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The #H2IQ Hour

Today's Topic:

Heavy-Duty Vehicle Decarbonization

This presentation is part of the monthly H2IQ hour to highlight hydrogen and fuel cell research, development, and demonstration (RD&D) activities including projects funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

Housekeeping

This webinar is being recorded.

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Questions?

- There will be a Q&A session at the end of the presentation
- To submit a question, please type it into the Q&A box; **do not** add questions to the Chat

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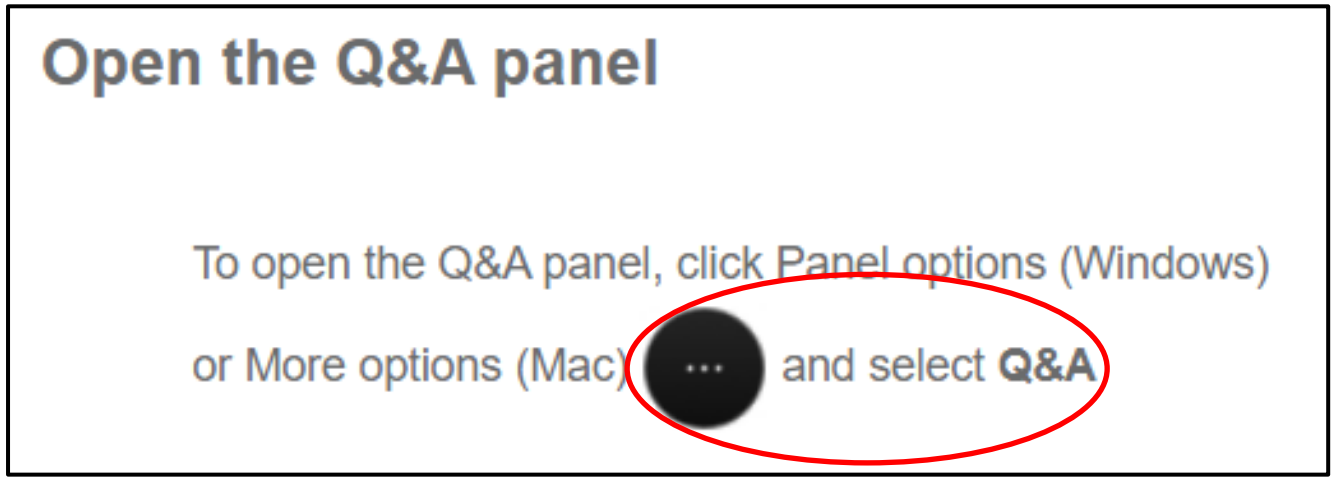
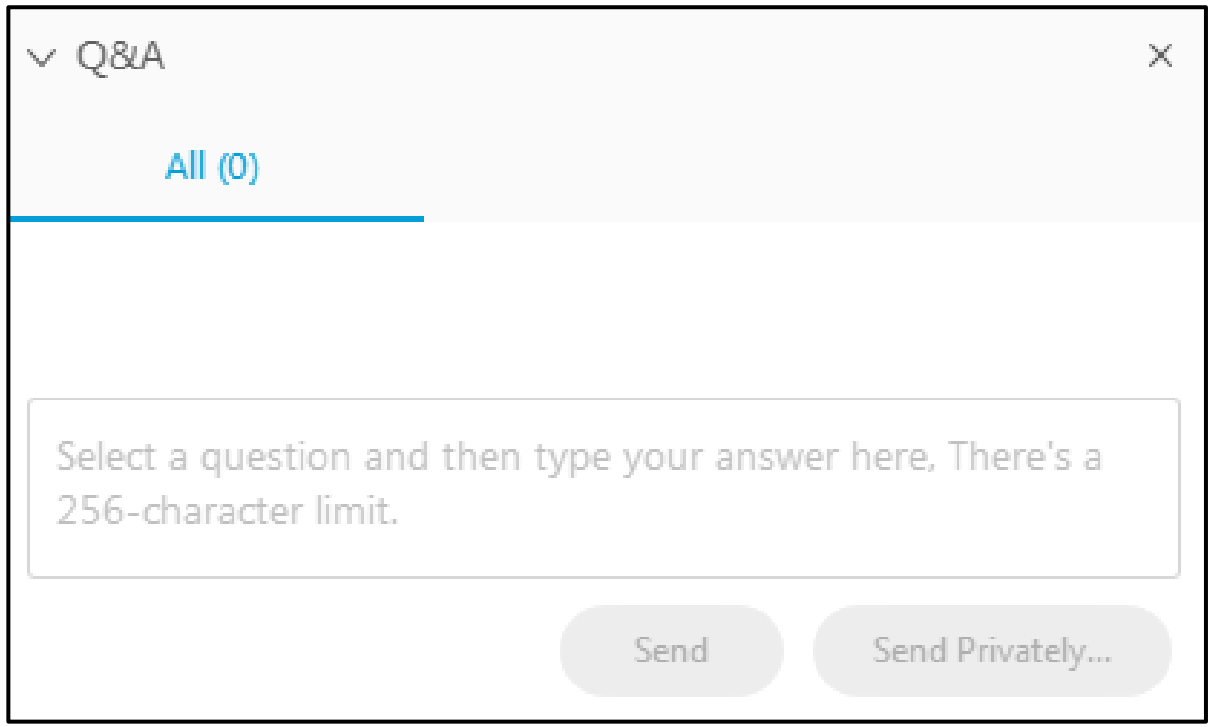
The #H2IQ Hour Q&A

Please type your questions into the Q&A Box





BERKELEY LAB
Bringing Science Solutions to the World

U.S. DEPARTMENT OF ENERGY

Decarbonizing Heavy -Duty Vehicles

H2IQ Webinar

Ahmet Kusoglu

Lawrence Berkeley National Laboratory

Million Mile Fuel Cell Truck Consortium

SEPTEMBER 21, 2023

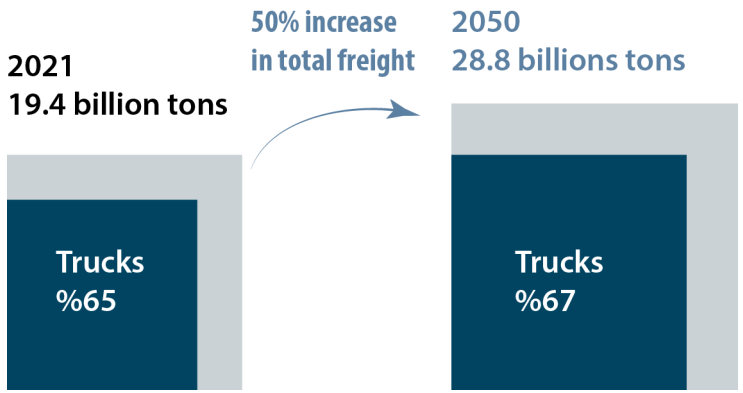
Part I

Trucks: Transportation Facts & Emissions

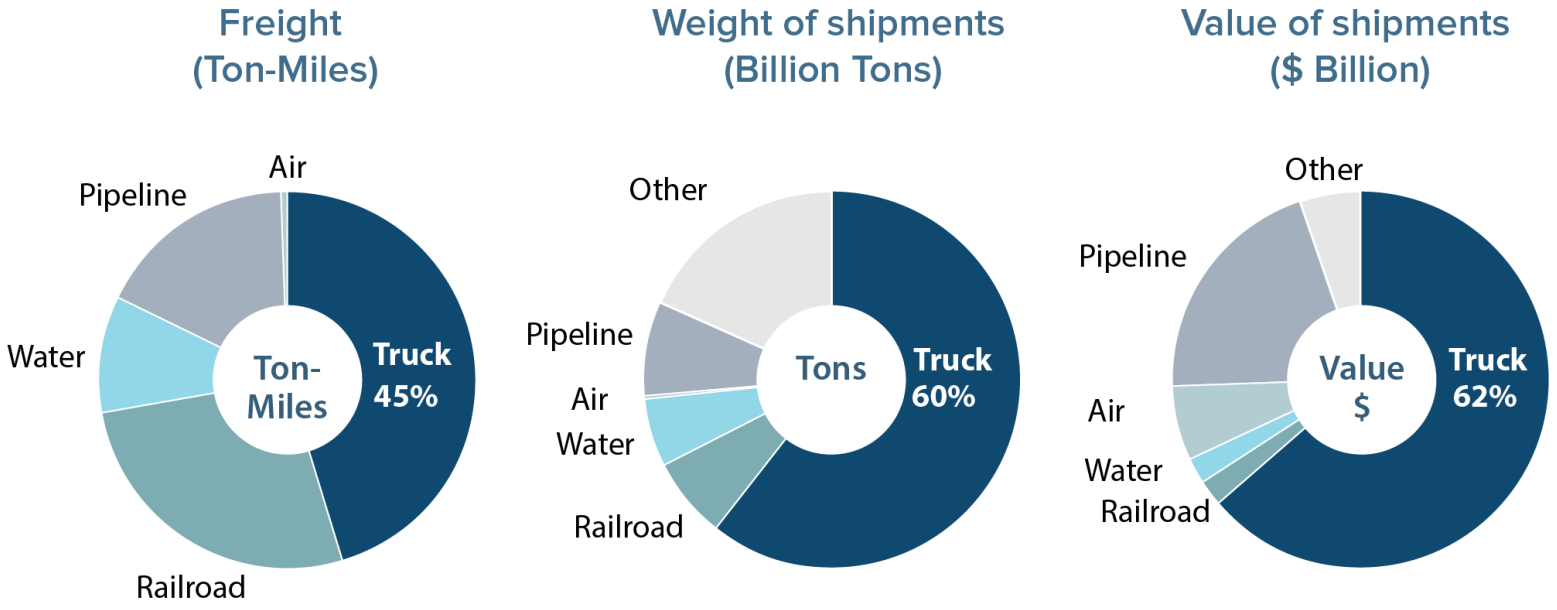
Trucks play a major role in Moving Goods & Freight in the Nation

Majority of freight in the U.S. moved by Trucks (in terms of value, tonnage and ton-miles)

Freight movement is expected to increase in the future with a growing share of trucks



Freight Movement in The United States
Share of Transportation Modes



Other Includes multiple modes

Source: U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Highway Administration (2020 Values) | Visualization By A. Kusoglu

MILLION MILE FUEL CELL TRUCK

Heavy Duty Trucks: Economic Indicators and Workforce

In 2021, transportation (for-hire, in-house, and household) contributed $1.3 trillion (5.6%) to U.S. GDP of $23.7 trillion

Trucking (for-hire and in-house) contributed $389 billion —the 2nd largest contribution to transportation GDP

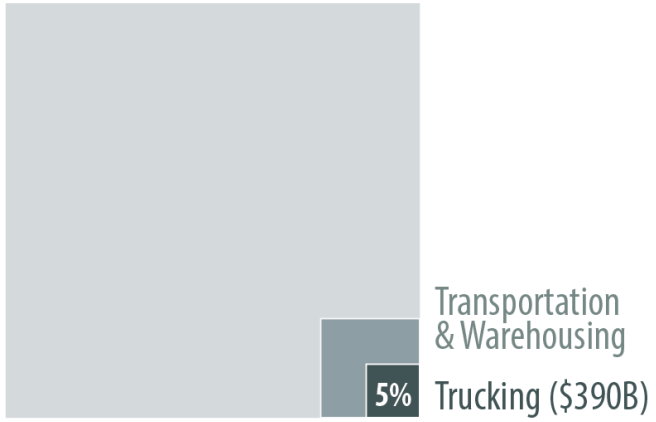
Truck driving is the largest freight transportation occupation in the U.S. Of the 3.35 million employed in drivers and sales, almost 2 million are heavy-duty truck drivers

Transportation: Economic activities and workforce

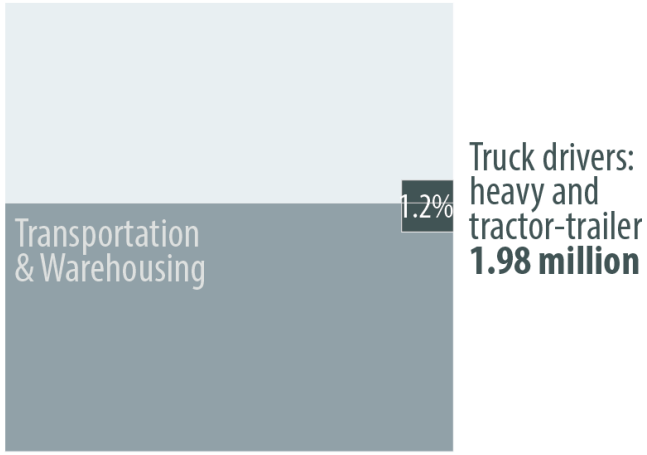
Trucking Sector and Drivers

Truck driving is the largest freight transportation occupation in the U.S.
Almost 2 million are employed as drivers for heavy-duty and tractor trailer.

U.S. GDP: $23.3 trillion (2021)



U.S. Labor Force: 155 million (2022)



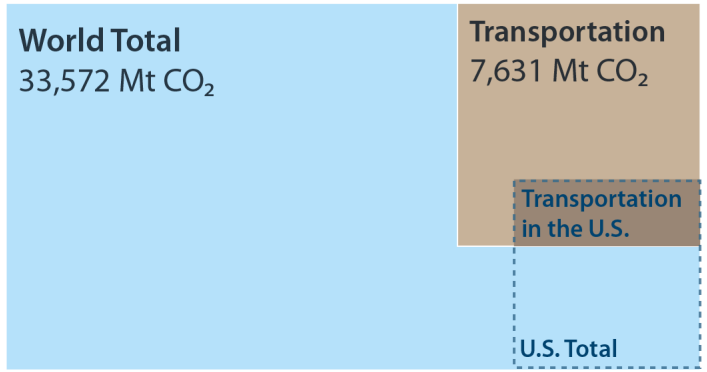
Source: U.S. BTS (https://data.bts.gov/)
By A. Kusoglu

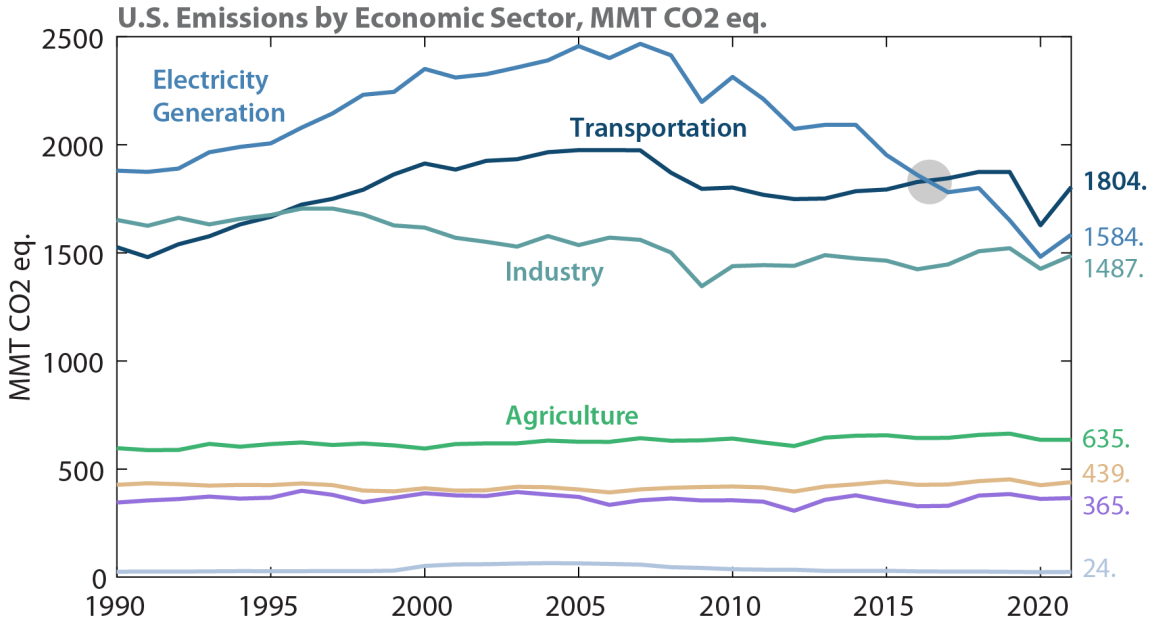
Transportation has become the largest source of carbon emission

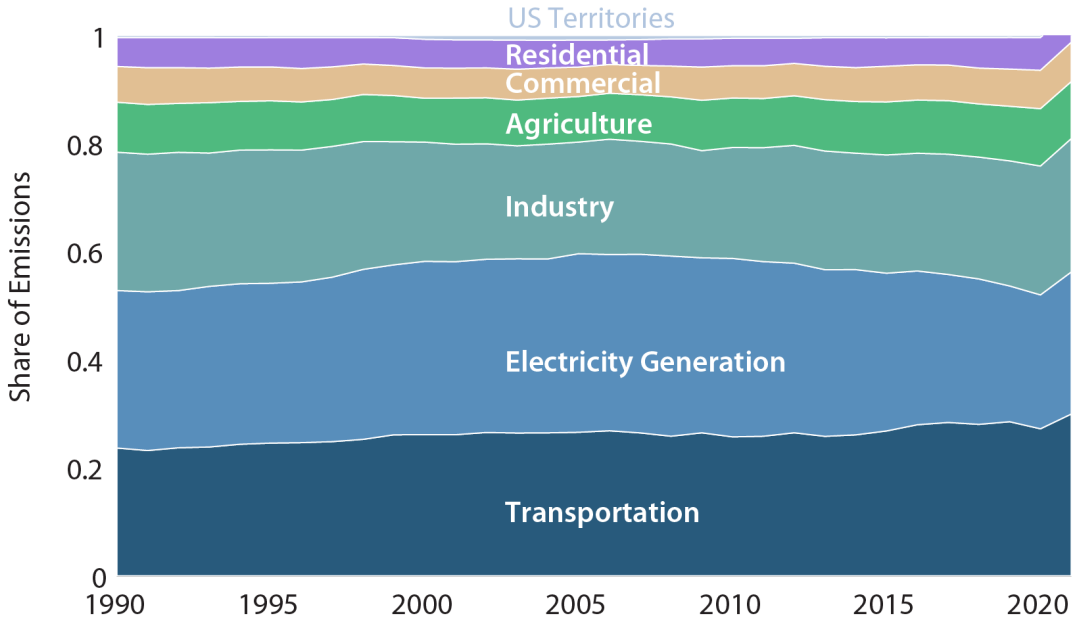
In the past few years, transportation sector has become the largest source of contributor to the carbon emissions in the United States

