2,200 tonnes per day for industrial purposes ³	Grey Hydrogen – High carbon intensity	Currently Operating
Fort McMurray Region	Producers include: CNR Ltd	~ 1,650 tonnes per day	Grey Hydrogen – High carbon intensity	Currently Operating
Medicine Hat Industrial Complex	Producers Include: CF Industries, Methanex, and CanCarb	~ 1,150 tonnes per day for industrial purposes ⁴	Grey Hydrogen – High carbon intensity	Currently Operating

Note: Hydrogen production volume is not guaranteed to be used for the transportation sector and may be used for industrial purposes or exported.

¹Source: <https://www.hydrogenexpo.com/media/industry-news-insights/2021/october/06/air-products-announces-multi-billion-dollar-net-zero-hydrogen-energy-complex-in-edmonton-alberta-canada/> ² Source: <https://www.hydrogenexpo.com/media/industry-news-insights/2021/october/06/air-products-announces-multi-billion-dollar-net-zero-hydrogen-energy-complex-in-edmonton-alberta-canada/> ³ Source: https://industrialheartland.com/wp-content/uploads/2022/03/AIHA_H2_Brochure.pdf ⁴ Source: https://transitionaccelerator.ca/wp-content/uploads/2023/05/TA-Report-4.3_Towards-Hydrogen-A-Hydrogen-HUB-Feasibility-Study-for-Southeast-Alberta-1.pdf

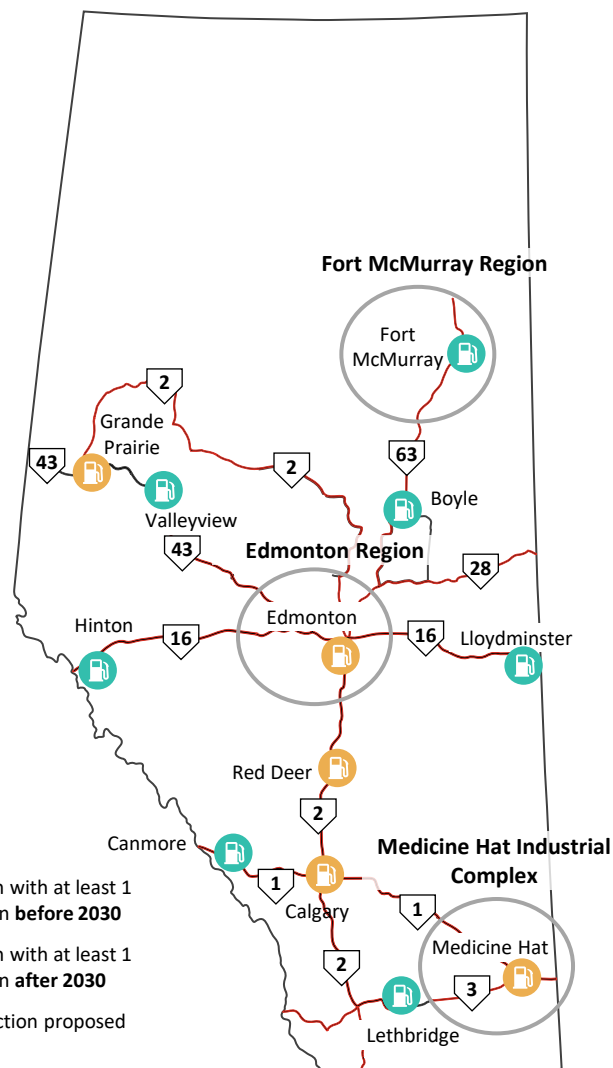
Snapshot of hydrogen pilots and fueling infrastructure in Alberta

There is demand for hydrogen in the Edmonton area with two temporary hydrogen fueling stations servicing pilots from the City of Edmonton, Edmonton International Airport, the Government of Alberta, and the Alberta Motor Transport Association. Edmonton has seen its first commercial fueling station open in March 2024 and will have additional stations built by Air Products to connect Edmonton to Calgary.



Identifying strategic HD hydrogen fueling stations in Alberta

Calgary, Red Deer, Medicine Hat, and Grande Prairie may have at least one fueling station before 2030 based on strategic location, access to hydrogen supply, and current demand from the transportation sector.



Timeframe	City	Alberta traffic data (high, medium, low)	Strategic highway location	Current hydrogen producers in the region
Before 2030	Edmonton	High	Highway 1, 16, 2, 28 go through the city	Suncor Shell Nutrien Sherritt Air Products
	Calgary	High	Highway 1 & 2	Bighorn Energy Nutrien Rocky Mountain GTL
	Red Deer	Medium/High	Highway 2	Nutrien Cvictus Azolla
	Medicine Hat	Medium	Highway 1 & 3	CF Industries
	Grande Prairie	Medium	Highway 2 & 43	Northern Petrochemical
After 2030	Fort McMurray	Medium	Highway 63	CNR Ltd.
	Boyle	Medium	Highway 63	N/A
	Valleyview	Medium	Highway 43	N/A
	Lloydminster	Medium/Low	Highway 16	N/A
	Canmore	Medium/Low	Highway 1	N/A
	Hinton	Medium/Low	Highway 16	N/A
	Lethbridge	Low	Highway 3	N/A

Note: Each location has at least one or more cardlock stations currently operating, except Canmore.

Additional considerations for hydrogen fueling station locations

Additional considerations should be taken into account when analyzing future strategic hydrogen fueling locations.

Criteria category	Category description	Why is this criteria is important?
Distance between fueling station locations	Fueling stations should be within 400 km to avoid range anxiety.	Towing is currently the only option when a hydrogen vehicle runs out of fuel, which can be costly and time consuming.
Pressure of fueling infrastructure	700-bar fueling stations are optimal as it allows for a step down in pressure for 350-bar-type vehicles. 700-bar fueling stations are likely to become the standard due to their ability to accommodate 350-bar vehicles as well. - The Hyla fueling station, a 700-bar fueling station, was the first Alberta commercial fueling station launched in March of 2024. The Hyla fueling station represents Nikola's energy brand and uses hydrogen supplied by Suncor.	Standardized pressures help fueling stations provide their services to all FCEVs.
Availability to service vehicles	Roadside assistance companies in Western Canada such as Verizon Connect or Truck Zone, which offer services such as towing and fuel delivery, need more specialized knowledge, equipment, and safety measures.	- Conventional roadside and vehicle service centers require the right tools and parts for FCEV technology. - Safety of the driver and mechanic need to be a top priority given hydrogen's flammability and high pressure.
Winter weather conditions	Safe conditions for heavy-duty trucking needs to be ensured due to a lack of visibility around FCEV safety in the case of a collision.	FCEVs are in the early adoption stage, meaning there the standards and regulations are in the development stages as well.

Key findings



Key findings

Technological and commercial factors impact hydrogen vehicle adoption in Alberta including cost of vehicles and fuel, commercial readiness of hydrogen propulsion technologies, supply of transportation grade fuel, enabling production, fueling and distribution infrastructure, and the availability of hydrogen fuel cell trucks.

1 Calgary, Red Deer, Medicine Hat, and Grande Prairie are expected to have at least one fueling station before 2030.

Methodology developed to identify strategic heavy-duty fueling station locations in British Columbia and Alberta.

2 Hydrogen fuel cost needs to decline to \$5.35/kg to begin achieving price parity with diesel.

TCO was examined for regional trucking (50,000 km per year) and long-haul trucking (100,000) for FCEV and dual fuel hydrogen technologies compared to other propulsion technologies. The current retail price of hydrogen in British Columbia and Alberta ranges from \$14 - \$35 per kg.

3 Edmonton is the most strategic location in Alberta for hydrogen vehicle adoption.

Edmonton is the most strategic location in Alberta for heavy-duty hydrogen vehicle adoption due to current and potential production of transportation grade hydrogen, its location on major trucking routes, and existing and proposed demand for hydrogen fuel.

4 Changes in fuel/electricity has the greatest potential to cause fluctuations in TCO, followed by ownership period, and mileage.

Sensitivity analyses were undertaken to examine the impacts in TCO for varying inputs including grants and incentives.

Appendices



Appendix A

Hydrogen medium- and heavy-duty vehicle catalogue

Hydrogen MHDV catalogue glossary

Gross vehicle weight	The weight of the vehicle plus actual cargo and passenger weight when the vehicle is fully-loaded. The methods and requirements for calculating gross vehicle weight is dependent on the jurisdiction.
Product stages	Different phases a product goes through from initial concept to final production and distribution. Each stage has specific objectives and tasks that need to be accomplished.
Small-scale project	A limited project undertaken to develop a new product, test a market, or evaluate a process.
Prototype	This is an early sample, model, or release of a product built to test a concept or process. It serves as a real-world test of the design but does not have to be fully functional or of the same materials as the final product.
Pre-production and tooling	This stage involves the preparation of all processes, materials, and systems necessary for full-scale production. It often includes the production of a small batch of products for rigorous testing to ensure they meet all specifications and quality standards. Any issues discovered during this stage can lead to design or process changes.
Rollout	This is the process of introducing the new product to the market. It often starts with a limited release to a specific region or customer segment before expanding to other markets. The goal of a rollout is to generate buzz and demand, gather customer feedback, and make any necessary adjustments before a full-scale launch.
Production ramp	This stage involves scaling up production activities to meet anticipated demand. It often requires significant coordination and optimization to ensure that all parts of the production process can handle the increased volume without compromising quality or efficiency.

