Zero-Emission Trucks: Benefits Analysis and Policy Synergy Recommendations

White Paper

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Executive Summary

Medium- and heavy-duty vehicles (MHDVs), including trucks and buses, account for an important and growing share of the direct carbon dioxide (CO_2) emissions from road transport globally. The benefits of truck electrification go far beyond reducing greenhouse gas emissions – reductions in diesel particulate matter and other types of air pollution have dramatic, positive impacts on health, particularly in communities closest to roadways, corridors, and shipping centers. Given the policy movement now occurring across the globe, the world is poised to enter a phase of rapid MHDV zero-emission vehicle (ZEV) market uptake. The conditions are in place for sales to grow rapidly and for costs to drop if national and sub-national governments follow through and address the challenges inherent in building these markets. It is the right time for countries around the world to adopt effective regulatory and incentive policies to promote ZEVs and start to grow these markets, so that the global stock of MHDVs can fully transition to ZEV by 2050 or earlier. The key ZEV technologies such as batteries, fuel cells and other vehicle components are ready, with many ZEV models available in various countries and in various vehicle categories. Our examples and case studies focus on battery electric trucking, as there are not yet many for fuel cell vehicles, but the policies described here can apply equally to both ZEV technologies. Battery electric trucks (BETs) are rapidly becoming more cost competitive with diesels in both the US and Europe. And the faster the global market is built; the faster on-going cost-reductions and necessary infrastructure buildout will occur.

This report reviews the current policy landscape and potential future evolution of ZEV MHDVs around the world and considers a number of important policies either in place or being developed around the world – particularly in leading countries such as Europe and Asia. These policies are helping transform the markets for trucks and buses toward zero-emission as well as supporting progress on solvable challenges such as infrastructure, capital costs, and current technology limitations. We find that while there are a variety of policy tools available across and in place across leading jurisdictions, we find that supply side regulation, either in the form of vehicle CO_2 standards or sales requirements, is a critical tool to ensure that benefits from ZEVs are delivered to consumers/fleets, communities, and related industries (e.g. EVSE providers). By rapidly following the "first mover" regulatory adopters, other jurisdictions can enjoy the cost reductions that are being generated and reap the benefits of reducing emissions.

For example, California along with Colorado, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island. Vermont, and Washington have adopted and begun implementing the Advanced Clean Truck (ACT) regulation, which requires sales of zero-emission MHDVs by manufacturers. Together these states account for every fourth truck registered in the U.S. Both the US EPA and European Commission are in the process of adopting new regulations on trucks and buses, intended to reduce average CO_2 emissions from the commercial fleets within their jurisdictions. These rules will reduce future average CO_2 limits to levels expected to require large numbers of ZEV sales in order to comply. As of November 2023, the European proposal included GHG reduction targets would be 45% for the period 2030-2034, 65% for 2035-2039 and 90% as of 2040. Both also extend the covered future years beyond 2030. These are expected to have substantial impacts on the numbers of ZEV product offerings in North America and Europe and help scale production and bring down vehicle purchase prices, among other dynamics. These types of supply-side regulations can help ensure ZEV product offerings are available to fleets and consumers.

One major benefit of a supply side regulation is that since truck manufacturers are required to sell ZEVs, those truck manufacturers must produce a product that the customer is willing to buy at a price they are willing to pay. Over time, as technology costs come down, and economies of scale kick in, the cost of production is expected to be below the price the customer is willing to pay, leading to profits. In other words, a supply side regulation effectively "guarantees" affordability for the customer throughout the transition – and this is one of the MOST important and powerful attributes of the policy.

In addition to examining regulatory actions, we also looked at the use across jurisdictions of various economic policies (such as purchase incentives, fuel and other operational incentives, and provisions incentivizing sufficient charging infrastructure); and governmental ambition (e.g. targets, multi-state agreements, etc.). Strong market signals lead to private commitments. Those private commitments include those made by fleets (e.g. the CERES Corporate Electric Vehicle Alliance, the Climate Alliance EV100+) as well as publicly announced production targets from major truck manufacturers. Major US truck manufacturers have committed to meet California's 2036 100% zero-emission sales requirement. This continues directionally in line with their individual commitments where original equipment manufacturers (OEM) project 50 to 60 percent of HD trucks sold being electric by 2030, carbon-neutral trucks in the United States (U.S.) by 2039, or 100 percent ZE by 2040. For example, Navistar's executives expect 50 percent new HD ZEV sales by 2030 and 100 percent by 2040; Daimler Truck has stated ZEVs will make up 60 percent of its sales by 2030 and 100 percent of sales by 2039; Volvo Trucks led by Europe and North America set a higher target of 70 percent in 2030 and 100 percent by 2040; and PACCAR predicts electric vehicles production in the U.S. will ramp up exponentially in the coming years to 100 percent by 2040.

Table ES-1 summarizes the progress in major truck markets around the world, in terms of zero-emission truck (ZET) uptake and the policies to spur this. Though the market shares are still low in most countries, in 2022 these increased and strong growth appears to be underway. China has achieved an appreciable market share, with many other markets showing strong early adoption rates. And all are putting policies in place now that should help spur this market more broadly. The specific policies and national circumstances are explored for each country in this report, along with more detailed reporting on specific targets and policies.

Table ES-1: Summary of zero-emission truck (ZET) targets and existence of various policies in a range of active countries

Country/ Region	ZET sales share within country, 2023	Regulatory (CO_2 or ZEV sales requirements)	Vehicle price Incentives	Other programs
US	0.3%	✓	✓	✓
California	2%	✓	✓	✓
China	4%		✓	✓
EU	1%	✓		
Denmark	1%	(✓)	✓	✓
Finland	0.4%	(✓)	✓	
France	1%	(✓)	✓	✓
Germany	1%	(✓)	✓	✓
Netherlands	1%	(✓)	✓	✓
Spain	0.4%	(✓)	✓	✓
Sweden	3%	(✓)	✓	✓
Norway	6%		✓	✓
South Korea	2%		✓	✓
Japan	1%		✓	✓

Table notes: Policies current through 2023. Details for each country are provided in the county overview section of the report. Check marks in parentheses are for EU countries covered by the EU regulatory system. 'Other Programs' can include any of the following: Infrastructure funding support or incentives, discounted tolling for ZEVs/ emissions-based tolling, express depreciation schedules, other tax incentives, funds for research and development, criteria pollutant regulations, or weight exemptions.

Conclusions: ZEV targets, regulations, and price incentives have varying positive impact on market certainty

This review has shown that the most aggressive countries and regions (such as California, the US and EU) are using combinations of target setting, regulations and price incentives to promote the adoption of zero-emission MHDVs. With that being said, all three of these jurisdictions have in place or are in advanced development of regulations that will target high percentages of ZEV adoption across M/HDV classes by 2040 (or in the case of California, 2036). Regulatory approaches include the very different "ZEV mandates" used by California, and CO2 fleet average regulations for OEMs in the US and EU that promote ZEVs by on-going tightening of the standard. Though different, these types of regulatory programs are central to all three of these jurisdiction's efforts to achieve rapid scale-up of ZEV MHDVs and provide the most market certainty of the policy levers. With enforceable mandates in place, solutions for infrastructure, reductions in capital costs, and evolution of technology will occur faster.

Fiscal incentives to ensure ZEVs are affordable and competitive in the market, as well as direct spending (such as on charging infrastructure) also are playing important roles in ZEV market development, to make vehicles and infrastructure more affordable and encourage ZEV uptake by fleets. With these policies, the purchase and investment costs are reduced, making them more attractive for trucking and transit companies to purchase earlier. Continued declines in battery costs and increased production volume savings foreshadow a future with reduced need for direct purchase subsidies. Fiscal incentives will likely play an evolving role moving from primarily a technology creation and advancement role to one of early pilot fleet support and market acceleration and maturing to a role of addressing broader equitable access and priority community issues.

Apart from monetary support and incentives, a range of non-monetary supporting policies can also assist ZEV uptake. Policies to address restrictive truck weight limits and in-use charging impacts on drivers (including meshing driver work rules and business practices) can also help to make ZEV MHDVs attractive and meet fleet needs in a variety of settings.

While it is still early days in terms of ZEV M/HDV sales around the world, the leading countries have put into place a strong set of policies that will require and/or strongly incentivize and facilitate ZEV sales and achieve rapid growth toward ambitious targets. As more countries around the world adopt such policies, global ZEV MHDV sales growth should advance rapidly.

1 Introduction

Medium- and heavy-duty vehicles (MHDVs), including trucks and buses, account for 35% of the direct CO2 emissions from road transport globally (IEA 2023). MHDVs are also a major source of air pollution and have negative impacts on public health. Many of the duty cycles for MHDVs have commercially available zero-emission options. - MHDVs are typically characterized by their weight and have increasingly powerful powertrains, and need increasingly large energy storage systems, moving from light to medium to heavy duty. Long-haul trucks need to store energy for 500 or more kilometers of daily driving, and typically need to move tens of tonnes of payload along with their own weight. For ZETs, particularly with the longer haul situations, these requirements pose a challenge because a very large battery can be required depending on the operational strategies. The enhanced flexibility of a simplest approach larger battery configuration may limit the total payload that the vehicle can haul per trip, though some of the weight penalty is reduced by eliminating the diesel engine, fuel, and other drive train components. Hydrogen fuel cell vehicles and megawatt DC fast charging networks for battery electric vehicles both offer examples of how the ZEV weight and volume constraints can be eased for even these highest demand duty cycle applications with active work ongoing to field both.

This White Paper provides an overview of the status of medium/heavy duty (MHDV, including trucks and buses) zero emission (ZEV) vehicle policies and ZEV uptake around the world. ZEVs are considered a critical part of global decarbonization strategies, since they emit no carbon (or other pollutants) and can be linked to the production of electricity that powers them using deeply decarbonized electricity sources, over time. For trucks and buses, transitioning to ZEVs is feasible, but a key question is the timing and speed of transition. This paper considers targets for future uptake, challenges faced, and specific plans and policies in various countries and regions. It also reviews types of policies that have been or could be implemented to overcome the challenges and achieve the targets. It is clear that to build ZEV markets and achieve a rapid transition from diesel trucks to battery electric and FC (fuel cell) trucks, barriers such as high purchase costs, low availability of models and outright vehicle production, and scarce charging infrastructure, will need to be overcome.

This paper is organized into four parts as follows: first, we present a review of ZEV trends and targets across the globe; then an overview of important policies for ZEV uptake is provided. Next, a review of specific policies in various countries and regions is presented, and finally, additional innovative policies are considered that can help other countries speed ZEV truck and bus adoption.

2 Targets and projections for ZEV M/HDV uptake around the world

Globally, the needed zero emission vehicle sales trajectories to meet global temperature and decarbonization goals (e.g. as outlined in the Paris Agreement, [UNFCCC, 2023) are shown in Table 1. All medium-duty and heavy-duty trucks and buses sold will need to be ZEV in all countries by 2045, but even by 2035, high ZEV sales shares will be needed for most vehicle types in most countries. Leading countries are expected to transition faster than this figure indicates. Overall, achieving these sales targets worldwide will result in over 90% ZEV vehicle stocks by 2050.

Table 1. A phasing approach to ZET (Zero Emission Truck) and ZEB (Zero Emission Bus) sales shares in major economies around the world to meet Paris trajectory.

Vehicle Type	2025	2030	2035	2040	2045
Bus (>3.5 tonnes)	7%–30%	75%-90%	90%–100%	100%	100%
Medium truck (3.5–16 tonnes)	3%–12%	40%–50%	75%–90%	100%	100%
Heavy truck (>16 tonnes)	2%–9%	30%–41%	60%–75%	90%–100%	100%
All HDVs (sales-weighted average per country)	3%-12%	40%–56%	69%–83%	94%–100%	100%
All HDVs (sales-weighted average for all ZEVTC members)	4%	45%	76%	97%	100%

Source: Yihao Xie, Tim Dallmann, & Rachel Muncrief (2022). Heavy-duty zero-emission vehicles: Pace and opportunities for a rapid global transition. ICCT https://theicct.org/publication/hdv-zevtc-global-may22/

Worldwide, across all truck and bus types (all medium/heavy duty road vehicles, or MHDVs), around 20 million are sold each year; in comparison, about 120,000 were ZEV in 2022, nearly all in China (Figure 1 below). However, this situation should change rapidly in the coming years.

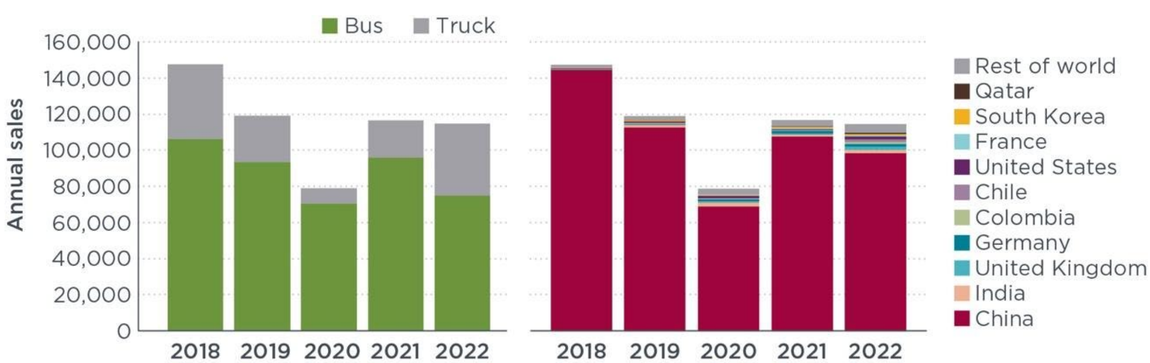

Figure 1. ZE HDV sales around the world, 2022 (Chu 2023)(https://theicct.org/wp-content/uploads/2023/06/Global-EV-sales-2022_FINAL.pdf)

Looking into the future, total global truck sales are expected to rise to over 30 million per year by 2040. Most of the growth will be in global south countries (as defined in the figure notes), with less in the more industrialized countries of the north. Though the north remains very important given the already high sales levels in these countries.

