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Green Hydrogen in Mexico: towards a decarbonization of the economy

Volume V: Applications in the transport sector

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Abbreviations

BAU	Business as Usual
BEV	Battery Electric Vehicle
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
GHG	Greenhouse Gas Emissions
H35	Hydrogen compressed to a pressure of 350 bar, as supplied in HRS
HRS	Hydrogen Refueling Station
ICEV	Internal Combustion Engine Vehicle
IMCO	Instituto Mexicano para la Competitividad, A.C., Mexican Center for Competitiveness (NGO)
INECC	National Institute of Ecology and Climate Change
INEGI	National Institute of Statistics and Geography
ITDP	Institute for Transportation and Development Policies
LCOE	Levelized Cost of Energy
LCOH	Levelized Cost of Hydrogen
MW	Megawatt
NDC	Nationally Determined Contributions
OEM	Original Equipment Manufacturer
PRODESEN	National Electric System Development Program
SEMOVI	Mexico City's Secretariat of Mobility
SENER	Secretaría de Energía, Ministry of Energy
SCT	Secretaría de Comunicaciones y Transportes, Ministry of Communications and Transport
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales, Ministry of Environment and Natural Resources
SENER	Secretaría de Energía, Ministry of Energy
TCO	Total Cost of Ownership
WRI	World Resources Institute

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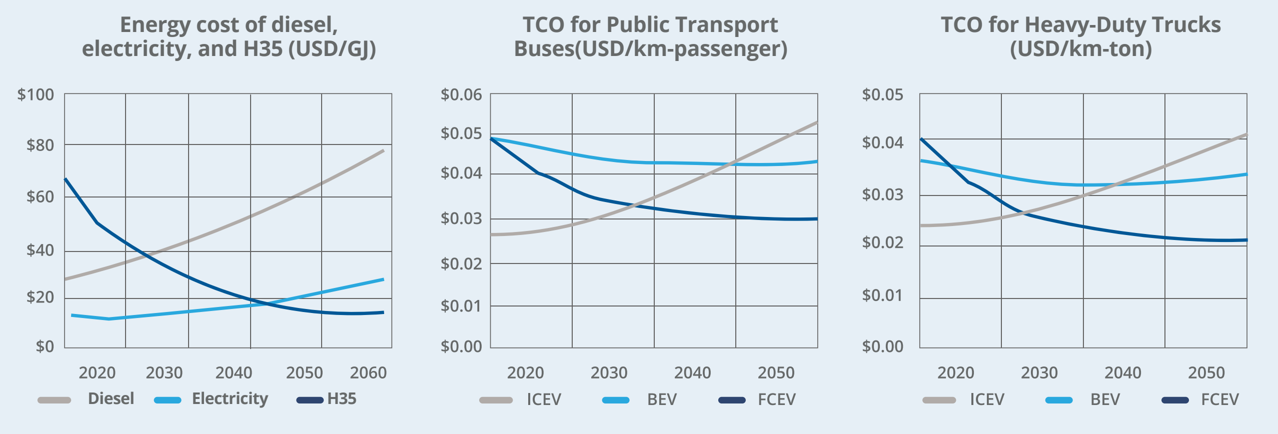
Executive summary

In Mexico, the transport sector is the largest GHG emitter, accounting for around one quarter of the national emissions. The electrification of the vehicle fleet is among the measures to comply with the NDC[1] to reduce 19% of the sector's emissions by 2030. Fuel cell and hydrogen heavy-duty trucks and buses could embody a highly promising zero-carbon alternative especially for the long-haul segment and in public transportation, with half a million units on the roads in Mexico by 2050, and a hydrogen fueling market worth 3.6 billion USD per year. This study focuses on two applications of hydrogen in heavy-duty vehicles with a large potential for the deployment of new fleets and decarbonization: public transport buses and long-haul freight transport.

Fuel Cell Electric Vehicles (FCEV) store energy in the form of hydrogen as an energy carrier and use it to generate electricity in a fuel cell which in turn drives an electric powertrain to propel the vehicle. If fueled with green hydrogen, FCEVs provide a zero-emissions transport alternative.

FCEVs are positioning against batteries for electric mobility in the segments where long range and fast refueling is critical, such as buses and freight trucks. Fuel cell and hydrogen heavy-duty trucks and buses could embody a highly promising zero-carbon alternative especially for the long-haul segment and in public transportation.

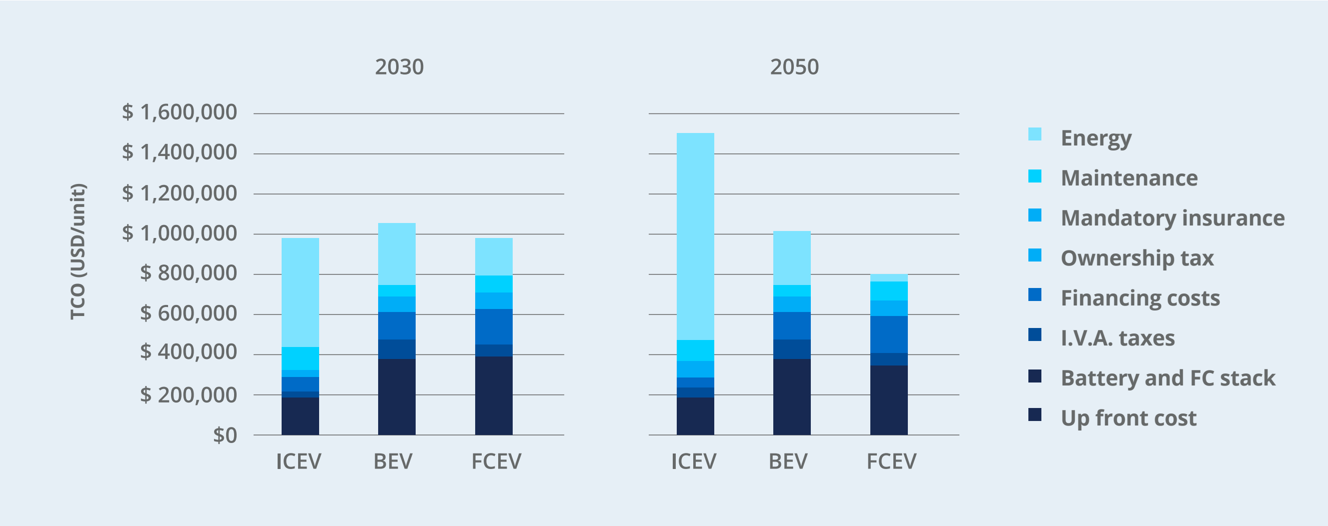
Figure 1. Energy cost curves for diesel, electricity, and green H35 (left); TCO curves for diesel, battery electric, and FCEV public transport buses (center); and heavy-duty freight trucks (right).



A Total Cost of Ownership (TCO) analysis integrates all costs for the owner throughout the vehicle's lifetime and provides a basis to compare the cost of different vehicle technologies for a particular use. The TCO analysis shows FCEVs will reach cost parity with BEVs and FCEVs before 2030 for both public and freight transport.

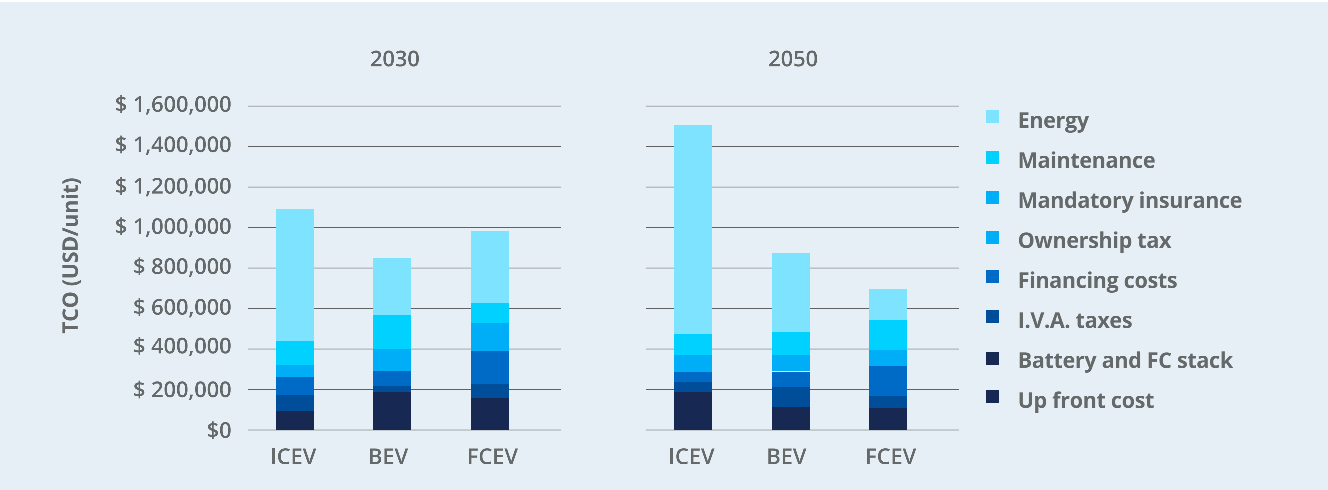
[1]. NDC: Mexico's Nationally Determined Contribution to reduce GHG emissions and comply with the Paris Agreement.

Figure 2. TCO breakdown of Public Transport Buses in 2030) and 2050.



The TCO breakdown shows that the highest cost for ICEVs both in 2030 and 2050 corresponds to energy (fuel), being considerably higher than for BEVs and FCEVs even before 2030. Acquisition costs remain the highest TCO components for both BEVs and FCEVs, with costs decreasing as technology upscales towards 2050.

Figure 3. TCO breakdown of long-haul freight trucks in 2030 and 2050.

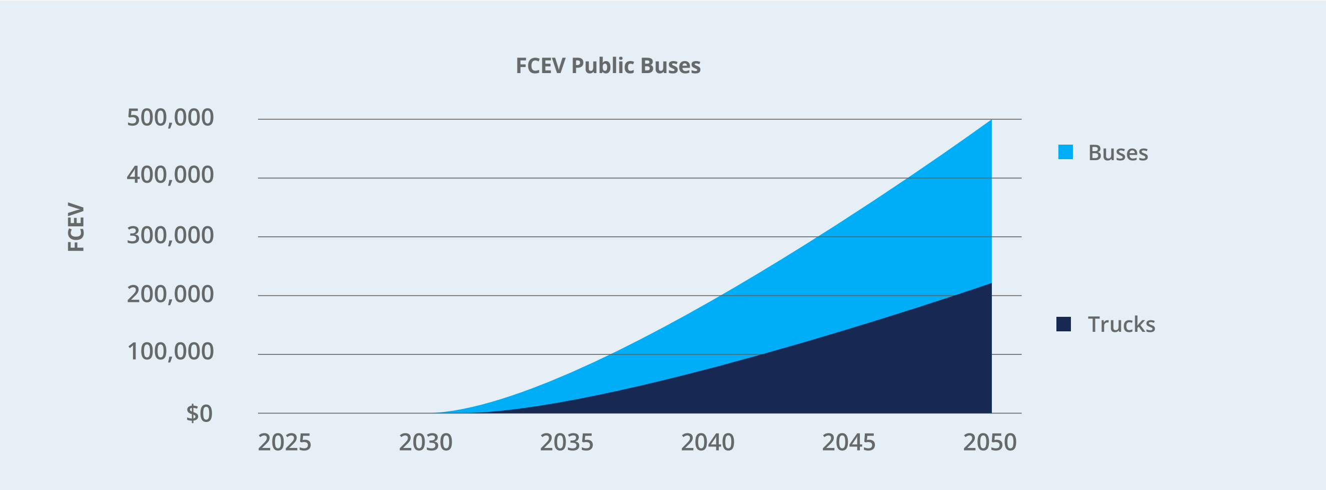


The joint projected hydrogen demand for public transport buses and trucks in Mexico is of 13 kilotons of H_2 per year in 2030, increasing at an exponential rate to around 550 kilotons of H_2 per year in 2040, and growing three-fold in the following decade to reach 1,780 kilotons of H_2 per year in 2050. The projected electrolysis capacity will nearly reach 150 MW in 2030, grow over twenty times in the following decade to 6,200 MW in 2040, and reach nearly 19,500 MW by 2050.

The hydrogen market value of compressed hydrogen (H35) supplied at hydrogen refueling stations (HRS) is projected to be of over 50 million USD by 2030 and increase sharply to 1.6 billion USD in 2040 and 3.6 billion USD by 2050.

