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ZEV TRANSITION COUNCIL

Decarbonizing road transport by 2050

Effective policies to accelerate the transition to zero-emission vehicles

DALE HALL, YIHAO XIE, RAY MINJARES, NIC LUTSEY, DREW KODJAK

The Zero Emission Vehicles Transition Council is an international forum focused on enhancing political cooperation on the transition to zero emission vehicles (ZEVs).

It brings together Ministers that represent over 50% of the global car market. Council members have agreed to collectively address some of the key challenges in the transition to ZEVs, enabling the transition to be faster, cheaper, and easier for all.

The Council will convene on a regular basis to discuss how to accelerate the pace of the global transition to ZEVs, to reduce emissions and help the global economy meet our goals under the Paris Agreement.

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Executive Summary

This briefing identifies and evaluates government policies used to accelerate the transition to zero-emission vehicles (ZEVs). After an examination of policies in the largest and leading ZEV markets, the paper draws implications for future action based on technology, market, and policy trends.

This document builds upon research presented in our first paper for the ZEV Transition Council, *Decarbonizing road transport by 2050: Zero-emission pathways for passenger vehicles*, in which we summarized the evidence that only battery electric (BEV) and hydrogen fuel cell electric vehicles (FCEVs) have the potential to fully decarbonize on-road vehicles. For the purposes of this briefing, ZEVs include BEVs and FCEVs as well as plug-in hybrid vehicles (PHEVs), which we view as a bridge technology towards a fully zero-emission vehicle fleet.

At the United Nations Glasgow Climate Change Conference (COP 26) in November 2021, 28 national governments signed the Glasgow Declaration on accelerating the transition to 100% zero-emission cars and vans, pledging to work toward making all sales of new cars and vans zero-emission by 2040 at the global level, and by 2035 in leading markets. The declaration was supported by dozens of city and regional governments, as well as several major automotive manufacturers. Regarding heavy-duty vehicles, the governments of fifteen countries—Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, the United Kingdom, Uruguay, and Wales—committed to a global Memorandum of Understanding to enable 100% zero-emission new medium- and heavy-duty truck and bus sales by 2040. This paper was written prior to COP 26 and does not incorporate all of the commitments made there.

Table ES1 charts the policy solutions that ZEV Transition Council members, plus China, have in place to overcome the major barriers to sales, or uptake, of EVs. These are summarized in more detail in the paragraphs following the table, and treated in the body of this briefing as well.

Table ES1. Policies in place for ZEV Transition Council members and China (X=LDV, O=HDV)

		Regulations		Incentives			Infrastructure			Demand	
Jurisdiction	Phase-out target [a b]	CO_2 standard	ZEV regulation	Bonus or rebate	Tax exemption	Heavy-duty in-use incentives	Infrastructure strategy	Public infrastructure funding	Private infrastructure incentives	Light-duty consumer education	Heavy-duty fleet purchase requirements
California	LDV: 2035; HDV: 2045 [c]	X/O	X/O	X/O		O	X/O	X/O	X/O	X	O
Canada	LDV: 2035	X/O		X/O			X	X	X		
China [d]		X/O	X[d]	X/O	X/O		X	X	O	X	O
European Union [e]		X/O				O	X/O	X/O			O
Denmark [f]	LDV: 2030	X/O			X			X			
France	LDV: 2040	X/O		X/O	X/O		X	X	X/O	X	
Germany		X/O		X/O	X	O	X/O	X	X/O	X	
India		X/O		X/O	X			X	O	X	
Italy		X/O		X/O	X		X/O		X		
Japan		X/O		X/O	X/O		X/O	X/O	X/O	X	
Mexico		X			X/O						
Netherlands	LDV: 2030	X/O		X/O	X		X/O	X		X	O
Norway	LDV: 2025	X		O	X		X	X			
Spain	LDV: 2040	X/O		X/O				X	X/O		
South Korea		X	X	X/O	X	O	X/O	X	O	X	O
Sweden		X/O		X/O	X		X/O	X/O	X	X	
United Kingdom	LDV: 2035 HDV: 2040 [g]	X/O		X/O	X		X	X	X	X	
United States		X/O		X/O					X/O		

[a] Phase-outs apply to all combustion vehicles, including conventional hybrids. China and Japan have targets requiring that all new passenger vehicles be ZEVs or hybrids (including conventional hybrids).
[b] The HDV targets tracked in this column are 100% HDV sector-wide phase-out targets. We do not include targets limited to specific sectors, e.g. transit buses, or targets that have ambitions below 100%.
[c] The California 2045 medium- and heavy-duty vehicle target is not a sales target, but an in-use fleet target (also called a vehicle stock target) that is to be implemented "where feasible." A proposal from CARB staff to implement a 100% HD ZEV sales requirement in 2040 was released for public comment in Aug 2021.
[d] China is not a ZEV Transition Council member.
[e] European Union-level actions, including Regulations and Directives, are noted (excluding national actions). EU Directives require member states' adoption and incorporation into national law within two years of EU adoption. They are not separately noted as policies by member states unless expressedly adopted.
[f] The target for Denmark refers to cars only, not vans.
[g] The UK government has proposed a Heavy Goods Vehicles phaseout. It is under public consultation as of August 2021.

Phase-out targets. Consistent with efforts to align with long-term climate mitigation goals, the most effective government phase-out dates for fossil-fuel vehicle sales, or targets for 100% electrification of new vehicles, center around the year 2035 for light-duty vehicles (LDVs) and 2040 for heavy-duty vehicles (HDVs).[1] This briefing includes only government targets announced in an official policy document or articulated in a law or similar framework. It does not include phase-out targets that allow conventional hybrids or vehicles fueled with CNG/LPG/ biofuels, or regulatory proposals that are not yet final.

The European vehicle market has the greatest concentration of LDV phase-out targets with 10 countries having fixed some form of phase-out date. In North, Central and South America, three countries (Canada, Costa Rica, and Chile) and four states and provinces (California, British Columbia, New York, and Québec) have announced light-

1 Although definitions vary from country to country, for the purposes of this paper light-duty vehicles means passenger cars, pickup trucks and minivans. Heavy-duty vehicles means commercial trucks and buses including long-haul tractor-trailers, straight trucks, urban delivery vans, and heavy-duty pickups and vans.

duty phase-out dates. Asia and Africa each have one government-announced phase-out date (Singapore and Cape Verde). An additional 11 governments have signed the International ZEV Alliance commitment to strive to make all passenger vehicle sales in their jurisdictions ZEVs as fast as possible, and no later than 2050.

Despite this significant list of phase-out date announcements, none of the largest vehicle markets in the world—including, in descending order, China, the United States, Europe, Japan, and India—has finalized phase-out targets for LDVs. Consequently, only 14% of global new passenger car sales in 2020 occurred in markets with a phase-out date. In the HDV space, the UK has proposed to end the sale of new non-zero-emission heavy-goods vehicles by 2040. Another fourteen governments, including Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, Uruguay and Wales, committed to working together to enable 100% zero-emission new truck and bus sales by 2040. The Austrian government aims to have 100% of new registrations of all medium- and heavy-duty vehicles be zero-emission starting in 2035.The Chilean government has a target of 100% zero-emission HDV sales by 2045. Fifteen US states and the District of Columbia have signed a Memorandum of Understanding to phase out internal combustion engine HDVs by 2050. California has set a HDV phase-out date for all HDV operations, which is to occur by 2045 where feasible. New York has signed into law a target of 100% zero-emission HDV sales by 2045.

ZEV regulations and CO_2 standards. ZEV regulations require vehicle manufacturers to produce for sale a growing percentage of EVs into a particular market. As a result, ZEV regulations are the most certain and effective policy mechanisms for ensuring a growing share of electric vehicles are available for purchase. For example, California's ZEV share of new passenger vehicles, at 8%, is 6 times greater than in the rest of the United States. Similarly, the share of ZEV sales in 2020 in ZEV-regulated Québec and British Columbia was 5–6 times as large as in the rest of Canada. California first introduced ZEV regulations for LDVs in the 1990s, and since that time China, Québec, British Columbia, South Korea, and Europe have adopted various forms of ZEV regulation for LDVs. California was the first to adopt a ZEV regulation for HDVs. Another US state, Oregon, has also adopted the same Advanced Clean Trucks rule.

Policies that require automakers to lower CO_2 emissions of new vehicles take a number of forms, including fuel-economy standards and greenhouse-gas standards (which together are called CO_2 standards in this paper). CO_2 standards effectively lower emissions from fossil-fuel vehicles and will increasingly spur EV uptake as cost parity approaches (e.g., EU). Europe has demonstrated that stringent, long-term CO_2 standards combined with fiscal incentives and strong enforcement can deliver significant EV uptake. In 2020, more than 80% of new passenger cars were sold into markets regulated by CO_2 standards. As the EV market develops for light-duty and heavy-duty vehicles, cities are exploring other binding regulations to promote EVs. These include the EV-only "zero-emission zones" implemented or planned for Amsterdam, London, Oslo, and Paris. Led by the Netherlands' national policy, 30 to 40 of the largest Dutch cities have pledged to implement zero-emission zones for freight vehicles in city centers.

Fiscal incentives. Fiscal incentives are intended as a bridge policy to address the higher cost of EVs until cost parity is reached. While large subsidies have proven to be highly effective (e.g., Norway and the Netherlands), lower subsidies paired with other policies have also led to high uptake (e.g., China, the UK). In 32 European markets between 2010 and 2017, each €1,000 in incentive value yielded a 5%–7% increase in sales shares.

In the United States, the sales boost was 8% per $1,000 of incentives. On the other hand, removing or reducing financial incentives is often followed by a 30% to 90% decline in electric vehicle sales (e.g., Georgia in 2015, the Netherlands and Denmark in 2016 [for plug-in hybrids], and China in 2019).

Although their design varies by jurisdiction, purchase incentives are more effective when immediately available to the consumer at time of purchase rather than through tax credits or deductions. By monitoring their market, governments can phase down purchase incentives, and more strategically target less-affluent drivers (e.g., California), as electric vehicle price parity with conventional vehicles is approached. For HDVs, governments provide purchase subsidies as well as in-use incentives such as reduced road and bridge tolls. In particular, in-use incentives magnify the significant operating cost advantage of HDV EVs.

Charging and refueling infrastructure. Numerous studies find a clear statistical link between public charging availability and electric vehicle uptake. For example, the Netherlands and Norway, with the world's highest shares of battery electric vehicle (BEV) sales through 2020, have about 20 times the global average number of chargers per person. South Korea, Sweden, France, China, Germany, and the United Kingdom have 3 to 7 times the global average; Canada, the United States, Italy, and Japan, 1.3 to 2.1 times. That said, the number of public chargers required to support a particular level of EV uptake varies widely depending in large part on consumer access to home charging. For this reason, it is not possible to provide a single recommended ratio of chargers per EV or per person.

No matter a country's starting point, public charging infrastructure will need to grow by about 30% annually to enable continued EV deployment toward 100% ZEVs. Governments can leverage private-sector investments in a variety of ways, including coordinated assessments; identification of charging gaps; direct and cost-shared investments; codes for buildings, parking areas, and truck stops; streamlined permitting; and incentives for private installations.

Charging infrastructure investments for HDVs currently lag behind LDVs, and are focused on fleets such as transit buses. While most ZEV Transition Council members have drafted plans or strategies for ZE HDV infrastructure, a smaller number have provided dedicated fiscal incentives and direct subsidies. California has one of the largest investment plans for ZE HDVs, including nearly half a billion dollars to support charging infrastructure.

Consumer awareness / Fleet purchase requirements. Government-supported ZE LDV awareness campaigns are important to increase prospective drivers' understanding of EVs and their benefits. Common policy designs include public-private partnerships to incorporate industry input and market developments, multi-media campaigns, online tools, charger locators, and vehicle comparisons to break down prevailing barriers. For HDVs, consumers are mostly commercial fleets whose purchase decisions are influenced heavily by cost considerations over the vehicle lifetime. Governments are in the early stages of establishing specific requirements for commercial fleets to purchase a growing percentage of zero-emission vehicles. Europe's Clean Vehicles Directive requires national governments to purchase a certain percentage of zero-emission buses, while California's proposed Advanced Clean Fleets regulation will go a step further and mandate zero-emission procurements over large segments of HDV applications in the state.

Table ES2. Recommendations

Policy	Status and Context	Implications
Phase-out targets	Seventeen (17) governments with LDV targets accounted for 14% of global passenger car sales in 2020. HDV phaseouts in place in Austria, Chile, U.S. states and under consultation in the UK, and being pursued by 15 governments.	Establish phase-out targets for LDVs (2035) and HDVs (2040), with emphasis on largest markets.
Regulations	Fifteen (15) governments have ZEV regulations for LDVs; California for HDVs. Nearly all major markets have adopted some form of CO_2 standards; these apply to more than 80% of global LDV and 50% of HDV sales.	Expand ZEV regulations and continue to set stringent, long-term CO_2 standards for LDVs and HDVs that align with ZEV targets and transport decarbonization goals.
Fiscal incentives	Fiscal incentives have stimulated ZE LDV sales in major markets, but are not widely available for HDVs. In-use incentives raise interest in HDVs by lowering their overall cost.	Maintain LDV incentives at least until cost parity (bonus/malus). Introduce or expand purchase and in-use incentives to HDVs as soon as possible.
Charging/ Refueling infrastructure	No matter today's starting point, all nations will have to increase charging infrastructure by about 30% per year over the next decade.	Develop charging infrastructure action plans for LDVs and HDVs in partnership with industry.
Consumer awareness / Fleet requirements	About half of drivers in the U.S., France, and Japan could not imagine themselves in an EV. Most HDV fleet purchase requirements today apply to transit buses or to fleets owned by the government.	Establish / ramp up consumer awareness programs for LDVs and HDVs. Adopt or expand fleet purchase requirements to government and private sector HDV fleets.