Hyundai Xcient



Product Stage
Production ramp

Fuel Cell Power & Make
190 kW / 255 HP
Hyundai

Gross Vehicle Weight
36 tonnes

Refueling Time
8 – 20 minutes

Hydrogen Storage Capacity
31 kg

Hydrogen Storage Pressure
350-bar

Range
400 km

Availability
Currently in the process of
expanding into North America
by 2025

Mercedes-Benz GenH2



Product Stage
Prototype

Fuel Cell Power & Make
300 kW / 402 HP
Mercedes-Benz

Gross Vehicle Weight
36 tonnes

Refueling Time
10 - 15 minutes

Hydrogen Storage Capacity
88 kg

Hydrogen Storage Pressure
Subcooled liquid
hydrogen

Range
1,000 km

Availability
TBA, customer trials in 2024

Nikola Tre



Product Stage
Pre-production and tooling

Fuel Cell Power & Make
400 kW / 536 HP
Bosch

Gross Vehicle Weight
37 tonnes

Refueling Time
20 minutes

Hydrogen Storage Capacity
70 kg

Hydrogen Storage Pressure
700-bar

Range
800 km

Availability
Orders available in Canada. First deliveries expected by mid-2024

Volvo FCEV



Product Stage
Prototype

Fuel Cell Power & Make
300 kW / 408 HP
Cellcentric

Gross Vehicle Weight
59 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
TBA

Hydrogen Storage Pressure
TBA

Range
1,000 km

Availability
**No stated commitment to
Canada. European customer
pilots in 2025**

Kenworth T680 FCEV

Product Stage
Prototype

Fuel Cell Power & Make
305 kW / 415 HP
Toyota

Gross Vehicle Weight
37 tonnes

Refueling Time
20 minutes

Hydrogen Storage Capacity
58.8 kg

Hydrogen Storage Pressure
350-bar

Range
720 km

Availability
Now accepting deposits in
Canada with deliveries
expected to begin in 2024



Scania FCEV (Developed for Asko)



Product Stage
Small-scale project

Fuel Cell Power & Make
90 kW / 121 HP
Hydrogenics / Cummins

Gross Vehicle Weight
27 tonnes

Refueling Time
N/A

Hydrogen Storage Capacity
33 kg

Hydrogen Storage Pressure
350-bar

Range
500 km

Availability
Scania has only partnered to develop FCEVs with a few European companies with varying FCEV specs

HYZON HYMAX (24 tonne)

Product Stage
Pre-production and tooling

Fuel Cell Power & Make
80 kW / 107 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
24 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
30 kg

Hydrogen Storage Pressure
350-bar

Range
400 km

Availability
No commitments to Canada.
Orders available in Europe,
Asia, and Australia

HYZON HYMAX (46 tonne)



Product Stage
Pre-production and tooling

Fuel Cell Power & Make
110 kW – 200 kW /
148 HP – 268 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
46 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
60 kg

Hydrogen Storage Pressure
350-bar

Range
680 km

Availability
No commitments to Canada.
Orders available in Europe,
Asia, and Australia

HYZON HYMAX (70 tonne)

Product Stage
Pre-production and tooling

Fuel Cell Power & Make
110 kW – 240 kW /
148 HP – 322 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
70 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
60 kg

Hydrogen Storage Pressure
350-bar

Range
600 km

Availability
No commitments to Canada.
Orders available in Europe,
Asia, and Australia

HYZON HYHD8-110



Fuel-cell with retrofit
is the product

Product Stage
**Pre-production and
tooling**

Fuel Cell Power & Make
110 kW / 148 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
37 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
50 kg

Hydrogen Storage Pressure
350-bar

Range
560 km

Availability
Available in Canada. First
deliveries expected in 2024

HYZON HYHD8-200



Fuel-cell with retrofit
is the product

Product Stage
**Pre-production and
tooling**

Fuel Cell Power & Make
200 kW / 268 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
37 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
50 kg

Hydrogen Storage Pressure
350-bar

Range
560 km

Availability
Available in Canada. First
deliveries expected in 2024

ESORO FCEV



Product Stage
Prototype

Fuel Cell Power & Make
100 kW / 134 HP
Swiss Hydrogen

Gross Vehicle Weight
34 tonnes

Refueling Time
10 minutes

Hydrogen Storage Capacity
31 kg

Hydrogen Storage Pressure
350-bar

Range
400 km

Availability
No commitments to Canada
or further production

JMC Weilong FCEV

Product Stage
Rollout

Fuel Cell Power & Make
150 kW / 201 HP
Horizon

Gross Vehicle Weight
42 tonnes

Refueling Time
20 minutes

Hydrogen Storage Capacity
N/A

Hydrogen Storage Pressure
N/A

Range
500 km

Availability
**Available in China. No
commitments to Canada**

Isuzu Giga Fuel Cell



Product Stage
Prototype

Fuel Cell Power & Make
103 kW / 138 HP
Honda

Gross Vehicle Weight
25 tonnes

Refueling Time
TBA

Hydrogen Storage Capacity
56 kg

Hydrogen Storage Pressure
700-bar

Range
800 km

Availability
**No current commitments to
Canada. Planned market
release in 2027**

VDL 27-ton Rigid Truck



Product Stage
Small-scale project

Fuel Cell Power & Make
88 kW / 118 HP
Ballard

Gross Vehicle Weight
24 tonnes

Refueling Time
N/A

Hydrogen Storage Capacity
30 kg

Hydrogen Storage Pressure
350-bar

Range
400 km

Availability
Project implemented in Europe with no commitments to Canada

HYZON REFUSE Waste-collection Truck



Product Stage
Pre-production and tooling

Fuel Cell Power & Make
110 kW / 148 HP
Horizon Fuel Cell Technologies

Gross Vehicle Weight
29 tonnes

Refueling Time
15 minutes

Hydrogen Storage Capacity
25 kg

Hydrogen Storage Pressure
350-bar

Range
200 km

Availability
Available for sale in Canada.
Customer deliveries expected to begin in 2025

New Flyer Xcelsior CHARGE FC (40 foot)



Product Stage
Pre-production and tooling

Fuel Cell Power & Make
100 kW / 134 HP
Ballard

Gross Vehicle Weight
20 tonnes

Refueling Time
6 - 10 minutes

Hydrogen Storage Capacity
37.5 kg

Hydrogen Storage Pressure
350-bar

Range
600 km

Availability
Orders available in Canada

New Flyer Xcelsior CHARGE FC (60 foot)



Product Stage
Pre-production and tooling

Fuel Cell Power & Make
100 kW / 134 HP
Ballard

Gross Vehicle Weight
33 tonnes

Refueling Time
12 - 20 minutes

Hydrogen Storage Capacity
56 kg

Hydrogen Storage Pressure
350-bar

Range
600 km

Availability
Orders available in Canada

ENC Axess EVO-FC (40 foot)



Product Stage
Production Ramp

Fuel Cell Power & Make
125 kW / 170 HP
Plug Power

Gross Vehicle Weight
20 tonnes

Refueling Time
12 - 20 minutes

Hydrogen Storage Capacity
57.5 kg

Hydrogen Storage Pressure
350-bar

Range
650 km

Availability
Orders available in Canada

Cummins H2-ICE 6.7-litre Project



Hydrogen combustion
engine sold independently

Product Stage
Prototype

Engine Power & Make
216 kW / 290 HP
Cummins

Gross Vehicle Weight &
Truck Make
24 tonnes
Mercedes-Benz Atego

Refueling Time
10 minutes

Hydrogen Storage Capacity
40 kg

Hydrogen Storage Pressure
700-bar

Range
500 km

Availability
Full production of engine in
Freightliner Cascadia trucks
expected in 2027 for use in
North America

FEV Hydrogen Combustion Engine Retrofit Solution



Product Stage
Prototype

Engine Power & Make
230 kW / 313 HP
FEV

**Gross Vehicle Weight &
Truck Make**
**Dependent on truck
converted**

Refueling Time
**Dependent on
converted truck**

Hydrogen Storage Capacity
**Dependent on
converted truck**

Hydrogen Storage Pressure
TBA

Range
**Dependent on
converted truck**

Availability
**No available timeline on
testing or production**



Product Stage
Prototype

Technology Description
High Pressure Direct Injection (HPDI)
A small amount of diesel fuel is injected at high pressure to enable compression ignition before hydrogen is added

Engine Power & Make
TBA
Westport Fuel Systems

Availability
On-road tests to begin in 2026 and are expected to be commercially available near the end of the decade

Hydra Energy



Hydrogen fuel is the product after free retrofit

Product Stage

Rollout

Convertible Truck Brands

**Freightliner, Western Star,
Peterbilt, Volvo, Mack Trucks**

Convertible Engines

DD15, DD16, or PACCAR engines

Business Model

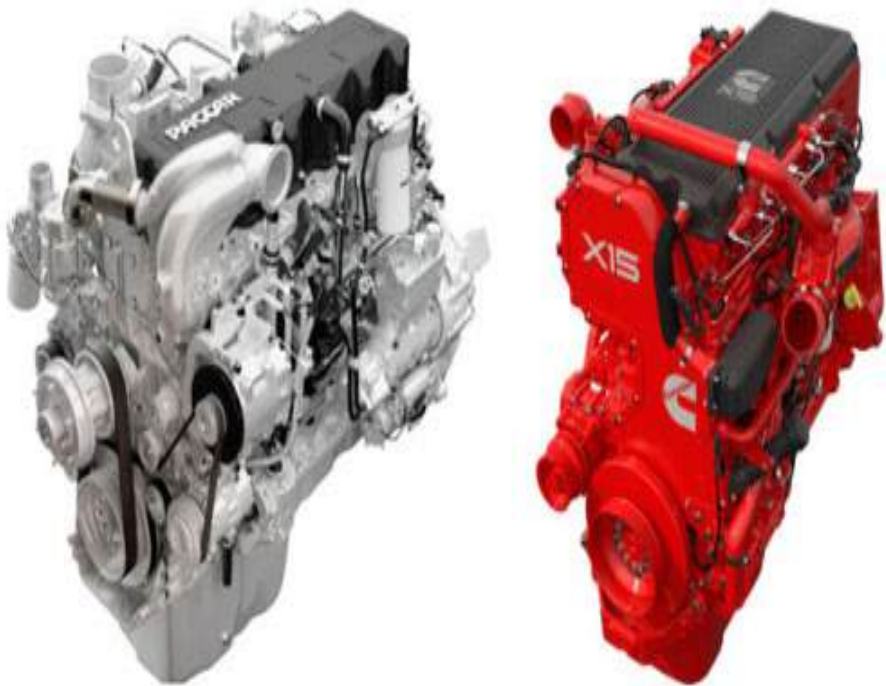
Available in Canada. Hydra provides engine retrofits and installs fueling stations nearby at no cost. In return, customers commit to 5-year contracts to purchase hydrogen from Hydra

**Dual fuel
Required for
Retrofitted
Engine**

**40%
Hydrogen**

60% Diesel

Innovative Fuel Systems Multi Fuel Technology Platform



Basic engine design is
not modified

Product Stage
Prototype

Convertible Trucks
Class 8 HD trucks

Convertible Engines
**Existing and next generation HD
diesel engines**

Business Model
**Will be available in Canada. Innovative
Fuel Systems sells an after-market
system that is easily integrated with
Class 8 diesel trucks**

Dual fuel
Required for
Retrofitted
Engine

**55%
Hydrogen**

45% Diesel

Diesel Tech Industries Guardian Hydrogen Diesel System



Non-invasive retrofit
for existing engines

Product Stage
Prototype

Convertible Trucks
Volvo D13

Convertible Engines
Tier 4 diesel engines

Business Model
Will be available in Canada. DTI sells and
installs the hydrogen diesel retrofit kit,
hydrogen cylinders, and electronics for
existing Class 8 trucks

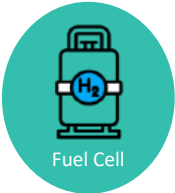
Dual fuel
Required for
Retrofitted
Engine

40 - 80%
Hydrogen

20 - 60%
Diesel

Sample user interface for web-based hydrogen MHDV catalogue

A sample interface for the web application which allows the user to narrow down the available brand of models by choosing the location, fuel type, vehicle architecture, and year of availability.

