UC Berkeley Center for Law, Energy & the Environment

ZERO-EMISSION TRUCKS: *A Factsheet Series*

2024 - 2025
Factsheet Series

#1: REGULATING TRUCKS: WHY & HOW

Policy design options and potential benefits

UC Berkeley Center for Law, Energy & the Environment

Zero-Emission Trucks: A Factsheet Series

June 2024

CONTEXT AND MOTIVATION

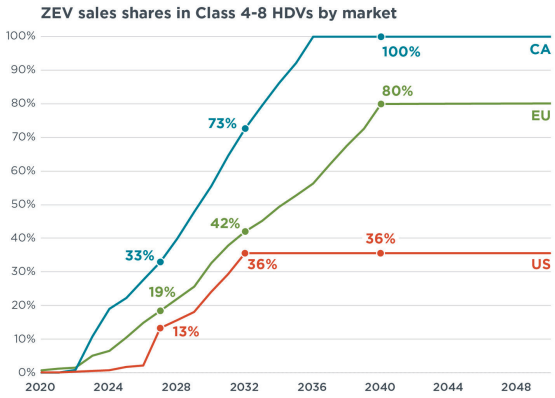
Although fewer than 8% of vehicles globally, trucks and buses are responsible for more than 35% of direct CO_2 emissions from global road transport. Emissions from trucks have grown rapidly since the early 2000s and are a major source of air pollution with significant health burdens that can disproportionately affect low-income communities. Transitioning to zero emission trucks (ZETs) is critical to combating climate and improving public health. While ZET technology and cost competitiveness are present for multiple market segments, deployment is insufficient to meet climate goals and demand is still outpacing supply. Analyses of commercial fleets highlight frustration with limited ZET models and demonstrate strong demand–for example, just 20 US fleets plan to purchase 60,000 ZETs by 2027.

ZET SALES		BUS	ALL HDVS
ACTUAL	2022	4.5%	1.2%
REQUIRED TO MEET PARIS GOALS	2025	7-30%	3-12%
	2030	75-90%	40-56%
	2035	90-100%	69-83%
	2040	100%	94-100%
	2045	100%	100%

Sources: IEA Global EV Outlook (2023) & ICCT Heavy-duty zero-emission vehicles: Pace and opportunities for a rapid global transition (2022)

REGULATORY OPTIONS

Binding regulations on manufacturers and/or importers can address the gap in supply and have a lower administrative and compliance burden than demand side regulation. Analysis has shown that supply-side regulations are the most effective policy levers for accelerating ZET deployment and capturing associated benefits. Options include: manufacturer sales requirements (like California's Advanced Clean Truck Rule), tailpipe emission standards (like the EU CO_2 HDV Standards and US Phase 3 HDV GHG Standards) and fuel economy standards (like Chile's fuel economy standards currently in development). While all require manufacturers and importers to ensure new truck sales meet gradually increasing requirements, their varied designs create different pathways for ZET deployment.



Source: ICCT Analysis (2023), note that the CA line includes 100% target from the Advanced Clean Fleets Rule

	FUEL ECONOMY AND GHG TAILPIPE EMISSION STANDARDS	SALES REQUIREMENTS FOR MANUFACTURERS
MANUFACTURER REQUIREMENT	Improve fuel efficiency and reduce GHGs in an increasing percentage of total annual truck sales.	Increase ZET sales as an increasing percentage of total annual truck sales.
COMPLIANCE TECHNOLOGY	Allows investment in any ZE technology and more efficient fossil fuel or internal combustion engines.	Allows investment in any ZE technology, can include partial credit for hybrids. Does not give credit for fossil fuel or internal combustion engines.
CREDIT TRADING SYSTEM STRUCTURE	A manufacturer accrues deficits if the fuel efficiency or the GHG emissions of all vehicles sold do not meet the established threshold. Deficits must be offset with previously banked surplus credits or credits purchased from manufacturers that performed in excess of the required threshold. Any deficits not offset by credits result in fines.	A manufacturer accrues deficits if the percentage of ZETs it sold in a year is below the established threshold. Deficits must be offset with previously banked surplus credits or credits purchased from manufacturers that sold a higher percentage of vehicles than those required by the regulation.
ZET SUPPLY & MARKET CERTAINTY	New ZET sales can be accelerated through sufficient stringency of the standard. However, the total deployment is more uncertain as fossil fuel engines can also become more efficient and the exact % of ZE technology is harder to predict.	New ZET sales are accelerated by a specific schedule set in the regulation and by the financial incentive of selling or banking surplus credits. This allows economic certainty around the expected increase in supply and scaling of production.

VALUE OF ECONOMIC CERTAINTY

Regulations drive manufacturer investment and innovation in technology. By setting gradually increasing requirements for the sale of new trucks, regulations create economic certainty allowing the market to plan around a predictable ZET deployment timeline. This unlocks financing through increased investor confidence, and encourages further cost reductions by accelerating economies of scale as well as increasing diversity and competition in zero emission truck products, services, and supply chains. It also provides certainty around future electricity demand, which is critical for utilities to plan and develop grid infrastructure expansions, which can take many years to complete. For example, when the revision of EU CO_2 regulations for new cars was completed in 2020, the market share of EVs in Europe jumped from 3% in 2019, to 11% in 2020, and to 19% in 2021, with a similar jump in infrastructure investment (public chargers more than doubled between 2018 and 2021), with much of these outcomes potentially attributable to the certainty provided by the new regulations.

POTENTIAL BENEFITS OF ACCELERATING ZERO EMISSION TRUCKS

BINDING REGULATIONS THAT ACCELERATE WIDESPREAD ZET DEPLOYMENT ARE A KEY MECHANISM FOR CAPTURING THE FOLLOWING BENEFITS

CLIMATE BENEFITS: Reduce global road transport CO_2 emissions ~ **64% by 2050** (from 2020 levels).

TOTAL COST OF OWNERSHIP SAVINGS: While costs vary by country, median estimates of **58 analyses** show that significantly lower maintenance and fuel costs will generate savings now or or within the decade: urban delivery vehicles (now-2027); short-haul freight trucks (now-2030); and long-haul tractor trailers (2027-2030).

AIR QUALITY AND HEALTH SAVINGS: US truck pollution reductions generate **$735 billion in health** benefits and avoid 66,800 premature deaths.

GREEN JOBS: **Significant job gains** predicted in zero emission transport industry and manufacturing job losses can **likely transition to green job alternatives**.

ELECTRIC GRID BENEFITS: **Significant potential value from managed EV charging** for improving energy system economics and reliability, including complementing large-scale solar and wind. **EVs have increased utility revenues** in the US, putting downward pressure on electric rates for everyone.