Glossary

Battery electric vehicles (BEVs)	Vehicles that run exclusively on electricity derived from on-board batteries, which are charged from an external charging station or Electric Vehicle Supply Equipment (EVSE).
Bonus/malus system	A set of incentives and disincentives used to persuade consumers to give up internal combustion engine vehicles in favor of zero-emission vehicles. Incentives often take the form of rebates or subsidies (bonus). Disincentives can be taxes or fees (malus).
CO_2 standards	Government regulations that set minimum levels of vehicle fuel efficiency and maximum emissions of vehicle carbon dioxide or other greenhouse gases.
Consumer awareness	Consumer familiarity and comfort with the characteristics of electric vehicles and the advantages of EV ownership.
Fast chargers	Electric vehicle chargers with a minimum power of 40 kilowatts (kW). Fast chargers typically use direct current (DC) power and are typically located at stations on highways, rather than at private homes. These are known in some jurisdictions as Level 3 or rapid chargers.
Fleet purchase requirements	A regulation requiring that a minimum share of a fleet be zero-emission, as a stimulant to market demand. Most fleet purchase requirements today apply to transit buses and to fleets owned by governments.
Fiscal incentives	Government financial policies for promoting electric vehicle ownership. These are often divided into subsidies (such as tax credits, rebates, and exemptions from tolls) and vehicle tax reductions (which can be one-time or annual).
Heavy-duty vehicles (HDVs)	Medium and heavy commercial vehicles including buses and trucks whose maximum gross vehicle weight rating is greater than 3500 kg (3856 kg in the US and Canada).
Hydrogen fuel cell electric vehicles (FCEVs)	Vehicles powered by hydrogen, which is converted to electricity by an onboard fuel cell.
Light-duty vehicles (LDVs)	Cars or trucks whose maximum gross vehicle weight rating is less than 3500 kg (3856 kg in the US and Canada). These are typically passenger cars, vans, and light trucks.
New Energy Vehicles (NEVs)	The label used in China for electric vehicles, including BEVs, FCEVs, and PHEVs.
Plug-in Hybrid Electric Vehicles (PHEVs)	Vehicles that can operate on electricity from an onboard battery, but also have an internal combustion engine as a backup source of power. PHEVs charge their batteries from an external charging station or EVSE.
Point-of-sale incentives	Incentives applied at the time of electric vehicle purchase, in contrast to tax rebates and other incentives paid to the purchaser well after the time of sale.

Regular chargers	Chargers that provide less than 40 kW of power at 110-240 volts alternating current (AC). These can be found at homes, workplaces, and other public and private destinations with long dwell times.
Targets	The aspirational visions set by a government to signal future policy directions. In this document targets refer to goals set to ensure that the stock of electric vehicles, as a share of all vehicles, is increasing. Targets assist manufacturers of zero-emission vehicles and related infrastructure in planning their products and investments.
Technological readiness	The level of testing and proving of electric vehicles. Technological readiness is often expressed in terms of laboratory, pilot, and commercial levels of readiness.
Total cost of ownership (TCO)	The cost of purchasing, using, and maintaining a vehicle over its term of ownership. TCO provides an understanding of the cost of a vehicle over the long term.
Zero-emission vehicles (ZEVs)	Vehicles, such as BEVs and FCEVs, that produce zero exhaust emissions. PHEVs, which are considered a bridge technology because they produce no exhaust emissions when operating in electric mode, are also counted as ZEVs in this paper.
Zero-emission zones (ZEZs)	A geographic area, often in an urban center, where no internal combustion engine vehicles are permitted, some or all of the time. These zones can encompass areas ranging from a single street to an entire city.
ZEV regulations	Regulations requiring that ZEVs account for a certain share of new vehicle sales by each automaker, with the share increasing over time.

Decarbonizing Road Transport by 2050

This report summarizes opportunities to accelerate the transition to zero-emission vehicles and identifies effective policies for achieving this goal. It is divided into two parts, covering light-duty vehicles (LDVs, or passenger vehicles and small vans), and heavy-duty vehicles (HDVs, including buses and trucks).

Part I: Zero-emission light-duty vehicles

Zero-emission vehicles offer benefits in terms of climate, air quality, energy independence, and driving experience, but they must overcome barriers (availability, affordability, convenience, and awareness) if they are to replace vehicles powered by internal combustion engines. To that end, governments are implementing actions across five major areas: zero-emission vehicle (ZEV) targets, regulations, incentives, infrastructure, and consumer awareness. Although most governments through 2020 included PHEVs in their ZEV policies, many now build policies and long-term transition targets solely around BEVs and FCEVs.

Policy Sets for LDVs

Targets

Scaling up the manufacture of zero-emission vehicles and supporting infrastructure requires long-term planning by car manufacturers and other market players. To guide planning, governments set targets for phasing out new combustion engine vehicles, generally in line with government climate goals. Figure 1 maps target dates for reaching 100% new ZE LDV sales (for ZEV Transition Council governments that have such targets), along with their historical share of new passenger ZEVs. Other governments have set targets without setting a firm timeline to 100%; for example, the United States aims for a 50% ZEV share of new light-duty vehicles by 2030.

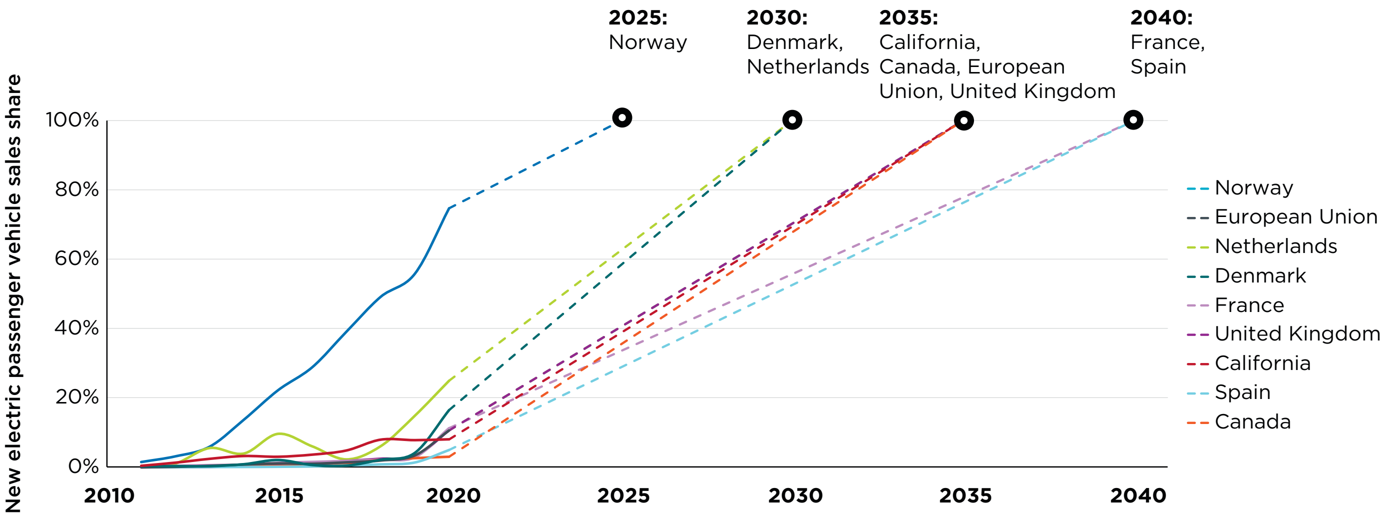

Figure 1. New ZE LDV sales shares by country from 2011–2020 and future 100% targets in select ZEV Transition Council markets.

Governments are increasing their efforts to grow ZE LDV market share, with some success. To date, 28 national and sub-national governments have announced phase-out targets for LDVs. The bulk of these national-level targets are found in Europe (10). Additional subnational governments have also announced phase-out targets: For example, the U.S. states of California, Massachusetts, and New York have targets for 100% ZE LDVs by 2035. An additional 11 governments have signed the International ZEV Alliance commitment to strive to make all passenger vehicle sales in their jurisdictions ZEVs as fast as possible, and no later than 2050.The 100% targets commonly cluster around 2035 (and sooner in some leading markets), to be consistent with long-term climate mitigation goals. Although the political momentum is critical, governments that set fossil-fuel vehicle phase-out targets accounted for 14% of global new passenger car sales in 2020, suggesting that there remain many opportunities to expand the adoption of phase-outs.

Regulations

Regulations that increase EV production and expand model availability take two major forms: 1) ZEV regulations, which require manufacturers to ensure that EVs account for an increasing share of sales, year by year, and 2) CO_2 standards, which require decreasing per-kilometer CO_2 emissions or fuel consumption for new vehicles. More than 80% of new LDVs are sold in markets with CO_2 standards, while California, China and several North American states and provinces have ZEV regulations in addition to CO_2 standards.[2]

Markets with strong regulations tend to have higher ZE LDV uptake and greater model availability. Consider:

- California's ZE LDV share of new passenger vehicles, at 8%, is 6 times that of the rest of the United States.
- The share of ZE LDV sales in 2020 in ZEV-regulated Québec and British Columbia was 5–6 times as large as in the rest of Canada.[3]
- 11 U.S. states that adopted the California ZEV regulations accounted for about 30% of the total U.S. auto market but more than two-thirds of U.S. ZE LDVs in 2019.[4]
- European CO_2 regulations that took effect in 2020 are credited with increasing Europe's ZE LDV share of new passenger car registrations from 3% to 11%. Europe's post-2020 standards include a "benchmark" standard to further incentivize the sale of ZEVs, relaxing an automaker's CO2 targets if at least 15% of new cars and vans are ZEVs or emit below 50 grams CO_2/kilometer in 2025.

As the ZEV market develops, governments are exploring other binding regulations to promote ZEVs. These include "zero-emission zones" (ZEZs) which ban the use of

2 Shikha Rokadiya and Zifei Yang, "Overview of Global Zero-Emission Vehicle Mandate Programs" (Washington, D.C.: International Council on Clean Transportation, April 24, 2019), https://theicct.org/publications/global-zero-emission-vehicle-mandate-program; Nic Lutsey, "Modernizing Vehicle Regulations for Electrification" (Washington, D.C.: International Council on Clean Transportation, October 21, 2018), https://theicct.org/publications/modernizing-regulations-electrification; ICCT, "Global PV Standards Chart Library," The International Council on Clean Transportation, 2016, http://theicct.org/global-pv-standards-chart-library.

3 Government of Canada, "New Motor Vehicle Registrations," Statistics Canada, May 26, 2021, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002101.

4 Anh Bui, Peter Slowik, and Nic Lutsey, "Update on Electric Vehicle Adoption across U.S. Cities" (Washington, D.C.: International Council on Clean Transportation, August 31, 2020), https://theicct.org/publications/ev-update-us-cities-aug2020.

internal combustion engines, typically in urban districts, thereby delivering the air quality benefits of ZEVs to areas with high levels of pollution. Implemented or planned in Amsterdam, London, Oslo, and Paris, the zones cover areas as small as single streets and as large as entire cities. In addition, governments are targeting specific vehicle segments with fleet regulations, such as California's Clean Miles Standard, which requires that 90% of miles driven by ride-hailing companies be zero-emission by 2030.[5]

Success in reaching governments' climate and 100% ZEV goals requires vehicle regulations that drive new vehicle emissions to zero. Whether achieved via CO_2 or efficiency standards, or through direct ZEV requirements, is less important than ensuring sufficient industry investment and adequate ZEV deployment across brands and market segments. Policy design elements to ensure success include annual requirements, sufficient stringency, and enforceability.

Incentives

ZE LDVs generally have a higher purchase price than similar conventional vehicles, but price parity is forecast for 2025–2030.[6] The sustained cost declines are the result of improved battery technology (supported by government funding for research and development) and economies of scale. Until then, financial incentives will be key to accelerating ZEV sales and delivering to consumers the fuel savings associated with ZEVs.[7]

Financial incentives have driven increased ZE LDV sales in 32 European markets (those with ZEV sales shares greater than 2%). In these countries, between 2010 and 2017, each €1,000 in incentive value yielded a 5%–7% relative increase in sales shares (e.g., a €1,000 incentive could move a market from 10% to 10.5%-10.7% sales share).[8] A similar study in the United States calculated an 8% relative increase per $1,000 of incentives.[9] Numerous studies from the United States find that federal and state financial incentives are the most important drivers of ZEV adoption.[10] On the other hand, removing or reducing financial incentives is often followed by a 30% to 90% decline in ZEV sales. Such declines occurred in the state of Georgia in 2015, the Netherlands in 2016 (for plug-in hybrids), Denmark in 2016, and China in 2019—which suggests the importance of maintaining financial benefits for ZE LDVs as prices fall.

5 "California Requires Zero-Emissions Vehicle Use for Ridesharing Services, Another Step toward Achieving the State's Climate Goals," California Air Resources Board, May 20, 2021, https://ww2.arb.ca.gov/news/california-requires-zero-emissions-vehicle-use-ridesharing-services-another-step-toward.

6 National Academies of Sciences, Engineering, and Medicine, "Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy—2025-2035" (Washington, DC, 2021), https://doi.org/10.17226/26092; Nic Lutsey, Hongyang Cui, and Rujie Yu, "Evaluating Electric Vehicle Costs and Benefits in China in the 2020–2035 Time Frame" (Washington, D.C.: International Council on Clean Transportation, April 14, 2021), https://theicct.org/publications/ev-costs-benefits-china-EN-apr2021.

7 Chris Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers" (Consumer Reports, October 2020), https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf.

8 Christiane Münzel et al., "How Large Is the Effect of Financial Incentives on Electric Vehicle Sales? – A Global Review and European Analysis," *Energy Economics* 84 (October 1, 2019): 104493, https://doi.org/10.1016/j.eneco.2019.104493.

9 Bentley C. Clinton and Daniel C. Steinberg, "Providing the Spark: Impact of Financial Incentives on Battery Electric Vehicle Adoption," *Journal of Environmental Economics and Management* 98 (November 1, 2019): 102255, https://doi.org/10.1016/j.jeem.2019.102255.

10 Alan Jenn, Katalin Springel, and Anand R. Gopal, "Effectiveness of Electric Vehicle Incentives in the United States," *Energy Policy* 119 (August 1, 2018): 349–56, https://doi.org/10.1016/j.enpol.2018.04.065; Alan Jenn et al., "An In-Depth Examination of Electric Vehicle Incentives: Consumer Heterogeneity and Changing Response over Time," *Transportation Research Part A: Policy and Practice* 132 (February 1, 2020): 97–109, https://doi.org/10.1016/j.tra.2019.11.004; Bui, Slowik, and Lutsey, "Update on Electric Vehicle Adoption across U.S. Cities"; Easwaran Narassimhan and Caley Johnson, "The Role of Demand-Side Incentives and Charging Infrastructure on Plug-in Electric Vehicle Adoption: Analysis of US States," *Environmental Research Letters* 13, no. 7 (July 2018): 074032, https://doi.org/10.1088/1748-9326/aad0f8.