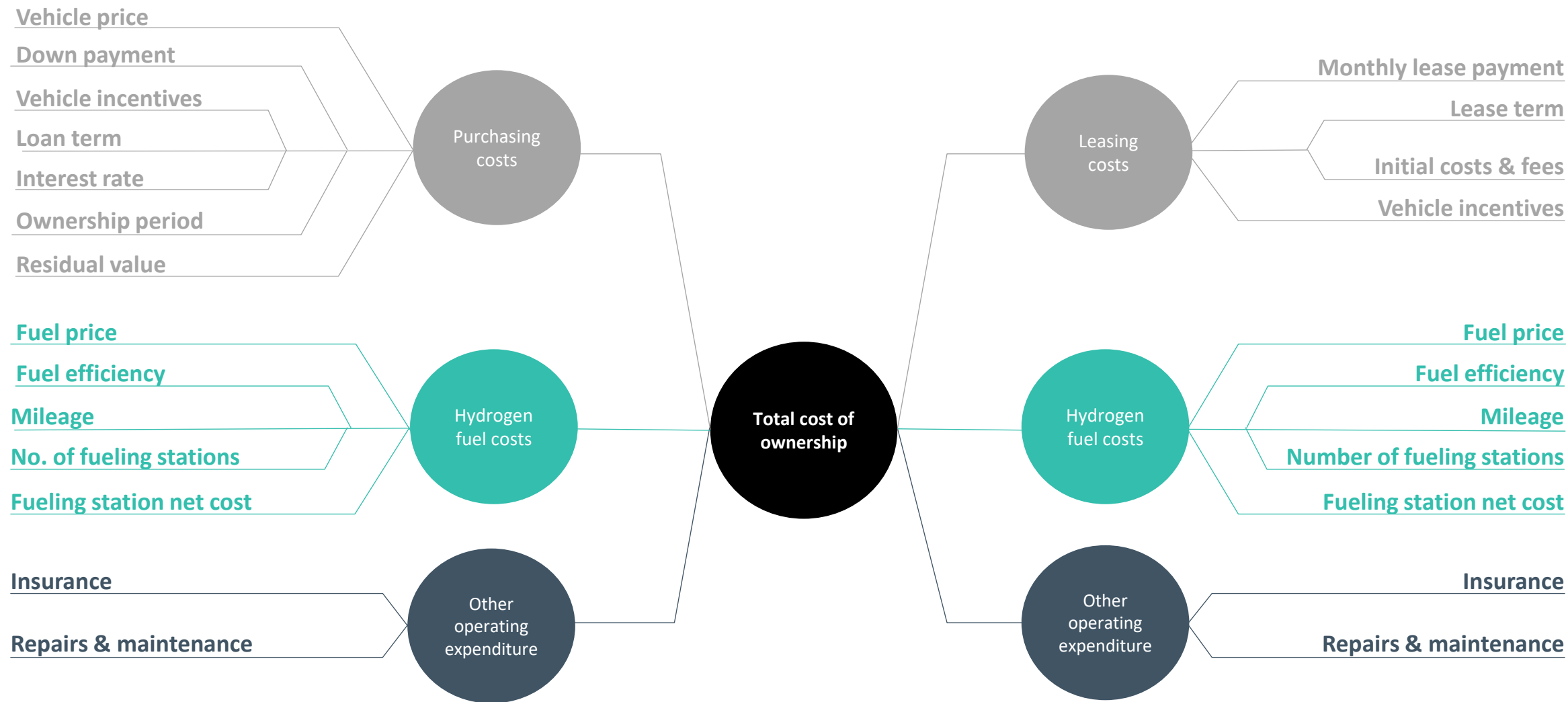
US & CANADA			EUROPE			CHINA			JAPAN & SOUTH KOREA											
SELECT FUEL TYPE						VEHICLE ARCHITECTURE														
 Dual fuel			 Hydrogen Combustion			 Fuel Cell			 Bus			 Rigid Truck			 Semi-truck			 Other		
SELECT AVAILABILITY			SELECT A BRAND OF MODEL																	
 Current 2025 2026 2027			 Mercedes-Benz  NIKOLA™  HYUNDAI  HYZON  KENWORTH  NEW FLYER  FREIGHTLINER®  ESORO INNOVATION ENGINEERING PROTOTYPING  ISUZU  JMC  VDL  CL  ENC  hydra  SCANIA  INNOVATIVE Fuel Systems  DTI DIESEL TECH INDUSTRIES  Cummins  FEV  VOLVO																	

Appendix B

Technology-specific total cost of ownership (TCO)

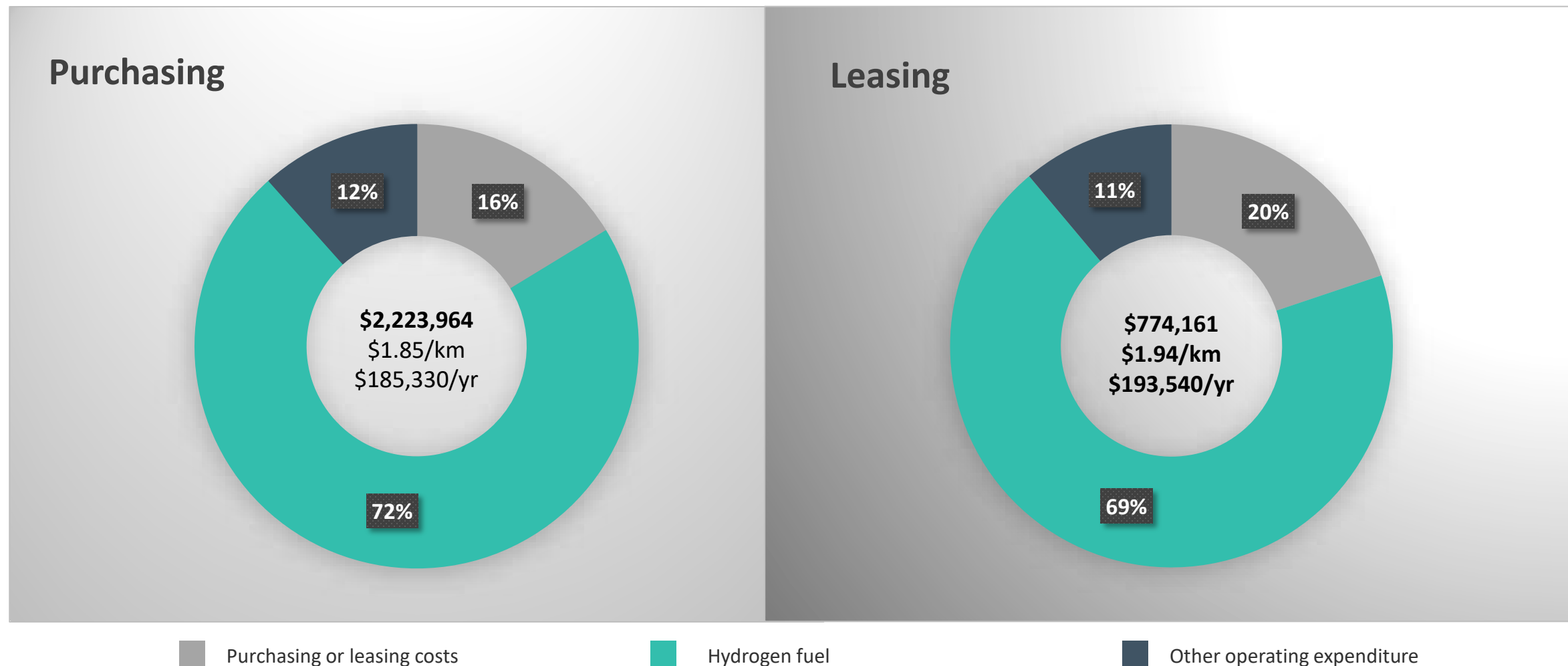
TCO inputs for purchasing or leasing an FCEV Truck

Leasing a vehicle results in less inputs required for the TCO calculator.



Cost breakdown of purchasing or leasing an FCEV truck

Hydrogen fuel makes up a large share of the total cost of ownership relative to other vehicle-types.



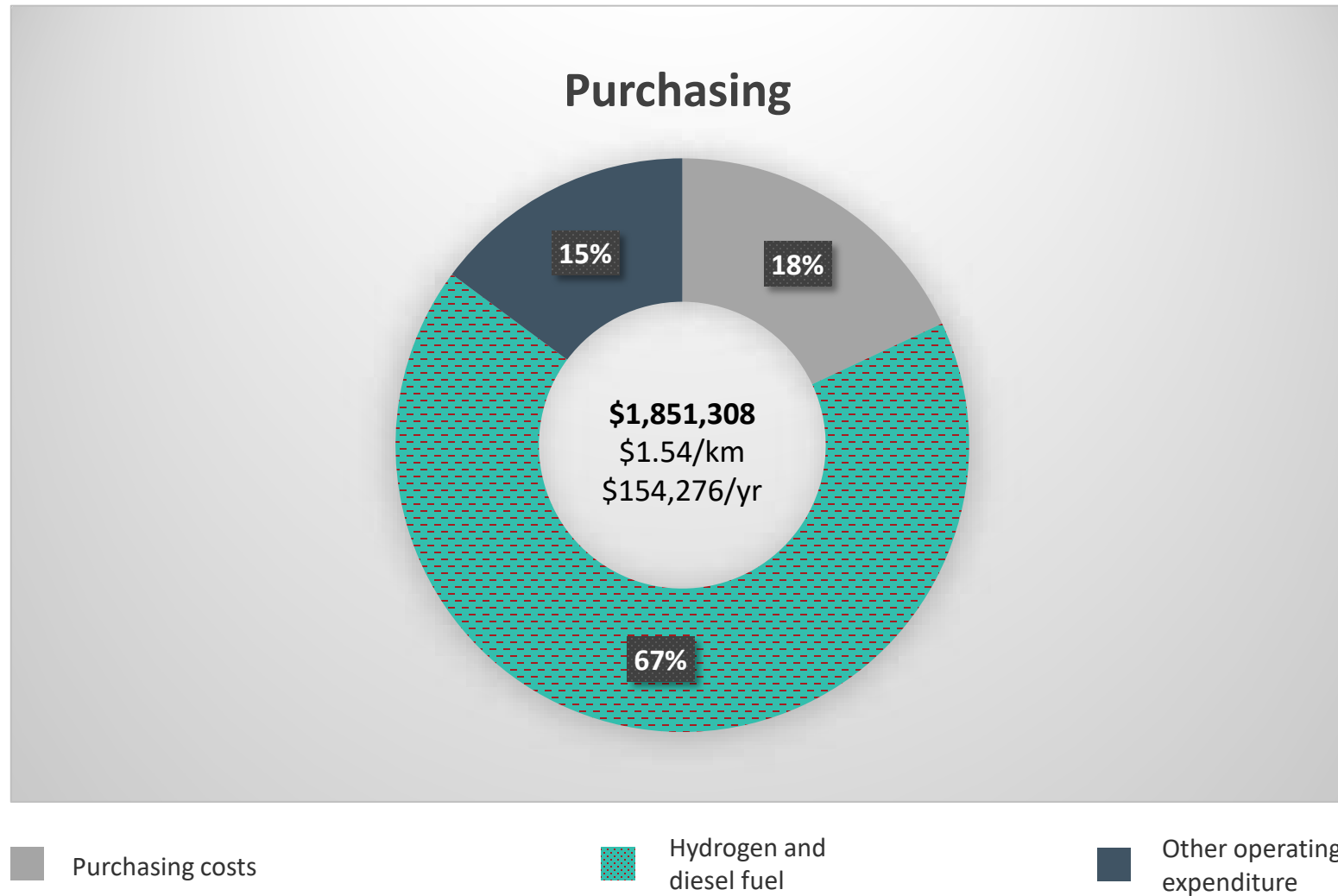
TCO inputs for purchasing a dual fuel truck