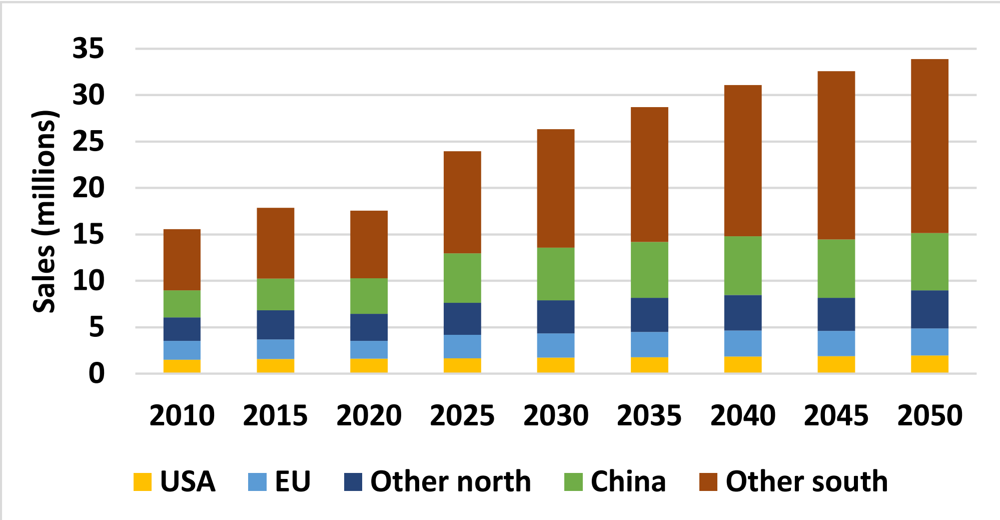

Figure 2. Total medium and heavy-duty vehicle sales projections, by region
(Source: UC Davis projections based on IEA Mobility Model. “Other north” includes Canada, Mexico, Japan, S. Korea and several other industrialized countries. “Other south” includes India, Brazil, and most other South Asian, Pacific, African and Latin American countries.)

Though the exact number of ZEV trucks and buses that will be sold in any given future year is of course uncertain, projections of ZEV sales to 2050 under a global high ambition scenario, which were developed as part of this report, are shown below in Figure 3. This projection is based on estimating the effects of policies already undertaken and targets set, and assumes that there will be a strong uptake of ZEVS to meet sub-national, national, and international goals for CO_2 reduction under the Paris agreement and related commitments.

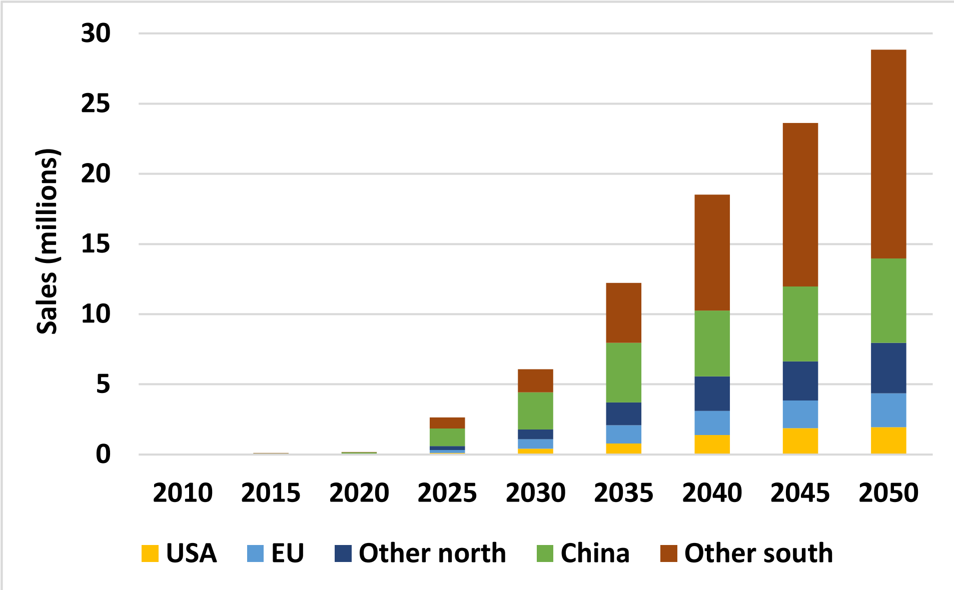

Figure 3. Existing goals and Paris-consistent Scenario ZE truck and bus sales by region to 2050
(Source: UC Davis projections under High Ambition Scenario)

As shown, in this high ambition scenario ZEV MHDVs reach about 30 million sales (about 85% of the global market) in 2050. Sales numbers are high in all regions, though show that China and other global south countries will account for an increasing share of sales through the time frame, as ZEV sales in current major markets saturate soon after 2035. Achieving these targets in both northern and southern countries will take on-going, strong policy and market-development efforts, as described throughout this paper.

Breaking these into percentage ZEV sales for 2025, 2030, and 2035 (Figure 4), and adding California to the figure (included in the previous figures as part of the US), market shares in the global north reach 40% or higher by 2035, California has the fastest trajectory, reaching 90% by 2035. The US and EU also have strong trajectories given that their CO_2 rulemakings are completed and stay on track through 2035. China also appears to be on a fast track through 2035, though does not have a clear national target at this time. Other global north countries (e.g. Japan, Korea) are on a slightly slower track and other global south countries are still gearing up to developing and implement policies, but are expected to reach a combined 30% market share by 2035, in this scenario.

The resulting global average reaches a 40% market share across all MHDV classes through 2035. This will need to be accelerated further to reach 100% global ZEV sales in a time frame that allows for a 100% ZEV stock (and thus overall zero-emissions from the full on-road fleet) by 2050 or soon after. If this can be reached, the benefits in terms of reduced CO_2 emissions as well as lower emissions of air pollutants around the world will be enormous. As a very rough estimate of the value of the CO_2 emissions reduction, at $100/ton, and an average of 10 tons per year per truck, this emissions reduction is worth about $1000/year per truck (and much higher for heavy-duty long-haul trucks, lower for small urban trucks). Given on the order of 200 million trucks and buses around the planet, if all of these could be replaced with zero emission vehicles operating on zero-carbon electricity, this would provide CO_2 reductions on the order of 2 gigatons (GT) per year, worth $200 billion at the CO_2 price of $100/ton mentioned above.

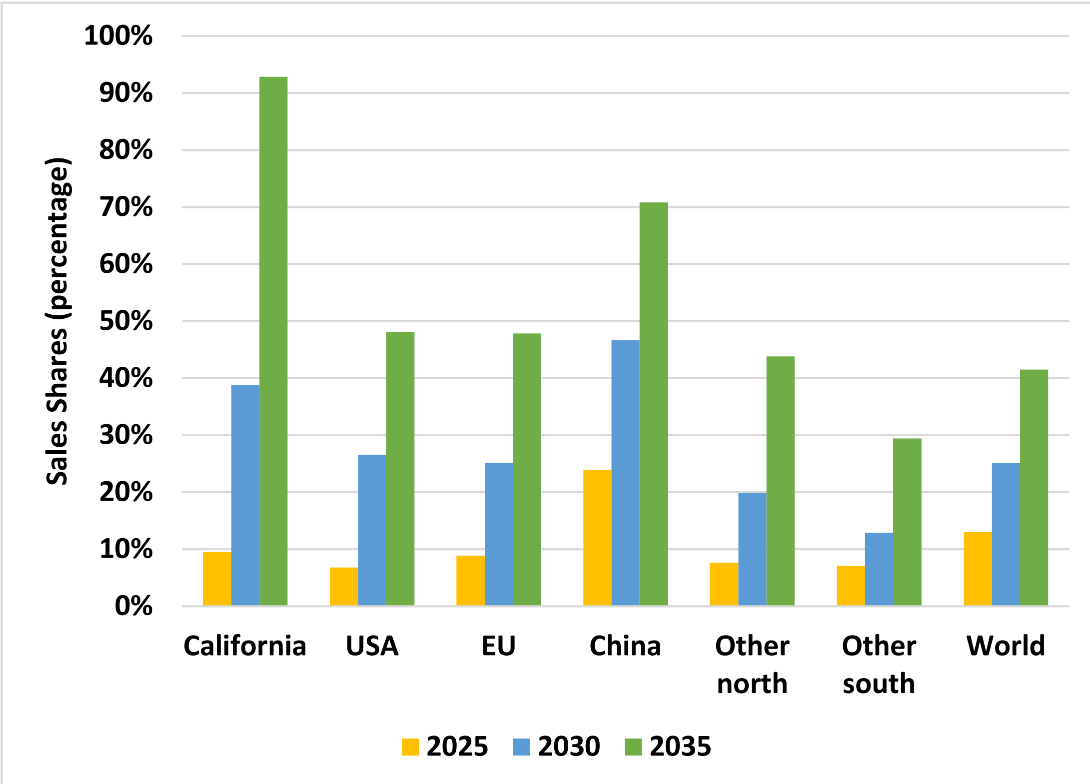

Figure 4. UCD projections of potential ZET/ZEB sales shares by country/region, to 2035
(Source: UC Davis projections under High Ambition Scenario)

3 Policy overview: major approaches for achieving MHDV ZEV market uptake

Seizing the benefits of electrification in transportation in terms of cost reduction, emissions exposure and GHG avoidance requires overcoming technology and cost barriers. Part of achieving this will come from on-going technology improvements and cost reductions. Some adjustments in fleet operating practices (such as logistics, workforce training, etc.) will also likely be needed. But government policy will also play a critical role. This includes first and foremost regulatory actions that send clear signals as to government targets, along with requirements that assist in achieving those targets. Regulatory policy may include CO_2 emissions standards and direct requirement for the sales or purchase of specific types of vehicles, such as ZEVs. Relaxing some other regulations may also be needed (such as weight limits, to better accommodate heavier electric trucks, for example).

Supporting fiscal actions can also play an important role. These include purchase incentives, fuel and other operating cost reductions, and incentives for (or direct government investments) in charging infrastructure (for electric vehicles) or refueling infrastructure (for hydrogen vehicles).

Incentives are typically aimed at reducing the purchase price or the total operating cost (TCO) of ZEVs, which must become competitive (and hopefully lower) than for today's diesel trucks in virtually all of the major trucking categories. But purchase costs (and prices) will come down as sales and production volumes increase, and with optimization of production systems. But during the next few years, a key transition phase, policies must ensure that ZETs are affordable and can achieve TCO parity (in many cases taking into account lower per-kilometer operating costs). But even if lower operating costs offset higher purchase costs, this represents a change in balance, and can create a finance and cost recovery challenge for fleets. Policies (such as incentives) to lower purchase price can play a critical role in this regard.

Clear regulatory direction and supporting policies can also help provide the environment for lowering costs by ensuring the market will grow, along with production volumes. Requiring ZET sales either directly, as a percentage of total sales, or indirectly, as a key implied strategy for reaching fleet average CO_2 emission requirements, sends a clear signal that the market will expand, and along with it production volumes. Production costs should decline over time as a result.

A range of technical solutions may also be encouraged for meeting the challenges of specific use cases: Cost reductions in deploying fast and super-fast chargers and ensuring sufficient numbers to allow convenient long-distance trucking are likely to be crucial in the medium term. And beyond fast charging, vehicle driving ranges may be extended by systems involving battery swapping, using overhead catenary or other “e-road” systems, or shifting to hydrogen and fuel cell vehicles. Adjusting payload limits on trucks may help with heavy loads, and adjusting the ways that payload is handled and how trucks are used as part of the bigger logistics system may be important.

3.1 Vehicle CO_2 reduction standards: an indirect regulatory approach

One important regulatory mechanism for encouraging ZEV uptake is the implementation of CO_2 standards set as an average across manufacturer vehicle sales. Requiring CO_2 limits for various vehicle classes (on average per manufacturer), with these limits dropping over time, encourages improvements in fuel economy and the uptake of other technologies that can cut CO_2 per vehicle kilometer. As described further below, both the US and EU have CO_2-based regulatory systems that may increasingly incentivize ZEV sales. Since ZEVs emit no CO_2 directly, selling them can affect fleet average tailpipe CO_2 fairly dramatically per vehicle sold. As conventional vehicle fuel economy improvement options become more limited and more expensive, this also encourages adoption of ZEVs to meet requirements.

Even taking into account the full “well-to-wheel” GHG emissions associated with EVs (e.g. from electricity generation), EVs can yield substantial GHG benefits, which only improve as grids are decarbonized. They also eliminate tailpipe pollutant emissions. Over time, production of renewable electricity (and hydrogen for fuel cell vehicles) will be required in all countries in order to meet electricity carbon intensity targets and standards, and the increasingly ZEV dominated vehicle fleet will continue to provide reductions overall compared to ICE vehicles. Thus the ongoing tightening of CO_2 standards can be a key strategy for both encouraging ZEV uptake and reducing average manufacturer fleet sales CO_2 intensity, eventually to near zero.