Globally, transportation contributes to 23% of emissions from fuel combustion

Total CO_2 emissions from fuel combustion
million-metric ton CO_2 equivalent in 2021



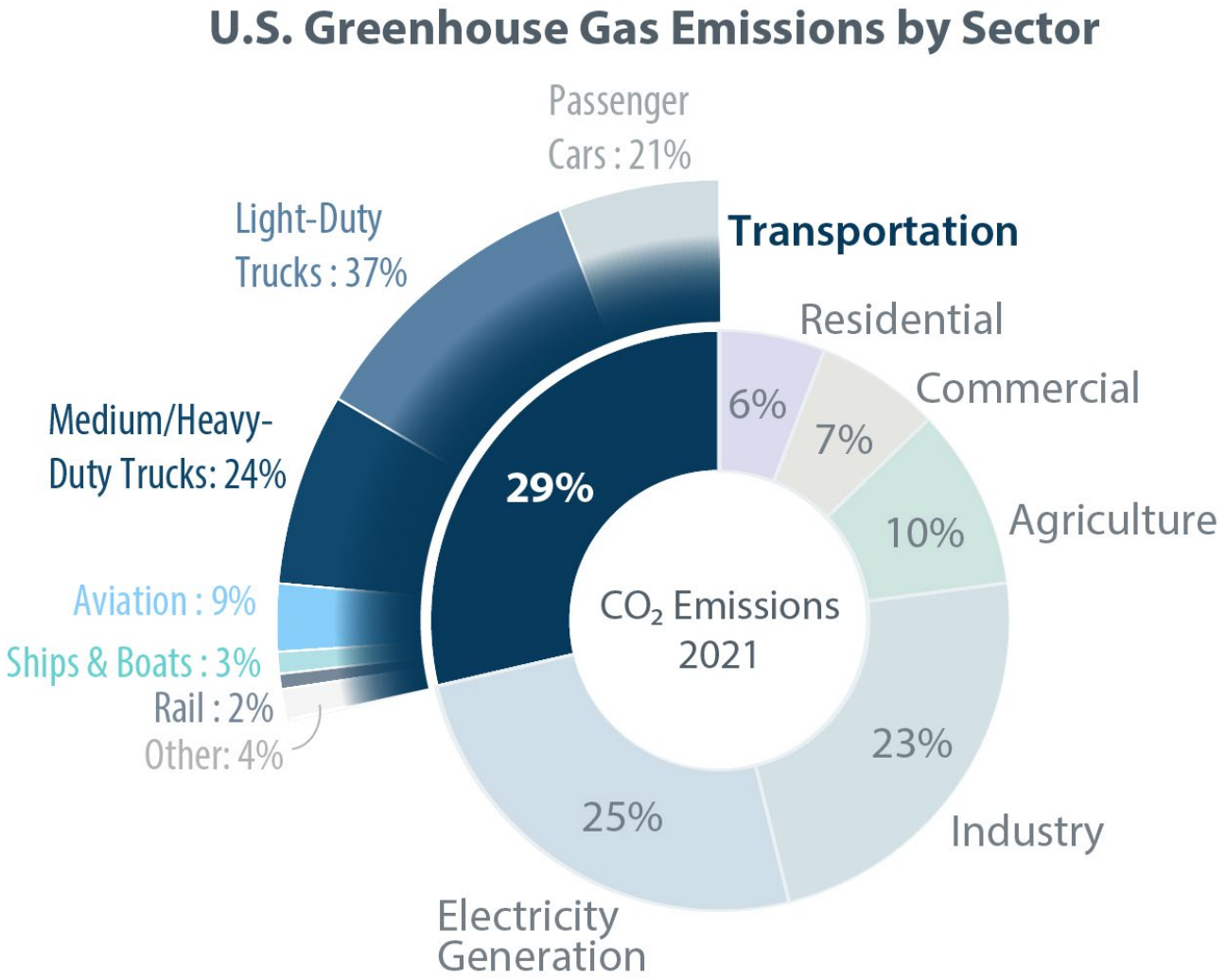




Source: IEA, U.S. EPA

Transportation is the largest source of greenhouse gas emissions

Emissions from Heavy-duty trucks alone (7% of total GHG) are comparable to the emissions from residential or commercial sectors

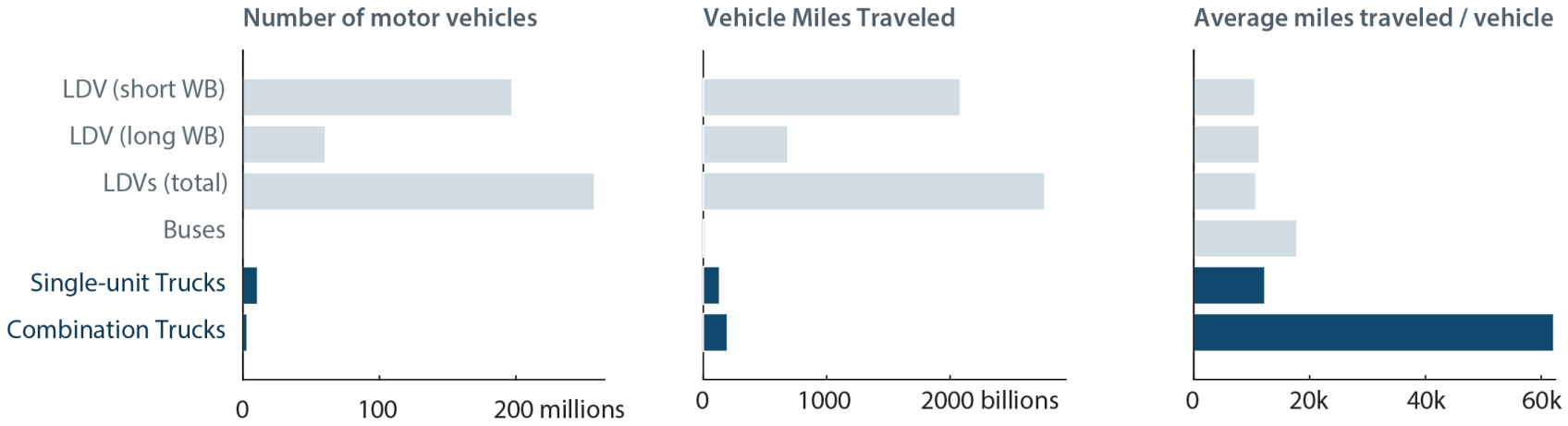


Source: EPA (2023)
By A. Kusoglu

LDV vs HDV: Examining the metrics

Majority of the vehicle fleet are Light-duty vehicles (LDV)

LDVs: Most of the highways miles and fuel consumptions



Source: U.S. DOT. BTS

LDV vs HDV: Examining the metrics

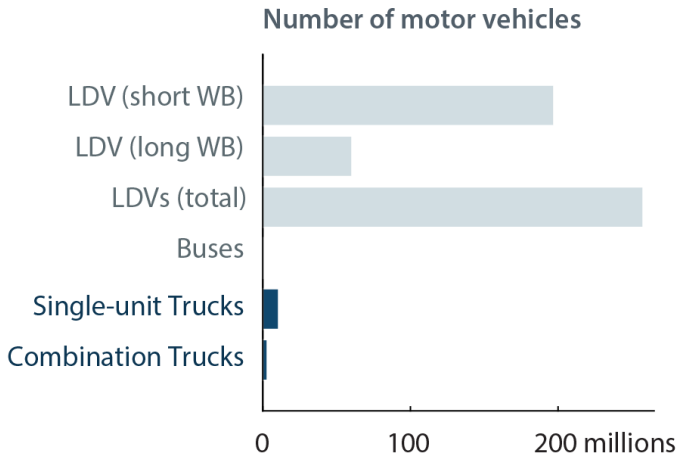
Majority of the vehicle fleet are Light-duty vehicles (LDV)

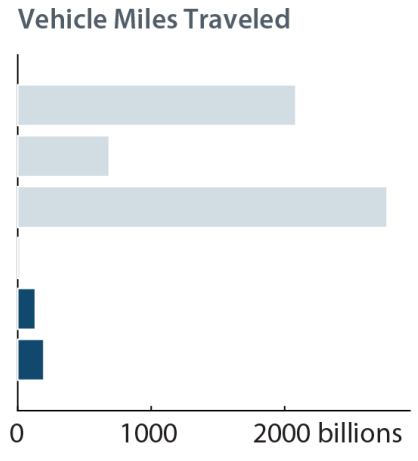
LDVs: Most of the highways miles and fuel consumptions

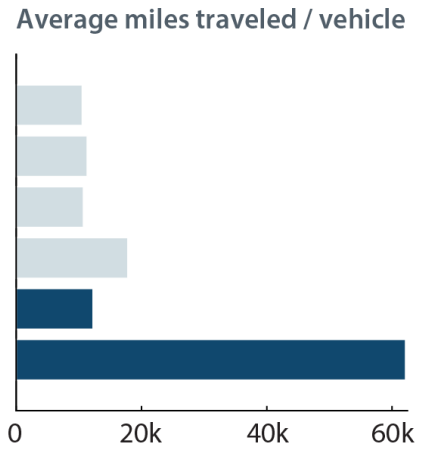
However, per vehicle basis,

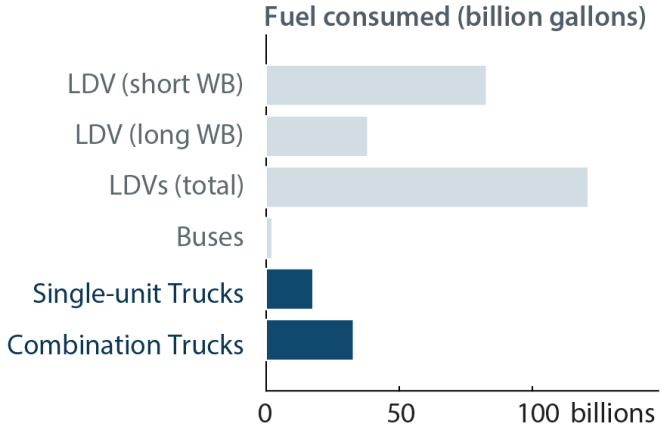
HDV truck travel 6x more than LDV annually

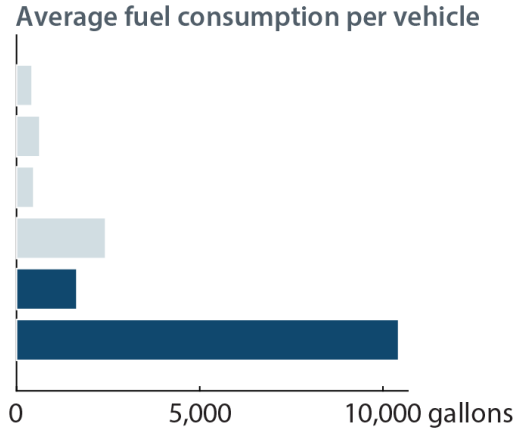
HDVs consume up to 20x more fuel per vehicle











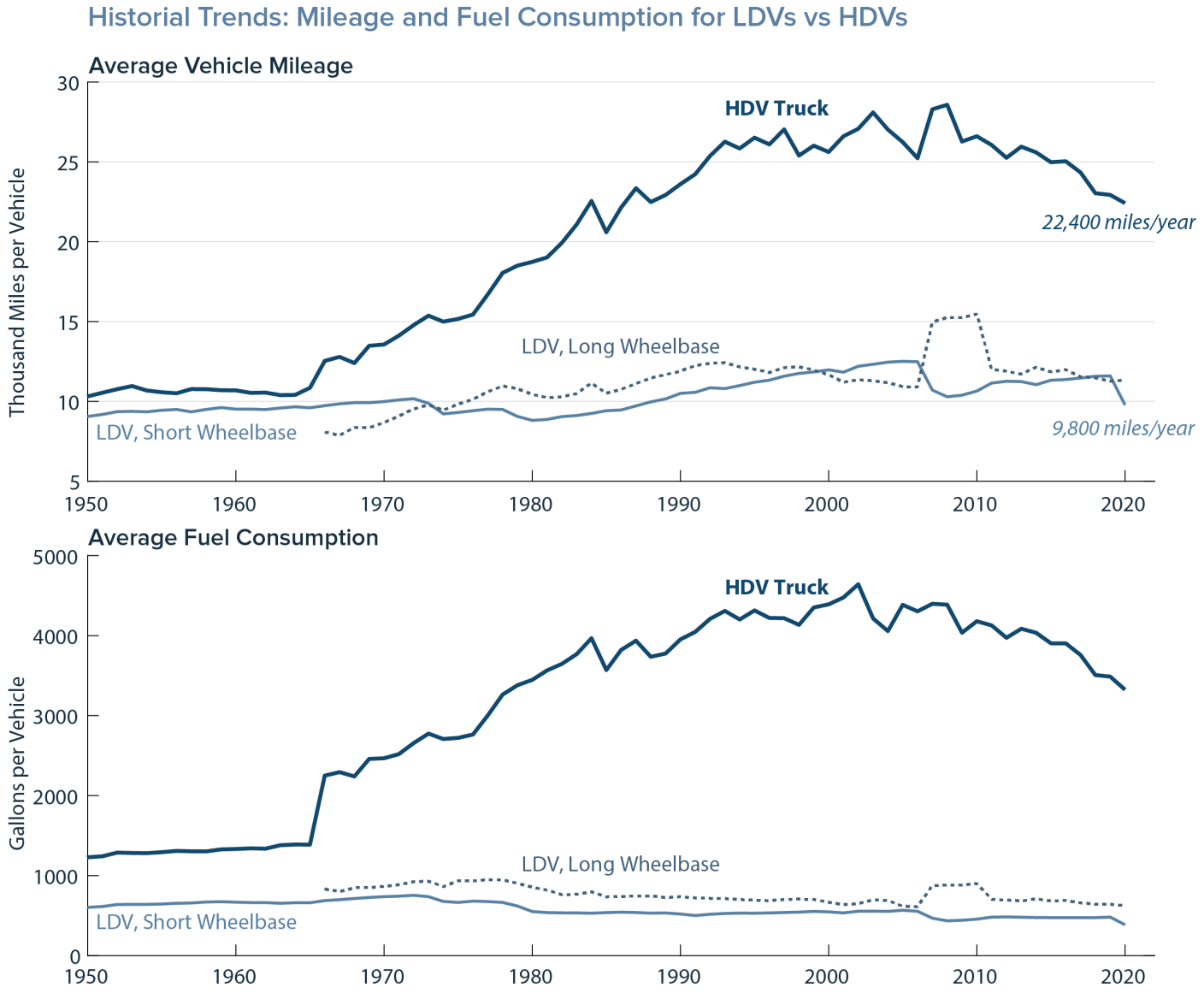
Source: U.S. DOT, BTS

Increased Mileage and Fuel Consumption for Trucks

Per-vehicle mileage has been increasing for HDV trucks compared to light-duty vehicles (LDVs) and cars

HDV trucks consume significantly more fuel despite comprising a smaller fraction of U.S. fleet

Decarbonization of heavy duty trucks will have stronger positive impact per vehicle / mile basis



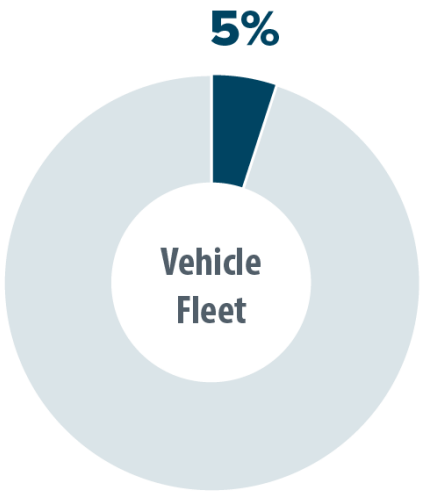
Source: EIA

Visualization By A. Kusoglu

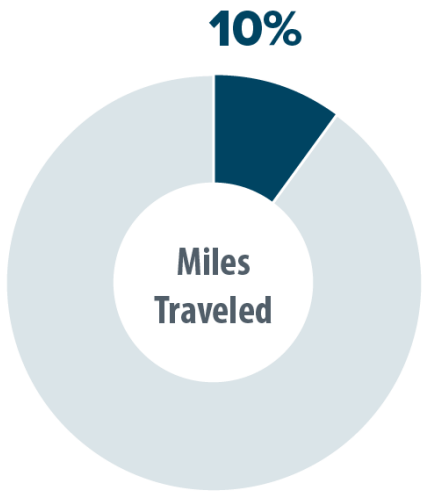
Heavy-Duty trucks disproportionally contribute to emissions

Heavy-duty vehicles (HDVs), including large trucks, constitute only 5% of the vehicle fleet, yet they are responsible for over a quarter of fuel consumption and transportation emissions in the U.S.

