Fuels Institute

Impact of Transportation-Related Environmental Initiatives

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Executive Summary

Impact of Transportation-Related Environmental Initiatives

Ricardo Strategic Consulting ("Ricardo") analyzed the effectiveness, impact, and cost of compliance of various "movements" that represent legislation, mandates, proposals, initiatives, and trends under discussion in the U.S.

We also considered global themes that may shape the U.S. landscape for the next 20 years (until 2040).

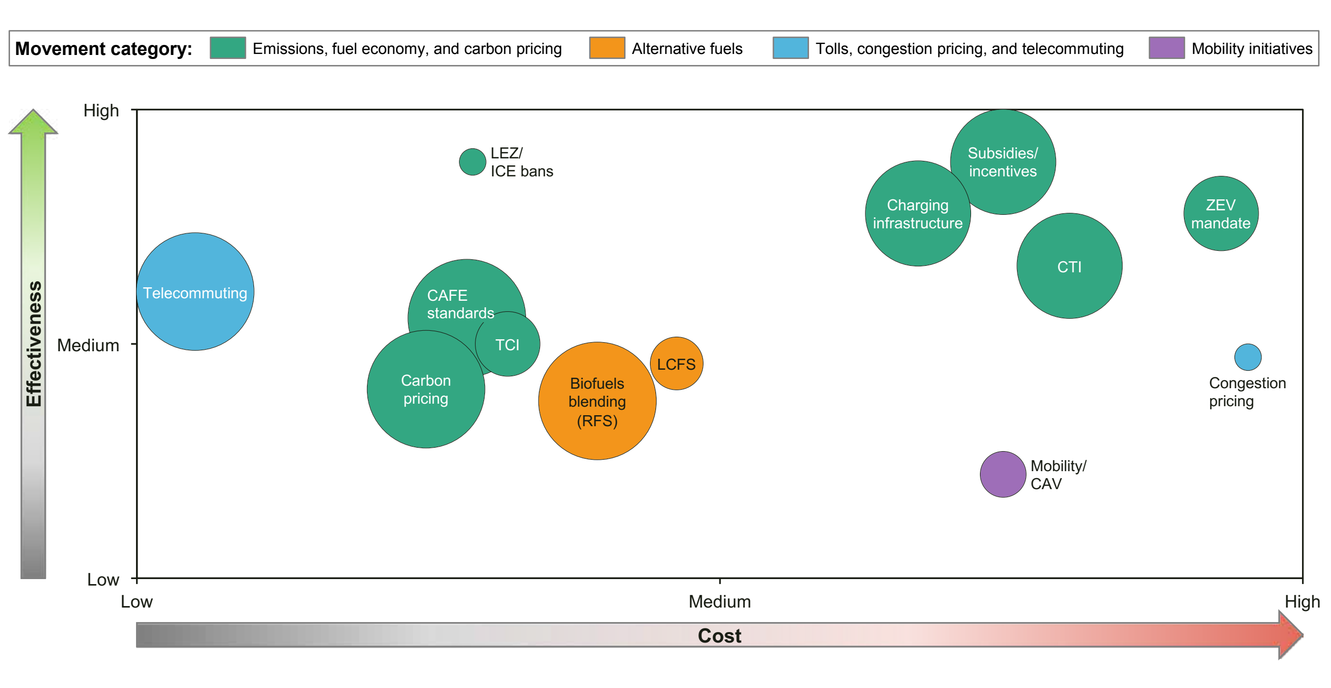
A few of the movements that have already been enacted are the zero-emission vehicle (ZEV) mandate, the Low Carbon Fuel Standard (LCFS), the Renewable Fuel Standard (RFS), and federal and state electric vehicle (EV) subsidies. A few, such as the Cleaner Trucks Initiative (CTI) and Transportation Climate Initiative (TCI), are in proposal phase while others, such as carbon pricing, are under discussion.

We conducted preliminary studies on a total of 37 U.S. and global movements and shortlisted 14 U.S.-specific movements for long-term impact assessment. The 14 movements are bucketed broadly into the following four categories:

1. **Emissions, fuel economy, and carbon pricing**
2. **Alternative fuels**
3. **Congestion pricing, tolls, and telecommuting**
4. **Mobility initiatives**

We mapped all these movements together on one chart, measuring effectiveness, impact, and cost. We define cost as the cost incurred by industry participants and/or consumers to comply with a movement. The effectiveness is a weighted average measure of emissions, fuel economy, and vehicle demand in terms of shift to alternative powertrains. The size of the bubble indicates whether the movement is nationwide, prevalent in some states, or limited to only a few regions or cities. The focus of study of these movements is not necessarily to delve into the minutiae of each movement or mandate but to compare one against the other in terms of effectiveness and cost. The movements' comparative assessment of effectiveness, impact, and cost are mapped in figure 1.

FIGURE 1. COMPARATIVE ASSESSMENT OF MOVEMENTS' EFFECTIVENESS, IMPACT, AND COST



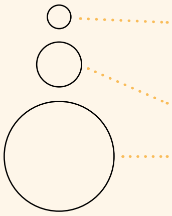
Source: Industry interviews, literature review and Electronic Code of Federal Regulations

FIGURE 1: LEGEND

Effectiveness: Influence of a movement on emissions reduction, fuel economy improvement, and plug-in electric vehicle demand weighted equally

Cost: Cost to comply with a movement

Impact: Scale of impact of a movement



Localized impact from movements, limited to urban areas/few cities

Movement adopted by few states

National-level movements that can be adopted federally

In this report, the effectiveness of a movement is a weighted average measure of emissions, fuel economy, and vehicle demand in terms of shift to alternative powertrains.

The effectiveness of each movement is directly proportional to its cost—higher spending corresponds to higher effectiveness. However, a few other themes emerge:

- **Telecommuting is an effective outlier** that would reduce emissions by 3-14% (equivalent to several other movements) but at a negligible cost.[1]
- **Subsidies, charging infrastructure, and the ZEV mandate** in the upper-right corner of figure 1 are mainly related to the uptake in plug-in electric vehicles (PEVs), which include battery electric and plug-in hybrid vehicles. These movements collectively have the highest emissions reduction effectiveness though with relatively high cost. Among these, subsidies are most effective in the near term.
- **The newly implemented SAFE rule** has reduced emissions targets. These targets, projected linearly, could be reached with EV sales contributing only 10-20% of new vehicle sales by 2040, compared to the ones from CAFE standards which would have required EV sales to contribute >50% of new vehicles sales by 2040.
- **Within the alternative fuels movements, the Renewable Fuel Standard (RFS) and LCFS appear to have moderate success.** The LCFS has proven reasonably effective but may rely on PEV uptake in the future to meet its targets. The U.S. Environmental Protection Agency continues to roll back RFS targets for two out of four alternative fuels categories, which has called into question the effectiveness of the RFS.
- **The TCI and carbon pricing**—though effective tools—may have marginal impact given the limited nationwide momentum they may generate in the near term.
- **Lastly, some of the smaller movements, such as low-emission zones (LEZs) and congestion pricing**, are effective but limited in impact because they are localized. The emissions and fuel-economy impact of autonomous shared mobility appears uncertain in the near term.

1 For simplicity, most numbers in this report are rounded to whole numbers or decimals to the tenth place, with the exception of currency.

Introduction

The Fuels Institute commissioned Ricardo Strategic Consulting ("Ricardo") to evaluate and compare the impact that different environmentally focused transportation-energy regulations, policies, and initiatives ("movements") will have on emissions (carbon and others) and costs to consumers over the next 20 years (2020 to 2040).

The Fuels Institute is a not-for-profit organization led by a collaborative group of fuel producers and refiners; alternative and renewable fuels producers; automobile manufacturers; and others with expertise in the fuels and automotive industries. The Institute delivers comprehensive and balanced research and analysis concerning fuels, vehicles, and related policy issues. Ricardo has aligned its research and opinions in this report to a similar unbiased philosophy.

POLICY CONTEXT

The number of movements dedicated toward increasing alternative fuels and vehicles and decreasing traditional petroleum fuels and internal combustion engines (ICEs) have been on the rise and will continue to increase. As the landscape and scope of policies, regulations, and initiatives expand, it is imperative to understand the nature of each program, their effects in terms of consumer and societal benefits and costs, and how they may interact with one another. Some examples include: 1) the impact of carbon pricing on transportation or 2) enacting ICE bans or low-emissions zones (LEZs) in regions similar to major cities across Europe.

Ricardo studied a total of 37 U.S. and global movements prior to identifying 14 U.S.-specific movements for assessing long-term impact. A summary of the 14 movements, which include federal mandates, local mandates, and mandates in proposal phase, are provided in table 1.

An assessment of the full 37 movements can be found on the "Research" page of our website along with this report.

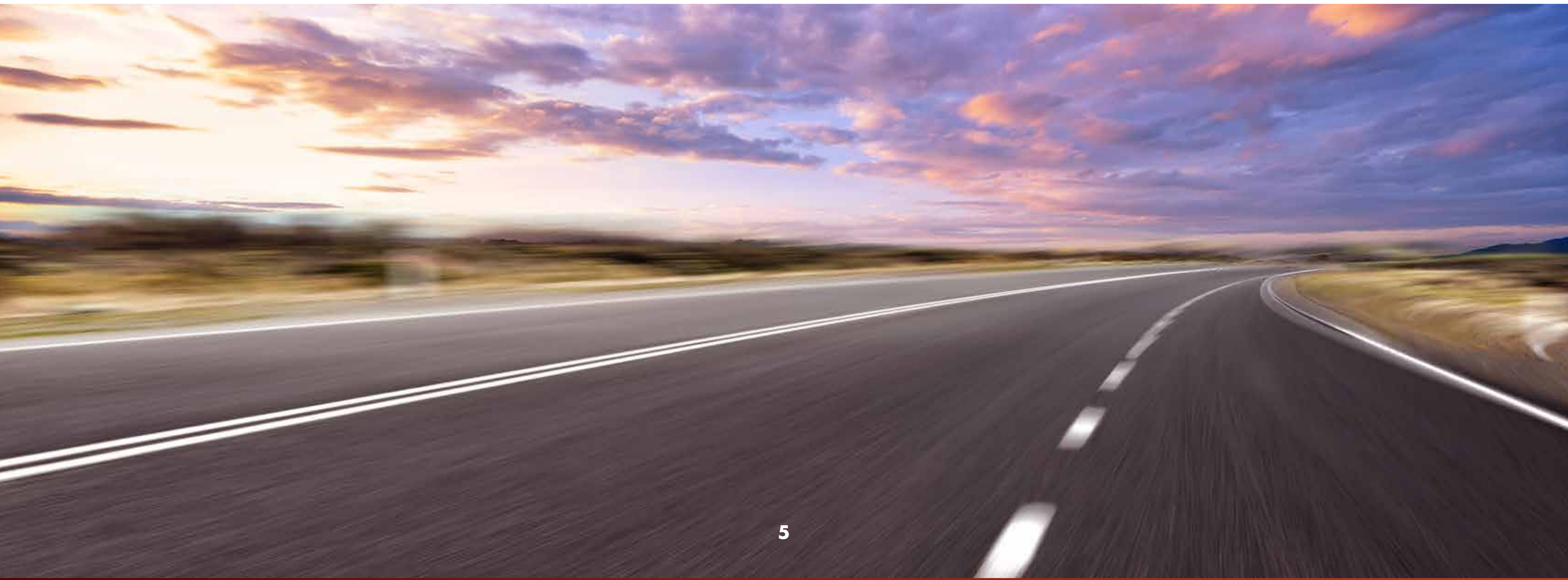


TABLE 1: SUMMARY OF 14 U.S.-SPECIFIC MOVEMENTS' OBJECTIVES

MOVEMENT	OBEJCTIVES AND LEGISLATION
Emissions, fuel economy, and carbon pricing	**Subsidies** are federal tax credits of $7,500 and state-level incentives of up to $5,000 that are offered to promote plug-in electric vehicle adoption. The **zero-emission vehicle (ZEV) mandate**, first adopted in 1990 by California, controls emissions from passenger vehicles and decrees increasing ZEV floor requirements through 2025 and beyond; the mandate has since been adopted by 11 other states (CT, ME, MA, VT, RI, OR, NY, NJ, MD, CO, WA). There are incentives for companies to receive tax rebates of up to 30% for installing **charging infrastructure** on premises. In addition, states such as New Jersey, per legislation S2252, have targeted 1,600 charging stations to be installed by 2025 to promote sale of PEVs. The **Corporate Average Fuel Economy (CAFE) standards** are fleet-wide average fuel-economy targets to be achieved by passenger vehicle original equipment manufacturers. The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule, implemented in March 2020, amended the CAFE standards to mandate 1.5% compound annual growth rate in fleet fuel economy for model years (MY) 2021–2026. The prior CAFE standards mandated 5% compound annual growth in fuel-economy improvement between 2020 and 2025. The **Cleaner Trucks Initiative (CTI)** is still in proposal phase and aims to address diesel commercial trucks NO_x emissions in low speed and load conditions. This is estimated to impact model years 2025 and beyond. The **Transportation Climate Initiative (TCI)** is a work-in-progress "cap-and-invest" initiative estimated to start in 2022. The TCI seeks to reduce transportation emissions and develop a clean energy economy in 12 northeastern regions. Numerous **carbon-pricing initiatives** have been proposed; however, none have been enacted into legislation. The distribution of revenue from most carbon-pricing proposals is not targeted towards transportation.
Alternative fuels	The **Low Carbon Fuel Standard (LCFS)** adopted by California and Oregon mandates a reduced carbon intensity (CI) of fuels over time, culminating in a 20% CI reduction target by 2030 (with respect to 2010 levels). The **Renewable Fuel Standard** is a federal biofuel standard originally enacted in 2005 and amended in 2007 with an aim of blending 36 billion gallons of qualified biofuels into the U.S. fuel mix by 2022.
Tolls, congestion pricing, and telecommuting	**Telecommuting:** The Telework Enhancement Act of 2010 mandates each federal agency establish a telecommuting policy and maximize telecommuting where applicable (federal employees only). Zone-based **congestion pricing** (surcharge to enter high traffic areas) legislation has only been adopted by New York City in the U.S. with implementation scheduled for 2021. This report considers a case if the city of Los Angeles were to adopt a **Low Emission Zone** (LEZ) by banning vehicles that are more than 20 years and older.
Mobility initiatives	No mandates currently in place for **connected and autonomous vehicles, and shared mobility**.

OBJECTIVE OF THE STUDY

In February 2020, Ricardo was commissioned to evaluate and compare the impact that different environmentally focused transportation-energy regulations, policies, and initiatives ("movements") will have on emissions (carbon and others) and costs to consumers over the next 20 years (2020 to 2040). The goal of the report is to educate policymakers and market stakeholders regarding the benefits and costs of each program from multiple perspectives to facilitate development of effective programs.

Methodology

BACKGROUND

A list of all the movements analyzed for this report is provided in table 2.

TABLE 2: 14 U.S.-SPECIFIC MOVEMENTS AND THEIR CORRESPONDING GLOBAL MOVEMENTS

U.S. LEGISLATION, MANDATE, INITIATIVE, OR PROGRAM	PARALLEL GLOBAL LEGISLATION, MANDATE, INITIATIVE, OR PROGRAM
All states: Corporate Average Fuel Economy Standard	**China:** Corporate Average Fuel Consumption Standard **European Union (EU):** EU Emission Standards **Japan:** Energy Conservation Law **South Korea:** Average Fuel Economy Program
California and 11 other states: Zero-Emission Vehicle Mandate	**China:** New Energy Vehicle Mandate
Incentive program—multiple state-level subsidies offered	**Incentive program**—Norway Electric Vehicle Program (Norsk Elbilforening)
All states: Renewable Fuel Standards	**EU:** Renewable Fuels Directive II
California: Low Carbon Fuel Standard	**EU:** Fuels Quality Directive
13 northeastern states: Transportation Climate Initiative	No parallel equivalent
Charging infrastructure: New Jersey Legislation S2252	**Norway:** Norsk Elbilforening
Congestion pricing: New York City Traffic Mobility Act, Article 44-C	**London:** London Congestion Charge **Milan:** Area C **Stockholm:** Trängselskatt I Stockholm
All states: Telework Enhancement Act	**Canada:** Telework Policy
Carbon pricing—all states: American Opportunity Carbon Fee Act	**EU:** Energy Taxation Directive
Connected and autonomous vehicles: Self Drive Act and AV START Act	**Germany:** Autonomous Vehicle Bill
Shared mobility—California: Transit Priority Program	Limited public information regarding legislation
All states: Environmental Protection Agency Cleaner Trucks Initiative	**EU:** Standard 2018/0143 (COD)
Vehicle use type restrictions/internal combustion engine bans—California: AB 40	**France:** Mobility Law

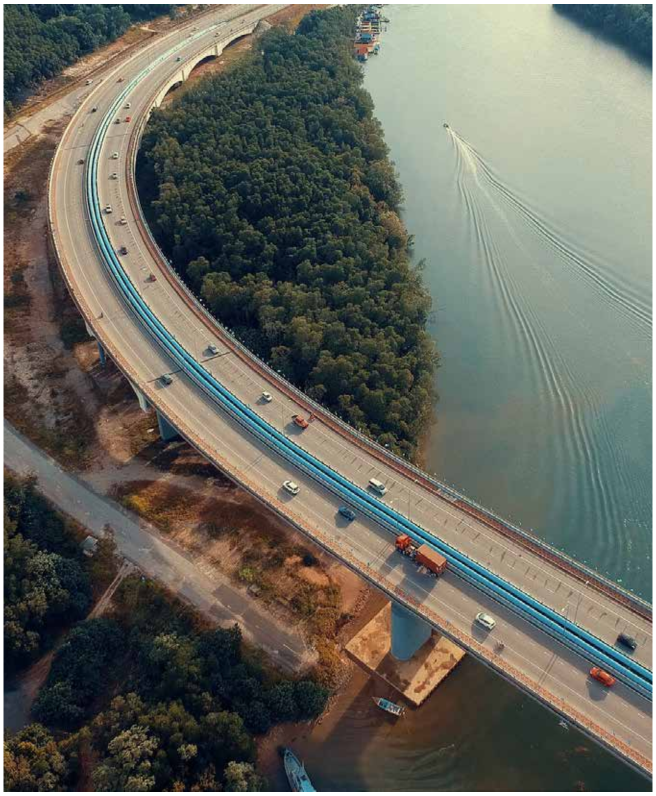
ASSUMPTIONS AND ELECTRIFICATION SCENARIOS

The following assumptions were made for projecting the impact of movements in 2040:

Subsidies: Continued federal tax credits and state-level subsidies and incentives offered until 2030; subsidies may taper off beyond 2030.

Zero-emission vehicle (ZEV) mandate: Limited to 12 states that adopted the ZEV mandate until 2040.

Charging infrastructure: Legislation similar to New Jersey's S2252,[2] which mandates a total of 1,600 chargers to be installed by 2025 to increase plug-in electric vehicle (PEV) uptake, including battery electric (BEV) and plug-in hybrid vehicles; similar legislation may also be undertaken in other states. More focus is placed on EV-charging infrastructure than that for hydrogen, primarily since the adoption of EVs is likely going to be of significantly higher magnitude than fuel-cell vehicles, especially in passenger cars.



Corporate Average Fuel Economy (CAFE) standards: Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule implemented (1.5% compound annual growth rate fuel-economy improvement until 2040).

Low Carbon Fuel Standard (LCFS): Current target: 20% carbon intensity (CI) reduction by 2030; this report assumes 30% CI reduction by 2040.

Renewable Fuel Standard (RFS): Assumed to continue in current format with discretionary waivers until 2040.

Cleaner Trucks Initiative (CTI): Standards not yet defined; mandate intended to impact lower load and speed conditions of medium- and heavy-duty trucks, which may occur beyond 2025.

Transportation Climate Initiative (TCI): Limited to 12 states signatory to the program; compliance begins in 2022 and aims to achieve 20–25% CO_2 reduction by 2032, increasing to 30–35% reduction target by 2040.

Carbon pricing: Carbon-pricing legislation on transportation fuel may be passed after 2025 with a maximum cost per ton of CO_2 lagging behind TCI states' carbon pricing; existing proposals suggest pricing range from $20–50/metric ton in 2020 to $45–160/metric ton by 2030.

Vehicle restrictions and ICE bans: Only major cities such as Los Angeles, New York, and Seattle may pass vehicle restriction laws.

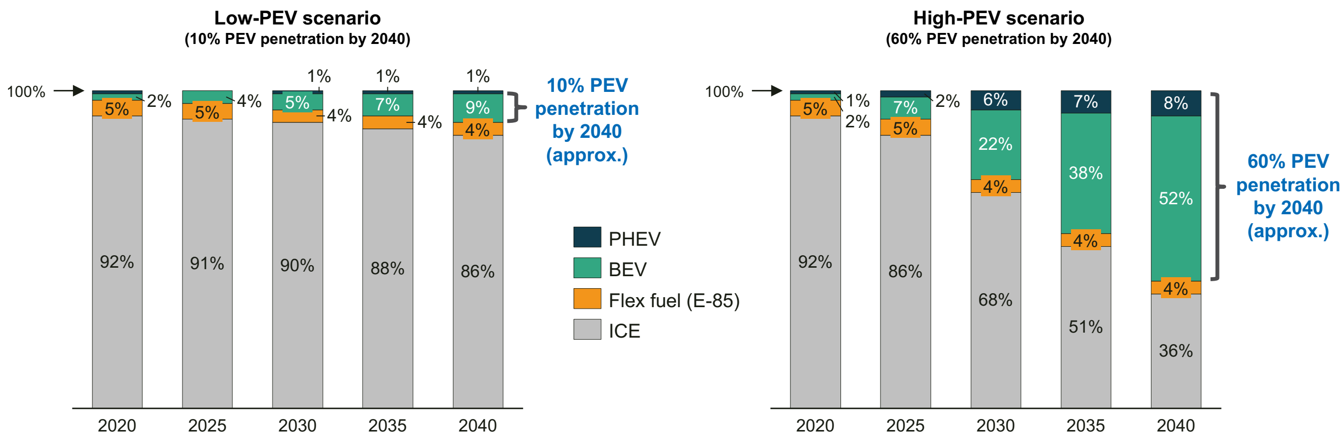
Congestion pricing: Only major cities such as Los Angeles, New York, and Seattle may pass congestion pricing laws.