In this regard, ICCT tracks the CO_2 standards (and for California, its ZEV mandate rules described below) in place in different countries (Figure 5) in terms of the expected impact on ZEV market share for different vehicle classes, over time. Some countries (such as the US and EU) have proposed CO_2 standards and have estimated the impacts on ZEV adoption as reflected in the figure. Other jurisdictions, such as California, have applied a ZEV mandate to directly require an increasing share of sales of zero-emission vehicles over time. As shown, the California ZET sales share approaches 100% by the mid-late 2030's, the fastest of any jurisdiction.

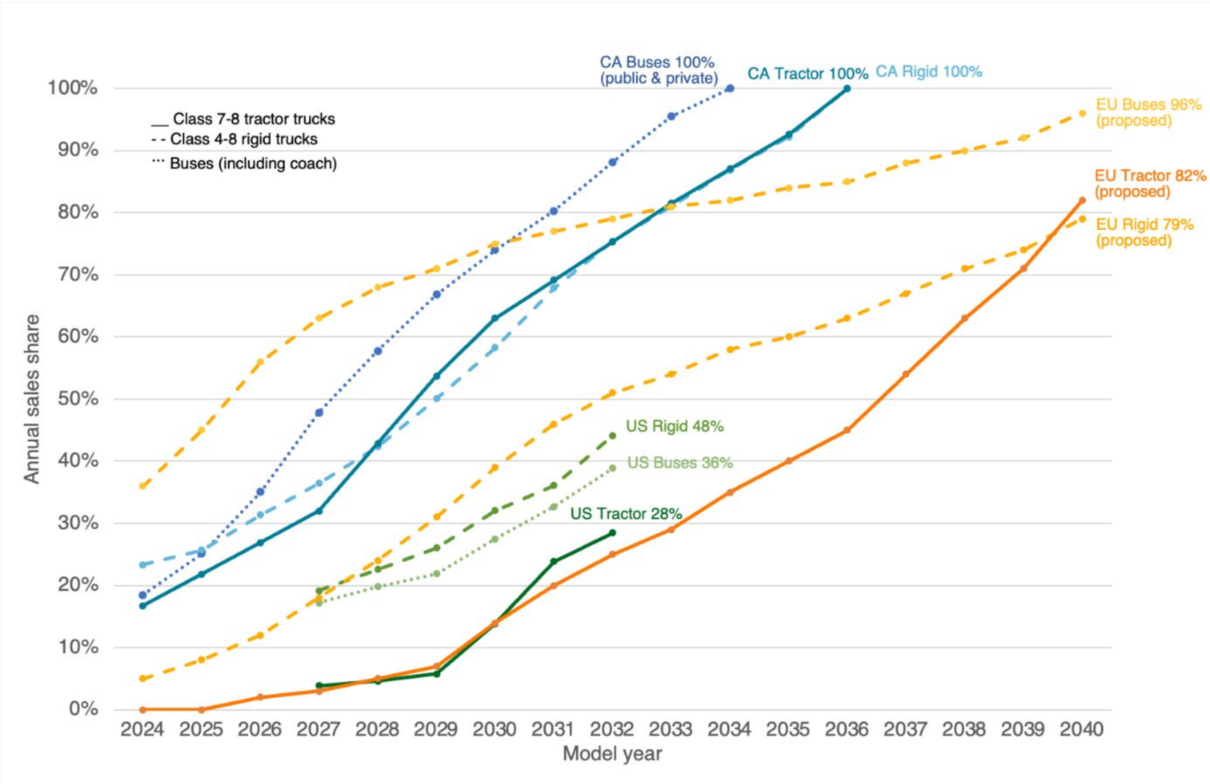

Figure 5. ICCT ZEV percent sales increase requirements or estimates due to vehicle policies in different countries (Xie 2023, Mulholand 2023)

3.2 Zero-emission vehicle sales/purchase requirements: a direct regulatory strategy

In contrast to indirectly encouraging the uptake of ZEVs via CO_2 regulation, another approach is to directly require manufacturers to sell them, and/or consumers to buy them. California pioneered a direct "ZEV mandate" approach with its light-duty vehicle programs beginning in the early 2000s. Much more recently, it developed and implemented sales requirements for ZEV trucks and buses, as a percentage of all such vehicles sold by manufacturers. This Advanced Clean Truck (ACT) program covers major manufacturers selling in the state. The state has also developed and is implementing requirements for many types of medium- and heavy-duty truck fleets to purchase ZEVs, (Advanced Clean Fleet Program, ACF) that is coordinated with ACT. It separately regulates transit bus purchases via the Innovative Clean Transit (ICT) bus rule, among the most aggressive of its policies (transit operators must purchase only ZEVs by 2029).

While some other countries have adopted versions of light-duty vehicle regulations to require increasing sales of ZEVs over time, to date California and has implemented a truck or bus policy of this type. It is also the only known government to adopt regulations on fleet purchases of ZEVs. However, a number of other states have adopted the ACT or both the ACT and ACF rules (CARB, 2023b), and most likely various countries are also considering adoption of these types of measures.

More details of California's programs are provided in the regional policy discussions below, but the basic concept of sales and purchase requirements is fairly straight-forward. For a manufacturer ZEV sales requirement such as ACT, major original equipment manufacturers (OEMs) must make a certain percentage of their sales within the state ZEV, with this percentage increasing over time. There are various enforcement and credit mechanisms to support the rule. The sales percentage requirements in ACT are shown in Table 2. These reflect a steadily increasing percentage through 2030 for all truck classes, with some rising through 2035 (Buysse 2020).

Table 2. Schedule for Required Percentage of ZEV Sales by market class under ACT rule (CARB 2019)

Model Year	Class 2-3b (light commercial)	Class 4-8 (medium duty)	Class 7-8 (tractor)
2024	5%	9%	5%
2025	7	11	7
2026	10	13	10
2027	15	20	15
2028	20	30	20
2029	25	40	25
2030	30	50	30
2031	35	55	35
2032	40	60	40
2033	45	65	40
2034	50	70	40
2035	55	75	40

3.3 Vehicle purchase cost reduction

Although medium and heavy-duty ZEVs are currently typically more expensive than comparable diesel trucks, with market prices as much as double, these costs are dropping as more models enter the market and production levels rise toward “mass market” levels. Reductions in technology costs (such as batteries) and rising vehicle production volumes (along with optimization of production and supply chain systems) all contribute to cost reduction, and the faster these changes occur the faster overall costs will drop.

Along with direct regulatory policies and programs, fiscal programs to reduce differential purchase costs can be important to help speed the process and make trucks attractive to fleets in the near term. Such policies typically cut the purchase price of ZEVs, or at least reduce the differential between that price and the price of the competition, usually diesel trucks.

Many countries and regions have developed ZEV truck or bus purchase incentives, reducing the up-front cost of ZETs and ZEBs relative to diesel vehicles. Countries can have very different truck types and underlying costs, and it is not generally clear yet just how much the differential price must be cut for ZEVs in each local situation to compete with diesels. Purchase costs may not need to reach parity with diesel if operational cost savings are taken into account. Using the “total cost of ownership”, or TCO, as a key comparison metric, means that both purchase cost reductions and operating cost reductions can play an important role in making ZEVs competitive. Reaching competitive TCOs, that achieve parity with diesel by balancing upfront with operational costs, should be the goal.

In this regard, ZETs have clear operational cost advantages (lower energy and maintenance costs than for diesels), which could grow over time if petroleum costs continue to rise. Fuel cell truck costs may take longer to reach parity given that hydrogen costs per kilometer of driving are typically higher than electricity costs. This will certainly vary by vehicle type and duty cycle, and more empirical data will help to sharpen the sense of the potential balance of ZEV advantages offsetting a long-term purchase price differential to be sustainable for different vehicle types.

Current levels of incentive subsidies in various countries and regions across North America and Europe are shown in Table 3 below. These are shown relative to the current typical purchase price of heavy-duty vehicles, as estimated by the IEA across a range of countries including the three in question.

In Europe, Spain has among the highest levels of subsidy, along with France and the Netherlands. Sweden has about half the level per vehicle, and Poland about one quarter. All of these are below half of the typical purchase cost of heavy-duty trucks, though many should cover the incremental cost of a ZEV compared to diesel, depending on truck type and location. Even if the ZEV purchase cost remains higher today, it will continue to drop annually and is expected to reach parity with diesels for most truck types before 2030; in many cases the total cost of ownership with incentives is already below diesel (see TCO section below).

Table 3. ZEV purchase incentives and subsidies by country for specific vehicle classes

Country	Powertrains	Class	Max Incentive for Stated Class in 2023
Germany	BEV, Hybrid, H_2	N3	80% of additional cost
Spain	H_2, BEV, Hybrid, CNG/LNG	N3	$142,000-€208,000 depending on company size
France	H_2, BEV, Hybrid, CNG/LNG	N3	$164,000
Netherlands	BEV, H_2	N3	Up to 37% or $144,000 for small businesses, less for large
US	BEV, H_2	~N2/N3	Up to $40,000 tax credit for ZET
CA	BEV, H_2	~N2/N3	Up to $410,000 in rebates for ZET
U.K.	Hybrid, BEV	N3	$32,000
China	BEV	N3	$4,000
South Korea	H_2, BEV		$190,000 for Hyundai XCIENT FC Truck, $198,000 for Hyundai Universe FC Bus
Japan	BEV, H_2	Over 8 Tons	¼ of the vehicle price
Sweden	Bio, H_2, BEV	Over 3.5 Tons	20% of total cost of the truck

Note: all fiscal values have been converted to US dollars, using conversion rates as of Mar 10, 2024. Truck classes reflect the European and generally global system: N2: 3.5-12 ton trucks, N3: Trucks over 12 tons.

3.4 Truck ownership costs and policies affecting TCO's

The total cost of ownership (TCO) of MHDVs depend on the purchase price and the cost of operations over their lifetime, including fuel prices, maintenance, insurance, road tolls, taxes, levies, and resale values. Alternatively, this can be viewed as costs during a specific period of ownership, such as 3 or 5 years, in which case the vehicle residual value must also be considered in the calculation.

While the purchase cost of battery electric trucks is expected to decrease rapidly over the next few years (for example as battery pack prices continue to decline), BETs are already less expensive to operate than diesel trucks in most cases, having fewer maintenance needs and lower energy prices per kilometer driven. Supportive policies, such as vehicle purchase subsidies, road toll fee changes, and carbon pricing, can considerably reduce the TCO gap between battery-electric and diesel trucks (Basma et al. 2021). ICCT recently estimated the year of potential break-even for various types of vehicles in the EU and the U.S (Figure 6), giving a rough picture that in many locations and for several different vehicle types, this can be achieved for battery-electric trucks by or before 2030.

Battery-electric transit buses will reach parity with ICE buses on a TCO basis earlier than other MDHV segments, as illustrated in Figure below. Battery-electric transit buses are already less expensive than diesel buses in Europe due to lower operational costs (Transport and Environment 2018; Meishner and Sauer, 2019). Other battery-electric truck segments, such as last-mile delivery trucks and short-haul tractor trucks, are expected to achieve TCO parity with their diesel counterparts in Europe before 2030 (Basma et al., 2023).

Most battery electric MDHV segments are expected to achieve TCO parity with diesel trucks in the U.S. between 2025 and 2030, with the exception of Class 8 sleeper cab trucks with longer driving distances and higher payload capacities (Burnham et al. 2021; Burke et al. 2022). By 2030, the TCO of BETs will be lower than diesel trucks in seven U.S. states (Basma et al., 2023). Larger batteries will be required to meet the driving needs of long-haul trucks, raising the upfront cost of BETs compared to diesel trucks. However, BETs have better TCOs when average daily mileage is taken into account. In California, battery-electric pickup trucks and vans, refuse trucks, and short-haul truck segments could reach TCO parity by 2025, according to the California Air Resources Board (CARB 2021).

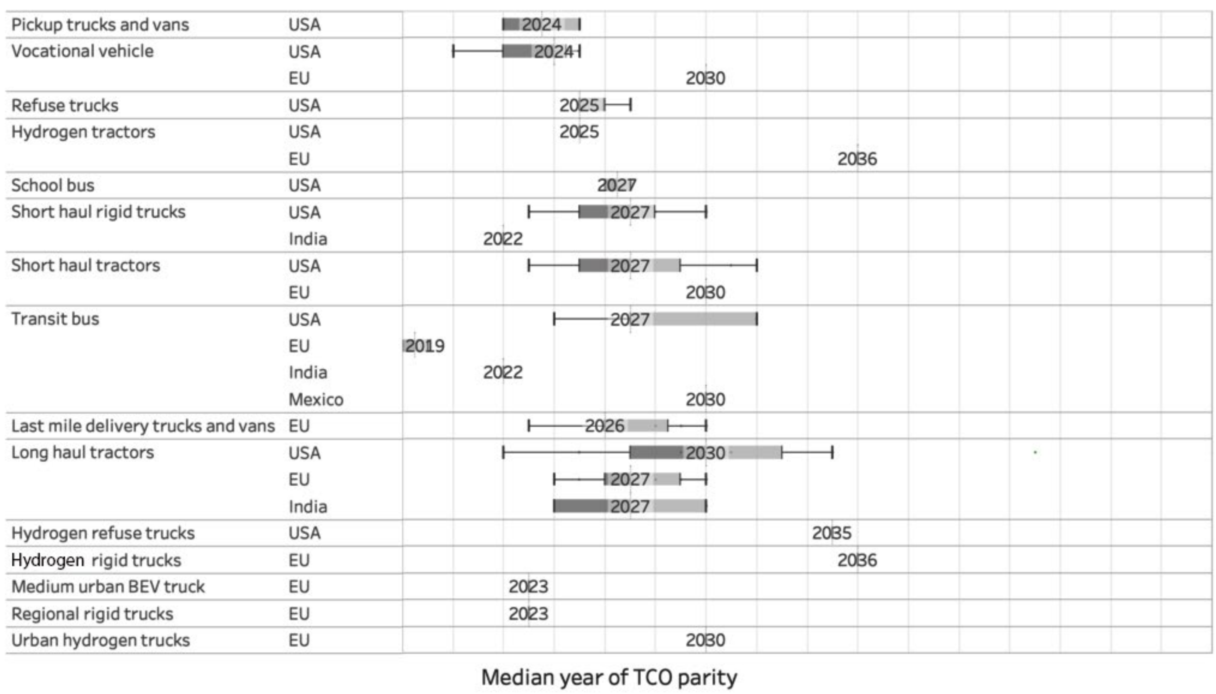

Figure 6. Estimated dates for "breakeven" TCOs for example truck types and regions (ZEVTC 2023; Source: ICCT, 2023)

The total ownership costs of MHDVs depend on the purchase price but also the cost of operation, which includes fuel and maintenance cost. Resale value also can matter considerably. While this paper does not attempt a detailed review of TCOs, it is clear that the relative TCO of different vehicle choices is highly context-specific, depending on how and how much a vehicle is driven, local fuel prices (with taxes), and the specifics of the cost of the trucks in question. ICCT recently estimated the year of potential break-even for various types of vehicles in various locations, giving a rough picture that in many locations and for a number of different vehicle types, this can be achieved by or before 2030, and in some instances has already.