Table 1. ZE LDV financial incentive design and typical values in select markets[11]

Government	Incentive format	Eligibility	Typical value[a]
California	Rebate	New BEVs, FCEVs, and PHEVs (reduced value); restricted by income and vehicle price	$2,000
Canada	Point-of-sale incentive	New BEVs and PHEVs (reduced value); restricted by vehicle price	$CAD 5,000 ($4,000 USD)
China	Point-of-sale incentive	New BEVs and PHEVs (reduced value); restricted and scaled based on range and technical specifications	RMB 19,000 ($2,900)
France	Point-of-sale incentive from bonus-malus system	New and used BEVs, FCEVs, and PHEVs (reduced value); restricted depending on vehicle price	€6,000 ($7,050), €1,000 used. ($1,160)
Germany	Rebate, split between government and industry	New BEVs, FCEVs, and PHEVs (reduced value); restricted depending on vehicle price	€6,000 ($7,300)
Italy	Point-of-sale incentive from bonus-malus system	New BEVs and PHEVs (reduced value); restricted by vehicle price	€4,000 ($4,800)
Japan	Rebate	New BEVs, FCEVs, and PHEVs (reduced value); additional value if pairing with vehicle-to-home charger or if using renewable power	¥400,000 ($3,600)
Netherlands	Point-of-sale incentive	New and used BEVs (purchased from dealer); restricted by vehicle price and range	€4,000 ($4,800), €2,000 used
Sweden	Rebate from bonus-malus system	New BEVs and PHEVs (reduced value)	SEK 70,000 ($8,050)
United Kingdom	Point-of-sale incentive from dealership	New BEVs and PHEVs with at least 112 km all-electric range	£2,500 ($3,500)
United States	Income tax credit	New BEVs, FCEVs, and PHEVs (reduced value); limited to 200,000 per manufacturer	$7,500

[a] Value refers to government share for typical new battery electric vehicles that meet price specifications

Incentives can take the form of reduced taxes or emissions-indexed taxes. These benefits are especially valuable where combustion vehicles are more heavily taxed. In Norway, BEVs have been exempted since 2001 from the purchase tax (based on vehicle emissions, performance, and weight), the 25% value added tax (VAT), and annual road taxes—representing an incentive of roughly €15,000 ($18,000) for a typical BEV compared to a similar combustion vehicle.[12] Austria, Denmark, Finland, and the Netherlands also waive registration or purchase taxes for ZE LDVs. In India, ZE LDVs are subject to lower VAT rates and buyers receive an income tax credit for interest on

11 Hongyang Cui and Hui He, "China Announced 2020–2022 Subsidies for New Energy Vehicles" (Washington, D.C.: International Council on Clean Transportation, July 13, 2020), https://theicct.org/publications/china-2020-22-subsidies-new-energy-vehicles-jul2020; Dale Hall et al., "European Electric Vehicle Factbook 2019/2020" (Washington, D.C.: International Council on Clean Transportation, July 17, 2020), https://theicct.org/publications/european-electric-vehicle-factbook-20192020; Dale Hall et al., "Electric Vehicle Capitals: Cities Aim for All-Electric Mobility" (Washington, D.C.: International Council on Clean Transportation, September 29, 2020), https://theicct.org/publications/electric-vehicle-capitals-update-sept2020; Hongyang Cui, Dale Hall, and Nic Lutsey, "Update on the Global Transition to Electric Vehicles through 2019" (Washington, D.C.: International Council on Clean Transportation, July 13, 2020), https://theicct.org/publications/update-global-ev-transition-2019; ACEA - European Automobile Manufacturers' Association, "ACEA Tax Guide 2020," April 27, 2020, https://www.acea.be/publications/article/acea-tax-guide; "EV and EV Charger Incentives in Europe: A Complete Guide for Businesses and Individuals," *EVOLVE* (blog), December 4, 2019, https://blog.wallbox.com/en/ev-and-ev-charger-incentives-in-europe-a-complete-guide-for-businesses-and-individuals/.

12 Sandra Wappelhorst et al., "Analyzing Policies to Grow the Electric Vehicle Market in European Cities" (Washington, D.C.: International Council on Clean Transportation, February 23, 2020), https://theicct.org/publications/electric-vehicle-policies-eu-cities.

ZE LDV loans, while several Indian states (e.g., Delhi, Maharashtra) provide incentives for ZE LDV purchase available either at the point of sale or shortly after purchase. Federal U.S. tax credits provide reductions to annual household taxes for ZEV purchasers, and several U.S. states offer a rebate on ZE LDV purchases that applies either at the point of sale or within several months of purchase.

As ZE LDVs approach cost parity with conventional vehicles, the continued effectiveness of financial incentives requires that they be stable and predictable in value, easy to access for consumers, and provided at the time of vehicle purchase rather than as rebates or tax credits afterward.[13] The incentives could be gradually phased down over 5–7 years, following the rate at which ZE LDVs reach cost parity with conventional vehicles, with sufficient advance notice.[14] Incentive eligibility can also be tightened based on vehicle price or consumer income to limit government outlays as vehicle sales volumes increase. Programs can also be adapted to target low-income drivers and heavily polluted areas, and to replace older vehicles, as demonstrated in California.[15]

Infrastructure

ZEVs are attractive alternatives to petroleum-fueled vehicles to the extent that charging them is convenient. Charging can be as easy as refueling internal combustion engine (ICE) vehicles, or perhaps easier, because it can be done at any grid connection, including home and work. Governments play an important role in developing charging infrastructure and providing incentives for investments in it, to ensure that access to charging is not a barrier to ZEV uptake.

Numerous studies find a clear statistical link between public charging availability and ZEV uptake, including in Europe,[16] the United States,[17] and globally.[18] Analysis of multi-year market developments in local-level markets indicates that public charging infrastructure and ZEVs grow in unison.[19]

Figure 2 uses three dimensions of public charging in 12 major ZE LDV markets to show that countries with the largest ZE LDV markets in 2020 tended to have the

13 Zifei Yang et al., "Principles for Effective Electric Vehicle Incentive Design" (Washington, D.C.: International Council on Clean Transportation, June 22, 2016), https://theicct.org/publications/principles-effective-electric-vehicle-incentive-design.

14 Peter Slowik & Nic Lutsey, "Evolution of incentives to sustain the transition to a global electric vehicle fleet" (Washington, D.C.: International Council on Clean Transportation, November 16, 2016), https://theicct.org/publications/evolution-incentives-sustain-transition-global-electric-vehicle-fleet; Peter Slowik et al., "Funding the transition to all zero-emission vehicles" (Washington, D.C.: International Council on Clean Transportation, October 15, 2019), https://theicct.org/publications/funding-ZEV-transition.

15 Román Partida-López, "California's Equity EV Incentive Programs," Greenlining Institute, May 8, 2020, https://greenlining.org/wp-content/uploads/2020/09/Greenlining-Factsheeet-EV-Incentive-equity-programs.pdf, Peter Slowik, "Expanding zero-emission mobility equity and access," (Washington, D.C.: International ZEV Alliance, December 10, 2019), http://www.zevalliance.org/expanding-zev-access/.

16 Gillian Harrison and Christian Thiel, "An Exploratory Policy Analysis of Electric Vehicle Sales Competition and Sensitivity to Infrastructure in Europe," *Technological Forecasting and Social Change* 114 (January 1, 2017): 165–78, https://doi.org/10.1016/j.techfore.2016.08.007.

17 Peter Slowik and Nic Lutsey, "Expanding the Electric Vehicle Market in U.S. Cities" (Washington, D.C.: International Council on Clean Transportation, July 24, 2017), https://theicct.org/publications/expanding-electric-vehicle-market-us-cities; Shanjun Li et al., "The Market for Electric Vehicles: Indirect Network Effects and Policy Design," SSRN Scholarly Paper (Rochester, NY: Social Science Research Network, May 1, 2016), https://doi.org/10.2139/ssrn.2515037.

18 Dale Hall and Nic Lutsey, "Emerging Best Practices for Electric Vehicle Charging Infrastructure" (Washington, D.C.: International Council on Clean Transportation, October 4, 2017), https://theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

19 Dale Hall and Nic Lutsey, "Electric Vehicle Charging Guide for Cities" (Washington, D.C.: International Council on Clean Transportation, February 25, 2020), https://theicct.org/publications/city-EV-charging-guide.

most developed public charging infrastructure. The Netherlands and Norway, with the world's highest shares of BEV sales through 2020, have about 20 times the global average of chargers per person. The expansive charging networks in these two countries were supported by government and power sector investments during the early stages, but have been largely driven by the private sector from 2019 onward—evidence that the business case for investing in charging infrastructure improves as the ZEV market matures.[20] South Korea, Sweden, France, China, Germany, and the United Kingdom have 3 to 7 times the global average charging per capita, while Canada, the United States, Italy, and Japan have 1.3 to 2.1 times the global average. Note, too, that South Korea, the Netherlands and China have the lowest ratios of electric vehicles per public charger, possibly reflecting more limited private off-street parking in dense cities where ZEV uptake and reliance on public charging are high.[21]

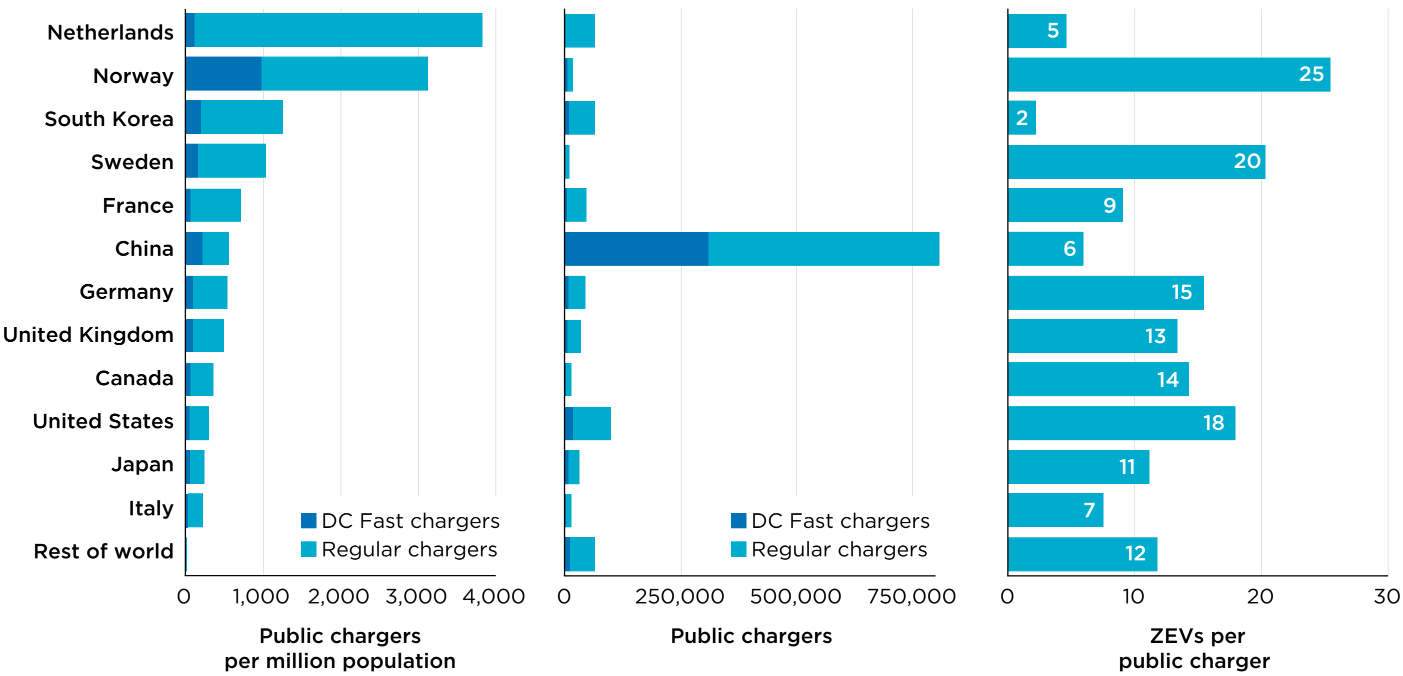

Figure 2. Public charging infrastructure in select countries, measured in absolute number of public chargers (left), chargers per million population (middle), and ZEVs (BEVs and PHEVs) per charger (right).

All jurisdictions will need far more charging to meet their targeted ZEV growth. Over the 2020–2030 period the public charging network will need to expand by 36% annually in Spain, 30% in the United Kingdom, 29% in Germany, 28% in France, and 26% in the United States.[22] Private charging, including at homes, apartment buildings, and workplaces, will also need to expand at roughly the rate of the electric vehicle market. Growth in charging infrastructure in markets with high ZEV uptake has generally been

20 Hall and Lutsey, "Emerging Best Practices for Electric Vehicle Charging Infrastructure"; Robert van den Hoed et al., "Emobility: Getting Smart with Data" (Amsterdam: Amsterdam University of Applied Sciences, June 2019), https://pure.hva.nl/ws/files/5796298/HvA_Emob_DIGI.pdf.

21 Hall and Lutsey, "Emerging Best Practices for Electric Vehicle Charging Infrastructure."

22 Michael Nicholas and Sandra Wappelhorst, "Spain's Electric Vehicle Infrastructure Challenge: How Many Chargers Will Be Required in 2030?" (Washington, D.C.: International Council on Clean Transportation, January 27, 2021), https://theicct.org/publications/spain-charging-infra-jan2021; Michael Nicholas and Nic Lutsey, "Quantifying the Electric Vehicle Charging Infrastructure Gap in the United Kingdom" (Washington, D.C.: International Council on Clean Transportation, August 27, 2020), https://theicct.org/publications/charging-gap-UK-2020; M Nicholas and S. Wappelhorst, "Quantifying Germany's Electric Vehicle Charging Infrastructure Gap through 2030" (The International Council on Clean Transportation, forthcoming 2020).

in line with the necessary growth, due to investments made by governments, pure-play charging companies, energy companies diversifying from petroleum fuels, electric power utilities, and automakers.

Governments have myriad ways to leverage private sector investments and support the buildout of ZE LDV charging. Regular assessment of future charging needs, following from ZEV goals and regulations, provides investors with more confidence to build charging and also identifies areas where public support may be needed. For example, the California Energy Commission analyzes and updates charging needs every 2 years.[23] Almost all governments in leading ZE LDV markets provide funding for expanded public charging (e.g., Canada invested $150 million in 2020; India has committed to installing over 2,600 chargers). Governments also provide incentives to support installation at homes or workplaces. Examples include tax credits of €300 (up to €960 in a multi-unit dwelling) in France; incentives of up to ¥1,300,000 ($11,700) for chargers in apartment buildings, and ¥68,000 ($6,100) for office buildings in Japan; and rebates of up to £350 for private home or workplace chargers in the United Kingdom.[24] Governments can also develop EV-ready building and construction codes to ensure buildings are prepared for charging, reducing the costs of installation. An example is the Energy Performance of Buildings directive from the European Commission requiring that all parking spaces at new residential buildings and 20% at non-residential buildings be wired for future charger installations.[25]

With input from public-private partnerships, governments can develop charging infrastructure action plans, which in turn send clear signals and identify gaps. Charging infrastructure investments need to match government targets for continued ZE LDV deployment toward 100% ZEVs, which often means increasing charging by 20–35% annually through 2030. Governments can encourage private sector investments in a variety of ways, including with coordinated assessments to identify charging gaps, direct and cost-shared investments, stronger building and parking codes, streamlined permitting, electricity rate reform to enable lower cost of charging, and incentives for private installations.

