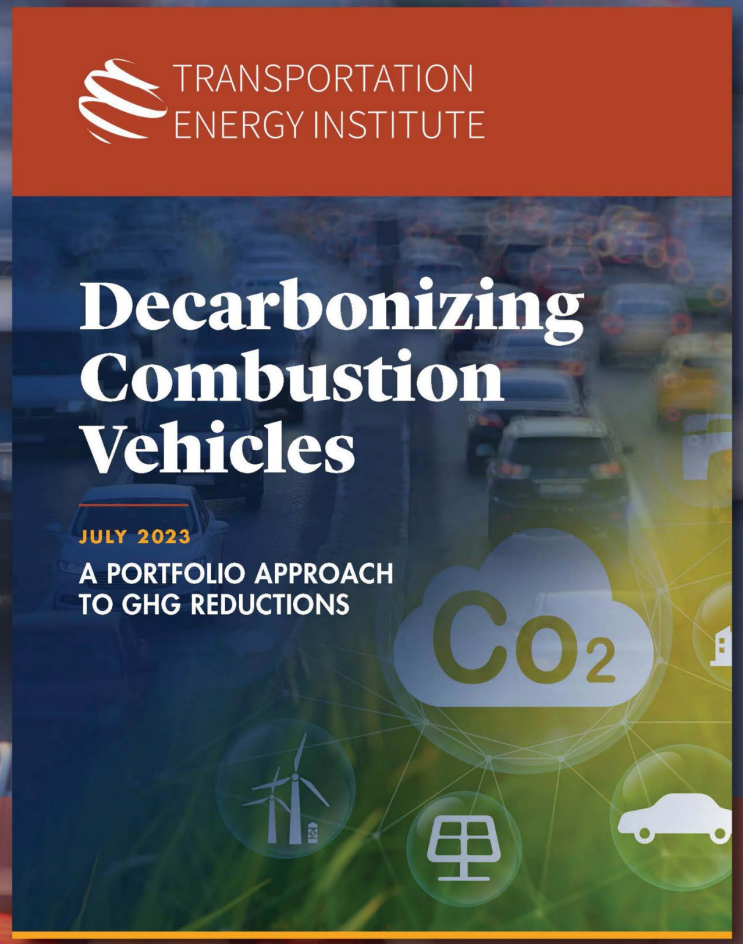
TRANSPORTATION ENERGY INSTITUTE

Stillwater Associates

WEBINAR:

Decarbonizing Combustion Vehicles: A Portfolio Approach to GHG Reductions

August 23 | 2:00-3:00pm EST



John Eichberger | *Executive Director, Transportation Energy Institute*

Adam Schubert | *Senior Associate, Stillwater Associates*

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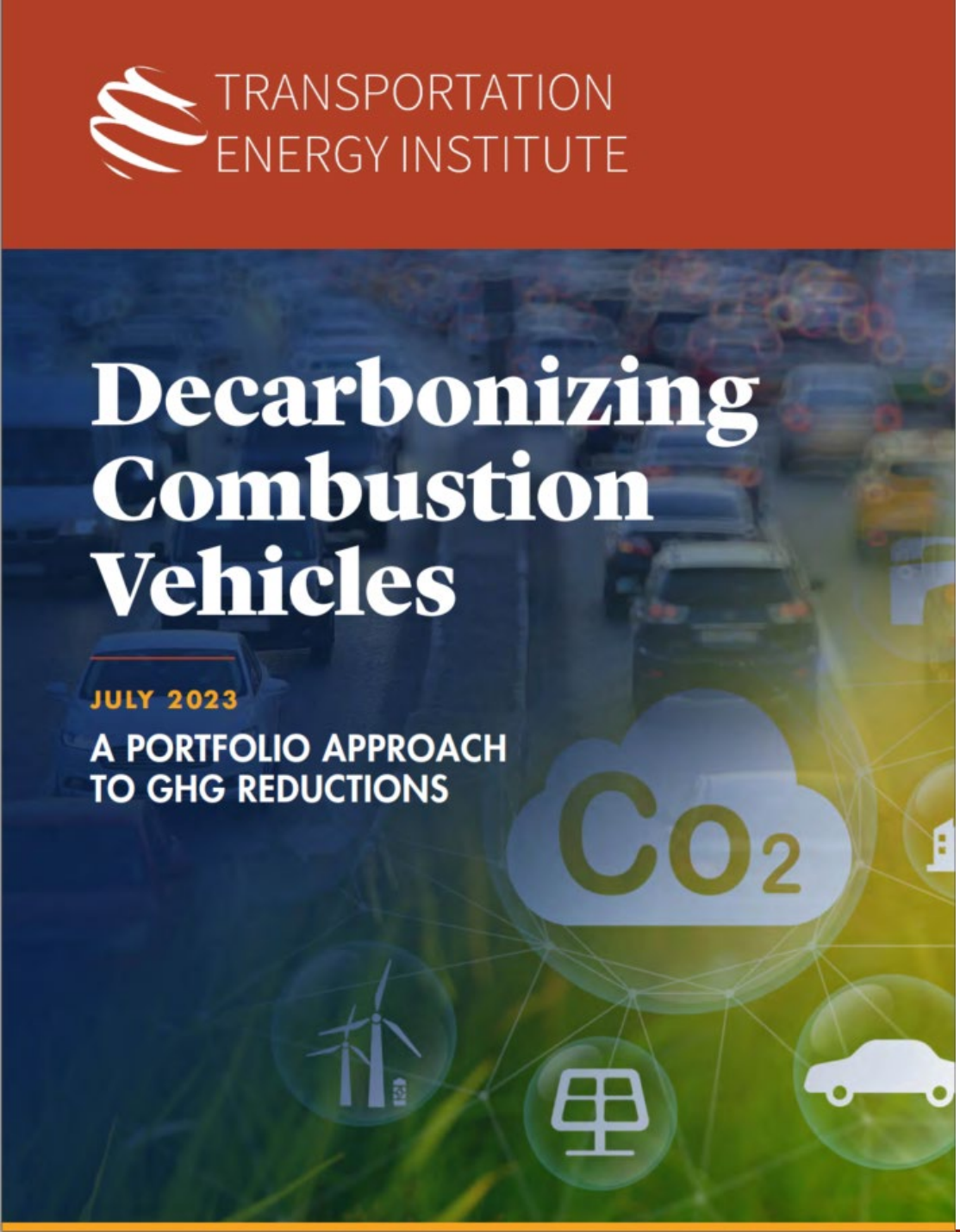

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Why did we commission?

Leaders throughout the world, both political and financial, have determined that reducing carbon emissions, especially from transportation, is a top priority. Many have implemented policies to support the transition of the market away from internal combustion engine vehicles (ICEVs) and towards zero-tailpipe emissions vehicles (ZEVs), like battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs). Yet there are nearly 300 million internal combustion engine vehicles (ICEVs) in the United States and 1.5 billion in the world. In light of this facts and the efforts of the decarbonization movement, the Transportation Energy Institute Board of Advisors commissioned Stillwater Associates to evaluate the current and future opportunities to reduce carbon emissions from ICEVs, both those currently in the market and those yet to be sold.

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Prevailing transportation-regulations are climate related… "decarbonization"

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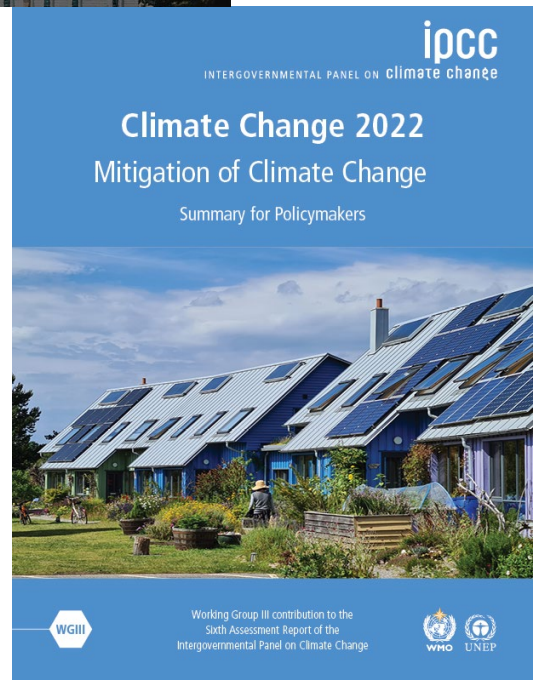
A "New Day for Climate Action in the United States" as U.S. Congress Passes Historic Clean Energy and Climate Investments

Bill will provide the most ambitious funding ever for tackling climate change.