3.5 Vehicle Recharging Infrastructure

Ensuring that vehicles can refuel, or in the case of electric vehicles, recharge, is a critical element of a balanced ZEV truck market growth strategy. It is important enough that within this project we have created a companion document, *International Zero-Emission Heavy-Duty Vehicle Infrastructure: Policy Playbook*, to review and describe key elements of recharging infrastructure policy, and examples of major initiatives in countries that have reached that stage.

For trucks and buses, charging facilities will be needed in a certain ratio to the numbers of vehicles, and at certain power levels depending on the needed speed (time duration) of recharging. Understanding the numbers and power levels needed is a critical first step for infrastructure policy. The exact number and types of chargers will depend on the types of charging that vehicles need; either at their own depot (private charging) or over the road, for example.

Once policy makers understand the operating environment and infrastructure needs, they will need to identify targets and a time frame for getting the infrastructure installed, either with direct regulation or by incentivizing the private sector to take the lead on needed investments.

The European Union (EU) has taken a strong regulatory position on this issue, implementing the Alternative Fuel Infrastructure Regulation (AFIR), which among other things requires EU Member States to ensure fast-charging stations at installed on certainly public highways at given distances by the mid-late 2020s. To accommodate medium/heavy duty vehicles, by 2025 15% of covered roadways must be equipped with fast-charging stations at least every 120 km. This increases to 50% by 202, and 100% by 2030, with the maximum distance dropping to 60 km in that year (ICCT, 2023). The exact manner in which each member state implements this policy is unspecified but should become clear during 2024.

In terms of incentivizing the construction and operation of MHDV charging infrastructure with subsidies or direct funding, many EU member states as well as the US, China and others have developed programs. These are summarized in Table 4 below, based on known policies as of late 2023. The table also provides some notes on infrastructure planning, and includes mention of hydrogen refueling programs, also critical to develop fuel cell vehicle markets. The programs and type of cost coverage vary considerably, but the main point is that many jurisdictions are supporting the implementation of this infrastructure.

Table 4. Charging infrastructure incentives and notes on planning

Country	Infrastructure Incentives	Related Investment Plans for Infrastructure
Spain	Up to 70,000 Euros is available per project	
Sweden	Up to 50% (private), 70% (public) cost share	Plans for the development of electric roads and stationary charging infrastructure
Poland	Up to 50% of eligible costs	
Germany	80% of the eligible project expenditure	Plans for overhead charging infrastructure, hydrogen infrastructure and established master plan for stationary charging
France	Charging infrastructure eligible for 60% support	Test projects for electric road technology
China	Subsidies depend on province	Battery swapping for trucks is already commonplace
Japan	Subsidizes 1/4 of charger price	
South Korea	Primary focus on hydrogen infrastructure	Plans for expansion of hydrogen stations, Targets for hydrogen to fall below 3,000 won/kg by 2040
US	DOT/DOE NEVI Program with specific highway infrastructure targets and funding programs	DOE also has extensive funding for hydrogen hubs that include truck infrastructure
CA	CEC Energiize Program	Extensive on-going funding for charging infrastructure and hydrogen refueling stations

4 Specific Country and Regional Policies in Place as of 2023

This section provides a more detailed overview of the specific ZEV truck and bus related policies that have been adopted in the US and the state of California.

4.1 US EPA Proposed "Phase 3" truck/bus CO_2 rules

While California is focused on ZEV sales and purchase requirements for M/HDVs, the US EPA has proposed new CO_2 emissions standards that would likely (but indirectly) require the sales of increasing percentages of ZEVs to meet (EPA 2023). These proposed Phase 3 standards continue the Phase 2 approach of manufacturer fleet-based standards based on average CO_2 emissions per ton-mile, with on-going reductions in average CO_2 emissions through 2032. The vehicles that are heavier and driven more miles, receive a lower allowance of CO_2 per ton-mile.

Fleets can use a variety of technologies to meet these standards, including transmission technologies, aerodynamic improvements, engine technologies, battery electric powertrains, hydrogen FC powertrains, etc. However, as the standards tighten, they are likely to find ZEVs (scored at net zero) to be increasingly attractive and a cost-effective way to meet the standards. EPA has considered this and made estimates of examples of ZEV uptake that would help meet the standards, such as shown in Table 5.

Table 5. EPA projections of ZEV adoption to help meet CO_2 standard by vehicle type and year (ZEV sales percentage) (EPA 2023)

Regulatory Subcategory	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Light-Heavy Duty Vocational	22%	28%	34%	39%	45%	57%
Medium Heavy-Duty Vocational	19%	21%	24%	27%	30%	35%
Heavy-Heavy-Duty Vocational	16%	18%	19%	30%	33%	40%
Day Cab Tractors	10%	12%	15%	20%	30%	34%
Sleeper Cab Tractors	0%	0%	0%	10%	20%	25%

The proposed rule estimates emissions reductions and finds a very high value for these reductions relative to the cost of adopting them within society. Additionally the proposal includes battery durability and warranty requirements for manufacturers in order to limit the adverse impacts of the policy to fleets.

4.2 US Funding Programs for MHD ZEVs

In addition to regulating CO_2 emission per vehicle sold, the US government has a range of funding programs to support the market development of HD ZEVs and ZEV infrastructure.

Perhaps the largest US funding program related to electric vehicles is "NEVI", the National Electric Vehicle Infrastructure program (NEVI, 2023), co-managed by the US Dept of Transportation and Department of Energy via a joint office (JOET, 2023). This program was created and authorized $5 billion of funds as part of the US "Infrastructure Investment and Jobs Act (IIJA)", passed in 2022. It creates a range of funding programs directed toward state-led efforts to build and maintain charging infrastructure for light, medium and heavy-duty vehicles. It is focused on public infrastructure located on the nation's highways, particularly along "alternative fuel corridors".

The US Dept. of Transportation also administers a Charging and Fueling Infrastructure (CFI) Discretionary Grant Program (DOT, 2023). This competitive funding program announced during 2022-23 that it will fund 47 EV charging and alternative-fueling infrastructure projects in 22 states and Puerto Rico, including construction of approximately 7,500 EV charging ports. Five of the projects are focused on MHD fast charging, with the largest a project in California to develop a major truck charging hub. It includes $56 million to construct two state-of-the-art truck charging sites to support two of the nation's busiest freight corridors. The sites will feature 90 DC fast chargers for passenger vehicles, 85 DC fast chargers for MHD electric vehicles, and 17 one-megawatt charging level chargers for HD vehicles. The sites will also enhance grid stability with 63 acres of solar panels and battery electric storage systems.

Regarding funding the purchase and operation of electric vehicles, the US government recently authorized investments of $1 billion to replace dirty heavy-duty vehicles with clean, zero-emission vehicles, support zero-emission vehicle infrastructure, and to train and develop workers. The US EPA will be distributing this $1 billion in funding for clean heavy-duty vehicles through 2031. It will include grants and/or rebates to eligible recipients to replace existing heavy-duty vehicles with clean, zero-emission vehicles. Funds will also be supplied for zero-emission vehicle infrastructure, workforce development and training, planning and technical activities. Applications for funding will be accepted beginning in 2024 (EPA, 2023).

Finally, a very important electric (and other clean) vehicle purchase incentive is contained in the US tax code. The Commercial Clean Vehicle Credit CCVC provision, administered by the IRS, provides tax credits for the purchase of medium/heavy-duty ZEVs (CCVC, 2023). The tax credit provided by CCVC is the lesser of the incremental cost of ZEVs (relative to diesel vehicles) or 30% of the vehicle cost for ZEVs. The amounts are capped at $40,000 for trucks over 14,000 lb. GVWR, and $7500 for those under 14,000 lb. GVWR. This, combined with state level incentives (such as in California, described below) can significantly reduce the additional cost of purchasing EVs.

4.3 California’s ACT, ACF and other ZEV-related programs

Although California is a state rather than a country, it arguably leads the world in developing policies to promote (and require) sales of ZEV M/HDVs. California has a wide range of regulations and incentive programs that support the adoption of medium- and heavy-duty zero-emission trucks and buses. The programs can be divided into vehicle regulation, incentive programs, fuels-related programs, and infrastructure programs. A number of the key programs are summarized here.

4.3.1 Regulations

4.3.1.1 Advanced Clean Truck Rule

As described to some extent above, California’s Advanced Clean Truck Rule (ACT) is perhaps the first of its kind worldwide. The rule was approved by the California Air Resources Board in June 2020 and established a timeline by which medium and heavy-duty truck manufacturers must increase their sales of zero emission vehicles between 2024 and 2035. It is intended to help increase the supply of these vehicles and availability in California’s market, so that fleets are able to purchase them (particularly since they will be required to under the companion ACF rule, below). The first year sales requirements in 2024 are relatively low (around 7-11%), but rise fairly rapidly reaching 40% or more in 2030. In 2035, 55% of Class 2b-3 truck sales, 75% of class 4-8 truck sales, and 40% of Class 7-8 truck sales must be zero emission (CARB ACT 2023). Percentages are based on the number of vehicles produced and delivered for sale in California by each manufacturer, in the designated model year.

Manufacturers must meet the requirement in each category of trucks they sell, though there are provisions to average across categories using a credit system. These credits can also be traded, allowing some manufacturers to exceed their nominal cap on the sale of non-ZEV vehicles by purchasing credits from those who have achieved a higher percentage ZEV sales level than needed to meet the requirements.

ACT additionally includes flexibilities to provide some credits for near-zero emission vehicles, including plug-in hybrid electric vehicles, which can generate credits until 2035. These vehicles receive only a percentage of the multiplier value of full zero emission vehicles. These vehicles can be used to satisfy up to 50% of the credits required each model year.

4.3.1.2 Advanced Clean Fleet Rule

The State's Advanced Clean Fleets (ACF) regulation, approved during 2023, requires "high priority" fleets (drayage fleets, large fleets (over 50 vehicles, public fleets and some specialty medium- and heavy-duty fleets) to purchase zero-emission trucks for use in California. (CARB 2023) It includes a schedule increasing the percentage purchase requirements over time out to 2035. It contains related requirements for large entities without their own fleets, but that hire fleets, to hire ones with qualifying numbers of zero-emission vehicles. The regulation is intended to provide assurance to truck OEMs that fleets will purchase the trucks they are required to manufacture under the ACT regulation.

Key components of ACF include:

- Drayage fleets
  - All drayage trucks entering ports and intermodal rail yards would be required to be zero-emission by 2035; all newly port-registered trucks must be ZEV beginning in 2024.
- High priority fleets
  - Fleets must purchase an increasing share of ZEVs beginning 2024 and, starting January 1, 2025, must remove internal combustion engine vehicles at the end of their useful life.
  - Instead of the Model Year Schedule, fleets may elect to meet ZEV targets as a percentage of the total fleet starting with vehicle types that are most suitable for electrification.
- State and local agencies
  - State and local government fleets must ensure 50 percent of vehicle purchases are zero-emission beginning in 2024 and 100 percent of vehicle purchases are zero-emission by 2027.

4.3.1.3 Innovative Clean Transit Rule

In 2020, CARB adopted the Innovative Clean Transit Rule requiring California transit agencies to purchase zero-emission buses (ZEBs) starting in 2023 and ultimately operate only ZEBs by 2040.

The required schedule (Table 6) for purchasing ZEBs shows the 25% requirement in the starting year, and that 100% of all bus purchases must be ZEBs in 2029.

Table 6. Innovative Clean Transit rule ZEV purchase requirements (CARB 2018)

Year	Large Transit Agency	Small Transit Agency
2023	25%	
2026	50%	25%
2029	100%	100%

4.3.2 Incentive Programs

California has a wide range of funding and incentive programs at the state and local levels. A few of the bigger programs are described here.

4.3.2.1 Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP)

California's HVIP program was started by CARB in 2009. The HVIP program provides vouchers on a first come, first served basis for the purchase of zero-emission and other low emission trucks and buses (CA HVIP). The program incentives are largely for fleets located in disadvantaged communities. The voucher amounts increase as the vehicle class increases and vouchers for trucks operating in disadvantaged communities, public school and transit buses, and class 8 FC trucks receive additional incentives.