Awareness

Even when ZE LDVs are available, affordable, and convenient to operate, many consumers may be unaware of ZE LDV options or unsure of whether these vehicles can meet their needs. Consumer understanding of ZE passenger vehicles remains limited, even in leading markets, but consumer education can likely change this. One international study found that 57% of drivers in the United States, 50% in France, and 46% in Japan could not imagine themselves in an electric car; lack of charging, limited range, and high price were the top areas of concern.[26] Another found that 30% of customers disinclined to buy a ZE passenger vehicle cited lack of information as a primary obstacle.[27] Beyond the previously mentioned programs to ensure that ZE LDVs

23 Noel Crisostomo et al., "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment" (California Energy Commission, January 2021), https://efiling.energy.ca.gov/getdocument.aspx?tn=236237.

24 "EV and EV Charger Incentives in Europe."

25 "Questions & Answers on Energy Performance in Buildings Directive," European Union Directorate-General for Energy, accessed January 22, 2020, https://ec.europa.eu/info/news/questions-answers-energy-performancebuildings-directive-2018-apr-17_en.

26 Enno Pigge, "Many People Still Doubtful About Electric Cars' Environmental Friendliness - Continental Mobility Study 2020," Continental, January 7, 2021, https://www.continental.com/en/press/press-releases/mobility-study-electric-mobility-244206.

27 "2021 U.S. Electric Vehicle Consideration (EVC) Study," J.D. Power, accessed May 28, 2021, https://www.jdpower.com/business/press-releases/2021-us-electric-vehicle-consideration-evc-study.

are affordable and convenient, education and awareness campaigns targeting potential drivers could play a key role in spurring ZE LDV sales.

Table 2 summarizes key attributes of ZE LDV consumer awareness programs led or supported by governments. Each program is a partnership between governments and private actors, including automakers, electric utilities, and non-profit organizations who advance the effort by contributing funding, providing up-to-date data and market trends, and broadening audience reach.[28] Common themes include the availability of financial incentives and cost-savings, charging options, driving performance, and environmental benefits. These campaigns can have a broad reach: The results from a 2016 Go Ultra Low campaign show that 53% of viewers said the campaign increased their interest in considering an electric vehicle the next time they buy a car. The Electric for All campaign, run by Veloz in California during 2019, produced more than 16 million video views and generated over 182 news stories.[29] At the same time, these programs are relatively inexpensive; the Veloz campaign cost $883,000 to operate in the 2019-2020 fiscal year.

Table 2. Examples of consumer awareness programs

Program	Supporting government(s)	Other stakeholders	Programs
Drive Change. Drive Electric.	6 Northeast U.S. states	Automakers	Informational videos, online tools, business engagement
Go Electric	India	To be determined	Informational videos, social media
Go Ultra Low	United Kingdom	Automakers, charging operators, energy companies	Television and radio ads, online tools
New Energy Vehicles Entering the Countryside	China, 12 provinces, cities	Automakers, China Association of Automobile Manufacturers	Television ads, social media, touring events
Roulons Vert	Québec	Équiterre (non-profit), electric utilities, drivers' associations	Informational videos, online tools, webinars
Veloz	California	Automakers, electric utilities, charging operators, non-profits	Television and newspaper ads, webinars, conferences, online tools

Governments can also provide guidance and funding to organizations well-positioned to reach drivers. Local governments and non-profit organizations often conduct ride-and-drive events, which are known to be effective: those who have ridden in a ZEV are three times as likely to consider purchasing one.[30] Electric power utilities eyeing ZEVs as a dependable and flexible source of electricity demand can provide ZEV information in monthly bills or on their websites. Governments can support training or certification programs to ensure that auto dealers have accurate information for customers. These activities set the stage for the day when automakers promote and market ZEVs as consistently as they do conventional models.

28 Lingzhi Jin and Peter Slowik, "Literature Review of Electric Vehicle Consumer Awareness and Outreach" (Washington, D.C.: International Council on Clean Transportation, March 24, 2017), https://theicct.org/publications/literature-review-electric-vehicle-consumer-awareness-and-outreach.

29 Gennet Paauwe, "2019 Veloz Annual Report" (Veloz, March 2020), https://www.veloz.org/resource/2019-veloz-annual-report/.

30 Jin and Slowik, "Literature Review of Electric Vehicle Consumer Awareness and Outreach"; "2021 U.S. Electric Vehicle Consideration (EVC) Study."

Standout consumer awareness programs tend to collect data on prospective ZE LDV purchasing decisions. They use public-private partnerships to incorporate industry input and market developments. And they make use of multiple media (video, television, social media, webinar), online tools, charger locators, and vehicle comparisons to increase awareness of the benefits of ZEVs and to break down prevailing barriers.

Policies in ZEV Transition Council member states

The actions described in previous sections—targets, regulations, incentives, infrastructure deployment, and awareness campaigns—have been important in spurring early ZE LDV market growth. ZEV Transition Council members have been leaders in developing and implementing policies in these areas. Table 3 summarizes the policies in place among select ZEV markets as of May of 2021 in each of these categories.

Table 3. Policies in place for LDVs in ZEV Transition Council member countries and China

			Regulations		Incentives		Infrastructure			Demand
Jurisdiction	100% ICE phase-out (based on new sales or registrations)	2020 ZEV sales share / BEV sales share	CO_2 standard	ZEV regulation	Bonus or rebate	Tax exemption	Charging infrastructure strategy	Public charging funding	Private charging incentives	Consumer education campaign
California	2035	8%/6%	X	X	X		X	X	X	X
Canada	2035	3%/2%	X		X		X	X	X	
China[a]	- [b]	6%/5%	X	X	X	X	X	X		X
European Union[c]		11%/5%	X				X	X		
Denmark	2030	17%/7%	X			X		X		
France	2040	11%/7%	X		X	X	X	X	X	X
Germany	-	13%/7%	X		X	X	X	X	X	X
India	-	<1%	X		X	X		X		X
Italy	-	4%/2%	X		X	X	X		X	
Japan	- [b]	1%/<1%	X		X	X	X	X	X	X
Mexico	-	<1%	X			X				
Netherlands	2030	25%/20%	X		X	X	X	X		X
Norway	2025	75%/54%	X			X	X	X		
Spain	2040	5%/2%	X		X			X	X	
South Korea	-	2%/2%	X		X	X	X	X		X
Sweden	-	32%/10%	X		X	X	X	X	X	X
United Kingdom	2035	11%/7%	X		X	X	X	X	X	X
United States	-	2%/2%	X		X				X	

[a] China is not a ZEV Transition Council member.
[b] Phase-outs apply to all combustion vehicles, including hybrids and plug-in hybrids. China and Japan have targets for all new passenger ZEVs or hybrids.
[c] European Union-level actions in place (not national actions) are noted. The European Union's CO_2 standards are counted as the prevailing policy for all member states.

Most ZEV Transition Council governments have adopted a wide array of promotional actions, but some have been more widely or strictly applied than others. For example, every ZEV Transition Council government has CO_2 standards in place that could spur automakers to deploy more ZEVs, although the standards vary in stringency and in their treatment of ZEVs. Only two markets—California and China—have national ZEV regulations with legally binding targets (Canada has provincial-level ZEV regulations), while the European Union has non-binding ZEV benchmarks as part of their CO_2 standards. Most governments (14 of 17) have provided significant public funding for the growth of the public charging network, but market-wide financial incentives for private charging (whether at homes or workplaces) are found in just 9 jurisdictions.

Table 3 is useful for helping governments to identify and plan new policies to fill gaps in their ZEV strategies. Most jurisdictions in the ZEV Transition Council have adopted at least 6 of the 9 actions recommended here. Four—California, France, Sweden, and the United Kingdom—have adopted 8 of the 9. The strength of actions also influences ZEV uptake; while Norway has only 4 of these actions in place, the size of its financial incentives and its charging infrastructure support have helped it to become the world's leading ZEV market. Even when actions are in place, governments can continue to learn from each other to strengthen, refine, and adapt these policies as their ZEV markets grow and evolve.

Part II. Zero-emission heavy-duty vehicles

Sector Background

HDVs represented around 10 percent of the global on-road vehicle fleet in 2020 but deserve attention because they are heavy polluters.[31] HDVs are responsible for 78% of global black carbon, or soot, emissions and 86% of nitrogen oxide emissions.[32] The total greenhouse gas emissions of the global HDV fleet are projected to surpass those of the LDV fleet by 2025, based on current trajectories.[33]

In contrast to the steady increase in sales of ZE LDVs, sales of zero-emission heavy-duty vehicles (ZE HDVs) are small but clearly on the rise. In 2020, more than 4,600 ZE HDVs were sold in ZEV Transition Council markets, less than one percent of all HDV sales (Figure 3). Buses accounted for two-thirds of ZE HDV sales across all ZEV Transition Council markets but just 2.6 percent of bus sales overall. Less than one percent of new trucks were zero-emission. Despite its modest start, the ZE HDV market shows clear promise because the technology is ready, declining in cost, and increasingly available, particularly among vehicles that can rely primarily on overnight depot charging of battery-electric powertrains.

31 International Council on Clean Transportation, *Prospects for Fuel Efficiency, Electrification, and Fleet Decarbonization*, Global Fuel Economy Initiative, (International Council on Clean Transportation: Washington, DC, 2019), https://www.globalfueleconomy.org/media/708302/gfeiworking-paper-20.pdf.

32 Susan C Anenberg, Joshua Miller, Daven Henze, and Ray Minjares, *A Global Snapshot of the Air Pollution-Related Health Impacts of Transportation Sector Emissions in 2010 and 2015*, (International Council on Clean Transportation, Washington, DC: February 26, 2019), https://theicct.org/publications/health-impacts-transport-emissions-2010-2015; Joshua Miller and Lingzhi Jin, *Global Progress toward Soot-Free Diesel Vehicles in 2019*, (International Council on Clean Transportation: Washington, DC: September 23, 2019), https://theicct.org/publications/global-progress-toward-soot-free-diesel-vehicles-2019.

33 International Council on Clean Transportation, *Prospects for Fuel Efficiency.*

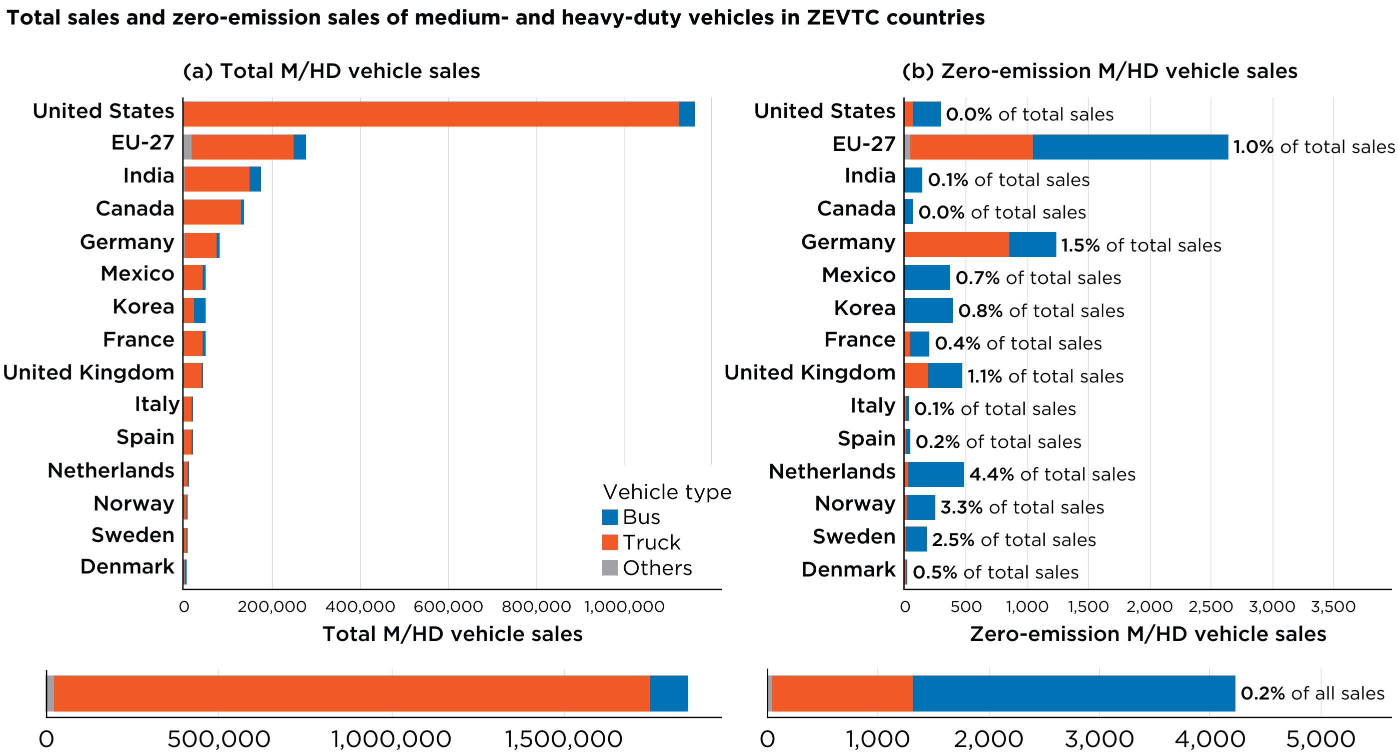

Figure 3. 2020 sales of medium- and heavy-duty vehicles among ZEV Transition Council members (a) All HDVs (b) ZE HDVs only

Technology Readiness

Battery-electric powertrains across multiple uses have achieved pilot- or commercialization-stage technological readiness. (Figure 4a and b)[34] Battery-electric transit buses and medium-duty battery-electric delivery trucks are now commercialized. Short range battery-electric heavy-duty delivery trucks and yard trucks (trucks that move trailers and containers in freight terminals, port facilities, etc. for short distances) have reached the mid- to late-pilot stage, and are being commercialized at small scales. Fuel cell electric heavy-duty delivery trucks are at the early pilot stage and are moving to commercial-scale deployment in Europe.[35]

The transition to zero-emission HDVs is led by battery-electric powertrains. Market segments with operational profiles similar to buses—those with predictable daily range, return-to-base operation, and lengthy dwell time to support depot charging—will quickly benefit from the components and lessons learned from the use of battery-electric powertrains in buses. Sanitation trucks, postal trucks, box trucks, drayage trucks, delivery vans, and other urban vehicles are applications where these investments will readily transfer. In other market segments, where high range, high payload, and short overnight dwell time require expensive high-speed charging infrastructure, hydrogen fuel cell powertrains and electric road systems offer alternative solutions. The technology to transition to zero-emission HDVs in key market segments is ready today, and nearly ready across other market segments.

34 California Air Resources Board, "2020-21 Long-Term Heavy-Duty Investment Strategy," (November 2020), https://ww2.arb.ca.gov/sites/default/files/2020-11/appd_hd_invest_strat.pdf.