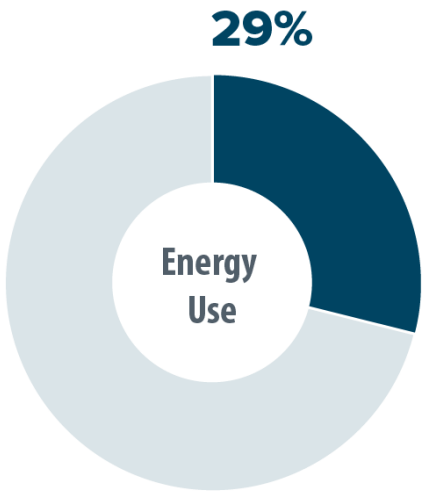
heavy-duty vehicles are only 5% of the entire vehicle fleet



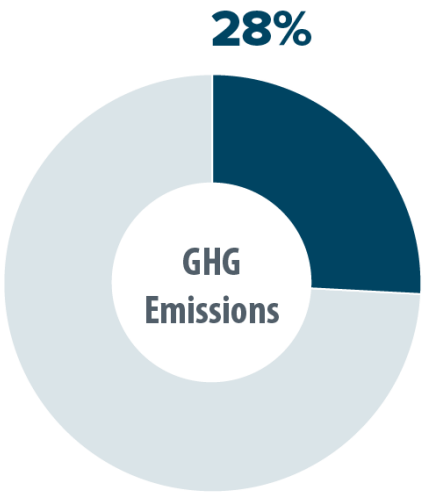
and they travel over 10% of total miles traveled



yet they consume annually 29% of the transportation fuel



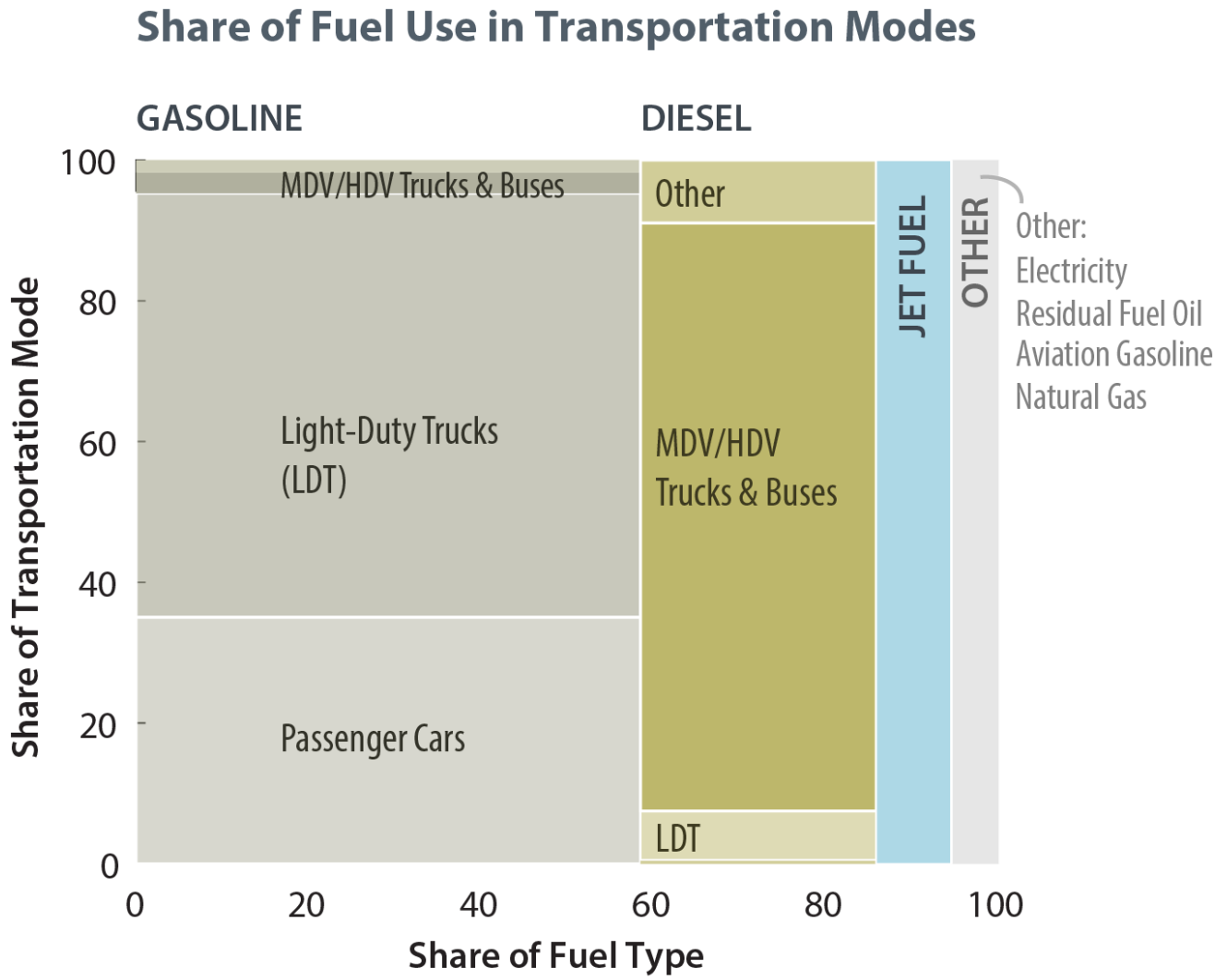
and contribute to over a quarter of transportation emissions



Source: EPA, BTS, DOT
By A. Kusoglu

Transportation emissions come from various uses of fuels in different sectors

A large fraction of gasoline consumed by light duty commercial vehicles and trucks, whereas a majority of diesel consumption is by heavy-duty vehicles



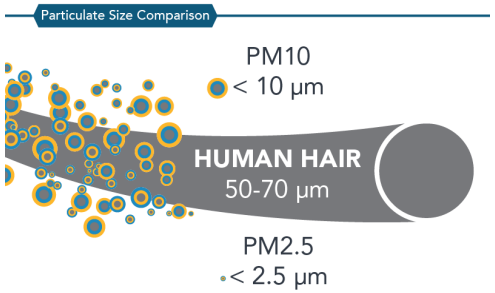
Source: EPA (2021 Values)
By A. Kusoglu

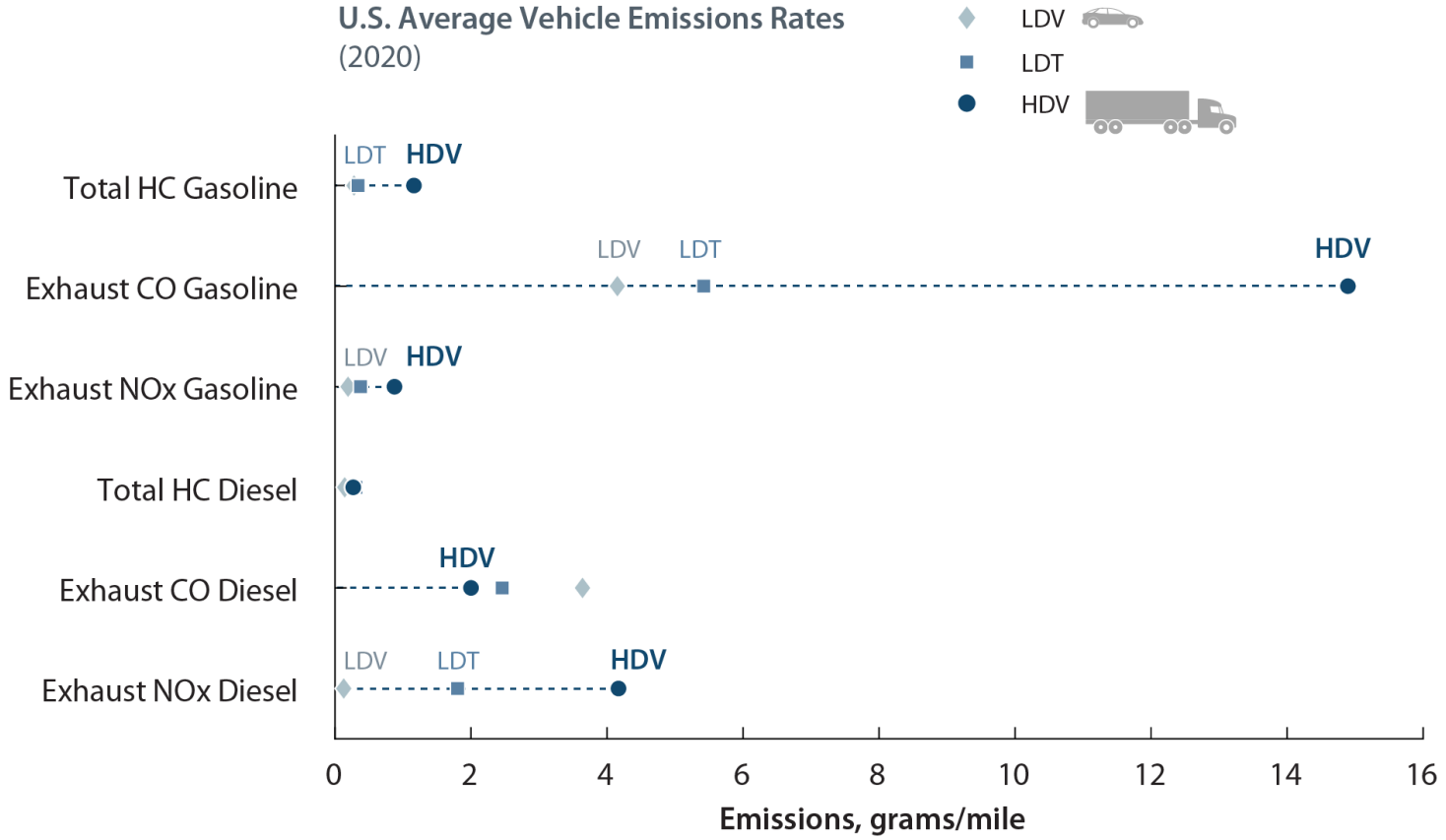
Transportation Emissions

Freight transportation is one of the major contributors to the emissions; especially in grams/mile basis

Significantly higher NOx and CO emissions from trucks (vs. LDVs) are a major environmental and health concern

- Of all the common air pollutants, PM2.5 is associated with the highest proportion of adverse health effects related to air pollution
- Most PM2.5 derives from combustion, gasoline & diesel fuels by motor vehicles, burning of gas



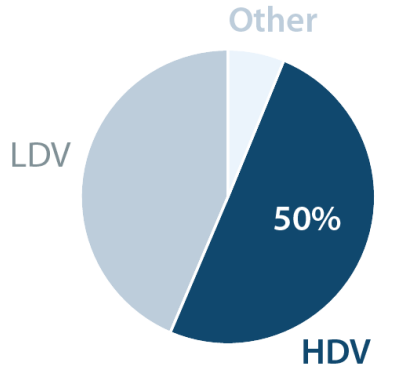


Underserved communities (e.g., near highways, ports and freight centers) are more vulnerable to exposure and experience adverse health effects

Source: EIA, BTS, EPA, https://ww2.arb.ca.gov

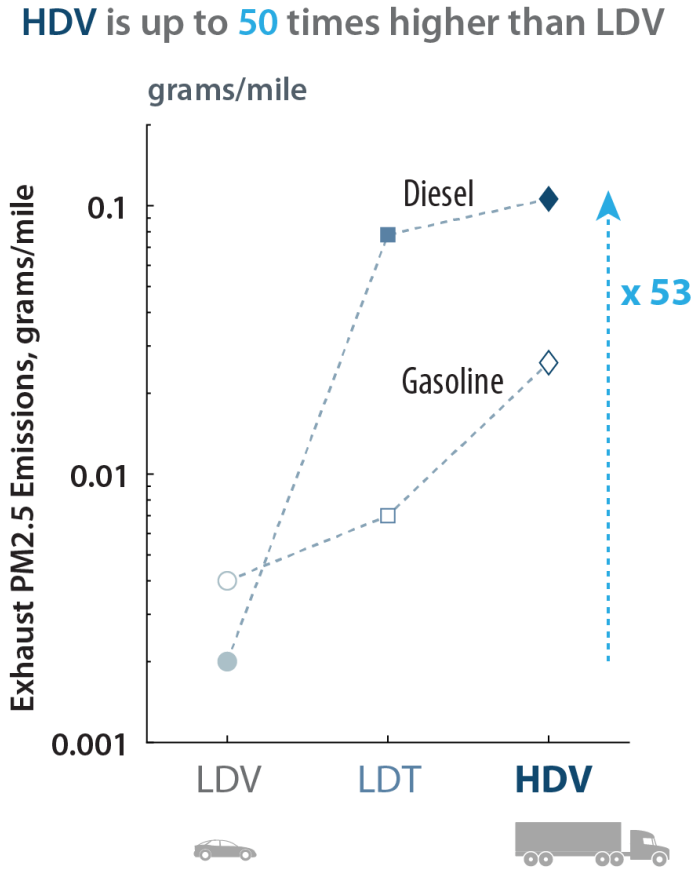
PM2.5 Emissions/mile is significantly higher for HDVs

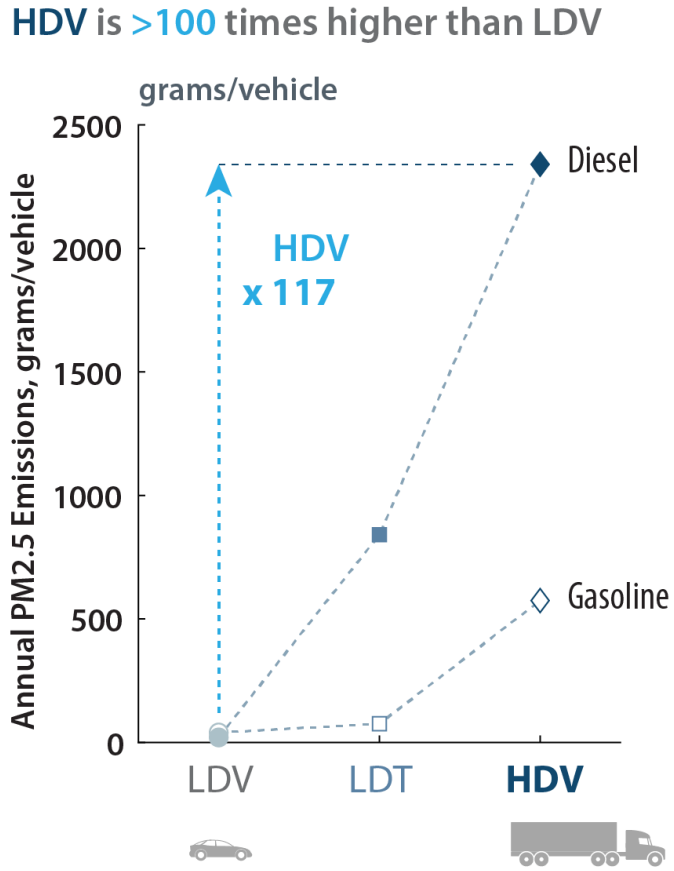
For PM2.5, short-term exposures (up to 24-hours duration) have been associated with premature mortality, increased hospitalizations for cardiovascular, heart or lung causes, acute and chronic bronchitis increased asthma attacks



Source: U.S. DOT, BTS (2020)
By A. Kusoglu

Average Annual PM2.5 Emissions in the U.S.

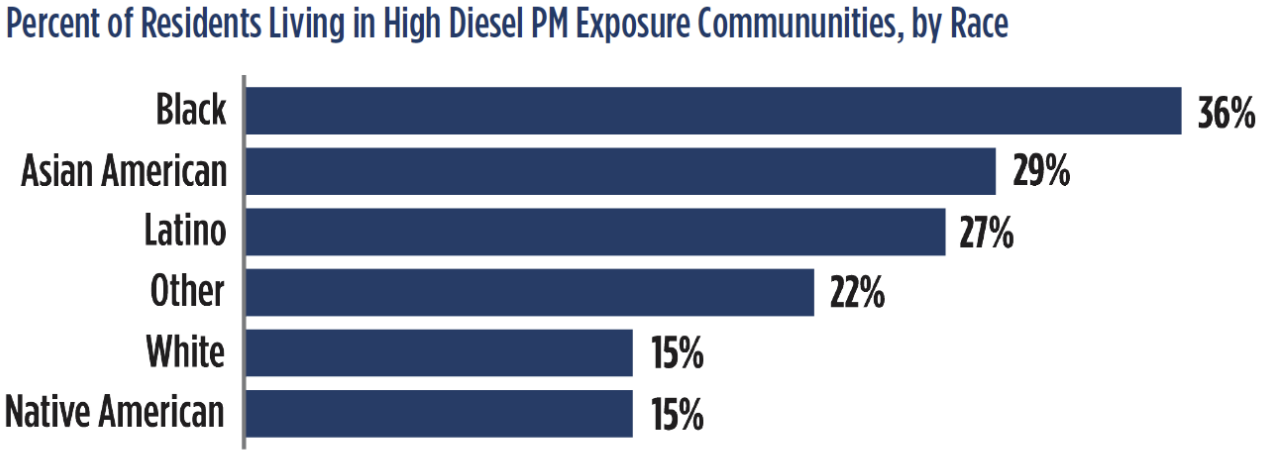


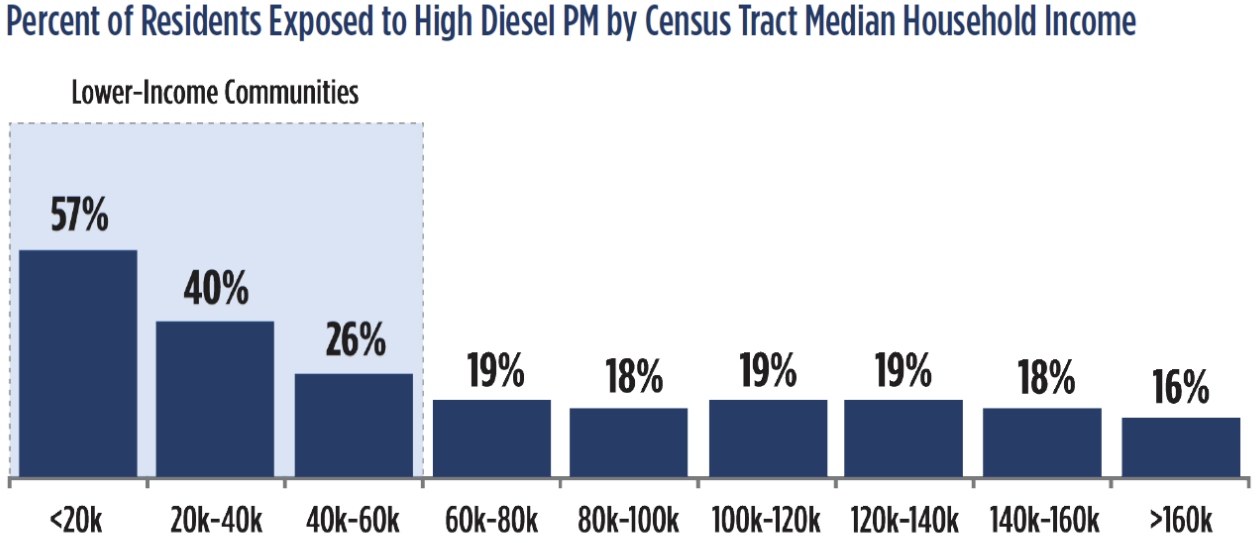


California: Disparities in Transportation -Related Pollution Exposure by Race and Income

While all Californians will benefit from the transition to ZEVs, those who stand to benefit most are those disproportionately impacted by transportation-related pollution.