Autonomous vehicle technology and shared mobility: Certain selected cities, highway zones, and geofenced areas may operate autonomous vehicles.

Sales of light-duty electric vehicles (EVs): Figure 2 shows the estimates used in this report to establish low-uptake and high-uptake scenarios, which serve as bookends for this report.

2 New Jersey Senate No. 2252 (adopted January 9, 2020). Available at https://www.njleg.state.nj.us/2018/Bills/S2500/2252_U2.HTM.

FIGURE 2: U.S. LIGHT-DUTY ELECTRIC NEW VEHICLE SALE PENETRATION SCENARIOS



Note: 16M vehicle sales per year considered from 2020 through 2040 (approx.)

Studies reviewed: AEO 2020 Outlook, BNEF 2019 EV Outlook, IEA 2019 Global EV Outlook, BCG Electric Car Tipping Point, Wood Mackenzie EV Outlook, UBS Auto and EV Outlook, Edison Electric Institute Electric Vehicle Trends, IHS Markit, etc.

MOVEMENTS ASSESSMENT APPROACH

The 14 selected movements were measured on three key factors to assess overall impact through 2040: effectiveness, cost, and impact.

The **effectiveness** of a movement is comprised of three key elements: emissions reduction, fuel-economy improvement, and vehicle demand (in terms of shift to alternate powertrains), each weighted equally. We considered these three factors as they directly or indirectly impact emissions reduction.

A few movements are targeted for their direct emissions reduction, such as the ZEV mandate, telecommuting, etc. Some movements target emissions reduction through fuel-economy improvement, such as the CAFE standards, and others target emissions reduction through vehicle replacement, such as ICE bans. Therefore, we considered these three factors as key criteria as they directly or indirectly impact emissions reduction.

Cost is defined as how much it costs to comply with a movement. As applicable for each movement, it is further broken down in terms of singular cost of compliance per person, such as purchase price, or of operational costs, such as incremental costs for operating a vehicle. The cost impact assessment methodology for selected movements is provided in the following section.

COST IMPACT ASSESSMENT METHODOLOGY FOR SELECTED MOVEMENTS

Telecommuting

- Telecommuting can be implemented at negligible cost.

TCI

- The maximum incremental annual fuel cost implication for the consumer to comply with TCI is only marginal - about $100 in 2022 to $150 in 2032.
- The total cost to consumer (cumulative) from the TCI over a 15-year duration is $1,500–2,300.

LCFS

- Alternative fuels and fuel blends deliver marginally lower fuel economy in comparison to baseline gasoline and diesel fuels; however, some blends are cheaper at the pump compared to gasoline and diesel.
- From a total cost of ownership perspective, these alternative fuels range from slightly cost positive to slightly cost negative for consumers depending on the blending ratio.

ZEV mandate

- Based on Ricardo analysis for the 2020 market conditions, the incremental cost to an original equipment manufacturer (OEM) to produce a battery electric vehicle (BEV) compared to a comparable ICE vehicle, depending on the size of passenger vehicle, is $8,000–12,000 per vehicle. Thus, the incremental cost to meet the ZEV mandate is $8,000–12,000 higher per vehicle than a comparable ICE vehicle. Furthermore, it is likely that ICEs will become more expensive to meet increased CAFE and emissions targets.
- The cost of compliance for the ZEV mandate is $8,000–12,000.

Congestion pricing

- The cost to access the congestion pricing zone in New York City ranges from $5–12 per vehicle.
- The annual cost of access, $5 multiplied by 260 working days per year, is $1,300; at $12 per vehicle, the annual cost increases to $3,120.
- The total cost for a consumer to access congestion pricing zone year-round over a 15-year duration is >$15,000.

Impact

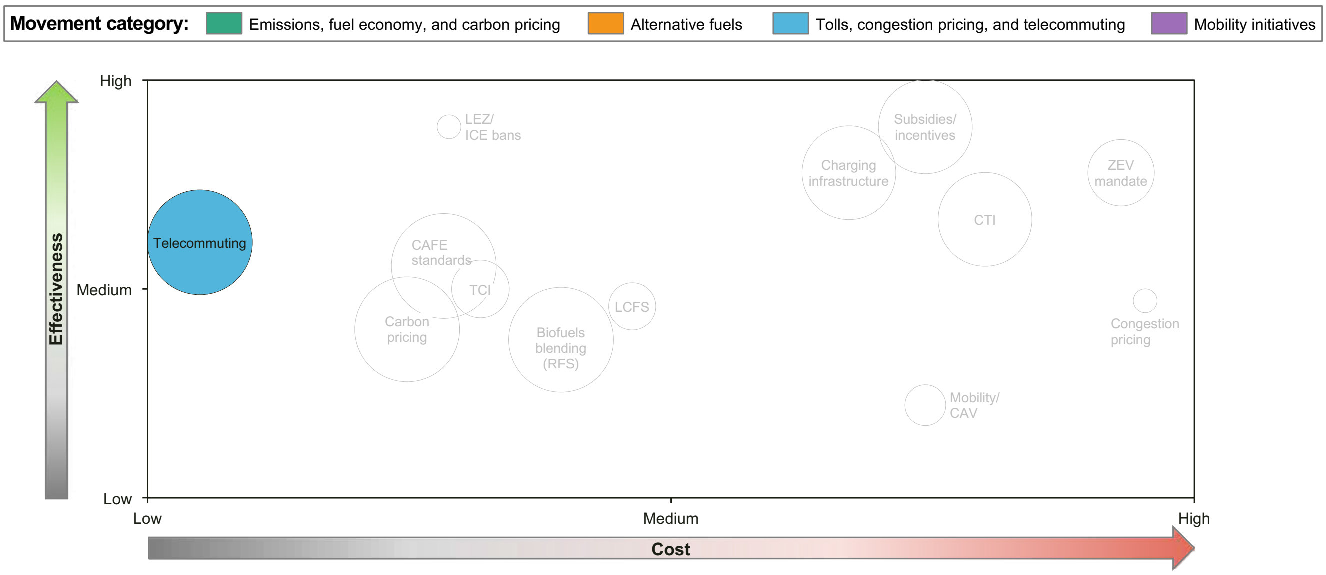
The magnitude of a movement's impact varies across the U.S. and depends on if it applies nationwide, to selected states, or only to certain cities. In the comparative assessment plot in figure 1, the magnitude of impact is represented by the size of the circle.

- Low: localized impact from movements, limited to urban areas or a few cities
- Medium: movement adopted by a few states
- High: national movements, can be adopted federally

Project Report

TELECOMMUTING

FIGURE 3: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: TELECOMMUTING



Source: Ricardo analysis; "How Many Jobs Can Be Done at Home?"; "COVID-19 and Remote Work: An Early Look at US Data"; assumes price of gasoline at $3/gallon

FINDINGS

Telecommuting is at the forefront of the discussion on emissions reduction due to the fundamental shift in working conditions prompted by COVID-19 mitigation efforts. Telecommuting is an effective tool to reduce emissions at a negligible cost when compared to other movements (see figure 3). Depending on the percentage of the U.S. workforce telecommuting and the number of days per week they telecommute, CO_2, greenhouse gas (GHG), NO_X, and $PM_{2.5}$ emissions would reduce about 3-14% with the advantage of negligible costs (see figure 4).

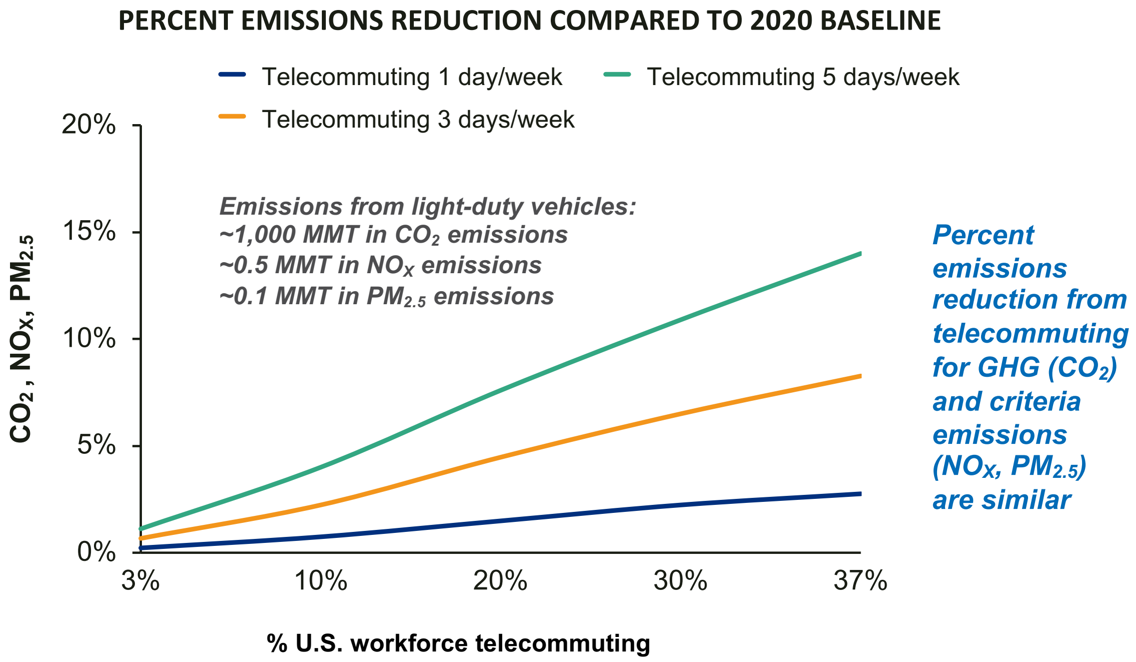
Based on a study from the National Bureau of Economic Research, 37% of the U.S. workforce can feasibly work from home.[3] The current U.S. workforce stands at 165 million, which means 61 million workers could feasibly work from home.[4]

The negligible cost impact of telecommuting is a key component compared to other movements, as other approaches require significant investments (in billions of USD) to implement mandates that achieve a similar percentage of emissions reduction.

3 Jonathan I. Dingel and Brent Neiman, "How Many Jobs Can Be Done at Home?" (working paper no. 26948, NBER Working Paper Series, National Bureau of Economic Research, Cambridge, MA, April 2020). Available at https://www.nber.org/papers/w26948.

4 Erik Brynjolfsson, John J. Horton, Adam Ozimek, Daniel Rock, Garima Sharma, and Hong-Yi TuYe, "COVID-19 and Remote Work: An Early Look at US Data" (working paper no. 27344, NBER Working Paper Series, National Bureau of Economic Research, Cambridge, MA, June 2020). Available at https://www.nber.org/papers/w27344.

FIGURE 4: EMISSIONS REDUCTION BASED ON PERCENT OF U.S. WORKFORCE TELECOMMUTING



Also, telecommuting has a marginal cost benefit to consumers due to fuel savings. On average, per person fuel savings from telecommuting one to five days per week is $150–800 annually. (We assumed $3 per gallon of gasoline rather than the abnormally low prices observed during the early part of the COVID-19 pandemic.)

Global regions registered significant reductions in GHG and pollutant emissions due to COVID-19–related stay-home orders from March to April 2020. For example, the U.S. Environmental Protection Agency (EPA) stated Los Angeles experienced its longest stretch of “good” quality air since 1995.[5] Several cities in India registered an approximate 70% drop in NO_X emissions. How telecommuting takes shape is not yet apparent and could be implemented either by government mandates or the private sector as initiatives for employee well-being—the latter more likely in the near term. Currently, the only federal-level mandate in the U.S. is the Telework Enhancement Act of 2010,[6] which dictates each federal agency to establish a telecommuting policy and maximize its use where applicable.

5 Drew Kann, “Los Angeles Has Notoriously Polluted Air. But Right Now It Has Some of the Cleanest of any Major City,” CNN, April 7, 2020, https://www.cnn.com/2020/04/07/us/los-angeles-pollution-clean-air-coronavirus-trnd/index.html

6 “Background & History,” Telework Legislation, U.S. Office of Personnel Management, accessed June 26, 2020, https://www.telework.gov/guidance-legislation/telework-legislation/background-history/.

ASSESSMENT METHODOLOGY

Inputs

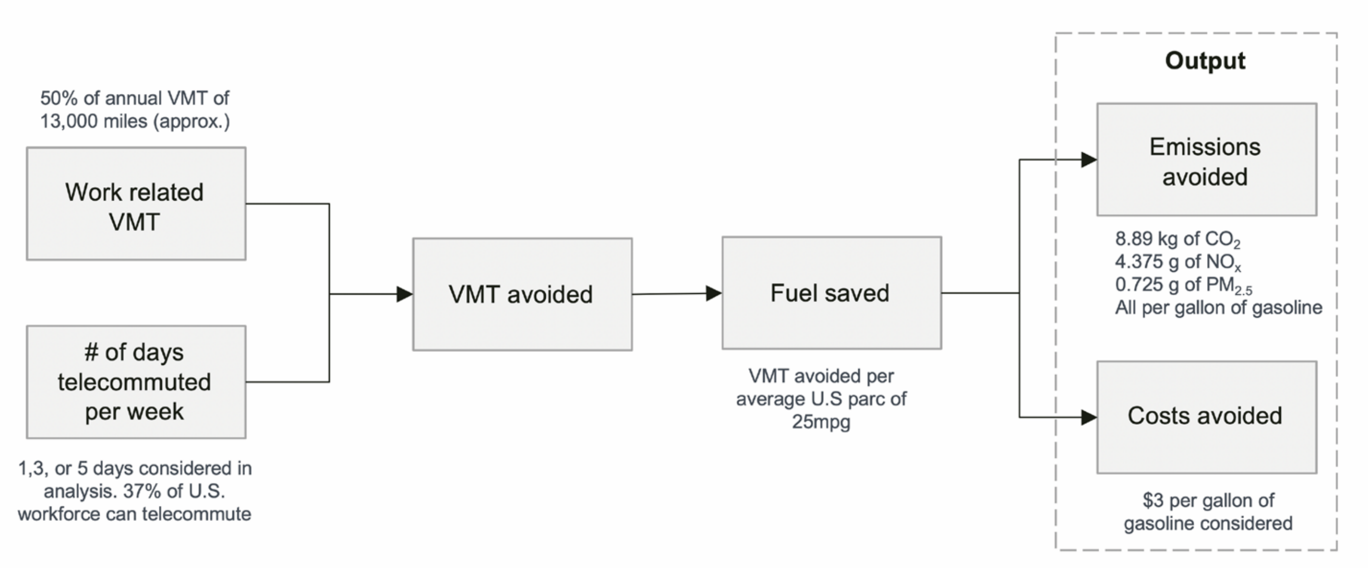
When estimating emissions reduction and fuel savings based on the percentage of the U.S. workforce and the number of days per week they could telecommute, Ricardo considered the following:

- **Three percent of the workforce is telecommuting, and the maximum percentage of the workforce capable of telecommuting is 37%.[7]**
- **Work-related VMT per person is estimated to be 50% of annual VMT, and the average annual VMT per person is estimated at 13,000 miles.[8]**
- **There are five working days per week.**
- **The price of gasoline is considered to be $3 per gallon.**
- **Avoided CO_2 emissions equal 8.89 kg per gallon of gasoline.[9]**
- **Avoided NO_X emissions equal 4.375 g per gallon of gasoline for the U.S. 2020 vehicles in operation (VIO) fleet with 25 mpg.[10]**
- **Avoided $PM_{2.5}$ emissions equal 0.725 g per gallon of gasoline for the U.S. 2020 VIO fleet with 25 mpg.[11]**
- **The average U.S. VIO with 25 mpg in 2020[12]**
- **Based on Ricardo analysis, the current annual average emissions from the U.S. light-duty VIO are:**
  - 1,000 million metric tons (MMT) in CO_2 emissions
  - 0.5 MMT in NO_X emissions
  - 0.1 MMT in $PM_{2.5}$ emissions

Methodology and output

Figure 5 illustrates the process flow of telecommuting emissions, cost-benefit methodology, and output.

FIGURE 5: TELECOMMUTING ASSESSMENT METHODOLOGY



7 Dingel and Neiman, https://www.nber.org/papers/w26948.pdf

8 U.S. Energy Information Administration, *Annual Energy Outlook 2020 with Projections to 2050* (Washington, DC: Office of Energy Analysis, U.S. Department of Energy, January 2020), https://www.eia.gov/outlooks/aeo/.

9 "Carbon Dioxide Emissions Coefficients," Environment, U.S. Energy Information Administration, released February 2, 2016, https://www.eia.gov/environment/emissions/co2_vol_mass.php.

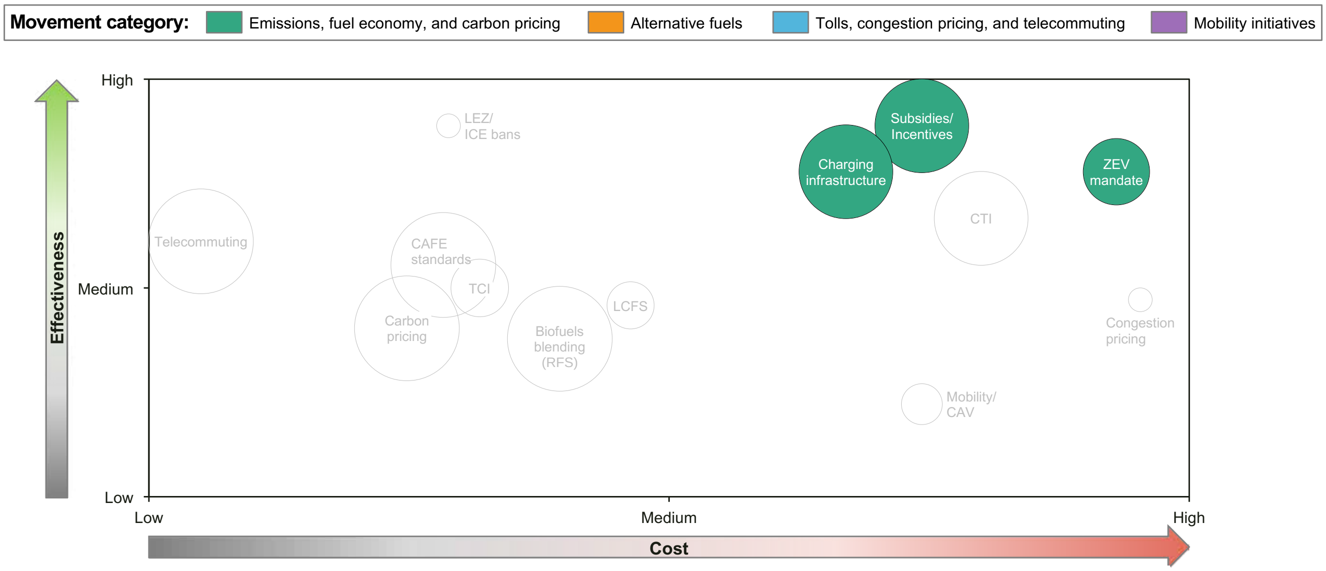
10 "Average Fuel Efficiency of U.S. Light Duty Vehicles," Bureau of Transportation Statistics, U.S. Department of Transportation, accessed June 26, 2020, https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles

11 "Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel," Bureau of Transportation Statistics, U.S. Department of Transportation, accessed June 26, 2020, https://www.bts.gov/content/estimated-national-average-vehicle-emissions-rates-vehicle-vehicle-type-using-gasoline-and, Ricardo analysis

12 "Average Fuel Efficiency of U.S. Light Duty Vehicles;" Ricardo analysis

SUBSIDIES AND INCENTIVES, CHARGING INFRASTRUCTURE, AND ZERO-EMISSION VEHICLE MANDATE

FIGURE 6: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: SUBSIDIES AND INCENTIVES, CHARGING INFRASTRUCTURE, AND ZERO-EMISSION VEHICLE MANDATE



FINDINGS

The cluster of PEV movement subsidies and incentives, charging infrastructure, and the ZEV mandate have the highest emissions reduction effectiveness, though with relatively high cost (see figure 6). Subsidies and a charging network are critical PEV uptake drivers in the short and medium term, whereas the ZEV mandate and a charging network will continue to be important in the medium and long term.

The PEV movement subsidies and incentives, charging infrastructure, and the ZEV mandate all work in unison to form a network effect in which the lack of one diminishes the impact of the other two. Currently, the cost of an EV is $8,000–12,000 higher than an equivalent ICE passenger vehicle, depending on the size of the car. The industry is moving towards attaining cost parity for EVs versus ICE vehicles (see figure 7), but until that is achieved, direct cash-in-hand for consumers through subsidies and incentives, such as the federal tax credit and state-level rebates, is one way to promote PEV sales. Another way is through the ZEV mandate: California and 11 other states mandate that a certain percentage of each OEM's sales must be ZEVs.