August 11, 2022



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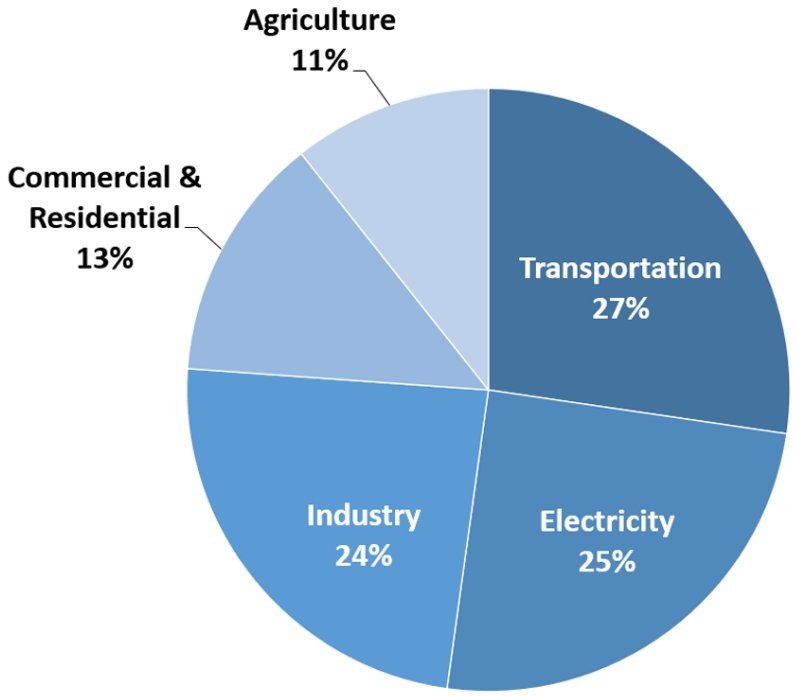
Transportation is a priority sector

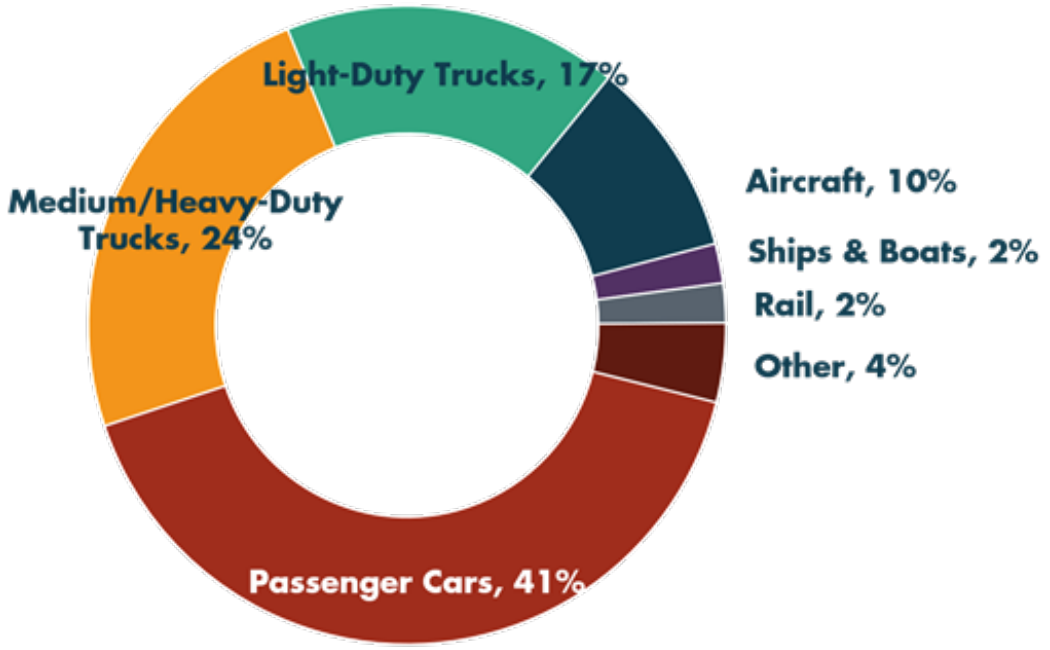
27% of U.S. GHG emissions come from transportation. Of that, 82% come from the on-road vehicle market.

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2020



U.S. Environmental Protection Agency (2022). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020

Transportation Greenhouse Gas Emissions (U.S. 2019)



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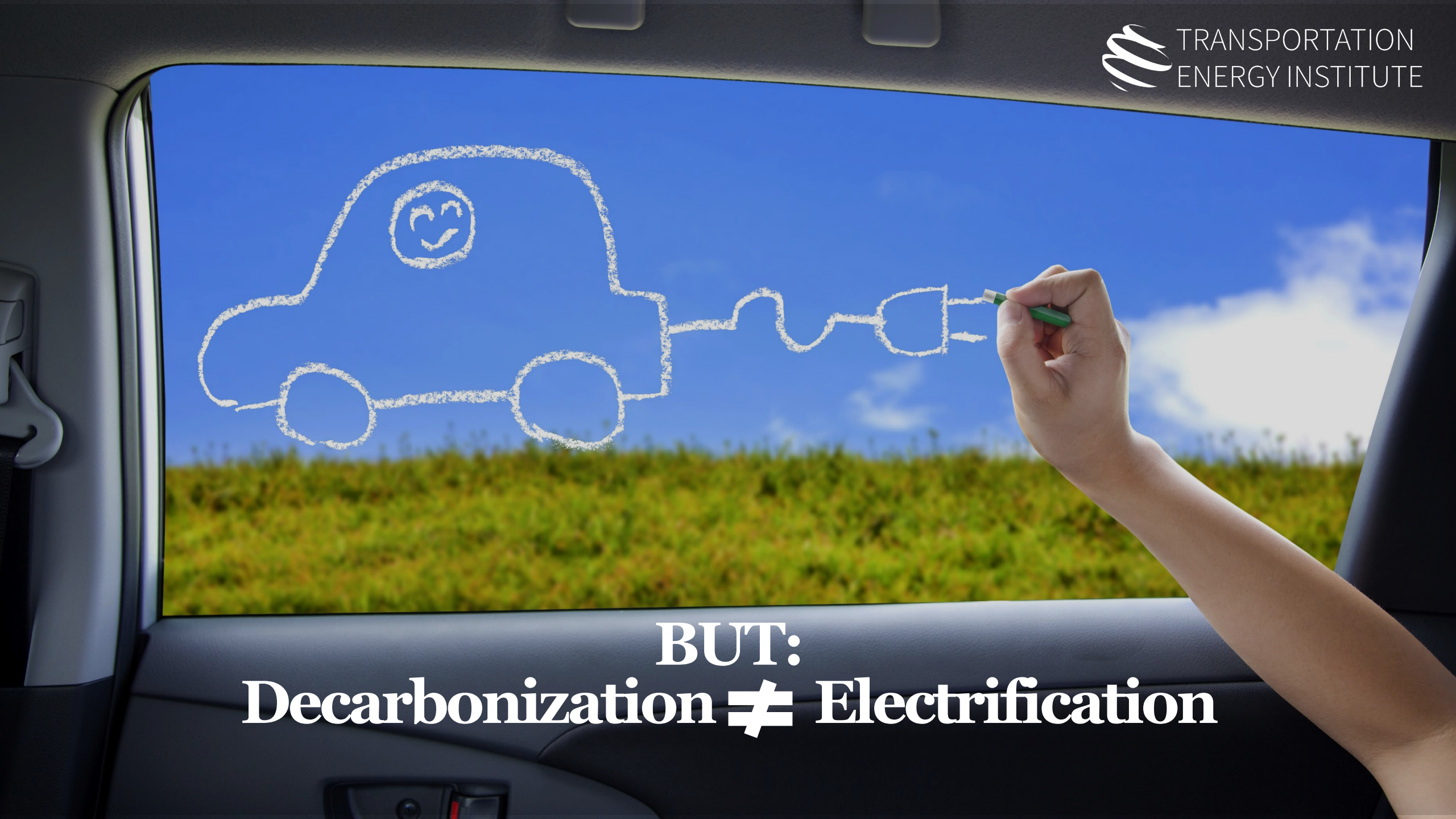
Source: US. Environmental Protection Agency via Statista