MDVs/HDVs are the largest source of diesel PM, leading contributing factor to cancer caused by air pollution. Residents living in low - income and disadvantaged communities are exposed to higher levels of transportation -related toxic diesel particulate matter





Credit: CEC analysis of census and CalEnviroScreen data (Note: "High Diesel PM Exposure" communities are census tracts that score in the highest 75th percentile of census tracts for diesel particulate matter. The vast majority [90 percent] of diesel PM emissions come from vehicles.)

Part II

Trucks & Freight: Challenges and New Directions

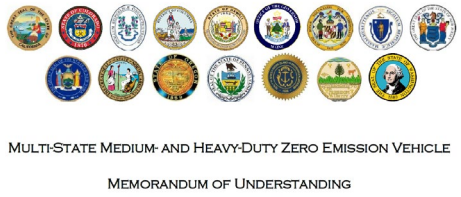
Zero emission vehicle regulations, truck operations and fleet metrics

Multi -State Medium - and Heavy -Duty Zero Emission Vehicle

Memorandum of Understanding

Recognizes the role of heavy-duty vehicles (HDVs) in GHG emissions, acknowledge this as an Environmental Justice (EJ) problem disproportionally impacting disadvantaged communities located near freight corridors, ports, distribution centers…

strategies to accelerate adoption of MHDVs as ZEV options for public transit buses and a growing number of high-mileage trucks and vans

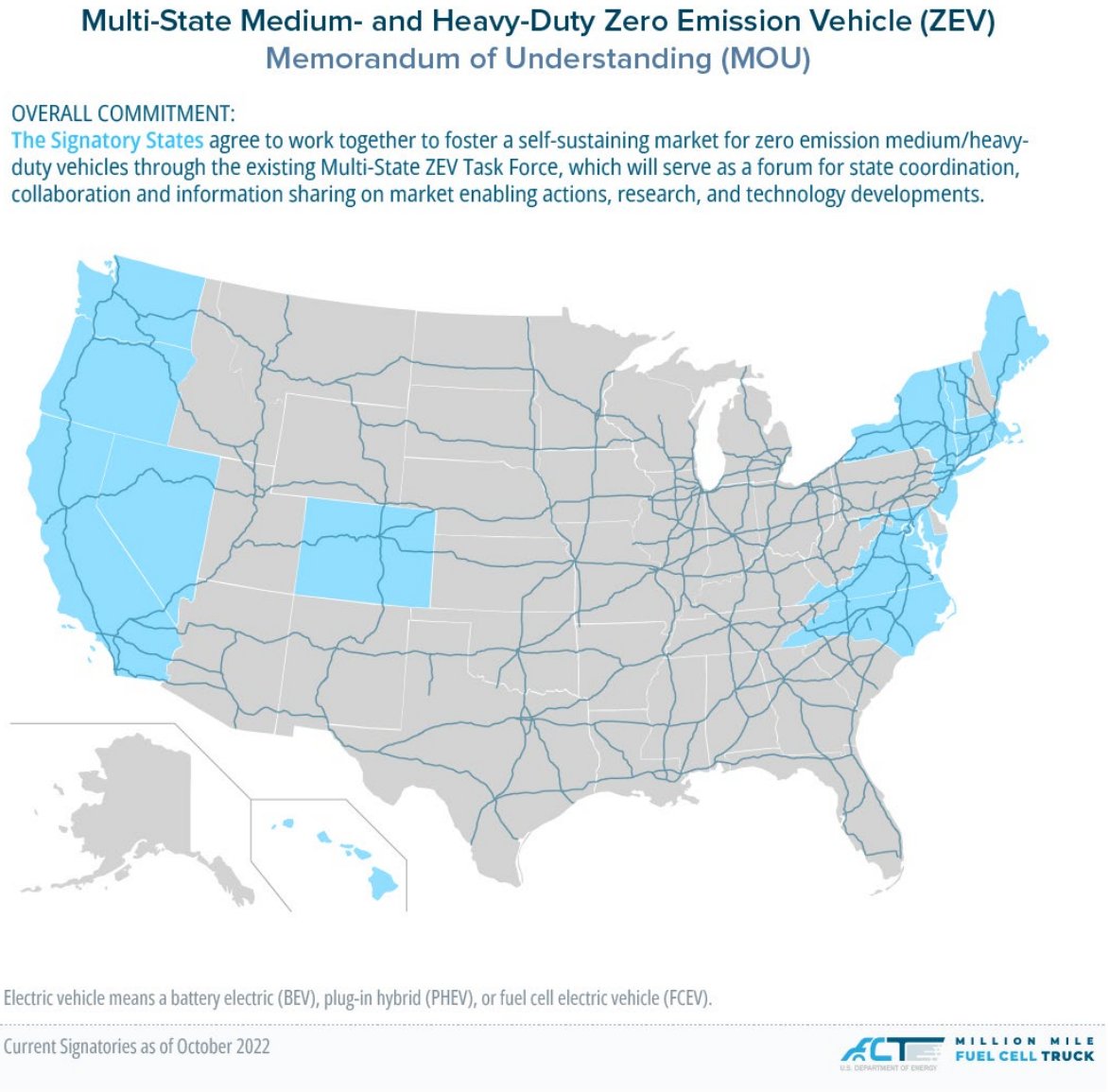


MULTI-STATE MEDIUM- AND HEAVY-DUTY ZERO EMISSION VEHICLE

MEMORANDUM OF UNDERSTANDING

Check our website for details and figures:

https://millionmilefuelcelltruck.org/zero -emission-trucks



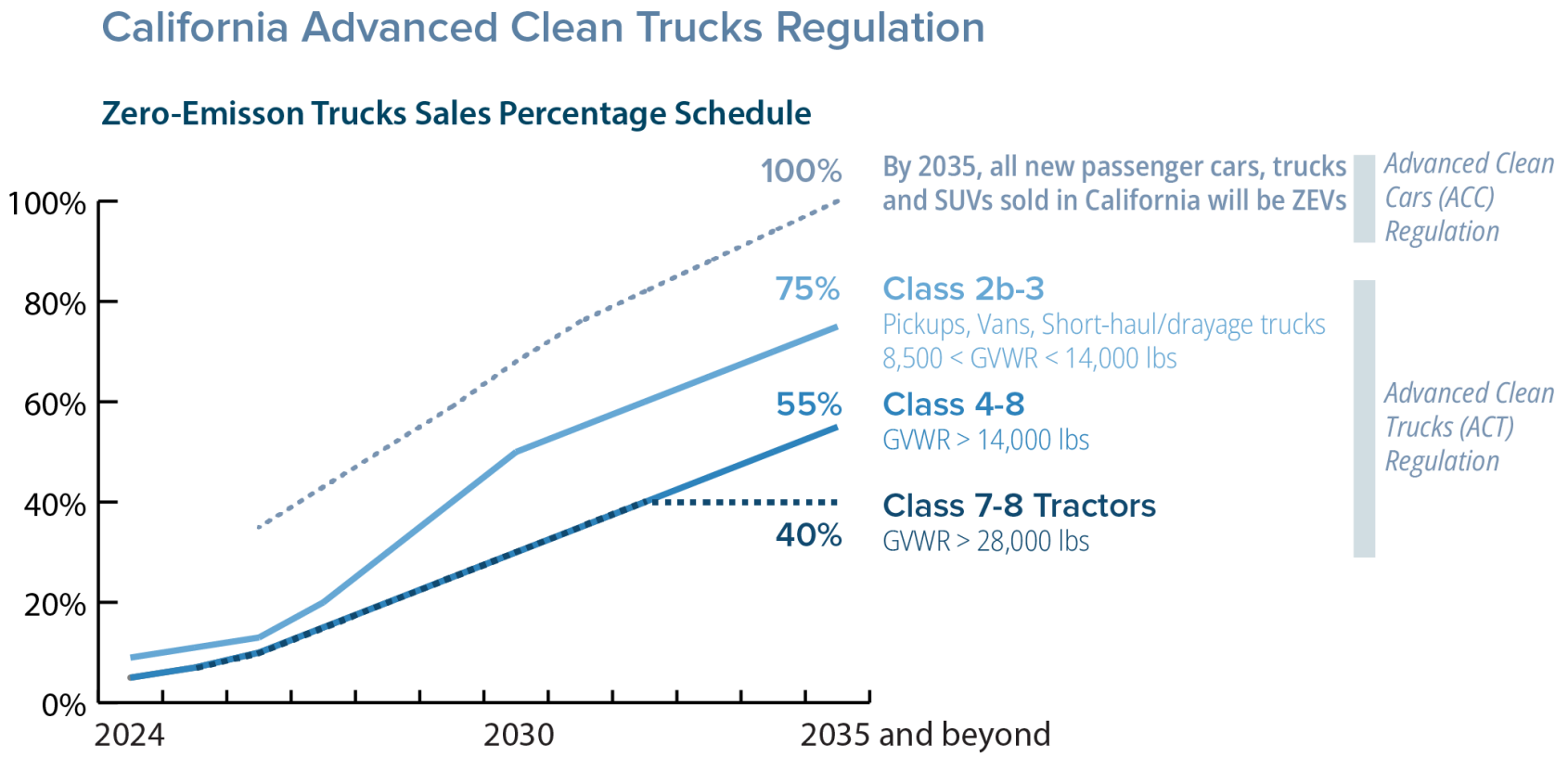
California Advanced Clean Trucks (ACT) Regulation

The ACT is part of a holistic approach to accelerate a large-scale transition of zero-emission medium-and heavy-duty vehicles from Class 2b to Class 8.

The regulation has two components (requirements):

1. **Zero-emission truck sales:** Manufacturers required to sell ZET as an increasing percentage of their annual California sales from 2024

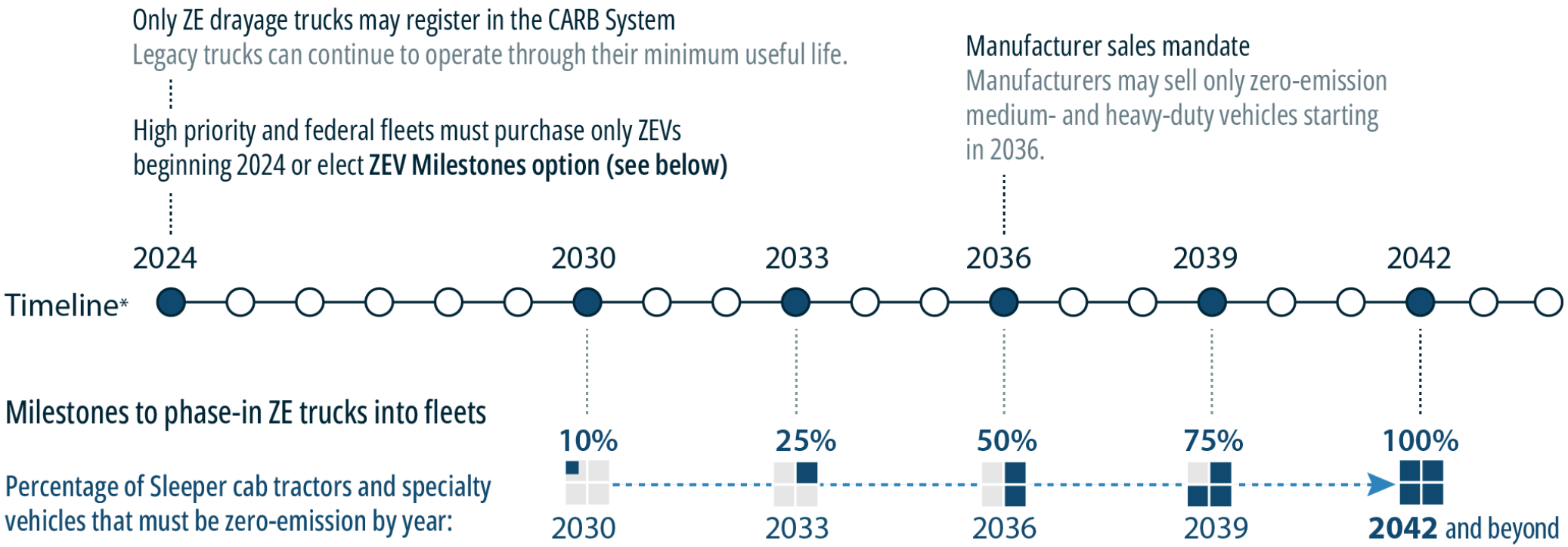
2. **Company & fleet reporting:** Large employers are required to report about their existing fleet operations



https://ww2.arb.ca.gov/ https://theicct.org

Zero Emission Trucks: Regulations for large -scale transition

The ACF regulation is part of the California Air Resources Board's (CARB) overall approach to accelerate a large-scale transition to zero-emission (ZE) medium- and heavy-duty vehicles (MDV/HDV). The proposed regulation would affect on-road vehicles with a gross vehicle weight rating greater than 8,500 pounds, off-road yard tractors, and light-duty mail and package delivery vehicles.



Source: California Air Resources Board (CARB) | *Selected components are highlighted. Does not capture the entire components or regulation details.

California Fleet Survey on Truck Operations (Advanced Clean Trucks)

Data collected (2021) through the one-time reporting requirement of the ACT regulation to assist policy development

Survey reveals key fleet characteristics for class 8 trucks and sleeper cabs;

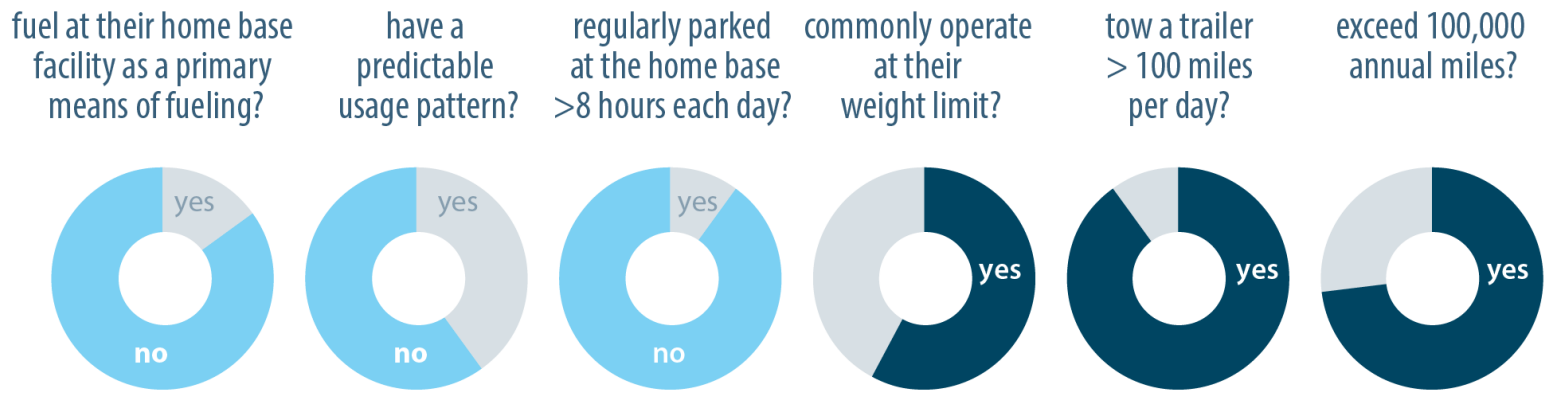
- longer daily operation
- less predictable routes
- operating at weight limit
- > 100,000 annual miles

Truck Fleet Operation and Characteristics

Key fleet characteristics for Class 7-8 trucks emerges from the California fleet survey...

Based on the one-time reporting requirement for government fleets and large entities that operate or dispatch vehicles with a manufacturer's gross vehicle weight rating (GVWR) greater than 8,500 lbs. in California.

For the reported vehicles (Weight Class 7-8, over 26,000 lbs), do/are they...



Majority of sleeper cabs...

- do NOT fuel at their home base facility
- do NOT have predictable useage pattern
- are NOT parked at the home base over 8 hours/days
- operate at their weight limit
- tow more than 100 miles / day
- travel over 100,000 annual miles

Source: California Air Resources Board, Large Entity Fleet Reporting Data
Visualization By A. Kusoglu

Understanding the Freight Movement: distance or weight?