AUTO MANUFACTURE (OEM) MARKET SHARE AND LONG-TERM VIABILITY: Modeling predicts that manufacturers can achieve the **most future profitability** and **retain the most market share** by rapidly transitioning to electrification and risk loss of profits and market standing if they move slowly.

MEET PRIVATE SECTOR DEMAND: The US (see **support here**) and EU (see **support here**) received letters requesting adoption of binding zero emission truck regulations from over 120 major businesses, fleets, and investors.

DECREASE FUEL DEPENDENCY AND IMPORTS: Switching to zero emissions can **reduce dependence** on **volatile and expensive imported fossil fuels**.

#2: REGULATING ZERO-EMISSION TRUCK SUPPLY: SAVINGS POTENTIAL

Total cost of ownership benefits and how financing can increase investment

UC Berkeley Center for Law, Energy & the Environment

Zero-Emission Trucks:
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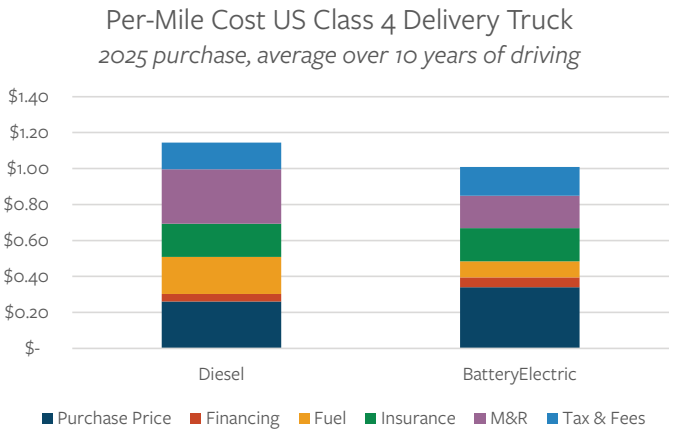
HIGHER UPFRONT COST BUT LOWER OPERATIONAL COSTS

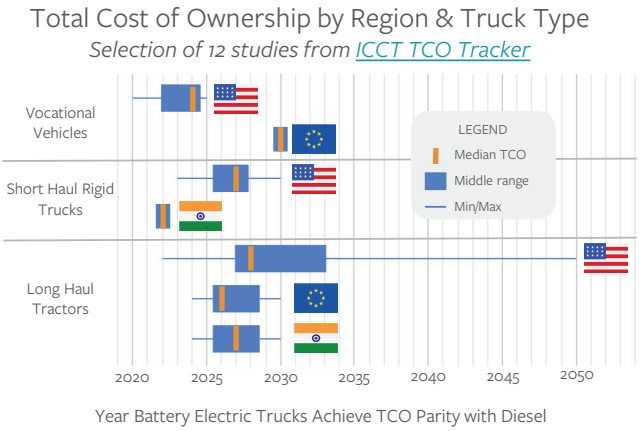
Zero emission trucks (ZETs) currently have higher price tags than diesel trucks, but this gap is expected to narrow as the market evolves. Despite the upfront costs, ZETs can offer considerable savings in operational expenses. Since most commercial trucks accumulate extensive mileage, fuel expenses are the majority of lifetime costs. Battery electric trucks offer the advantage of markedly lower fuel costs compared to diesel trucks. Moreover, the simpler mechanical design of ZETs, characterized by fewer moving parts than their internal combustion counterparts, leads to lower maintenance costs. Together, these factors contribute to substantial financial savings over the life of the vehicle.



Per-Mile Cost US Class 4 Delivery Truck 2025 purchase, average over 10 years of driving. Source : Argonne National Laboratory (2021)

TOTAL COST OF OWNERSHIP SAVINGS

Many ZETs currently have a higher purchase price compared to diesel trucks. However, when considering purchase price and lower operational costs together as the total cost of ownership (TCO), most urban delivery and some regional haul ZETs already offer savings over the life of the vehicle. The remaining urban/regional ZETs will reach total TCO parity or superiority between 2025 and 2035, with long haul following shortly after. These TCO savings are an attractive opportunity for private fleets and will continue to improve over time.



Total Cost of Ownership by Region & Truck Type. Source : ZEV Transition Council, TCO Tracker (2024)

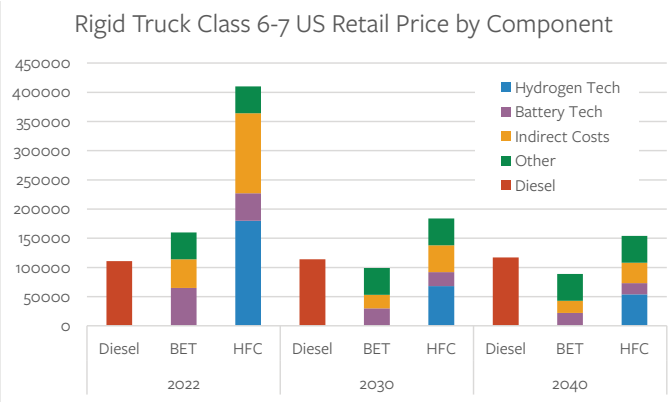
MARKET BENEFITS OF REGULATIONS

Regulations have been shown to increase manufacturer investment and innovation in technology. By setting gradually increasing requirements for the sale of new trucks, regulations create economic certainty — now the market can plan around a predictable ZET deployment timeline. This accelerates economies of scale across all ZET products, services, and supply chains. Economies of scale at the manufacturing level can bring down marginal production costs; economies of scale at a market level can encourage further cost reductions by increasing diversity and competition. Economic certainty is also key to investor confidence in new technologies and can motivate innovative financing mechanisms and business models that help small businesses overcome high capital costs and unlock cost savings.

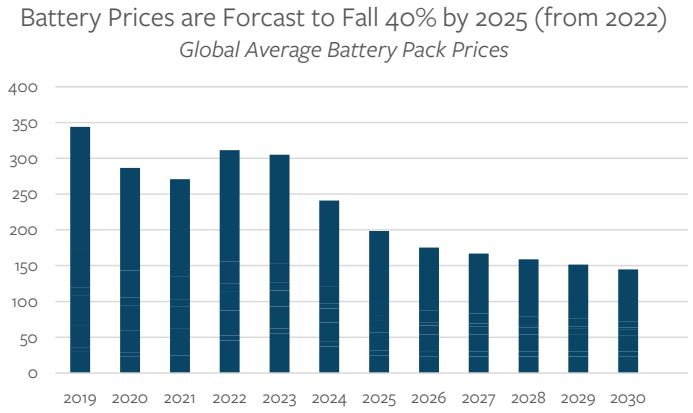
Regulations can also enable 'self-financing' by the industry, including for new entrants, through credit trading: those who can produce ZETs at least cost are financially incentivized by the opportunity to sell their extra credits to those manufacturers who need more time to scale up production.