Source: U.S. Environmental Protection Agency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BUT:
Decarbonization ≠ Electrification

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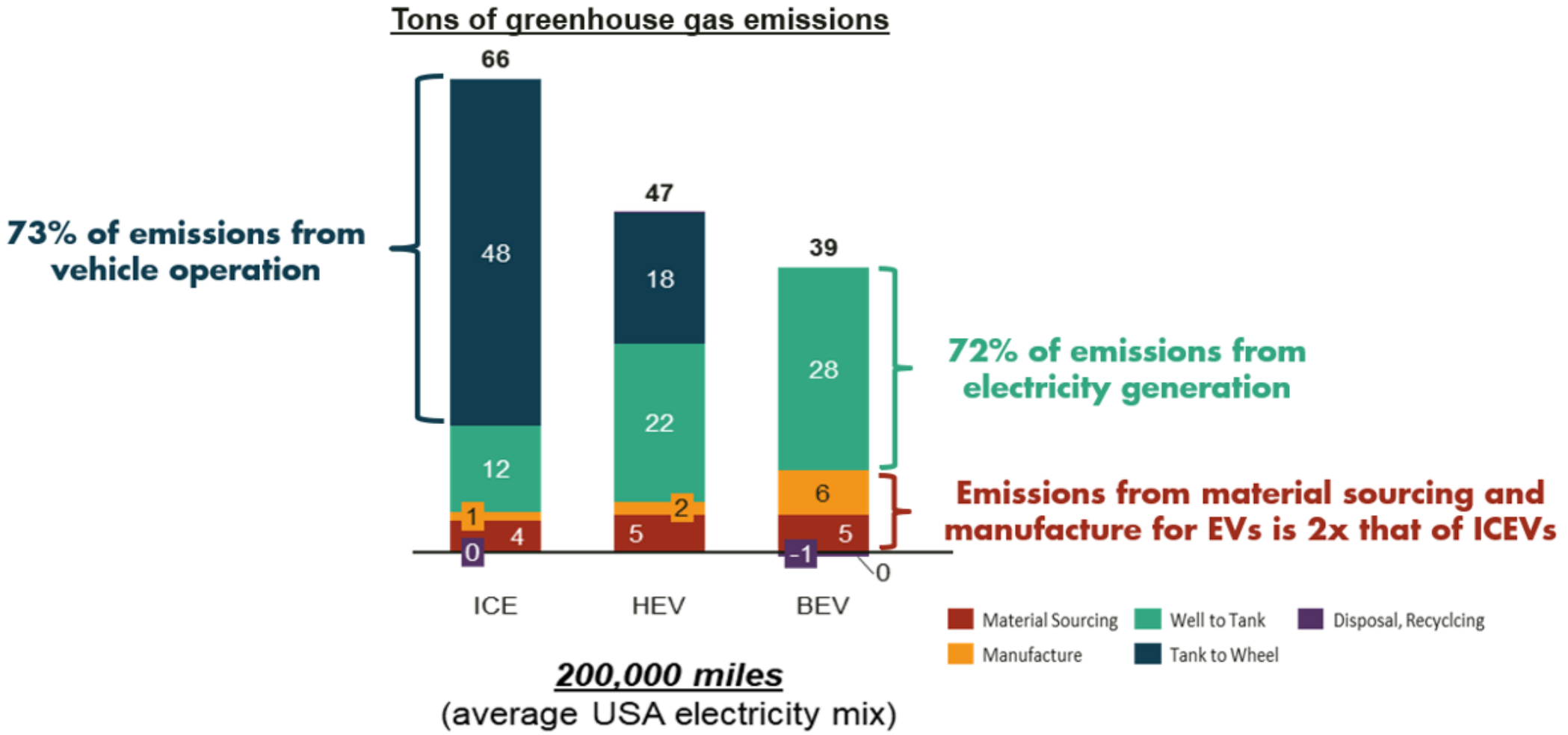
Where do carbon emissions originate?

Nearly ¾ of carbon emissions come from the carbon in the fuel or electricity generation, not the tailpipe



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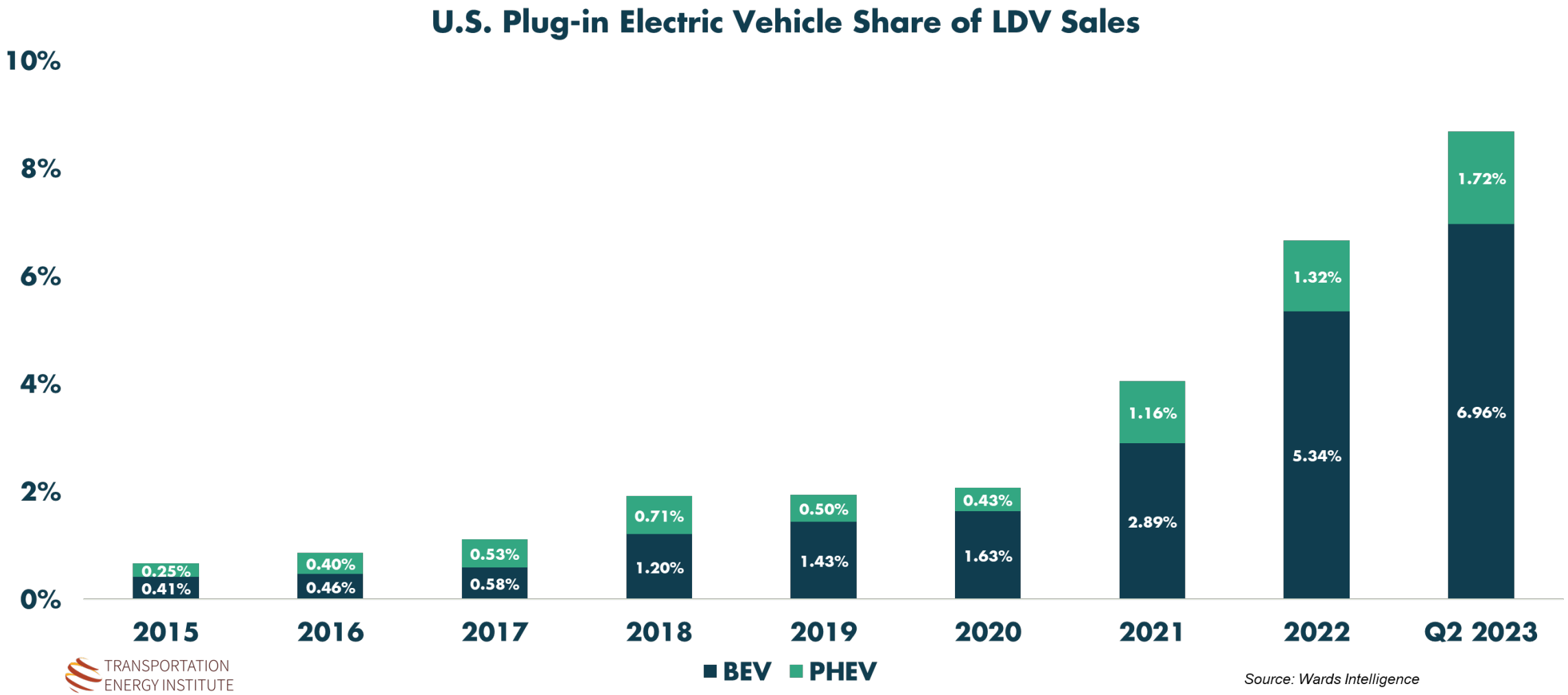
BEV Sales Growth is Strong - 6.9% Q2 2023

BEVs on pace for 1 million units sold in 2023 with 530k sold through Q2

For context - the top three vehicle models sold in 2022 (F150, Silverado, RAM) sold more than 1.5 million.