Based on tonnage, majority (>80%) of cargo transport by trucks occur within 250 miles (<85%)

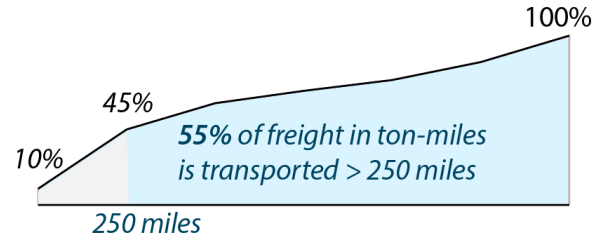
However, in terms of ton -miles, most of the freight (> 55%) move over 250 miles

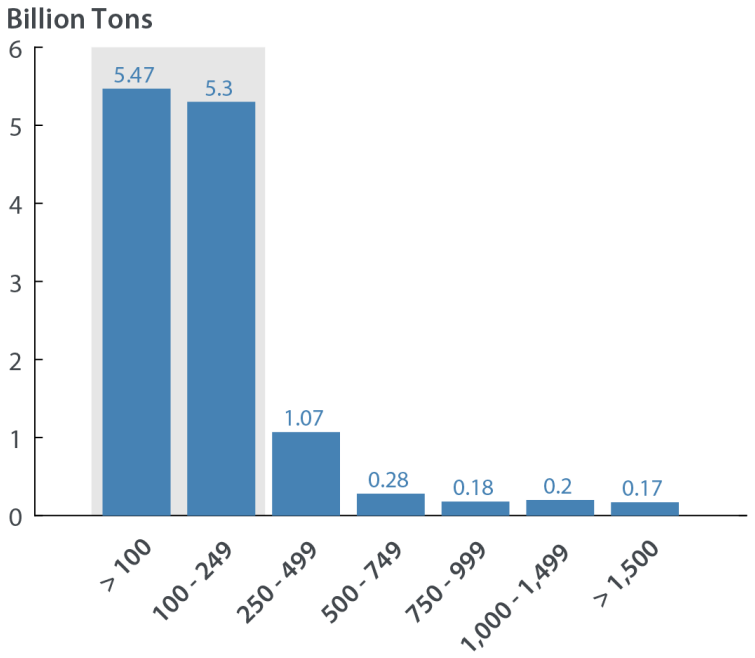
Distance alone cannot capture the characteristics of freight transport

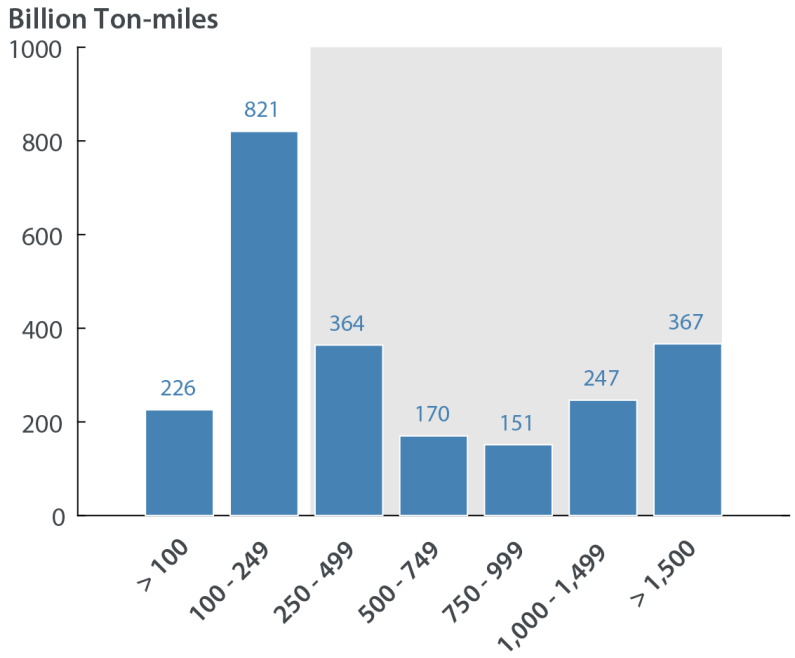
Freight Movement in the United States: Trucks

Domestic Freight Tonnage Transported by Trucks by Distance Band

In terms of tonnage, most of the cargo transported by trucks traveled less than 250 miles. However, in terms of freight ton-miles, majority of the cargo was carried by trucks over longer distances (>250 miles)







Source: U.S. DOT, Bureau of Transportation Statistics and Federal Highway Administration
By A. Kusoglu

Fleet Characteristics: Zero -emission Trucks Case Study

Case Study: Los Angeles Area – most shipments travel relatively short distances within California or to nearby cities

- 66% of tons go to destinations fewer than 1,000 miles away.
- **72% of ton-miles, a rough proxy for truck travel time and energy use, take place on journeys over 1,000 miles.**

Table 3. Typical drayage truck route profiles and frequency under different cases

Trip type	Port ↔ Near dock	Port ↔ Rail yards	Port ↔ Inland Empire	Port ↔ Beyond Inland Empire	Trip outside of port
Distance (miles)	5	20	50	80	30
Average speed (mph)	20	30	38	48	45
Percentage of truck trips	64%	10%	15%	2%	9%

ICCT- Infrastructure for Zero Emission Trucks

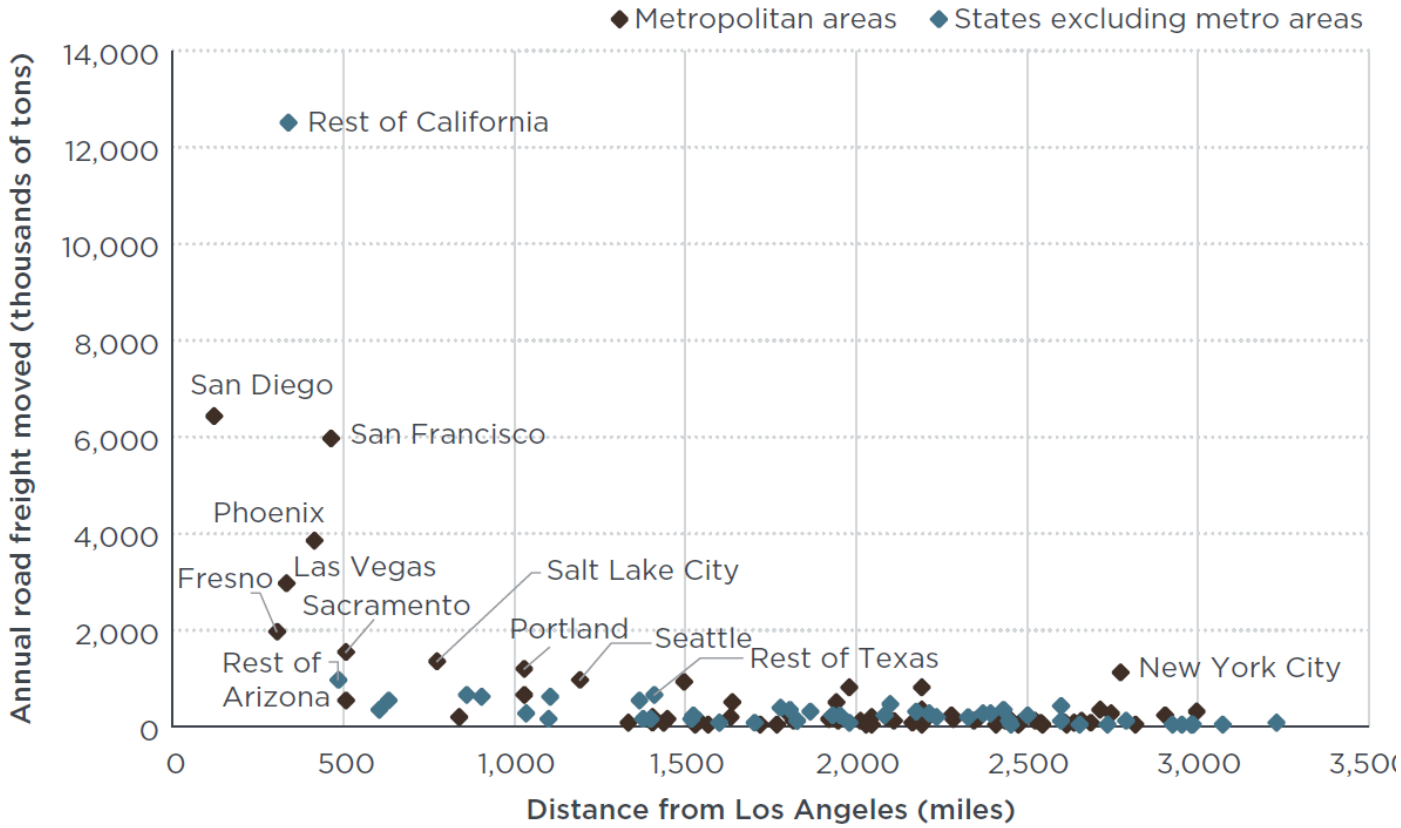


Figure 3. Road freight movement patterns to and from the Los Angeles metropolitan area in 2016 based on the FAF4 database

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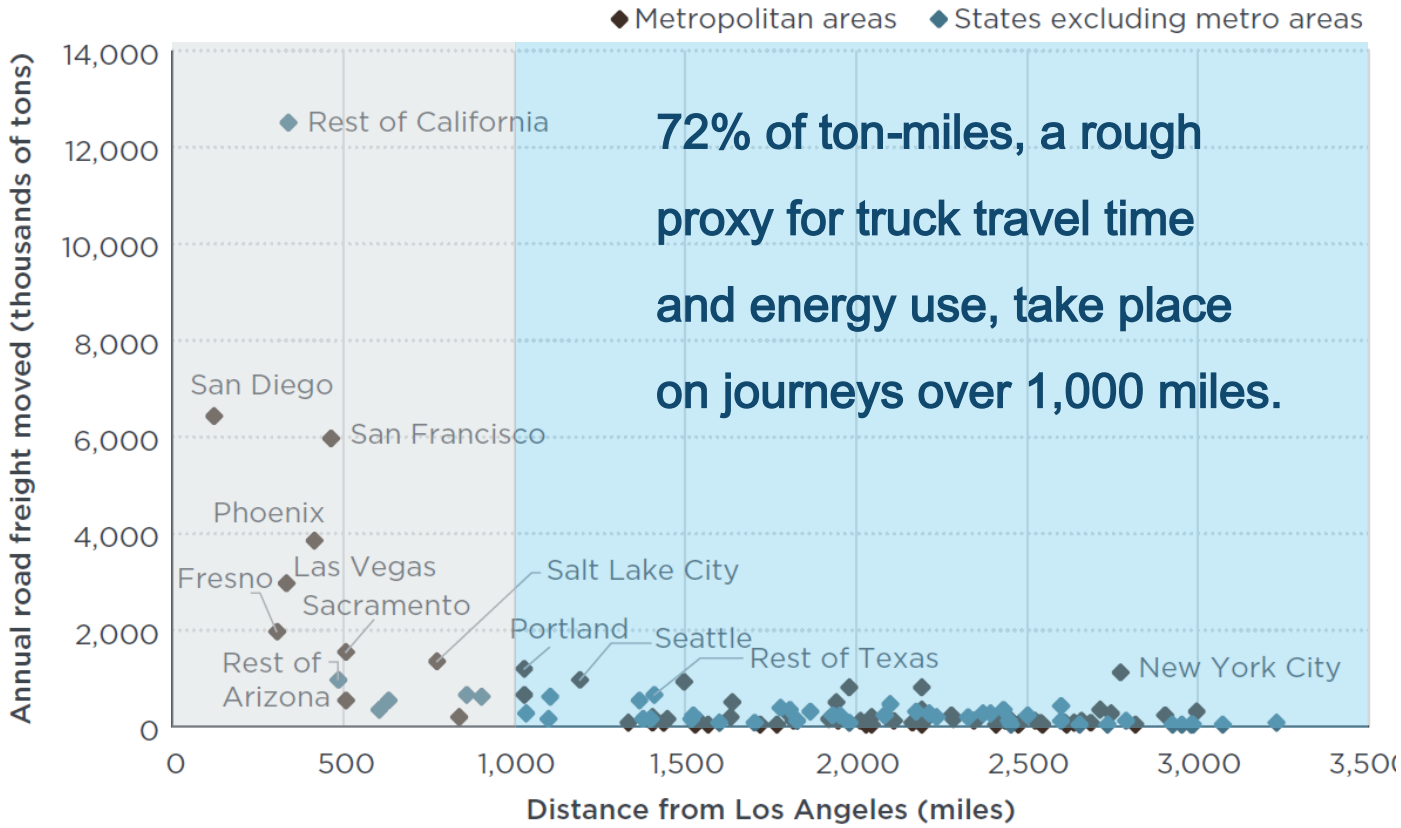

Figure 3. Road freight movement patterns to and from the Los Angeles metropolitan area in 2016 based on the FAF4 database

Evaluating HD Trucks: Fleet Operation and Key Characteristics

$$\frac{\text{Ton–mile}}{\text{Day (Truck)}} = \frac{\text{Ton}}{\text{(Truck)}} \times \frac{\text{Miles}}{\text{Shift}} \times \frac{\text{Shift}}{\text{Day}}$$

Freight Transported | **Maximize Weight** | **Maximize Range (miles)** | **Minimize Fueling/charging time**

- Range (penalty)
- Weight (penalty)
- Charge/Fuel Time
- Daily Shifts / Utilization

Focusing on maximizing range could be misleading

If the fleet goal/metric is freight -moved over time

Evaluating HD Trucks: Fleet Operation and Key Characteristics

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Freight Transported	Maximize Weight	Maximize Range (miles)	Minimize Fueling/charging time

- Range (penalty)
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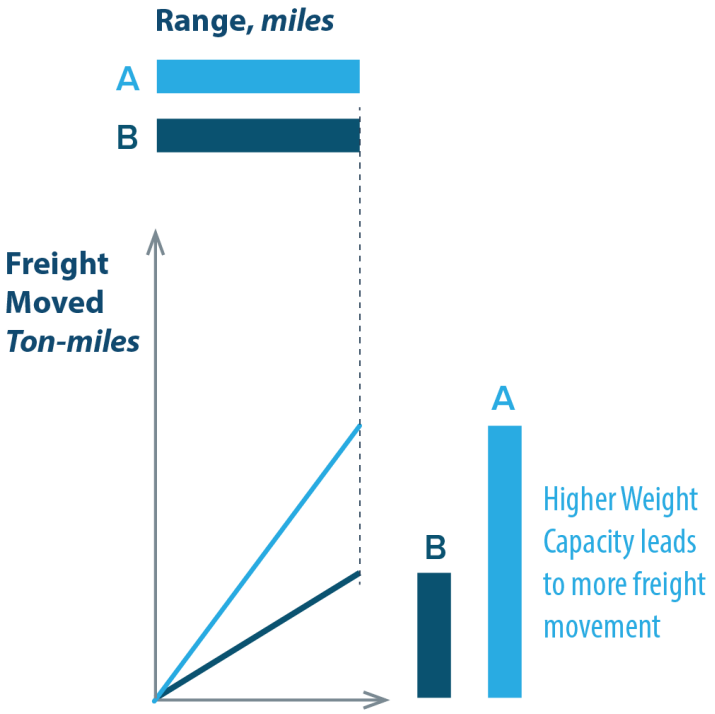

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Evaluating HD Trucks: Fleet Operation and Key Characteristics

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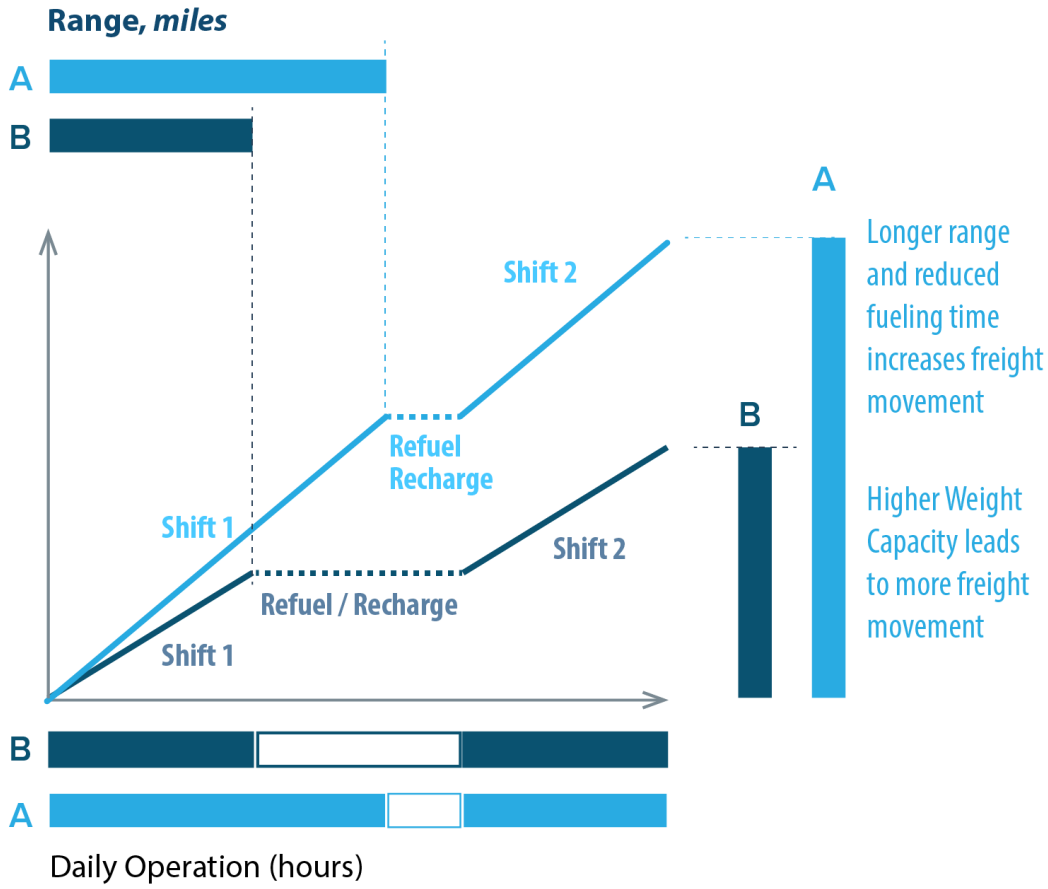


Long-Haul Routes: Technology Comparison

CATF study compares two alternative drivetrains, battery electric (BEV) and hydrogen fuel cell electric (FCEV) to diesel vehicles to determine smoothest transition for long -haul operation.

The performance of a single truck on a long-haul route part of the 11th most popular trade corridor between Los Angeles, the busiest U.S. port, to Newark, NJ, a key East Coast hub was modeled.

The simulation includes a diesel truck with a 240 gallon tank, a BEV with a 1000kWh battery, and a FCEV with 100 kg of hydrogen stored in on-board tanks.

Table 1: Drivetrain Assumptions

	Diesel	BEV	FCEV
Tank Size	240 gallons (120-gallon tank on each side)	–	100 kg
Battery Size	–	1000 kWh	20 kWh
Drivetrain Power	310 kW	315 kW	300 kWh
Peak Efficiency (ICE/Battery/Fuel Cell)	52%	97%	63%
Fueling or Charging Time	10 minutes	330 minutes (250 kW charging)	20 minutes (5 kg per minute)

Long-Haul Routes: Technology Comparison

At a high-level, for long-haul routes FCEV configuration outperforms the BEV configuration in terms of number of stops required, total dwell time, and available room for cargo, potentially making it the more viable alternative drivetrain for this task.