35 Hyundai has delivered 50 Xcient fuel cell trucks in Switzerland out of a planned 1,600 units by 2025. "Hyundai Hydrogen Mobility Grabs 'Watt d'Or 2021' for Advancing Swiss Decarbonization Efforts,", Hyundai, accessed August 25, 2021, https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-hydrogen-mobility-grabs-%E2%80%98watt-d%E2%80%99or-2021%E2%80%99-for-advancing-swiss-decarbonization-efforts-0000016613

Continued investment in research and development will further enhance the technological readiness of battery-electric and fuel-cell electric technologies in HDV market segments.

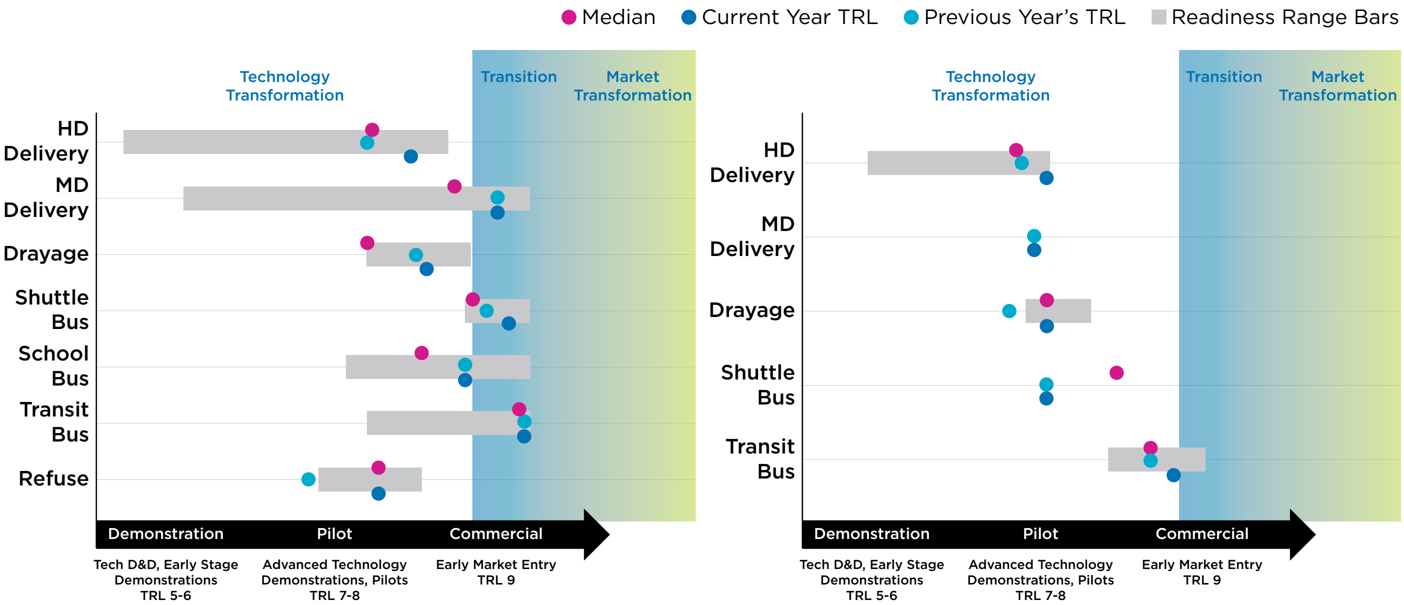

Figure 4. Technology readiness level (TRL) across major HDV market segments. Left: (a) on-road battery-electric powertrains. Right: (b) hydrogen fuel cell powertrains. Adopted from California Air Resources Board (2020).

Total Cost of Ownership

The ZEV literature suggests that by 2030, the TCO of a zero-emission HDV will be equal to or lower than an ICE-powered HDV across all major market segments, under current policy scenarios, thanks to ZE HDVs' greater efficiency, lower energy costs, and declining upfront costs. Transit buses, urban delivery vehicles and other HDVs with a similar operational profile–predictable daily range less than 320 km (200 mi), long and predictable idle time, and predictable schedules–demonstrate equal or lower TCO today when compared with an equivalent fossil-powered vehicle.[36] This result is especially clear when effective policies such as fiscal incentives and CO_2 standards capture externalities of air pollution and climate change.[37] More details of relevant TCO analyses can be found in Appendix A3.

A study of North American long-haul tractors over 11.8 tonnes—vehicles with the longest daily mileage and least predictable idle time and route—demonstrated likely TCO parity without incentives by around 2030.[38] The Zero Emission Vehicle Alliance found that a 19-ton regional haul truck would achieve cost parity by 2028, while a 40-tonne long-haul truck and a yard tractor capable of pulling 44 tonnes would

36 ICF, "Comparison of Medium- and Heavy-Duty Technologies in California," (December 2019), https://efiling.energy.ca.gov/GetDocument.aspx?tn=236878&DocumentContentId=70033.

37 Hanjiro Ambrose, Nicholas Pappas, and Alissa Kendall, "Exploring the Costs of Electrification for California's Transit Agencies," ITS Reports 2017, no. 03 (October 1, 2017), https://doi.org/10.7922/G2PZ570Z.

38 Dale Hall, and Nic Lutsey, *Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks*, (International Council on Clean Transportation: Washington, DC: August 9, 2019), https://theicct.org/publications/zero-emission-truck-infrastructure.

achieve cost parity by 2029.[39] In a follow-up focusing on European applications, another study found that battery-electric 42-tonne tractor-trucks can achieve TCO parity with diesel counterparts in seven European countries before 2030 even without new policy interventions and incentives.[40] While diesel tractor-trailers are expected to become more efficient, any resulting cost savings are expected to be outweighed by increased vehicle costs to meet emission standards beyond 2025–2030, increasing diesel tractor-trailers' TCO by 3%. Meanwhile, the cost of zero-emission trucks is expected to decline in the coming years thanks to declining battery and electric motor costs.[41]

Product Availability

In total, 468 commercially available medium- and heavy-duty vehicle models were available from more than 100 manufacturers in 2020.[42] As many as 125 zero-emission medium- and heavy-duty vehicles are in the pipeline or commercially available in the North American market with more manufacturers poised to invest.[43] The number of zero-emission heavy-duty vehicle models worldwide is expected to grow to 606 by 2023.[44] Model availability varies by market segment and powertrain, since most models today are in the buses category and use battery-electric powertrains.

Model availability explains why zero-emission buses lead the early transition in the HDV market. All major manufacturers of school buses in North America are taking orders for zero-emission products today, and new manufacturers are entering the market. In 2019, at least 25 bus products were available from as many as twelve manufacturers in this market. Elsewhere, ZEV Transition Council markets can find commercially available zero-emission bus models from a range of manufacturers including Daimler, MAN, Solaris, VDL, Volvo, Alexander Dennis, Tata, Yutong, BYD and others. Europe has seen the introduction of 150 hydrogen fuel-cell buses in total since 2012.[45] Sixty-four hydrogen fuel-cell buses are in active service in the United States, with 30 more in the planning stage.[46]

In the heaviest vehicle weight category, including US Class 7-8, the availability of models varies by vehicle application and powertrain. In the refuse truck category, for example, four manufacturers—Mack, Paccar, BYD and Lion Electric—are taking orders on battery-electric models in North America. With respect to tractor-trailers in this weight class, Freightliner (Daimler), Volvo, and Peterbilt (Paccar) have either released a prototype or announced plans to bring a battery-electric tractor-trailer product

39 Dan Welch, Cristiano Façanha, Rob Kroon, David Bruil, Floris Jousma, and Harm Weken, "Moving Zero-Emission Freight toward Commercialization," (ZEV Alliance: October 2020), http://www.zevalliance.org/wp-content/uploads/2020/12/Zero-Emission-Freight-Commercialization-dec2020.pdf.

40 Hussein Basma, Arash Saboori, and Felipe Rodriguez, *Total Cost of Ownership for Tractor Trailers in Europe: Battery Electric vs. Diesel*, (International Council on Clean Transportation: Washington, DC: Forthcoming).

41 Hall and Lutsey, *Estimating the Infrastructure Needs*.

42 "Biggest Zero-Emission Trucks Hit Market at Accelerating Rate, Boast Impressive Ranges," CALSTART, accessed August 25, 2021, https://calstart.org/zeti-analytics-may2021/.

43 Benjamin Sharpe, Claire Buysse, Jason Mathers, and Victor Poudelet, *Race to Zero: How Manufacturers Are Positioned for Zero-Emission Commercial Trucks and Buses in North America*, (International Council on Clean Transportation: Washington, DC: October 29, 2020), https://theicct.org/publications/canada-race-to-zero-oct2020.

44 CALSTART, "Biggest Zero-Emission Trucks."

45 "Fuel Cell Bus Projects in the Spotlight: Fleets, Manufacturers, Trends," *Sustainable Bus*, January 21, 2021, https://www.sustainable-bus.com/fuel-cell-bus/fuel-cell-bus-hydrogen/.

46 NREL, "U.S. Fuel Cell Bus Projects," (November 3, 2020), https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.html.

to market by 2022.[47] BYD, Lion Electric, and Tesla are taking orders on new battery-electric tractors with claimed ranges up to 800 km (500 mi).

Heavy-duty hydrogen fuel cell models are not as widely available. Toyota and Kenworth (Paccar) are collaborating on pilot testing of ten hydrogen fuel cell tractor trucks in the Port of Los Angeles, delivering the first two commercial trucks to customers in December 2020.[48] In Switzerland, Hyundai supplied forty-six hydrogen fuel-cell tractor trucks in 2020 on a lease basis with plans to deliver an additional 140 units in 2021 and 1,600 by 2025. Hyundai announced plans to deploy on a lease basis 30 Xcient fuel cell trucks in California by 2023.[49] And in 2020, Daimler and Volvo formed a joint venture in 2020 to design, produce, and commercialize hydrogen fuel cell powertrains for heavy-duty vehicle applications.[50]

Significant potential exists to transition a large share of HDVs to battery-electric powertrains while hydrogen fuel cell products mature. Governments concerned with the risk of stranded assets would be wise to maximize deployment of depot-charging battery-electric solutions that have proven their commercial viability. For market segments such as tractor-trailers that depend on en-route charging and refueling outside of urban areas, governments can work with the private sector to make strategic investments in publicly accessible high-speed charging or hydrogen refueling stations along key transportation corridors.

Private Sector Goals

Large global engine and vehicle manufacturers have adopted ambitious plans for producing new zero-emission bus and truck models. In 2021 Daimler announced its goal to "phase down" the internal combustion engine from its product line within 10 to 15 years. The TRATON Group, the parent company of brands including MAN, Scania, and Navistar, aims to reduce conventional engines to just one-fifth of all product development by 2025. These commitments do not include the sizable number of all-electric products to be produced by new manufacturers. These commitments are also complemented by those of large customers of HDVs, fleet owners, who are shaping the demand for ZEVs. Table 4 gives a sense of the expected pace of private sector activity in the ZE HDV market. Governments might use these as a starting point for securing a similar pace in their own markets, by employing effective policies and defining greater ambition.

47 Sharpe et al., *Race to Zero: How Manufacturers Are Positioned.*

48 Jason Cannon, "First Toyota, Kenworth Hydrogen Trucks Headed to Customers," *Commercial Carrier Journal*, December 10, 2020, https://www.ccjdigital.com/business/article/14940178/first-toyota-kenworth-hydrogen-trucks-headed-to-customers.

49 "Hyundai Motor Upgrades Design and Performance of XCIENT Fuel Cell Truck for Global Expansion," Hyundai Motors, Accessed August 25, 2021, https://www.hyundai.com/worldwide/en/company/newsroom/-0000016662 and "Hyundai's XCIENT Fuel Cell Hitting the Road in California," Hyundai Motors, accessed August 25, 2021, https://www.hyundai.com/worldwide/en/company/newsroom/-0000016695

50 "Fuel-Cell Joint Venture by Volvo and Daimler Trucks," Daimler, accessed August 25, 2021, https://www.daimler.com/company/news/fuel-cell-joint-venture-volvo.html.

Table 4. Select OEM and fleet owner commitments to zero-emission sales

Vehicle Manufacturers	
Daimler Trucks[51, 52]	Full zero-emission product line-up by 2027 100% carbon neutral sales in EU, North America, and Japan by 2039
Traton Group[53]	50% zero-emission sales of Scania brand trucks in 2030 60% zero-emission sales of MAN brand delivery trucks in 2030 40% zero-emission sales of MAN brand long-haul vehicles in 2030
Volvo Trucks and Buses[54]	35% fully electric product sales by 2035 100% net zero greenhouse gas emissions by 2040
Hyundai[55]	500,000 unit fuel cell capacity for EVs by 2030
Ford Motor Company[56]	40% global EV sales by 2030
Fleet Owners	
Fedex [57]	Convert worldwide pickup and delivery fleet to zero-emission vehicles by 2040
WalMart[58]	Transition the entire fleet to zero-emission trucks by 2040
Inkga Group[59]	Provide 100% zero-emission delivery as soon as 2025
Deutsche Post/DHL Group[60]	Deploy 80,000 last-mile delivery EVs and achieve 60 percent electrification of the fleet by 2030

Policy Sets for HDVs

Policies to accelerate adoption of ZE HDVs overlap to some degree with those designed for passenger cars, although they often differ on specifics. In the section below, we describe six sets of policies, explaining the rationale for each and providing best practice examples from ZEV Transition Council member jurisdictions. A

51 "Daimler Truck Strategy Day on May 20, 2021," Daimler, accessed July 6, 2021, https://www.daimler.com/investors/events/capital-market-days/2021-daimler-truck-strategy-day-may.html.

52 "CO_2-Neutral Commercial Vehicle Fleet by 2039," Daimler, accessed July 6, 2021, https://www.daimler.com/sustainability/co2-neutral-commercial-vehicle-fleet-until-2039.html.

53 "The TRATON GROUP Is Systematically Preparing for the Transition to Electric Drives," TRATON, accessed July 6, 2021, https://traton.com/en/newsroom/press_releases/press_release_22032021.html.

54 "Reducing Carbon Emissions," Volvo Group, accessed August 25, 2021, https://www.volvogroup.com/en/sustainability/climate-goals-strategy/reducing-carbon-emissions.html

55 "Hyundai Motor's Delivery of XCIENT Fuel Cell Trucks in Europe Heralds Its Commercial Truck Expansion to Global Markets," H2energy, accessed July 6, 2021, https://h2energy.ch/en/2020/10/07/hyundai-motors-delivery-of-xcient-fuel-cell-trucks-in-europe-heralds-its-commercial-truck-expansion-to-global-markets/.

56 Tom Krisher, "Ford: Electric Vehicles to Be 40% of Global Sales by 2030," *AP News*, May 26, 2021, https://apnews.com/article/electric-vehicles-technology-business-d874b87e8b7f9e2aa25330b31040c8d4.