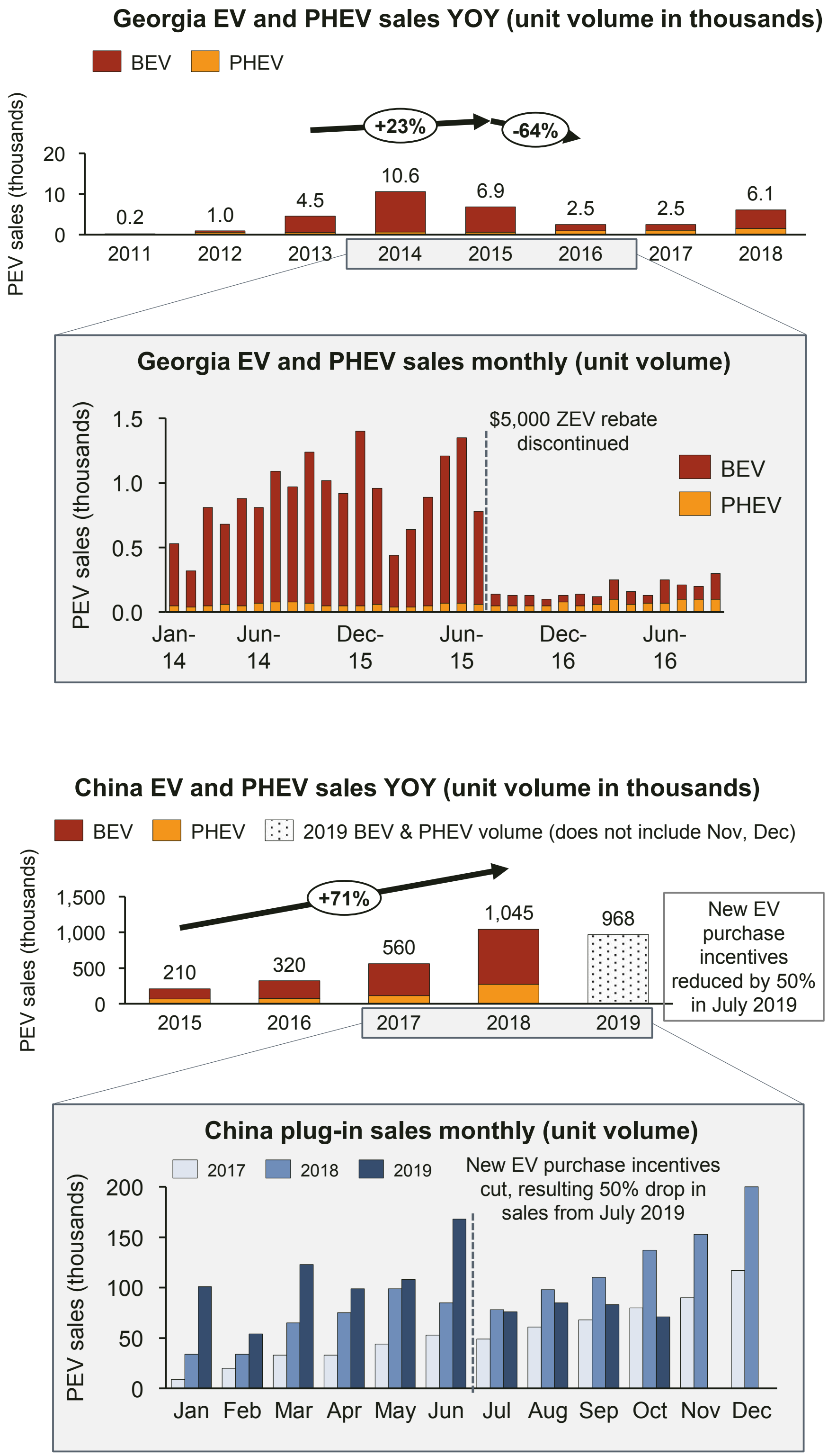
Impact of subsidies on PEV sales

The impact of subsidies on EV sales is acute when subsidies are rolled back. For example, when Georgia rescinded their $5,000 state rebate during 2015–2016, EV sales plummeted by 60%.[13] Similarly, when China reduced purchase incentives by 50% in July 2019, EV sales dropped by 50% compared to the prior six months.[14] The consequences of both rollbacks are shown in figure 7.

13 "U.S. Light-Duty Advanced Technology Vehicle (ATV) Sales (2011–2019)," Advanced Technology Vehicle Sales Dashboard, Alliance of Automobile Manufacturers, accessed June 26, 2020, https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/.

14 "China Considers Extending Electric-Car Subsidies After Sales Slump," Hyperdrive, Bloomberg News, February 20, 2020, updated February 21, 2020, https://www.bloomberg.com/news/articles/2020-02-20/china-considers-prolonging-electric-car-subsidies-as-sales-slump.

FIGURE 7: IMPACT OF SUBSIDIES ON ELECTRIC VEHICLE DEMAND



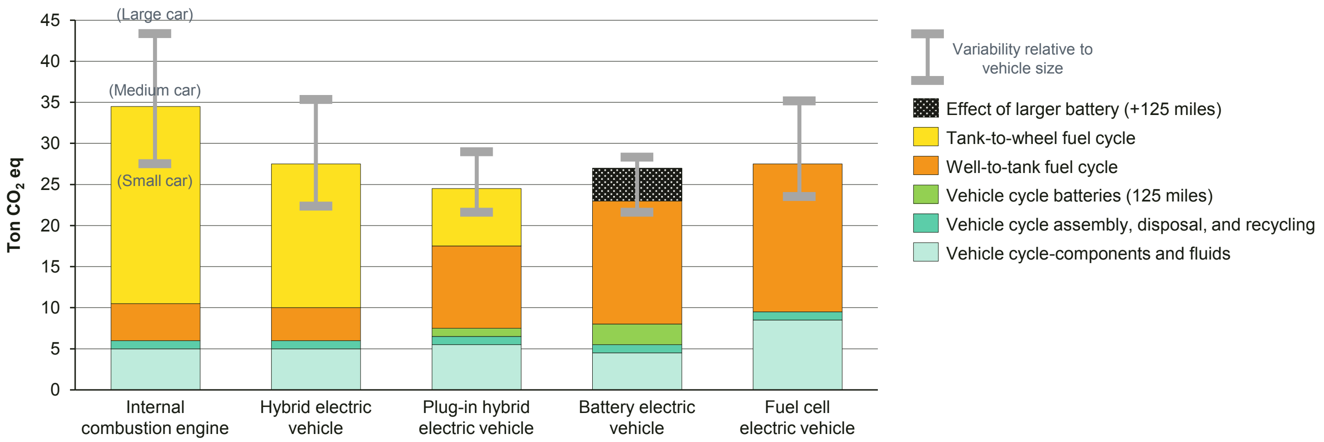
Source: "U.S. Light-Duty Advanced Technology Vehicle (ATV) Sales (2011–2019);" U.S. Energy Information Administration, Analysis of the Effect of Zero-Emission Vehicle Policies: State-Level Incentives and the California Zero-Emission Vehicle Regulations, U.S. Department of Energy, September 2017, https://www.eia.gov/analysis/studies/transportation/zeroemissions/pdf/zero_emissions.pdf; Jeff Cobb, "The World Just Bought Its Two-Millionth Plug-in Car," hybridCARS.com, January 16, 2017, https://www.hybridcars.com/the-world-just-bought-its-two-millionth-plug-in-car/; Vehicle Technologies Office, "More Than 1 Million Plug-in Vehicles Were Sold in China in 2018," Office of Energy Efficiency & Renewable Energy, April 29, 2019, https://www.energy.gov/eere/vehicles/articles/fotw-1079-april-29-2019-more-1-million-plug-vehicles-were-sold-china-2018; Roland Irle, "China NEV Sales for 2019 Q3 + October," EV-volumes.com, accessed September 16, 2020, http://www.ev-volumes.com/country/china/; Jill Shen, "EV subsidies in China are making a comeback," Technode.com, March 5, 2020; "China Considers Extending Electric-Car Subsidies After Sales Slump"

Lifecycle CO_2 greenhouse gas emissions by powertrain type

EVs and a low-carbon grid (electricity power generation) are primary drivers for reducing emissions compared to other alternative fuels. PEVs, including BEVs, offer slightly lower lifecycle emissions compared to ICEs even when considering conventional energy sources for power generation.

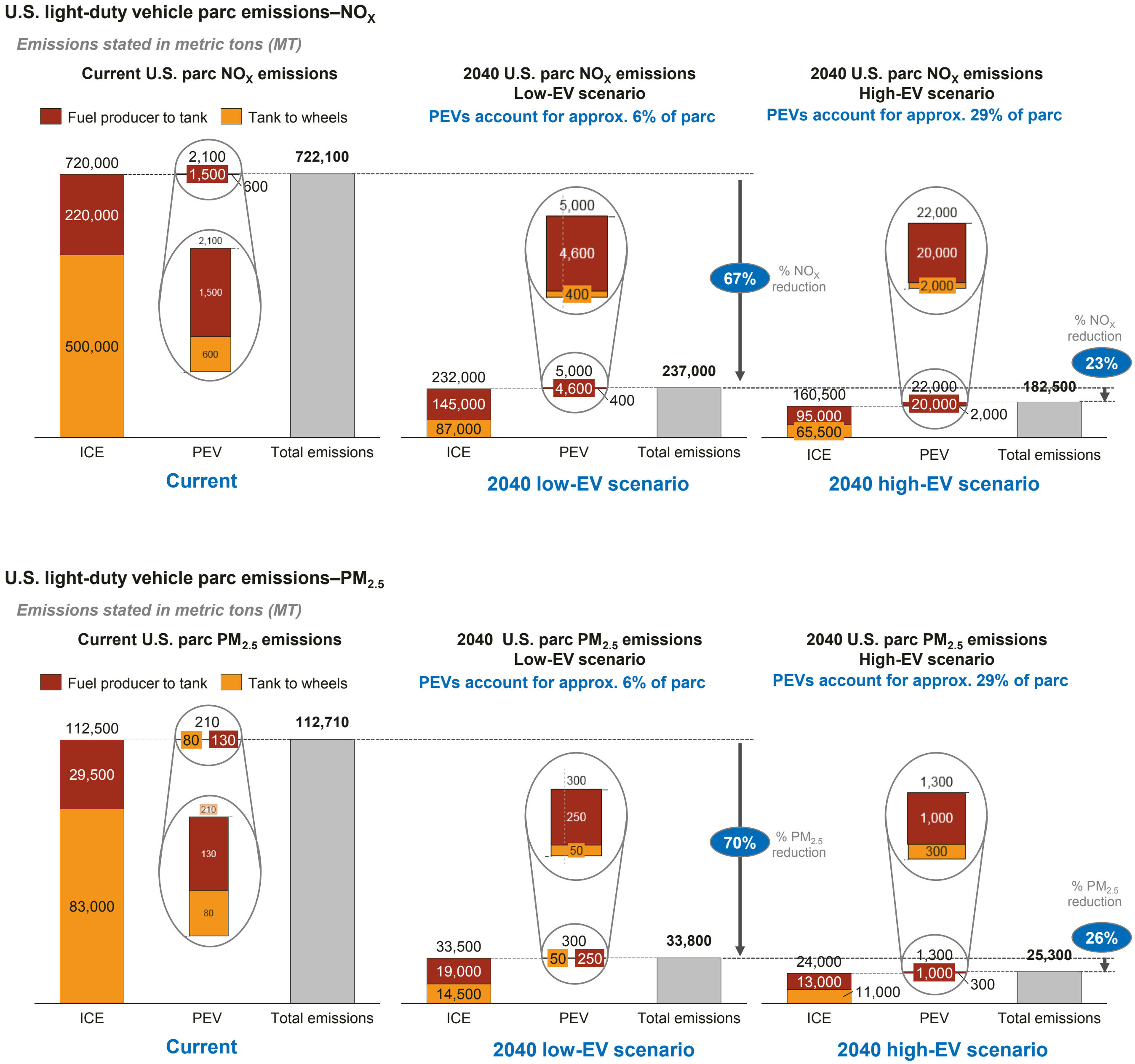
The lifecycle CO_2 GHG emissions of an ICE passenger car is 27–43 tons CO_2 equivalent based on car size, whereas a BEV's lifecycle CO_2 GHG emissions is 22–28 tons CO_2 equivalent (see figure 8). As renewable energy use in the grid increases, the overall lifecycle emissions from BEVs are expected to reduce significantly with respect to comparable ICE platforms lifecycle emissions.

FIGURE 8: LIFECYCLE GREENHOUSE GAS EMISSIONS FOR PASSENGER CARS BY POWERTRAIN, 2018[15]

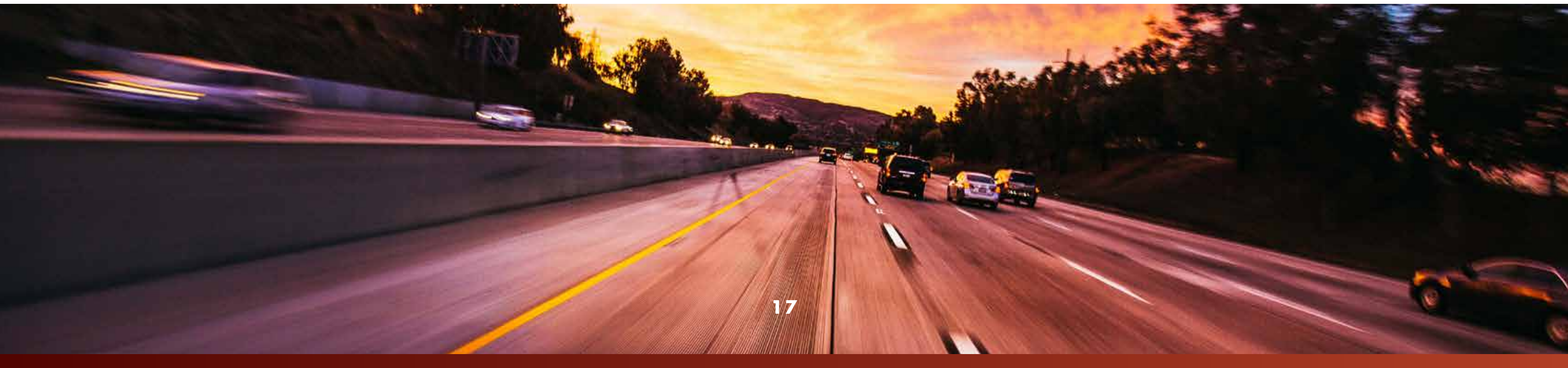


15 International Energy Agency, "Global EV Outlook 2019: Scaling Up the Transition to Electric Mobility," May 2019, https://www.iea.org/reports/global-ev-outlook-2019.

FIGURE 9: WELL-TO-WHEEL CRITERIA POLLUTANT EMISSIONS FOR PASSENGER CARS[16]



16 International Energy Agency, "Global EV Outlook 2019; Hao Cai, Jeongwoo Han, Michael Wang, and Amgad Elgowainy, "Regional Differences in Life-Cycle Greenhouse Gas and Criteria Air Pollutant Emissions of Light-Duty Vehicles in the United States" (presentation, International Emission Inventory Conference, Tampa, FL, August 16, 2012), available at https://www3.epa.gov/ttnchie1/conference/ei20/session8/hcai.pdf; "GHGRP Refineries," Greenhouse Gas Reporting Program (GHGRP), U.S. Environmental Protection Agency, accessed Sept. 16, 2020, https://www.epa.gov/ghgreporting/ghgrp-refineries;



Projected cost of BEVs compared to ICE powertrains

Technological advancements and economies of scale are rapidly reducing battery costs. We reviewed several industry reports, including Ricardo's own analysis on battery cost projection. Since battery designs continue to evolve and adoption rates remain uncertain, it is difficult to pinpoint a specific battery cost profile over the next 20 years. However, it appears that an industry-wide battery cell cost of $100 per kilowatt-hour (kWh) could be achievable in 2024–2030 with further reductions to $62 per kWh possible in 2030–2040 (see figure 10).

Due to EV uptake, several of the allied movements will enjoy benefits in terms of reaching their emissions targets, but those movements are not necessarily driving the EV uptake. The key factors driving EV uptake are subsidies, the ZEV mandate, and charging infrastructure. Other movements, such as the LCFS, will benefit from PEV uptake but will have limited causal impact.

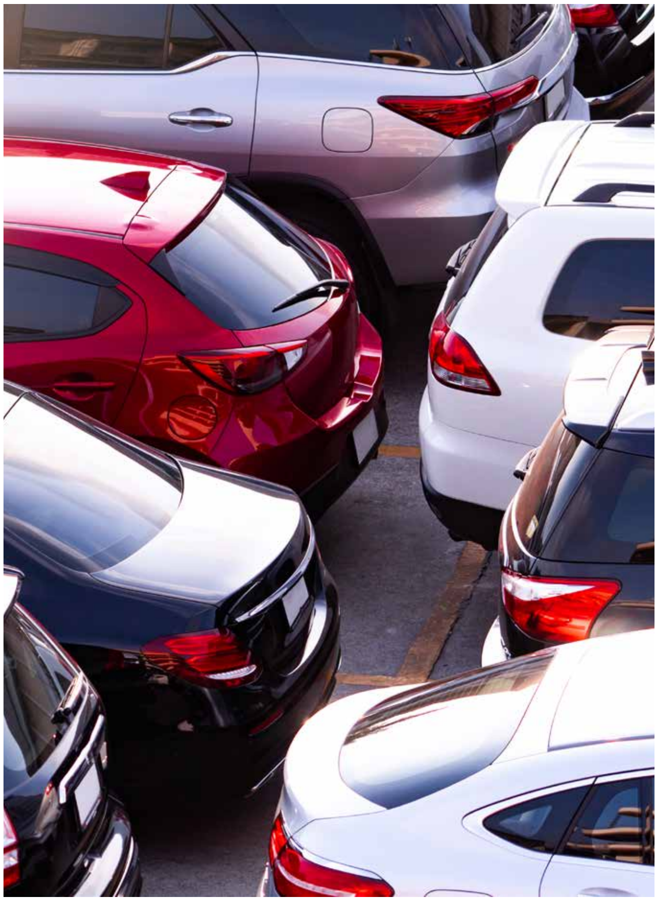
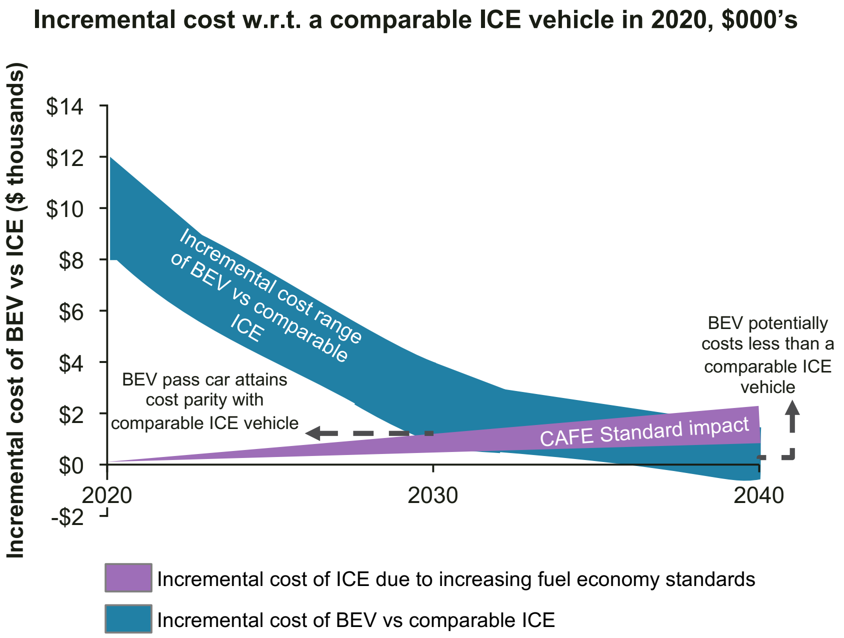


FIGURE 10: COST OF COMPLIANCE OF NEW VEHICLE SALES FROM SUBSIDIES, CORPORATE AVERAGE FUEL ECONOMY STANDARDS, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE[17]

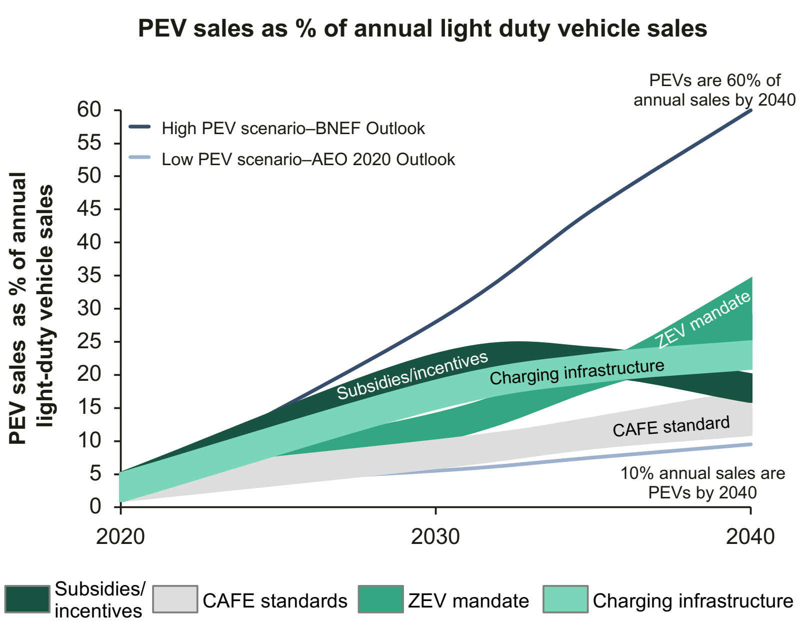


17 Colin McKerracher, Ali Izadi-Najafabadi, Aleksandra O'Donovan, Nick Albanese, Nikolas Soulopolous, David Doherty, Milo Boers, et al., *Electric Vehicle Outlook 2020* (London, UK: BloombergNEF, May 19, 2020), https://about.bnef.com/electric-vehicle-outlook/; Logan Goldie-Scot, "A Behind the Scenes Take on Lithium-ion Battery Prices," BloombergNEF, March 5, 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/.

Impact of subsidies, the ZEV mandate, and charging infrastructure on PEV sales

Ricardo stacked the three movements of subsidies and incentives, charging infrastructure, and the ZEV mandate and estimated the 2040 outlook for each movement. A few themes emerged in terms of how each movement impacts PEV uptake through 2040, measured as the percent of annual new light-duty vehicle sales. Subsidies currently play a significant role in driving PEV sales but are expected to be rolled back in the future, and the importance of other movements such as the ZEV mandate and charging infrastructure will take a predominant role in driving PEV sales in the medium to long term (see figure 11).

FIGURE 11: SUBSIDIES, CORPORATE AVERAGE FUEL ECONOMY STANDARDS, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE ESTIMATED IMPACT, YEAR-OVER-YEAR PLUG-IN ELECTRIC VEHICLE SALES PERCENTAGE[18]



18 U.S. Energy Information Administration, Annual Energy Outlook 2020; McKerracher et al.; International Energy Agency; Xavier Mosquet, Hadi Zablit, Andreas Dinger, Gang Xu, Michelle Andersen, and Kazutoshi Tominaga, *The Electric Car Tipping Point: The Future of Powertrains for Owned and Shared Mobility* (Boston, MA: Boston Consulting Group, January 11, 2018), https://www.bcg.com/publications/2018/electric-car-tipping-point; Wood Mackenzie, Electric Car Forecast to 2040, Verisk, accessed June 26, 2020, https://www.woodmac.com/our-expertise/capabilities/electric-vehicles/2040-forecast; Colin Langan, UBS Autos Outlook Today and Beyond, UBS Securities LLC, August 2017, https://www.cargroup.org/wp-content/uploads/2017/08/Langan.pdf; Edison Electric Institute, *Electric Vehicle Trends & Key Issues*, March 2018, https://www.eei.org/issuesandpolicy/electrictransportation/Documents/EV_Trends_and_Key_Issues_March2018.pdf

Impact of subsidies, the ZEV mandate, and charging infrastructure on lifecycle CO_2 emissions

Overall, CO_2 GHG emissions will reduce significantly from PEV sales. Ricardo's analysis estimates that if PEVs account for 60% of new vehicle sales by 2040, the result would be a 50% reduction in lifecycle GHG CO_2 emissions with respect to 2020 sales (see figure 12). The ZEV mandate, subsidies, and charging infrastructure all contribute to higher PEV uptake, thus contributing to reducing CO_2 emissions.