Along the same route, the FCEV requires 3 stops and typically needs to refuel three-quarters of the tank, and the diesel drivetrain only needs one stop. This increase when moving from the diesel drivetrain to the FCEV to the BEV

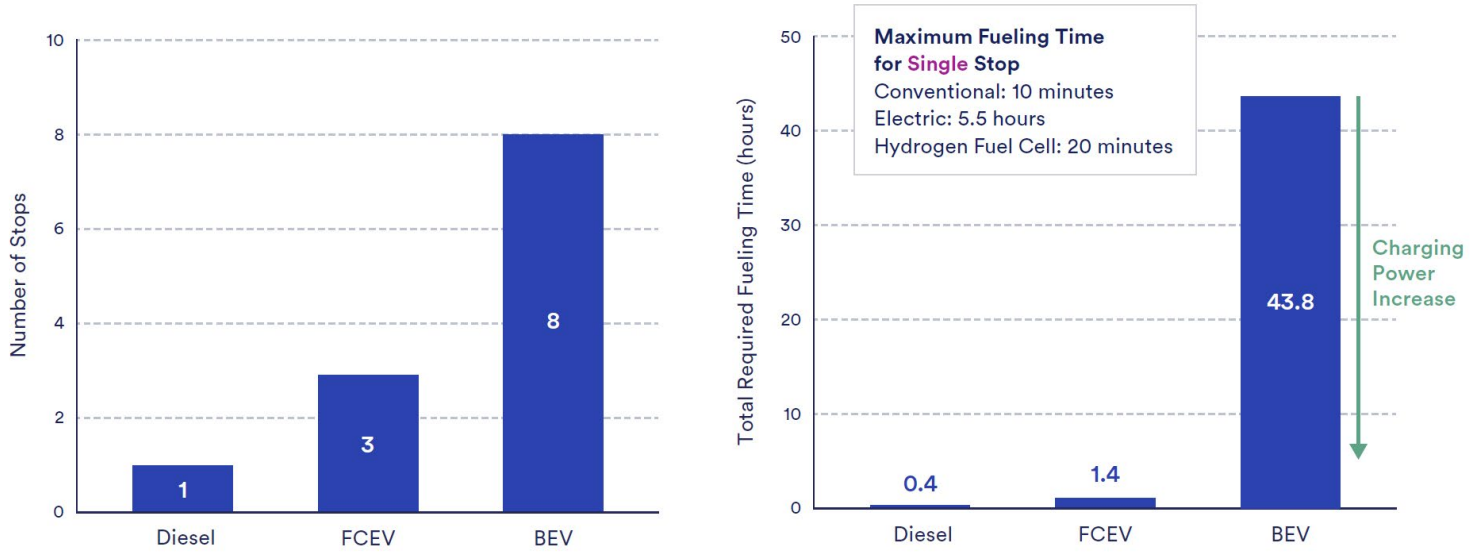
Table 2: Range and Fuel Economy for Each Drivetrain

Range		
Diesel	2123	miles
BEV	470	miles
FCEV	1019	miles

Fuel Economy		
Diesel	8.85	mpdge
BEV	17.39	mpdge
FCEV	11.31	mpdge

mpdge = miles per diesel gallon equivalent

Figure 2: Number of Stops and Total Fueling or Charging Time



[iii] The FASTSim fuel economy results are theoretical, representative of a new truck on an idealized route. While these numbers are likely higher than actual on-road vehicles, the assumptions for each drivetrain are the same, allowing for the comparisons presented in this paper.

Long-Haul Routes: Technology Comparison

CATF study compares two alternative drivetrains, battery electric (BET) and hydrogen fuel cell electric (FCET) to diesel vehicles to determine smoothest transition for long -haul operation.

The single truck analysis on a cross country, long-haul heavy-duty truck route:

- FCET is able to make fewer stops
- FCET needs less time to fuel
- FCET has more room for cargo, performing well compared to diesel in all key parameters, proves to be the more viable alternative drivetrain for long-haul trucking.

Figure 3: Total Trip Time Including Driver Rest

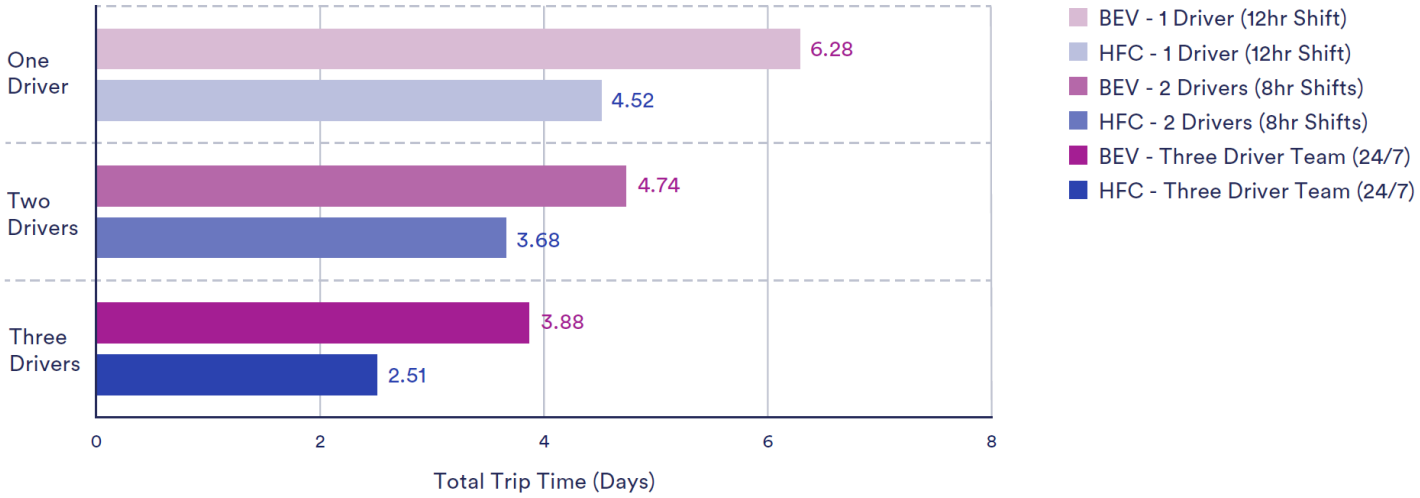
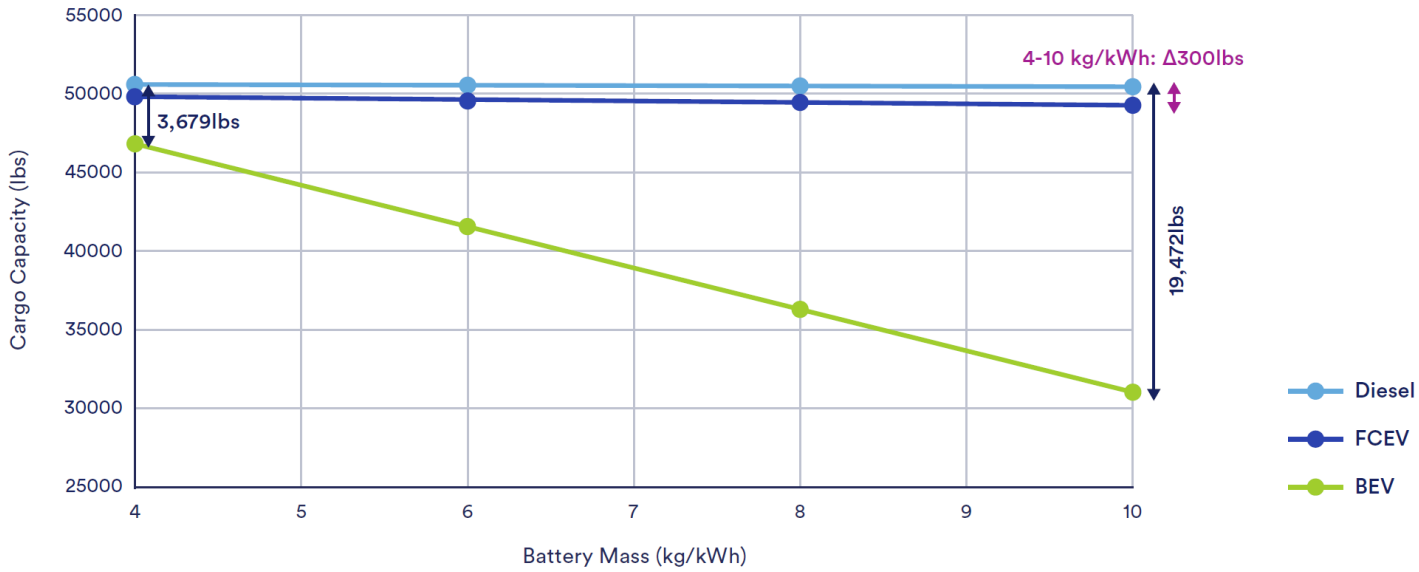


Figure 4: Cargo Capacity Sensitivity to Battery Weight for a Weight Limited Scenario



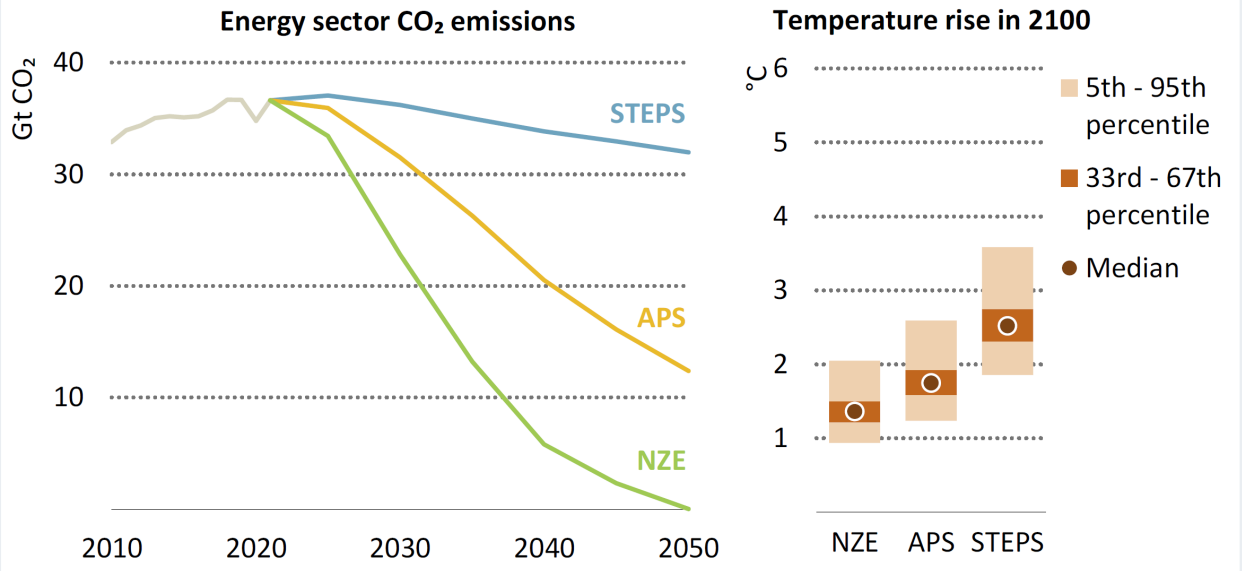
Part III

A global perspective for decarbonization

Zero emission truck technologies and emergence of fuel cells as viable options

IEA Net Zero Emissions by 2050 (NZE) Scenario

Figure 1 ▷ **Energy sector CO_2 emissions by scenario, 2010 – 2050, and temperature rise by scenario, 2100**

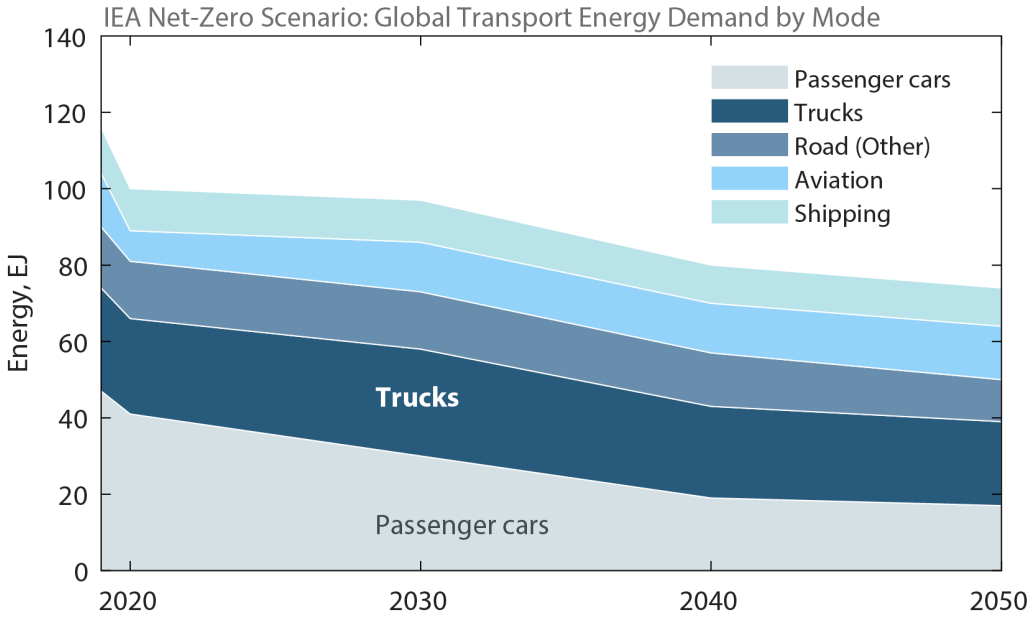


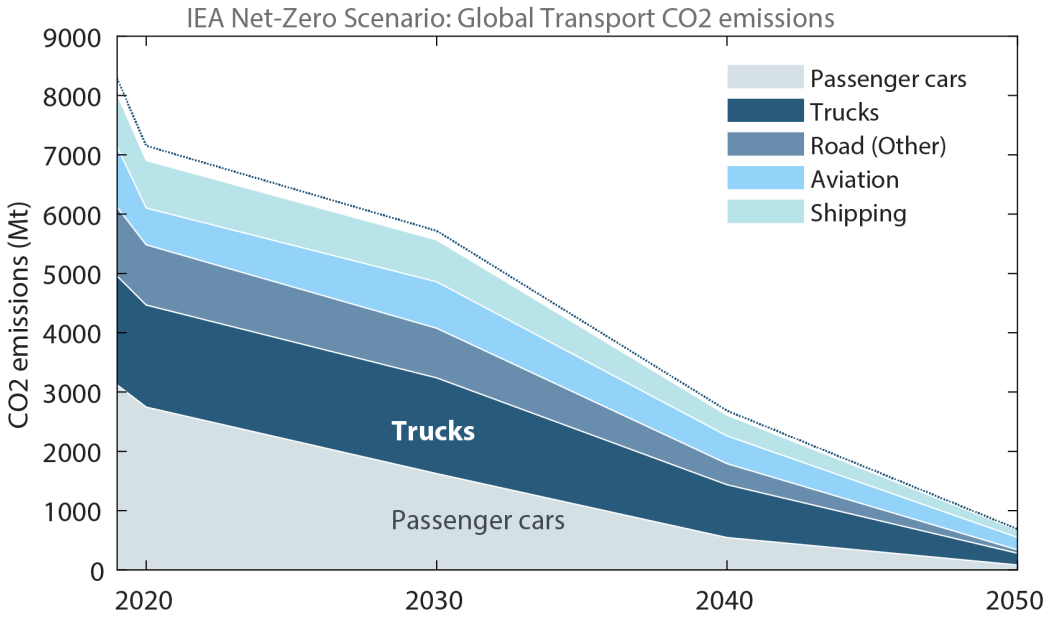
If implemented fully, net zero pledges see warming of 1.7 °C in 2100, an improvement compared to the trajectory of current policies, but still not in line with the 1.5 °C limit

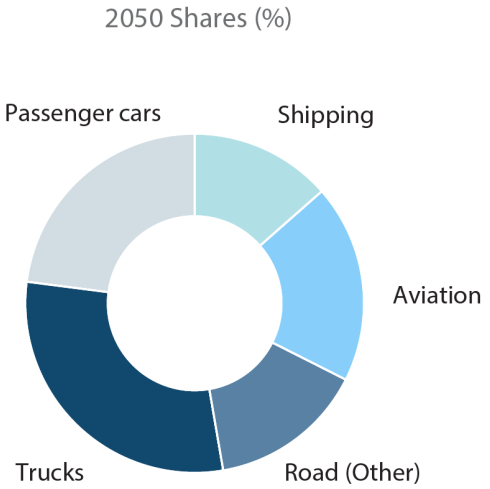
IEA NZE Scenario: Decarbonizing Transportation

"Passenger cars can make use of low-emissions technologies in the market, but **major advances are needed for heavy trucks, shipping and aviation to reduce their emissions"**

Trucks will have the largest share of global energy demand in a net-zero scenario by 2050