EXPECTED COST REDUCTIONS

Regulations could accelerate expected reductions in ZET purchase price and operational costs. While ZETs have grown in popularity and availability in recent years, with over 850 zero-emission models capable of meeting the majority of commercial truck needs, there are still substantial opportunities for manufacturer learning and economies of scale. Economic analyses of clean technologies have found significant and sustained learning curves, predicting much more rapid cost declines than previous technological advancements. Primary technology improvements and related savings will be in ZET batteries, fuel cells, and drive trains. Global average battery prices are forecast to fall 40% by 2025 and even battery costs for heavy duty (sleeper and day cab tractor) trucks are expected to halve by 2030 compared to 2022. The energy density of batteries is expected to continue increasing, allowing greater range and higher payload capacity as battery weight decreases. The cost of manufacturing chargers for trucks are expected to follow a similar learning curve, as, for example, US level 2 charger costs fell 66% from 2010 to 2019.



Rigid Truck Class 6-7 US Retail Price by Component. Source : The International Council for Clean Transportation (2023)



Battery Prices are Forcast to Fall 40% by 2025 (from 2022) Global Average Battery Pack Prices. Source: Goldman Sachs Analysis (2023)

INNOVATIVE FINANCING CAN UNLOCK SAVINGS

While larger fleets have better access to capital for financing the upfront purchase price of ZETs and charging infrastructure, most fleets globally are small businesses with limited capital and less ability to maintain and repair new technologies like ZETs. Business models such as truck-as-a-service (TaaS) and battery-as-a-service (BaaS), allow small businesses to access ZET benefits without having to purchase the truck and/or the battery. These "as-a-service" models are rental or leasing packages that use operational savings to cover the higher capital costs of ZETs and can also reduce small business concerns around the unfamiliarity of new technology by including maintenance, insurance, and shared charging. Other mechanisms such as extended warranties, loan loss reserves, residual value guarantees, and credit enhancements can help reduce risk, increasing access for small businesses and attracting additional private capital.

#3: TRUCK MANUFACTURERS AND THE ZERO EMISSION TRANSITION

Producer supply, consumer demand, and overall business case

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Zero-Emission Trucks:
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June 2024

STRONG COMMITMENTS

Zero emission truck models are becoming more available and growing, while sales are just starting out and need to increase rapidly. This need requires automakers (OEMs) to introduce more models and actively promote sales.

Many internal combustion engine truck manufacturers have committed to zero emission transition targets. However, these voluntary announcements often use unclear language. For example, all of the "100%" targets in the table at right have committed to being "fossil-free" or "net-zero"— wording which allows for non-zero-emission technologies. Notably these commitments are geographically limited to regions that have, or are developing, supply-side regulations or binding targets that accelerate zero emission trucks (ZETs). This includes the US (with states that have adopted the Advanced Clean Truck (ACT) Rule and the national Phase 3 HDV GHG Standards), the European Union (EU) (with CO_2 HDV Standards), and China (with central and city-level mandates).

ZERO-EMISSION TARGET			
MANUFACTURER	**REGION**	**2030**	**2040**
Mack	US & Canada	35%	100% *
MAN	EU & EFTA	44%	100%
IVECO	EU & EFTA	50%	100% *
Renault Trucks	EU & EFTA	50%	100% *
Volvo Trucks	US & Canada	50%	100% *
Scania	EU & EFTA	50%	100%
Navistar	US & Canada	50%	100%
Foton	China	50%	
Mercedes-Benz	EU & EFTA	60%	100%
Volvo Trucks	EU & EFTA	70%	100% *
DAF	EU & EFTA		100% *
Dongfeng	China		100%
Freightliner	US & Canada		100%
Tata	Inda	100% by 2045	

Table 1 : Zero Emission Targets
Source : Transport and Environment 2023

MODEL AVAILABILITY & SALES ARE STILL LIMITED

Manufacturers are developing the technology - there are over 450 ZET models worldwide for a wide range of truck applications. However, once again, the availability of these models is mostly limited to those regions with binding regulations or strong policy support. Over 90% of ZETs sold in 2022 were in China. Excluding buses, fewer than 4,000 ZETs were sold outside of China (<1% of new commercial truck sales) and these sales were almost entirely in the EU and North America.

DEMAND OUTPACES SUPPLY

Manufacturers are not meeting the demand for ZETs. Many ZET models have had extensive waiting lists. Analyses by McKinsey & Company have demonstrated significant demand in the US and EU, along with company frustration at the lack of supply and resulting challenges around ordering the ZET models required for specific operations and geographies.

Increasing the production and sales of ZET will reduce costs through economies of scale and eventually achieve total cost of ownership (TCO) parity. According to a recent ICCT study, by 2030 the TCO for ZET's is projected to be lower than that of their diesel counterparts in all representative states across the US. ZET regulations can ensure that sales continue to grow in line with government pollution and climate targets.

REGULATION DESIGN TO IMPROVE SUPPLY

California has a long history of developing vehicle regulations to help reduce air pollution and address climate change. The state originally planned to develop a regulation to accelerate the deployment of ZETs in last-mile delivery. However, stakeholder engagement revealed that large delivery companies who wanted to purchase ZETs had trouble finding available models and were concerned that manufacturers would not be able to support increased demand. Manufacturers were making ZETs, but not always offering them in the California market. California ended up developing the Advanced Clean Trucks (ACT) Rule, requiring manufacturers to gradually improve ZET sales in California. The rule increases the supply and diversity of ZETs at a pace that reflects technology improvements, declining costs, and infrastructure expansion requirements, while letting the market decide which zero emission technologies and truck models are best.

LOBBYING AGAINST REGULATIONS THAT ALIGN WITH STATED GOALS

Despite public support for decarbonization, manufacturers continue to lobby against regulations with emissions or sales requirements, even when these requirements track with their own zero emission goals. In the EU, truck makers that set a 100% zero emission (or "fossil free") by 2040 goal, including MAN Truck & Bus, Scania, Volvo, and DAF, still actively opposed the EU adopting similar timelines for a 100% heavy-duty CO_2 emission reduction target. Similarly, major European industry associations have advocated to weaken the EU Commission's proposed CO_2 HDV Standards.