4.3.2.2 Clean Transportation Program

The California Energy Commission oversees the Clean Transportation Program, which invests up to $100 million in advanced transportation and fuels technologies (CEC 2023). The funding comes from vehicle registration, vehicle license plates, and smog abatement fees. The program funds projects which

- assist installation of fueling and charging infrastructure,
- increase purchases of advanced technology vehicles including zero-emission medium- and heavy-duty trucks,
- increase production of low carbon renewable fuels.

4.3.2.3 Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program)

The Carl Moyer Program is a partnership between CARB and California's air districts. The program funds low emission technologies including zero-emission trucks and buses. On-road vehicle categories funded by the Carl Moyer Program include drayage trucks, emergency vehicles, heavy-duty trucks and buses, transit and school buses, solid waste collection vehicles, and transport refrigeration units (Carl Moyer, 2023).

4.3.2.4 Heavy-Duty Zero Emission Vehicle (ZEV) Replacement Grant Program

The South Coast Air Quality Management District funds the replacement of Class 8 heavy-duty vehicles with zero-emission trucks with money from the Volkswagen Environmental Mitigation

Trust. The funds are distributed as grants that can cover up to 75% of non-government project costs and up to 100% of government project costs. The funding is distributed on a first-come, first-served basis. Vehicle applications that are covered are concrete mixers, freight trucks, dump trucks, waste haulers, and drayage trucks (AFDC 2023).

4.4 EU and Member State (National) Policies

The EU has already established CO_2 emission reduction targets for truck sales that are designed to reduce the average CO_2 of the fleet, with the current rule applying to model year 2025 (European Commission, 2019). A new draft directive (rule) extends this to 2032 and reduces the allowed average CO_2 emissions from trucks by truck class, with a clear intent to incentivize the sales of zero emission vehicles. Under the rule, manufacturers must reduce average CO_2 emissions of their sales of applicable vehicles by 15% by 2025 compared to a 2020 reference period, and 30% by 2030. After 2030, stricter targets will begin to apply based on how many ZEVs are sold. A super credit system (more than 1 credit per vehicle sold) for ZEVs is designed to further incentivize sales (ICCT 2019).

The current regulation only applies to the following N2 (3.5-12 tonnes) and N3 (>12 tonnes) vehicles (EUR Lex):

- rigid lorries with an axle configuration of 4×2 and a technically permissible maximum laden mass exceeding 16 tonnes
- rigid lorries with an axle configuration of 6×2
- tractors with an axle configuration of 4x2 and a technically permissible maximum laden mass exceeding 16 tonnes
- tractors with an axle configuration of 6x2.

Vocational vehicles such as refuse trucks or concrete mixers are currently exempt from the standards, as well as buses and vehicles with axle configurations not listed above.

The draft rule will expand on the vehicles considered and strengthen the current emissions regulations as shown in Table 7.

Table 7. EU proposed CO_2 emissions reductions by vehicle class and year (EUR Lex 2023)

Sub-groups	2025 – 2029	2030 – 2034	2035 – 2039	After 2040
All medium lorries & vans, as well as Heavy lorries > 7,4t	0%	43%	64%	90%
Heavy lorries > 16 t with 4x2 and 6x4 axle config	15%	43%	64%	90%
Heavy lorries > 16 t with special axle config or Motor Coaches over 8 seats	0%	43%	64%	90%
Urban buses over 8 seats	0%	100%	100%	100%
Other trailers over 3.5 tons	0%	7.5%	7.5%	7.5%
Semi Trailers over 3.5 tons	0%	15%	15%	15%

The proposal would also require all new purchases of transit buses in the EU to be zero emission by 2030. Transit buses are considered easier to electrify compared to heavy-duty trucks because they serve consistent routes and have time to charge overnight. However, there are exemptions for a number of vehicle types, including trucks produced by small manufacturers, vehicles involved in mining operations, forestry or agriculture, military vehicles and railway service vehicles, vehicles used for emergency purposes or to maintain civil order, and vocational vehicles such as refuse trucks or concrete mixers.

These exemptions relate to the difficulty of electrifying these, given their duty cycles and other concerns. However, the exemptions introduce a potential concern: too many exemptions may limit the overall effectiveness of the policies. For example, refuse trucks are an important urban vehicle, and there are already many battery electric refuse trucks in operation in Europe and elsewhere. Also, according to a recent (ICCT) report (Mulholland 2023), these exemptions could create a loophole where fleets could legally purchase a diesel vocational truck and swap the body to a desired configuration, allowing them to be exempted from the CO_2 standards. Since BETs are currently more than twice as expensive as a diesel model, this may be a cost-effective strategy for some fleets.

To see how the new proposal might impact purchases of ZETs, and total emissions, we consult a recent ICCT report on the CO_2 standards required to meet climate goals (Mulholland 2022). In their report they consider 4 different policy scenarios, including the current adopted policies, and an EU Sustainability and Smart Mobility Strategy, which is an early version of the current proposal discussed above. Their report models the sales of ZET based on different climate standards and constructs diffusion curves that would meet those standards. Based on these diffusion curves, and yearly estimates for vehicle miles traveled, they can approximate the emissions reductions from each emissions standard.

Europe will also need charging stations, which is addressed under a new European "Fit for 55" set of rules that aims to have at least 55% less net greenhouse gas emissions by 2030, compared to 1990 levels. Among other things, it would require EU countries to install recharging stations "dedicated to heavy-duty vehicles with a minimum output of 350 kW need to be deployed every 60 km along the TEN-T core network, and every 100 km on the larger TEN-T comprehensive network from 2025 onwards, with complete network coverage to be achieved by 2030". Additionally, hydrogen refueling infrastructure must be deployed every 200 km along the TEN-T core network, ensuring a sufficiently dense network to allow hydrogen vehicles to travel across the EU".

4.4.1 EU Member State policies

Within the EU there are a wide range of country strategies (or in some cases, lack of strategies), for reaching EU and national targets. The coverage here includes larger EU countries and a sampling of smaller ones (such as Sweden and Poland). Since these countries are members of the EU, there are binding rules and regulations set at the level of the EU, while other policies, particularly fiscal ones, specific investments, and regional/local policies, are set within each country. All taxation and pricing incentives related to the sales and uptake of ZETs are done at the national level.

Currently the sales of ZETs are very small in most parts of Europe (Figure 7). As of late 2022, Sweden had the highest known sales share of ZETs, at about 3% of overall sales. These shares should grow dramatically in the next 3-5 years given the EU and member state commitment to this market development.

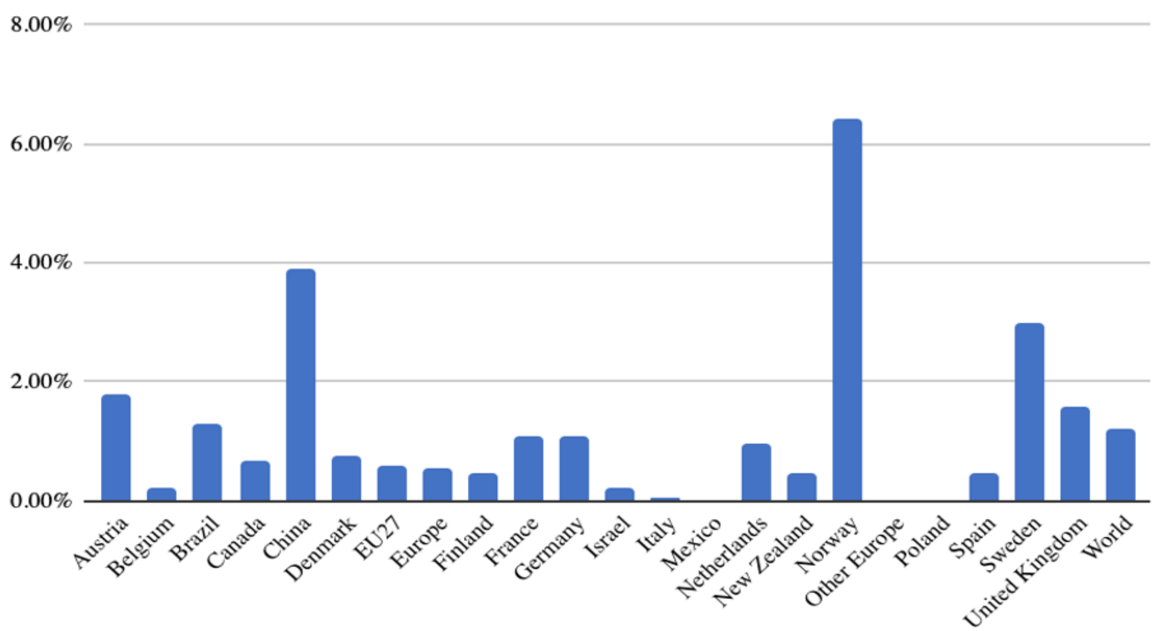

Figure 7. ZEV Truck Sales Percentage, 2022 (IEA GEVO 2023)

4.4.1.1 Spain

Spain is currently one of the leaders in Europe in terms of incentive programs for ZETs. Spain has implemented a program that provides subsidies for ZET purchases, grants for charging infrastructure, money for scrapping older trucks, and incentives for retrofitting existing vehicles.

Spain has allocated 400 Mil Euros for private transport companies to fund these activities. The subsidy for ZETs varies by vehicle class and fuel category (BEV, Hydrogen, etc.). The amounts are larger for small businesses that have less access to capital and are more sensitive to long payback periods for investments in trucks (Disposición 2022).

For example, a large company purchasing a BET over 16 tons can receive 130,000 euros or $126,000 USD (Disposición 2022). A small company can receive an additional 60,000 Euros over the large company limit. There are different subsidies for other vehicle categories, and other fuel types including hydrogen. The current budget will accommodate subsidies for around 2000 trucks and 500 buses according to the program website.

In addition to subsidies for ZET purchases, up to 70,000 Euros is available for the installation of charging infrastructure. This ranges from Eur 10k for chargers up to 100kw up to 70k for chargers over 350kW. The amount of subsidy is also limited to 40-60% of eligible costs, depending on company size.

Spain also has a funding program related to public transport and municipal fleets. The aid includes an incentive based on the characteristics of the vehicles for the acquisition of zero emission vehicles for urban public transportation and for municipal waste collection and cleaning fleets, ranging from Eur 80k to 260k depending on vehicle type. As of mid-2023, funding has been granted for the acquisition of 651 urban buses and 48 vehicles for waste collection and cleaning, for an amount of €137.5 million (13.7% of the total amount of aid for the 2021 call), in 43 municipalities. In addition, €53M (5.3% of the total amount of aid for the 2021 call) has been granted for the infrastructures necessary for their operation (recharging points and additional equipment), which adds up to a total investment of €190.5M to promote zero-emission transport fleets under the EU's Recovery and Resilience Mechanism (RRM).

4.4.1.2 Sweden

Sweden has a variety of different programs in order to reduce climate impacts from road transport including:

- Funding for research and development of sustainable freight transport solutions
- Plans for the development of electric roads
- Promotion of biofuels in the short term
- HCT-higher capacity trucks that reduce emissions per ton of freight (HCT)
- Plans for stationary charging infrastructure
- Incentives for public and private charging infrastructure for trucks
- Incentives for FC and BETs

Sweden has incentives available for ZETs under two different programs, the Klimatklivet and Klimatpremien. The Klimatklivet is sponsored by the Swedish EPA, while the Klimatpremien is from the Swedish Energy Agency. The Swedish Energy Agency Climate Premium, Klimatpremien, pays

20% of vehicle purchase price for trucks over 3.5 tons (IEA 2022). Eligible fuel sources include bioethanol, FC, and battery electric. The 2022 program budget was SEK 1,140 Mil (101 Mil USD) (Statligt Stöd Till Vissa Miljöfordon). The program has been extended until 2024 currently. The amount cannot exceed 40% of the incremental cost of a ZEV. This program is open all year, and doesn't have any specific application periods. The Klimatklivet provides funding based on cost effective emissions reductions and has 4 application periods per year that are open for 14 days. The Klimatklivet provides funding for 40% of the incremental cost of a ZEV but can be increased by 20% for small businesses.

Sweden has implemented funding programs for charging infrastructure for heavy duty vehicles. In 2021, SEK 500 Mil(44 Mil USD) and SEK 550 Mil (49 Mil USD) in 2022 was allocated for charging infrastructure ("Summary of the Budget Bill for 2022"). The Klimatklivet provides 50% support for non-public charging infrastructure, and 70% support for public charging infrastructure.

Finally, Sweden has programs for investing in electric roads. An electric road would allow a BET to charge while it is driving either via overhead catenary lines or in-road charging systems. This would allow for smaller battery sizes to be used, and a lower purchase price of BETs, with extended driving range. Since trucks in Sweden generally drive on concentrated routes, only major trucking routes would need to be equipped with this technology. The Swedish government has stated that its ZET strategy must include both electric roads, and stationary charging infrastructure. They are also researching hydrogen technology in certain applications.

4.4.1.3 Poland

In Poland, medium and heavy duty (N2 and N3) vehicles are not currently eligible for any government incentives but that may be subject to change in the future. There were previously proposals for incentives but funding was never allocated and the programs were terminated. Electric and hydrogen city buses did have large incentives available under The Green Public Transport program for a brief period of time, up to 90% of the cost, but the budget was depleted very quickly, and support is no longer available.