Impact of electrification on gasoline demand

Ricardo also estimated the impact on fuel consumption under varying PEV-penetration scenarios. Based on Ricardo analysis, a low-PEV scenario (PEVs constitute 10% of new vehicle sales in 2040) results in a U.S. PEV VIO of 18 million vehicles and 7 billion gallons of gasoline displacement in 2040 (see figure 13). A high-PEV scenario (PEVs constitute 60% of new vehicle sales in 2040) results in a U.S. PEV VIO of 85 million vehicles and 30 billion gallons of gasoline displacement in 2040 (see figure 13).

FIGURE 12: IMPACT ON GREENHOUSE GAS EMISSION OF NEW VEHICLE SALES FROM SUBSIDIES, CORPORATE AVERAGE FUEL ECONOMY STANDARDS, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE REPRESENTED IN TERMS OF AVOIDED EMISSIONS THROUGH THE LIFETIME

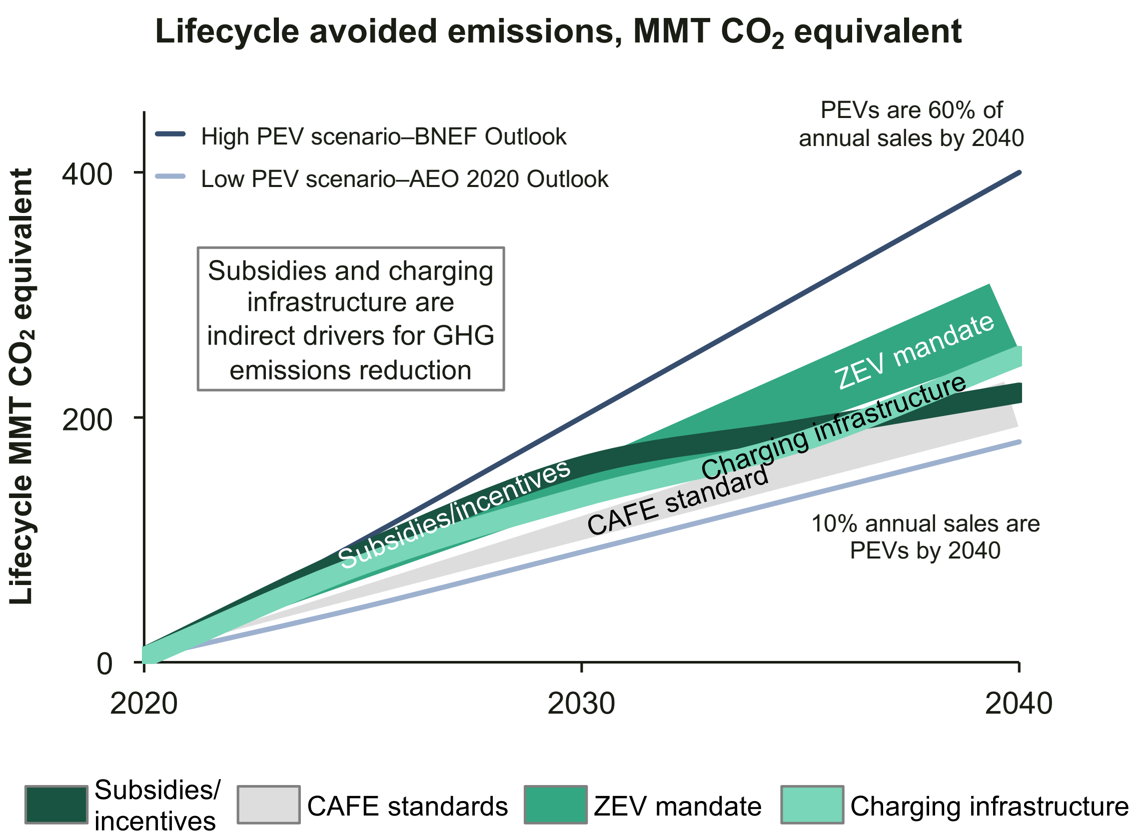
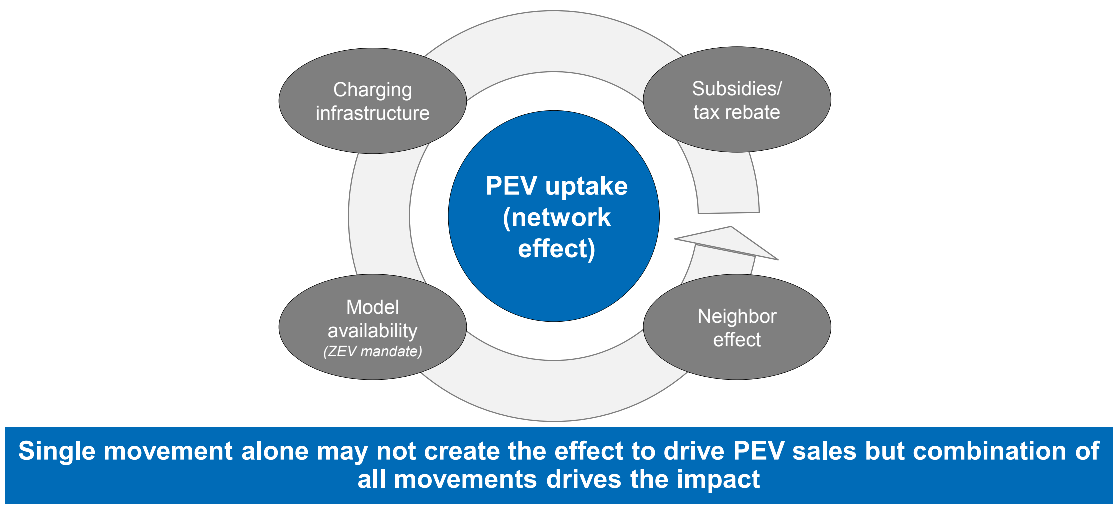


FIGURE 13: GASOLINE DISPLACED FROM SUBSIDIES, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE

	Low–EV scenario	High–EV scenario
PEV sales as a percentage of light-duty vehicle sales in 2040	10% PEV penetration	60% PEV penetration
PEV parc in 2040	18M vehicles (approx.)	85M vehicles (approx.)
Displaced gasoline consumption in 2040 (annual)	7B gallons (approx.)	30B gallons (approx.)

FIGURE 14: NETWORK EFFECT OF SUBSIDIES, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE

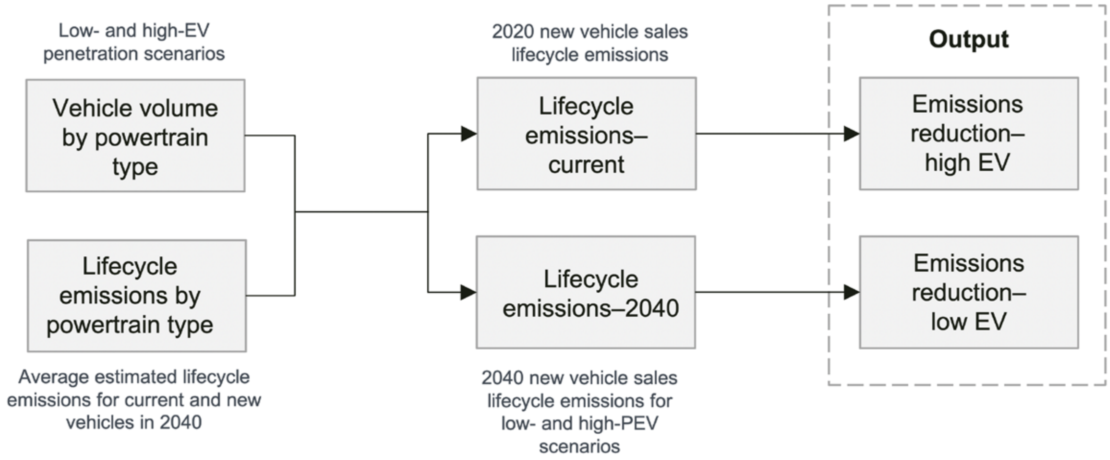


Symbiotic relationship of subsidies and incentives, the zero-emission vehicle mandate, and charging infrastructure

The three subsidies and incentives, the ZEV mandate, and charging infrastructure movements along with a fourth factor, the neighbor effect, create a network effect for the EV ecosystem (see figure 14). The neighbor effect is a phenomenon where a person in a neighborhood owning an EV leads others in the neighborhood to also desire an EV.[19] Ricardo's assessment found that each movement alone is not a key factor in driving EV purchases. All factors in unison are required: Subsidies alleviate cost pressure on the consumer, charging infrastructure reduces range anxiety, and the ZEV mandate drives OEMs to invest in technology advancement. These factors, including the neighbor effect, are symbiotic, and reducing the impact of one diminishes the impact of others.

19 Zeinab Rezvani, Johan Jansson, and Jan Bodin, "Advances in Consumer Electric Vehicle Adoption Research: A Review and Research Agenda," *Transportation Research Part D: Transport and Environment 34* (January 2015): 122-136. https://doi.org/10.1016/j.trd.2014.10.010.

FIGURE 15: SUBSIDIES AND INCENTIVES, ZERO-EMISSION VEHICLE MANDATE, AND CHARGING INFRASTRUCTURE ASSESSMENT METHODOLOGY



ASSESSMENT METHODOLOGY

Inputs

For estimating emissions reduction based on subsidies and incentives, the ZEV mandate, and charging infrastructure, Ricardo considered the following:

- **A low-EV scenario** mean PEVs consist of 10% of annual sales by 2040 (see figure 2).
  - The average fleet mpg in 2040 is estimated to be 55 mpg.
- **A high-EV scenario** means PEVs consist of 60% of annual sales by 2040.
  - The average fleet mpg in 2040 is estimated to be 90–95 mpg.
- **The lifecycle emissions per passenger vehicle** as provided in tons CO_2 equivalent:[20]
  - ICE vehicle in 2020: 50 tons CO_2
  - ICE vehicle in 2040: 40 tons CO_2 *(Ricardo assumption)*
- **BEV in 2020**: 30 tons CO_2
- **BEV in 2040**: 15 tons CO_2 *(Ricardo assumption)*
- **Well-to-wheel NO_x emissions** per passenger vehicle:[21]
  - ICE vehicle in 2020: 2.3 kg NO_x
  - ICE vehicle in 2040: 0.8 kg NO_x *(Ricardo analysis)*
  - BEV in 2020: 0.9 kg NO_x
  - BEV in 2040: 0.2 kg NO_x

  (Ricardo analysis)
- **Well-to-wheel $PM_{2.5}$ emissions** per passenger vehicle:[22]
  - ICE vehicle in 2020: 0.3 kg $PM_{2.5}$
  - ICE vehicle in 2040: 0.1 kg $PM_{2.5}$
  - BEV in 2020: 0.1 kg $PM_{2.5}$
  - BEV in 2040: 0.02 kg $PM_{2.5}$
- **States with a ZEV mandate account** for 30% of new U.S. vehicle sales.

Methodology and output

The bookends of emissions reduction impact from subsidies and incentives, the ZEV mandate, and charging infrastructure methodology and output are shown in figure 15.

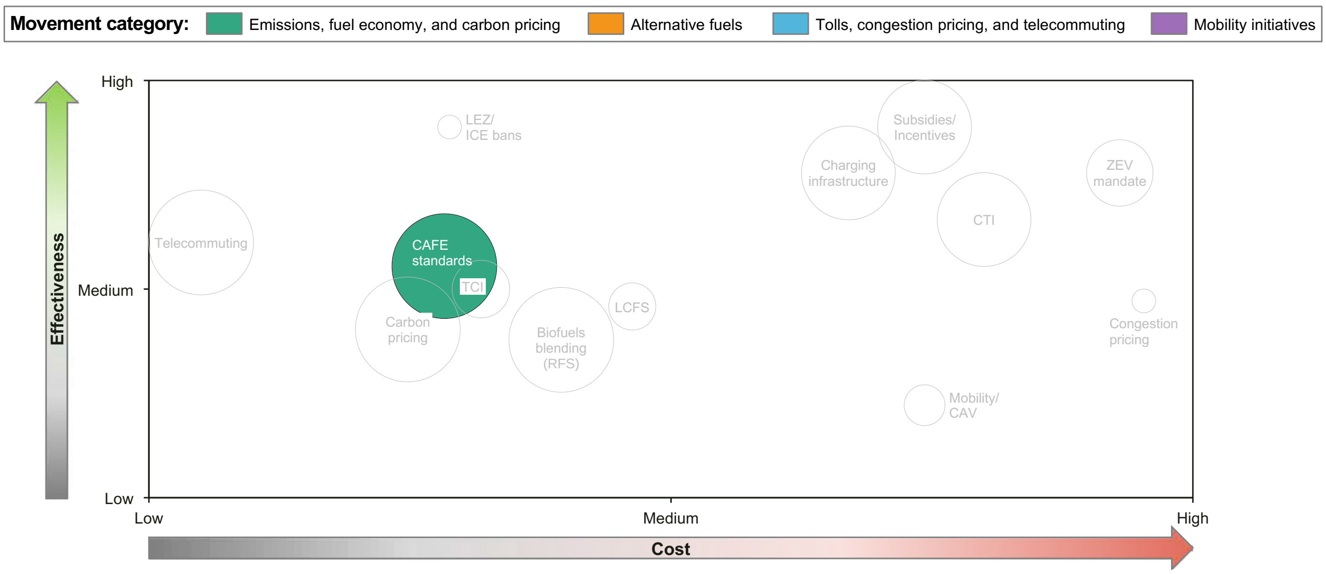
20 International Energy Agency, "Global EV Outlook 2019;" Hao Cai et al., "Regional Differences in Life-Cycle Greenhouse Gas and Criteria Air Pollutant Emissions of Light-Duty Vehicles in the United States;" "GHGRP Refineries," Greenhouse Gas Reporting Program (GHGRP); "2017 National Emissions Inventory (NEI) Data," Air Emissions Inventories, U.S. Environmental Protection Agency, accessed Sept. 16, 2020, https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data; Ricardo analysis.

21 International Energy Agency, "Global EV Outlook 2019"

22 International Energy Agency, "Global EV Outlook 2019"

CORPORATE AVERAGE FUEL ECONOMY STANDARDS

FIGURE 16: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: CORPORATE AVERAGE FUEL ECONOMY STANDARDS



FINDINGS

The federal CAFE standards were amended in 2020 and replaced with the new SAFE Vehicles Rule, which will affect emissions reductions for ICE vehicles. The SAFE Vehicles Rule fuel-economy improvement extrapolated until 2040 results in an 50% lower emissions reduction potential compared to prior CAFE standards extrapolated to 2040.

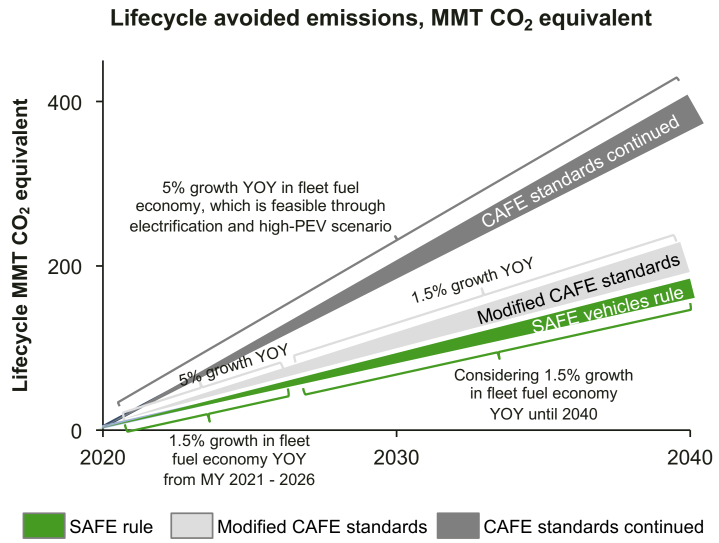
The prior CAFE standards were to impact vehicles until MY 2025 and mandated a 5% yearly fleet fuel-economy improvement, whereas the implemented SAFE Vehicles Rule impacts vehicles until MY 2026 and mandates a 1.5% yearly fleet fuel-economy improvement. Ricardo estimated the bookends by extrapolating the impact of standards until 2040. Continuing the CAFE standards fuel-economy growth rate of 5% compound annual growth rate until 2040 results in a lifecycle CO_2 emissions reduction of 400 MMT from new vehicle sales (see figure 17).

Achieving the prior CAFE standards relies on high-EV sales: more than 50% of new vehicle sales would need to be PEVs by 2040. The SAFE Vehicles Rule improvement of 1.5% extrapolated until 2040 results in 180 MMT of avoided lifecycle CO_2 emissions from new vehicle sales (see figure 17). A low-PEV scenario (PEVs constitute 10% of new vehicle sales by 2040) is enough to meet SAFE Vehicles Rule targets. The impact to criteria pollutants such as NO_x and PM due to CAFE standards or the SAFE Vehicles Rule by themselves may not be as drastic. The EPA's emissions targets are quite stringent (see figure 18). As such, most of the criteria pollutant impact will come from retiring older vehicles and adapting to Tier 3 and Tier 4 emissions standards. As shown in figure 9, meeting CAFE standards (which may mean a scenario close to high PEV by 2040) may yield a further 23–26% reduction in NO_x and PM compared to the SAFE Vehicles Rule (scenario close to low PEV in 2040).

The following assumptions were considered for the analysis:

- **The SAFE Vehicles Rule** mandates a 1.5% compound annual growth rate improvement in fleet-wide fuel economy until 2040.
- **The modified CAFE standards** mandate a 5% compound annual growth rate in fleet fuel economy until 2025 and 1.5% compound annual growth rate from 2025–2040.
- **The CAFE standards** mandate a 5% compound annual growth rate growth until 2040.

FIGURE 17: IMPACT ON GREENHOUSE GAS EMISSIONS OF NEW VEHICLE SALES FROM CORPORATE AVERAGE FUEL ECONOMY STANDARDS REPRESENTED IN TERMS OF AVOIDED EMISSIONS THROUGH THE LIFETIME



Source: Electric Vehicle Outlook 2020; Annual Energy Outlook 2020*; "Average Fuel Efficiency of U.S. Light Duty Vehicles;" Ricardo analysis*

FIGURE 18: ENVIRONMENTAL PROTECTION AGENCY EMISSION STANDARDS FOR LIGHT-DUTY VEHICLES

U.S. emissions standards	Average vehicle registration age that meets the standards	NO_X (g/mile)		PM (g/mile)	
Tier 1	Fleetwide phase-in from 1997	0.6		0.1	
Tier 2	Fleetwide phase-in from 2007	0.07	88%	0.01	90%
Tier 3	Fleetwide phase-in to be completed in 2025	0.03	57%	0.003	70%
Tier 4 *(Ricardo est.)*	Fleetwide phase-in to be completed in 2031	0.015	50%	0.0015	50%

Source: Environmental Protection Agency, EPA Emission Standards for Light-Duty Vehicles and Trucks and Motorcycles, March 2016
https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-light-duty-vehicles-and-trucks-and

ASSESSMENT METHODOLOGY

Inputs

For estimating emissions reduction based on the CAFE standards, Ricardo considered the following:

- **2020 new vehicle average fleet fuel economy:** 37 mpg[23]
- **Prior CAFE standards fuel-economy growth:** 5% compound annual growth rate[24]
  - MY 2020–2025
  - Extrapolated growth rate until 2040 for high-impact scenario
- **SAFE Vehicles Rule fuel-economy growth:** 1.5% compound annual growth rate[25]
  - MY 2021–2026
  - Extrapolated growth rate until 2040 for low-impact scenario

Methodology and output

Extrapolating the fleet fuel economy from the SAFE Vehicles Rule until 2040 results in fleet fuel economy of 50 mpg and yields emission reduction benefits similar to those achieved from the low-PEV scenario, in which PEVs account for 10% of vehicle sales in 2040. The prior CAFE standards extrapolated until 2040 result in fleet fuel economy of 90-95 mpg and would yield an emissions reduction similar to those achieved from the high-PEV scenario, in which PEVs account for 60% of vehicle sales in 2040.

To determine the cost of compliance for the CAFE standards and SAFE Vehicles Rule, we reviewed four studies:

1. **EPA Final Determination (2017), impacting MY 2022–2025**
2. **The National Highway Traffic Safety Administration (NHTSA) *Technical Assessment Report* (2016), impacting MY 2022–2028**
3. **Proposed EPA SAFE Vehicles Rule (2018), impacting MY 2021–2029**
4. **Indiana University's *A Macroeconomic Study of Federal and State Automotive Regulations* (2017), funded by Auto Alliance (consists of 12 OEMS, including General Motors Company, Ford Motor Company, and Fiat Chrysler Automobiles)**

The results from these studies are quite varied. The 2017 EPA report claims an average incremental technology cost of $570 per passenger vehicle to comply with CAFE standards. The 2018 EPA SAFE

23 U.S. Energy Information Administration, *Annual Energy Outlook 2020*, Table 41. Light-Duty Vehicle Miles Traveled by Technology Type, available at https://www.eia.gov/outlooks/aeo/tables_ref.php.

24 Office of Transportation and Air Quality, U.S. Environmental Protection Agency; National Highway Traffic Safety Administration; U.S. Department of Transportation; and California Air Resources Board, *Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025*, July 2016, https://www.enotrans.org/wp-content/uploads/2019/08/P100OXEO.pdf.

25 "The Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026," Regulations for Emissions from Vehicles and Engines, U.S. Environmental Protection Agency, accessed June 26, 2020, https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-final-rule.