The TCO calculator does not provide a dual fuel leasing option because it is assumed retrofits would not occur on a leased vehicle.



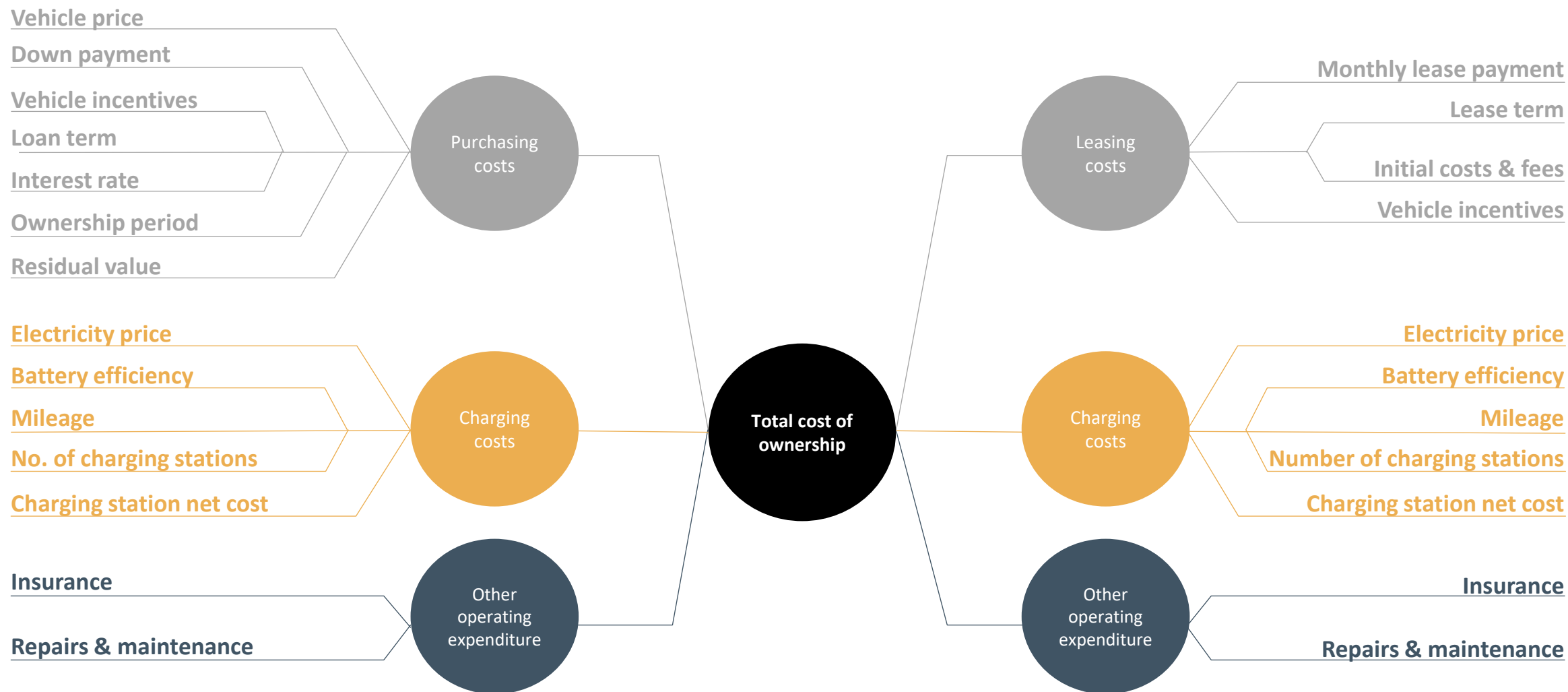
Cost breakdown of purchasing a dual fuel truck

Due to a lack of incentives, purchasing costs make up a greater share of the cost of ownership relative to FCEV trucks.



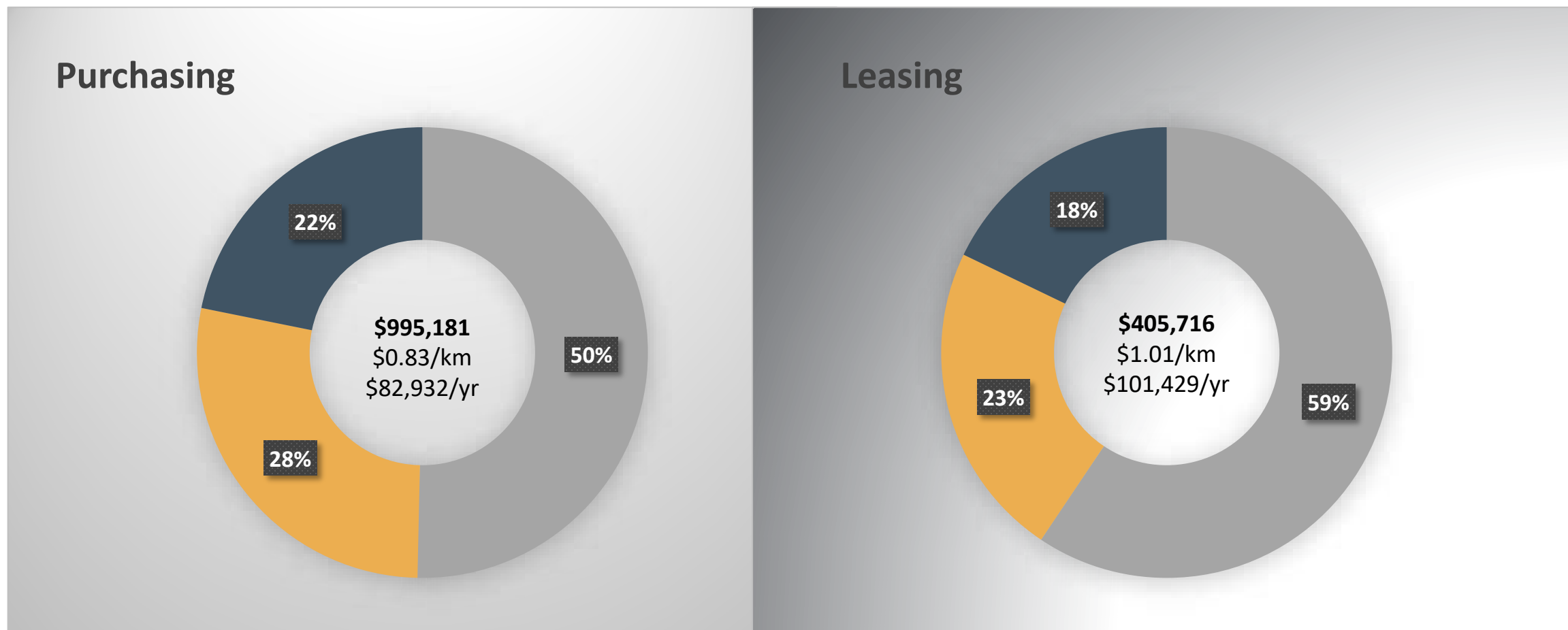
TCO inputs for purchasing or leasing a BEV truck

Inputs of a BEV truck differ significantly relative to other vehicle-types due to having a non-fuel source of energy.



Cost breakdown of purchasing or leasing a BEV truck

Low charging and maintenance costs result in purchasing and leasing costs being the main contributor to the cost of ownership.