57 "FedEx Commits to Carbon-Neutral Operations by 2040," FedEx Newsroom, accessed June 22, 2021, https://newsroom.fedex.com/newsroom/sustainability2021/.

58 "Walmart's Regenerative Approach: Going Beyond Sustainability," Walmart, accessed June 22, 2021, https://corporate.walmart.com/newsroom/2020/09/21/walmarts-regenerative-approach-going-beyond-sustainability.

59 "Zero Emissions for Home Deliveries," IKEA, accessed August 11, 2021, https://about.ikea.comhttps://about.ikea.com//en/Sustainability/Becoming-climate-positive/Zero-emissions-for-home-deliveries.

60 "Accelerated Roadmap to Decarbonization: Deutsche Post DHL Group Decides on Science Based Targets and Invests EUR 7 Billion in Climate-Neutral Logistics until 2030," Deutsche Post DHL Group, Accessed June 22, 2021, https://www.dpdhl.com/en/media-relations/press-releases/2021/dpdhl-accelerated-roadmap-to-decarbonization.html.

comprehensive list of ZE HDV policies in ZEV Transition Council members is provided in Appendix A2.

Targets

As with passenger ZEVs, overarching political statements that set non-binding targets communicate the direction of government policy and help manufacturers and consumers to make investment, planning, and purchasing decisions. As of July 2021, the only ZEV Transition Council government with a concrete, 100% HDV sector-wide target is California. The UK has proposed to shift all HDV sales to zero-emission by 2040, subject to public consultation.[61] A total of 5 ZEV Transition Council members have established phase-out targets for the sale of new ICE HDVs, the deployment of a certain number or percentage of ZE HDVs, and the operation of a certain share of ZE HDVs. (See Appendix A2.) In addition, Canada, Denmark, Netherlands, Norway, Sweden and the UK are among a group of fifteen governments committed to working together to enable 100% zero-emission new truck and bus sales by 2040.[62] Outside the ZEV Transition Council, Austria and Cape Verde have 100% phase-out targets of new medium- and heavy-duty vehicles, by 2035, and Chile has a target of 2045, while the U.S. state of New York has passed legislation requiring a 100% HDV phase-out by 2045. Experience in the LDV sector suggests that such targets are effective,[63] especially when targets are enforceable.

Actions taken in California reflect target-setting best practices. In 2020 California governor Gavin Newsom set a statewide non-binding target of 100% zero-emissions for drayage truck operations by 2035 and 100% ZE HDV operations, where feasible, by 2045.[64] California's non-binding targets are comprehensive in vehicle segment coverage and ambitious in the pace of ZEV phase-in, two characteristics that make California a leader in ZE HDV policy.

Regulations

Legally-binding vehicle regulations can accompany political phase-out targets to cement manufacturers' shift to ZE HDV production and overcome the supply barrier. Regulations can take the form of 1) ZEV regulations and 2) CO_2 standards. As noted in Part I, both types of regulations have proven effective in accelerating the uptake of ZE technologies for LDVs.

ZEV regulations require that a certain share of a manufacturer's HDVs be zero-emission, with the required share varying across vehicle classes based on differences in production cost, feasibility, and emission footprints. CO_2 standards shape the technologies manufacturers choose to sell to consumers, by setting standards for fuel consumption and pollutant emissions, and by setting minimum requirements for the

61 Department of Transport, "Consultation on When to Phase out the Sale of New, Non-Zero Emission Heavy Goods Vehicles" (June 2021), https://www.gov.uk/government/consultations/heavy-goods-vehicles-ending-the-sale-of-new-non-zero-emission-models.

62 Global Commercial Vehicle Drive to Zero, "Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles" (October 2021), https://globaldrivetozero.org/site/wp-content/uploads/2021/11/Global-MOU-ZE-MHDVs.pdf.

63 ICCT and EV100, *Driving a Green Future: A Retrospective Review of China's Electric Vehicle Development*, (International Council on Clean Transportation: Washington, D.C., January 2021), https://theicct.org/publications/china-green-future-ev-jan2021.

64 "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change," California Office of Governor,accessed March 26, 2021, https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.

environmental and energy performance of vehicles or engines. Countries with such regulations—most ZEV Transition Council members have them today—often increase the stringency of these standards to deepen manufacturers' commitment to cleaner technologies that have become commercially available. This action reduces the market advantages of lower-cost, higher-polluting technologies by requiring manufacturers to incorporate the cost of pollution into their products. By adopting standards with sufficient stringency, governments can improve the performance and increase the compliance cost of ICEs, and shift the market towards zero-emission power trains as the best performing technology.

For HDVs, the only ZEV regulation as of mid-2021 is the Advanced Clean Trucks (ACT) Regulation in California. The regulation requires at least 30% ZE HDV sales in certain market segments by 2030 and as much as 75% by 2035. (Figure **5**).[65] The binding targets clearly define applicable vehicle categories and qualifying ZE powertrains and have interim milestones (see Appendix A2 for more details).

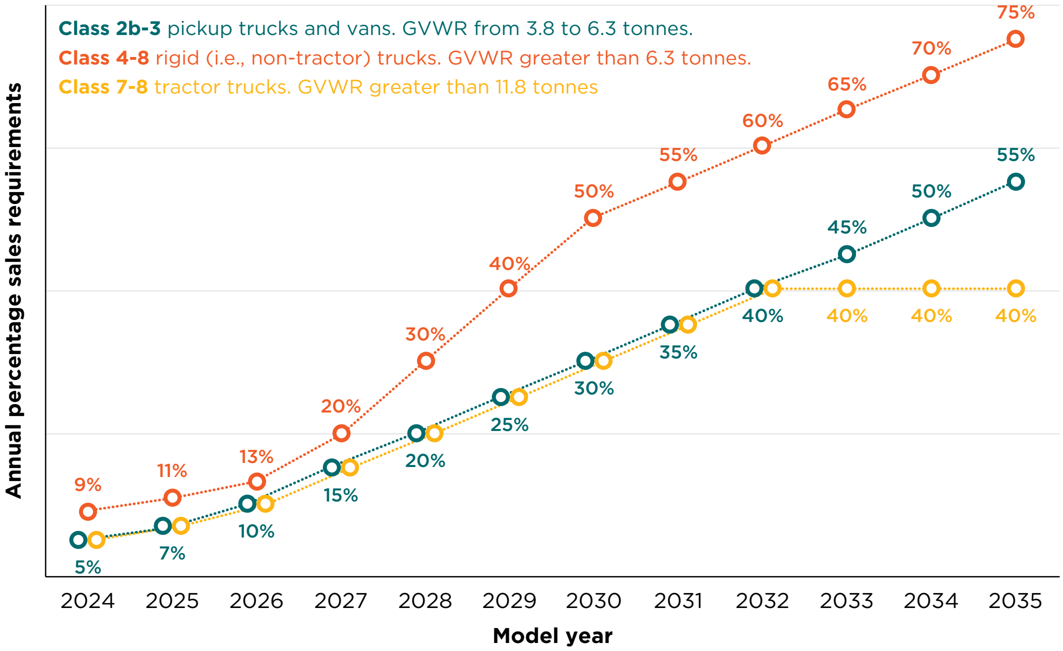

Figure 5. California Advance Clean Trucks Regulation zero-emission sales percentage schedule by vehicle group and model year

In contrast to ZEV regulations that prescribe minimum levels of ZE HDV sales, no HDV CO_2 standard today requires the sale of ZEVs. Current provisions in HD CO_2 standards in Europe or HDV GHG standards in the United States rely on a credit multiplier system, where the sales of ZE HDVs are counted multiple times in the calculation of fleet average CO_2/GHG for manufacturers, a benefit to them that encourages compliance. In Canada and the United States, the Phase 2 HDV GHG targets award Advanced Technology Multipliers to battery-electric and hydrogen fuel-cell HDVs

65 Claire Buysse and Benjamin Sharpe, *California's Advanced Clean Trucks Regulation: Sales Requirements for Zero-Emission Heavy-Duty Trucks*, (International Council on Clean Transportation: Washington, D.C., July 20, 2020), https://theicct.org/publications/california-hdv-ev-update-jul2020.

under the regulation.[66] In the EU, a similar credit multiplier design is in place in the HDV CO_2 regulations until 2025, when a 2 percent minimum benchmark will replace credit multipliers.[67] A weakness of the credit multiplier approach is its dilution of the effectiveness of the fleet-wide standard. In the future, governments can eliminate credit multipliers for ZEVs, and increase the stringency of CO_2 standards that encourage the adoption of ZE technologies in line with ZEV regulations and phase-out targets.

Incentives

Fiscal incentives such as purchase rebates and tax deductions supplement existing policies to shift market behavior, particularly in the early stages of the transition to ZE HDVs. The volume of government expenditure necessary to support ongoing incentives, especially purchase incentives and incentives that encourage the operation of zero-emission vehicles, increases as sales volumes grow. The scope and duration of fiscal incentives should focus on segments (e.g., heavy, long-haul trucks) and technologies where the price differential with ICEs is greatest. Unless supported in a revenue-neutral manner, such as a bonus-malus system, fiscal incentives are generally temporary measures that can be withdrawn when ZE HDVs reach price parity without incentives or when CO_2 standards are adopted that will sustain their market advantage.

Several ZEV Transition Council members have adopted purchase rebate and tax deduction policies to reduce upfront costs. For example, California has adopted point-of-sale purchase incentives for ZE-HDVs, including the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), the Carl Moyer Memorial Air Quality Standards Attainment Program, and the VW Mitigation Trust.[68] These policies are funded by revenues from fees levied on polluting vehicles and activities, a bonus/malus system that improves the financial sustainability of fiscal incentives.

Maintenance and operation costs constitute a large part of the TCO of HDVs. Reductions in ownership and use taxes, along with road toll discounts and favorable energy pricing, reduce expenses incurred after vehicle purchase. For example, under California's Low Carbon Fuel Standard (LCFS), HDV fleets that invest in, own, and operate charging and hydrogen refueling infrastructure earn credits based on the amount and source of fuel they use. These fleets can sell credits to fossil fuel users and generate revenue. CARB estimates that a battery-electric powered Class 8 (>14,969 kg) short-haul tractor purchased in 2024 can generate total LCFS revenues worth more than $120,000 over a 12-year service life.[69] In Europe, the June 2021 provisional

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66 Benjamin Sharpe, et al., *United States Efficiency and Greenhouse Gas Emission Regulatiton for Model Year 2018–2027 Heavy-Duty Vehicles, Engines, and Trailers* (International Council on Clean Transportation, August 25, 2016), http://www.theicct.org/US-phase2-HDV-efficiency-GHG-regulations-FRM; Benjamin Sharpe, *Final Second-Phase Greenhouse Gas Emissions Standards for Heavy-Duty Engines and Vehicles in Canada*, (International Council on Clearn Transportation: Washington, DC, September 21, 2018), http://www.theicct.org/publications/second-ghg-standards-hdv-Canada.

67 "Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 Setting CO_2 Emission Performance Standards for New Heavy-Duty Vehicles and Amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC," *Official Journal of the European Union* L 198, July 25, 2019, https://eur-lex.europa.eu/eli/reg/2019/1242/oj#d1e1921-202-1

68 California Air Resources Board, "Implementation Manual for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)" (June 4, 2020), https://californiahvip.org/wp-content/uploads/2020/09/HVIP-FY2019-20-Implementation-Manual-1.pdf; California Environmental Associates, and California Air Resources Board, "The Carl Moyer Program Guidelines 2017 Revisions" (April 27, 2017), https://ww2.arb.ca.gov/sites/default/files/2020-06/2017_cmpgl.pdf; California Air Resources Board, "Zero-Emission Class 8 Freight and Port Drayage Trucks Category," accessed February 27, 2021, https://xappprod.aqmd.gov/vw/zero-emission.html.

69 California Air Resources Board, "Advanced Clean Trucks Total Cost of Ownership Discussion Document Preliminary Draft for Comment" (February 22, 2019), https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf.

agreement to revise the *Eurovignette* Directive[70] would, among other things, increase the road toll for internal combustion engine vehicles by up to €0.16 per kilometer for tractor-trailers, while waiving up to 75% of tolls for ZE-HDVs. Revised *Eurovignette* road tolls will accelerate the time for battery-electric buses to achieve cost parity.

Infrastructure

Vehicles and fuels are a single system, and governments have an important role to play in ensuring the availability of charging and fueling infrastructure to support electrification targets. Most early commercial deployments of ZE HDVs will utilize battery-charging infrastructure installed by the vehicle owner at a private depot. However, governments can establish programs and incentives that support growth in the market beyond these early deployments, and that tackle foreseeable challenges, such as capacity limitations of the current grid. The installation of publicly accessible infrastructure—available at any time to any vehicle owner who needs it—is key to this growth.

Nearly all battery-electric HDVs will require low-power overnight charging of around 100 kW, while a minority of vehicles will require up to 1 MW or greater publicly accessible en-route charging. Governments can coordinate the selection of sites along key transportation corridors and within urban centers to ensure sufficient density of stations to support a diverse range of vehicle applications. As a good example, the French government announced subsidies for HDV charging infrastructure investments, depending on the power level at the charging point. Investments in very high grid connection power (above 500 kVA) charging are rewarded with the highest subsidies.[71] Korea has also published detailed subsidy guidelines for hydrogen HDV charging to support the country's ambition of developing hydrogen fuel-cell trucks and buses.[72]

Good government infrastructure support should also recognize heterogenous HDV applications that call for different and flexible infrastructure deployment strategies. Battery-electric transit buses today use a combination of en-route fast charging and depot overnight charging. Other fixed-route, short-haul vehicles in urban areas can adopt this strategy, while long-haul trucks will need charging and refueling infrastructure along heavily trafficked highway freight corridors, near logistics hubs. A recently published study on the location of major trucks stops and their electrification in Europe will help inform the EU's update to its Alternative Fuels Infrastructure Directive.[73] This analytical approach of using empirical data to guide infrastructure design and deployment will help maximize service for highway freight traffic.

Governments may be concerned about stranded publicly accessible infrastructure. To reduce this risk, governments would be wise to focus their efforts on planning, standardization, and incentives. In particular, standardization of charging and refueling infrastructure guarantees interoperability during cross-border freight movement, improves economies of scale, and ensures the safety of operators.

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70 European Parliament Think Tank, "Revision of the Eurovignette Directive," accessed May 11, 2021, https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2017)614625.

71 ADVENIR, "Nouvelle prime pour les flottes poids lourds. [New premium for heavy vehicle fleets.]" (2021), https://advenir.mobi/2021/05/03/nouvelle-prime-flottes-poids-lourds/.

72 Ministry of Environment, "「2021년 수소연료전지차 수소연료전지차 보급 및 수소충전소 설치사업」보조금 업무처리지침 [2021 hydrogen fuel cell vehicle hydrogen fuel cell vehicle supply and hydrogen charging station installation project」 Guidelines for handling subsidies]" (April 28, 2021), https://www.ev.or.kr/portal/board/14/8405/?