Vehicles Rule report suggests an average incremental cost of $3,141 per passenger vehicle to comply with the SAFE Vehicles Rule. CAFE standards, of course, are stricter compared to the SAFE Vehicles Rule, so the two EPA analyses appear contradictory to one another. The International Council on Clean Transportation takes a favorable position to the 2017 EPA study and the NHTSA technical assessment but disagrees with the cost analysis in the SAFE Vehicles Rule (2018). Indiana University's cost analysis suggests $1,289–1,881 per vehicle to meet CAFE standards. Ricardo has not conducted an in-depth analysis on this topic; however, our first-order estimate suggests an incremental cost of $1,000–1,800 per vehicle to meet the SAFE Vehicles Rule and >$1,800 per vehicle to meet CAFE standards. The purpose of this report is to assess the first-order impact of a movement. In keeping with that philosophy, we have used Ricardo estimated ranges for our analysis.

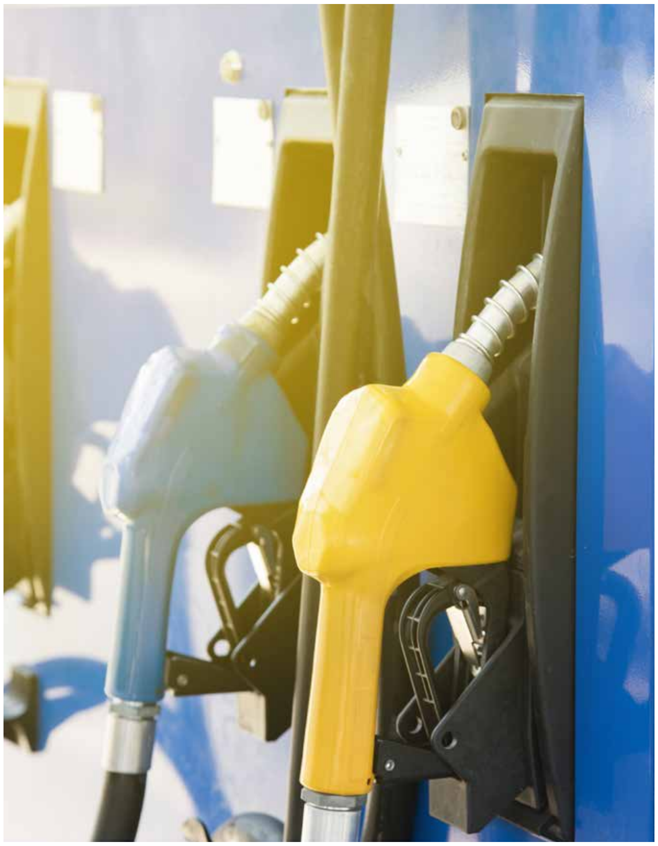
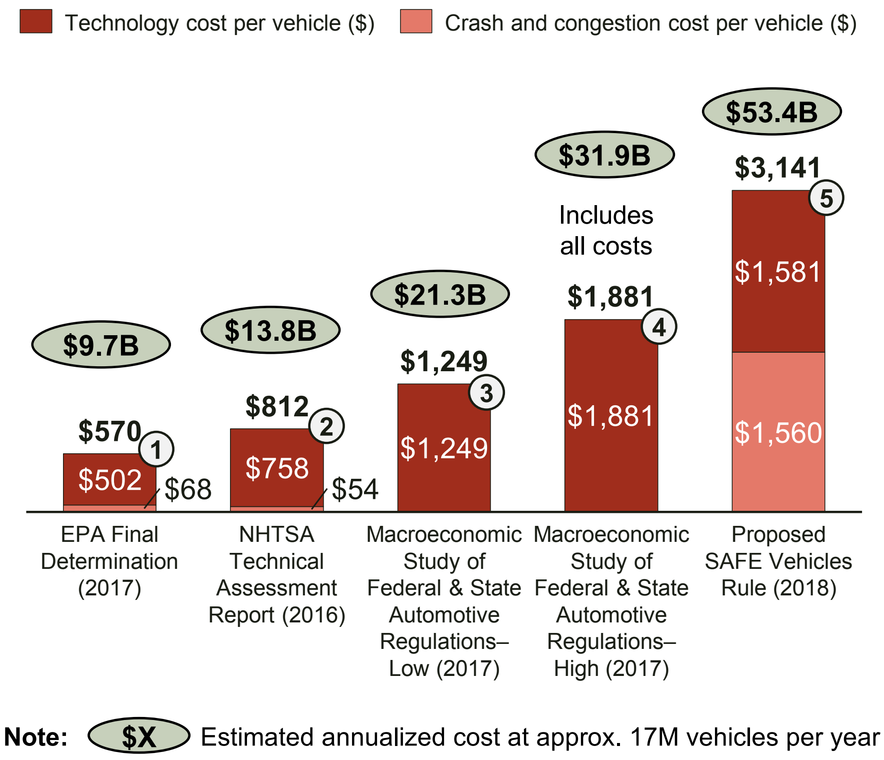


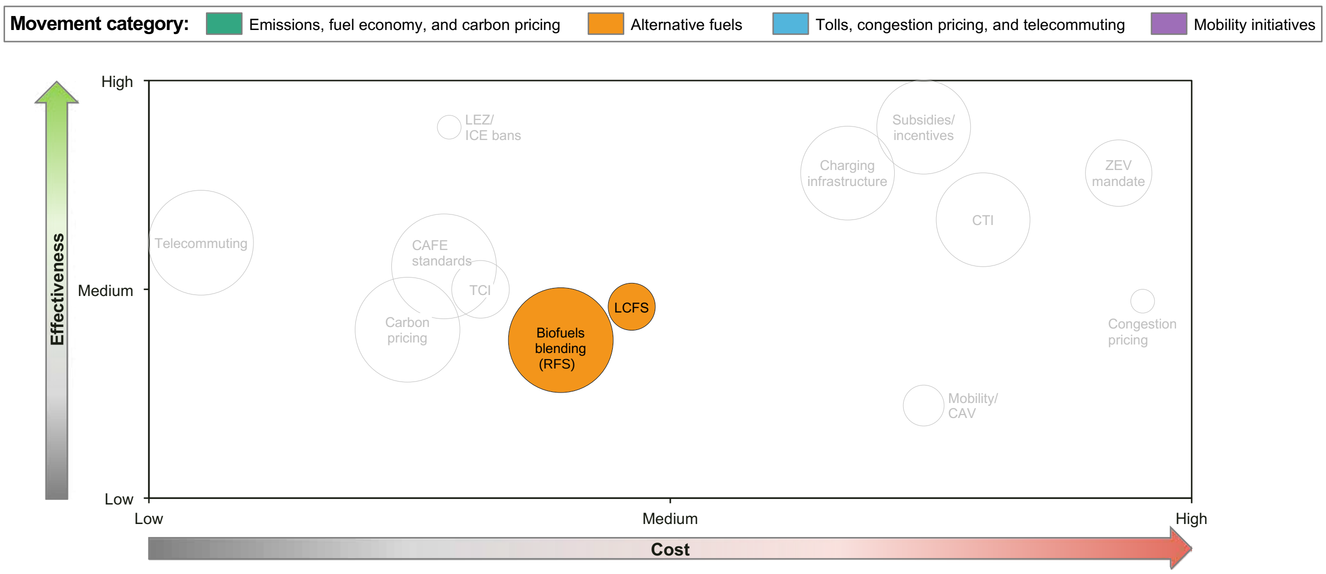
FIGURE 19: AGGREGATION OF VARIOUS STUDIES ON COST OF COMPLIANCE FOR CORPORATE AVERAGE FUEL ECONOMY STANDARDS AND SAFER AFFORDABLE FUEL-EFFICIENT VEHICLES RULE



Source: Sanya Carley, Denvil Duncan, John D. Graham, Saba Siddiki, and Nikolaos Zirogiannis, A Macroeconomic Study of Federal and State Automotive Regulations with Recommendations for Analysts, Regulators, and Legislators (Indiana University School of Public and Environmental Affairs, March 2017), https://oneill.indiana.edu/doc/research/working-groups/auto-report-032017.pdf; International Council on Clean Transportation, The flawed benefit-cost analysis behind proposed rollback of the U.S. light-duty vehicle efficiency standards, June 2019, https://theicct.org/sites/default/files/publications/ICCT_US-rollback-CBE-flaws_20190621.pdf; U.S. Environmental Protection Agency, Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation, January 2017, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100QQ91.pdf; U.S. Environmental Protection Agency Office of Transportation and Air Quality, U.S. Department of Transportation National Highway Traffic Safety Administration, and California Air Resources Board, Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025, July 2016, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100OXEO.PDF?Dockey=P100OXEO.PDF; The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, 83 Fed. Reg. 42986- 43500 (August 24, 2018), available at https://www.govinfo.gov/content/pkg/FR-2018-08-24/pdf/2018-16820.pdf.

LOW CARBON FUEL STANDARD AND RENEWABLE FUEL STANDARD

FIGURE 20: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: LOW CARBON FUEL STANDARD AND RENEWABLE FUEL STANDARD



FINDINGS

The LCFS, a regional program adopted by California and Oregon, and the RFS, a federal program, have both had varying success. The LCFS pursues a CI-based approach to meet emission reduction targets, whereas the RFS considers a volume-based approach for certain targeted renewable fuels for emissions reduction.

SUMMARY OF FINDINGS

APPROACH	FINDINGS
LCFS' CI target approach is more effective than RFS' volume-based approach	The RFS has needed to lower its volume targets significantly, whereas the industry appears to only slightly lag behind LCFS targets.
Four main alternative fuels contribute to the LCFS	Starch ethanol, biodiesel, renewable diesel, and biomethane are the main fuels contributing to the LCFS.
The LCFS does not cause EV popularity but will benefit from it	EVs are popular due to industry's technological advancements, not because of LCFS targets. The LCFS will continue to benefit from EV uptake, as the mandate offers credits to electricity used in transportation.
If EVs plateau, some other alternative fuel will need to incentivize consumers	Outside of EVs, other alternative fuels (based on current projections) do not appear to cause a significant market shift in adoption, mainly because they do not offer consumers an appreciable operational cost benefit or driving feature enhancements as EVs do.

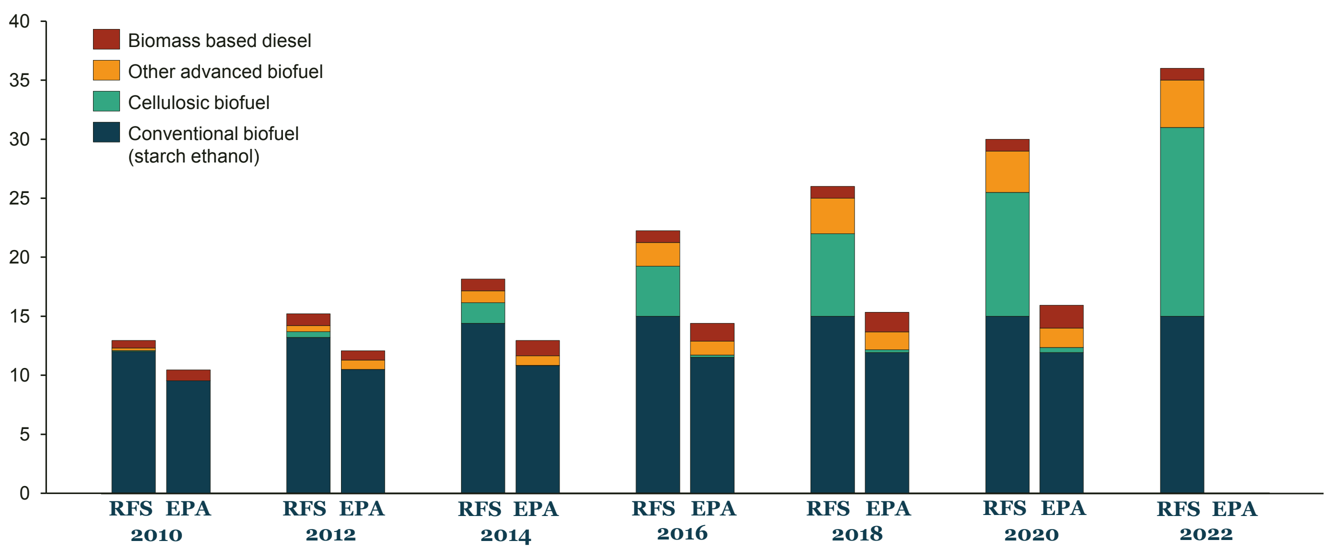
Renewable Fuel Standard targets and results
EPA waivers for the RFS show a significant lag in meeting original targets, and the RFS is estimated to meet 50% of its targeted 36 billion gallons of renewable fuels by 2022 (see figure 21). Over the years, the EPA has consistently waived some of the renewable fuel volumes required by its standard. The RFS considers four renewable fuel categories in its program: biomass-based diesel, other advanced biofuel, cellulosic biofuel, and conventional biofuel (such as starch ethanol). Starch ethanol–based renewable fuel and biomass-based diesel have on average tracked to the target. However, the other two renewable fuels have not met their targets mainly due to a high relative cost of production, and the EPA has scaled down its targets significantly. Due to continued waivers granted by the EPA, the effectiveness of this program is under scrutiny.

Numerous new fuel pathways are awaiting EPA approval. The new pathways, if approved, may have a significant positive impact on meeting the overall RFS goal. One significant pathway awaiting approval would allow for EV fuel consumption made from renewable sources (in kWh) to generate credits. Credits are defined as renewable identification numbers (RIN), and the new RIN for electric vehicles would use the nomenclature eRIN. The eRIN could be used to fill the cellulosic fuel demands that have plagued the program. The eRIN was finalized in a 2014 rulemaking, and the EPA is expected to discuss this and other proposed rules on new pathways in late 2020 or early 2021.

Low Carbon Fuel Standard targets and projected alternative fuel and credit mix
The LCFS mandates a CI reduction target of 20% by 2030 compared to 2010 levels (see figure 22). Linear extrapolation suggests achieving a 30% CI reduction target by 2040. Ethanol, biodiesel, renewable diesel, and biomethane will likely be key drivers alongside electrification to meet these LCFS targets.

From a credit mix perspective, biomethane (such as natural gas and liquified natural gas processed from a landfill) may garner a share; however, from a cost

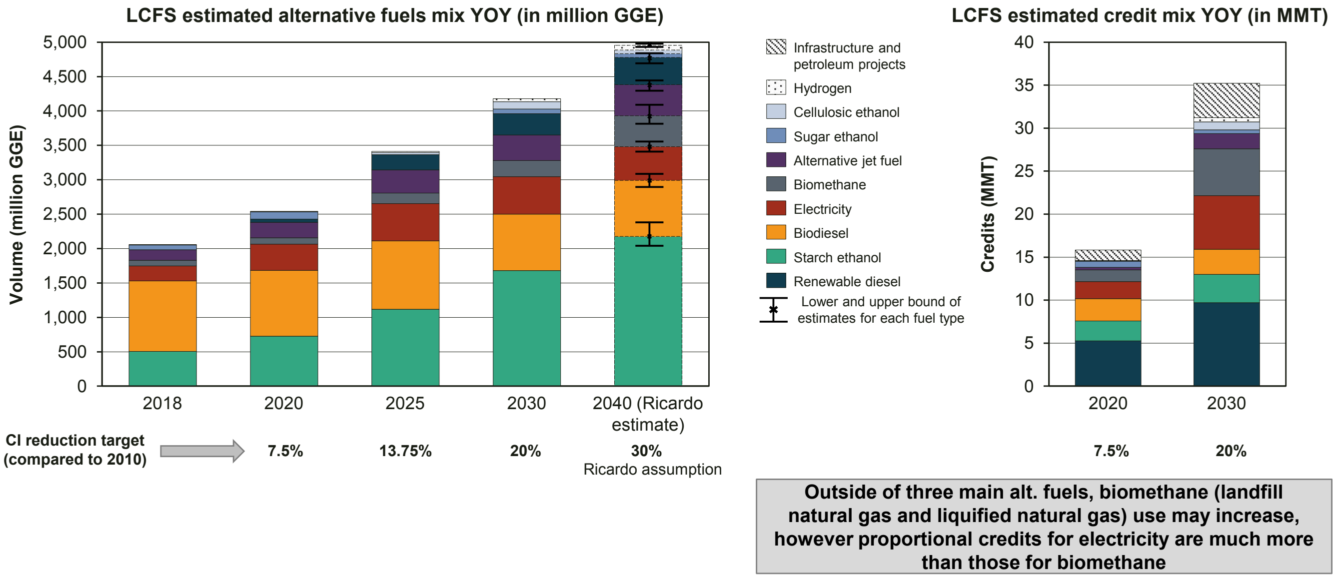
FIGURE 21: YOY VOLUME REQUIREMENTS OF RENEWABLE FUEL STANDARD STATUTE VS. ENVIRONMENTAL PROTECTION AGENCY FINAL RULES[26]



NOTE: *RFS Statute enacted under Energy Independence and Security Act of 2007 extends the yearly volume requirements out to 2022*
TBD*: *EPA sets final volumes each year for the following year. Hence, data is available for 2020 (finalized on December 19, 2019) but not for 2021 and beyond*

26 "Final Renewable Fuel Standards for 2020, and the Biomass-Based Diesel Volume for 2021," Renewable Fuel Standard Program, U.S. Environmental Protection Agency, accessed June 26, 2020, https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2020-and-biomass-based-diesel-volume.

FIGURE 22: MAIN ALTERNATIVE FUELS CONTRIBUTING TO LOW CARBON FUEL STANDARD[27]



perspective, they do not appear to be as effective as BEVs today. BEVs are expected to continue to play an important role along with starch-based ethanol and renewable diesel. Other fuels, such as cellulosic ethanol, which the RFS has banked on, have not seen any desirable results yet due to cost. The LCFS avails the benefits of electrification and will continue to do so based on the projected growth of electrification. However, the LCFS is not a key factor in driving PEV uptake.

A 2018 California Air Resources Board LCFS amendment includes credit generation for EV supply equipment and hydrogen operators (public retail and fleets). Dollars generated through the sale of LCFS EV charging credits are to benefit consumers and/or be used for further marketing of EV charging.

27 "Illustrative Compliance Scenario Calculator," 2018 Amendments to the LCFS and ADF Regulations, LCFS Regulation, California Air Resources Board, August 15, 2018, downloadable Microsoft Excel file available at https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-regulation; Ricardo analysis.

In addition to generating LCFS credit for dispensed fuel, the eligible hydrogen station, or DC fast charger, can generate infrastructure credits based on the capacity of the station or charger minus the quantity of dispensed fuel.

This new rule will improve an operator's ROI and further incentivize the EV market in states adopting LCFS programs.

Average Low Carbon Fuel Standard fuels carbon intensity values

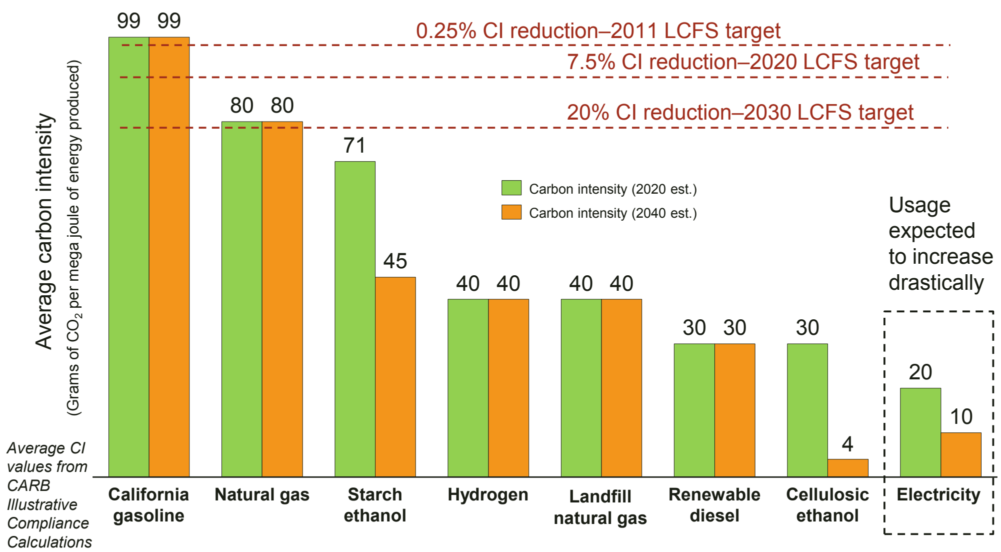
The LCFS measures its targets on a CI basis, which is the lifecycle impact of CO_2 per mega joule of energy produced. The CI of electricity is much lower than that of ethanol and, as EV uptake increases, the impact on CI is significant in enabling the LCFS to meet its targets (see figure 23). Though other fuels, such as cellulosic ethanol, are lower in CI than other options, the cost equation does not line up. Meanwhile, some of the other fuels lack both pull from the consumers and push from the industry.

Fuel economy and cost impact of renewable fuels

Alternative fuels and fuel blends deliver marginally lower fuel economy in comparison to baseline gasoline and diesel fuels; however, some blends are cheaper at the pump compared to gasoline and diesel. From a total cost of ownership perspective, these alternative fuels range from slightly cost positive to slightly cost negative for consumers depending on the blending ratio (see figure 24). Coupled with the constraints over widespread fuel availability at filling stations, individual consumers and commercial-vehicle fleet managers may not find a compelling reason to switch to these fuels.

In mid-2020, it appears that the cost-benefit equation is leaning towards electrification relative to some alternative fuels (though not tilted completely yet), considering the total cost of ownership and emissions impact. Whether advancements in hydrogen fuel cell and other alternative fuels make these fuels become equally or more attractive as PEVs or not remains to be seen.