Source: Wards Intelligence

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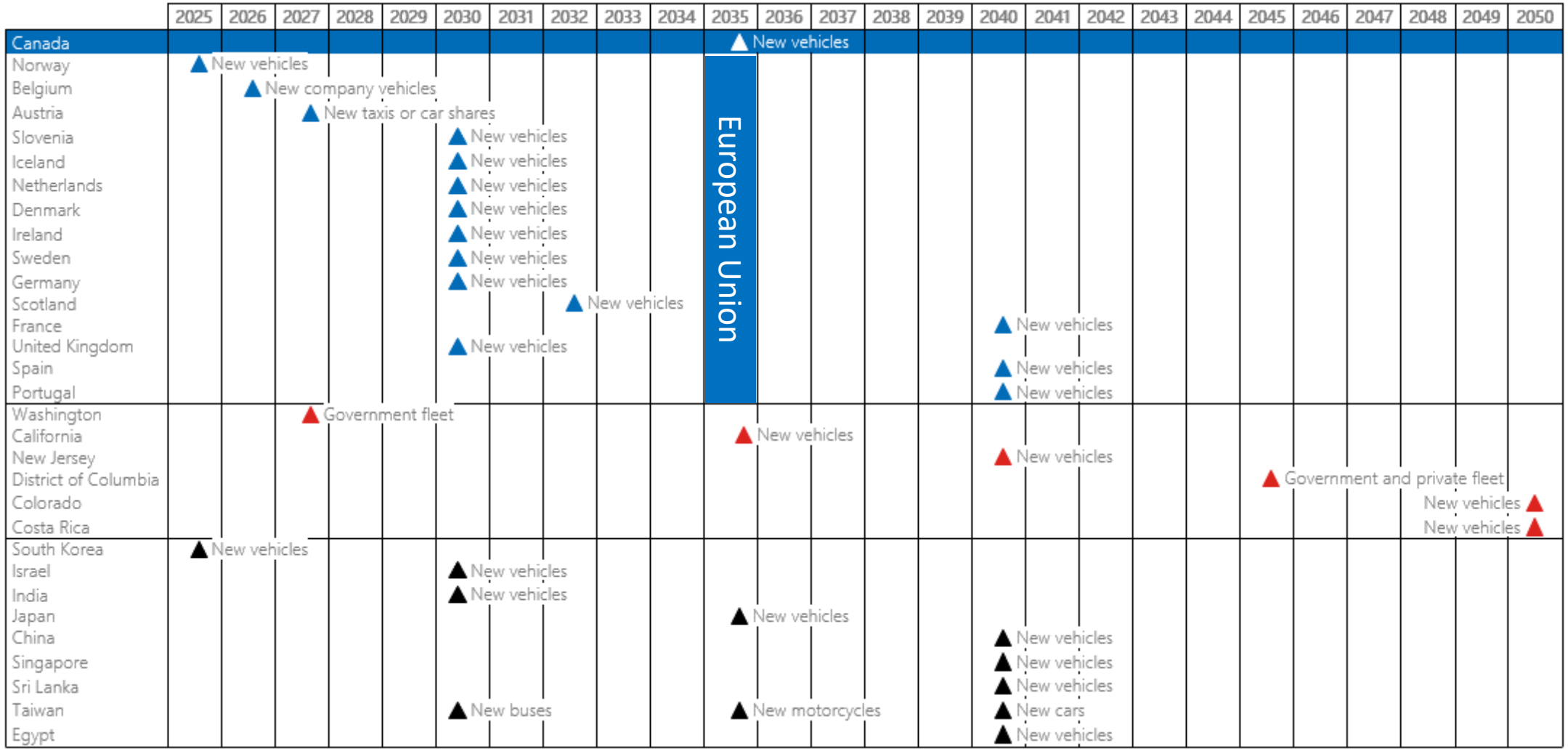
Governments enacting bans on combustion

Summary of Potential and Existing ICE Sales & Registration Bans



Source: Ricardo Strategic Consulting for Canadian Transportation Alliance

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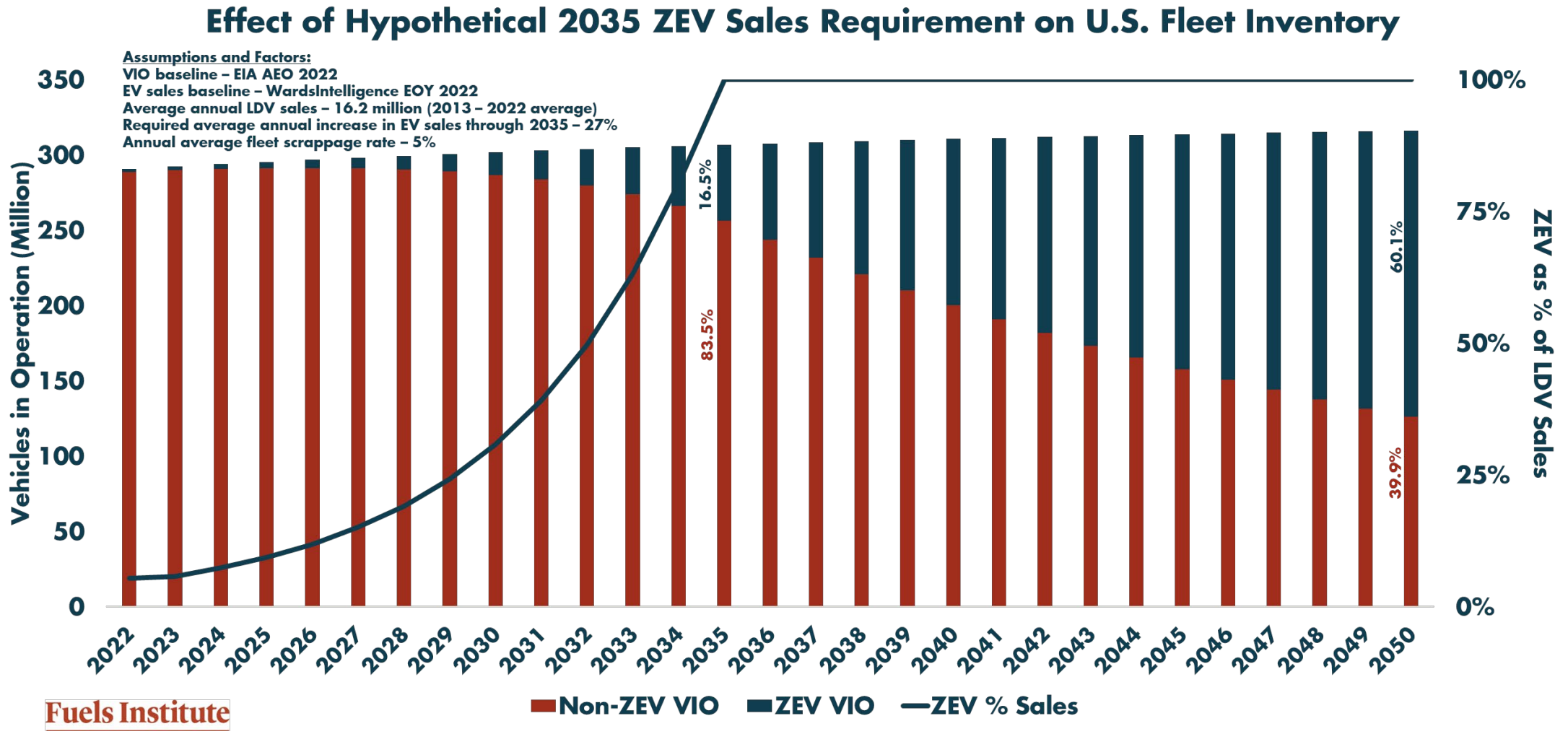
Turnover is slow, even w/rapid sales growth

If PEVs reach 100% sales in 2035, they may only represent 16.5% of LDVs on the road, leaving 266 million ICEVs.