The share of hydrogen demand and the corresponding electrolysis capacity and market value fluctuates around 40% for public transport buses and 60% for heavy-duty trucks from 2030 to 2040 and transitions to around one third to public and two thirds to freight transport in 2050.

Figure 4. Projected fleet of FCEV public transport buses and freight trucks in Mexico.



The projected H35 market values consider only its production and supply, while large complementary markets will also be created, for national production or import of FCEVs, components, dedicated maintenance service, hydrogen transport and refueling infrastructure, among other. The hydrogen refueling infrastructure is projected to grow as H_2 demand from FCEVs does, requiring an increasing number of hydrogen refueling stations (HRS) starting at 14 in 2030 and growing to 340 in 2040 and nearly 450 in 2050.

Table 1. Projected yearly hydrogen demand, accumulated electrolysis capacity, and hydrogen market value per year for public and freight transport.

	H_2 Demand (ktonH$_2$/year)			Electrolysis Capacity (MW)			H_2 Market Size (MUSD)		
Year	Public	Freight	TOTAL	Public	Freight	TOTAL	Public	Freight	TOTAL
2030	5	8	13	56	91	147	20	33	54
2040	212	342	554	2,374	3,827	6,201	623	1,003	1,626
2050	587	1,190	1,777	6,433	13,039	19,471	1,194	2,419	3,613

1. Introduction

The large-scale deployment of zero emission vehicles is considered vital to meet climate targets globally. Fuel cell and hydrogen heavy-duty trucks and buses embody a highly promising zero-carbon alternative especially for the long-haul segment and in public transportation. Their large-scale adoption could be a key lever to fulfil the operational requirements of heavy-duty road transport in terms of payload capacity, refueling time, and range to establish a more sustainable heavy-duty transport system.

While being an enabler of the global economy and urban transport, especially in large cities, the heavy-duty transport segment is also accountable for a considerable amount of greenhouse gas (GHG) emissions. This makes its decarbonization a priority to comply with climate targets and reduce air pollution in cities.

In Europe for example, the EU Green Deal aims for the European Union to reach carbon neutrality by 2050 and calls the transport and logistics industry to reduce GHG emissions in 90% by mid-century. The role zero emissions powertrains could play is significant given that over three-quarters of the current freight transport relies on road transportation.

In Mexico, the transport sector is the largest GHG emitter accounting for around one quarter of the national emissions. The electrification of the vehicle fleet and increasing the efficiency of public transport systems are among the measures to comply with the established goal to reduce 19% of the sector's emissions by 2030 compared to the BAU baseline[2].

The heavy-duty transport segment is crucial to the Mexican economy. Data from INECC for 2015 reveals that federal trucking is an important generator of jobs registering 1.8 million direct jobs nationwide.

Additionally, freight trucking in Mexico mobilizes 82% of land cargo and 56% of national cargo, as well as 97% of public transport passengers. Put together, federal trucking participates with 5.9% of total GDP in Mexico[3].

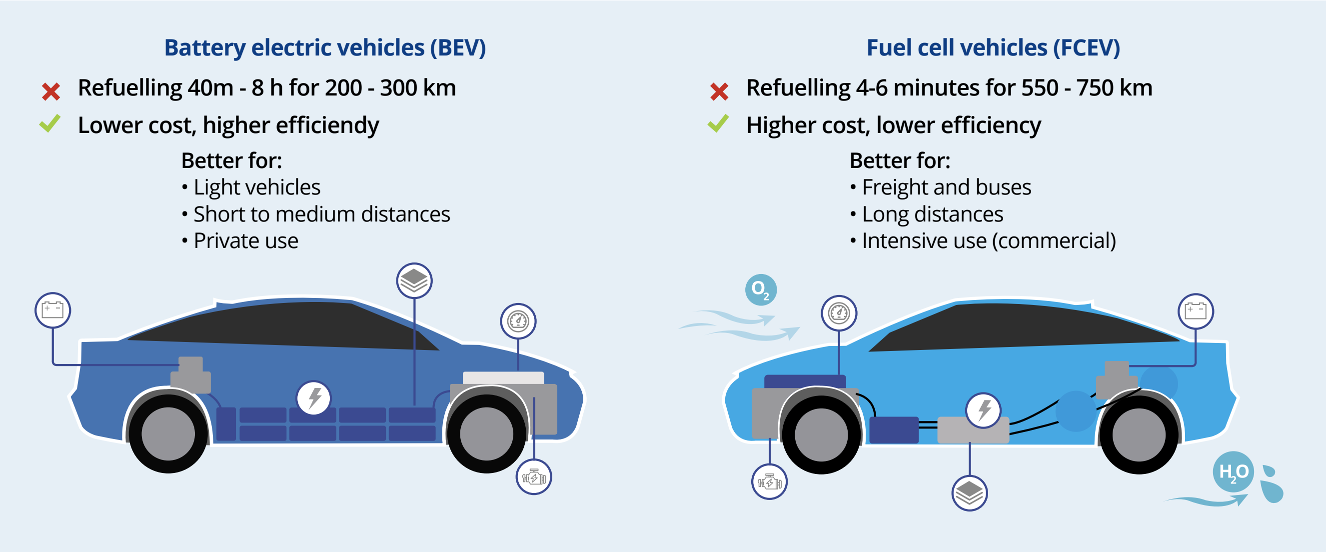
Public transportation plays a major role in the livelihoods and economies of cities and an opportunity for hydrogen-powered vehicles for decarbonization and reduction of air pollution. In Mexico City, for example, around half of the individual transportation is done on the public transport system, of which 14% is covered by suburban buses and the Metrobus system[4], both with potential for the adoption of zero-emissions technologies.

Fuel cell and hydrogen technology

From a technological standpoint, hydrogen fuel cell vehicles are electric vehicles (EV), thus commonly known as Fuel Cell Electric Vehicles (FCEV). FCEVs store energy in the form of hydrogen, using it as an energy carrier, and employ it to generate electricity using a fuel cell, which in turn drives an electric powertrain to propel the vehicle. If fueled with green hydrogen, produced using renewable electricity, they provide a zero-emissions transport alternative, having water vapor as the only exhaust. This results in a tendency to compare FCEV with battery electric vehicles (BEV) as alternatives for the electrification and decarbonization of road transport.

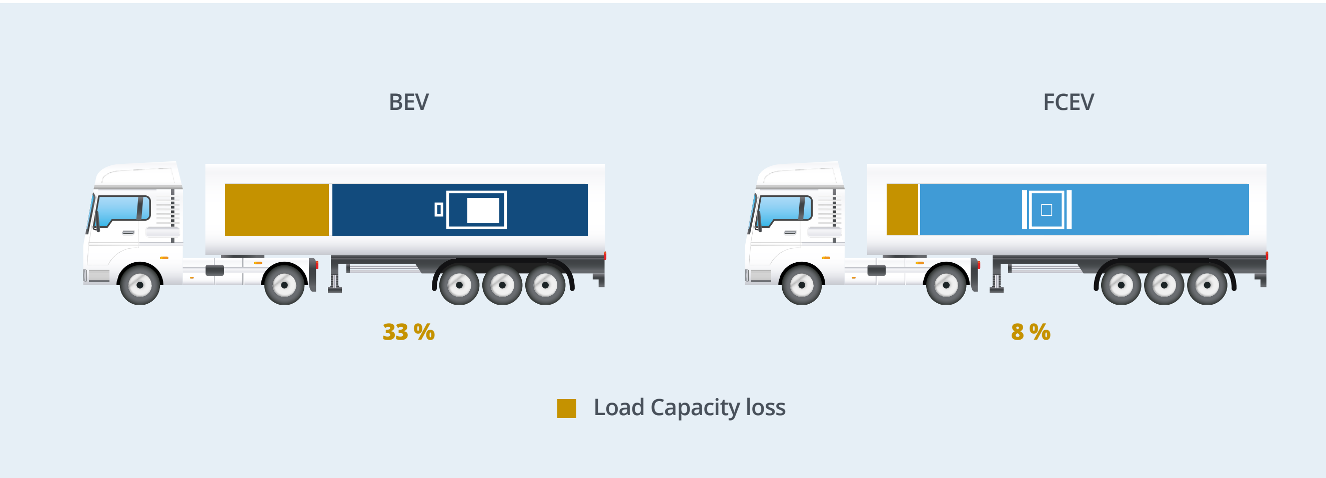
2. SEMARNAT, Mexico's Nationally Determined Contributions – 2020. Mexico, 2020.
3. INECC, Technological Route NDC in the Transportation Sector, Mexico 2015.
4. SEMOVI, Strategic Mobility Plan of Mexico City 2019. Mexico, 2019.

Figure 1-1. Comparison of battery electric and fuel cell electric vehicles.



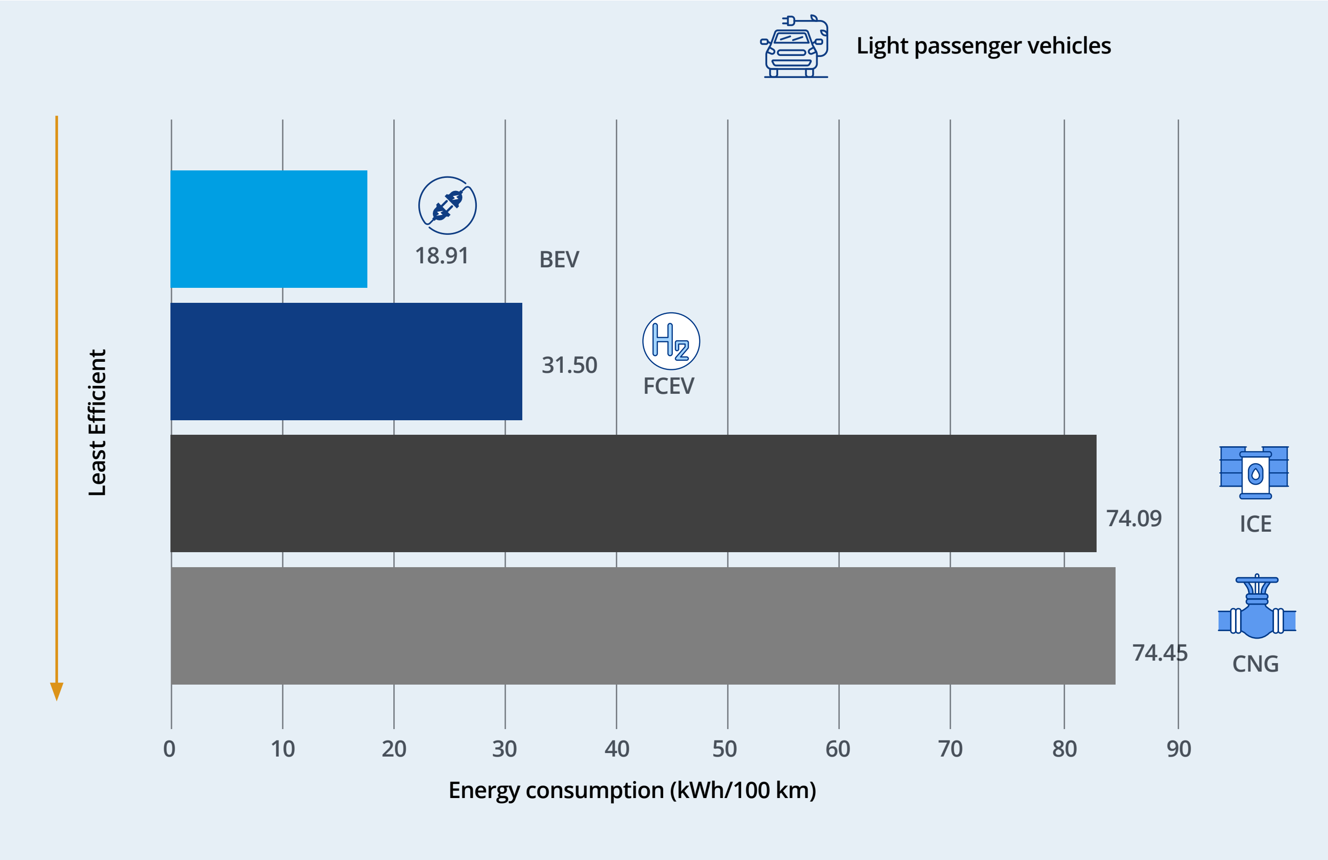
FCEVs are positioning against batteries for electric mobility in the segments where long range and fast refueling is critical, such as passenger buses and freight trucks, presenting refueling times similar to conventional Internal Combustion Engine Vehicles (ICEV). Hydrogen has a very high energy density, storing more energy per kilogram of storage system than other technologies such as batteries. This is a critical advantage for the commercial transport segment because FCEVs allow to carry more passengers or more payload for the same total weight of a vehicle than BEVs. Higher energy density also translates in higher ranges and reduced load capacity loss; FCEV in all transportation segments have a similar range as ICEV, with a loss of load capacity below 10%, while BEV typically lose a third of their load transport capacity to the energy storage system.