FIGURE 23: CARBON INTENSITY FOR VARIOUS ALTERNATIVE FUELS[28]



28 "Illustrative Compliance Scenario Calculator"

FIGURE 24: FUEL ECONOMY AND COST IMPACT OF ALTERNATIVE FUELS

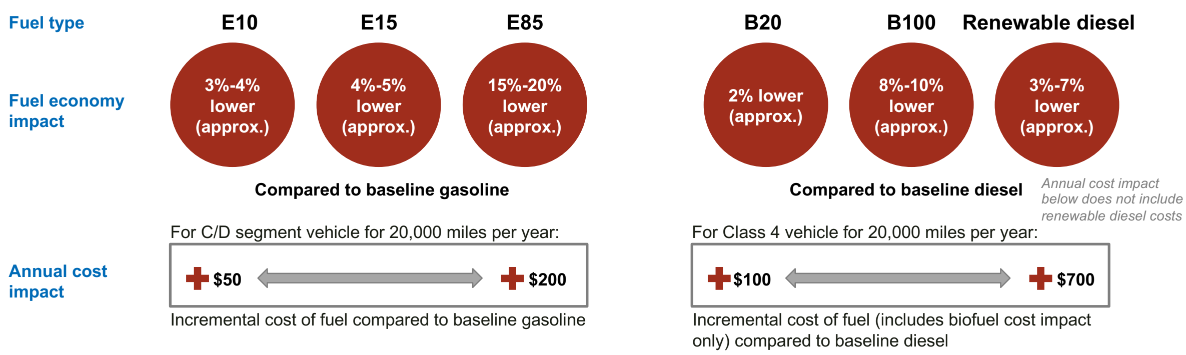
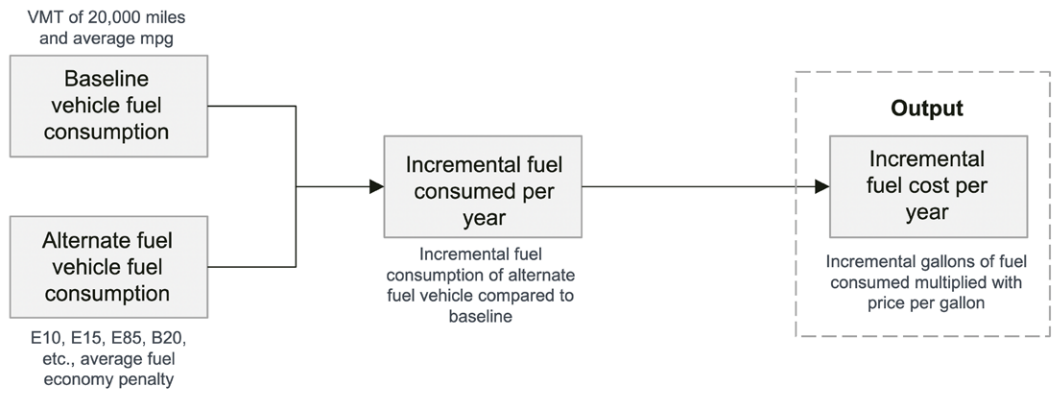


FIGURE 25: RFS AND LCFS INCREMENTAL FUEL COST ASSESSMENT METHODOLOGY



ASSESSMENT METHODOLOGY

Inputs

For estimating fuel-economy penalties from the LCFS and RFS, Ricardo considered the following:

- **According to the EPA, the average annual VMT for passenger vehicles is 13,000 miles; for commercial vehicles of Class 4–6, it is 25,000 miles; and for Class 7–8, it is 45,000 miles.** We have taken the weighted average as 20,000 miles for the U.S. fleet of all vehicles.
- **C/D passenger car:** baseline 37 mpg; **Class 4 diesel trucks:** baseline 13 mpg
- **Fuel economy percentage reduction of alternative fuel blends over baseline fuels:**
  - E10: 3–4%, E15: 4–5%, and E85: 15–20%[29]
  - B20: 2%, B100: 8–10%, renewable diesel: 3–7%[30]
- **Cost impact uses the January 2020 national average for retail fuel prices[31]**

Methodology and output

The process flow for estimated annual incremental fuel costs incurred by using alternative fuels methodology and output is shown in figure 25.

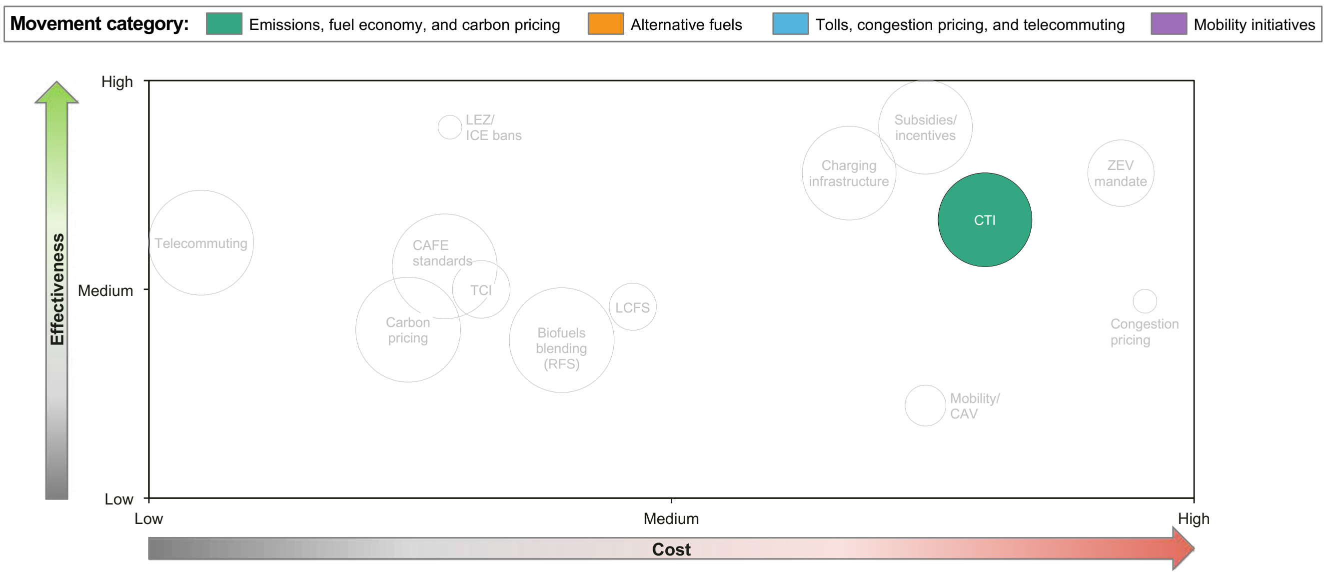
29 "Ethanol," Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, accessed June 26, 2020, https://www.fueleconomy.gov/feg/ethanol.shtml.

30 "Biodiesel," Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, accessed June 26, 2020, https://www.fueleconomy.gov/feg/biodiesel.shtml; Kenneth Kelly and Adam Ragatz, *Economy and Emissions Impacts from Solazyme Fuel in UPS Delivery Vehicles* (Washington, DC: National Renewable Energy Laboratory, August 2018), https://www.nrel.gov/docs/fy18osti/68896.pdf.

31 Clean Cities, *Clean Cities Alternative Fuel Price Report*, U.S. Department of Energy, January 2020, https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_jan_2020.pdf.

CLEANER TRUCKS INITIATIVE

FIGURE 26: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: CLEANER TRUCKS INITIATIVE



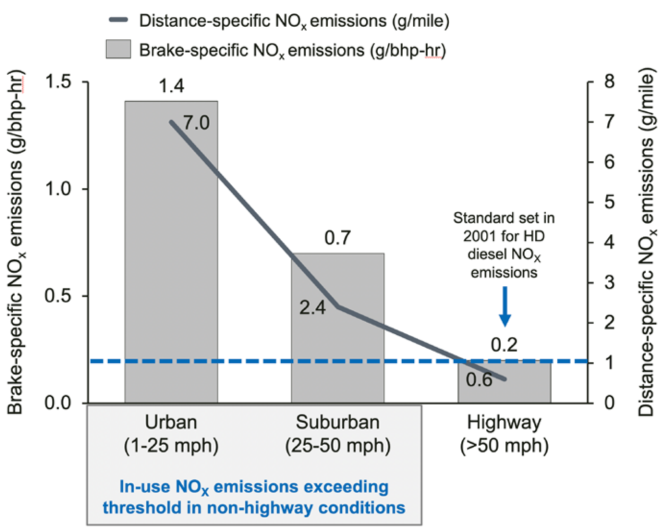
FINDINGS

The CTI is targeted at medium- and heavy-duty commercial vehicles and aims to lower NO_X emissions with a focus on lower load and speed conditions.[32] The CTI is still in its proposal phase, and its expected impact is after 2025. The EPA's existing rule of 0.6 g per mile (0.2 g per bhp-hr) for NO_X is met largely only under highway operation. If trucks meet the 0.6 g per mile target across all load and speed conditions, then by 2040, NO_X emissions of medium- and heavy-duty diesel truck VIO will reduce by >65% in a low-electrification scenario and >75% in a high-electrification scenario (see figure 28).

Current status of commercial vehicles NO_x emissions standards

The EPA's current emissions standards have lowered overall NO_X emissions but have not resulted in effective emissions control under low-load conditions such as urban and suburban driving (see figure 27). Its existing rule of 0.6 g per mile (0.2 g per bhp-hr)

FIGURE 27: AVERAGE IN-USE NO_X EMISSIONS FROM MODEL YEAR 2010–2016 HEAVY-DUTY DIESEL VEHICLES



32 "Cleaner Trucks Initiative," Regulations for Emissions from Vehicles and Engines, U.S. Environmental Protection Agency, accessed June 26, 2020, https://www.epa.gov/regulations-emissions-vehicles-and-engines/cleaner-trucks-initiative.

for NO_x is being met mostly under highway operation. The International Council on Clean Transportation's analysis of the EPA's Manufacturer-Run In-Use Testing Program for heavy-duty diesel engines found that >50% of heavy-duty vehicles average use time is under low-load conditions.[33] The EPA stated the objective of CTI is to achieve lower NO_x emissions with a focus on lower load conditions, i.e., idle vehicles or slowing moving or stop-and-go traffic.[34] The EPA last revised its NO_x standards for heavy-duty trucks in 2001, impacting MY 2007–2010.[35] These standards were:

- **NO_x emissions** of 0.20 g per bhp-hr
- **PM emissions** of 0.01 g per bhp-hr
- **Non-methane hydrocarbons** of 0.14 g per bhp-hr

On January 6, 2020, the EPA signed an Advance Notice of Proposed Rule requesting comments on the CTI from various industry bodies. A final rule is not expected until 2021.

Estimated NO_x tailpipe emissions impact from Cleaner Trucks Initiative

While projecting the impact of the CTI, Ricardo assumed that the CTI would target 0.6 g per mile NO_x emissions across all load profiles of diesel truck operation from MY 2025. By 2040, even in a low-PEV scenario (where PEVs are less than 5% of annual sales for medium- and heavy-duty diesel commercial vehicles), meeting a 0.6 g per mile target across all load conditions reduces NO_x emissions by > 65% compared to the baseline (current emissions), as shown in table 3 and figure 28. Primarily the reduction in NO_x emissions is driven by newer vehicles replacing the older generation of vehicles.

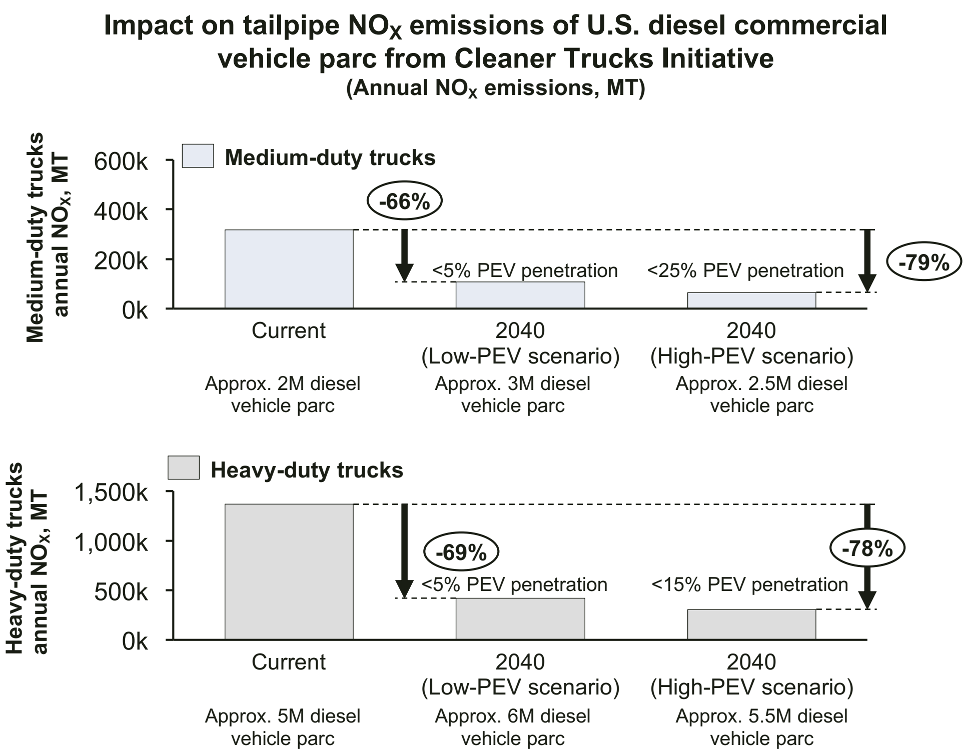
In addition, a high-PEV scenario (where PEVs account for 25% of medium-duty truck sales and 15% of heavy-duty truck sales) results in a >75% NO_x emissions reduction, or a >10% incremental benefit over the low-PEV scenario, as shown in table 3 and figure 28. The high-EV scenario outlines the incremental benefit offered by EVs; however, vehicle retirement alone remains the primary factor for significant emissions reductions with the added benefit from electrification.

33 Huzeifa Badshah, Francisco Posada, and Rachel Muncrief, *Current State of NOx Emissions from In-Use Heavy-Duty Diesel Vehicles in the United States* (Washington, DC: International Council on Clean Transportation, November 2019), https://theicct.org/sites/default/files/publications/NOx_Emissions_In_Use_HDV_US_20191125.pdf.

34 Cleaner Trucks Initiative, https://www.epa.gov/regulations-emissions-vehicles-and-engines/cleaner-trucks-initiative

35 "Final Rule for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements," Regulations for Emissions from Vehicles and Engines, U.S. Environmental Protection Agency, accessed June 26, 2020, https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-control-air-pollution-new-motor-vehicles-heavy.

FIGURE 28: IMPACT OF CLEANER TRUCKS INITIATIVE ON TAILPIPE NO_x EMISSIONS OF U.S. DIESEL COMMERCIAL VEHICLE VEHICLES IN OPERATION



CTI to impact only model years 2025+ and assumes CTI target of 0.6 g/mile NO_x emissions across all load profiles of diesel truck operation

Meeting 0.6 g/mile target across all load conditions reduces medium- and heavy-duty duty diesel trucks parc NO_x emissions by > 65% in low-electrification scenario and >75% in high-electrification scenario

Note: Analysis considers that PEVs replace highest emitting vehicles in the parc. Average annual VMT considered: medium-duty diesel trucks – 25k miles; heavy-duty diesel trucks – 45k miles

TABLE 3: MEDIUM- AND HEAVY-DUTY COMMERCIAL TRUCKS IN OPERATION BREAKDOWN BY POWERTRAIN TYPE[36]

VEHICLE CLASS	POWERTRAIN	CURRENT	2040 LOW-PEV SCENARIO	2040 HIGH-PEV SCENARIO
Medium-duty trucks (Class 4-6)	Diesel	61%	61%	48%
	Gasoline	38%	35%	27%
	PEV	<1%	approx. 2%	approx. 22%
	Others	<1%	approx. 2%	approx. 3%
	Total vehicles	**approx. 3.5 million**	**approx. 5 million**	**approx. 5 million**
Heavy-duty trucks (Class 7-8)	Diesel	98%	98%	86%
	Gasoline	N/A	N/A	N/A
	PEV	<1%	approx. 1%	approx. 12%
	Others	<1%	approx. 2%	approx. 2%
	Total vehicles	**approx. 5 million**	**approx. 6 million**	**approx. 6 million**

36 "Annual Energy Outlook 2020, Table 49. Freight Transportation Energy Use," U.S. Energy Information Administration, accessed January 29, 2020, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=58-AEO2020&cases=ref2020&sourcekey=0; Bernd Heid, Russell Hensley, Stefan Knupfer, and Andreas Tschiesner, "What's sparking electric-vehicle adoption in the truck industry?," McKinsey & Company, September 26, 2017, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry#; Ricardo analysis

ASSESSMENT METHODOLOGY

Inputs

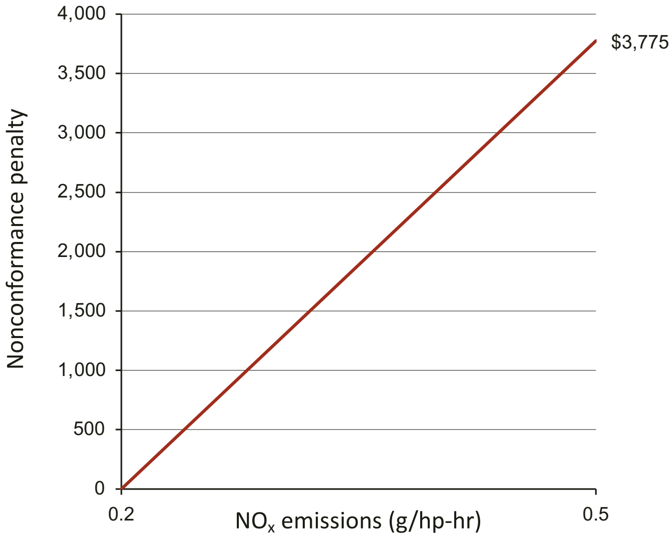
For estimating emissions reduction based on CTI, Ricardo considered the following:

- **The CTI targets 0.6 g per mile of NO_x emissions across the entire operating profile of a diesel truck**
  - The initiative was phased in by 25% increments and will be fully phased in by 2027
- **Current diesel truck VIO NO_x emissions:** 6 g per mile[37]
- **New vehicle sale NO_x emissions:** 4 g per mile (weighted)
- **Medium-duty VMT:** 25,000 miles per year[38]
- **Heavy-duty VMT:** 45,000 miles per year
- **Based on Ricardo analysis, commercial vehicle VIO powertrain penetration** (see table 3):
  - Low-EV scenario
    - Medium duty: <5%, Heavy duty: <5%
  - High-EV scenario
    - Medium duty: <25%, Heavy duty: <15%

The CTI in its current proposal does not provide an estimate of cost penalties. However, there is historical precedence of the EPA applying penalties for not meeting emissions targets. As a reference, figure 29 shows the calculated per-engine penalties up to $3,775 for emission rates between 0.20 and 0.50 g per hp-hr NO_x for MY 2012 heavy-duty engines. The maximum penalties will increase by several hundred dollars per engine each year for later model years.[39]

The rule does not state whether the penalties are yearly or one-time, but it seems logical that it would be one-time since once an engine is sold, it would be unreasonable to levy yearly penalties as the manufacturer has no control when those engines/vehicles will be scrapped.

FIGURE 29: ENVIRONMENTAL PROTECTION AGENCY NONCONFORMANCE PENALTIES FOR 2012 HEAVY-DUTY DIESEL ENGINES



37 U.S. Environmental Protection Agency, Office of Transportation and Air Quality, personal communication, April 6, 2018; Office of Transportation and Air Quality, *Non-Conformance Penalties for Heavy-Duty Diesel Engines Subject to the 2010 NOx Emission Standard*, U.S. Environmental Protection Agency, January 2012, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100DHDL.TXT.

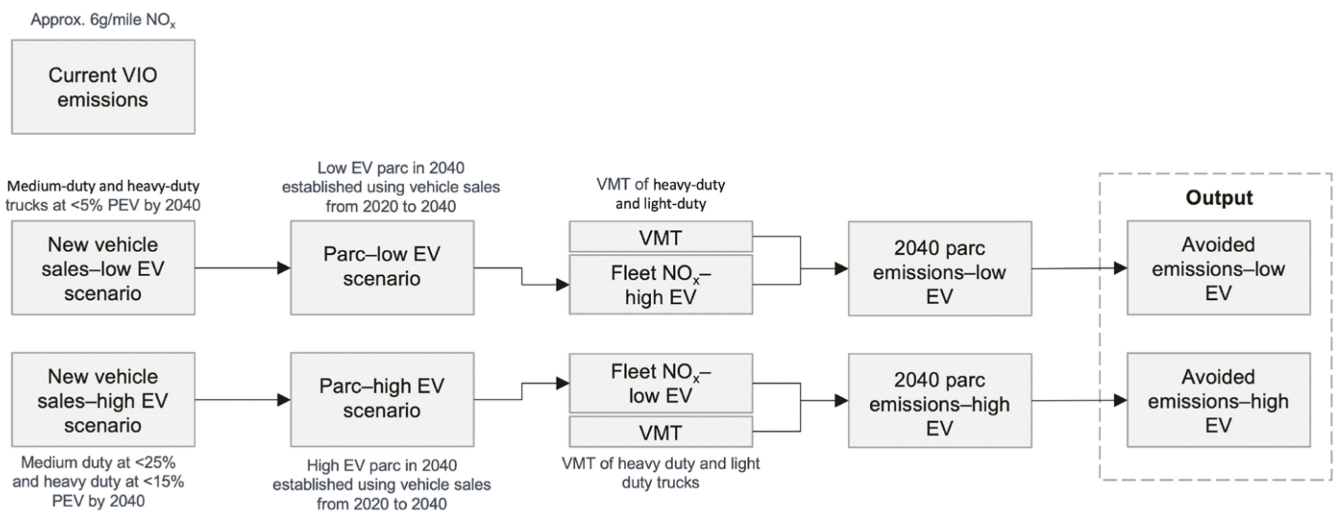
38 Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine Standards, 86 Fed. Reg. 3306 (January 21, 2020), available at: https://www.govinfo.gov/content/pkg/FR-2020-01-21/pdf/2020-00542.pdf.