Not fast enough for leaders… but is faster even possible?

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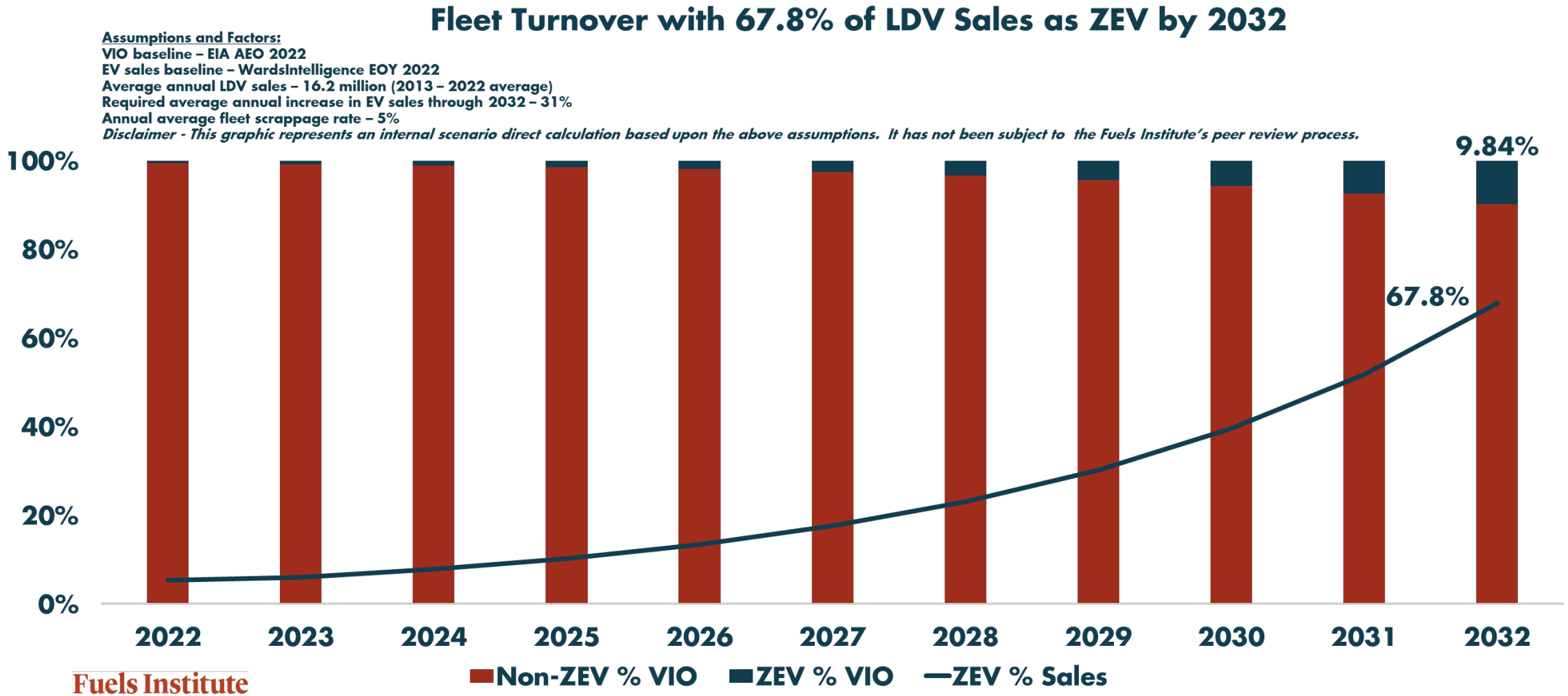
Biden administration's new emissions rules expected to drive EV sales to nearly 67% by 2032



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Report structure

Study is presented in four primary sections, which address key issues as follows:

Part 1 – Prelude

- Establishes the importance of early GHG emissions reductions
- Examines the current vehicle fleet, associated emissions and pace of turnover

Part 2 – Lifecycle Analysis of Options

- Evaluates and compares the lifecycle emissions of ICEV fuel options
- Examines pending developments that could affect the lifecycle emissions of ICEV fuels
- Reviews trends related to criteria pollutant emissions

Part 3 – Biofuels

- Reviews biofuels utilization and projected consumption
- Examines feedstock production and diversification, including opportunities for cellulosic feedstocks
- Reviews regulatory issues affecting biofuels

Part 4 – Market Transition Requirements

- Reviews feasibility of various low-carbon ICEV fuels, opportunities and challenges to deliver each to market
- Reviews ICE vehicle options for lower carbon operations
- Compares and contrasts ICEV fuels based upon emissions reduction potential, compatibility, cost and market/regulatory hurdles

Decarbonizing Combustion Vehicles:
A Portfolio Approach to GHG Reductions

Prepared for the Transportation Energy Institute

August 23, 2023

Disclaimer

Stillwater Associates LLC prepared this report for the sole benefit of the Transportation Energy Institute's August 23, 2023 webinar attendees.

Stillwater Associates LLC conducted the analysis and prepared this report using reasonable care and skill in applying methods of analysis consistent with normal industry practice. All results are based on information available at the time of preparation. Changes in factors upon which the report is based could affect the results. Forecasts are inherently uncertain because of events that cannot be foreseen, including the actions of governments, individuals, third parties, and competitors. Nothing contained in this report is intended as a recommendation in favor of or against any particular action or conclusion. Any particular action or conclusion based on this report shall be solely that of the Transportation Energy Institute's August 23, 2023 webinar attendees.

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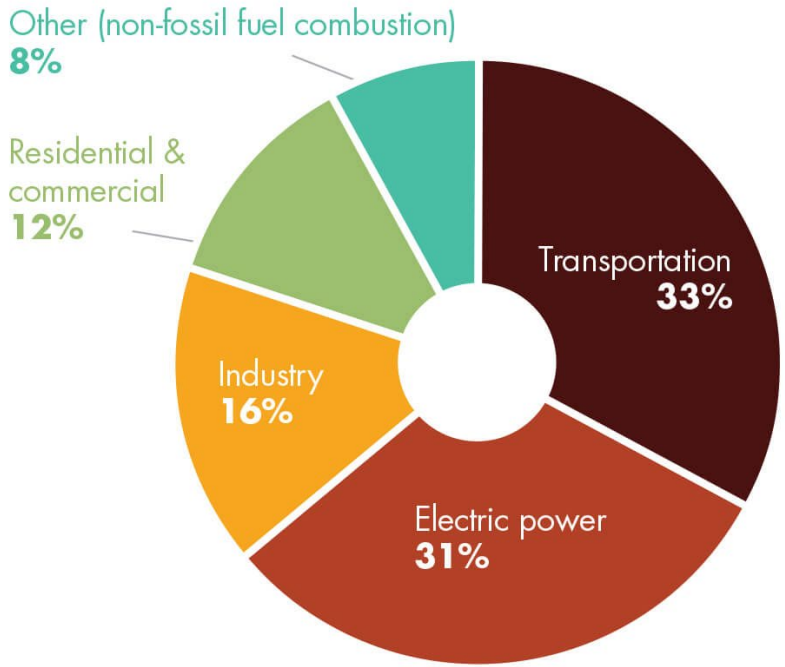
Fueling the future of transportation energy with trusted industry experience

1. Stillwater Associates leverage decades of experience to help clients navigate transportation fuels market challenges. **We see things others miss.**
2. Our clients: government agencies, oil and renewable fuels companies, trade associations, technology developers, private equity firms, and law firms.
3. Leading experts on Low Carbon Fuel programs, Cap & Trade (C&T), the U.S. Renewable Fuel Standard (RFS), and the fuels provisions of the Inflation Reduction Act of 2022 (IRA).
4. Stillwater's **LCFS and C&T Newsletters and suite of Credit Market Outlooks** offer producers, importers, traders, and investors the right information to make smart credit market decisions.
5. **Questions about the transportation energy transition?** Our team of experts is available to provide specific analysis and tailored strategy for your needs.