Figure 1-2. Loss of load capacity due to the energy storage system for BEV (left) and FCEV (right).



This makes FCEVs especially competitive for long distance passenger transport, regional and national cargo logistics, and other operations with intensive distance and load requirements. Benchmarks for fuel consumption reveal a much higher tank-to-wheel efficiency for FCEV than ICEV, although not as high as BEV, as shown in Figure 1-3. This efficiency measures the output in the or kinetic energy or motion of the vehicle for each unit of energy supplied in form of electricity (BEV), hydrogen (FCEV), or diesel, gas, or other fossil fuel (ICEV), and is inversely proportional to the fuel consumption shown in the figure.

Figure 1-3. Tank-to-Wheel Efficiency of light passenger BEV, FCEV, ICEV, and compressed natural gas (CNG) vehicles.



Today FCEV technologies are still in a demonstration phase with commercialization in an early stage depending on a broader deployment of both vehicles and hydrogen refueling infrastructure. However, trial and demonstration projects as well as FCEV industrial ventures, are expected to contribute to a sharp cost reduction of the technologies in this decade and allow for FCEVs to be economically competitive by 2030[5].

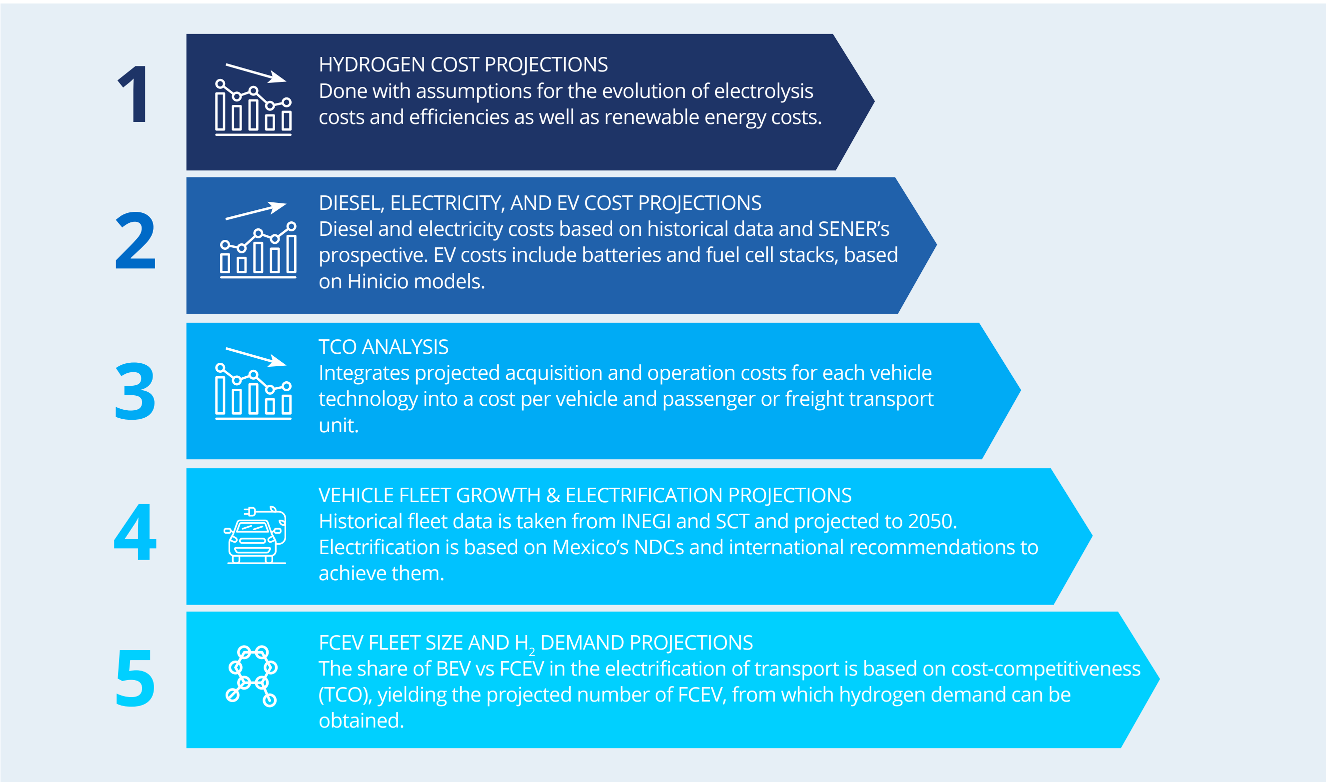
This study will focus on two applications of hydrogen in heavy-duty vehicles with a large potential for the deployment of new fleets and decarbonization: public transport buses and long-haul freight transport. An analysis of total cost of ownership (TCO) is presented for FCEV in these segments in comparison with BEV and ICEV powered by fossil fuels. Projections were made to estimate the size of the hydrogen powered vehicle fleets, hydrogen demand, and market size for both public and freight transport towards 2030 and 2050 in Mexico.

[5] FCH JU, Study on Fuel Cells Hydrogen Trucks. EU, 2020.

2. Methodology

Green hydrogen demand projections and economic analysis were developed to visualize the opportunities in the public and heavy-duty freight transport sectors in Mexico up to 2050. The methodology followed in this report is divided in two main stages which are a Total Cost of Ownership (TCO) analysis[6] and projections of the hydrogen-powered vehicle fleets and their hydrogen demand for each application towards 2050. The TCO analysis provides a basis to compare the cost of different vehicle technologies for a particular use, and its results are an input for the FCEV fleet and hydrogen demand projections. The overall process is portrayed in Figure 2-1.

Figure 2-1. Methodologic process of to project the size of FCEV fleets and of green hydrogen demand.



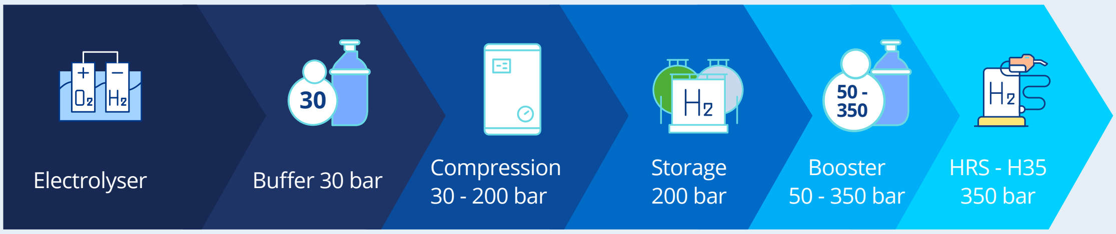
2.1. Projections of LCOH for green hydrogen

Cost projections for green hydrogen were made using Hinicio models for LCOH and adapted to the Mexican context. The models consider technological factors such as electrolyser costs, efficiencies, water consumption, and lifetime; and specific characteristics for the country, such as the renewable energy resource and estimated capacity factors, cost of electricity, and adjusted costs of installation and operation of the electrolysers. The assumptions for the green hydrogen cost projections consider a scenario favorable for the development of hydrogen technologies and the deployment of its infrastructure, following projections by the Hydrogen Council[7] and are the same as those used in the Hydrogen Breakthrough scenario in Report 3 "Opportunities for state-owned companies PEMEX & CFE" and Report 4 "Opportunities for the private sector" from this series.. The LCOHs considered are a reference value for green hydrogen produced in Mexico and for hydrogen compressed to a pressure of 350 bar (H35) which is how it is supplied at hydrogen refueling stations (HRS).

6. The Total Cost of Ownership calculation considers the expenses during the lifetime of the vehicles. Expenses are classified into four categories: acquisition cost (CAPEX), average preventive and corrective maintenance costs (OPEX), ownership taxes, compulsory insurance policies and financing expenses (Administrative) and energy consumption (fossil fuel, electricity or hydrogen). The TCO is the sum of all the expenses in net present value.

7. The Hydrogen Council is a global initiative uniting CEOs of leading energy, transport and industry companies with a common vision and long-term ambition for hydrogen to foster the energy transition.

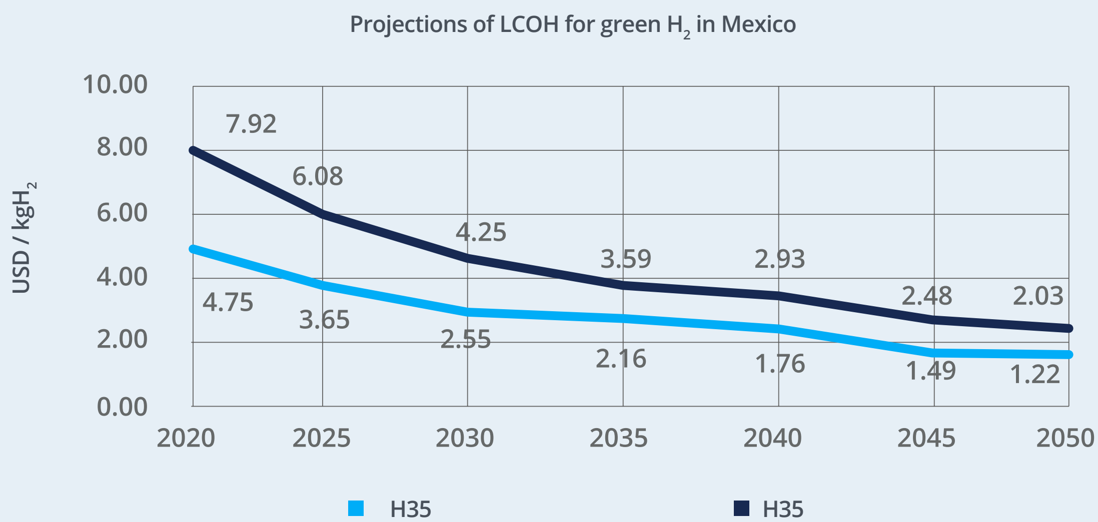
Figure 2-2. Hydrogen value chain from production to dispatch at the HRS.



The cost for H35 increases by two-thirds relative to the cost of hydrogen produced at the electrolyser output, attributed to its compression, transport, storage, and supply at the HRS, as shown in Figure 2-2.

Projected LCOHs for green hydrogen at the electrolyser output start at 4.75 USD/kg in 2020 and decrease sharply as technology costs drop for renewable energy and electrolysis as they gain scale with wide deployments already committed worldwide LCOH in projected to be as low as 1.22 USD/kg. The costs of H35 are proportional to the LCOH and go from 7.92 USD/kg in 2020 to 4.25 USD/kg in 2030 and 2.03 kg/USD in 2050 as shown in Figure 2-3.

Figure 2-3. Projected LCOH for Green Hydrogen in 2020-2050, for hydrogen at the electrolyser output and H_2 supplied at refueling stations compressed to 350 bar (H35).



2.2. Methodology for TCO Analysis

To provide a comprehensive cost-comparison between technologies for heavy duty transport, the TCO was calculated for conventional internal combustion diesel, battery electric, and hydrogen fuel cell hydrogen electric and trucks. The TCO integrates all costs for the owner throughout the vehicle's lifetime. To do so, a number of variables are projected to obtain a consolidated measure of economic comparison between fossil, battery electric, and hydrogen fueled vehicles, normalized to a TCO in dollars per vehicle unit or by passenger or load per distance carried considering equal lifetimes and operation regimes for a direct assessment.

The vehicle-related variables considered for the TCO analysis include the up-front cost (CAPEX) for the unit, its range, fuel efficiency, powertrain capacity, capacity and lifetime for energy storage units (for BEVs and FCEVs) and the fuel cells (FCEV); operating capabilities such as load or passenger capacity for freight and public transport, respectively; and operating costs including battery and fuel cell stack replacement —where applicable—, ownership, maintenance, and fuel costs (OPEX). The same lifetime, distance traveled per year, and financing and insurance schemes[8] were considered for all technologies and adjusted to the requirements of either freight or public transportation. BEV and FCEV are considered to be exempt of the 20% import taxes applied to ICEV buses and trucks as published in an official decree in September 2020[9].