When budget funds are available, incentives for electric and hydrogen infrastructure are available as follows:

- EV charging stations between 50kW and 150kW: support up to 30-45% of eligible costs
- EV charging stations over 150kW: support up to 50% of eligible costs
- Hydrogen filling stations: support up to 50% of eligible costs

4.4.1.4 Germany

Germany has implemented multiple measures in order to reduce the impact of commercial transport on climate change (Hall 2021). They currently have plans to have ⅓ of the km traveled by heavy transport vehicles be electric vehicles or e-fuels by 2030 (*BMWK* 2023). Additionally, they are providing large subsidies available for battery electric, hydrogen FC, and hybrid trucks. For N2, and N3 vehicles with a battery electric drivetrain, 80% of the additional expenditure when compared to an ICE model is covered. There is a limit of 25 mil euros of funding available per trucking company (BMDV 2022).

Germany has also created a master plan for charging infrastructure including plans for overhead charging infrastructure (Bundesamt für Logistik und Mobilität, UNFCCC). Charging infrastructure is subsidized at 80% of the eligible project-related total expenditure (Klimafreundliche Nutzfahrzeuge). Incentive programs are also provided for ZEB (Schirrmann). Besides charger incentives, they had a funding call for hydrogen filling stations that emit 100 percent renewable hydrogen during operation. The funding rate is up to 80 percent of eligible expenses. Applications can be submitted from now until May 10, 2023. There is another funding call at the end of 2023.

4.4.1.5 France

France has multiple programs designed to support the adoption of ZETs and reduce emissions from freight transportation (Hall 2021). The French government is targeting 65,000 electric heavy duty trucks on the road by 2028.

Support will be provided for projects involving development of electric mobility solutions for freight transport, clean solutions for urban logistics, aid schemes for vehicles as well as support for retrofitting ICE vehicles with ZEVs (Décret n° 2020-456). Vehicle subsidies may reach up to 65% of the difference in cost between an electric vehicle and a diesel equivalent. Up to 100,000 Euros per vehicle is available for trucks with a GVWR of under 26 tons (N2), or 150,000 Euros for vehicles with a GVWR over 26 tons (N3) vehicle (French Ministry of Ecological Transition 2022). For motor coaches and buses, 100,000 Euros per vehicle is available. Charging infrastructure for these vehicles is also eligible for 60% support (Ministères Écologie Énergie Territoires).

4.5 China

China is currently one of the leaders in terms of BET sales (Hall 2021). In China, each province has different targets and laws for ZET and ZEB, but national policies also exist (交通运输部). At the national level, fuel economy standards are currently being enforced for new trucks and buses, where fuel use must be reduced by 15% compared to previous standards (IEA 2019). Hong Kong currently has a tax incentive for low emission MHDV (IEA 2021). The government in the Guangdong province is targeting all future bus sales after 2021 to be low or zero emission vehicles (Guangdong Provincial Government. (2021)). The government in the Tianjin province is targeting 80% of vehicles involved in public transit, delivery, rental, and logistics to be low or zero emission vehicles by 2025 (Tianjin 2022). Additionally, the Chinese ministry of transport is targeting 72% of public transit vehicles and 20% of vehicles in the logistics industry to be low or zero emission by 2025 (Ministry 2021). Overall, China has aggressive policies to accelerate the development of low or zero emission vehicles.

4.6 Japan

Japan has a variety of programs to reduce emissions from medium and heavy duty vehicles (Hall 2021). They were one of the earliest countries to establish a fuel economy standard for heavy duty trucks (国土交通省). In terms of ZETs, up to ¼ of the vehicle cost of a ZET are subsidized (自動車：自動車環境総合改善対策費補助金). Additionally, charging infrastructure is subsidized at ¼ of the installation cost (環境：自動車環境総合改善対策費補助金). The Japanese government has stated that they have sales targets of 5,000 ZETs before 2030 (Green Growth Strategy). According to the

2022 Global Electric Vehicle Outlook from the IEA, Japan currently has 0% ZEV sales for trucks, but with their incentive programs, ZEV sales will likely increase in the near future.

4.7 South Korea

South Korea is one of the few countries that has been putting more emphasis on hydrogen FC technology than battery electric (Hall 2021). This is partially due to the fact that Hyundai, the largest Korean auto manufacturer, has made significant investments in the development of FC technology. The government is currently targeting 30,000 hydrogen FC trucks by 2040, and 40,000 hydrogen buses (““국고보조금.” 환경부 전기차 충전소”). They are currently providing funding of 250 mil won for the Hyundai XCIENT FC Truck and 260 mil won for the Hyundai Universe FC Bus. The government has plans for the expansion of hydrogen stations and has targets for hydrogen prices to fall below 3,000 won/kg by 2040 (보도/해명: “세계 최고수준의 수소경제 선도국가로 도약”). Approaching these prices, and citing the hydrogen stations more widely, willenable realization of many of the operational convenience and flexibility aspects of hydrogen FC trucks and ZET in general.

5 Additional and Innovative Policies for MHDV ZEV Uptake

As described above, there are a range of challenges to the uptake of ZEVs that must be addressed to achieve high sales and stock shares in a fairly compressed time frame (e.g. 100% stock turnover to ZEVs by 2050). The national and regional policy frameworks and strategies described above that have been adopted by countries around the world provide many good examples and insights into what policies are needed. However, there are still others that could be adopted, or have been adopted but deserve more description, which are presented here. The most critical are related to improving the operational characteristics of vehicles (e.g. via payload requirement changes), vehicle operating cost reduction, and improving performance aspects.

5.1 Truck driving range and payload rules

In order for a BET to have sufficient driving range, heavy batteries are required that will reduce the payload of the vehicle. This can have an impact on trucking company operations and profit, as more trips (or more trucks) could be required to haul the same amount of freight. In many cases trucks “cube out”, where the volume of the truck is exhausted before weight limits are reached (Figure 8). In this case, BETs would generally be viable, with the truck operating below its weight limits. It may be cost effective to make special weight allowances for BETs, as some countries have done. In the US, an additional 2,000 pounds has been added to the weight limit for CNG and BETs. However, higher weight limits mean potentially greater wear and tear on roads, and possibly incremental safety risks. Each jurisdiction must consider these aspects when setting rules and exceptions.

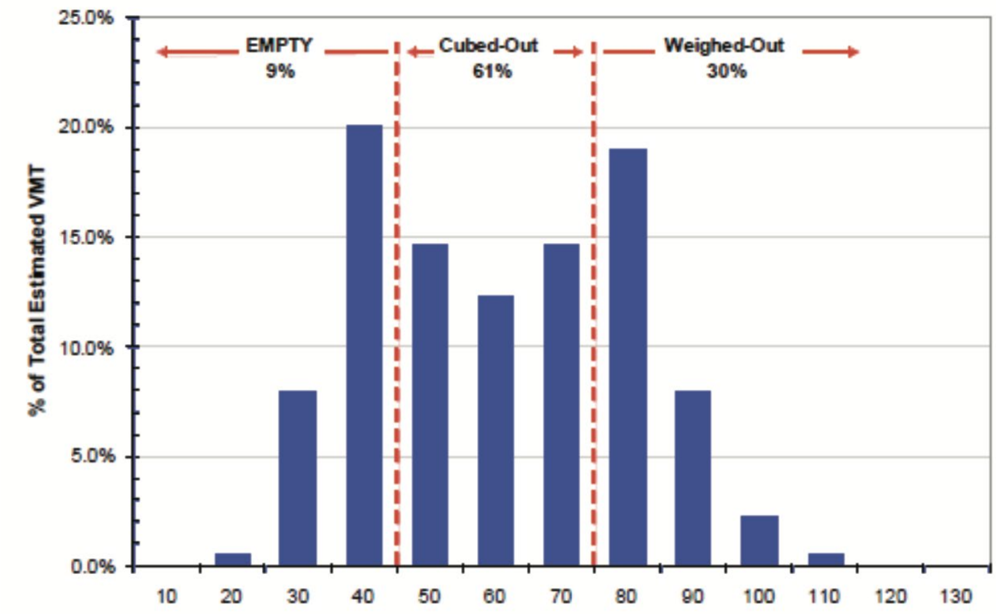

Figure 8. Share of VMT in the US that is either empty, "cubed out", or "weighed out" (Bradley 2009, NRC 2010).

The current weight rules in various EU countries are shown in the Table 8 below.

Table 8 Heavy-duty vehicle weight rules (in tonnes) by EU country (ITF 2019)

Country	Weight per non-drive axle	Weight per drive axle	Lorry 2 axle	Lorry 3 axle	Road Train 4 axle	Road Train 5+ axle	Articulated vehicle 5+ axle
France	12	12	19	26	38	40/44	40/44
Germany	10	11.5	18	26	36	40	40
Poland	10	11.5	18	26	36	40	40
Spain	10	11.5	18	25	36	40	42/44
Sweden	10	11.5	18	25/28	38	40	44

5.1.1 US Weight Limits

In the US, the weight limits vary by state with different weight limits for the total vehicle weight, a single axle, tandem axle or tridem axle. Additionally, trucks need to comply with federal and state-level bridge weight laws. Generally the weight allowed on an interstate highway is 80,000 pounds but many states have exemptions, including Michigan which allows up to 164,000 lbs. on 11 axles.

There are different limits in some states on certain routes or on interstate/vs non interstate routes. Additionally trucks hauling certain types of cargo may have exemptions or additional allowances depending on the time of year, including Aggregate Products (Rock, sand, gravel, road base, etc.), Agricultural/Farm Products & Commodities, Construction Equipment/ Highway Machinery, Alternatively Fueled Vehicles, Fire Trucks, Government-owned Vehicles, Farm Implements, Snowplows, Solid Waste/Rubbish/Trash, Timber Products & Commodities and Tow Trucks.

Table 9 shows current heavy truck weight limits for various US states, including some with particularly high limits or no limit. Whether broad exemptions could be given to MHDV ZEVs across states and across other various countries is unclear, but worthy of further research.

Table 9. Weight limits for various US states (FHWA 2023)

State:	Single Axle	Tandem Axle	Tridem Axle	Gross Weight (pounds)
California	20,000	34,000	N/A	80,000
Texas	20,000	34,000	N/A	80,000
Ohio	20,000	34,000	I.- FBF, N.I.-48,000	80,000
Illinois	20,000	34,000	42,500	80,000
Michigan	20,000	34,000	Depends on spacing of axles	Up to 164,000 (11 axles and A.S.)
Alaska	20,000	38,000	42,000	No upper limit as long as FBF is followed
Wyoming	20,000	38,000	42,000	Up to 117,000 with A.S.

Notes: FBF-Federal Bridge Formula, I.- Interstate, N.I.-Non Interstate, A.S.- Appropriate Spacing of Axles

5.2 Recharging: Implications of “Hours of Service” rules

Commercial drivers within the EU and US are subject to various operating rules such as daily “hours of service” restrictions. These exist mainly to insure the drivers have adequate time to sleep and reduce the chance of a driver falling asleep at the wheel while operating a heavy vehicle. Drivers in the US and the EU are required to utilize electronic logging devices to ensure compliance, with limited exemptions. These rules also affect the ability and convenience of operating BETs, since required breaks are also generally opportunities to charge the batteries.

Table 10 compares aspects of these rules for the US and EU. The hours of service rules within the EU are more restrictive and would potentially allow for more time to charge BET during rest breaks than in the US. This is assuming that there is adequate availability of chargers in the locations where drivers are able to park during mandatory rest breaks.

Table 10: US and EU driving rules (FMCSA and your Europe)

	US	EU
Daily Drive Time	11 hr	9 hr
Daily Breaks	30 mins after 8 hours driving	45 mins after 4.5 hours driving
Daily on Duty Time	14 hr	13 hr
Daily Off duty time	10hr	11 hr
Weekly max	No more than 60 hours in 7 days or 70 hours in 8 days	56 hours per week driving or 90 hours per 2 weeks drive time
Weekly Reset	34 hour reset	45 hour reset

There are certain situations where a more restrictive hours of service may actually create additional challenges for drivers of BETs. For example, in the US, if a driver starts his shift at 6am, they must go off duty before 8pm; If the driver needs to take a one-hour break to charge mid shift they are using up some of their 14 hours on-duty time, despite the fact that they could likely rest while the vehicle is charging. In this situation, the hours of service restrictions and charging needs would limit the drivers total time available to work.

Given existing targets and policies around there will likely remain a significant percentage of ICE trucks sold in 2035, and thus legacy ICE trucks on the road in 2050 (as our modeling for this report suggests). A range of policies is being used in various places that could be more widely adopted, such as the ACT and ACF policies of California. Depending on the market, there may be different types of vehicles that are particularly challenging to ensure rapid and complete uptake of ZEVs, and where policies should particularly focus. Long haul trucking appears to be a particular challenge for most places.

5.3 Operational Incentives and Access Rules

This section discusses several possible policies that could be adopted to speed the uptake of ZEVs and reduce the 2050 stock of legacy ICE trucks. The main policies described here are:

- Sustainable Incentives (feebates)
- Accelerated vehicle retirement
- Zero-emission zones
- Indirect source rules
- Prioritized curb access
- Port gate fees

We describe these in a generic manner, though some have been adopted in certain locations (particularly a few in California) We indicate this where appropriate.

5.3.1 Sustainable Incentives (feebates)

Sustainable incentives, often called “feebates”, result in a self-funded incentive (SFI) system to help encourage sales of MHDV ZEVs. The policy concept typically includes applying a fee on internal combustion engine (ICE) trucks which generates a pool of funds. These funds are then allocated to provide financial incentives for ZEVs. The goal is to encourage purchases of ZEVs and shift purchases from ICEs to ZEVs without requiring taxpayers to foot the bill. All fees for incentives would be generated within the specific vehicle markets (such as specific truck classes). A SFI system would need to be carefully designed and calibrated to the specific market, technological, and transportation conditions within which it will operate. There will need to be mechanisms to allow flexible adjustment to changing conditions. Questions around structure, such as whether a fee should be “flat” (i.e. same for all trucks) or calibrated to truck price, size, class, CO_2 emissions, etc., would need to be determined in designing the system.