TRANSITION TO ZERO EMISSION IS CHALLENGING BUT SMART BUSINESS

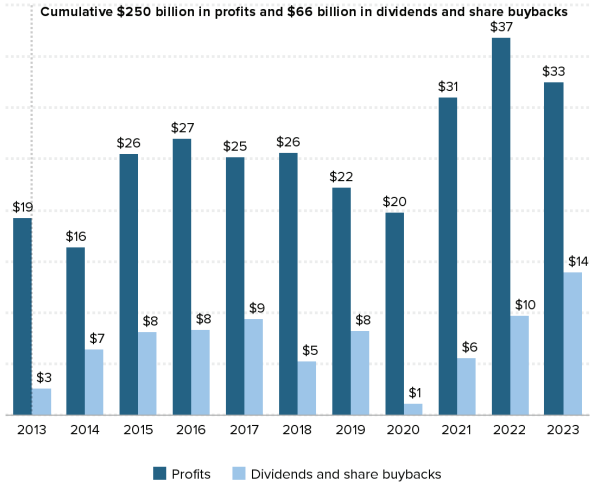
Legacy truck makers need major modifications to assembly lines as well as workforce composition and training. Battery technology requires significant R&D investment as well as securing critical mineral and component sources from across a global network. Supply bottlenecks and cost spikes can arise as this new supply chain expands. However, these are likely temporary hurdles that reflect similar growing pains associated with previous technological and market transformations in other sectors. Analysis shows that US truck manufacturers have the capacity to produce enough ZETs to accommodate the gradually increasing sales requirements of the ACT Rule. Overall, truck manufacturer profits are expected to grow, with zero emission opportunities as a major source of new revenue. Incumbents will likely need to evolve if they are to avoid losing market share and remain competitive with new entrants. Economic modeling predicts that vehicle manufacturers can achieve the most future profitability and retain the most market share by rapidly transitioning to electrification, while avoiding the risk of both profits and market standing if they move too slowly.

HIGH PROFITS, SLOW TRANSITION

Legacy internal combustion engine manufacturers such as Daimler, Volvo, GM, Navistar have announced record profits. Evidence suggests a good portion of those profits are going towards growing CEO pay, shareholder dividends, and stock buy-backs (chart at right from analysis of US automakers, see also this report on EU carmakers). Global rankings for truck and car companies have found that the majority of traditional manufacturers are lagging when it comes to industrial strategy and investments for transitioning to zero emission. All together, it appears that traditional manufacturers have the profits to invest, yet are still far from aligning their products and marketing with their stated goals.

Big 3 automakers achieved more than $250 billion in profits over the past decade

Profits and dividends and share buybacks of Big 3 automakers (billions), 2013–2022 and 2023 forecast



Note: Big 3 automakers include Ford, General Motors, and Stellantis.

Source: EPI analysis of Ford, GM, and Stellantis quarterly financial reports.

Economic Policy Institute

#4: ZERO EMISSION TRUCK MARKET & TECHNOLOGY

Deployment status and performance

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Zero-Emission Trucks: A Factsheet Series

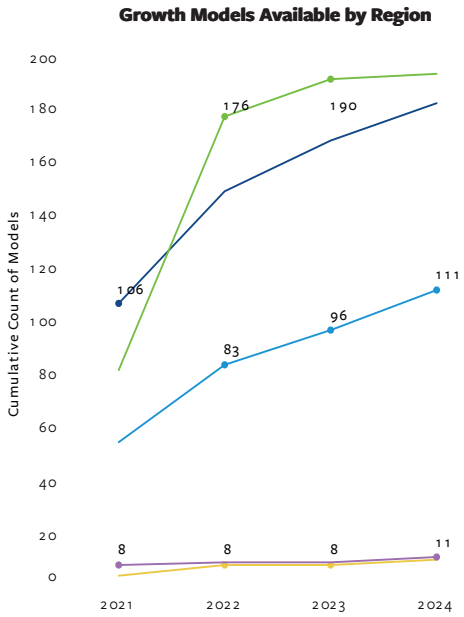
June 2024

ZERO EMISSION TECHNOLOGY BASICS

There are two basic formats for zero emission trucks (ZETs): battery electric and hydrogen fuel cell. Both technologies require an electric motor, electric drivetrain, battery, and inverter. However, instead of having a bigger battery, a hydrogen-powered truck has a more complex array of hydrogen fuel cells, hydrogen tanks and hydrogen delivery equipment. Hydrogen trucks have a higher upfront cost, but offer the major benefit of requiring only 10-20 minutes to refuel (even for long-haul applications), compared to the potentially multi-hour charging required for a battery electric truck. Fuel and maintenance costs for hydrogen trucks can be higher, as hydrogen (especially "green" hydrogen made from sustainable non-carbon emitting sources) is currently hard to come by and the technology is mechanically more complex.

MODELS AVAILABLE FOR MOST COMMERCIAL USES

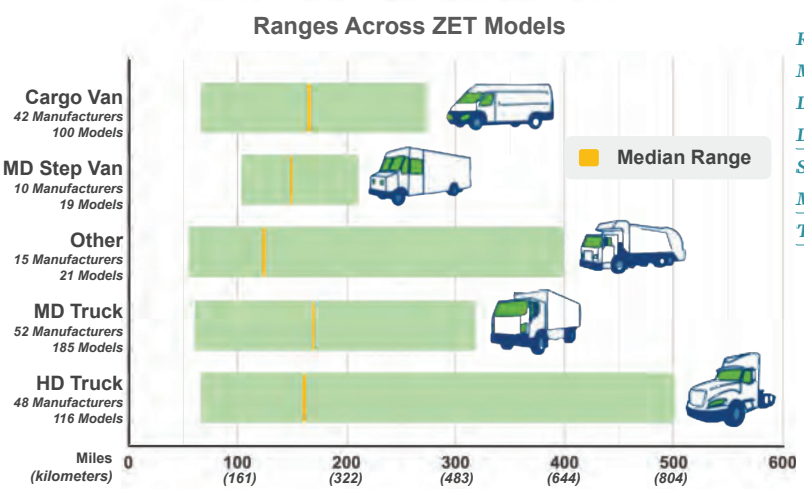
Worldwide, nearly 60 manufacturers have developed over 450 ZET models for a wide range of truck applications. Notably, most of these models are available in regions that have or are in the process of adopting supply side regulations or binding targets that accelerate ZETs. This includes the US (with state Advanced Clean Truck (ACT) Rule and national Phase 3 HDV GHG Standards), the EU (with CO_2 HDV Standards), and China (with central and city-level mandates). By creating economic certainty, regulations increase manufacturer investment and innovation in technology and drive a diverse and expanding supply of competitive products and services across commercial truck applications.