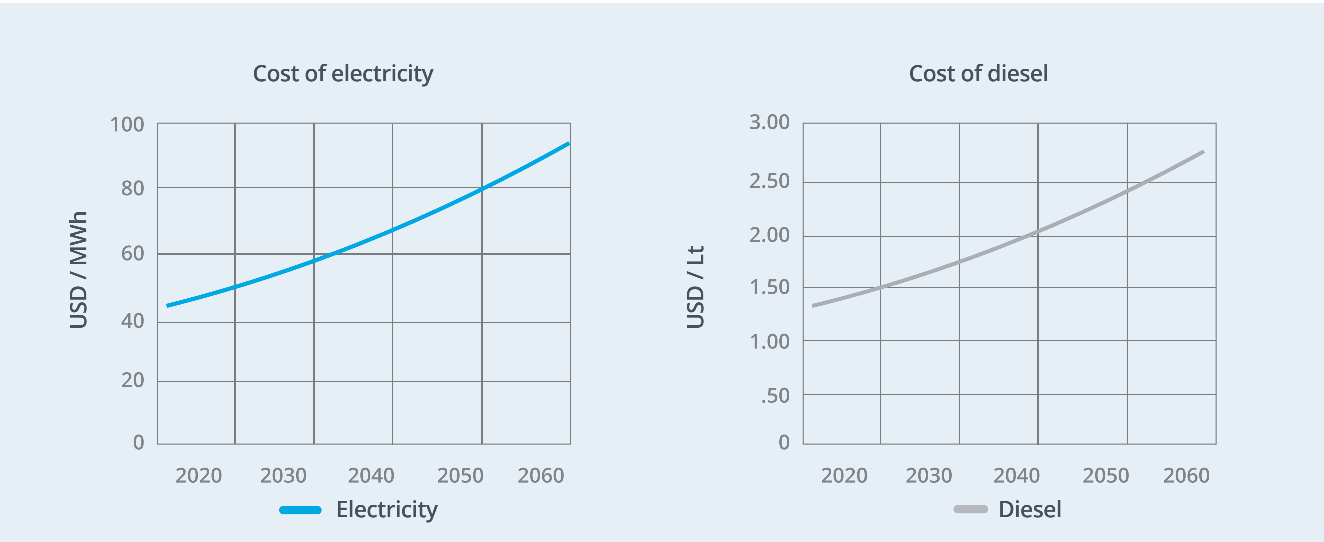
Projections are made for the cost evolution of batteries, fuel cell stacks, fuel cell efficiency, and the corresponding overall vehicle costs for all three technologies. Additionally, cost projections for diesel and hydrogen (LCOH) are obtained, as well as for renewable electricity to supply the BEVs, and carbon taxes which positively affect the competitiveness of the electric technologies.

For both applications and all three technologies the characteristics of actual commercially available vehicles were considered for the analysis.

Cost Projections for Energy and EV Technology

The projected prices for electricity and diesel are taken from SENER's Energy Sector Outlook 2018-2032 planning scenario and extrapolated to 2060 to provide the fuel input for calculating the TCO of vehicles acquired from 2020 to 2050, which have a 10 year lifetime, as shown in Figure 2-4.

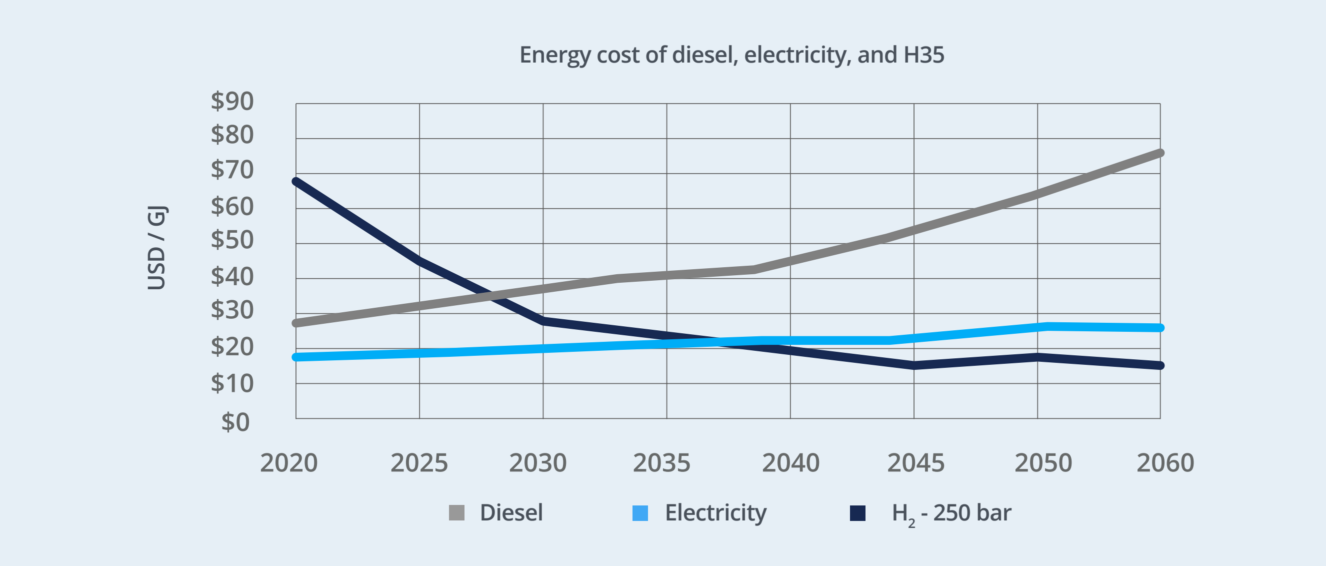
Figure 2-4. Projected costs of electricity and diesel in Mexico.



When comparing the cost per energy for each source, namely diesel, electricity, and hydrogen (H35), hydrogen reaches cost-parity with diesel in 2030 and with electricity in 2044, as seen in Figure 2-5. The power sourced to produce green hydrogen is assumed to come directly from renewable installations with a low Levelized Cost of Electricity (LCOE), which is lower than the cost of electricity supplied by the grid, allowing H35 to be cheaper than the power used to charge BEVs.

8. Financing conditions of 16% yearly interest rate, 60 months period for buses and 84 months for trucks. Mandatory insurance costing 0.39% of the vehicle's up-front cost per month for buses and 0.98% for trucks.
9. Diario Oficial de la Federación: Decreto por el que se modifica la Tarifa de la Ley de los Impuestos Generales de Importación y de Exportación, 03/09/2020.

Figure 2-5. Cost projections by energy content of diesel, electricity, and hydrogen at 350 bar.



In terms of EV technology and following Hinicio models the costs of fuel cell stacks are projected to drop by 40% from 2020 to 2050 and show an increase in efficiency of between 25% and 35%.

For both public transport buses and long-haul heavy-duty trucks, the price of ICEV are projected to remain constant towards 2050, while for the BEV and FCEV, reductions are expected of around 20% and 30%, respectively.

2.3.Methodology for FCEV fleet and hydrogen demand projections

To project the size of the FCEV fleet for each application and its green hydrogen demand and market, five major steps are followed:

I. Data gathering on historical vehicle fleet in Mexico from SCT and INEGI.

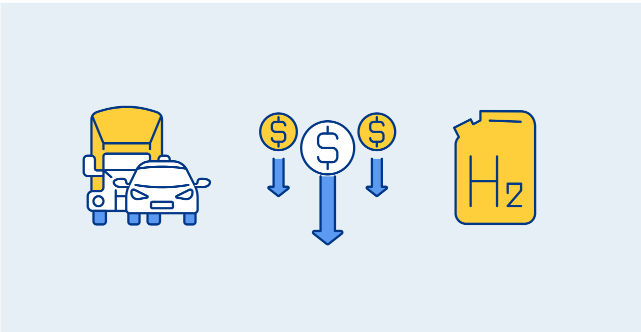
II. Fleet growth projections based on projections for GDP per capita and motorization rate in Mexico, as well as the share of public transport buses and heavy-duty freight trucks within those fleets.

III Electrification rate of fleets or market penetration of EVs aligned to comply with Mexico's decarbonization goals as established in the Nationally Determined Contributions (NDC), integrating recommendations on corresponding electrification rates from the World Resources Institute (WRI), comparison with international EV markets, and information EVs already planned or in operation in Mexico.

IV. Determination of the share of the electrified fleet that corresponds to BEV and FCEV, respectively, based on the results from the TCO Analysis. This yields the projected size of both BEVs and FCEVs in Mexico for public and freight transport up to 2050.

V. From the FCEV fleet size and projected fuel cell efficiencies, the required hydrogen demand and its yearly market value are calculated.

A detailed account of the process and the results found for each step can be found in Chapter 4. Opportunities in green hydrogen for freight and public transport.



3. Total Cost of Ownership of freight and public transport FCEVs

As mentioned in the Methodology, the TCO analysis provides a comprehensive cost-comparison between technologies for both public and freight transport integrating all costs for the owner throughout the vehicle's lifetime. This allows to compare cost-competitiveness based on each vehicle category purpose: cost to move passengers in public transport buses normalized in USD/km□passenger, and cost to carry commercial load for freight trucks, expressed in USD/km•ton.

Different passenger and payload capacities for public transport buses and freight trucks, respectively, are considered since BEV buses lose passenger capacity to the space taken up by the batteries, and BEV trucks give up payload capacity to carry the weighty batteries. However, since the same conditions are used for the three technologies in each of the analyses, the TCO shown in cost per unit can also provide a snapshot of the competitiveness of each and is also used throughout this report, albeit this consideration must be kept in mind to avoid undermining the FCEVs' competitiveness against BEVs.

3.1. TCO Analysis of Public Transport Buses

All models compared for public transport buses ICEV, BEV, and FCEV, respectively, are similar and from the same manufacturer, Yutong, which gives the comparative advantage of sharing components and characteristics[10]. Yutong, was selected because it signed an agreement with the government of Mexico City in 2019 to supply the city with a fleet of FCEV buses. The models included are the Yutong ZK6118HGA diesel bus, the Yutong E12 electric bus, and the Yutong ZK6125FCEVG1 hydrogen fuel cell bus.

Table 3-1. Technical data sheet for ICEV, BEV, and FCEV of the passenger buses.

	ICEV	BEV	FCEV
Model	**Yutona ZK6118HGA**	**Yutona E12**	**Yutona ZK6125FCEVG1**
Fuel	Diesel	Electricity	Hydrogen
Range (km)	450	300	500
Efficiency (MJ/100 km)	1,890	486	960
Motive Power (kW)	213	215	191
Passenger Capacity	40	35	40
Maintenance Cost (USD/1000 km)	170	100	100
Retail Price (USD)	$200,000	$397,400	$510,000

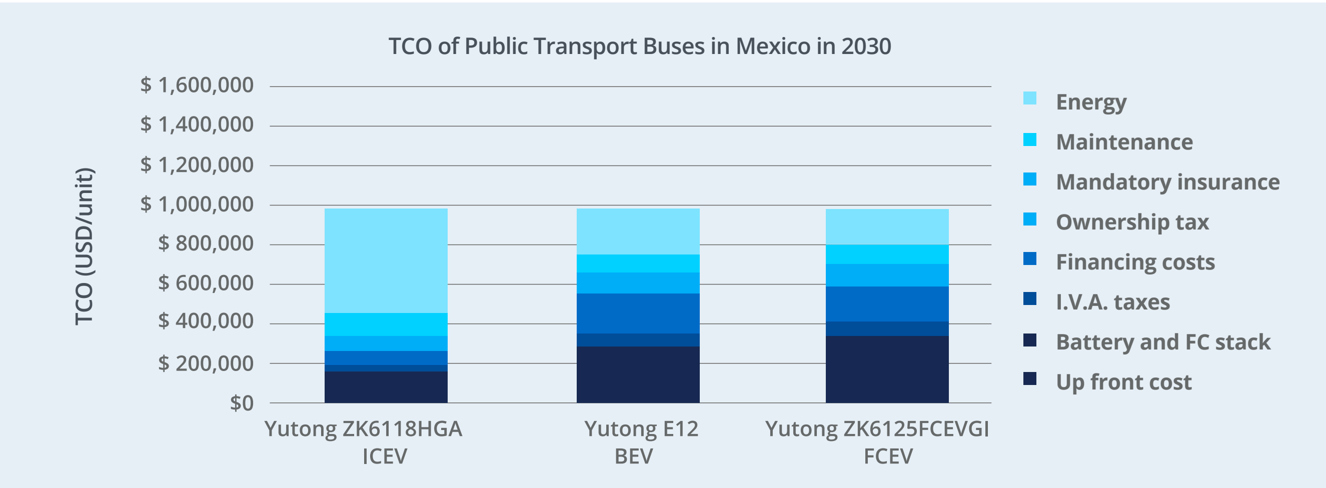
[10] Yutong, "63 Yutong Dual-Source Trolleybuses Enter Mexico across the Ocean!", 2019. https://en.yutong.com/pressmedia/yutong-news/2019/2019JNOhRqN4yq.html

For 2021, in terms of range, the FCEV is the best performing, with 500 km, followed by ICEV with 90% of that range, and finally BEV with 60% of the FCEV range. In terms of energy conversion efficiency, however, the BEV is the most favorable with around half the energy per kilometer than the FCEV, and a quarter of ICEV's, showing an aspect of absolute advantage for the electric versions. In up-front cost the situation is the opposite having the ICEV the lowest cost at around 200 thousand USD, the BEV almost twice as much, and the FCEV version hovering slightly above half a million USD. For the EV buses, the batteries require a replacement every 8 years. The cost of maintenance for EVs (both BEV and FCEV) is smaller since they have fewer moving parts in the powertrain, resulting in a reduction of 40% of maintenance expenses.