5.3.2 Accelerated vehicle retirement

Accelerated vehicle retirement programs support the withdrawal of older, higher-polluting vehicles from service. Typically, they replace these vehicles with a newer, less-polluting one. Clean vehicle purchase incentives can provide complementary incentives to support accelerated vehicle retirement. Often, accelerated vehicle retirement programs require the older vehicle to be scrapped or otherwise taken irrevocably out of service. In practice, fleets may identify a higher emission vehicle they wish to retire and use the incentive funding to purchase a replacement vehicle that will reduce emissions such as criteria pollutants or greenhouse gases. If approved by the program rules, fleets receive vouchers, or other incentives, that directly decrease their cost to acquire the new vehicle. To receive the voucher, they may have to provide documentation demonstrating that the older vehicle was crushed, or that the engine block was irreparably damaged.

Vouchers are simple to use, directly lower vehicle purchase price, and have an immediate effect. The incentives require relatively little administrative effort, such as grant writing, and fleets do not need to have any tax liability to benefit from the program. Vouchers provide certainty of funding, and unlike tax credits, immediate financial impact. An industry survey asking about policies for advanced truck technologies found that vouchers were ranked most effective above other policies such as research and development funding, tax credits, and oil surcharges [Amberg 2010].

5.3.3 Zero-emission zones

Zero-emission zones (ZEZs) are typically geographic areas created by local or regional governments where vehicles are not permitted unless they produce zero tailpipe emissions. They are often in central business districts or sensitive air quality areas, with a boundary defined either by the identification of that zone or a political boundary. They do not prevent the existence of pollutant-emitting vehicles but prevent them from traveling in a given area. As such, they may be highly effective at limiting the local atmospheric concentration of certain pollutants such as NOx or PM2.5, but may not have much impact on overall CO_2 emissions unless the zones are large enough to affect the types of vehicles purchased and the overall inventory of emitters and emissions. Once created, these zones could be expanded to a greater percentage of a given region.

5.3.4 Prioritized Curb Access

In many cities truck parking and curb access are in high demand. Finding curb space in order to complete the “last 50 feet” in delivering freight from the truck to the customer can be exceedingly difficult. Policy makers can designate “green loading zones” to incentivize electric vehicles. These zones could give priority access to ZEV trucks or could exempt ZEV trucks from parking fees.

5.3.5 Port Gate Fees

Port gate fees are fees paid by entities that own the truck or the cargo to enter or leave a port. The fees can be made differential for different truck technologies, or can be used to create a specific fund to spend on infrastructure or other approaches to enable transitioning to lower emissions trucks. As ZEV trucks become more affordable, the charge rate could be adjusted (such as raised on ZEVs) to ensure overall revenue requirements are met.

6 Bibliography

4296 - Federal Register/Vol. 88, No. 15/Tuesday, January 24, 2023/Rules and Regulations. *Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards*, Govinfo, 24 January 2023, https://www.govinfo.gov/content/pkg/FR-2023-01-24/pdf/2022-27957.pdf. Accessed 26 July 2023.

ACT Final Reg Order Final. *California Air Resources Board*, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf. Accessed July 2023.

Advanced Clean Fleets Regulation Summary, California Air Resources Board, April 13, 2023, https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary.

Alternative Fuels Data Center: Heavy-Duty Low Emission Vehicle Replacement and Repower Grants. *Alternative Fuels Data Center*, https://afdc.energy.gov/laws/12514. Accessed 26 July 2023.

An Overall Approach to Climate-Friendly Commercial Vehicles. *BMDV*, https://bmdv.bund.de/SharedDocs/EN/publications/overall-approach-climate-friendly-commercial-vehicles.pdf?__blob=publicationFile. Accessed 26 July 2023.

Basma, H., & Rodríguez, F. (2023, November 13). A Total Cost of Ownership Comparison of Truck Decarbonization Pathways in Europe. The International Council on Clean Transportation. https://theicct.org/publication/total-cost-ownership-trucks-europe-nov23/

Basma, H., Buysse, C., Zhou, Y., & Rodríguez, F. (2023, April 27). Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-Haul Trucks in the United States. The International Council on Clean Transportation. Retrieved from https://theicct.org/publication/tco-alt-powertrain-long-haul-trucks-us-apr23/

Bradley, M.J. and Associates LLC. 2009. Setting the Stage for Regulation of Heavy-Duty Vehicle Fuel Economy and GHG Emissions: Issues and Opportunities. Washington D.C.: International Council on Clean Transportation.

Budget 2021 - charging infrastructure for heavy vehicles – Policies. *IEA*, 8 July 2021, https://www.iea.org/policies/12465-budget-2021-charging-infrastructure-for-heavy-vehicles. Accessed 26 July 2023.

Budget 2021 - charging infrastructure for heavy vehicles – Policies. *IEA*, 8 July 2021, https://www.iea.org/policies/12465-budget-2021-charging-infrastructure-for-heavy-vehicles. Accessed 26 July 2023.

Burnham, A., Gohlke, D., Rush, L., et al. (2021, April). Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. Argonne National Laboratory. Retrieved from https://publications.anl.gov/anlpubs/2021/05/167399.pdf

Burke, A., Miller, M., Sinha, A., & Fulton, L. (2022, August 4). Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results. UC Davis Research

Reports. Retrieved from
https://escholarship.org/content/qt1g89p8dn/qt1g89p8dn.pdf?t=rg5613&v=lg

Buysse, Sharpe, California's Advanced Clean Trucks Regulation: Sales Requirements for Zero-emission Heavy-duty trucks, (ICCT: Washington, DC, 2020), https://theicct.org/publication/californias-advanced-clean-trucks-regulation-sales-requirements-for-zero-emission-heavy-duty-trucks/

CARB. (2023). Advanced Clean Fleets Regulation Summary. Retrieved from https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-fleets-regulation-summary

CARB (2023b), States that have Adopted California's Vehicle Regulations, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/states-have-adopted-californias-vehicle-regulations

California HVIP. *California HVIP: Home - Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project*, California HVIP, 2023, https://www.californiahvip.org Accessed 26 July 2023.

Calstart. (2023). Advanced Vehicle Technology and Infrastructure Funding Finder Tool. Retrieved from https://fundingfindertool.org/

CARB Advanced Clean Trucks (ACT) Market Segment Analysis. *EMA Truck Analysis*, https://ww2.arb.ca.gov/sites/default/files/2018-11/181204emaanalysis_0.xlsx Accessed 26 July 2023

CARB (2021) https://ww2.arb.ca.gov/sites/default/files/2021-08/210909costdoc_ADA.pdf

Carl Moyer Memorial Air Quality Standards Attainment Program | California Air Resources Board. *California Air Resources Board*, https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program. Accessed 26 July 2023.

CCVC, 2023, Commercial Clean Vehicle Credit, provision in the US tax code via IRS, https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit

Chu, Y., & Cui, H. (2023, June 16). Annual Update on the Global Transition to Electric Vehicles: 2022. The International Council on Clean Transportation. Retrieved from https://theicct.org/wp-content/uploads/2023/06/Global-EV-sales-2022_FINAL.pdf

Clean Transportation Program Overview. *California Energy Commission*, https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-program-overview Accessed 26 July 2023.

CMDIT - Transport routier | Ministères Écologie Énergie Territoires. *Ministère de la Transition écologique*, 14 February 2022, https://www.ecologie.gouv.fr/transition-energetique-du-transport-routier-annonce-du-nouveau-dispositif-soutien-poids-lourds Accessed 26 July 2023.

CMDIT - Transport routier | Ministères Écologie Énergie Territoires. *Ministère de la Transition écologique*, 14 February 2022, https://www.ecologie.gouv.fr/transition-energetique-du-transport-routier-annonce-du-nouveau-dispositif-soutien-poids-lourds Accessed 26 July 2023.

CO2 standards for heavy-duty vehicles in the European Union. *International Council on Clean Transportation*, 17 April 2019, https://theicct.org/sites/default/files/publications/CO2%20HDV%20EU%20Policy%20Update%202019_04_17.pdf Accessed 26 July 2023.

Compilation of Existing State Truck Size and Weight Limit Laws - Appendix A: State Truck Size and Weight Laws - FHWA Freight Management and Operations. *FHWA Operations*, https://ops.fhwa.dot.gov/freight/policy/rpt_congress/truck_sw_laws/app_a.htm#il Accessed 26 July 2023.

Décret n° 2020-456 du 21 avril 2020 relatif à la programmation pluriannuelle de l'énergie. *Légifrance*, https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041814432/ Accessed 26 July 2023.

Déduction exceptionnelle : véhicules lourds utilisant des énergies propres. *Les-aides.fr*, 2023, https://les-aides.fr/aide/QScv3w/ddfip/deduction-exceptionnelle-vehicules-lourds-utilisant-des-energies-propres.html . Accessed 26 July 2023.

Disposición 3294 del BOE núm. 52 de 2022. *BOE.es*, 2 March 2022, https://www.boe.es/eli/es/o/2022/02/28/tma138/dof/spa/pdf . Accessed 26 July 2023.

DORNOFF, JAN. How to make Euro 7 more effective: An analysis of the European Commission's proposal for light and heavy-duty vehicles. *International Council on Clean Transportation*, https://theicct.org/wp-content/uploads/2023/01/euro7-analysis-recommendations-jan23.pdf. Accessed 26 July 2023.

DOT, 2023, Federal Highway Administration's Charging and Fueling Infrastructure Discretionary Grants Program, 2023 list of grants, https://highways.dot.gov/sites/fhwa.dot.gov/files/CFI%20Grant%20Awards%20Project%20Descriptions%20FY22-23.pdf

El Gobierno aprueba el Real Decreto que regula la transferencia de 400 millones de euros en subvenciones para descarbonizar el transporte profesional por carretera. *Ministerio de Transportes, Movilidad y Agenda Urbana*, 16 November 2021, https://www.mitma.gob.es/el-ministerio/sala-de-prensa/noticias/mar-16112021-1646 . Accessed 26 July 2023.

ENVIRONMENTAL PROTECTION AGENCY. Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3. *40 CFR Parts 1036, 1037, 1054, 1065, and 1074*, Govinfo, 27 April 2023, https://www.govinfo.gov/content/pkg/FR-2023-04-27/pdf/2023-07955.pdf. Accessed 26 July 2023.

EPA, 2023, Inflation Reduction Act, Clean Heavy Duty Vehicle Program, https://www.epa.gov/inflation-reduction-act/clean-heavy-duty-vehicle-program#:~:text=The%20Inflation%20Reduction%20Act%20invests,vehicles%20between%20now%20and%202031

EU rules for working in road transport - Your Europe. *European Union*, 5 January 2023, https://europa.eu/youreurope/citizens/work/work-abroad/rules-working-road-transport/index_en.htm. Accessed 26 July 2023.

EU, 2023, European Council, Heavy-duty vehicles: Council and Parliament reach a deal to lower CO2 emissions from trucks, buses and trailers, https://www.consilium.europa.eu/en/press/press-releases/2024/01/18/heavy-duty-vehicles-council-and-parliament-reach-a-deal-to-lower-co2-emissions-from-trucks-buses-and-trailers/

Eurostat. Share of new zero-emission vehicles in all new vehicles of the same type, by type of vehicle and type of motor energy. *ROAD_EQR_ZEVPC__custom_6631119*, Eurostat and EAFO, 2023, https://ec.europa.eu/eurostat/databrowser/view/ROAD_EQR_ZEVPC__custom_6631119/default/table.

FAQ zum 2. Förderaufruf Nutzfahrzeuge sowie dem Sonderaufruf für Sonderfahrzeuge für das Förderprogramm Klimaschonende Nutzfahrzeuge und Infrastruktur (KsNI). *Bundesamt für Logistik und Mobilität*, 7 6 2023, https://www.balm.bund.de/SharedDocs/Downloads/DE/Foerderprogramme/KsNI/2_Foerderaufruf/KsNI_FAQ_Foedergegenstand_KsN.pdf?__blob=publicationFile&v=5 . Accessed 2023.

Federal Ministry of Finance - Scholz: Clear signal for climate action and digitalisation. *Bundesfinanzministerium*, 27 April 2021, https://www.bundesfinanzministerium.de/Content/EN/Pressemitteilungen/2021/2021-04-27-german-recovery-and-resilience-plan-adopted.html . Accessed 26 July 2023.

Förderaufruf für den Ausbau öffentlicher Wasserstofftankstellen mit Schwerpunkt Schwerlastfahrzeuge (03/2023). *NOW GmbH*, https://www.now-gmbh.de/foerderung/foerderfinder/foerderaufruf-fuer-den-ausbau-oeffentlicher-wasserstofftankstellen-mit-schwerpunkt-schwerlastfahrzeuge-03-2023/ . Accessed 26 July 2023.

Förordning (2016:836) om elbusspremie. *Sveriges riksdag*, https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-2016836-om-elbusspremie_sfs-2016-836 . Accessed 26 July 2023.

Förordning (2020:750) om statligt stöd till vissa miljöfordon. *Sveriges riksdag*, https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/forordning-2020750-om-statligt-stod-till-vissa_sfs-2020-750/ . Accessed 26 July 2023.

Fuel Economy Standards on Heavy Duty Vehicles – Policies - IEA. *International Energy Agency*, 11 February 2022, https://www.iea.org/policies/11664-fuel-economy-standards-on-heavy-duty-vehicles . Accessed 26 July 2023.

Funding of commercial vehicles with alternative, climate-friendly drives. *BMWK*, https://www.bmwk.de/Redaktion/EN/Hydrogen/Funding-National/019-commercial-vehicles-alternative-drives.html . Accessed 26 July 2023.