Transportation is the leading source of U.S. GHG emissions

In the U.S., **transportation represents 33%** and electric power generation represents 31% **of national CO_2 emissions.**

FIGURE 17. U.S. ANTHROPOGENIC CO_2 EMISSIONS BY SOURCE (1990-2020)



Total U.S. emissions in 2020 = 5,981 million metric tons of CO_2 equivalent (excludes land sector). Percentages may not add up to 100% due to independent rounding.

Source: Overview of Greenhouse Gases | EPA

(Figure 17, page 36)

The value of early carbon mitigation

1. Greenhouse gases can remain in the atmosphere for more than 100 years.
2. Given the compounding effect of emissions over time, reducing GHG emissions today will have a more profound effect on the environment than waiting to reduce emissions in the future.

TABLE 2. TRANSPORTATION-RELATED GREENHOUSE GAS CONCENTRATIONS AND GLOBAL WARMING POTENTIAL

GREENHOUSE GAS	CONCENTRATION IN ATMOSPHERE*	ATMOSPHERIC LIFETIME	GLOBAL WARMING POTENTIAL
Carbon Dioxide (CO_2)	416 ppm	Varies	1
Methane (CH_4)	1.895 ppm	100 years	29.8
Nitrous Oxide (N_2O)	0.334 ppm	114 years	273

Sources: Argonne GREET Model (anl.gov) using the IPCC Sixth Assessment Report values and the Global Monitoring Laboratory

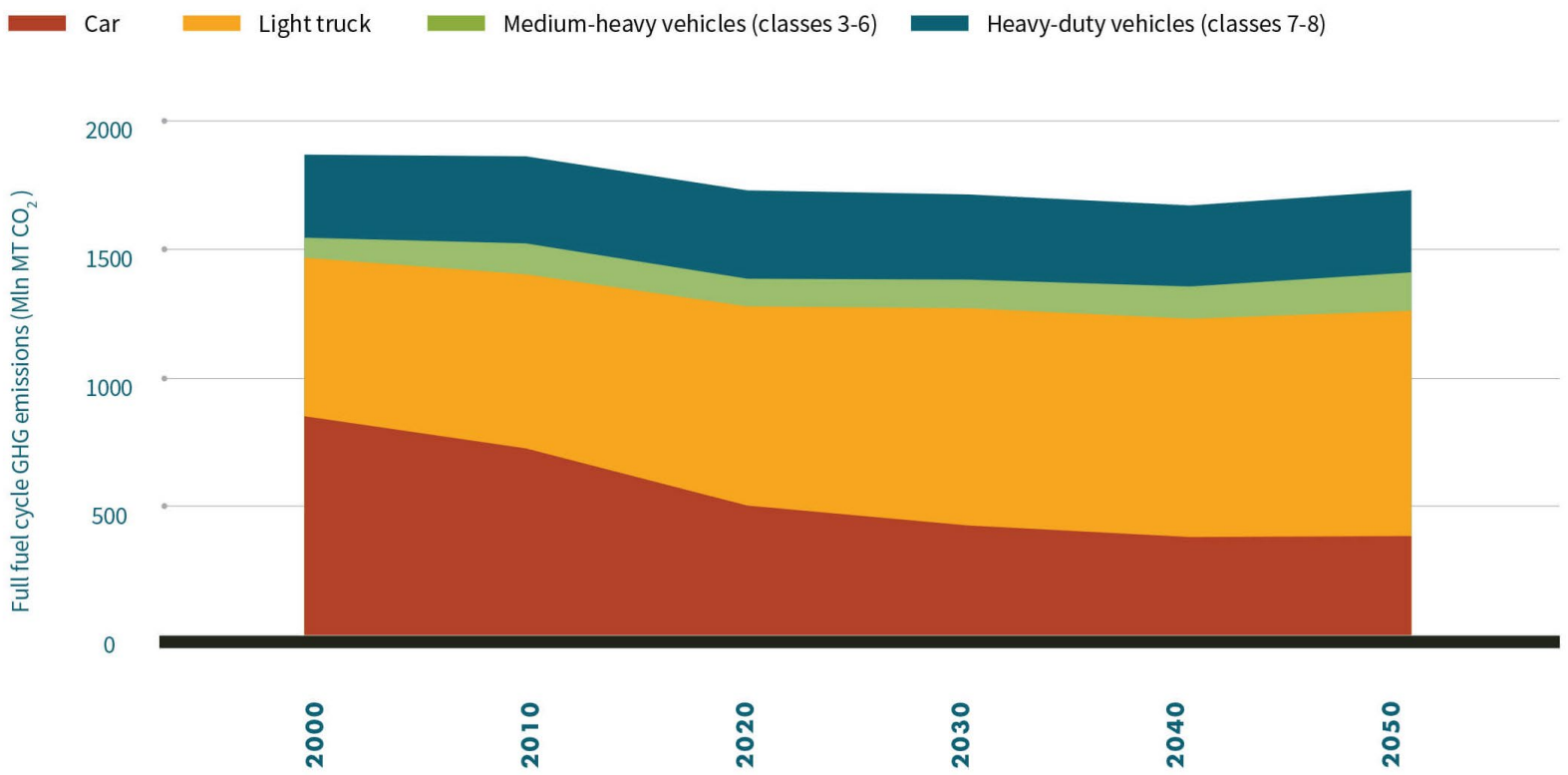
** As of November 2022*

(Table 2, Page 16)

Reducing GHG emissions from fleet is critical

1. The current fleet emits nearly 2 billion MT CO_{2e} per year.
2. To seriously address carbon emissions, we must address the ICEV fleet.

FIGURE 11. ON-ROAD VEHICLES GHG EMISSIONS



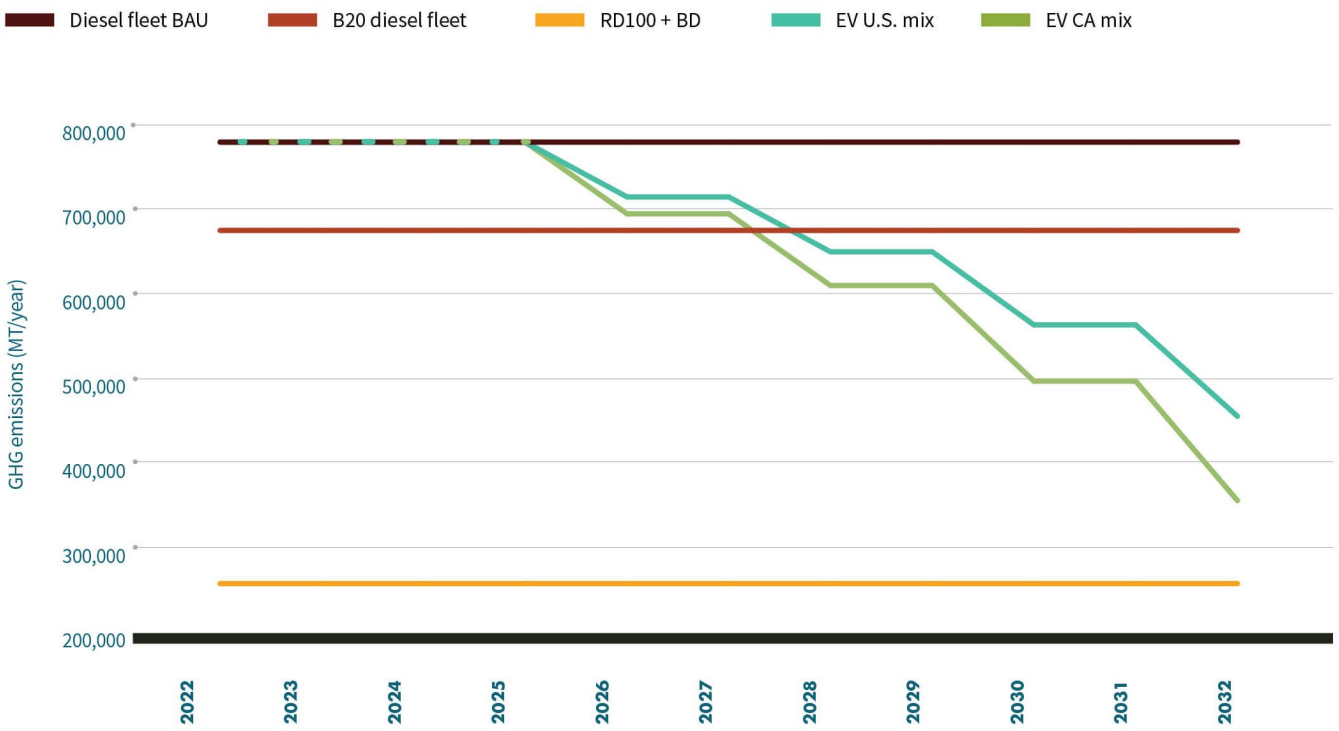
Source: Argonne National Labs VISION 2021 Base Case