The same operating conditions are considered for all three public transport buses, including a useful life of 10 years and an average yearly traveled distance of 65,000 km. Similarly, equal financing and insurance conditions are considered for the three vehicle technologies, with the beforementioned import tax exemption on BEV and FCEV.

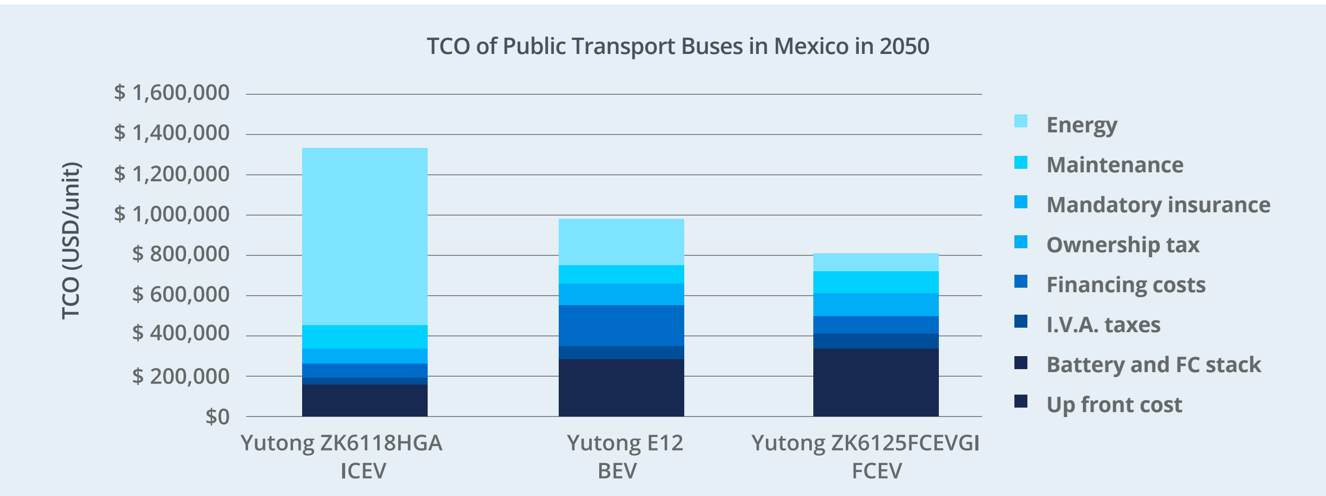
The TCO results are shown in the following figures, displaying a breakdown of components for all technologies in 2030 and 2050.

Figure 3-1. TCO breakdown by cost component for ICEV, BEV, and FCEV public transport buses in 2030.



The TCO breakdown per vehicle reveals that the highest cost component for ICEVs for 2030 and 2050 corresponds to energy consumption, a component in which BEVs are more competitive but FCEVs show a clear advantage, being around a third of the cost in 2030 and nearly a tenth of the cost by 2050 relative to the ICEV. In 2030 acquisition costs are the largest TCO component for BEVs and around twice as the ICEV. Acquisition costs which include up-front cost of the vehicles, taxes, mandatory insurance, and battery replacement for the BEV.

Figure 3-2. TCO breakdown by cost component for ICEV, BEV, and FCEV public transport buses in 2050.



It can be noted that as early as 2030 the FCEV is the most competitive option in terms of TCO, both by unit owned and by passenger cost. When TCO is analyzed per unit owned, the TCOs are of $1.018 MMUSD for the ICEV, $1.014 for the BEV, and $0.980 MMUSD for the FCEV.

When the TCO for public transport buses is analyzed based on the cost to transport passengers, factoring in the passenger capacity loss of the BEVs, the results are also more favorable for the hydrogen powered buses, with TCOs in2030 of $0.039 USD/km·passenger for ICEV buses, of $0.045 USD/km·passenger for BEV, and of $0.038 USD/km·passenger for FCEV buses.

By 2050 the fuel cost effects are more drastic, increasing the competitiveness of BEVs and more sharply of FCEVs. Paired with decreasing costs of acquisition of the vehicles, this results in the hydrogen bus being the most competitive option in terms of cost at around 40% lower than the TCO of the ICEV and more than 20% lower than the TCO of the BEV in 2050.

When TCO is analyzed per unit owned, the TCOs in 2050 are of $1.343 MMUSD for the ICEV, $1.004 MMUSD for the BEV, and $0.790 MMUSD for the FCEV. When the TCO for public transport buses is analyzed based on the cost to transport passengers, the results are also more favorable for the hydrogen powered buses, with TCOs in 2050 of $0.052 USD/km·passenger for ICEV buses, of $0.044 USD/km·passenger for BEV, and of $0.030 USD/km·passenger for FCEV buses.

3.2.TCO Analysis of Heavy-Duty Freight Trucks

Commercially available models in 2021 are compared for ICEV, BEV, and FCEV, each from a different manufacturer. The trucks considered are the Freightliner Cascadia 2020 for ICEVs trucks, the Volvo FE Electric for BEV trucks, and the hydrogen-powered Kenworth T680s for FCEV trucks.

For 2021, in terms of range, the ICEV is by far the best performer, with 930 km, followed by FCEV with around half of that range, and finally BEV with over one fifth of the ICEV range. In terms of energy conversion efficiency, however, the BEV is the most favorable with less than half the energy per kilometer than the FCEV, and less than a third of ICEV's, showing an aspect of absolute advantage for the electric versions. In up-front cost, the situation is the opposite, having the ICEV the lowest cost at around 110 thousand USD, the BEV being 65% higher, and the FCEV over twice the cost. For the EV trucks, both the batteries and the fuel cell stacks require a replacement every 8 years. The cost of maintenance for EVs is smaller since they have fewer moving parts in the powertrain, resulting in a reduction of 25% of maintenance expenses.

The same operating conditions are considered for all three heavy-duty freight trucks, including a useful life of 10 years and an average yearly traveled distance of 160,000 km. Similarly, equal financing and insurance conditions are considered for the three vehicle technologies, with the beforementioned import tax exemption on BEV and FCEV.

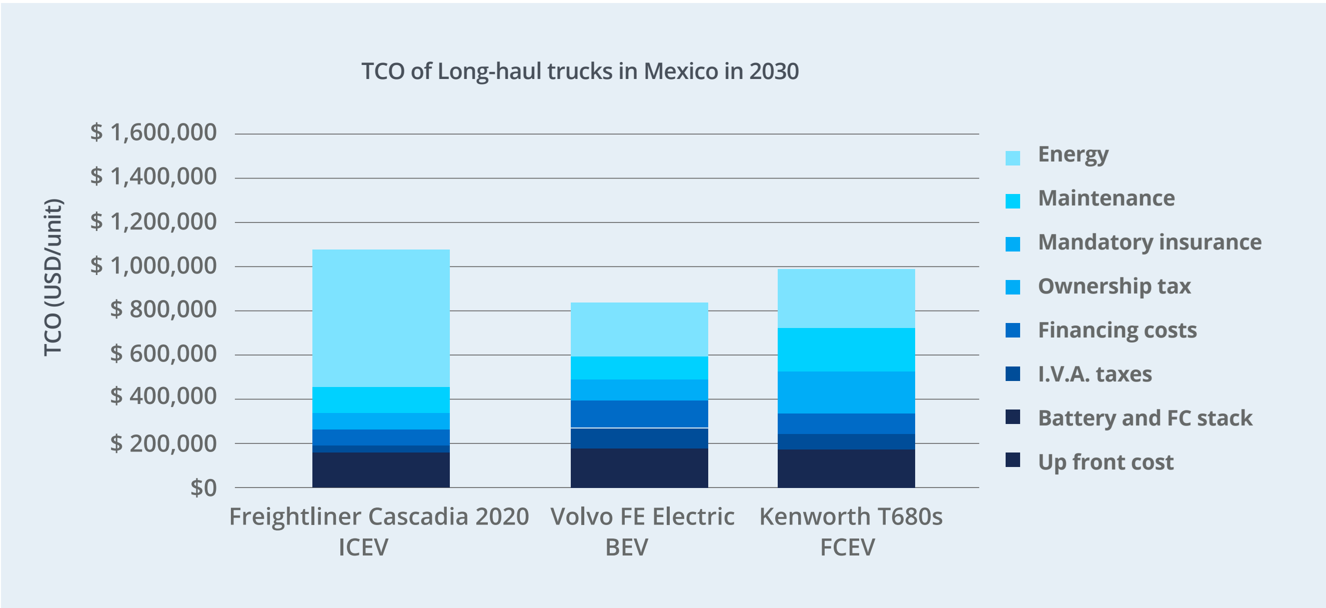
Table 3-2. Technical data sheet for ICEV, BEV, and FCEV of the heavy-duty freight trucks.

	ICEV	BEV	FCEV
Model	Freightliner Cascadia 2020	Vovlo FE Electric	Kenworth T680s
Fuel	Diesel	Electricity	Hydrogen
Range (km)	930	200	480
Fuel Efficiency (MJ/100 km)	940	360	840
Motive Power (kW)	380	330	350
Load Capacity (ton)	23	17	23
Maintenance Cost (USD/1000 km)	120	90	90
Retail Price (USD)	$109,000	$180,000	$226,000

The TCO results are shown in the figures bellow, displaying a breakdown of components for all technologies in 2030 and 2050, as well as the evolution of each for 2020-2050.

From the TCO breakdown per vehicle it can be seen that the highest cost for ICEVs both in 2030 and 2050 corresponds to energy (fuel), where BEVs are more competitive but FCEVs show a clear competitive advantage, being around 60% of the cost in 2030 and less than 20% of the cost by 2050. In 2030 BEVs and ICEVs show the largest TCO component in acquisition costs, which include the purchase of the vehicle, taxes, mandatory insurance, and battery replacement for the BEV, being around twice as much as the ICEV.

Figure 3-3. TCO breakdown by cost component for ICEV, BEV, and FCEV long-haul freight trucks in 2030.