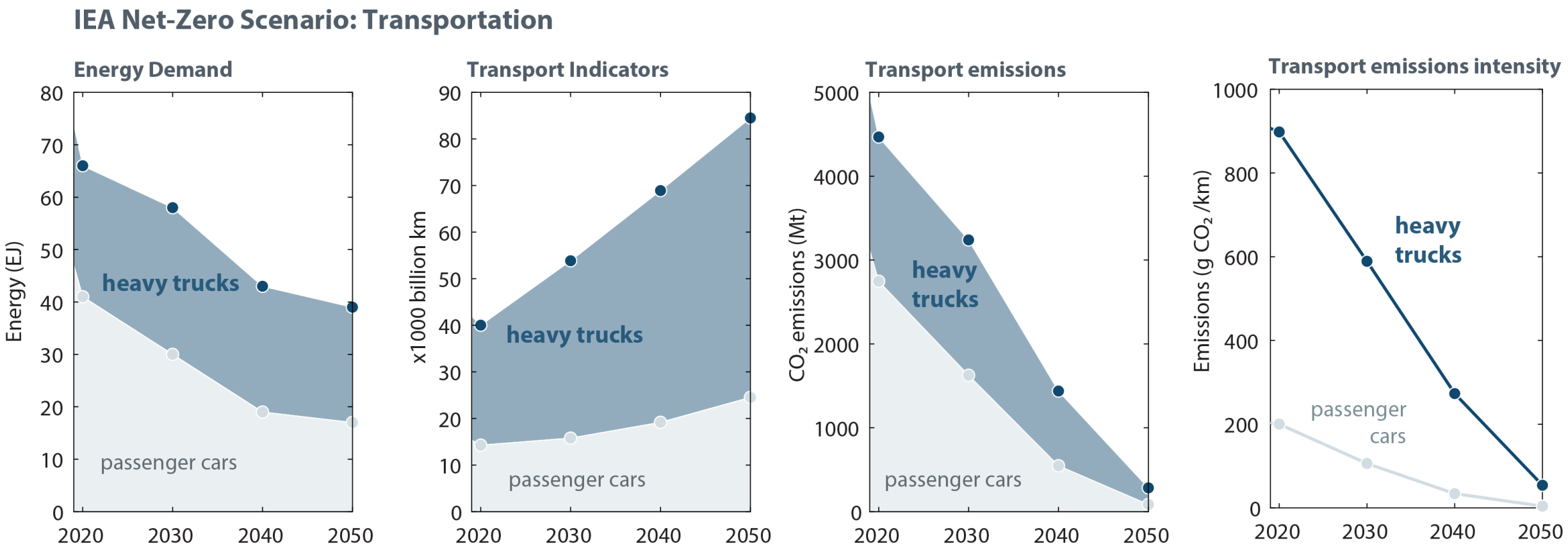


"In 2050, cars on the road worldwide run on electricity or fuel cells."
– **IEA**

International Energy Agency (2021), Net Zero by 2050, IEA, Paris & WEO 2021

Global Projections: NZE Indicators for Transportation

Heavy-duty trucks will accumulate more miles but require reduced emission intensity per vehicle basis to reach net-zero



Source: IEA, Net-Zero by 2050 Scenario

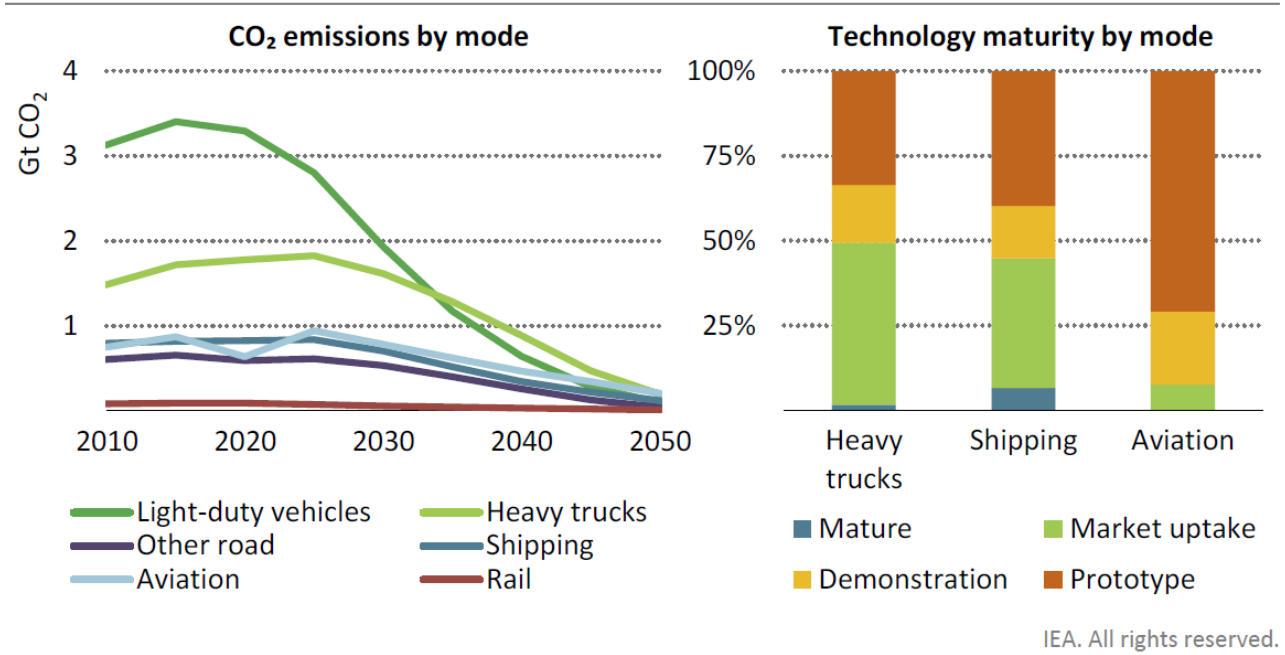
Reaching NetZero: Role of Transportation

IEA Net Zero by 2050: A Roadmap for the Global Energy Sector provides key milestones

- "Passenger cars can make use of low-emissions technologies in the market, but **major advances are needed for heavy trucks, shipping and aviation to reduce their emissions"**

- "The electrification of heavy trucks moves slowly due to the weight of the batteries, high energy and power requirements required for charging, and limits on driving ranges. **But fuel cell heavy trucks make significant progress, mainly after 2030."**

Figure 3.21 ▷ Global CO_2 transport emissions by mode and share of emissions reductions to 2050 by technology maturity in the NZE



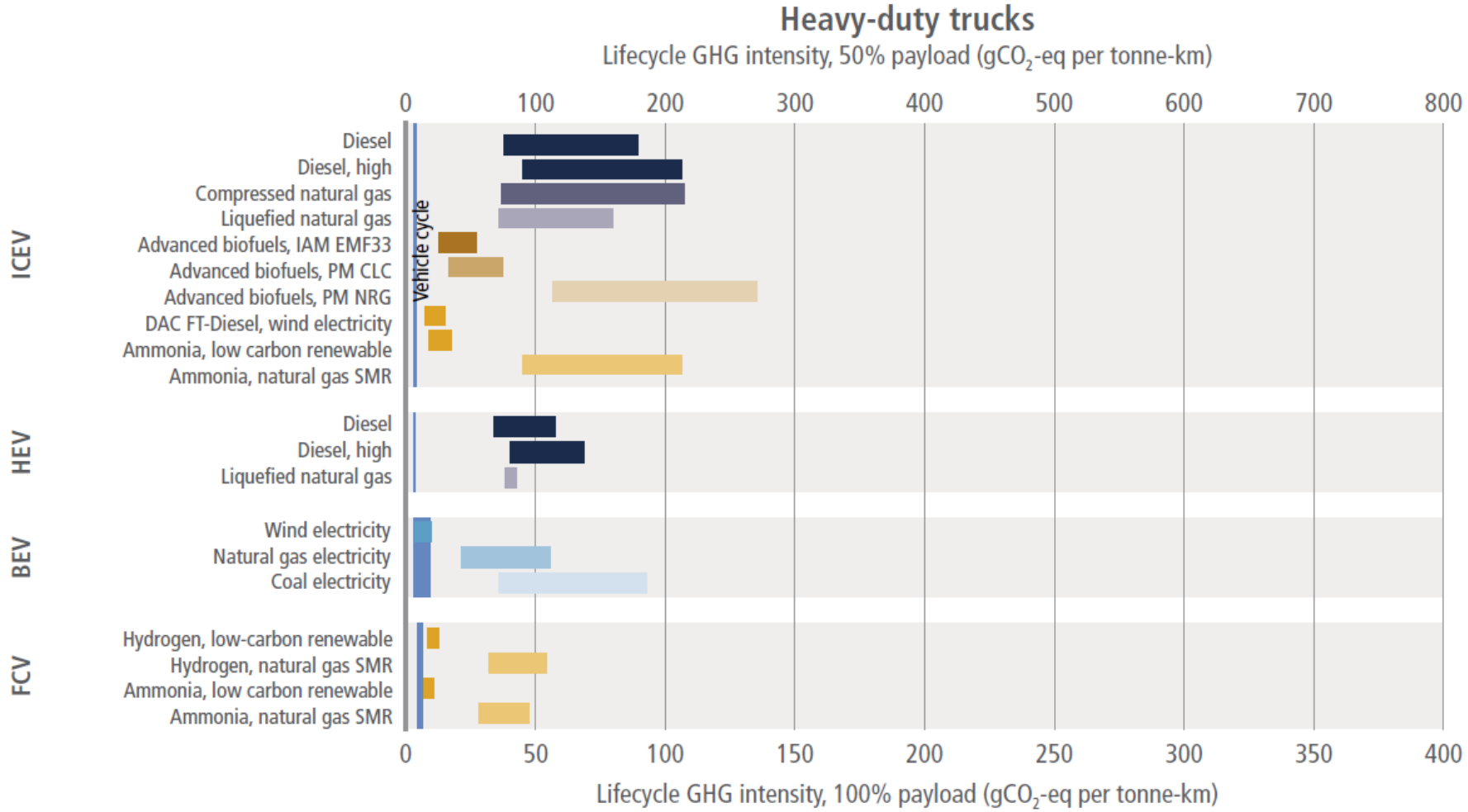
Passenger cars can make use of low-emissions technologies on the market, but major advances are needed for heavy trucks, shipping and aviation to reduce their emissions

Notes: Other road = two/three wheelers and buses. Shipping and aviation include both domestic and international operations. See Box 2.4 for details on the maturity categories.

Transport Lifecycle emissions (IPCC) - Freight

Lifecycle greenhouse gas intensity of land-based freight technologies and fuel types

Trucks with low-carbon electricity or hydrogen have substantially lower emissions than incumbent technologies



Fuel Cells for Heavy -Duty Transportation

Fuel Cells are becoming viable options for Zero-Emission Trucks due to their unique features

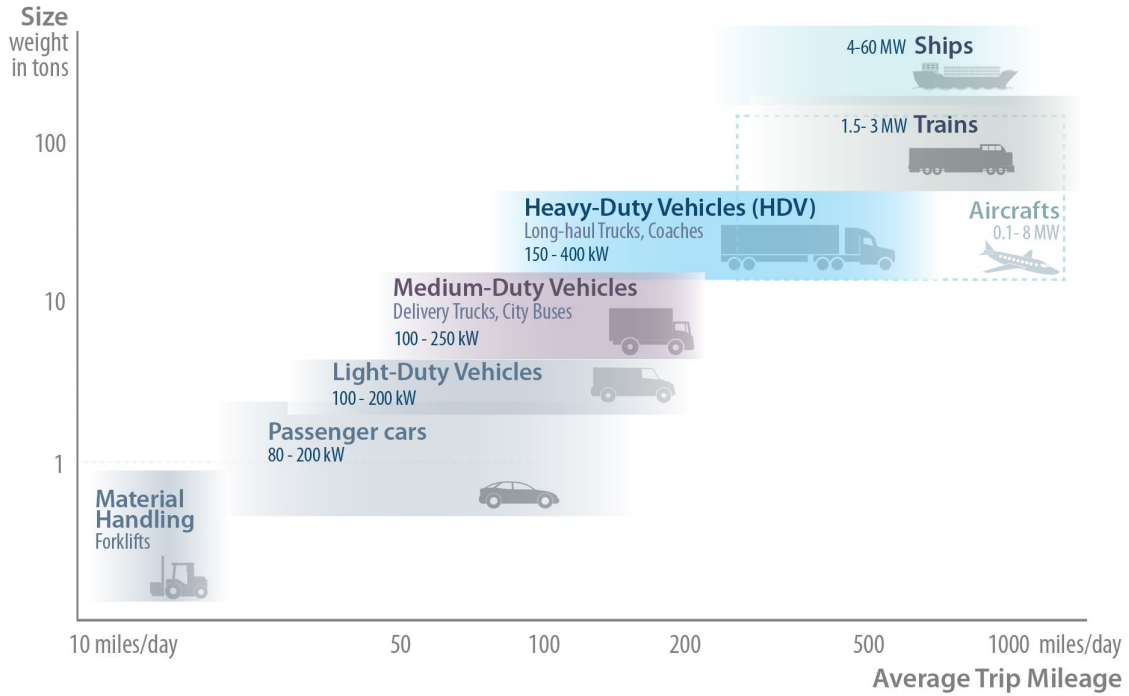
PEM Fuel Cells are increasingly examined for HDV space where there is a need for high power and reduced emissions

HDV applications benefit from separation of energy storage and power output, the inherent strength of fuel -cell systems.

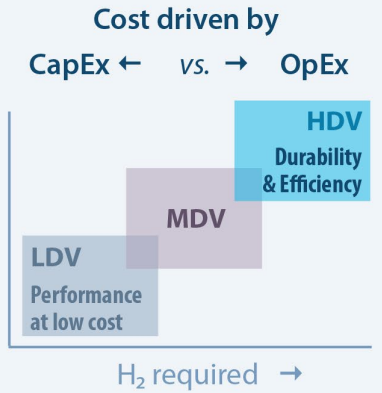
Factoring in short refueling time and the intrinsic power density, PEMFCs come with important performance advantages for HDV without sacrificing freight capacity

Hydrogen Fuel Cells for Transportation

Transition from light-duty and automotive fuel cells to medium- and heavy-duty applications highlight the paradigm shift in daily mileage and power output needs



The dramatic increase in lifetime mileage of heavy-duty applications shifts the focus from capital to operating costs



Source: Cullen,...,Kusoglu, Nature Energy 6, 462–474 (2021) "New roads and challenges for fuel cells in heavy-duty transportation"

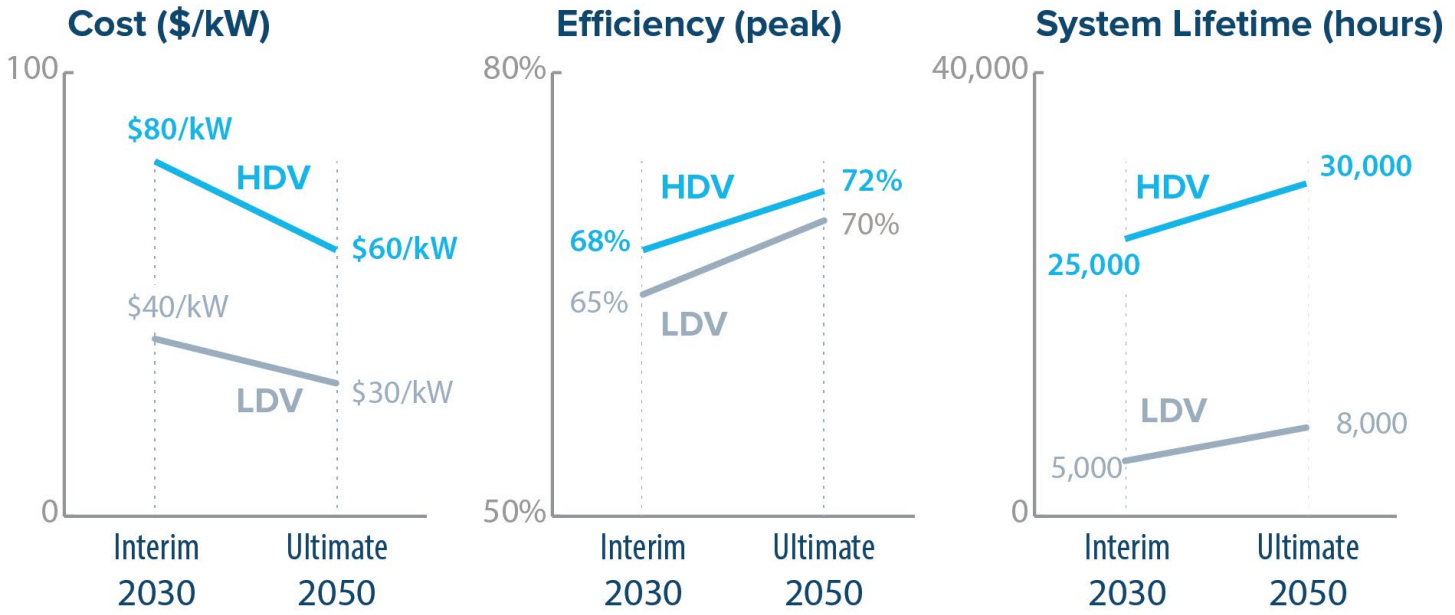
Fuel Cells for HDV

HDVs require a paradigm shift in fuel-cell research and development compared to current state of the technology for LDVs

Instead of a focus on increased power densities and lower cell costs in LDVs, **commercialization of fuel - cell trucks (HDVs) demand a greater focus on efficiency and significantly longer lifetimes, up to 5x improvements in durability.**

DOE Targets for Fuel-Cell Vehicles

Light Duty Vehicles (LDV) vs. Heavy Duty Vehicles (HDV)



Fuel-Cell Vehicles Durability Targets

Source: DOE HFTO Program Record #19006 | Cullen,...,Kusoglu, *Nature Energy* 6, 462–474 (2021)

Notes: Current target of $50/kW for LDV is based on 100,000 units/year. HDV Targets are for Class 8 Tractor-Trailers. Ultimate targets are based on simple cost of ownership assumptions and reflects anticipated timeframe for market penetration.