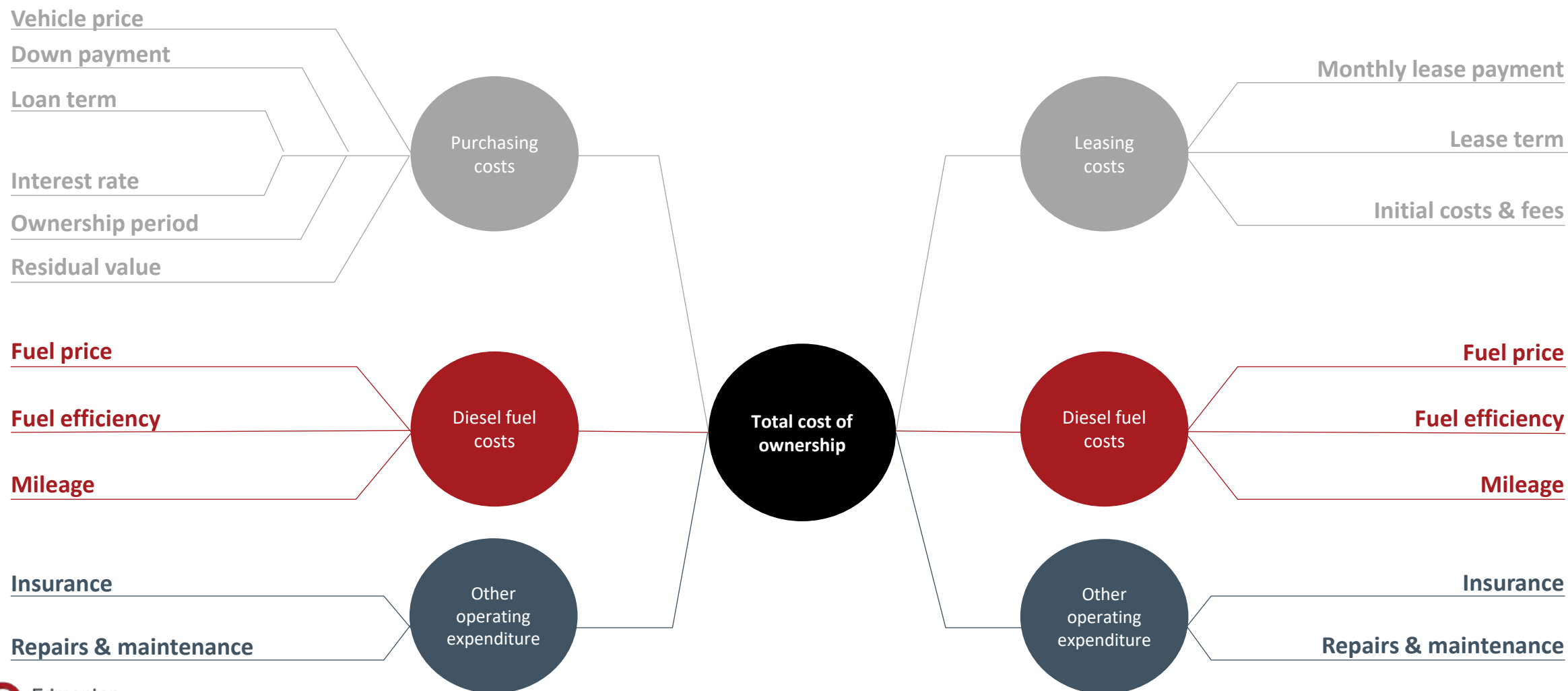
■ Purchasing or leasing costs

■ Charging

■ Other operating expenditure

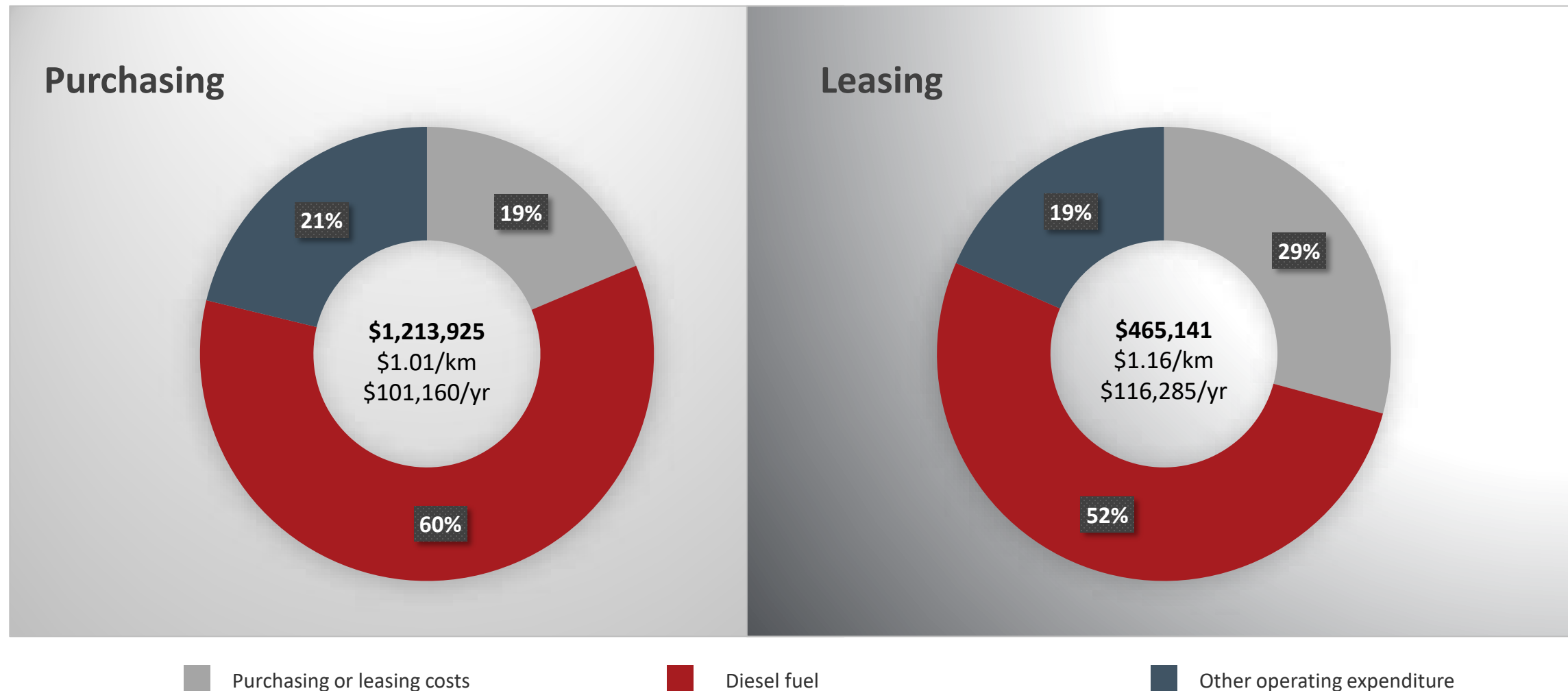
TCO inputs for purchasing or leasing a diesel truck

Diesel trucks have the lowest number of inputs required for the TCO calculator.



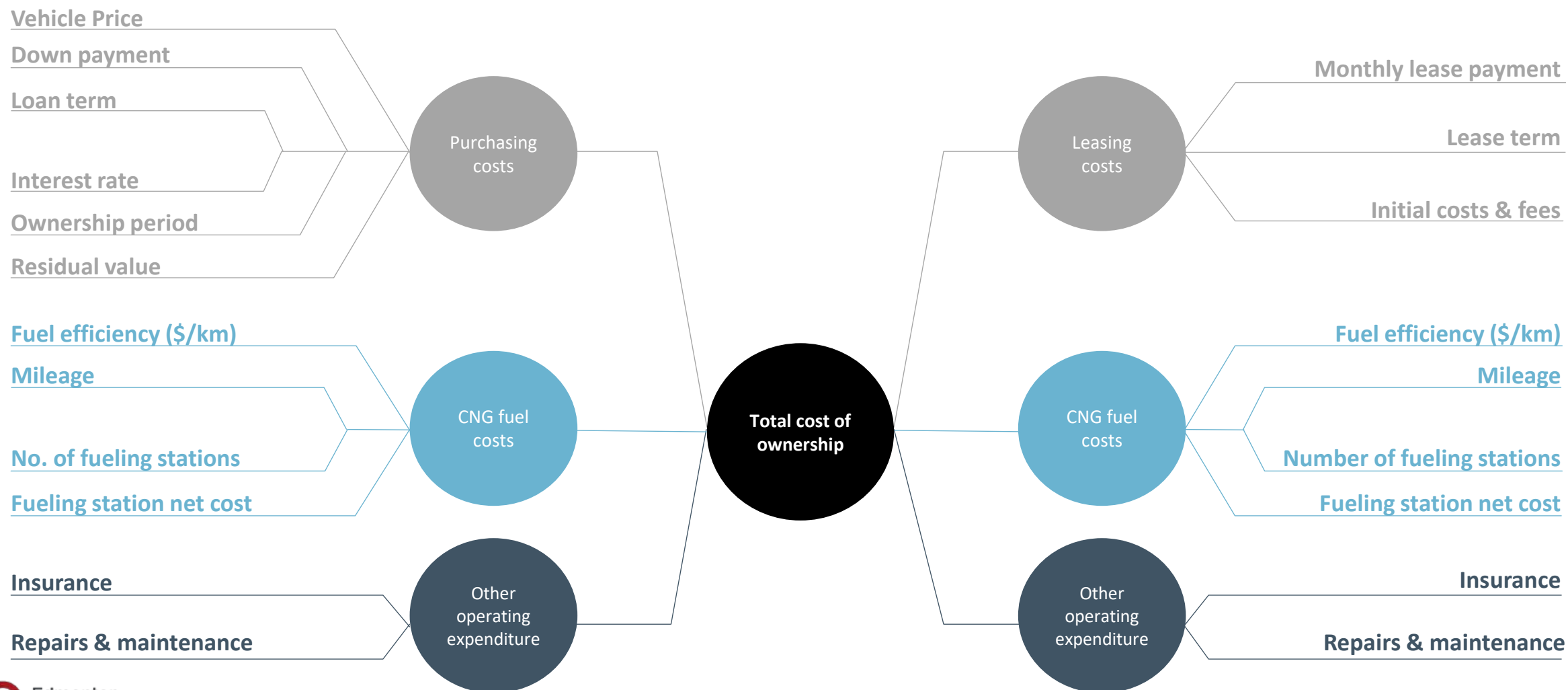
Cost breakdown of purchasing or leasing a diesel truck

Fleet managers that choose to lease are subject to a higher portion of their cost of ownership being from leasing costs relative to purchasing costs.



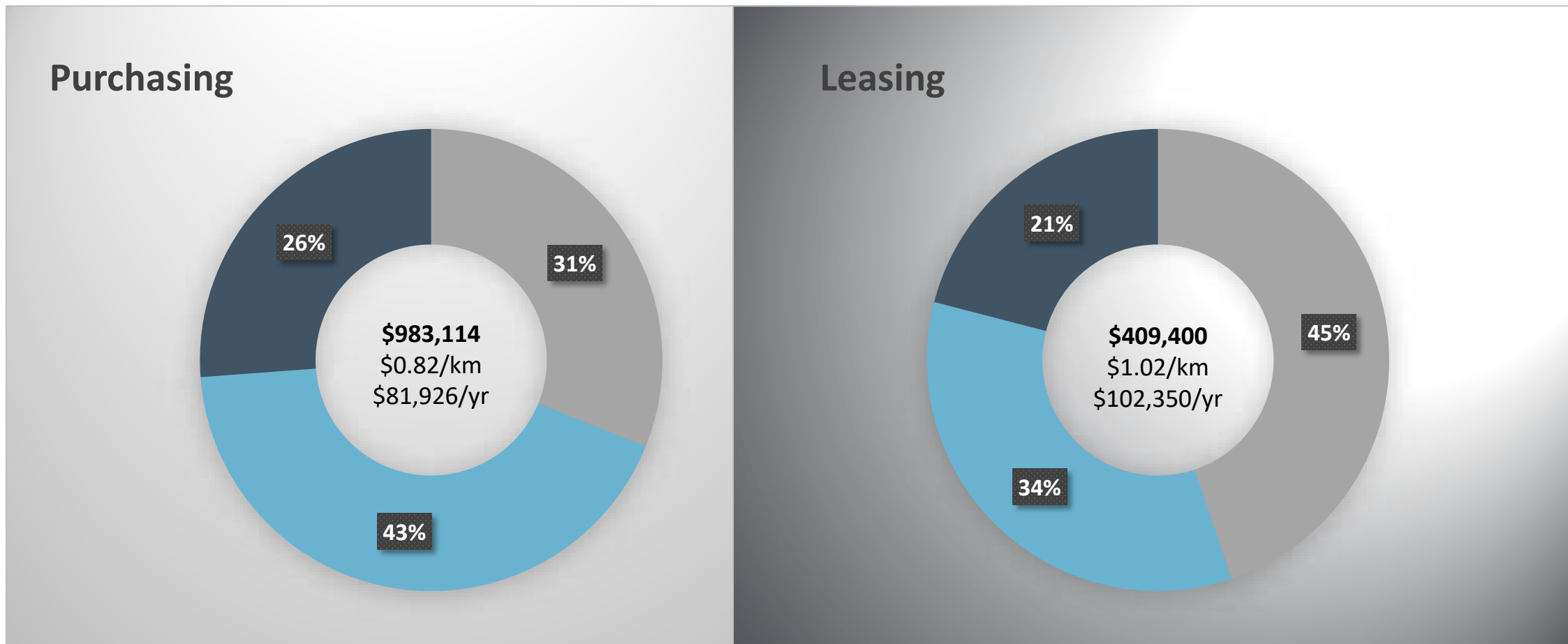
TCO inputs for purchasing or leasing a CNG truck

Fuel efficiency of CNG trucks is in dollars per kilometer rather than kilometers per liter, which is the case for other fuels.