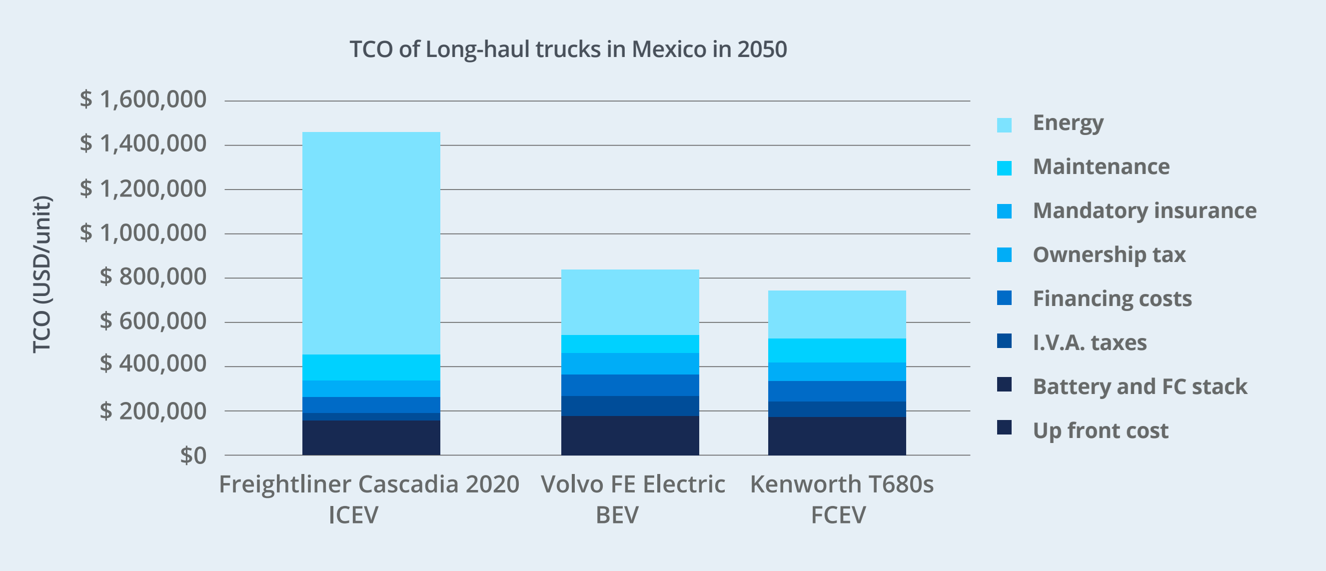


By 2030 the FCEV truck is the most competitive option in terms of TCO. When the analysis is done by vehicle owned, the TCOs in 2030 are of $1.100 MMUSD for the ICEV, $0.857 MMUSD for the BEV, and $0.988 MMUSD for the FCEV. When the analysis is done based on the cost to transport a load factoring in the payload capacity loss of the BEVs the results also reveal the lowest cost for the FCEV truck, with TCOs in 2030 of $0.030 USD/km·ton for ICEV, of $0.032 USD/km·ton for BEV, and of $0.027 USD/km·ton for FCEV.

The effects of the accelerated drop in the energy costs for BEVs and FCEVs has a more profound effect in 2050 and is more noticeable for FCEVs. As FCEV and BEV technologies evolve and their acquisition costs continue to decrease, the FCEV is the option with the lowest TCO, being around half of the ICEV and more than 15% lower than the BEV in 2050.

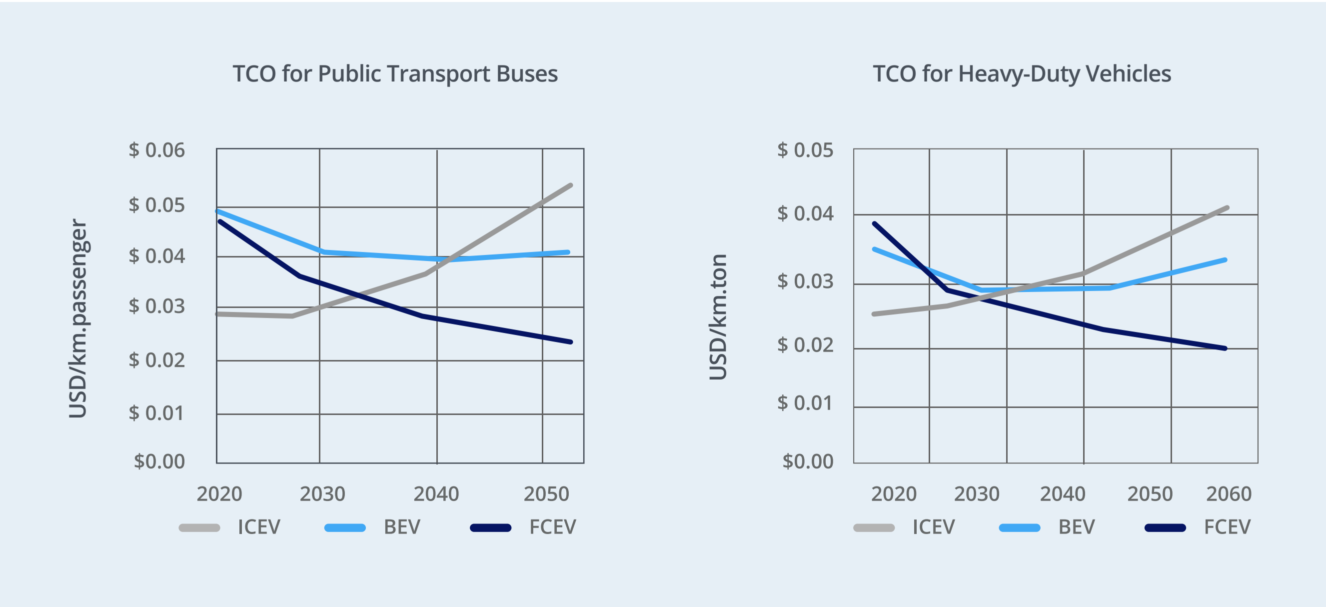
On a unit ownership basis, the TCOs in 2050 are of $1.498 MMUSD for the ICEV, $0.887 MMUSD for the BEV, and $0.737 MMUSD for the FCEV. When the analysis focuses on the cost to transport payload, FCEVs remain the lowest cost alternative, with TCOs in 2050 of $0.041 USD/km·ton for ICEV trucks, of $0.033 USD/km·ton for BEV, and of $0.020 USD/km·ton for FCEV trucks.

Figure 3-4. TCO breakdown by cost component for ICEV, BEV, and FCEV long-haul freight trucks in 2050.



The TCO trajectories from 2020 to 2050 for the three technologies and both uses, public and freight transport, are shown in Figure 3-5.

Figure 3-5. Projected TCO comparison of ICEV, BEV, and FCEV in Mexico for passenger buses (per passenger by distance) and heavy-duty trucks (per weight transported by distance) for 2020-2050.



4. Opportunities in green hydrogen for freight and public transport

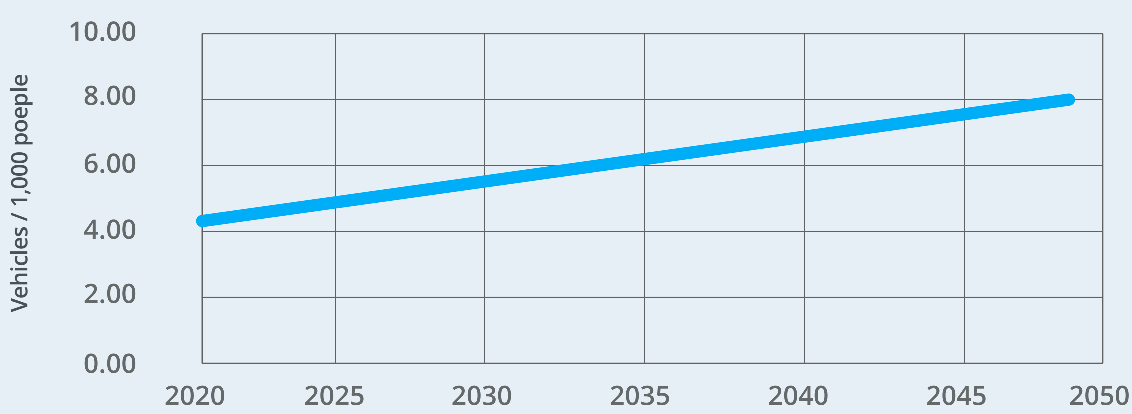
4.1. Projected fleet of freight trucks and public transport buses

The initial step to estimate the potential hydrogen demand for transport or that of its alternative is to project the growth in the national fleet of freight and public transport buses regardless of the technology.

An indicator used in the methodology to estimate the growth of the vehicle fleet in Mexico is the motorization index and its projected evolution in the country. The motorization index or motorization rate is the ratio between the motor vehicles and the population of a given country or geography, usually expressed in vehicles per thousand people. For Mexico it can be calculated for 2019 at around 400 vehicles per 1,000 inhabitants with data from INEGI for vehicle fleet and population, respectively.

The motorization rate is expected to rise following a decades-long tendency of more rapidly growing vehicle fleet than population in the country[11], also aligning to a global trend where the rate increases as the economy grows, as seen in the GDP per capita. Following the same compound annual growth rate as that reported for 2012-2018, Mexico would reach a GDP per capita in 2050 that would equal to countries such as Spain, France, or Japan today, which have a motorization rate hovering around 600 road vehicles per thousand people[12]. Thus, a projected growth in the motorization rate can be obtained, which, coupled to the expected increase in population from INEGI data, yields the projected size of the vehicle fleet in Mexico. From 2020 to 2050 the fleet nearly doubles to 90 million vehicles by mid-century.

Figure 4-1. Projected motorization rate in Mexico 2020-2050.



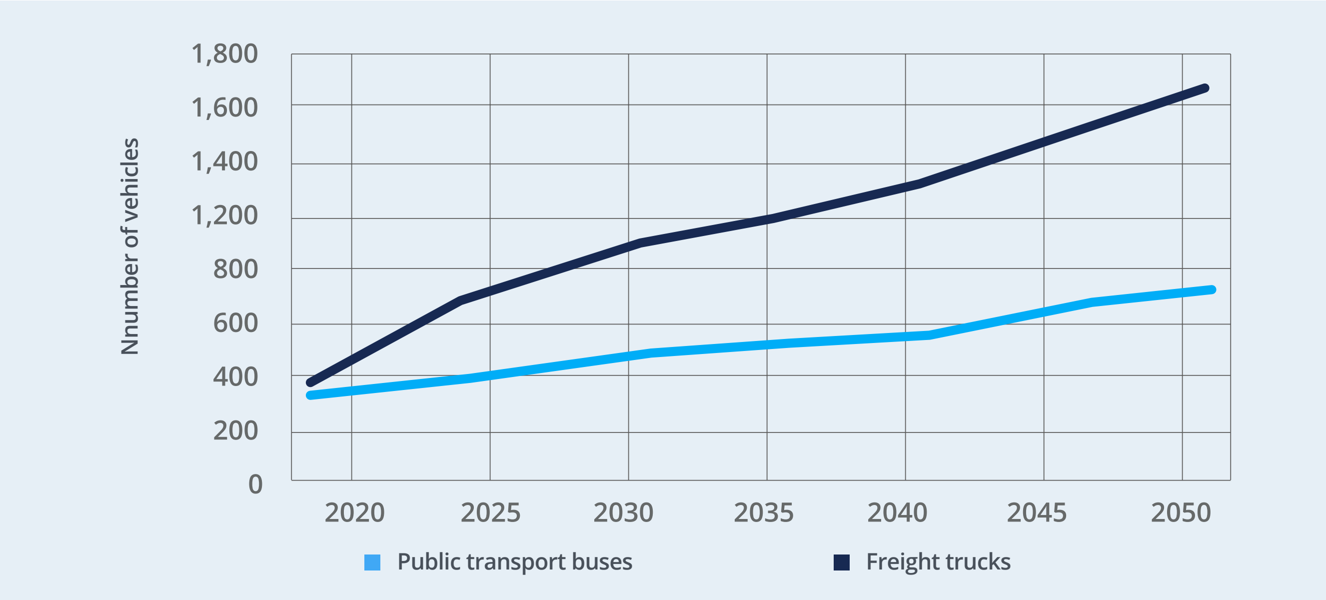
The number of passenger buses and freight vehicles can be obtained as a share of the total vehicle fleet, following historical data from INEGI[13] and SCT (the Ministry of Communications and Transport). For example, in 2020 passenger buses were roughly 1% of the total fleet. After this year, their share is considered to grow slowly following the global tendency to increase the use of public transportation and disincentivize the use of private vehicles as measures to reduce vehicular congestion and the environmental footprint, among other reasons. This share of passenger buses is

11. IMCO, Index for Urban Mobility, 2019.
12. Our World in Data, Motor vehicles per 1000 inhabitants vs GDP per capita, 2014.
13. INEGI, Statistics for Registered Motor Vehicles, Mexico, 2020.

projected to double to 2% by 2050 as a result of these measures. Finally, the share times the projected total fleet yields the size of passenger bus fleet and, after subtracting the smaller fraction of inter-city buses, yields a projected public transport fleet in Mexico of 1.65 million buses in 2050.

As for private freight vehicles the fleet has grown sharply since the 80´s going from 1.5 million units in 1980 to nearly 7 million in 2005 and to 10.6 million units in 2020, as shown by data from INEGI, growing by about 50% in the last 15 years. However, growth is projected to deaccelerate. If the same proportional growth in volume from 2005-2020 is considered but for a period of 30 years, rising at half the CAGR[14], with which the fleet reaches 15.3 million vehicles in 2050. The number in freight buses and trucks as a share of the total vehicle fleet has decreased by around 40% since 2004, as passenger vehicle numbers have increased sharply. A similar trend is projected to 2050. The share of T3 freight trucks[15] has remained nearly constant in the last decade, growing by only 5% in that period hovering around 0.7% of the total fleet. With a similar growth tendency, the fleet for freight trucks can be projected to 2050, where it reaches almost 730,000 units, more than doubling from the 350,000 units reported for 2019 by SCT[16].