73 Patrick Plötz, and Daniel Speth. "Truck Stop Locations in Europe." (Fraunhofer ISI: Karlsruhe, Germany, June 2021), https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2021/ACEA_truckstop_report_update.pdf; European Commission, "Proposal for a Regulation of the European Parliament and of the Council on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU of the European Parliament and of the Council" (July 14, 2021), https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf.

Fleet purchases

Fleet purchase requirements create market demand for ZE HDVs by mandating a minimum share of zero-emission vehicles in fleet purchases. These requirements are made possible by the fact that the main HDV buyers are large fleets that can be regulated more easily than individual customers. Most fleet purchase requirements today apply to transit buses and to fleets owned by the government. In the EU, the Clean Vehicles Directive requires national governments to purchase a certain percentage of ZE buses. Similar requirements have been adopted in the Netherlands, China, and Colombia. California adopted the Innovative Clean Transit Regulation in 2019, which requires 100% of all new transit bus purchases to be zero-emission by 2029.

A second Advanced Clean Fleets regulation, currently under development, would expand California's mandate to include zero-emission purchases across a large array of publicly and privately owned fleets, including the heaviest trucks.[74] The regulation would recognize differences in technology readiness among fleets and would set purchase targets based on assessment of feasibility.

Zero-emission zones

Zero-emission zones (ZEZs) are areas that require zero-emission operations from vehicles within a geographic boundary. Other vehicles are either barred from entering the area or must pay an access charge, which makes ZE HDVs attractive for operators like logistics companies. In practice, ZEZs are most likely to apply to a subset of fleets—such as buses or freight vehicles—and will expand to include other types of HDVs as the market for ZE HDVs matures.[75] Localized ZEZs are an extra demand-side push for ZE HDVs that complements national level policies such as phase-out dates and fiscal incentives.

The Dutch government is a leader in adopting ZEZs as a mechanism to regulate and incentivize ZEV adoption.[76] In addition to the commitment in Amsterdam mentioned in Part I, the city of Rotterdam introduced a ZEZ that only allows ZE trucks (>3.5 tonnes).[77] Many local governments, inspired by C40 Cities, have committed to designating major areas under their jurisdictions as zero-emission by 2030, as part of the Green and Healthy Streets Declaration.[78]

Policies in ZEV Transition Council member states

Table 5 summarizes the actions to encourage ZE HDV uptake, in select ZEV markets as of August 2021 in the five areas identified in previous sections—targets, regulations, incentives, infrastructure deployment, and fleet purchases. For detailed information of policies, including scope, ambition and applicable vehicle segments, see Appendix A2.

74 California Air Resources Board, "Advanced Clean Fleets Regulation Workshop" (March 2, 2021), https://ww2.arb.ca.gov/sites/default/files/2021-02/210302acfpres_ADA.pdf.

75 "Zero-Emission Zones: Don't Wait to Start with Freight" (Transportation Decarbonization Alliance, C40, and POLIS, December 3, 2020), https://www.polisnetwork.eu/wp-content/uploads/2020/12/ZEZ-F_How-to-Guide_low.pdf.

76 The Government of the Netherlands, "Climate Agreement" (June 28, 2019), https://www.government.nl/documents/reports/2019/06/28/climate-agreement.

77 City of Rotterdam, "Vrachtautoverbod 's-Gravendijkwal [Truck ban in 's-Gravendijkwal]", accessed August 25, 2021, https://www.rotterdam.nl/werken-leren/sgravendijkwal/.

78 C40 Cities, "C40 : Green and Healthy Streets," Accessed August 11, 2021, https://www.c40.org/other/green-and-healthy-streets.

Table 5. ZE HDV policies in place for HDVs for ZEV Transition Council members and China

Jurisdiction	Phase-out target [a]	Regulations		Incentives			Infrastructure			Demand
		CO_2 standard	ZEV regulation	Bonus or rebate	Tax exemption	In-use incentives	Infrastructure strategy	Public infrastructure funding	Private infrastructure incentives	Fleet purchase requirements
California	2045 [b]	O	O	O		O	O	O	O	O
Canada		O		O						
China [c]		O		O	O				O	O
European Union [d]		O				O	O	O		O
Denmark		O								
France		O		O	O				O	
Germany		O		O		O	O		O	
India		O		O					O	
Italy		O		O			O			
Japan		O		O	O		O	O	O	
Mexico					O					
Netherlands		O		O			O			O
Norway				O						
Spain		O		O					O	
South Korea				O		O	O		O	O
Sweden		O		O			O	O		
United Kingdom	2040 [e]	O		O						
United States		O		O					O	

[a] The targets tracked in this column are 100% HDV sector-wide phase-out targets and do not include targets for specific sectors, e.g. transit buses, or targets that have ambitions below 100%.

[b] The California 2045 medium- and heavy-duty vehicle target is an in-use fleet, or vehicle stock target rather than sales target, for HDV segments “where feasible”. A proposal from CARB staff to implement a 100% HD ZEV sales requirement in 2040 was released for public comment in Aug 2021.

[c] China is not a ZEV Transition Council member.

[d] European Union-level actions, including Regulations and Directives, are noted (excluding national actions). EU Directives require member states’ adoption and incorporation into national law within two years of EU adoption. They are not separately noted as policies by member states unless expressedly adopted.

[e] The UK government has proposed a Heavy Goods Vehicles phaseout. It is under public consultation as of August 2021.

Most ZEV Transition Council governments have adopted some promotional actions, but the actions are less developed than those for LDV policies. Five ZEV Transition Council members have set or plan to set phase-out targets for ICE-HDVs, two of which are sector-wide targets. California is the sole government in ZEV Transition Council to implement a ZE HDV regulation with legally binding sales targets. While almost all ZEV Transition Council governments have HDV CO_2 standards, their degrees of stringency vary and few have ZE HDV incentives built in. In addition to purchase bonuses and rebates, ZEV Transition Council member governments including California, the EU, and Germany provide in-use incentives in the form of reduced road tolls and other operational discounts, which can effectively lower the TCO of ZE HDVs. Compared to greater governmental support in ZE LDV charging infrastructure, only seven ZEV Transition Council members have announced dedicated ZE HDV infrastructure strategies. There are also fewer ZEV Transition Council governments that have made specialized funding available for public and private HD-ZEV infrastructure investments. Fleet requirements for urban buses are in place in the EU and California, with the latter set to adopt a much broader ZE HDV purchase regulation that will cover large segments of HDV applications.

Leaders in today's early ZE HDV policy framework are the governments that take a holistic approach in all five policy sets. California stands out as the market with the most comprehensive policy actions to spur the growth of ZE HDVs. It is also important to recognize the degree of heterogeneity and diversity of HDV applications, and the need to contextualize best practices to address local needs.

The ZEV Transition Council is in a strong position to jumpstart the creation of zero-emission road transport systems. By adopting the policy sets described here, member countries can grow their fleets of zero-emission vehicles rapidly in the decades ahead. In the process they will build clean, climate-friendly road transport for their home constituencies while modeling effective policymaking.

Appendix A1. State of the ZEV Transition Council ZE HDV market by country

	2020 total HDV sales (nearest thousand)	2020 ZE HDV sales share		
	Total	All HDVs	Buses	Trucks
Canada	137,000	0.0%	1.7%	0.0%
Denmark	4,000	0.5%	2.2%	0.4%
EU-27 total	278,000	1.0%	5.9%	0.4%
France	49,000	0.4%	2.6%	0.1%
Germany	81,000	1.5%	5.9%	1.2%
India	176,000	0.1%	0.6%	0.0%
Italy	23,000	0.1%	0.7%	0.0%
Korea	50,000	0.8%	1.6%	0.0%
Mexico	51,000	0.7%	5.3%	0.0%
Netherlands	11,000	4.4%	69.3%	0.4%
Norway	7,000	3.3%	16.5%	0.3%
Spain	21,000	0.2%	1.8%	0.0%
Sweden	7,000	2.6%	9.9%	0.3%
United Kingdom	44,000	1.1%	6.2%	0.5%
United States	1,116,000	0.0%	0.6%	0.0%

Appendix A2. ZE HDV Policies of ZEV Transition Council members as of June 2021

Target dates to limit the sale and operation of ICE HDVs				
Market	Target year	Target	Vehicle segment	Source
Austria	2030	100% zero-emission new registrations	Heavy-duty vehicles <18 tonnes	Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie. "Mobilitätsmasterplan 2030 Für Österreich." Austria, July 2021. https://www.bmk.gv.at/ themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html
	2035	100% zero-emission new registrations	Heavy-duty vehicles >18 tonnes	
California	2045	100% zero-emission operations, where feasible	All medium- and heavy-duty vehicles	State of California. "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change." California Office of Governor, September 23, 2020. https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.
Cape Verde	2050	100% zero-emission fleet	All medium- and heavy-duty trucks	2019 Electric Mobility Policy Charter http://www.ecowrex.org/sites/default/files/documents/projects/cabo-verde-electric-mobility-policy-chapter.pdf.
Chile	upper: 2035; lower: 2045	100% zero-emission new sales	upper: transit buses; lower: long-distance buses and all heavy-duty vehicles	Government of Chile. "Estrategia Nacional de Electromovilidad Un Camino Para Los Vehículos Eléctricos," October 2021. https://www.energia.gob.cl/sites/default/files/estrategia_electromovilidad-8dic-web.pdf.
Netherlands	2025	100% zero-emission new sales	Urban buses	Government of the Netherlands (2019). "Climate Agreement." The Hague. https://www.government.nl/binaries/government/documents/reports/2019/06/28/climate-agreement/Climate+Agreement.pdf.
New York	2045	100% zero-emission new sales	All medium- and heavy-duty vehicles	New York State Governor's Office. "In Advance of Climate Week 2021, Governor Hochul Announces New Actions to Make New York's Transportation Sector Greener, Reduce Climate-Altering Emissions." Accessed October 7, 2021. https://www.governor.ny.gov/news/advance-climate-week-2021-governor-hochul-announces-new-actions-make-new-yorks-transportation.
Norway	2025	100% zero-emission or biogas; new sales	Urban buses	Norwegian Ministry of Transport. "Meld. St. 20 (2020–2021) Report to the Storting (White Paper) National Transport Plan 2022-2023 English Summary," June 2021. https://www.regjeringen.no/contentassets/117831ad96524b9b9eaadf72d88d3704/en-gb/pdfs/meld-st-20-national-transport-plan-summary.pdf.
	2030	50% zero-emission new sales	Trucks	
	2030	75% zero-emission new sales	Long distance coach	

Target dates to limit the sale and operation of ICE HDVs				
Market	**Target year**	**Target**	**Vehicle segment**	**Source**
Korea	2040	30,000 fuel-cell electric buses sold	Buses	Ministry of Trade, Industry and Energy. "Hydrogen Economy Roadmap of Korea." Accessed June 29, 2021. https://docs.wixstatic.com/ugd/45185a_fc2f37727595437590891a3c7ca0d025.pdf.
		40,000 fuel-cell electric trucks sold	Trucks	
United Kingdom	To be determined	100%	Heavy goods vehicles	https://www.gov.uk/government/consultations/heavy-goods-vehicles-ending-the-sale-of-new-non-zero-emission-models
Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, United Kingdom, Uruguay, Wales	2030	30% zero-emission new sales	Medium- and Heavy-Duty Vehicles	"Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles." Global Commercial Vehicle Drive to Zero, October 5, 2021. https://globaldrivetozero.org/site/wp-content/uploads/2021/11/Global-MOU-ZE-MHDVs.pdf.
	2040	100% zero-emission new sales		
15 U.S. States (CA, CT, CO, HI, ME, MD, MA, NJ, NY, OR, PA, RI, VT, WA, DC) and the District of Columbia	2050	100% zero-emission new sales	All medium- and heavy-duty vehicles	"15 States and the District of Columbia Join Forces to Accelerate Bus and Truck Electrification, Sign Memorandum of Understanding – Pledge to Develop Action Plan to Eradicate Toxic Diesel Emissions by 2050," (July 14, 2020). https://www.nescaum.org/documents/multistate-truck-zev-governors-mou-20200714.pdf/.

Binding vehicle regulations to produce ZE-HDVs			
Market	**Vehicle segment**	**Target**	**Source**
California	Trucks	Class 2b-3 trucks/vans: 55% zero-emission sales by 2035 Class 4-8 rigid trucks: 75% zero-emission sales by 2035 Class 7-8 tractor trucks: 40% zero-emission sales by 2035	Advanced Clean Trucks regulation California Air Resources Board. "Advance Clean Trucks Regulation Final Regulation Order," January 29, 2021. https://ww3.arb.ca.gov/regact/2019/act2019/fro2.pdf.
Oregon	Trucks	Class 2b-3 trucks/vans: 55% zero-emission sales by 2035 Class 4-8 rigid trucks: 75% zero-emission sales by 2035 Class 7-8 tractor trucks: 40% zero-emission sales by 2035	Oregon Department of Environmental Quality. "Clean Truck Rules 2021 : Rulemaking at DEQ : State of Oregon," November 17, 2021. https://www.oregon.gov/deq/rulemaking/Pages/ctr2021.aspx.

CO_2 standards for new vehicles

Market	Type	Regulated metric	Vehicle scope		Year of first implementation		Mandated improvement[b]		Source
California	Fleet average	NO_x (g/bhp-hr) Separate standards for warranty and PM emissions	GVW > 4.5 tonnes	6 sub-categories	Phase 1: MY 2024	Phase 2: MY 2027	Phase 1: 75% below current US federal limits	Phase 2: 90% below current US federal limits	https://ww2.arb.ca.gov/sites/default/files/classic/regact/2020/hdomnibuslownox/isor.pdf
Canada and United States	Fleet average	CO_2 (g/ton-mile) Separate standards for CH_4 and N_2O.	GVW > 3.85 tonnes	19 sub-categories	Phase 1: 2014, 2017	Phase 2: 2021, 2024, 2027	Phase 1: 5% to 23%	Phase 2: 10% to 27%	http://www.theicct.org/US-phase2-HDV-efficiency-GHG-regulations-FRM. https://theicct.org/publications/second-ghg-standards-hdv-Canada.
European Union	Fleet average	CO_2 (g/tonne-km)	GVW >16 tonnes	9 sub-categories	2025 and 2030		15% by 2025	30% by 2030	https://theicct.org/publications/co2-stds-hdv-eu-20190416.
India	Individual vehicle	Fuel economy (km/L)	GVW > 12 tonnes	10 sub-categories	Phase 1: 2018	Phase 2: 2021	Phase 1: None	Phase 2: 5% to 16%	https://theicct.org/publications/fuel-consumption-stds-hdvs-india-update-201712.
Japan	Fleet average	Fuel economy (km/L)	GVW > 3.5t	25 sub-categories	Phase 1: 2015	Phase 2: 2025	Phase 1: 1% to 12%	Phase 2: 3% to 16%	https://theicct.org/publications/second-phase-fuel-economy-standards-road-heavy-duty-vehicles-japan.