Growth Models Available by Region Source : CALSTART Data Explorer

CAPABLE OF NECESSARY RANGE

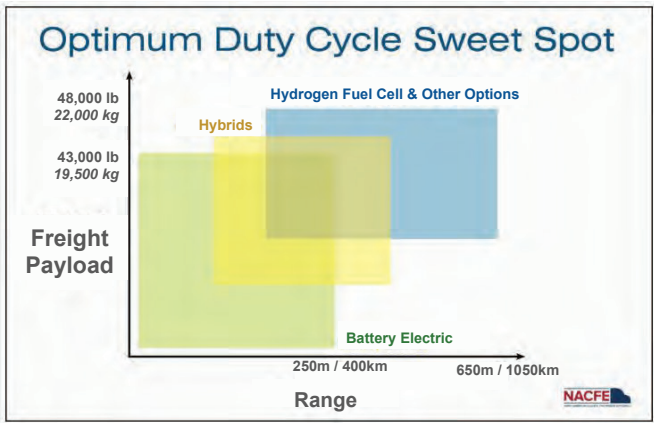
Current ZET technology meets the daily travel needs of most commercial trucks. Trucks often travel to predictable destinations with consistent mileage and a majority operate over short urban routes and stop frequently. In the US, more than 80% of trucks have an operating range of less than 100 miles (160 km) from their home base; nearly 70% have an operating range of less than 50 miles (80 km).



Ranges Across ZET Models, Source 1: Range Data: CALSTART ZETI Data Explorer Source 2: Manufacturer Model Data ICCT TCO Tracker

PAYLOAD RESTRICTIONS ARE MANAGEABLE

Compared to diesel trucks, some ZETs have payload limitations due to heavy batteries or large hydrogen tanks. For most trucks, especially those with urban deliveries or short-haul routes under 250 miles (400 km) per day, this is not a concern and battery electric trucks are often a cost-saving option. Many trucks that carry large payloads can be more limited by volume than by weight. For trucks with heavier payloads, longer routes, and brief, infrequent stops, megawatt-level (e.g ultra-fast) charging or quick-fueling hydrogen can be suitable solutions. For now, regulators can offer exemptions for dimensions or weight to mitigate payload restrictions. The EU allows electric trucks an additional 4 tonne, while California in the U.S. allows up to 2,000 lb. However, with expected advancements in battery energy density, hydrogen storage, and more light-weight, efficient truck designs ZETs will eventually catch up with and even exceed the payload of diesel trucks.



Optimum Duty Cycle Sweet Spot
Source : NACFE(2023)

EXTREME TEMPERATURE

The range of battery electric vehicles is reduced in extremely high or low temperatures, due to impacts on battery chemistry and the driver's heating and cooling needs. Multiple analyses have found that average speed has a greater impact on driving range than temperature. Thus, driving behavior training to encourage eco-driving that optimizes range can help offset environmental factors. Although some amount of weather-related range loss is unavoidable, fleets have demonstrated solutions and strategies to maintain effective performance. Cold weather tactics include: switching from resistance heaters to more efficient heat pumps and vehicle pre-heating while plugged-in. Ongoing improvements in electric truck range will reduce these impacts over time.

ALREADY ON THE ROAD

Many ZETs are already in operation around the world. Run on Less (map right) is an initiative of the North American Council for Freight Efficiency (NACFE). They track electric trucks operated by private fleets in a variety of commercial use-cases across North America. They've shown that electric trucks are already feasible and cost competitive alternatives for fleet vehicles operating defined routes, especially those with central depots. Market segments ready for electrification now include: vans and step vans, medium-duty box trucks, terminal tractors, and heavy-duty regional haul tractors.

Source : NACFE(2022)

#5: BATTERIES & CRITICAL MINERAL SUPPLY CHAINS

Technology trends and opportunities for reform

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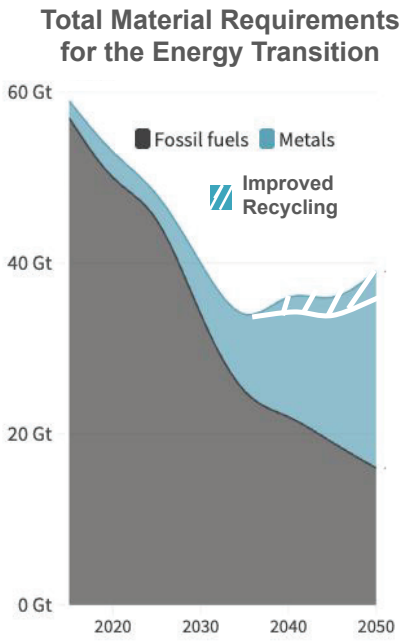
June 2024

GROWING SUPPLY AS OPPORTUNITY FOR IMPROVEMENT

Demand for batteries and critical minerals is surging. The International Energy Agency (IEA) estimates that if all announced and anticipated supplies of critical minerals come online as scheduled, sufficient supply should exist to meet increased demand through 2025. This dynamic will likely hold true through 2030, but with a relatively thin margin that will require significant effort to expand supply and reduce the growth rate of demand through improved efficiency. The next few years present a unique window to ensure supply chain growth is sustainable, just, and low-carbon.



Source: Nijnens et al. (2023)