Cost breakdown of purchasing or leasing a CNG truck

Relative to diesel trucks, purchasing costs of the vehicle are greater fuel is less costly.



 Purchasing or leasing costs

 CNG fuel

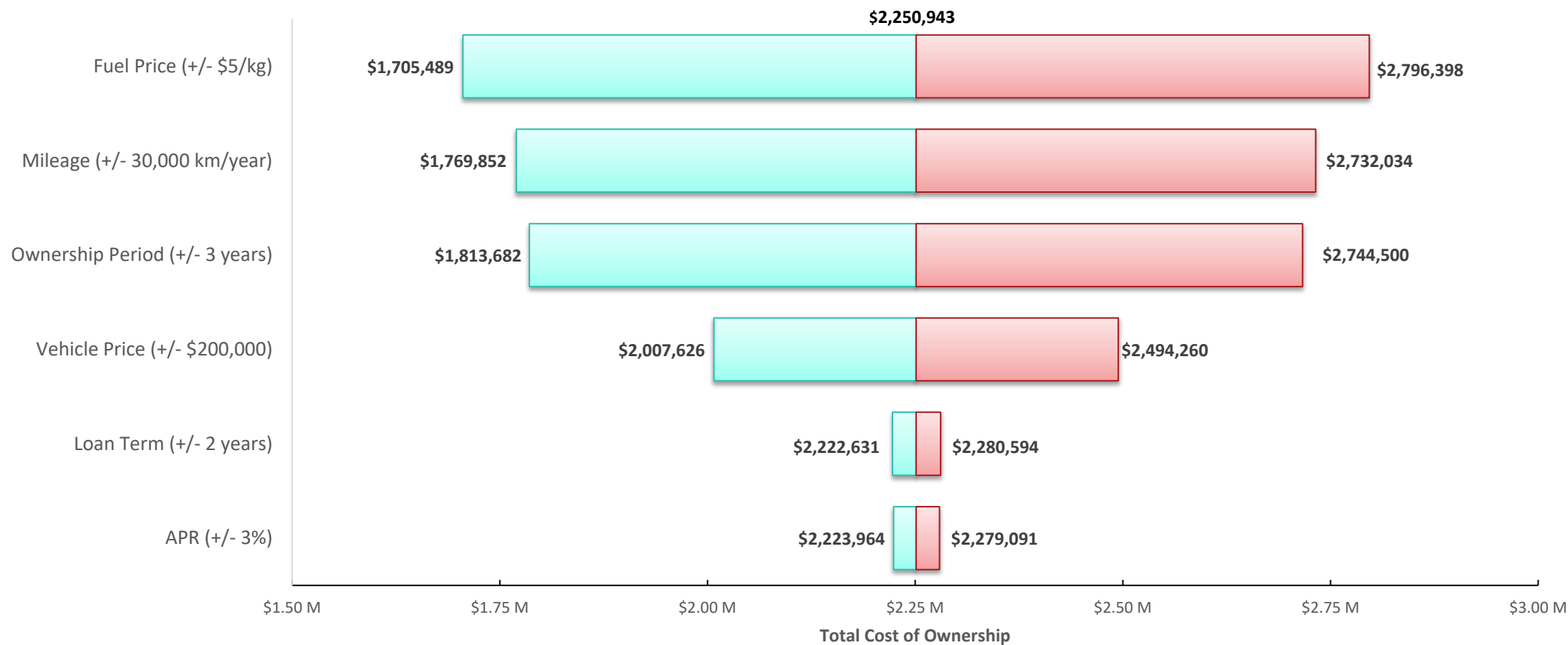
 Other operating expenditure

Appendix C

Purchase price sensitivity analyses

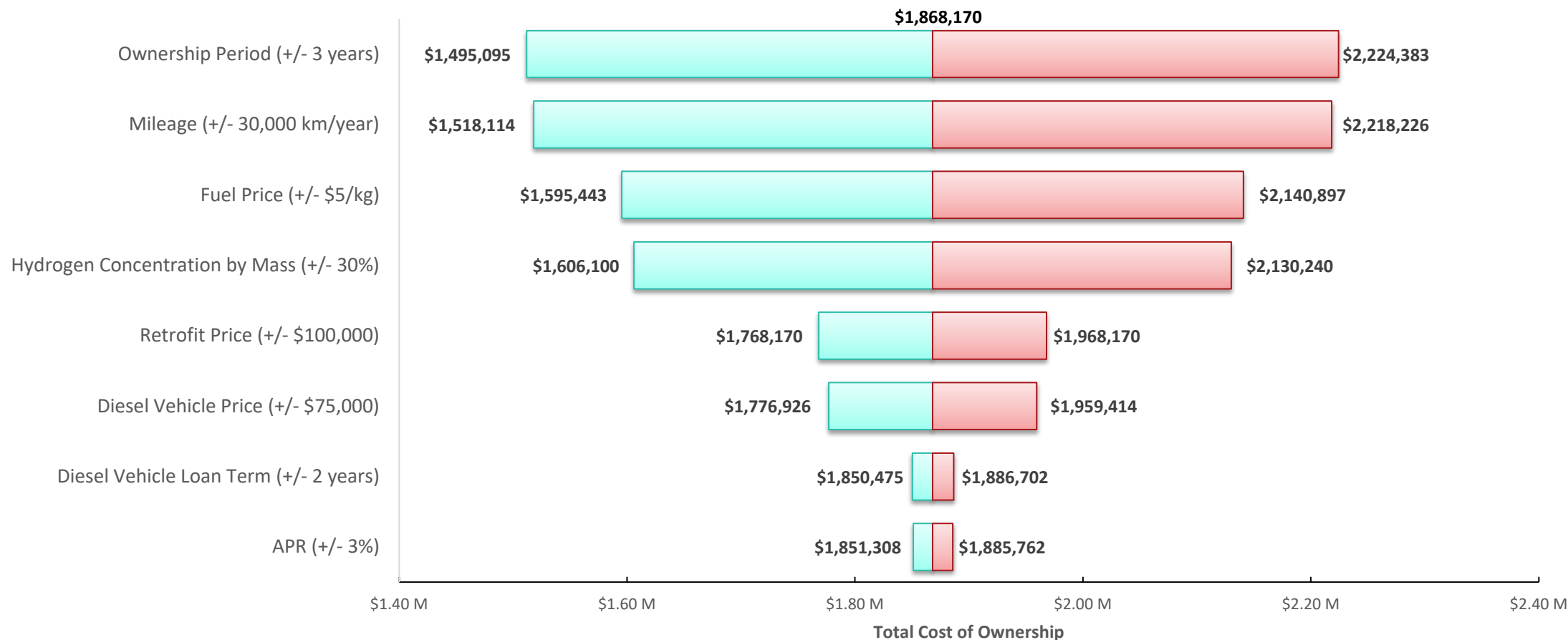
FCEV truck sensitivity to potential changes in inputs relative to its baseline TCO

Hydrogen fuel price volatility is capable of greatly impacting the fuel cell total cost of ownership in the future.



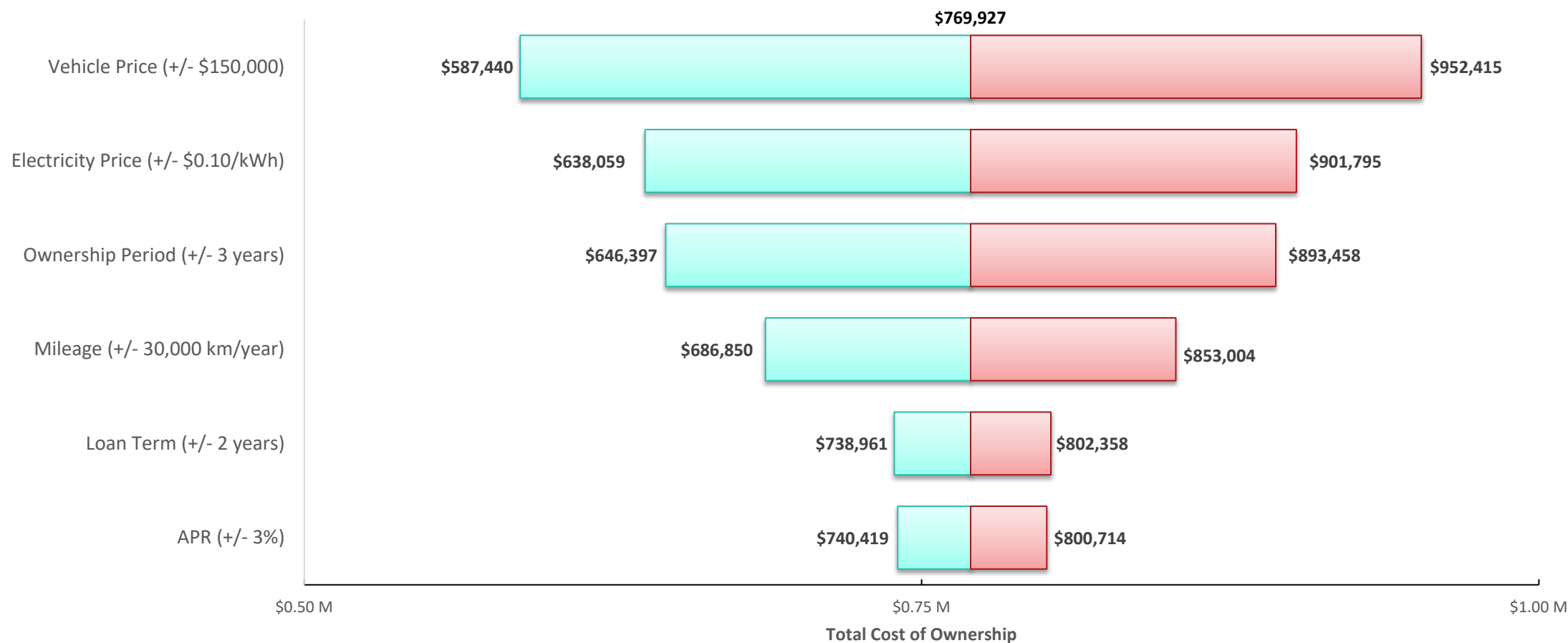
Dual fuel truck sensitivity to potential changes in inputs relative to its baseline TCO

Dual fuel trucks have a lower total cost of ownership and a lower propensity to become cheaper or more expensive to operate with a change in hydrogen fuel prices relative to fuel cell trucks.