Fiscal incentives				
Market	**Incentive program**	**Vehicle segment**	**Type**	**Source**
California	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project	Buses and trucks	Purchase subsidy, up to $315,000 per vehicle	California Air Resources Board. “Implementation Manual for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP),” June 4, 2020. https://californiahvip.org/wp-content/uploads/2020/09/HVIP-FY2019-20-Implementation-Manual-1.pdf.
	Carl Moyer Memorial Air Quality Standards Attainment Program	Buses and trucks	Purchase subsidy, up to $200,000 per vehicle. Up to 80% of vehicle cost for fleets smaller than 10 vehicles. Up to 50% of vehicle cost for larger fleets.	California Environmental Associates, and California Air Resources Board. “The Carl Moyer Program Guidelines 2017 Revisions,” April 27, 2017. https://ww2.arb.ca.gov/sites/default/files/2020-06/2017_cmpgl.pdf.
	California VW Mitigation Trust	Class 8 freight trucks	Purchase subsidy, up to $200,000 per vehicle. Up to 100% of cost for government-owned vehicles. Up to 75% for non-government vehicles.	California Air Resources Board. “Zero-Emission Class 8 Freight and Port Drayage Trucks Category.” California VW Mitigation Trust. Accessed February 27, 2021. https://xappprod.aqmd.gov/vw/zero-emission.html.
	Low Carbon Fuel Standard	Buses and trucks	In-use incentive	California Air Resources Board, “Low Carbon Fuel Standard,” 17 CCR § 95480-95503 (2020), https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.
Denmark	No information			
EU-27	Road toll discounts in proposed updates to *Eurovignette* Directive	Trucks	In-use incentive	European Parliament Think Tank, “Revision of the Eurovignette Directive,” accessed May 10, 2021, https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2017)614625.
France	Ministerial decree	Buses and trucks	Purchase subsidy	Ministère de la Transition écologique, “Décret N° 2021-37 Du 19 Janvier 2021 Relatif Aux Aides à l’acquisition Ou à La Location de Véhicules Peu Polluants,” 2021-37 § (2021), https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043014941.
Germany	Directive on the promotion of commercial vehicles with climate-friendly drives	All commercial vehicles	Purchase subsidy of up to 80% of price differential between HD-ZEV and Euro VI diesel equivalent.	BAG.de. “Promotion of light and heavy commercial vehicles with alternative and climate-friendly drives.” Bundesamt für Güterverkehr. Accessed August 16, 2021. https://www.bag.bund.de/DE/Foerderprogramme/KlimaschutzundMobilitaet/KSNI/KSNI.html.
	HGV Tolling Scheme exemptions	Trucks over 7.5 tonnes	In-use incentive	Bundesministerium für Verkehr und digitale Infrastruktur, “Lkw-Maut,” 2021, https://www.bmvi.de/SharedDocs/DE/Artikel/StV/Strassenverkehr/lkw-maut.html.

Fiscal incentives				
Market	**Incentive program**	**Vehicle segment**	**Type**	**Source**
India	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India Phase 2 (FAME II)	Buses	Purchase subsidy (40 percent of the estimated cost of the buses, with maximum amounts of INR 6.5 million for standard buses, INR 4.5 million for midi buses and INR 3.5 million for minibuses)	Department of Heavy Industry and Ministry of Heavy Industries & Public Enterprises. "Sanction of Electric Buses under Phase-II of Faster Adoption and Manufacturing of Electric Vehicles in India Scheme (FAME India Scheme)." Accessed March 11, 2021. https://dhi.nic.in/writereaddata/fame/famepressrelease/1-E__didm_WriteReadData_userfiles_Press%20Release%20for%20Buses.pdf.
Italy	Piano Strategico Nazionale della Mobilità Sostenibile (National Strategic Plan for Sustainable Mobility)	Buses	Purchase subsidy (€ 3,7 billion are allocated to renew the circulating bus fleet in the time frame 2019-2033, providing up to 80% co-financing for battery-electric or hydrogen fuel-cell urban buses)	https://www.mit.gov.it/normativa/decreto-presidente-consiglio-ministri-n-1360-del-24042019
	Ministerial decree	Trucks	Purchase subsidy (Up to €20,000 for fully electric trucks over 7 tonnes)	Ministero delle Infrastrutture e dei Trasporti, "Decreto Ministeriale 203," Pub. L. No. 203 (2020), https://www.mit.gov.it/sites/default/files/media/documentazione/2020-07/DM%20203%20-%202020.pdf.
Japan	自自動車環境総合改善対策費補助金 (地域交通のグリーン化に向けた次世代自動車の普及促進事業), Subsidy for comprehensive improvement of automobile environment (promotion of next-generation automobiles for greening regional transportation)	Battery-electric buses and trucks	Purchase subsidy (1/3 of battery-electric bus prices and 1/4 of battery-electric truck prices.)	Ministry of Land, Infrastructure, Transport and Tourism https://www.mlit.go.jp/jidosha/jidosha_tk1_000003.html
Korea	EV Subsidy Program	Buses and trucks	Purchase subsidy, varies by model	https://www.ev.or.kr/portal/buyersGuide/incenTive
Norway	EV Subsidy Program	Buses and trucks	Purchase subsidy of up to 50 percent reimbursement of the extra costs incurred by converting to zero emission technology	https://doi.org/10.3390/su13031346
Mexico	Exemption of *trámite aduanero* (customs paperwork) and *impuesto general de importación* (General Import Tax)	Zero-emission buses and trucks	Import tax exemption	https://www.elfinanciero.com.mx/economia/autos-electricos-quedaran-exentos-de-aranceles-para-incentivar-uso-de-tecnologias-limpias-en-mexico/
Spain	MOVES II Program	Buses and trucks	Purchase subsidy	IDAE.es. "MOVES II PLAN: Impulso a la movilidad sostenible," 2020. https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/plan-moves-ii.

Fiscal incentives				
Market	**Incentive program**	**Vehicle segment**	**Type**	**Source**
Sweden	*Förordning om statligt stöd till vissa miljöfordon, SFS 2020:750* (Ordinance on State aid for certain environmental vehicles, SFS 2020:750) *Förordning (2016:836) om elbusspremie* (Ordinance (2016:836) on electricity bus premium)	Buses and trucks	Purchase subsidy	https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-2020750-om-statligt-stod-till-vissa_sfs-2020-750 https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-2016836-om-elbusspremie_sfs-2016-836
UK	Plug-in vehicle grant scheme	Trucks	Purchase subsidy	UK.gov. "Low-Emission Vehicles Eligible for a Plug-in Grant." GOV.UK, 2020. https://www.gov.uk/plug-in-car-van-grants.
	Zero Emission Buses Regional Area (ZEBRA) scheme	Transit buses	Purchase subsidy	Department of Transport, and The Rt Hon Grant Shapps MP. "Multi-Million Pound Scheme for Zero-Emission Buses across England Launched." GOV.UK, March 30, 2021. https://www.gov.uk/government/news/multi-million-pound-scheme-for-zero-emission-buses-across-england-launched.
US	15 Department of Transport Funding and Financing Programs with EV eligibility, including FTA Low-No Grant	Various	Purchase subsidy	

Infrastructure programs and incentives	
Market	**Program/incentive details**
California	California Energy Commission EnergIIZE Commercial Vehicles project https://www.energy.ca.gov/news/2021-04/energy-commission-announces-nations-first-incentive-project-zero-emission-truck California Public Utilities Commission approved investments from the three major utility companies in California to support electric M/HDV infrastructure California Public Utilities Commission. “CPUC Approval of Utility Projects Keeps California at Forefront of Transportation Electrification.” California Public Utilities Commission, May 31, 2018. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M215/K467/215467739.PDF.
Denmark	No information
EU-27	Proposed Alternative Fuels Infrastructure Regulation. European Commission. “Proposal for a Regulation of the European Parliament and of the Council on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU of the European Parliament and of the Council,” July 14, 2021. https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf.
France	*ADVENIR* Program ADVENIR. (2021). “Nouvelle prime pour les flottes poids lourds. [New premium for heavy vehicle fleets.]” Retrieved from https://advenir.mobi/2021/05/03/nouvelle-prime-flottes-poids-lourds/
Germany	*Masterplan Ladeinfrastruktur* (Charging Infrastructure Masterplan) https://www.bmvi.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur.pdf?__blob=publicationFile.
India	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India Phase 2 (FAME II) https://dhi.nic.in/writereaddata/fame/famepressrelease/1-E__didm_WriteReadData_userfiles_Press%20Release%20for%20Buses.pdf.
Italy	*Piano Nazionale Infrastrutturale per la Ricarica Elettrica,* PNIRE (National Infrastructure Plan for Electric Recharging) https://www.mit.gov.it/normativa/decreto-presidente-consiglio-ministri-n-1360-del-24042019
Japan	自動車環境総合改善対策費補助金 (地域交通のグリーン化に向けた次世代自動車の普及促進事業), Subsidy for comprehensive improvement of automobile environment (promotion of next-generation automobiles for greening regional transportation) https://www.mlit.go.jp/jidosha/jidosha_tk1_000003.html
Korea	Hydrogen Roadmap 2040 https://www.rvo.nl/sites/default/files/2019/03/Hydrogen-economy-plan-in-Korea.pdf
Mexico	No information
Netherlands	National Charging Infrastructure Agenda
Spain	MOVES II Program https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/plan-moves-ii.
Sweden	Climate Leap program https://www.klimatpolitiskaradet.se/wp-content/uploads/2020/05/2020reportoftheswedishclimatepolicycouncil.pdf
UK	No information
US	No information

Fleet purchase requirements

Market	Vehicle segment	Target	Source
California	Transit buses	100% zero-emission new purchase by 2029	Innovative Clean Transit regulation https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet
	All medium- and heavy-duty trucks	100% zero-emissions, where applicable	Advanced Clean Fleets regulation (proposed) https://ww2.arb.ca.gov/sites/default/files/2021-02/210302acfpres_ADA.pdf
	Airport shuttle buses in 13 airports	100% zero-emission fleet by 2035	Zero-emission Airport Shuttle Regulation https://ww2.arb.ca.gov/sites/default/files/2019-10/asb_reg_factsheet.pdf
EU-27	Buses	Varies by country. 12% by 2021 and 16.5% by 2030 in countries like Romania 22.5% by 2021 and 32.5% by 2030 in countries like Germany	Clean Vehicles Directive
Netherlands	Urban buses	100% zero-emission new purchase by 2025, 100% zero-emission fleet by 2030	Climate Agreement https://www.government.nl/binaries/government/documents/reports/2019/06/28/climate-agreement/Climate+Agreement.pdf

Zero-emission zones

City	Status	Implementation date	Mechanism	Vehicles affected	Area affected	Operating hours
Rotterdam, the Netherlands	Implemented	January 2015	Road access privilege	Heavy-duty trucks > 3.5 tonnes	One street	24/7
	Planned	2025		Light commercial vehicles and heavy-duty trucks	~ 22 km^2	
Santa Monica, United States	Pilot	February 2021 (11-month pilot)	Voluntary program	Light, duty and medium-duty vehicles	~ 2.5 km^2	Not specified
30-40 cities, the Netherlands	Planned	2025	Not specified	Light commercial and heavy-duty trucks	Not specified	Not specified

Appendix A3. Total Cost of Ownership Analyses Referenced in the Paper

Institution/Study	Application	TCO components	Energy Efficiency	Main findings	Source
CARB (2019)	• Diesel, battery-electric, and hydrogen Class 3 passenger van (4.5t-6.4t) • 15,000 mi/year and 50 mi daily mileage • 12-year analysis period	• Vehicle purchase • Energy & Maintenance • LCFS • Infrastructure • Other miscellaneous	• Battery-electric: 0.56 kWh/mi (~0.35 kWh/km) in 2018	• Battery-electric step vans and regional tractors will reach TCO parity with diesel equivalents by the 2024 timeline • Battery-electric passenger vans will reach TCO parity a little after 2024. • Hydrogen fuel-cell MHDVs are closing the TCO gap and may reach parity by 2030 with diesel baseline. • LCFS and charging infrastructure are major variables for zero-emission drivetrains	https://ww2.arb.ca.gov/sites/default/files/classic/regact/2019/act2019/apph.pdf
	• Diesel, battery-electric and hydrogen Class 6 step van (8.9t-11.8t) • 15,000 mi/year and 80 mi daily mileage • 12-year analysis period		• Battery-electric: 0.96 kWh/mi (~0.60 kWh/km) in 2018		
	• Diesel, battery-electric and hydrogen Class 8 regional tractor (>15t) • 15,000 mi/year and 180 mi daily mileage • 12-year analysis period		• Battery-electric: 2.1 kWh/mi (~ 1.3 kWh/km) in 2018		
International Council on Clean Transportation Dale Hall and Nic Lutsey, "Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks" (Washington, D.C.: International Council on Clean Transportation, August 9, 2019), s.	• Diesel, battery-electric, and hydrogen Class 7-8 long-haulers (>11.8t) • 140,000 mi/year and 190 mi daily driving range • 10-year analysis period	• Truck Purchase • Energy & Maintenance • Infrastructure	• Battery-electric: 1.9 kWh/mi (~1,2 kWh/km) in 2019 without trailer	• Battery-electric tractor-trailers meet TCO parity with diesel tractor-trailers by 2030. • Purchase price of battery-electric tractor-trailers becomes less expensive by 2026 and fuel-cell electric trucks by 2028 compared to diesel baseline. • Battery-electric continues to have a better economic performance in comparison to fuel-cell electric up to 2030.	https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf
International ZEV Alliance (Welsh et al., 2020)	• Diesel and battery-electric, Class 7 cargo van (12t) • 8.5-year analysis period	• Truck Purchase • Service/Maintenance • Energy • Depreciation	• Battery-electric: 1.6 kWh/km in 2020	• Battery-electric cargo vans will reach TCO parity with diesel by 2026	http://www.zevalliance.org/wp-content/uploads/2020/12/Zero-Emission-Freight-Commercialization-dec2020.pdf
International Council on Clean Transportation (Basma et al, 2020)	• Diesel and battery-electric, long-haul tractor-trailer (40t) • 500 km daily driving range • 5 years (first-ownership perspective)	• Truck Purchase • Financing and Depreciation • Fuel and Energy • Maintenance • Battery replacement • Registration and ownership taxes • Road tolls • Infrastructure	• Battery-electric: 1.38 kWh/km in 2020	• Battery-electric tractor-trailers can achieve cost parity with diesel tractor-trailers in the next 10 years in Germany, Italy, Poland, Spain, UK, France and the Netherlands without new policy interventions • Differences in year of cost parity across countries are mainly driven by the disparities in the electricity and diesel prices, as well as on road tolls	Forthcoming