CLEAN ENERGY REQUIRES LESS MINING

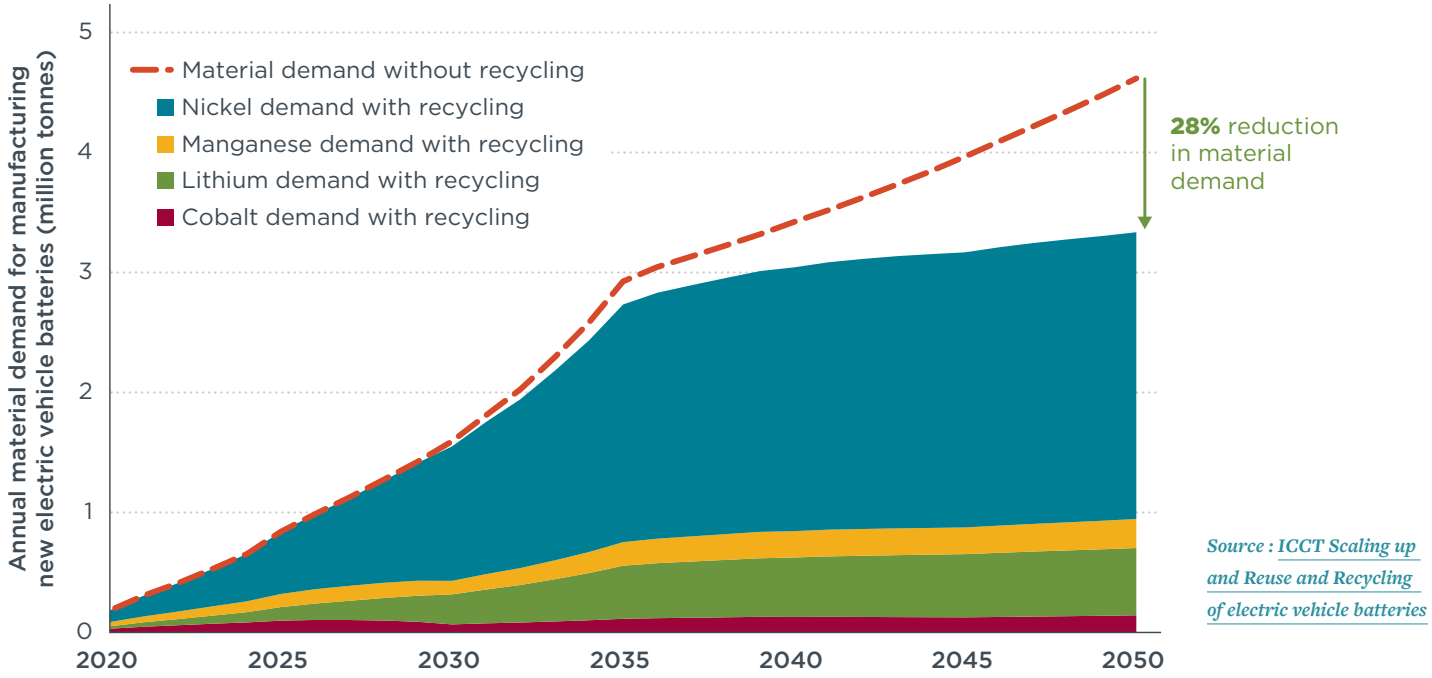
The IEA estimates that annual demand for critical minerals (for all technologies) could reach 43 million tons by 2040 in the most ambitious and mineral-intensive Net-Zero Scenario. This is a fraction of current annual global extraction and mining of 15 billion tons of fossil fuels. However, some minerals exist in very low concentrations within rocks. Several recent analyses account for this by looking at what this means for total "material moved" — not just the ore used, but the amount of earth disrupted to extract the resource. Even accounting for low and potentially declining ore concentrations, a clean energy economy will significantly reduce overall extraction compared to a fossil fuel economy. Expected improvements in technology, recycling, and policy will further enhance this benefit.

ZERO EMISSION TRUCKS LOWER EMISSIONS COMPARED TO DIESEL

The carbon intensity of mineral extraction and battery manufacturing means that ZET production is higher-emission than diesel truck production. However, truck manufacturer Scania found that BETs make up for these production emissions in just the first 68,000 kilometers (42,250 miles) of zero emission driving. ICCT analysis found that 2021 BETs produce at least 63% lower lifetime emissions compared to diesel when using the EU's average electricity grid mix (with a 92% emission reduction projected when 100% renewable electricity is used). These findings hold true for light-duty vehicles as well, all around the world, even when charged from more carbon-intensive electricity grids.

IMPROVING RECYCLING AND LIFE EXTENSION

Markets for battery recycling and life extension (such as refurbishing for continued vehicle use or reuse for grid storage) are still in the beginning stages, with significant opportunities for innovation and technological advancement. These markets will grow as more EVs reach end of life, with a predicted 1.2 million batteries available 2030 rising to 50 million in 2050. There is also significant opportunity for supportive policy and industry coordination to drive innovation and help overcome technological and logistical barriers. China and the European Union have leading policy frameworks to ensure end-of-life batteries are handled responsibly, including: extended producer responsibilities making manufacturers responsible for end-of-life batteries, battery tracing platforms or passports, and targets for improving mineral recycling recovery rates. Implementation of EU Battery Regulation recycling rates would result in an estimated 28% reduction in material demand. Notably, there are a range of estimates for how much recycling and life extension can reduce demand across different minerals. For example, estimates for 2040 demand reductions for nickel range from 12% to up to 35%. While it is technologically possible to recover multiple critical minerals at rates above 90%, current recovery is limited by the lack of strong economic or policy drivers.



Source : ICCT Scaling up and Reuse and Recycling of electric vehicle batteries

BATTERY IMPROVEMENT TRENDS

Advancements in battery chemistry have enabled increased battery density while reducing battery weight. With various battery chemistries available, including lithium-ion and solid-state, the industry has driven significant improvements in battery energy storage capabilities. Moreover, the emergence of recycling and repurposing technologies for batteries signifies a sustainable approach, decreasing the demand for new batteries and contributing to sustainable mining practice efforts.

REDUCING DEMAND THROUGH EFFICIENCY

Reducing demand for critical minerals through improved efficiency will require concerted policy effort and industry coordination but could significantly cut the need for new mining. There are several opportunities for reducing overall battery demand, including: modal shift for freight, such as moving goods by rail or smaller vehicles for last-mile delivery; modal shift for people, such as encouraging public transit and e-bicycles; right-sizing batteries; and technology improvements for reducing the mineral intensity of batteries. One study estimates that reducing car dependence and limiting the size of EV batteries in the US could reduce lithium demand by 18-66%. Investing in innovative technology can reduce mineral demand not only in battery design and chemistry, but also through methods such as "clean-sheet" designs and light-weighting. These take advantage of new materials and zero-emission-specific vehicle architectures that can reduce the weight and cost of vehicles while improving their overall efficiency.

IMPROVING MINING & SUPPLY CHAINS

Below are two key best practice frameworks for improving human rights and the local environmental impact in mining and supply chains. See also the leading policy frameworks in China and the European Union.

- **Standards**: Initiative for Responsible Mining Assurance (IRMA) is an independent third-party standard-setting organization for responsible international mining practices. IRMA stands out by including human rights and environmental issues, setting standards through multi-stakeholder engagement, and offering fully transparent auditing. IRMA is in the process of developing additional standards for minerals processing and refining.

- **Battery Passport**: The Global Battery Alliance (GBA) describes a battery passport as establishing a digital twin of a physical battery with information about all lifecycle elements based on a comprehensive definition of a sustainable battery. It aims to bring new levels of transparency to the global battery value chain by reporting trusted data among all lifecycle stakeholders on the material sources, the battery's chemical make-up and manufacturing history, and its sustainability performance. This technology could allow better decision-making along the various steps of battery supply chains, including post-vehicle life and recycling, helping to improve human and environmental outcomes.