39 U.S. Environmental Protection Agency, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100DHDL.TXT

Methodology and output

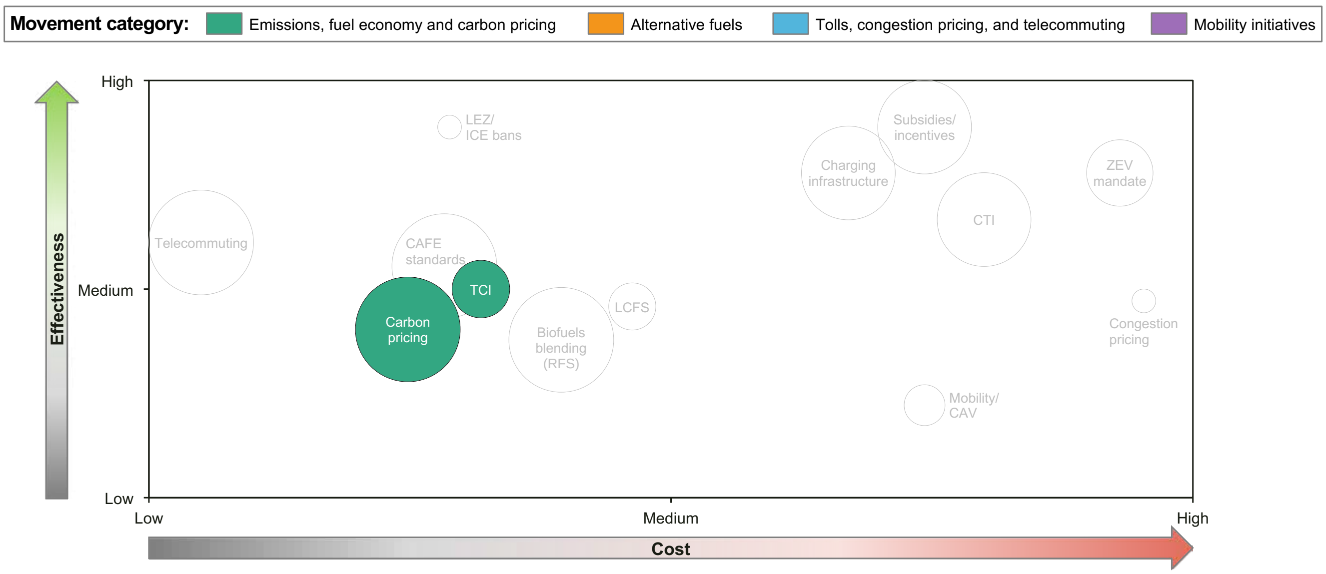
The process flow for the CTI emissions methodology and output is shown in figure 30.

FIGURE 30: CLEANER TRUCKS INITIATIVE EMISSIONS ASSESSMENT METHODOLOGY



TRANSPORTATION CLIMATE INITIATIVE AND CARBON PRICING

FIGURE 31: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: TRANSPORTATION CLIMATE INITIATIVE AND CARBON PRICING



FINDINGS

The TCI and carbon pricing may have a limited direct impact on emissions reduction given their limited nationwide momentum. The TCI is estimated to contribute 1–6% of the overall target of 20–25% of carbon emissions reduction,[40,41] with the rest achieved through electrification and fuel efficiency improvement (see figure 32).[42] Revenue from this initiative will be invested to support other low-carbon transportation initiatives (see table 4). Numerous carbon-pricing legislative initiatives have been proposed; however, distribution of revenues is not targeted towards transportation (see figure 33). For this reason, the TCI is more effective compared to other carbon-pricing initiatives.

Transportation Climate Initiative emissions reduction impact

The TCI is an in-process cap-and-invest initiative that is estimated to start in 2022.[43] The initiative evaluates a cap reduction target of 20–25% by 2032, where the target is set against 2022 estimated emissions of 254 MMT CO_2 equivalent. Based on the stringency of the target, the average yearly incremental cost to consumers for gasoline and diesel in TCI states is estimated to range from $30–90 in 2022 and max to $100–150 in 2032. To curb transportation emissions, TCI signatory regions, as outlined in their working group proposal, plan to invest revenue from TCI into low-carbon transportation initiatives (table 4).

40 Transportation and Climate Initiative, "Regional Proposal for Clean Transportation Reaches Milestone," news update on *TCI's Regional Policy Design Process* webpage, December 17, 2019, https://www.transportationandclimate.org/main-menu/tcis-regional-policy-design-process-2019, executive summary available at https://www.transportationandclimate.org/sites/default/files/TCI%20Modeling-Results-Summary_12.17.2019.pdf.

41 Transportation and Climate Initiative, "TCI jurisdictions share updates on policy design process," news update, October 1, 2019, https://www.transportationandclimate.org/oct-1-2019-tci-jurisdictions-share-updates-policy-design-process, "Framework for a Draft Regional Policy Proposal" available at https://www.transportationandclimate.org/sites/default/files/TCI-Framework_10-01-2019.pdf

42 Transportation and Climate Initiative, https://www.transportationandclimate.org/main-menu/tcis-regional-policy-design-process-2019

43 Transportation and Climate Initiative, https://www.transportationandclimate.org/main-menu/tcis-regional-policy-design-process-2019

FIGURE 32: TRANSPORTATION CLIMATE INITIATIVE STATES GREENHOUSE GAS EMISSIONS IMPACT

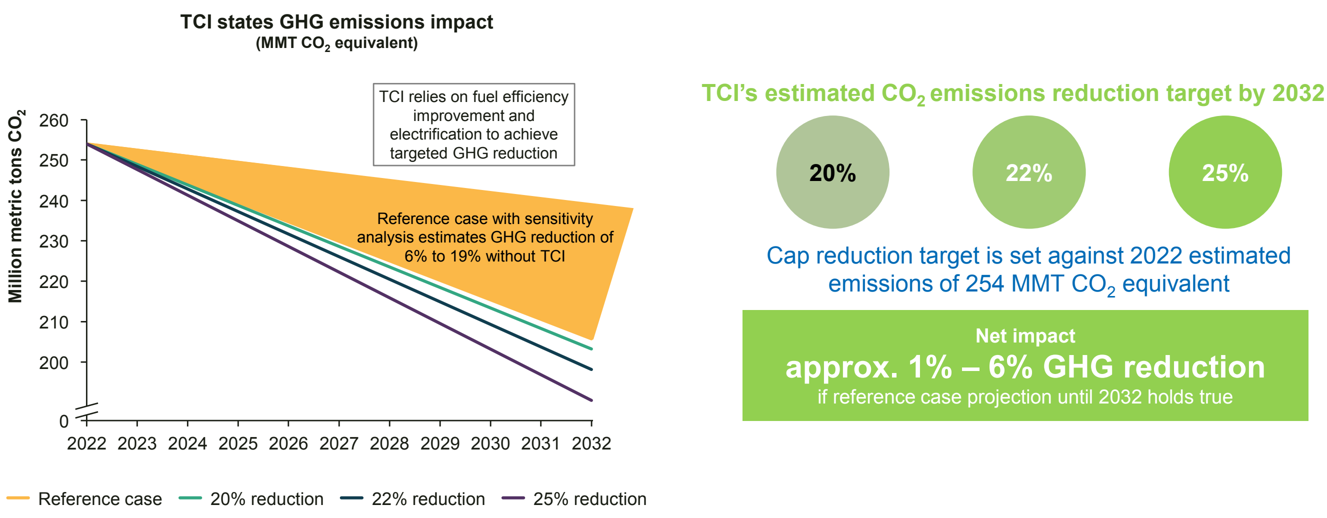


TABLE 4: PORTFOLIOS OF CLEAN TRANSPORTATION INVESTMENTS AS OUTLINED IN TRANSPORTATION CLIMATE INITIATIVE WORKING GROUPS' ANALYSIS[44]

GROUP	SCENARIO A	SCENARIO B	SCENARIO C
Electric cars, light trucks, and vans	5%	30%	54%
Low- and zero-emission buses and trucks	21%	23%	27%
Transit expansion and upkeep	35%	18%	–
Pedestrian and bike safety, ride-share	16%	14%	10%
System efficiency	7%	8%	8%
Indirect/other	17%	8%	–

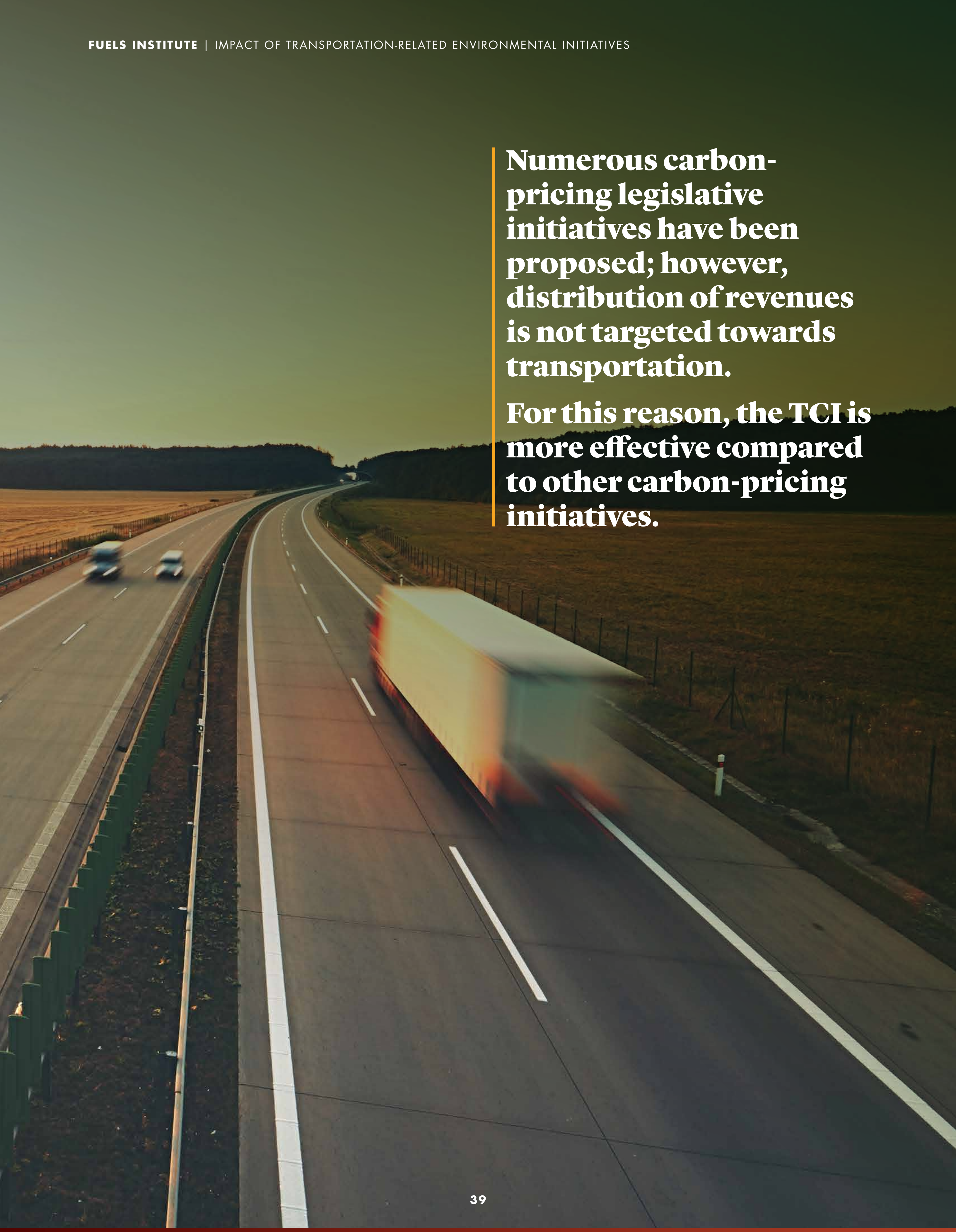
The incremental benefit of the TCI is modest, as only 1–6% of the overall target of 20–25% is expected to be a direct result of the initiative, with the rest achieved through electrification and improved fuel efficiency. The cost to achieve the TCI target is in the order of a few billion dollars. In comparison, a scenario of 20% of the U.S. workforce telecommuting three days per week results in 5% emissions reduction without incremental cost.

Carbon-pricing proposals and revenue distribution

European countries are at the forefront of carbon pricing in transportation. Finland, for example, instituted carbon pricing on transportation in 1990.[45] Carbon pricing in the U.S. has been limited to the power-generation sector and is still in its nascency for transportation with numerous transportation-related

44 Transportation and Climate Initiative, "Draft Memorandum of Understanding & 2019 Cap-and-Invest Modeling Results" (PowerPoint presentation of live webinar, December 17, 2019), https://www.transportationandclimate.org/sites/default/files/TCI%20Public%20Webinar%20Slides_20191217.pdf; see Transportation and Climate Initiative, "TCI jurisdictions share updates on policy design process."

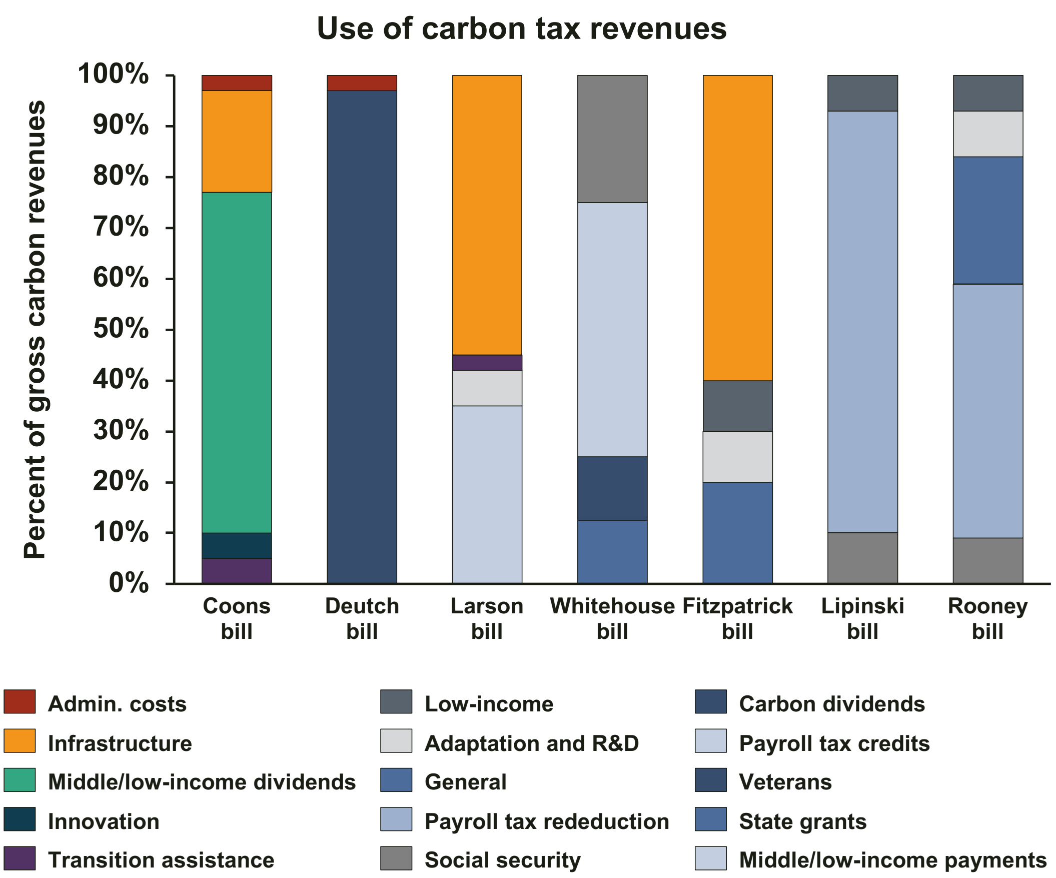
45 "Carbon Tax (CO_2 Tax)," Division for Sustainable Development Goals, United Nations, accessed June 26, 2020, https://sustainabledevelopment.un.org/index.php?page=view&type=99&nr=183&menu=1449.



Numerous carbon-pricing legislative initiatives have been proposed; however, distribution of revenues is not targeted towards transportation.

For this reason, the TCI is more effective compared to other carbon-pricing initiatives.

FIGURE 33: PROPOSED LEGISLATION CARBON TAX REVENUE DISTRIBUTION



carbon-pricing legislative proposals only in discussions. However, the tabled proposals on carbon pricing lack consensus on revenue distribution, which ranges widely from social security to tax credits to low-income household dividends (see figure 33). Carbon-pricing legislation proposals are not targeted towards low-carbon transportation initiatives, unlike the TCI, resulting in diminished emissions reduction effectiveness. Ricardo expects the U.S. will advance in transportation-related carbon-pricing initiatives over the next 20 years but will still lag behind European countries in legislative action.

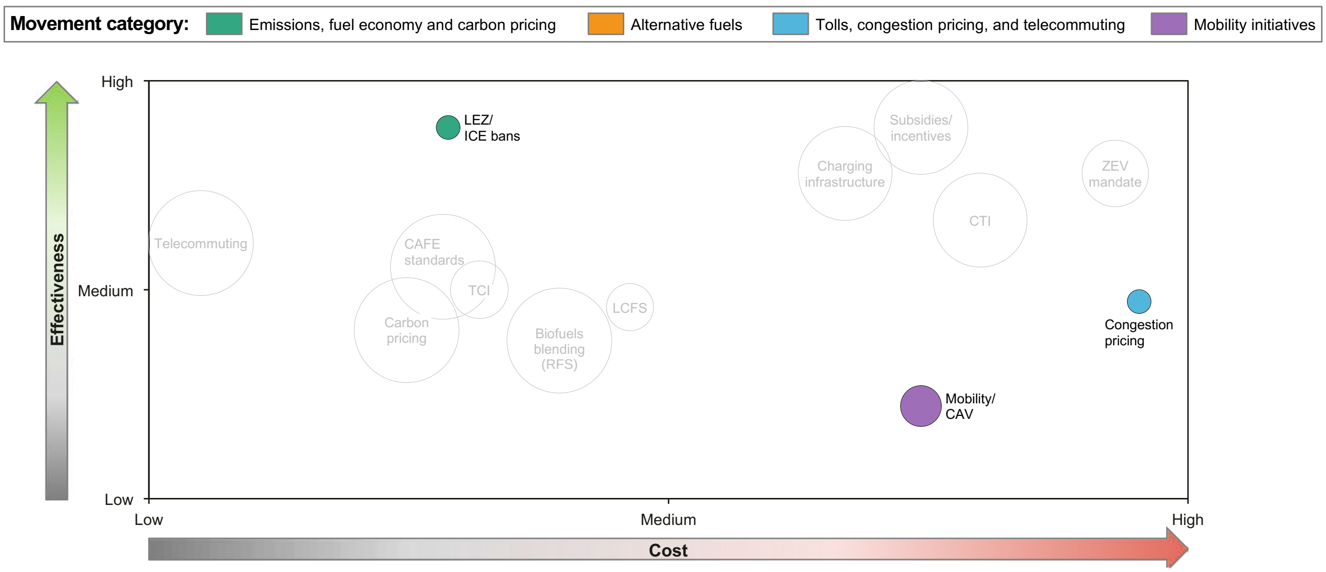
ASSESSMENT METHODOLOGY

The TCI reference case sensitivity analysis model evaluating the cap-and-invest program benefits outlined that the emission reduction potential from the TCI is limited to just 1–6% of the overall potential target of 20–25% emissions reduction.[46] The TCI is more effective compared to carbon pricing because it includes investing the revenue into low-carbon transportation initiatives, whereas current carbon-pricing legislation proposals lack consensus on revenue distribution.

46 Transportation and Climate Initiative, "Regional Proposal for Clean Transportation Reaches Milestone," https://www.transportationandclimate.org/sites/default/files/TCI%20Modeling-Results-Summary_12.17.2019.pdf

LOW-EMISSION ZONES AND INTERNAL COMBUSTION ENGINE BANS, CONGESTION PRICING, MOBILITY INITIATIVES, AND CONNECTED AND AUTONOMOUS VEHICLES

FIGURE 34: COMPARATIVE ASSESSMENT OF EFFECTIVENESS, IMPACT, AND COST: LOW-EMISSION ZONES, INTERNAL COMBUSTION ENGINE BANS, CONGESTION PRICING, MOBILITY INITIATIVES, AND CONNECTED AND AUTONOMOUS VEHICLES



FINDINGS

Movements such as LEZs and ICE bans, congestion pricing, and mobility initiatives are localized and limited to urban regions.

- **LEZ deployment in Los Angeles County** potentially reduces NO_x by >10% and CO_2 by 4–8% based on the implementation scenario (see figure 35).
- **Congestion pricing** offers localized emissions reduction benefits with a high cost of compliance (see figures 36 and 37). Investment in clean public transport is required to sustain and improve emissions reduction.
- **Increase in shared and autonomous mobility** impacts U.S. VIO due to decreasing vehicle ownership (per thousand people) by 10% compared to 2019 value (see figure 39). Shared and autonomous mobility have an uncertain (positive or negative) effect on emissions based on VMT.

FIGURE 35: LOW-EMISSION ZONE IN LOS ANGELES COUNTY

Impact if passenger vehicles older than 20 years are banned from driving in Los Angeles County Area

LA county has approx. 7.6M registered passenger vehicles in 2019. approx. 8% of vehicle population (approx. 0.6M vehicles) are ≥ 20 years in age

Impact \ Scenario	Option 1: Replaced with public transport or ZEVs (0.6M vehicles replaced with ZEVs or public transport)	Option 2: Replaced with EPA Tier 3 ICEs (0.6M vehicles replaced with EPA Tier 3 ICEs)
NO_X reduction compared to baseline–no action is taken	approx. 16% reduction	approx. 14% reduction
CO_2 reduction compared to baseline–no action is taken	approx. 8% reduction	approx. 4% reduction

Baseline: 7.6M parc in LA county leads to approx. 31,000 tons of NO_X emissions in 2019

Baseline: 7.6M parc in LA county generates approx. 38 MMT of CO_2 emissions in 2019

Note: Impact on emissions from shift to public or alternative transport not considered

Impact if passenger vehicles older than 20 years are banned from driving in Los Angeles County

Numerous urban regions across the globe operate LEZs. Forty-seven cities in Germany operate a LEZ with varying levels of stringency.[47]

Ricardo considered Los Angeles County as a reference case to assess the impact of LEZs. LEZ deployment in Los Angeles County banning vehicles 20 years or older potentially reduces NO_X by >10% and CO_2 by 4–8% based on the implementation scenario (see figure 35). An LEZ is an effective movement for emissions reduction compared to others; however, the reduction benefits are localized and applicable only to high-density cities and may not be scaled nationally due to local political challenges.