Gesamtkonzept. *Klimafreundliche Nutzfahrzeuge*, https://www.klimafreundliche-nutzfahrzeuge.de/gesamtkonzept/ . Accessed 26 July 2023.

Global Electric Vehicle Outlook 2022. *NET*, https://iea.blob.core.windows.net/assets/ad8fb04c-4f75-42fc-973a-6e54c8a4449a/GlobalElectricVehicleOutlook2022.pdf . Accessed 26 July 2023.

Global EV Outlook 2023 – Analysis. *IEA*, https://www.iea.org/reports/global-ev-outlook-2023 . Accessed 26 July 2023.

Green Growth Strategy Through Achieving Carbon Neutrality in 2050. *Green Growth Strategy Through Achieving Carbon Neutrality in 2050*, 18 June 2021, https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf . Accessed 26 July 2023.

Green Public Transport - Phase I [Poland]. *National Fund for Environmental Protection and Water Management*, 2021, https://www.gov.pl/web/nfosigw/zielony-transport-publiczny-faza-i-2021 .

Gurman, Robert. Taking Commercial Fleet Electrification to Scale. *Calstart*, Proenergy Consulting, March 2021, https://calstart.org/taking-commercial-fleet-electrification-to-scale-financing-barriers-and-solutions/ . Accessed 2023.

Hall. D, et al. Decarbonizing road transport by 2050: Effective policies to accelerate the transition to zero-emission vehicles. *International Council on Clean Transportation*, 2021 https://theicct.org/wp-content/uploads/2021/12/ZEVTC_EffectivePolicies_dec2021.pdf. Accessed 26 July 2023.

HCT - längre och tyngre fordon bidrar till smart logistik och minskad klimatpåverkan. *Trafikverket.se*, https://bransch.trafikverket.se/for-dig-i-branschen/forskning-och-innovation/aktuell-forskning/transport-pa-vag/branschprogram-for-godstransporter-med-hog-kapacitet---hct/ . Accessed 26 July 2023.

HDV Fuel Economy Standard – Policies - IEA. *International Energy Agency*, 1 February 2023, https://www.iea.org/policies/7903-hdv-fuel-economy-standard . Accessed 26 July 2023.

Hong Kong - Tax Incentives for Environmentally Friendly Commercial Vehicles – Policies - IEA. *International Energy Agency*, 16 April 2021, https://www.iea.org/policies/2110-hong-kong-tax-incentives-for-environmentally-friendly-commercial-vehicles . Accessed 26 July 2023.

IEA (2023), Global EV Data Explorer, IEA, Paris https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

IEA (2023), Trucks and Buses, IEA, Paris https://www.iea.org/energy-system/transport/trucks-and-buses, License: CC BY 4.0

Innovative Clean Transit Regulation, A Replacement Of The Fleet Rule For Transit Agencies., CARB 2018, https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-regulation

JOET, 2023, Joint Office of Energy and Transportation, main web page, https://driveelectric.gov/

June 2019 setting CO2 emission performance standards for new heavy-duty vehicles and amending Regulations. EUR-Lex, 25 July 2019, https://eur-lex.europa.eu/eli/reg/2019/1242/oj . Accessed 26 July 2023.

Klimatpremie. *Energimyndigheten*, https://www.energimyndigheten.se/klimat--miljo/transporter/transporteffektivt-samhalle/klimatpremie/ . Accessed 26 July 2023.

Masterplan Ladeinfrastruktur II der Bundesregierung auf der Zielgeraden. *BMDV*, 8 July 2022, https://bmdv.bund.de/SharedDocs/DE/Pressemitteilungen/2022/048-masterplan-ladeinfrastruktur-2.html?nn=12830 . Accessed 26 July 2023.

Meishner, F., & Sauer, D. U. (2019). Technical and economic comparison of different electric bus concepts based on actual demonstrations in European cities. IET Electrical Systems in Transportation. Advance online publication. doi:10.1049/iet-est.2019.0014

Ministerial Order TMA/892/2021. *BOE.es*, 17 August 2022, https://www.boe.es/eli/es/o/2021/08/17/tma892 . Accessed 26 July 2023.

Morrey, Denise. Automotive test drive cycles for emission measurement and real-world emission levels - A review. ResearchGate, 2002, https://www.researchgate.net/publication/258176837_Automotive_test_drive_cycles_for_emission_measurement_and_real-world_emission_levels_-_A_review#fullTextFileContent . Accessed 26 July 2023.

Mulholland, E., & Rodríguez, F. (2023, May 22). An Analysis of the Revision of Europe's Heavy-Duty CO2 Standards. The International Council on Clean Transportation. Retrieved from https://theicct.org/publication/europe-heavy-duty-vehicle-co2-standards-may23/

National Research Council. 2010. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: The National Academies Press. https://doi.org/10.17226/12845.

NEVI, 2023, National Electric Vehicle Infrastructure program, main web page, https://afdc.energy.gov/laws/12744

Permissible Maximum Weights Of Lorries In Europe (in tonnes). *ITF*, https://www.itf-oecd.org/sites/default/files/docs/weights-2019.pdf. Accessed 26 July 2023.

Policy, rules- and regulations development | Closer. *CLOSER Lindholmen*, https://closer.lindholmen.se/en/projects/reel/policy-rules-and-regulations-development. Accessed 26 July 2023.

Program elektrifiering av det statliga vägnätet - Bransch. *Trafikverket.se*, https://bransch.trafikverket.se/for-dig-i-branschen/forskning-och-innovation/aktuell-forskning/transport-pa-vag/program-elektrifiering-av-det-statliga-vagnatet/. Accessed 26 July 2023.

Programa de transformación de flotas: Actividad 1, achatarramiento de vehículos. *Ministerio de Transportes, Movilidad y Agenda Urbana*, https://www.mitma.gob.es/ministerio/proyectos-singulares/prtr/transporte/ayudas-empresas-transporte/activiad-1. Accessed 26 July 2023.

Programa de transformación de flotas: Actividad 3, retrofit. *Ministerio de Transportes, Movilidad y Agenda Urbana*, https://www.mitma.gob.es/ministerio/proyectos-singulares/prtr/transporte/ayudas-empresas-transporte/activiad-3. Accessed 26 July 2023.

Programa de transformación de flotas: Actividad 4, instalación de puntos de recarga. *Ministerio de Transportes, Movilidad y Agenda Urbana*, https://www.mitma.gob.es/ministerio/proyectos-singulares/prtr/transporte/ayudas-empresas-transporte/activiad-4. Accessed 26 July 2023.

Questions and Answers: Revision of the CO2 emission standards for Heavy-Duty Vehicles. *European Commission*, 14 February 2023, https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_763. Accessed 26 July 2023.

Questions and Answers: Revision of the CO2 emission standards for Heavy-Duty Vehicles. *European Commission*, 14 February 2023, https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_763. Accessed 26 July 2023.

Randall, Chris. Spain subsidising electric mobility with €45 million. *electrive.com*, 27 February 2019, https://www.electrive.com/2019/02/27/spain-subsidizing-electric-mobility-with-e45-million/. Accessed 26 July 2023.

Reducing CO_2 emissions from heavy-duty vehicles. *Language selection | Climate Action*, 2019, https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/reducing-co2-emissions-heavy-duty-vehicles_en. Accessed 26 July 2023.

Regulation (EU) 2019/ of the European Parliament and of the Council of 20 June 2019 setting CO2 emission performance standards. *EUR-Lex*, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1242&from=EN. Accessed 26 July 2023.

Schirrmann, Felix. Taskforce „Backcasting – Ladeinfrastruktur für schwere Nutzfahrzeuge legt erste wichtige Grundlage für den öffentlichen Ladeinfrastrukturaufbau für E-Lkw. *Klimafreundliche Nutzfahrzeuge*, 19 January 2022, https://www.klimafreundliche-nutzfahrzeuge.de/task-force-backcasting/. Accessed 26 July 2023.

Spain. Disposición 18811 del BOE núm. 275 de 2021. *BOE.es*, 17 November 2021, https://www.boe.es/boe/dias/2021/11/17/pdfs/BOE-A-2021-18811.pdf. Accessed 26 July 2023.

Sprawozdanie z realizacji Krajowych ram polityki rozwoju infrastruktury paliw alternatywnych Warszawa, sierpień 2019 r. *Gov.pl*, https://www.gov.pl/attachment/d8178ee2-cbdf-4290-8b2b-d34205715ead. Accessed 26 July 2023.

Summary of Hours of Service Regulations | FMCSA. *Federal Motor Carrier Safety Administration*, 28 March 2022, https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations. Accessed 26 July 2023.

Summary of the Budget Bill for 2022. *Government Offices of Sweden.*, 2021, https://www.government.se/4a73a0/contentassets/ddfaf5ce78494ce991ec231acf9c5b83/summary-budget-statement.pdf.

The Ministry of Transport introduces the 14th Five-Year Plan for Green Transportation. *Ministry of Transport of the People's Republic of China*, 2021, http://www.mot.gov.cn/xinw/2021/zwgk_202111/t20211110_3625432.html.

Transport & Environment. (2018, November). Electric Buses Arrive on Time: Marketplace, Economic, Technology, Environmental, and Policy Perspectives for Fully Electric Buses in the EU (L. Mathieu, Ed.). [PDF]. Retrieved from https://www.transportenvironment.org/wp-content/uploads/2021/07/Electric-buses-arrive-on-time-1.pdf

UNFCCC, 2023, What is the Paris Agreement, https://unfccc.int/process-and-meetings/the-paris-agreement?gclid=Cj0KCQiA1rSsBhDHARIsANB4EJbqagTEFc1MbWr4tC2USvY4vHOeaRMzc75PWXRmO9tPlEHy8oOEL7IaAjGvEALw_wcB

Update to the long-term strategy for climate action of the Federal Republic of Germany. *UNFCCC*, 2 November 2022, https://unfccc.int/sites/default/files/resource/Anlage%202_Update%20to%20the%20long-term%20strategy%20for%20climate%20action%20of%20the%20Federal%20Republic%20of%20Germany_02Nov2022_0.pdf. Accessed 26 July 2023.

Van Amberg, B. and Hall, J., Speeding High-Efficiency Truck Adoption: Recommended Policies, Incentives and Investments, Calstart 2010.

Xie, Y., & Minjares, R. (2023, September 19). How U.S. and EU Proposals Could Steer the Transition to Zero-Emission Truck and Bus Fleets. The International Council on Clean Transportation. Retrieved from https://theicct.org/us-and-eu-proposals-zev-truck-and-bus-fleets-sept23/

Yang, Liuhanzi, and Hui He. China's Stage VI emissions standard for heavy-duty vehicles (final rule). *International Council on Clean Transportation*, https://theicct.org/publication/chinas-stage-vi-emissions-standard-for-heavy-duty-vehicles-final-rule/#:%7E:text=China%20VI-b%20will%20take,China%20to%20meet%20the%20standard. Accessed 26 July 2023.

Zero-Emission Vehicle Fleet: Meetings & Workshops | California Air Resources Board. *California Air Resources Board*, https://ww2.arb.ca.gov/our-work/programs/zev-fleet-rules/zero-emission-vehicle-fleet-meetings-workshops. Accessed 26 July 2023.

ZEV Transition Council. (2023, December 5). ZEV Cost: Total Cost of Ownership. Managed by the International Council on Clean Transportation. Retrieved from https://zevtc.org/tracking-progress/zev-cost-total-cost-of-ownership/

국고보조금. *환경부 전기차 충전소*, https://www.ev.or.kr/portal/buyersGuide/incenTive. Accessed 26 July 2023.

국고보조금. *환경부 전기차 충전소*, https://www.ev.or.kr/portal/buyersGuide/incenTive. Accessed 26 July 2023.

보도/해명. *보도/해명| 산업통상자원부 홈페이지*, 17 January 2019, http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&cate_n=1&bbs_seq_n=161262. Accessed 26 July 2023.

보도/해명. *보도/해명| 산업통상자원부 홈페이지*, 17 January 2019, http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&cate_n=1&bbs_seq_n=161262. Accessed 26 July 2023.

交通运输部关于印发《绿色交通十四五发展规划》的通知_国务院部门文件. *中国政府网*, https://www.gov.cn/zhengce/zhengceku/2022-01/21/content_5669662.htm. Accessed 26 July 2023.

各局資料. *国土交通省*, https://www.mlit.go.jp/sogoseisaku/environment/content/001609311.pdf. Accessed 26 July 2023.

天津市人民政府办公厅关于印发天津市生态环境保护十四五规划的通知. *天津市人民政府*, 17 January 2022, https://www.tj.gov.cn/zwgk/szfwj/tjsrmzfbgt/202201/t20220117_5781111.html. Accessed 26 July 2023.

广东省人民政府办公厅关于印发《广东省综合交通运输体系十四五发展规划》的通知广东省人民政府门户网站. *广东省人民政府*, 29 September 2021, http://www.gd.gov.cn/zwgk/wjk/qbwj/yfb/content/post_3554890.html. Accessed 26 July 2023.

環境：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）. *国土交通省*, https://www.mlit.go.jp/jidosha/jidosha_tk1_000003.html. Accessed 26 July 2023.

環境：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）. *国土交通省*, https://www.mlit.go.jp/jidosha/jidosha_tk1_000003.html. Accessed 26 July 2023.

自動車：自動車環境総合改善対策費補助金（事業用自動車における電動車の集中的導入支援）事業（令和４年度補正）. *国土交通省*, https://www.mlit.go.jp/jidosha/jidosha_tk10_000040.html. Accessed 26 July 2023.