#6: ZERO-EMISSION TRUCKS WORKFORCE TRANSITION & JOBS

Impacts and Options to Manage

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Zero-Emission Trucks: A Factsheet Series

August 2025

ZERO-EMISSION VEHICLE GLOBAL TRANSITION HAS LED TO A SURGE IN GREEN JOBS

The rapid growth in global electric vehicle sales in general has created substantial new green jobs and laid the foundation for a continued future of overall job growth. While data on heavy-duty zero-emission vehicle job impacts is still scant, experts anticipate new jobs in the sector will offset any losses in the internal combustion engine vehicle and fossil fuel, as has happened in the light-duty sector. For example, in Europe, the European Climate Foundation forecasted a surge in employment in the light duty sector (as well as for more efficient internal combustion engine vehicles), with the estimated creation of 500,000 to 850,000 jobs by 2030. Furthermore, researchers project the transition overall to increase gross domestic product in the European Union by 1%. Future investments in complementary industries, such as charging, battery production and mining will have additional potential to create jobs. Finally, the transition could lead to an economic boost for vehicle owners and operators, due to reduced fuel and maintenance expenses, which they can then reinvest economy wide, leading to job growth in other sectors.

As the trucking industry invests in electrification, these economy-wide job impacts are likely to occur in this sector as well. As an example, a joint venture of major truck makers announced the building of a 21 gigawatt battery production factory in Mississippi that analysts expect will create more than 2,000 U.S. manufacturing jobs. In addition, a large U.S. manufacturer hired over 1,000 workers to increase semi-truck production in Nevada in early 2025.

The broader electric vehicle transition also necessitates a completely new and extensive infrastructure buildout for charging stations, and this deployment requires many new workers. The International Council on Clean Transportation estimated that growth in U.S. charging infrastructure could create roughly 160,000 jobs by 2032, with even greater job growth potential from increased domestic production and supply chain integration. They estimated that electric vehicle tax credits would enable such a growth in truck charging infrastructure.

As another example of how this transition is unfolding in ways that benefit overall job production, California has been a leader in the electric vehicle transition, with electric vehicles transition zero-emission vehicles comprising about 25% of light duty vehicle sales and approximately 16% of new medium- and heavy duty vehicle sales as of August 2024, which is supporting a nation leading number of zero emission manufacturing jobs. The UCLA Luskin Center for Innovation's Workforce Impacts of Achieving Carbon-Neutral Transportation in California (Sept. 2022) estimated that between 2020 and 2045, while the state may lose 730,000 full-time equivalent jobs in industries related to internal combustion engine vehicles and fossil fuels, it will simultaneously create over 7.3 million full-time equivalent job-years' worth of employment. This growth will result from the expansion of zero-emission vehicle-related industries, along with the deployment of charging and hydrogen fueling infrastructure.

On the infrastructure side, the California Energy Commission estimated that installing the required chargers to meet the state's zero-emission vehicle targets will generate up to 71,500 job-years, encompassing roles for electricians, general contractors, planners, and designers. This surge in demand will not only create thousands of skilled, well-paying jobs but also foster workforce training and development.

As another example, the Economic Survey 2023 estimated that by 2030, the zero-emission vehicle industry is expected to create 5 million direct jobs and 30 million indirect jobs. In addition, market research documented that between 2021 and 2023, the average employee count in the electric vehicle industry has risen by 110%. This shift necessitates significant skilling and reskilling efforts to equip the workforce for these advanced positions. This effort also includes ensuring that manufacturers support the transition in disadvantaged communities and build community-sustaining jobs.

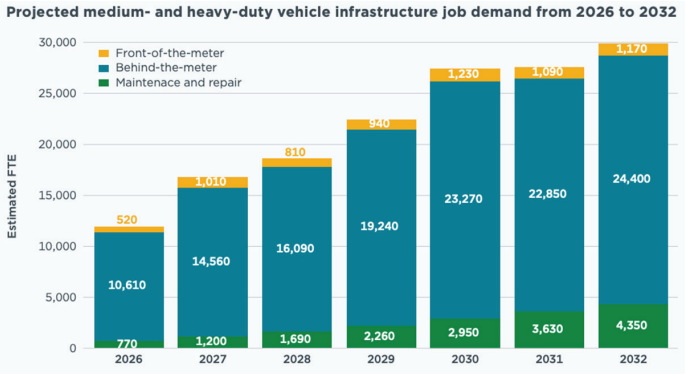

Figure 1: Estimated full-time equivalent jobs in the U.S. Source: ICCT, May 2025.

AFFECTED JOB SECTORS

Despite projected overall growth in jobs, the transition to zero-emission heavy duty vehicles will negatively impact specific sectors and require new digital advanced manufacturing and specialized skills. However, policy makers and industry leaders can offset some of the impacts via retraining or by allowing the current workforce to retire, along with decreased demand for internal combustion engine vehicles, without encouraging new entrants to these careers. For example, the advent of battery electric drivetrains in trucks will lead to declines in jobs related to traditional automotive manufacturing sectors, such an internal combustion engine repair, maintenance, exhaust and fuel system manufacturing, as well as their parts suppliers.

The transition could also impact sectors that produce components for both internal combustion engine and electric-heavy-duty vehicles, although these workers may more easily be able to transition with the new demand and diversify to other sectors. Some internal combustion engine manufacturing jobs have already been effectively transferred to the electric vehicle sector, including design, engineering, and assembly. Ultimately, workers involved in internal combustion engine manufacturing for heavy-duty vehicles could adapt to the technology changes through retraining. In fact, researchers at the University of Michigan found that the number of assembly jobs in production plants increased when plants transition to electric vehicles from internal combustion ones. Additionally, suppliers of steering and suspension and lighting systems, as well as other interior components will likely experience low or no employment impact given the commonality of components across electric and internal combustion engines. This dynamic is similar with tire or paint manufacturing.