MILLION MILE FUEL CELL TRUCK

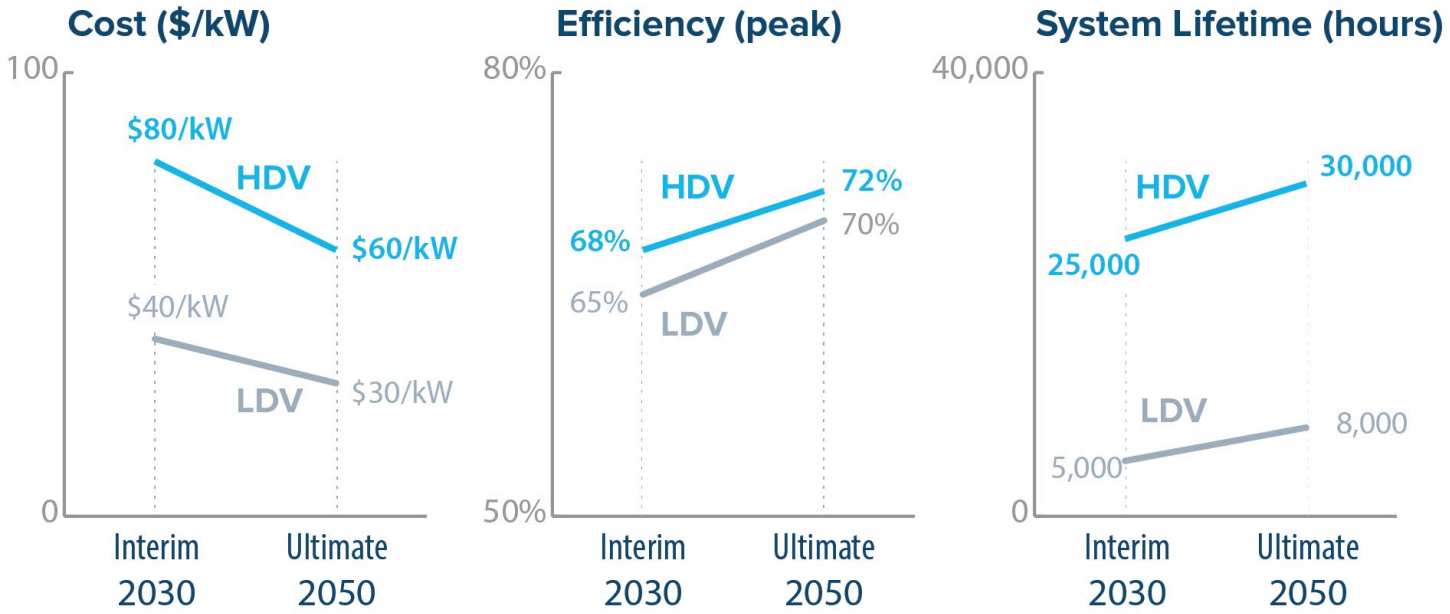
M2FCT

Million Mile Fuel Cell Truck (M2FCT) is a Department of Energy (DOE) funded consortium formed by five primary national labs to overcome durability and efficiency challenges in PEMFCs for HDV applications with an initial focus on long-haul trucks.

M2FCT coordinates National Lab activities related to fuel-cell efficiency and durability, provides technical expertise, and harmonizes activities with industrial developers across the Hydrogen Fuel Cell and Technology Office HDV PEMFC portfolio, which is located in DOE's Office of Energy Efficiency & Renewable Energy, thus amplifying their impact.

DOE Targets for Fuel-Cell Vehicles

Light Duty Vehicles (LDV) vs. Heavy Duty Vehicles (HDV)



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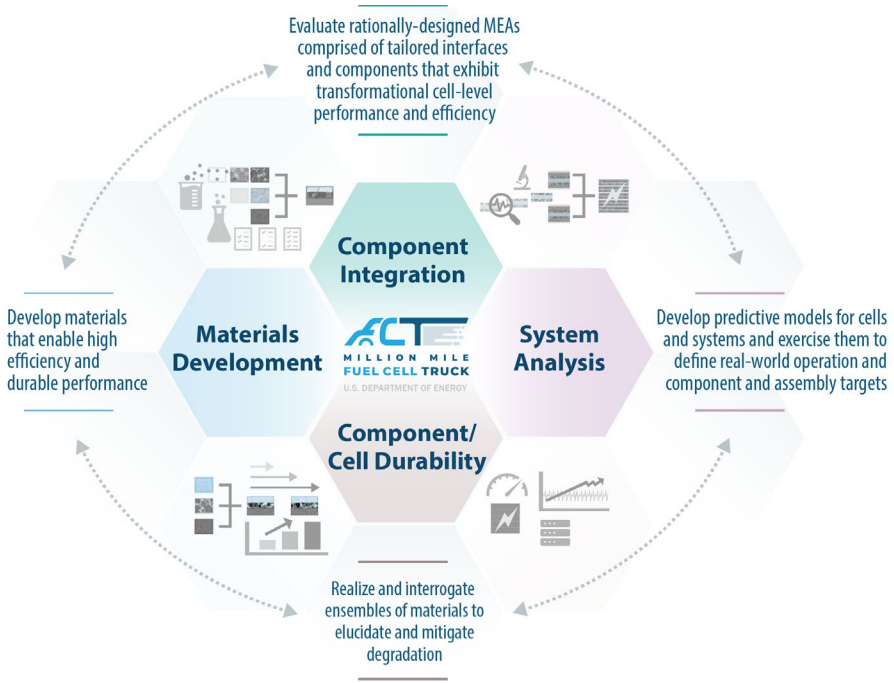
MILLION MILE FUEL CELL TRUCK

Million Mile Fuel Cell Truck Consortium Research

Research efforts coordinated and undertaken to cover key areas:

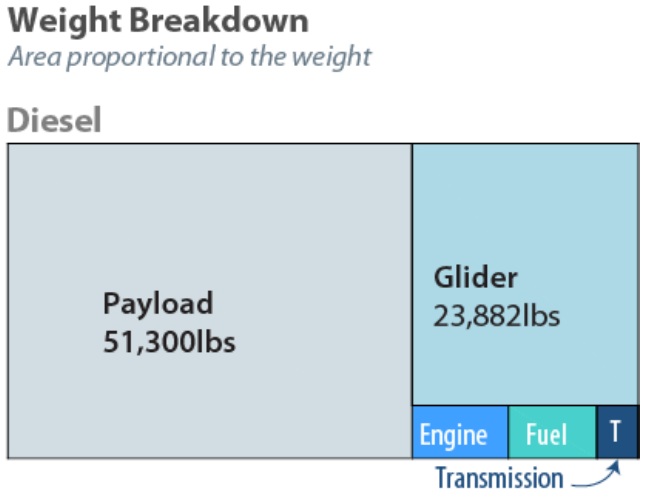
- Materials development
- Materials & Component Integration
- Durability development
- System Analysis

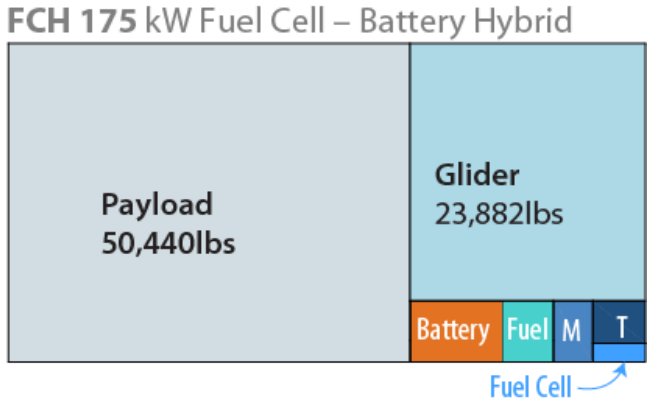


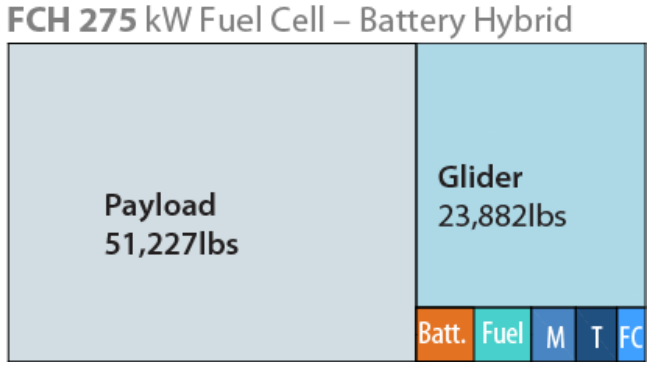
M2FCT Analysis: Weight Breakdown of Fuel Cell vs. Diesel Trucks

A preliminary analysis to determine the payload capacity of Class-8 long haul fuel cell (FC) trucks relative to diesel truck metrics of 50,000-lb payload using hybrid platforms with 175- and 275-kW fuel cell systems

There is no loss in payload capacity even without factoring in exemptions available for alternative fuels & engines







Fuel Cell Trucks: Characteristic Metrics

Based on the currently available and recently announced fuel cell trucks, an inventory of technical specs have been compiled

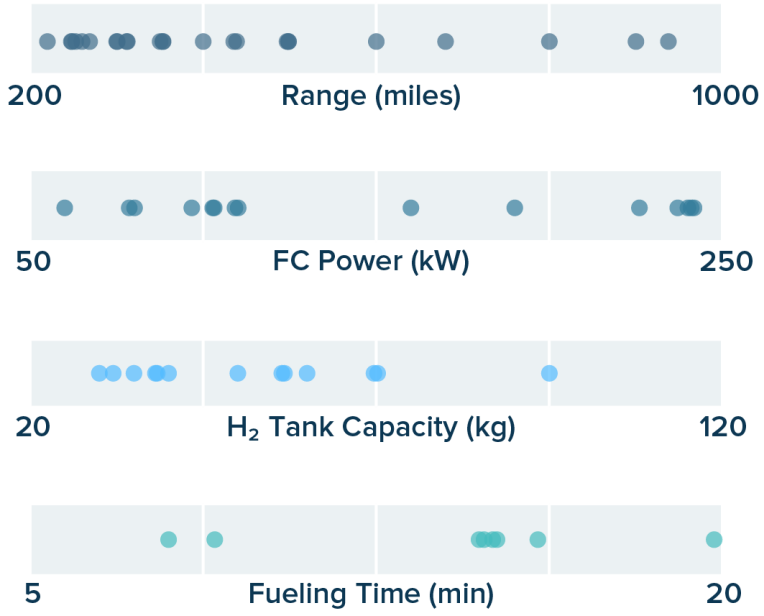
Results highlight the key benefits of fuel cell trucks as zero emission vehicles

- **Longer Range enabled by hydrogen**
- **Payload capacity on par with diesel**
- **Rapid Fueling Time**

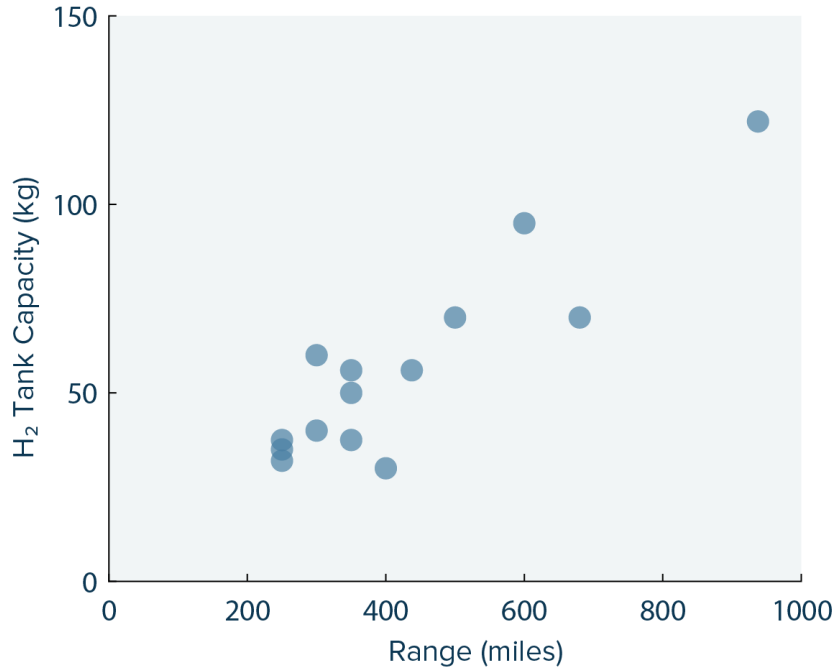
Fuel Cell Heavy-Duty Vehicle Inventory

Range of key specifications for fuel-cell systems powering heavy-duty vehicles

Values shown for each vehicle specifications listed on OEM websites, including announced vehicles



Range of Fuel Cell Trucks increases with the Hydrogen Storage Capacity



Source: CALSTART ZETI Tool (2022), IEA Global Hydrogen Review (2022) | Visualization By A. Kusoglu

Summary: Decarbonizing Heavy -Duty Vehicles

- Heavy-duty trucks carry the majority of freight in the nation
  - Heavy-duty transportation is tied to many economic activities (5% of GDP) and workforce, and requires high energy demand
- HDV trucks is a major contributor to transportation emissions
  - **in terms of emissions/mile or per vehicle basis** despite constituting a smaller fraction of vehicle fleet
- Decarbonizing heavy-duty transportation will not only reduce global emissions but also eliminate harmful pollutants (PM2.5)
  - A diesel truck could generate up to 50x more PM2.5 / mile than a car
- Analysis of HDV trucks for freight movement should account for the relevant metrics and key operational characteristics
  - Distance Bands ➔ Freight movement ➔ Ton-miles
  - Range (mileage)➔ Daily utilization ➔ Reduced charge/fuel time
- HDV applications benefit from separation of energy storage and power output, the inherent strength of fuel-cell systems
  - Fuel Cells are becoming viable options for Zero-Emission Trucks due to their unique features; rapid fueling, long ranges without payload penalty

References and Links

millionmilefuelcelltruck.org/resources

- U.S. National Blueprint for Transportation Decarbonization link
- DOE Hydrogen Program Plan link
- D.A. Cullen, …A. Kusoglu, Nature Energy (2021) 462-474
- IPCC, Climate Change 2022: Mitigation of Climate Change – Transport link
- International Energy Agency (2021), Net Zero by 2050
- State of California, Integrated Energy Policy Report Update (2020)
- The International Council on Clean Transportation - Estimating Infrastructure Needs And Costs for the Launch Of Zero-emission Trucks link
- NACFE: Hydrogen Trucks: Long-Haul's Future? link
- CATF: Zero Emission Long-Haul Heavy-Duty Trucking link
- Transportation Statistics Annual Report link
- https://ww2.arb.ca.gov https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health
- https://data.bts.gov/ https://www.bts.gov/product/freight-facts-and-figures
- https://www.eia.gov/totalenergy/data/monthly/index.php

Acknowledgments

- DOE EERE **Hydrogen Fuel Cell Technologies Office** (HFTO) Fuel Cells Program Manager & Technology Manager:
  - Dimitrios Papageorgopoulos
  - Greg Kleen
  - Julie Fornaciari (Orise fellow)
- **Million Mile Fuel Cell Truck** Consortium member labs, PIs

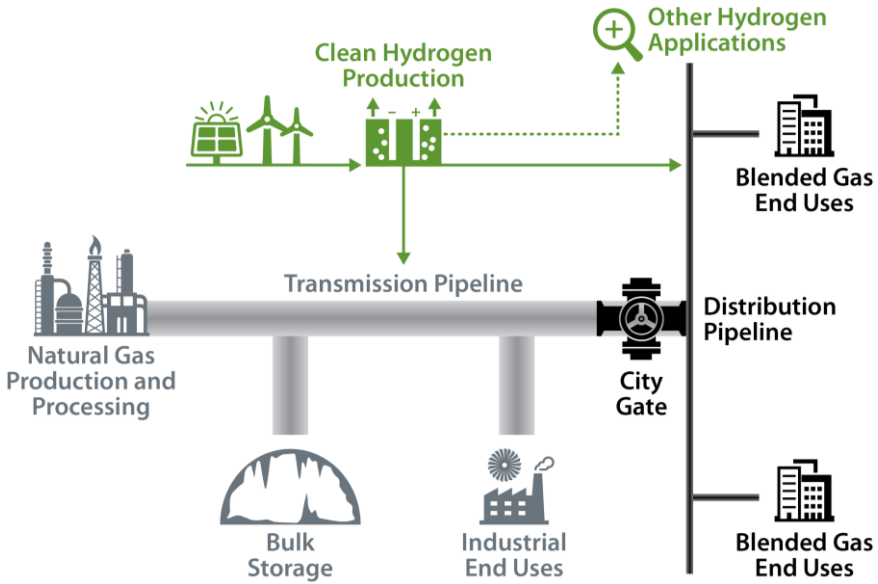
Hydrogen Blending in Natural Gas Pipelines

HyBlend
U.S. DEPARTMENT OF ENERGY

Reducing the Carbon Intensity of the Natural Gas Grid via Hydrogen Blends

Phase I: Two-year, $15MM CRADA Project

- 4 National Labs + 31 partners from industry and academia
- Objectives
  - Pipeline materials compatibility R&D
  - Techno-economic and life-cycle analyses



Key Findings and Outputs

- Metals R&D (SNL)
  - Providing scientific bases and probabilistic tools for structural integrity assessment of H_2 pipelines (HELPR software release date: Fall 2023)
- Polymer R&D (PNNL)
  - Blended gases affect the semicrystalline morphology of high-density polyethylene (HDPE), impacting toughness, pipe stability, and outcome depending on polymer chemistry
- Life-cycle Analysis (ANL)
  - Maintaining energy delivery limits the H_2 blending ratio to ~30%, resulting in ~6% life cycle GHG emissions reduction
- Techno-economic Analysis (NREL)
  - Open-source software providing case-by-case economic analysis of preparing transmission pipelines to blend H_2 (PPCT software release date: Fall 2023)

- **Learn more at the October H2IQ Hour**
  - Lab leads will present results from first CRADA at the webinar
  - Thursday October 26 at 12:00 Eastern time

Visit the HyBlend™ Initiative webpage for details and links to tools and publications

Hydrogen Blending in Natural Gas Pipelines

HyBlend
U.S. DEPARTMENT OF ENERGY

Seeking Partners to Contribute to a Second Pipeline Blending CRADA

In Planning Stage of Follow-on CRADA (Phase II)

- Same core labs 
- 3-year CRADA open to new partners from industry, academia, nonprofits
- $12MM DOE funding*
- Seeking $5.4MM cash cost share
  - Asking partners for minimum $25k/year cash commitment
  - Additional in-kind contributions welcome
- In-person kickoff meeting anticipated in December 2023

Benefits of Partnership

- Partners get access to the following:
  - National Lab expertise
  - Data generated by the labs for the CRADA
  - Input on scope of work
  - Monthly project update meetings
  - Quarterly materials meetings
  - Quarterly analysis meetings
  - Lab-generated reports prior to publication
- Partners can advertise they are part of / contributors to HyBlend CRADA

Contact HyBlend_CRADA@nrel.gov for more details

** subject to the availability of appropriated funds, contingent on cost share, not a FOA*