(Figure 11, page 30)

Scenarios – Decarbonization of Diesel Fleet

Leveraging existing biofuels options can reduce GHG emissions today and into the future.

FIGURE 20. MEDIUM- AND HEAVY-DUTY VEHICLE ANNUAL GHG EMISSION SCENARIO (2022-2032)



Source: Stillwater assessment using 2021 GREET and EPA MOVES3 assumptions

Hypothetical fleet of 10,000 Medium- and Heavy-Duty trucks

Cases

1. Base Case – 100% petroleum diesel
2. Immediate transition of all fuel to B20
3. Immediate transition to renewable diesel + biodiesel
4. 20% of fleet replaced each year with EVs (starting in 2026, U.S. and California power grid mix)

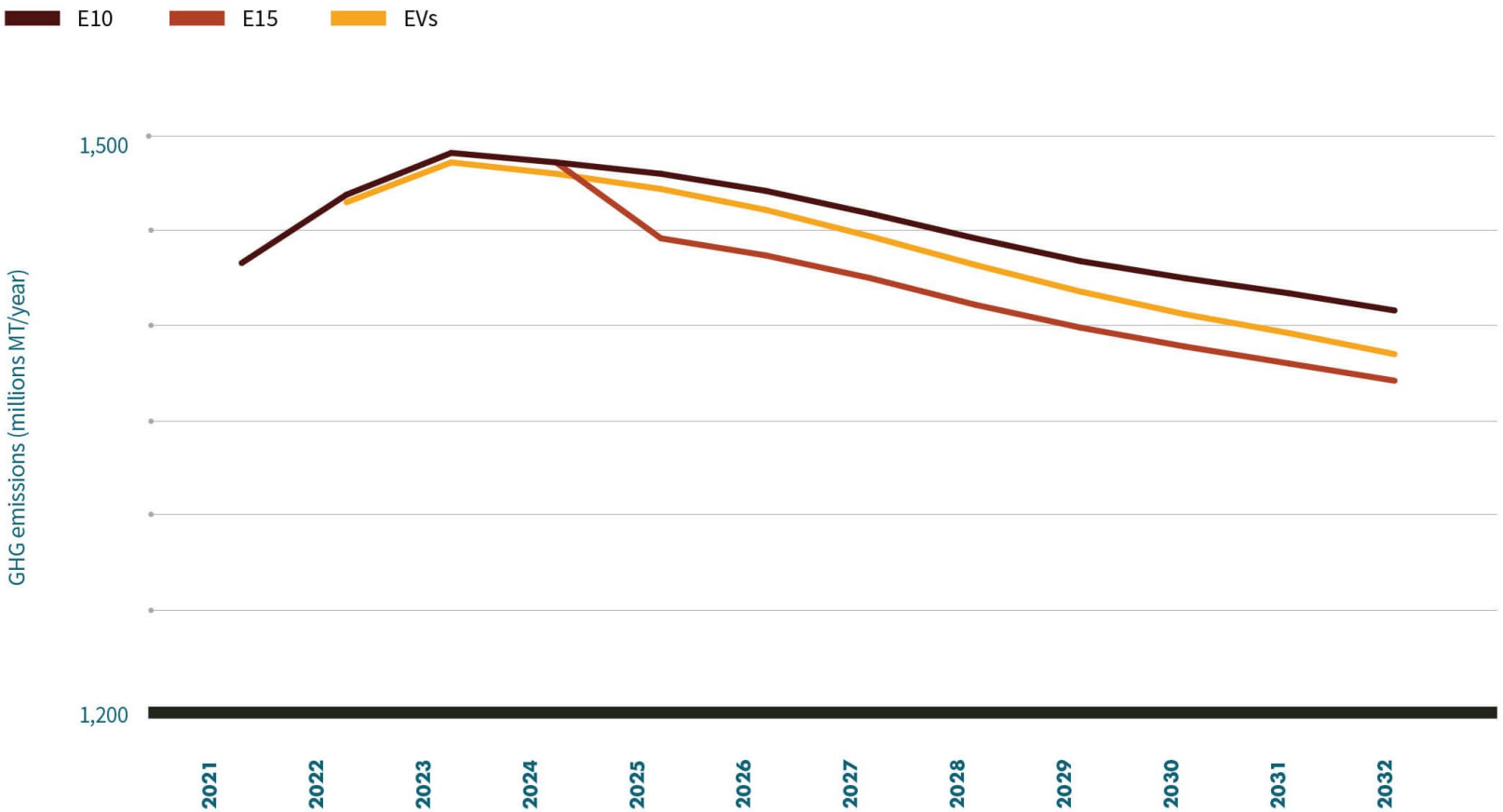
- In 1Q2023, the California diesel pool was 49% renewable diesel and 8% biodiesel.
- Displacement of petroleum diesel is expected to continue increasing.

(Figure 20, page 39)

Scenarios – Pace of LD Transition

1. Gasoline demand increased 2021-23 with Covid recovery
2. Black line shows pace of emissions decline with E10 and no additional electrification
3. Red line shows the impact of replacing all E10 with E15 starting in 2025
4. Yellow line shows anticipated reductions due to electrification (EIA 2022 AEO)

FIGURE 21. LIGHT- AND MEDIUM DUTY VEHICLE ANNUAL GHG EMISSIONS REDUCTION SCENARIO (2022-2032)