Figure 4-2. Projected number of public transport buses and freight trucks in Mexico in 2020-2050. Source: Hinicio projection, based on data from INEGI and SCT.



4.2. Projected electrification of the freight and public transport fleet

The next step is to obtain the projected electrification of both fleets, for which different criteria are used. Mexico's Nationally Determined Contribution (NDC) for transport as submitted by Mexico to comply with the Paris Agreement commits the country to a reduction of 18% of GHG emissions compared to the base line projections for the transport sector by 2030 and a 40% GHG reduction by 2050.

Criteria for setting electrification goals

The World Resources Institute (WRI) published a workpaper to guide the measures necessary to comply with the Mexican NDCs target of 22% emissions reduction for the whole country by 2030. In an intermediate scenario, a 2% electrification of the transport fleet is suggested for both passenger and heavy-duty vehicles by 2030[17], which is taken as reference for the evolution of the electrification of the vehicle fleet in this report.

14. CAGR: Compound Annual Growth Rate
15. T3 is the category for freight trucks ("trailers" in Mexico) given by SCT.
16. SCT, Main Statistics of the Communications and Transport Sector. Mexico, 2019.
17. WRI, Achieving Mexico's Climate Goals: An Eight Point Action Plan, USA, 2016.

By 2030, the 2% electrification suggested for public transport buses by the WRI is considered as is. For heavy-duty vehicles (HDV), however, the IEA's Global EV Outlook 2020 suggests up to 1% of the global stock of HDV to be electric as in 2030. Given the delay that Mexico has compared to countries such as China, the US, and Europe, the Mexican stock of E-HDV is considered to not exceed 0.5 %.

By 2050 for public transport, the stated goal for passenger buses is to be equivalent to a full electrification of the fleets of the states with the largest cities in the country, i.e., Mexico City, Nuevo Leon, and Jalisco; where the actual EVs could be spread around the country, constituting around one quarter of the national fleet. For heavy-duty vehicles, given their early technical and economic competitiveness, 100% of the emissions reduction goals for the segment could be covered with the partial electrification of freight transport by 2050, requiring a 40% electrification of the national freight transport fleet. These GHG reduction and electrification goals can be summarized in Table 4-1.

Table 4-1.Committed GHG reductions for the transport sector aligned with Mexico's NDC and suggested electrification rates for public and freight transport to comply with it.

	NDCs - Transport	Suggested Electrification Rate	
Year	GHG Reduction	Public Transport	HDV
2030	18%	2%	0.5%
2050	40%	25%	40%

4.3. Projected share of BEV vs FCEV

To determine how the share of electrification will split between BEVs and FCEVs the TCO analysis described in the previous chapter of this report is taken as a basis (see Figure 3-5).

After their breakeven points with ICEVs, the market share for each technology is assumed to be proportional to their cost-competitiveness relative to ICEVs, given by their TCO expressed in USD/km·passenger for public transport buses and in USD/km·ton for freight transport.

For example, by 2050 the projected TCOs for public transport buses per unit owned, expressed in are of $1,343,254 USD for ICEVs, $1,003,895 USD for BEVs, and $ 790,845 USD for FCEVs. The cost difference between conventional ICEVs and their electric counterpart is of $339,359 USD for BEVs and $553,409 USD for FCEVs. Following a share proportional for each's cost advantage, obtained by dividing the cost difference by their added value ($892,768 USD) yields a 38% share of the electrified public transport bus fleet to BEVs and the remaining 62% share to FCEVs. Given that by this year the whole fleet is projected to be electric, those shares also correspond to that of the whole bus fleet, with 157,000 BEV buses and 257,000 FCEV busesFigure 4-3. The same methodology is followed for heavy duty vehicles.

4.4. FCEV Fleet for Public and Freight Transport

Once the electrification rate evolution is projected as well as the split between BEV and FECVs for the newly electrified fleet, the total number of battery electric vehicles and hydrogen powered fuel cell electric vehicles is obtained. The electrification of both the heavy-duty and the public transport fleets is expected to be slower in the initial years as the technology commences its deployment, especially for the hydrogen-powered FCEVs, and to gradually increase to reach the NDC-complying targets for each with growth accelerating after 2030 when both battery and fuel cell vehicles reach cost parity with combustion engine vehicles.

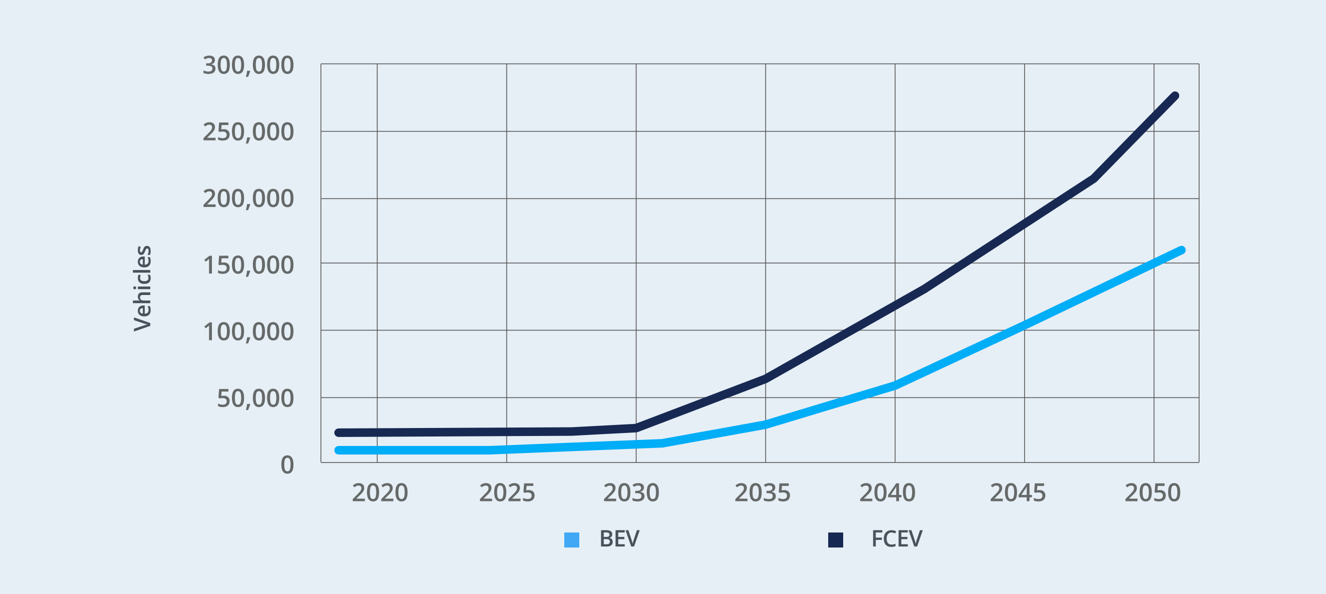
Public Transport FCEV Fleet

To start laying down numbers, actual data of EVs already in place or planned to run for public transport in Mexico provide a verifiable starting point for these projections. The first public transport BEV were trolleybuses (or Trolebús) deployed in Mexico City in 2020. These vehicles are part of the Trolleybus System of Mexico City which has been running across the city for decades bust just included vehicles with batteries for energy storage in a fleet of 63 units ordered in 2019 and operational in 2020. Additionally, 130 units were order in 2020 to Chinese company Yutong[18], providing a second data point to continue projections towards 2030 and 2050.

The first hydrogen public transport buses are projected to come online three years later with around 100 units in 2023, and following and accelerated decrease in cost as the technology scales-up globally, FCEVs will be more competitive than both ICEVs and BEVs by 2030 for public transport in Mexico, reaching nearly two thousand

[18] El Universal, "CDMX da contratos por mil 850 mdp a empresa china". October 2020. https://www.eluniversal.com.mx/metropoli/cdmx-da-contratos-por-mil-850-mdp-empresa-china

Figure 4-3. Projected fleet of public passenger buses for BEV and FCEV in Mexico 2020-2050.

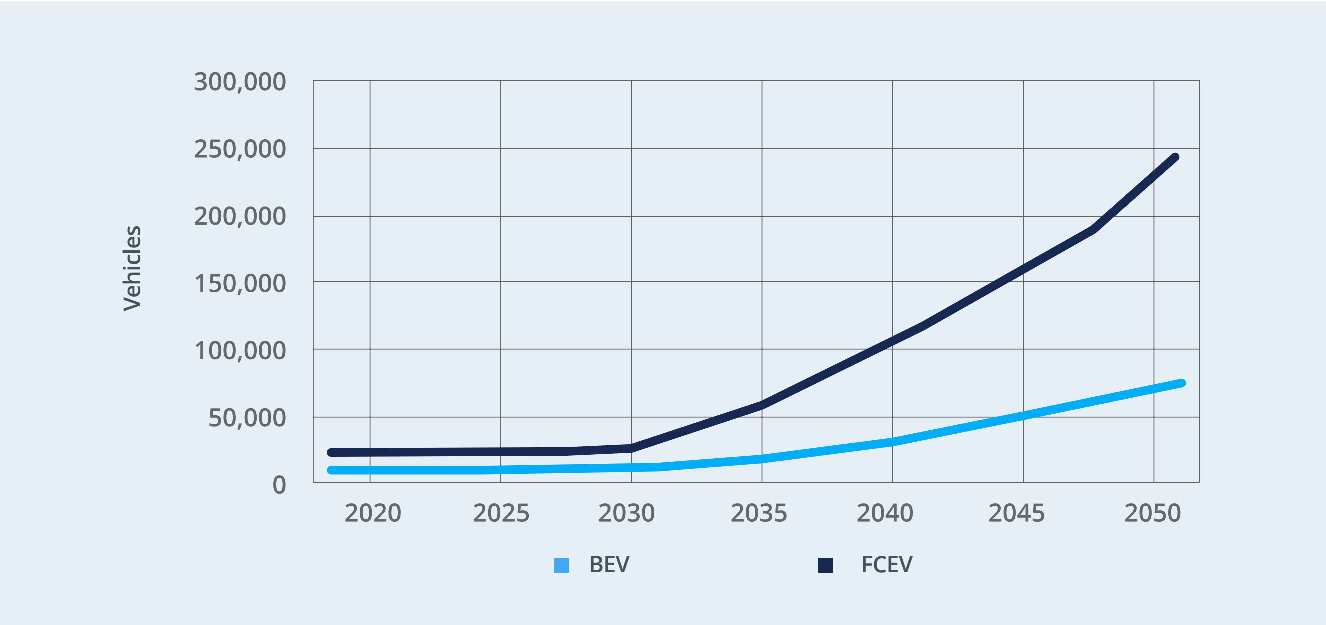


units in that year and quickly gaining share and units deployed to reach over a quarter-million FCEVs for public transport in 2050, when they will be considerably cheaper than the other alternatives, as shown in Figure 4-3.

Heavy-Duty Transport FCEV Fleet

Electric vehicles for freight transport are projected to be introduced in Mexico in 2022 as the first pilot units come online for both BEV and FECV and to raise in number as adoption broadens. Technology costs would drop more sharply for fuel cell vehicles, reaching cost parity in 2025 with BEVs and in 2028 with ICEVs, after which deployment of both electric transportation technologies are projected to grow more rapidly.

Figure 4-4. Projected fleet of electric freight trucks for BEV and FCEV in Mexico in 2020-2050.



By 2030 nearly 2,400 heavy-duty EVs are projected to be on the roads, with 60% of the fleet being powered by hydrogen. Benefitting from a larger range and lower cost per wight transported, among other competitive advantages, the FCEV fleet will grow at a much faster rate than BEVs for freight transport, accounting for 80% of the electric fleet and nearly one third of all heavy-duty vehicles in Mexico, reaching over 240,000 FCEV units by 2050, as shown in Figure 4-4 and Table 4-2

Table 4-2. Projected size of FCEV fleet for public transport buses and heavy-duty trucks.