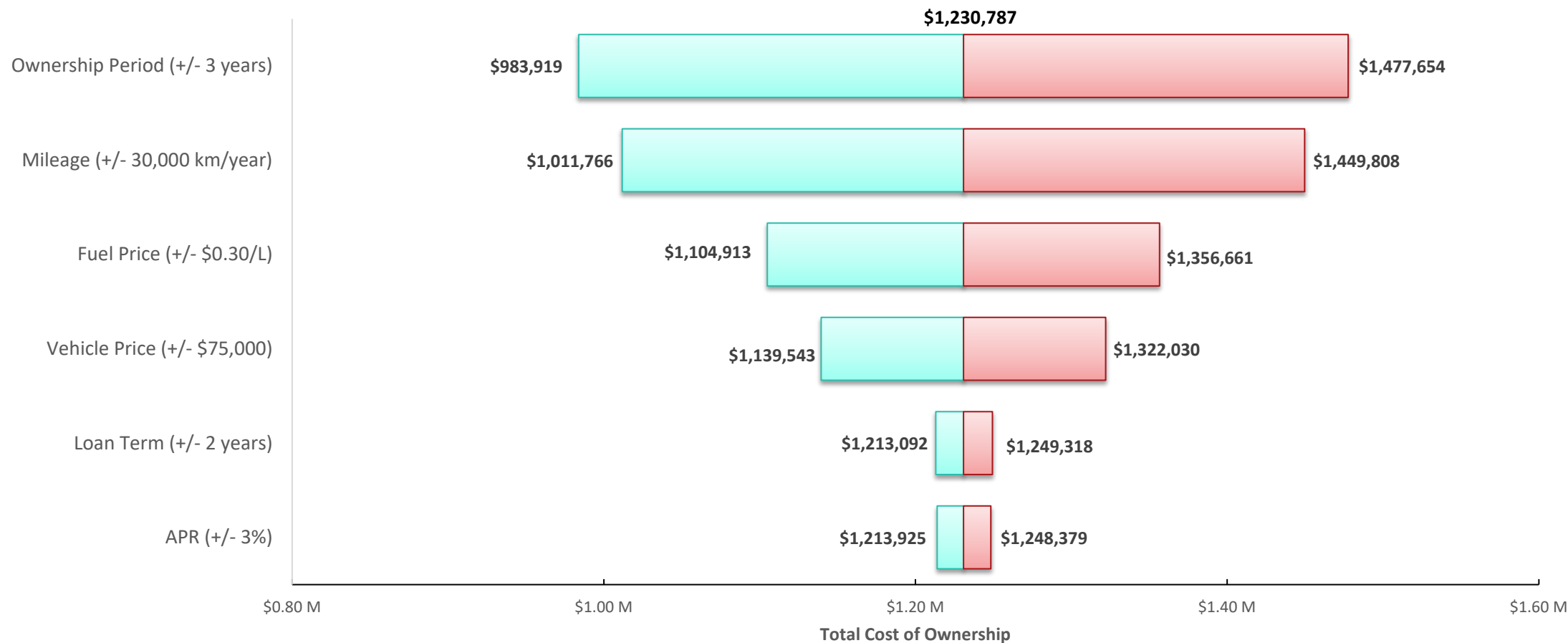
BEV truck sensitivity to potential changes in inputs relative to its baseline TCO

BEV trucks' high range of vehicle prices has the greatest impact on the total cost of ownership of the vehicle.



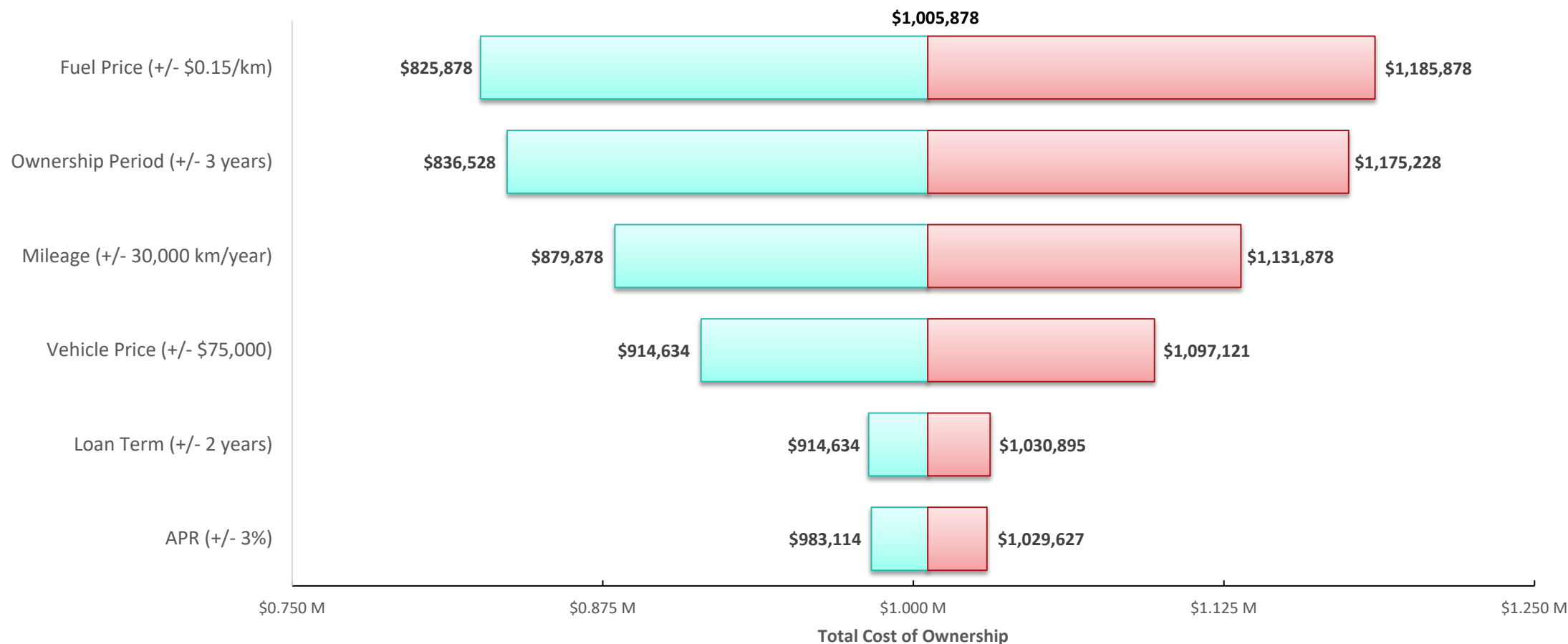
Diesel truck sensitivity to potential changes in inputs relative to its baseline TCO

Diesel trucks are not susceptible to large changes in total cost of ownership due to the technology's maturity in the market.



CNG truck sensitivity to potential changes in inputs relative to its baseline TCO

Cost of ownership of CNG trucks are sensitive to changes in fuel prices due to limited commercial fueling options.