Impact if congestion pricing is implemented in New York City, Seattle, and Los Angeles

Emission reduction benefits of congestion pricing are localized and sustained through clean public transport. Cities such as Stockholm, London, Milan, and Singapore have implemented congestion pricing zones, and the movement's success in emissions reduction is based on stringency, exemptions, and primarily access to transportation substitutes of low-carbon public transportation. For example, emissions reduction benefits in London's congestion pricing zone, implemented in 2003, have diminished due to fee exemptions for private for-hire vehicles such as Uber and Lyft,[48] whereas in Stockholm, where significant investments were made in low-carbon public transportation, the benefits have been sustained.[49]

In the U.S., New York City has taken steps to implement congestion pricing zone in 2021. Seattle and Los Angeles are also evaluating congestion zone implementation.[50,51] Ricardo considered New York, Seattle, and Los Angeles as reference cities to

47 "Urban Access Regulation by Map," Urban Access Regulations in Europe, website operated by Sadler Consultants Ltd. on behalf of the European Union, accessed June 26, 2020, https://urbanaccessregulations.eu/userhome/map.

48 Transport for London, *Travel in London: Report 11*, 2018, http://content.tfl.gov.uk/travel-in-london-report-11.pdf.

49 Maria Börjesson, Jonas Eliasson, Muriel B.Hugosson, and Karin Brundell-Freij, "The Stockholm Congestion Charges—5 Years On. Effects, Acceptability and Lessons Learnt," *Transport Policy 20* (March 2012): 1-12, https://doi.org/10.1016/j.tranpol.2011.11.001.

50 Seattle Department of Transportation, *Seattle Congestion Pricing Study*, May 2019, https://www.seattle.gov/Documents/Departments/SDOT/About/SeattleCongestionPricingStudy_SummaryReport_20190520.pdf.

51 Eleanor Lamb, "Los Angeles Feasibility Study Will Look at Congestion Pricing," *Transport Topics*, November 25, 2019, https://www.ttnews.com/articles/los-angeles-feasibility-study-will-look-congestion-pricing.

FIGURE 36: CONGESTION PRICING IMPACT ON GREENHOUSE GAS EMISSIONS IF DEPLOYED IN NEW YORK, SEATTLE, AND LOS ANGELES

Transportation CO_2 emissions (in MMT) are as following for each city: NY: 15 MMT, Seattle: 3 MMT, LA: 25 MMT

Impact \ Scenario	Low impact: Low per vehicle charge and significant exemptions granted (*$5–7 per-vehicle charge*)	High impact: High per vehicle charge and shift to clean public transport (*>$10 per-vehicle charge*)
CO_2 reduction–localized (compared to local transportation emissions)	approx. 7% reduction	approx. 20% reduction
CO_2 reduction–U.S. wide (compared to U.S.-wide transportation emissions)	approx. 0.2% reduction	approx. 0.6% reduction

Transportation sector (3 cities) resulted in approx. 45 MMT of CO_2 emissions in 2019

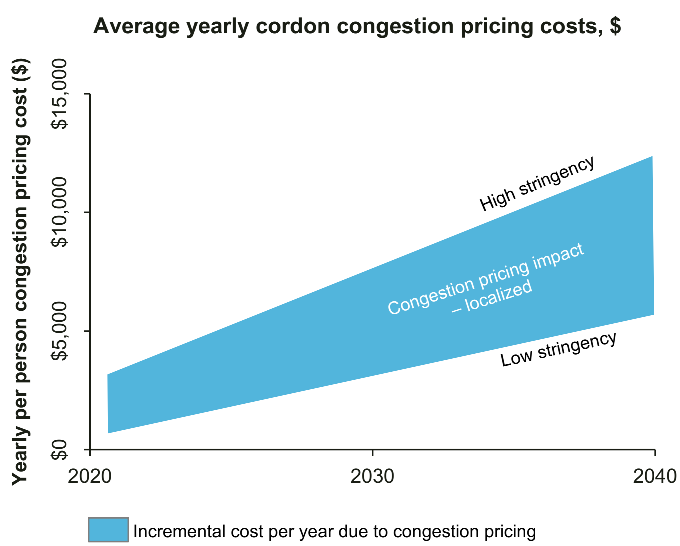
U.S. transportation sector resulted in approx. 1,500 MMT of CO_2 emissions in 2019

Note: Impact on emissions from shift to public or alternative transport not considered

assess impact. Congestion zone implementation is expected to reduce CO_2 emissions between 7–20% based on implementation at a local level (see figure 36). However, benefits are trivial (0.2–0.6% reduction) when scaled to the national level.

Additionally, cost of access to congestion pricing zone is expensive with a yearly per-person cost of >$1,000 (see figure 37), based on the evolution of congestion pricing in London. Similar to LEZs, implementing congestion pricing nationwide in U.S. urban areas may face resistance from some consumers and local regulatory bodies.

FIGURE 37: YEARLY OPERATIONAL COST FROM CONGESTION PRICING PER PERSON—WHERE IMPACTED



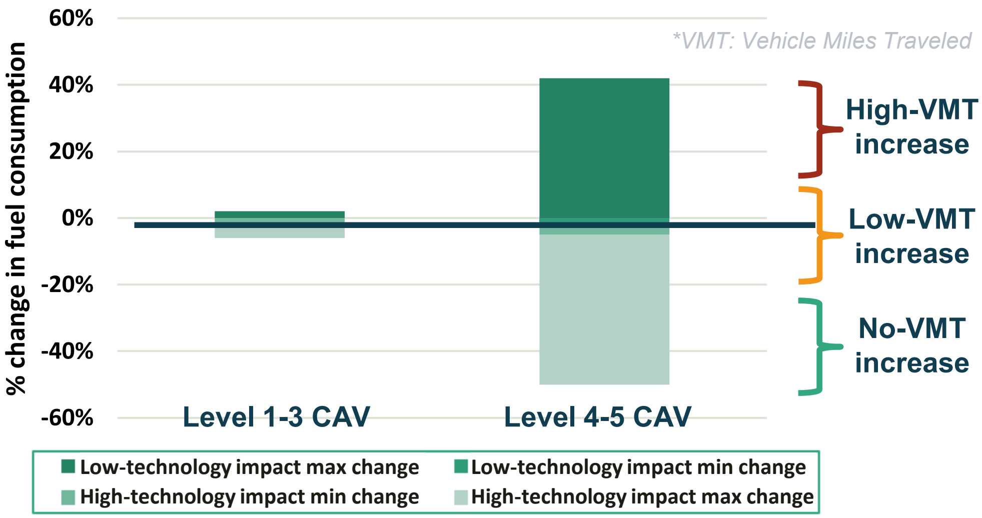
Impact of shared and autonomous mobility

Shared and autonomous mobility may have uncertain effects on emissions based on VMT due to divergent vehicle usage profiles. A combination of both electrification and autonomous technologies are expected to shape shared mobility. Based on Ricardo analysis, a significant portion of current VMT by shared platforms are empty miles, i.e., trips without passengers, resulting in wasted fuel that leads to higher emissions. Even with increased electrification, energy consumption from empty miles traveled would need to be addressed for shared mobility to be effective.

By 2050, shared and autonomous mobility could potentially increase fuel or energy consumption by 42% or decrease it by 44.4% (see figure 38).[52]

Also, this movement has the potential to reduce passenger vehicle VIO growth and could reduce vehicle ownership from 850 per 1,000 people in mid-2020 to 777 per 1,000 people by 2040 (see figure 39).[53]

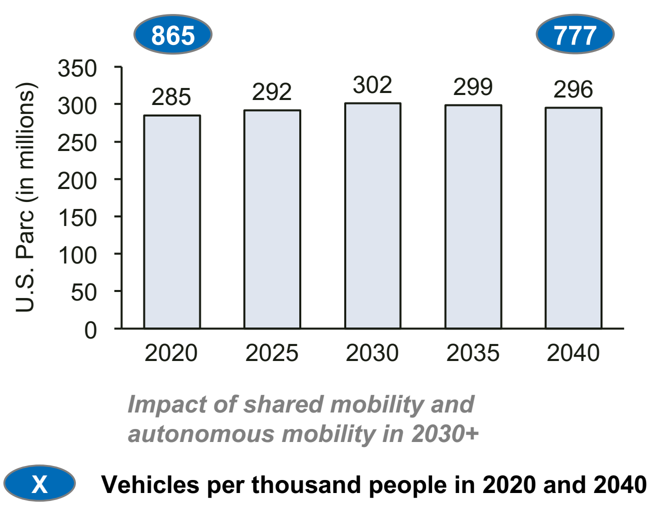
FIGURE 38: CONNECTED AND AUTONOMOUS VEHICLES—FUEL/ENERGY CONSUMPTION IMPACT IN 2050[54]



Connected and autonomous vehicles have an ambiguous future effect on emissions based on VMT as there could be a fundamental shift in usage. There could be a potential uptick in use due to ease of travel and increased access to previously underserved communities.

By 2050, light-duty vehicles could potentially increase in fuel consumption by 42% or decrease it by 44.4%.

FIGURE 39: IMPACT OF SHARED AND AUTONOMOUS MOBILITY ON U.S. VEHICLE VEHICLES IN OPERATION

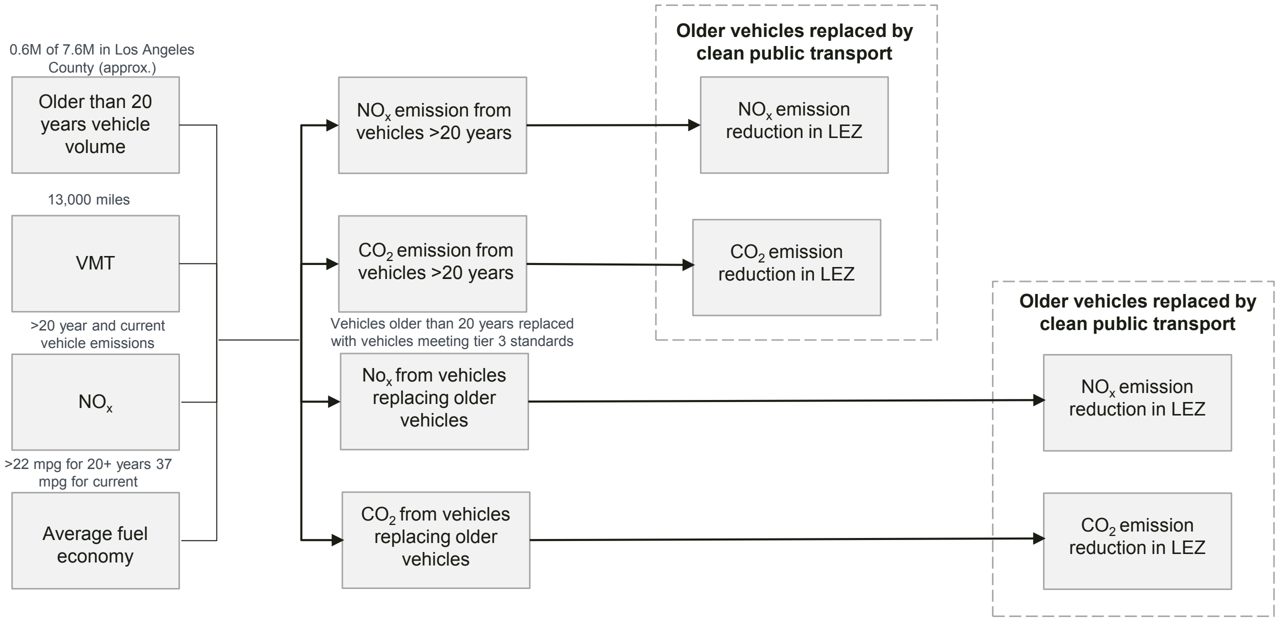


52 U.S. Energy Information Administration, *Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles*, March 2017, https://www.eia.gov/analysis/studies/transportation/automated/pdf/automated_vehicles.pdf.

53 Sandra L. Colby and Jennifer M. Ortman, *Projections of the Size and Composition of the U.S. Population: 2014 to 2060*, Current Population Reports, March 2014 (Washington, DC: U.S. Census Bureau), https://www.census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf.

54 U.S. Energy Information Administration, *Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles*

FIGURE 40: LOW-EMISSION ZONE EMISSIONS ASSESSMENT METHODOLOGY



ASSESSMENT METHODOLOGY

Inputs

For estimating emissions reduction based on implementing an LEZ in Los Angeles County, Ricardo considered the following:

- **Los Angeles County passenger vehicle VIO:** 7.6 million[55]
- **Vehicles older than 20 years:** 0.6 million (based on Ricardo analysis)
- **Average fuel economy of a vehicle manufactured in 2000:** 22 mpg[56]
- **Average NO_x of vehicles manufactured before 2000** (tier 1 emissions)[57]
    - Passenger cars: 0.6 g per mile
    - Light-duty trucks: 0.97 g per mile
- **Average NO_x of vehicles currently manufactured** (tier 2 emissions)[58]
    - Passenger cars: 0.06 g per mile
    - Light-duty trucks: 0.07 g per mile
- **Average fuel economy current vehicle:** 37 mpg[59]
- **Annual VMT:** 13,000 miles

Methodology and output

The process flow of the LEZ emissions methodology and output is provided in figure 40.

55 "Vehicle Registrations Los Angeles County," Given Place Media, publishing as Los Angeles Almanac, © 1998–2020, accessed June 26, 2020, http://www.laalmanac.com/transport/tr02.php.

56 "Table 4-23: Average Fuel Efficiency of U.S. Passenger Cars and Light Trucks," Bureau of Transportation Statistics, U.S. Department of Transportation, updated May 20, 2017, accessed June 26, 2020, https://www.bts.gov/archive/publications/national_transportation_statistics/2001/table_04_23.

57 "All EPA Emission Standards," Emission Standards Reference Guide, U.S. Environmental Protection Agency, accessed June 26, 2020, https://www.epa.gov/emission-standards-reference-guide/all-epa-emission-standards.

58 "All EPA Emission Standards"

59 U.S. Energy Information Administration, *Annual Energy Outlook 2020*

Conclusions and Outlook

When all movements are scrutinized against each other, it becomes evident that the effectiveness of an individual movement is directly proportional to the cost to comply with assigned targets.

As such, telecommuting offers the advantage of non-trivial emissions reduction at a negligible cost. It remains to be seen if federal or local government will initiate such a mandate or if the private sector will allow more working from home for employee well-being. Certainly, in 2020, COVID-19 has forced the U.S. workforce to figure out ways to maintain work momentum from home. Ongoing technology advancements will allow more people to work from home, and it seems feasible that employers (as noted by Toyota[60]) will be able to access broader talent pools if such workstyle changes are embraced. Furthermore, corporate social responsibility groups within companies will welcome such a change, allowing them to gain credit for their contribution to reduce emissions.

60 Larry P. Vellequette, "Remote work will broaden talent pool, Toyota exec says," *Automotive News*, May 20, 2020, https://www.autonews.com/manufacturing/remote-work-will-broaden-talent-pool-toyota-exec-says

Technological advancements in electrification coupled with a push for renewable energy sources will positively contribute toward emissions reduction. As noted in figure 26, electricity offers significant CI benefit compared to some of the other sources of fuel. It is critical to extract benefits out of this source along with other low-CI fuels to achieve emissions reduction. The challenge, of course, is demand generation for all profiles of consumers. Technology cost reduction is aided by PEV popularity driving economies of scale amongst the innovator and early adopter consumers. To maintain this momentum, governments could leverage this popularity and continue with these three critical movements: subsidies, charging infrastructure, and the ZEV mandate. These will help transition PEV adoption by the early majority and late majority consumers.

Alternative fuels movements (the LCFS and RFS) will continue to play a significant role to reduce emissions. The LCFS may enjoy benefits of electrification but may not necessarily contribute toward technology cost reductions upon adoption. Ethanol-blended fuels, driven by the RFS, have provided moderate emissions benefits. Biomethane and cellulosic ethanol will provide significant emissions reduction, although their cost-benefit equation has not yet proven attractive. Electrification along with hydrogen fuel cells, biodiesel, renewable diesel, biomethane, and potentially cellulosic ethanol are important alternative fuels that may drive the next phase of emissions reduction; however, some of these may face cost and performance benefit hurdles for widespread adoption.

AS URBANIZATION INCREASES, CONGESTION PRICING, CARBON PRICING, AND LEZS MAY TAKE SHAPE, ALTHOUGH DIVERGENT POLITICAL VIEWS ON THESE TOPICS COULD HINDER THEIR IMPLEMENTATION. SIMILARLY, THE EFFECT OF AUTONOMOUS SHARED MOBILITY ON EMISSIONS REMAINS TO BE SEEN.

This report captures the outlook of movements as of June 2020 and is a high-level assessment of cost to effectiveness. As time passes by, it is natural for these movements to have updated targets and several new and unforeseen ones to be added. For an updated view on cost-benefit assessment of each of the current movements, such an exercise could be pursued every five years.

Appendix

Acronyms & Abbreviations

BEV Battery Electric Vehicle

CAFE Corporate Average Fuel Economy

CAGR Compound Annual Growth Rate

CARB California Air Resources Board

CAV Connected and Autonomous Vehicle

CI Carbon Intensity

CNG Compressed Natural Gas

CSE Center for Sustainable Energy

CTI Cleaner Trucks Initiative

CVRP Clean Vehicle Rebate Program

EPA Environmental Protection Agency

EU European Union

EV Electric Vehicle

GHG Greenhouse Gas

HEV Hybrid Electric Vehicle

ICE Internal Combustion Engine

kWhr Kilowatt-Hour

LCFS Low Carbon Fuel Standard

LDV Light-Duty Vehicles (Pass Cars and Light Trucks)

LEZ Low-Emission Zone

LNG Liquified Natural Gas

MMT Million Metric Tons

NEV New Energy Vehicles

OEM Original Equipment Manufacturer

VIO Vehicles in Operation

PEV Plug-in Electric Vehicle

PM Particulate Matter

RFS Renewable Fuel Standard

SAFE Safer Affordable Fuel-Efficient

TCI Transportation Climate Initiative

VAT Value-Added Tax

VMT Vehicle Miles Traveled

YOY Year-Over-Year

ZEV Zero-Emission Vehicle

About the Fuels Institute

The Fuels Institute, founded by NACS in 2013, is a 501(c)(4) non-profit research-oriented think tank dedicated to evaluating the market issues related to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Fuels Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders. Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Fuels Institute are dedicated to promoting facts and providing decision makers with the most credible information possible so that the market can deliver the best in vehicle and fueling options to the consumer.

For more about the Fuels Institute, visit fuelsinstitute.org.

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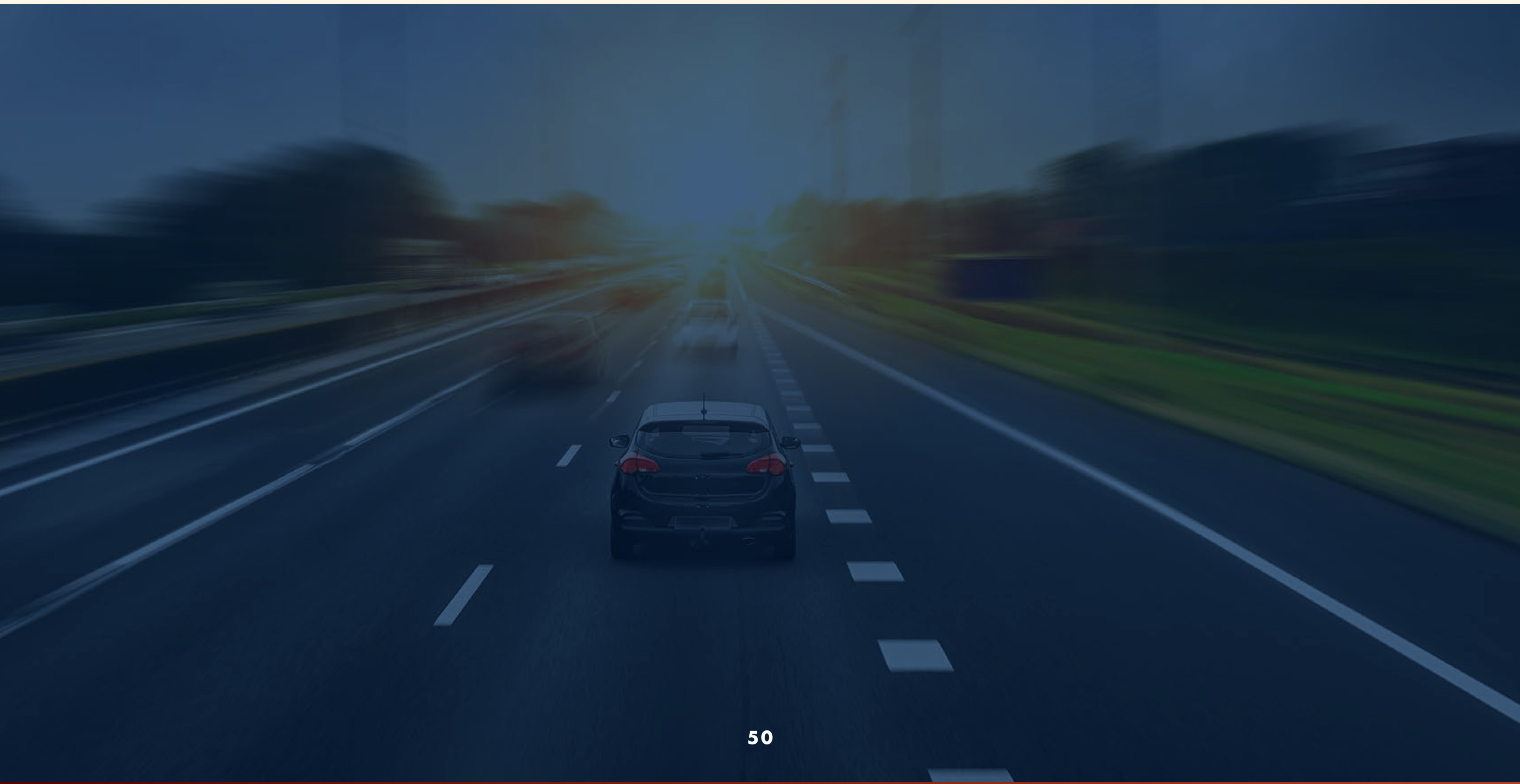
The Fuels Institute was founded in 2013 by NACS, the international association that advances convenience and fuel retailing. Through recurring financial contributions and daily operational support, NACS helps the Fuels Institute to invest in and carry out its work to foster collaboration among the various stakeholders with interests in the transportation energy market and to promote a comprehensive and objective evaluation of issues affecting that market and its customers both today and in the future. NACS was founded August 14, 1961, as the National Association of Convenience Stores and represents more than 2,100 retail and 1,600 supplier company members.

www.convenience.org



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