	FCEV Fleet		
Year	Buses	Trucks	Total
2030	1,889	1,436	3,325
2040	93,055	69,633	162,689
2050	257,373	242,202	499,575

4.5. Hydrogen Demand for Public and Freight Transport

The green hydrogen demand to fuel the FCEVs in public and freight transport can be calculated using of the number of vehicles, their average distance travelled per year, and energy efficiency. The electrolyzer efficiency and load factor are used to calculate the electrolysis capacity required to produce the hydrogen demanded, and the LCOH can be used to obtain the hydrogen market size for a given year.

The market value for each year is estimated based on the cost to deliver H35 hydrogen in HRS. However, final prices to the customer could rise in uncertain but varying amounts due to factors such as supplier profit margins, resulting in larger hydrogen supply markets.
a en mercados de suministro de hidrógeno más grandes.

Public Transport Hydrogen Demand

By 2030 the projected hydrogen demand for public transport will lead to the deployment of 56 MW of electrolysis by 2030 and represent a yearly market of 20 million USD of hydrogen supply.

By 2040 the market will have grown to over 600 million USD of hydrogen supply reaching more than 200 kilotons of hydrogen per year, comparable to PEMEX's current demand, and require an installed capacity of more than 2,370 MW of electrolysis.

By 2050, as the national public transport FCEV fleet reaches over a quarter-million units, they will be demanding close to 590 kilotons of hydrogen per year with a value of 1.2 billion USD and require an electrolysis capacity of 6,400 MW.

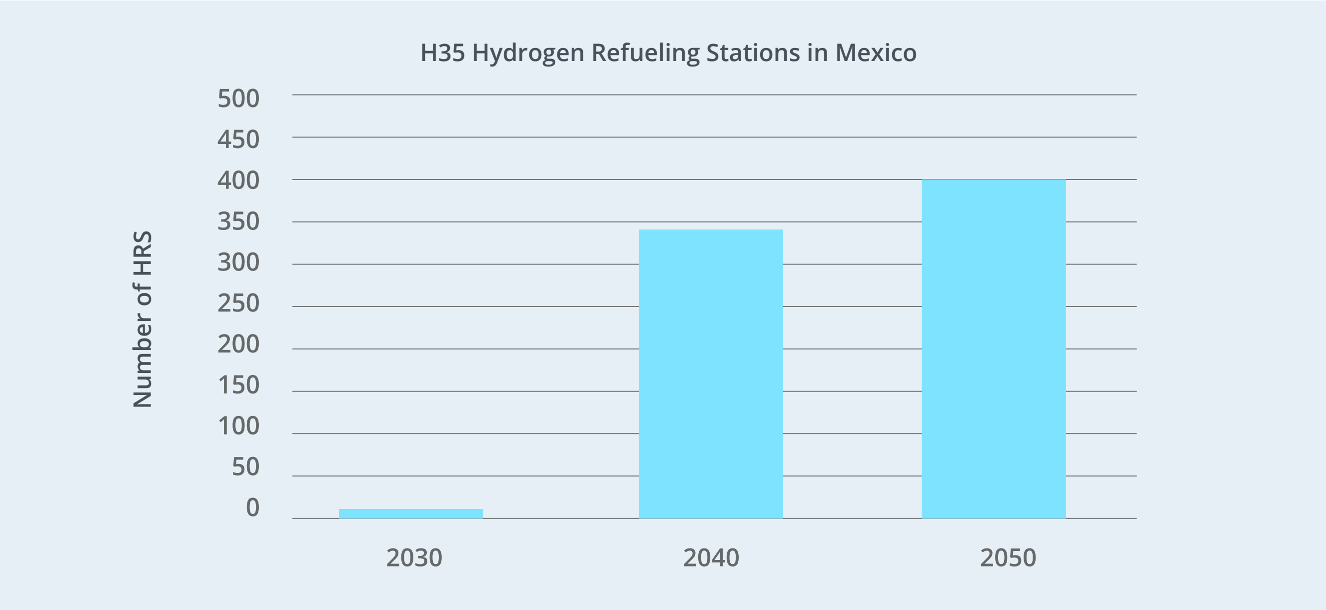
Heavy-Duty Transport Hydrogen Demand

By 2030 the projected hydrogen demand for public transport will lead to the deployment of 91 MW of electrolysis by 2030 and represent a yearly market of 33 million USD of hydrogen supply.

By 2040 the market will have surpassed a value of 1 billion USD of hydrogen supply reaching more than 340 kilotons of hydrogen per year and require an installed capacity of more than 3,800 MW of electrolysis.
By 2050, as the national freight transport FCEV fleet reaches 240,000 units, they will be demanding close to 1,200 kilotons of hydrogen per year with a value of 2.4 billion USD and require an electrolysis capacity of 13 GW.

4.6. Necessary hydrogen infrastructure

Figure 4-5. Projected number of H35 Hydrogen Refueling Stations for public transport and heavy- duty freight transport FCEVs in Mexico in 2030-2050.



The penetration of FCEVs in Mexico will set off a chain reaction in the industrial sector, making it necessary to deploy vehicle hydrogen recharge infrastructure, hydrogen production plants and even renewable power plants, resulting in direct and indirect employment in the hydrogen industry and an indisputable economic growth for Mexico.

The hydrogen supply infrastructure is projected to grow as H_2 demand from FCEVs does, requiring an increasing number of hydrogen refueling stations (HRS) going from 14 in 2030 to 340 in 2040 and nearly 450 in 2050. As HRS infrastructure broadens deployment, so does their hydrogen refueling capacity, going from 2 ton/day in 2030 to 8 ton/day in 2050, so their growth in numbers isn't as accelerated

This analysis only considers the HRS required to supply the public and heavy-duty freight transport FCEV fleets with hydrogen at 350 bar (H35). HRS for hydrogen at 700 bar and for other FCEV applications (passenger cars, light vehicles, etc.) should be analyzed independently.

5. Conclusions

The TCO analysis shows FCEVs will be at cost parity with BEVs and ICEVs before 2030 for both applications. The TCO breakdown shows that the highest cost for ICEVs both in 2030 and 2050 corresponds to energy (fuel consumption), being considerably higher than for BEVs and FCEVs even before 2030. Acquisition costs remain the highest TCO components for both BEVs and FCEVs, with costs decreasing as technology upscales towards 2050.

The joint projected hydrogen demand is of 13 kilotons of H_2 per year in 2030, increasing at an exponential rate to around 550 kilotons of H_2 per year in 2040, and growing three-fold in the following decade to reach 1,780 kilotons of H_2 per year in 2050.

The projected electrolysis capacity will nearly reach 150 MW in 2030, grow over twenty times in the following decade to 6,200 MW in 2040, and reach nearly 19,500 MW by 2050.

The hydrogen market value is projected to be of over 50 million USD by 2030 and increase sharply to 1.6 billion USD in 2040 and 3.6 billion USD by 2050[19].

The share of hydrogen demand and the corresponding electrolysis capacity and market value is around 40% for public transport buses and 60% for heavy-duty trucks from 2030 to 2040 and transitions to around one third to public and two thirds to freight transport in 2050.

Table 5-1. Projected yearly hydrogen demand, accumulated electrolysis capacity, and hydrogen market value per year for public and freight transport.

	H_2 Demand (ktonH$_2$/year)			Electrolysis Capacity (MW)			H_2 Market Size (MUSD)		
Year	Public T.	HDV	TOTAL	Public T.	HDV	TOTAL	Public T.	HDV	TOTAL
2030	5	8	13	56	91	147	20	33	54
2040	212	342	554	2,374	3,827	6,201	623	1,003	1,626
2050	587	1,190	1,777	6,433	13,039	19,471	1,194	2,419	3,613

The projected hydrogen market values consider only its production and supply, while large complementary markets will also be created, for national production or import of FCEVs, components, dedicated maintenance service, hydrogen transport and refueling infrastructure, among other. The hydrogen refueling infrastructure is projected to grow as H_2 demand from FCEVs does, requiring an increasing number of hydrogen refueling stations (HRS) starting at 14 in 2030 and growing to 340 in 2040 and nearly 450 in 2050.

19. The market value is estimated based on the cost to deliver H35 hydrogen in HRS. However, final prices to the customer could rise in uncertain but varying amounts due to factors such as supplier profit margins, resulting in larger hydrogen supply markets.

Bibliography

Fuel Cells and Hydrogen Joint Undertaking, Fuel Cells Hydrogen Trucks – Heavy-Duty's High Performance Green Solution. Belgium, 2020.

Hydrogen Council, Hydrogen Scaling Up, 2017.

IEA, Energy Technology Perspectives 2020. France, 2020

IEA, The future of hydrogen – seizing today's opportunities, IEA, Japan, 2020.

Instituto Mexicano para la Competitividad A.C., Index for Urban Mobility 2019. IMCO, Mexico, 2019.

INECC, Technological Route NDC in the Transportation Sector, Mexico 2015.

INEGI, Statistics for Registered Motor Vehicles, Mexico, 2020.

México, Gobierno Federal, Compromisos de mitigación y adaptación ante el cambio climático para el periodo 2020-2030, Mexico 2016.

Oronoz, Brian. Piquero, Eduardo. Nota técnica – Impuesto al Carbono en México, Mexico, 2020.

Our World in Data, Motor vehicles per 1000 inhabitants vs GDP per capita, 2014. Global Change Data Lab, Oxford University. UK,

SCT, Main Statistics of the Communications and Transport Sector. Mexico, 2019.

SEMARNAT, Mexico: Mitigation and adaptation commitments to climate change for the period 2020-2030, Mexico, 2016.

SEMARNAT, Mexico: Sixth National Communication and Second Biennial Report of Update before the UNFCCC. Mexico, 2018.

SEMOVI, Strategic Mobility Plan of Mexico City 2019. Mexico, 2019.

SENER, Balance Nacional de Energía 2017, Mexico, 2018.

SENER, Balance Nacional de Energía 2018, Mexico, 2019.

SENER, Prospectiva del Sector Energético 2018-2032, Mexico, 2018.

WRI, Altamirano, J.E. Ortiz Sánchez, J. Rissman, K. Ross, T. Fransen, C. Brown Solá, and J. Martínez. 2016. "Achieving Mexico's Climate Goals: An Eight Point Action Plan". Work document. Washington, DC: World Resources Institute. Available online at: http://www.wri.org/publication/achieving-mexicos-goals.

Appendix 1 – Assumptions and modeling inputs

General considerations

Consideration	Description
Electricity costs	• For hydrogen production, the primary power sources considered were solar photovoltaic and wind power. • Levelized costs were calculated using CAPEX projections of 320 USD/kW for solar photovoltaics and 825 USD/kW for wind power by 2050. • For recharging electric vehicles, the electricity costs considered are those provided by the grid, as projected in the Program for the National Electric System Development 2018 (PRODESEN), published by SENER.
Fossil fuel cost	• Fossil fuels' future costs were obtained from the PRODESEN 2018. • PRODESEN 2018 includes three scenarios for fossil fuel costs evolution: (1): Low scenario, (2) Planned scenario, and (3) High Scenario. The study uses Planned Scenario for calculations.
Carbon pricing/tax	• Nowadays, Mexico has a tax (Special Tax for Production and Services, IEPS) for fossil fuels' carbon content (except natural gas). NCD Compliance scenario projects to 2050 the increasing trend that IEPS has had from 2014 to 2020. Natural gas is taxed by 2030 in this scenario. • IEPS keeps growing as usual until 2030. From 2030 to 2050, it grows faster, reaching 60 USD/ton of CO_2 by 2050.
Sectors demand forecast	• The study uses historical data of vehicle fleets published by INEGI and SCT. • For the fleet growth projections, Hinicio linked the international trends on the market with Mexico's characteristics like current market size, expected growth on the GDP, or market size of related goods, for example, fertilizers linked to ammonia.

Levelized Cost of Electricity (LCOE)	• Just one forecast for electricity cost was calculated. Parameters considered for the calculations are "business as usual," and they are used for both green hydrogen adoption scenarios.
	• LCOE for solar PV was calculated using the following consideration:
	  • CAPEX 2050: 320 USD/kWh
	  • OPEX: 2% of CAPEX per year
	  • Lifetime: 30 years
	• LCOE for wind power calculated under the following assumptions:
	  • CAPEX 2050: 825 USD(kW
	  • OPEX: 3% of CAPEX per year
	  • Lifetime: 30 years

Levelized Cost of Hydrogen (LCOH)	• The considered scenario has a positive hydrogen cost evolution, following the best cost forecast for hydrogen infrastructure.
	  • CAPEX 2050: 300 USD/kW
	  • Electrolysis efficiency 2050: 48 kWh/kgH_2
	  • Stack Lifetime 2050: 90,000 hours