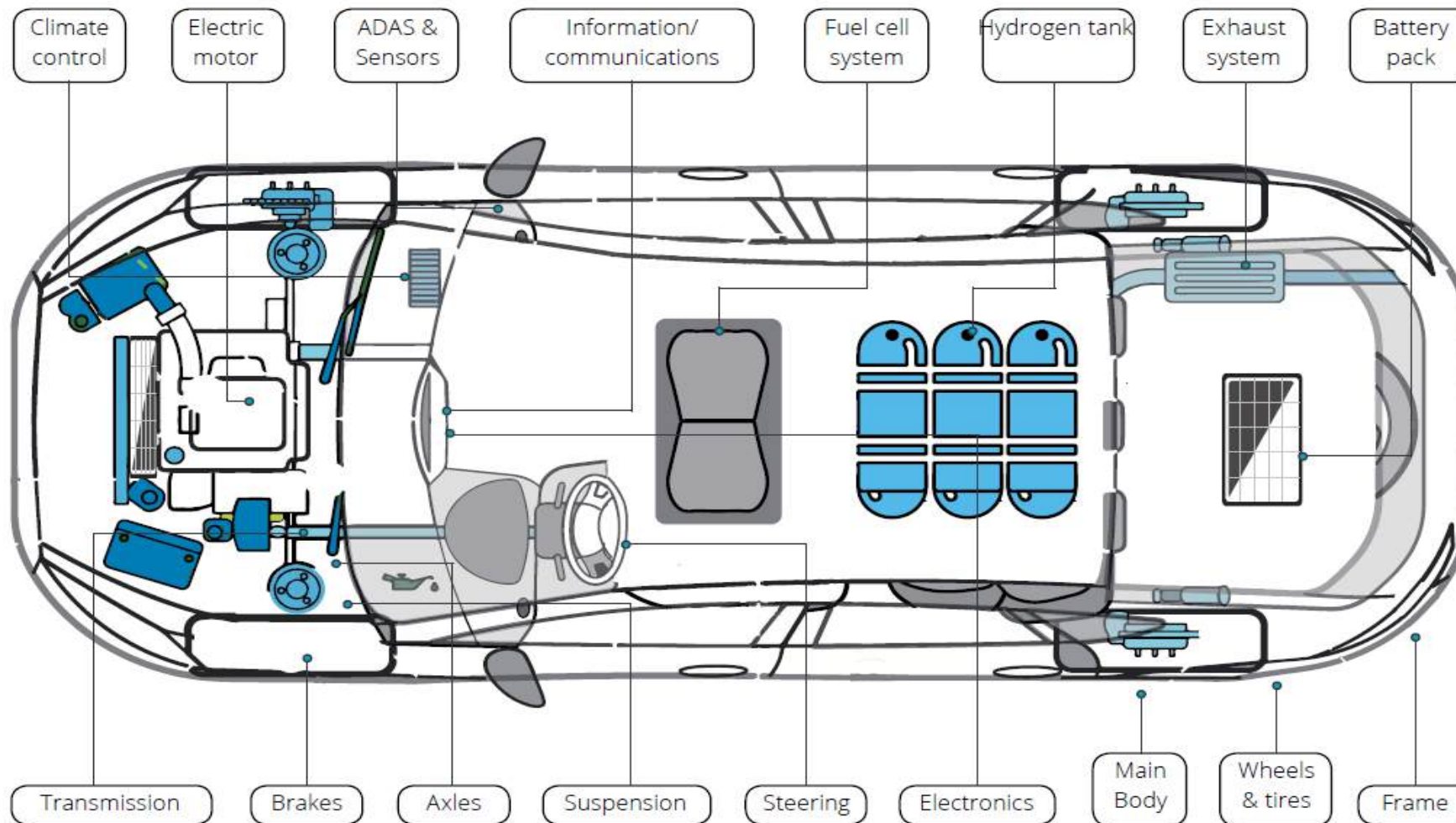


Appendix D

Hydrogen vehicle technology schematics

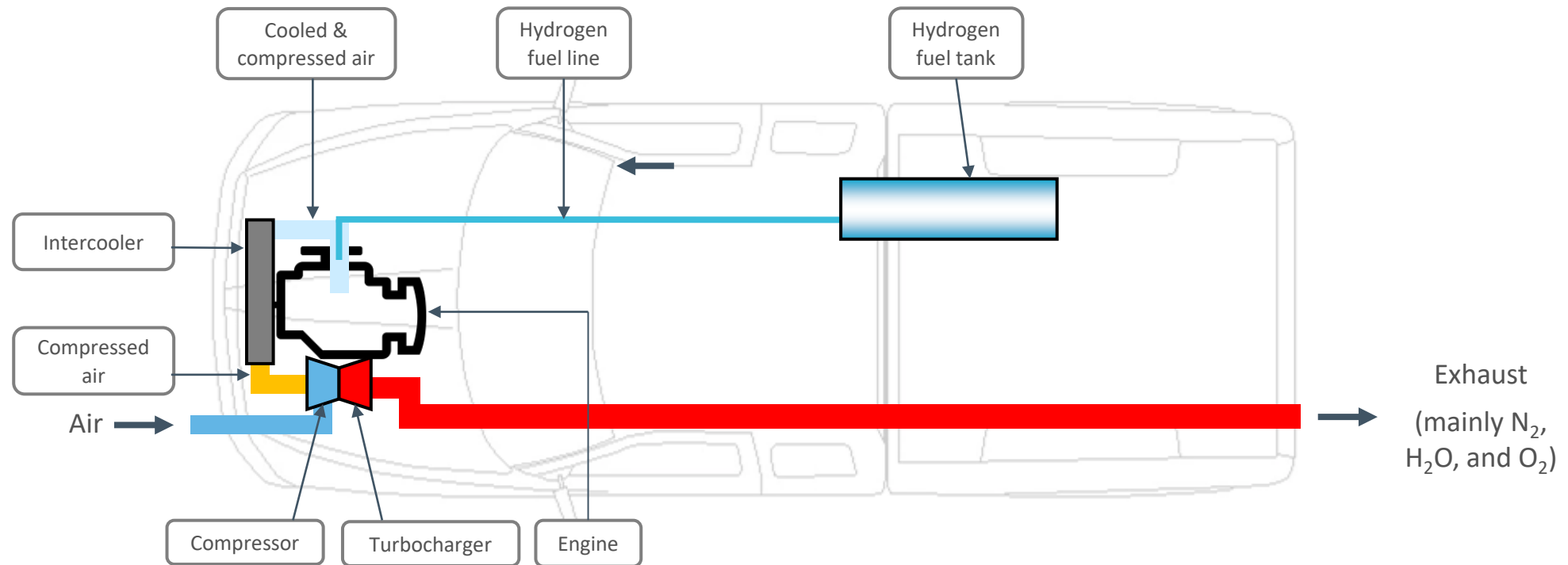
FCEV technology overview

Schematic of a fuel cell electric vehicle.



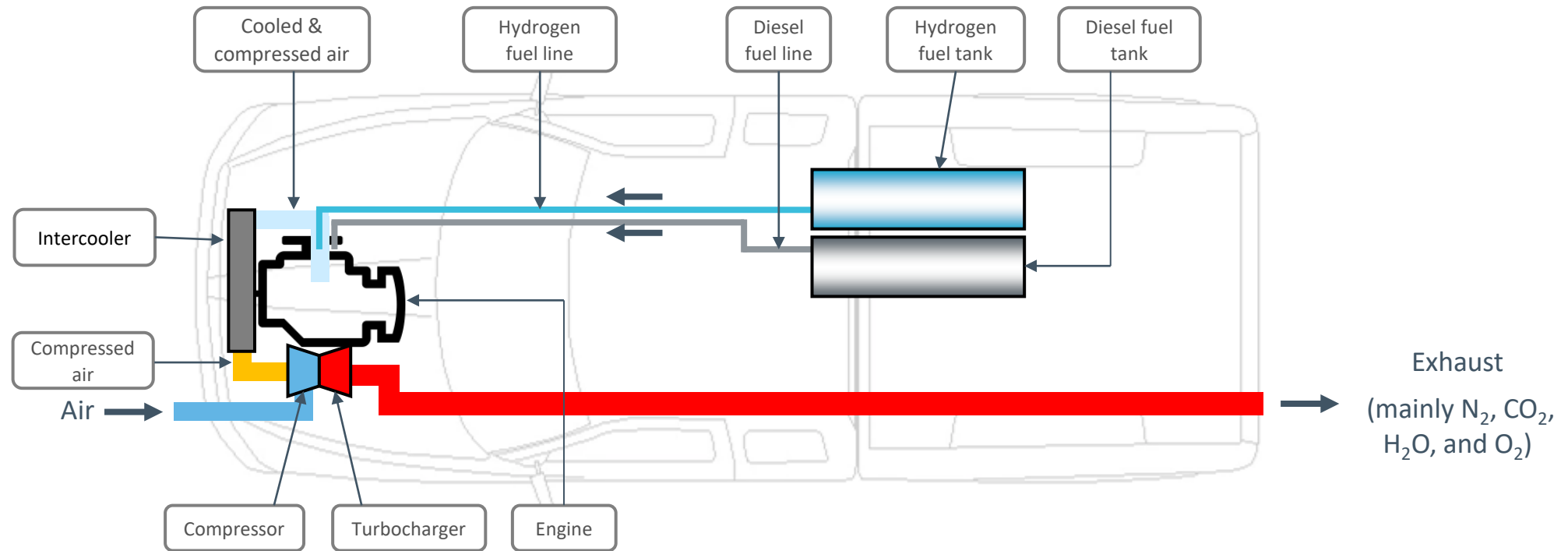
HICE technology overview

Schematic of a hydrogen internal combustion engine.



Dual Fuel Hydrogen Vehicles

Schematic of a hydrogen dual fuel system.



Appendix E

Approach and methodology

Development of a hydrogen MHDV vehicle catalogue

The hydrogen medium- and heavy-duty vehicle catalogue covers all hydrogen propulsion technologies, key vehicle specifications, and their current and projected availability for purchase.



OBJECTIVES OF THE CATALOGUE



Define the target vehicle types:

- ✓ Identify Edmonton Global's target users for the hydrogen MHDV catalogue.
- ✓ Align the catalogue's capabilities with Edmonton Global and the target user's interests.



Select key specifications and information about the vehicles:

- ✓ Review specifications of vehicles that are publicly available.
- ✓ Determine which metrics and information are important when the target users are making purchasing or leasing decisions.



Determine which vehicles should be published in the catalogue:

- ✓ Generate a diverse and extensive list of MHDV hydrogen vehicles that are manufactured globally.
- ✓ Collect key specifications of each vehicle that increases the comparability between the vehicles and provides the user a key beginning point prior to making purchasing or leasing decisions.



OUTCOME: HYDROGEN VEHICLE CATALOGUE

Developed a hydrogen MHDV catalogue that provides users purchasing options and their key specifications found in Appendix A.



Trucking route criteria and vehicle specifications required for a hydrogen transition

The following outlines the approach to determine the vehicles capable of transitioning to hydrogen vehicle technologies and travel routes.



OVERVIEW OF APPROACH



Develop a heat map of major long-haul fleet movements:

- ✓ Reviewed publicly available traffic volume data of each Alberta highway to find main routes travelled by MHDVs.
- ✓ Utilized geolocation data of each highway, create a heat map that is easily understood and visually appealing.
- ✓ Determine major trucking routes between Alberta and British Columbia.



Determine optimal fueling station locations:

- ✓ Based on trucking route findings from the heat map, establish where fueling stations should be located in Alberta for servicing fleets and transit buses.



Determine hydrogen vehicle and trucking route constraints:

- ✓ Determine route-related constraints that need to be solved to increase the utility of FCEVs
- ✓ Determine the specifications of the FCEV that would be optimal for adoption.



OUTCOME: Fueling Station Locations and Optimal Vehicle-Types for Transitioning

Developed a MHDV heat map for Alberta and determined fueling station, route, and vehicle-related requirements to increase the probability of hydrogen adoption.



Development of a total cost of ownership (TCO) calculator

Defining the scope of vehicles, selecting inputs and generating the formulas and assumptions, affects the accuracy and useability of the TCO calculator.



OVERVIEW OF DEVELOPMENT



Define the target vehicle types:

- ✓ Identify Edmonton Global's target users for the TCO calculator.
- ✓ Align the calculator's capabilities with Edmonton Global and the target user's interests.



Select inputs:

- ✓ Review purchasing and leasing options and the inputs that have a material impact on the costs to operate each vehicle type.
- ✓ Establish a list of important inputs for the calculation and refine the list by conducting interviews with the goal of having inputs **readily available, easy to fill in**, and having a **genuine impact on the end-user's decision**.



Calculate the total cost of ownership:

- ✓ Generate numerous formulas that calculate the cost of ownership dependent on the technology, leasing and purchasing options, and/or the potential for the vehicle to be retrofitted.
- ✓ Create a model with a level of functionality and display that allows the user to compare different trucking technology cost metrics such as \$, \$/year, and \$/km.



OUTCOME: TCO CALCULATOR

Developed a total cost of ownership calculator for MHDV trucks with the capability to compare truck technologies costs.