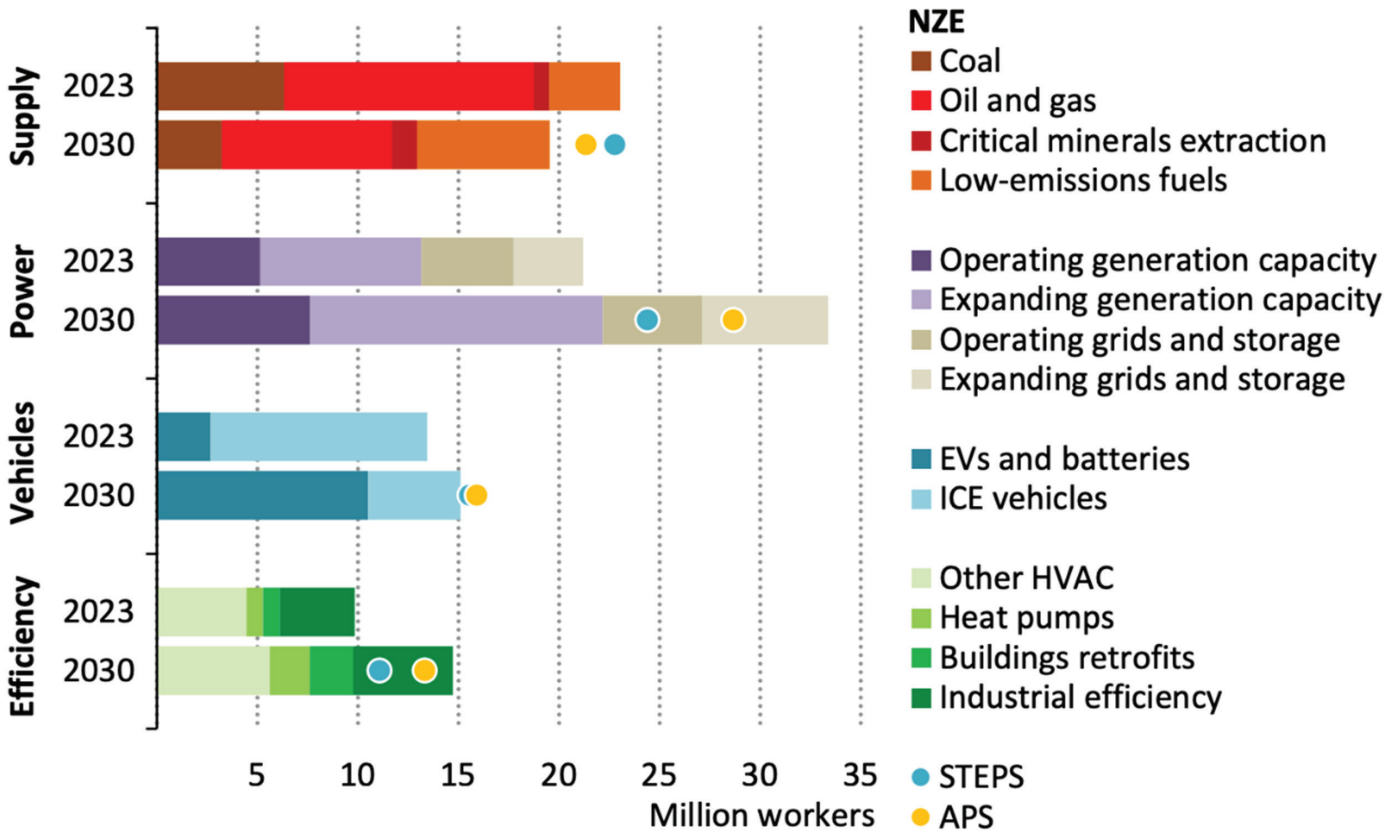

Figure 2: Source: IEA Energy employment by technology and scenario, 2023 and 2030; Stated Policies Scenario (STEPS): Announced Pledges Scenario (APS).

SUPPORTING WORKERS DURING THE TRANSITION

While the overall impact of the transition to zero-emission heavy-duty vehicles on jobs will likely be net positive, jobs related exclusively to internal combustion engines will decrease. Yet researchers have difficulty distinguishing between recent job changes due to the transition to zero-emission vehicles and those lost due to increasing automation of manufacturing, which is a separate and largely unrelated trend compared to the transition to zero-emission vehicles.

However, companies and governments can avoid many of these job losses if they provide retraining. For example, workers in internal combustion engine sectors often have skills that are similar to those needed in green sectors, making them competitive for other green jobs. Investment in worker education and training could therefore minimize the adverse employment impacts of the transition to zero-emission heavy-duty vehicles and potentially make the motor vehicle workforce more resilient to the transformation already underway.

For the commercial trucking sector, the UC Berkeley Labor Center recommended in 2020 that California policymakers prioritize subsidies and assistance for high-road trucking companies that classify drivers as employees, using responsible employer policies for public funding and contracts to protect workers and uphold labor standards. A high-road approach to economic development could optimize climate policy outcomes while supporting the creation of and access to family-supporting jobs. The Labor Center further recommended that workforce development funds should support high-road training partnerships that provide on-the-job training for drivers and retrain diesel mechanics for new clean vehicle technologies.

Several countries and regions have developed policies to help prepare motor vehicle workers for this transition by providing training programs:

- **European Union's Just Transition Fund**: This fund aims to support regions heavily reliant on traditional industries, such as automotive manufacturing, to transition to cleaner technologies like electric vehicles. It provides financial support for reskilling and upskilling programs for workers.
- **Japan's Green Growth Strategy**: The strategy outlines the creation of over ¥50 trillion in new environment-related markets and anticipates the generation of 1.4 million new green sector jobs. This initiative is part of a broader effort to reduce worldwide greenhouse gas emissions by leveraging Japanese private-sector technology.
- **The German Government** supports workers during the transition by investing in re-education and training initiatives. For instance, in 2022, the German Federal Employment Agency allocated €1.3 billion for training programs spanning various sectors including electric vehicles, with an additional budget of €1.7 billion allocated in 2023.

THESE ADDITIONAL REFORMS AND TRAININGS COULD HELP ENSURE A JUST TRANSITION:

Skill Development Trainings: Policymakers responsible for workforce development can identify specific employment needs and gaps within the zero-emission heavy-duty vehicle industry. They can then support and provide curriculum development and skill set trainings tailored to meet the specific needs of the industry. In addition, policymakers and stakeholders can partner with training providers and educational institutions to establish standardized certification programs for heavy-duty zero-emission vehicle production jobs. This approach could facilitate a smooth transition for current motor vehicle workforce while ensuring they remain competitive for the changing technology landscape.

Job Security and Economic Well-Being: Policymakers can offer financial support to temporarily displaced workers, particularly those in disadvantaged communities affected by the transition, providing a safety net as they pursue new employment opportunities within the zero-emission heavy-duty vehicle industry.

Long Term Planning: Policymakers can collaborate with educational institutions, training agencies, labor unions, and other stakeholders to align workforce development strategies with industry needs. In addition, they can conduct long-term strategic planning to anticipate future industry trends, helping to prepare the workforce for these upcoming changes.