Source: Stillwater assessment using 2022 GREET and EIA AEO 2022 Reference Case

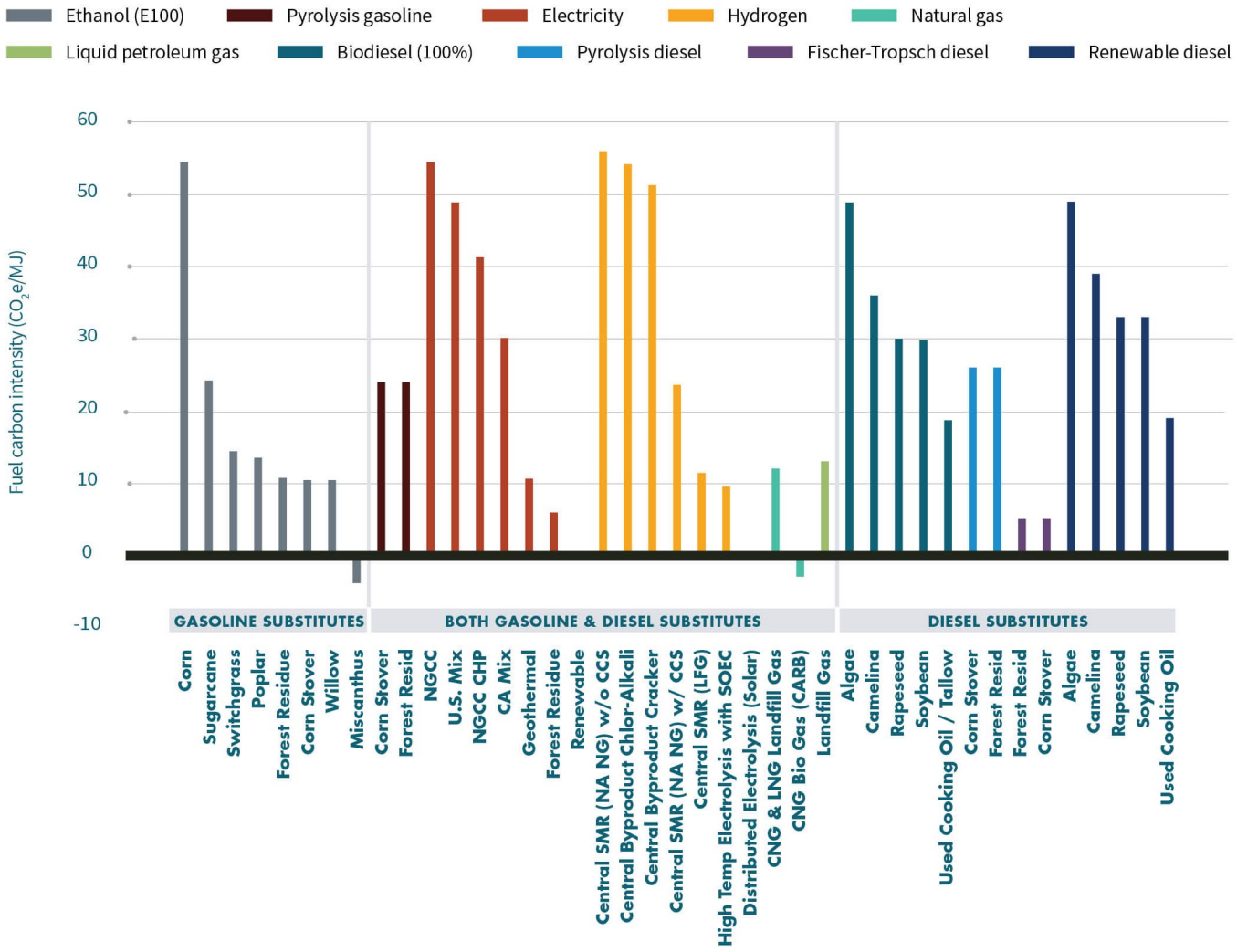
(Figure 21, page 40)

Fuel options with a low life cycle CI are available

1. GREET Model evaluates 41 existing transportation fuel options relative to gasoline at 90 gCO_2e/MJ.
2. Illustrated options all offer GHG reductions similar to or greater than EVs fueled with U.S. mix electricity
3. 24 biofuel options are compatible with existing infrastructure and vehicles and deliver GHG emissions at or below that achieved with EVs charged with the U.S. grid mix.
4. Low-carbon fuels such as E15, E85, B20, RD, and RNG are currently available in the market and could be used more broadly with existing vehicles.

Note: The fuels listed here are unblended; blend restrictions exist for BD and ethanol.

FIGURE 22. LOW-CARBON FUEL OPTIONS AVAILABLE FOR TRANSPORTATION FUELS



Source: GREET 2021 & 2022. Assumes EV EER of 2.4 and FCEV 1.7.

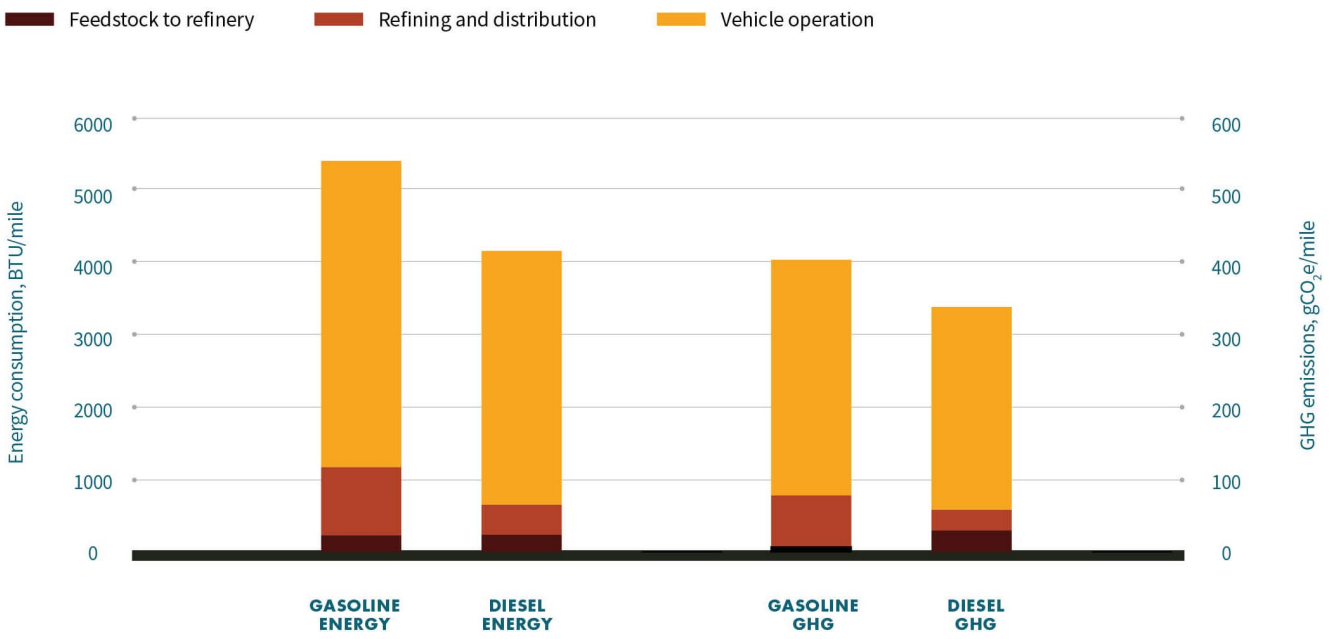
(Figure 22, page 43)

Options for lower carbon petroleum

There are a variety of opportunities to reduce the life cycle CI of petroleum products, many of which yield economic benefits as well.

1. **Crude Oil Production:**
   a. Renewable energy for power needs
   b. Reduce flaring and fugitive emissions
2. **Refining and distribution:**
   a. Increase energy efficiency
   b. Use renewable electricity and renewable natural gas
   c. Use carbon capture and storage at optimal locations; could reduce GHG emissions by 15% for gasoline production and 30% for diesel production
   d. Increase electrification
   e. Use renewable natural gas to produce hydrogen

FIGURE 24. ENERGY CONSUMPTION AND GHG EMISSIONS FROM PRODUCTION AND USE OF GASOLINE AND DIESEL



Source: GREET model, Stillwater analysis

(Figure 24, page 48)

Options for lower carbon biofuels – Feedstock Production

Most GHG emissions currently come from diesel used in equipment and nitrogen-based fertilizers.

1. Fuel equipment with biodiesel or renewable diesel
2. Use low fertilizer-dependent seeds to reduce nitrogen application
3. Implement sustainable agronomic practices
4. Use corn kernel fiber to produce ethanol (EPA pathway approval pending)

(Pages 51-54)

Options for lower carbon biofuels – Plant Operations

Most GHG emissions currently come from natural gas and electricity usage.

image source: Reuters

1. Maximize production of Wet Distillers Grains with Solubles (WDGS) vs Dry Distillers Grains with Solubles (DDGS) – location dependent
2. Use renewable natural gas and electricity
3. Invest in more efficient technologies such as membrane dryers
4. Implement carbon capture and storage, most effectively on the fermenter effluent at a dry mill plant, which could reduce CO_2e emissions by about 40%

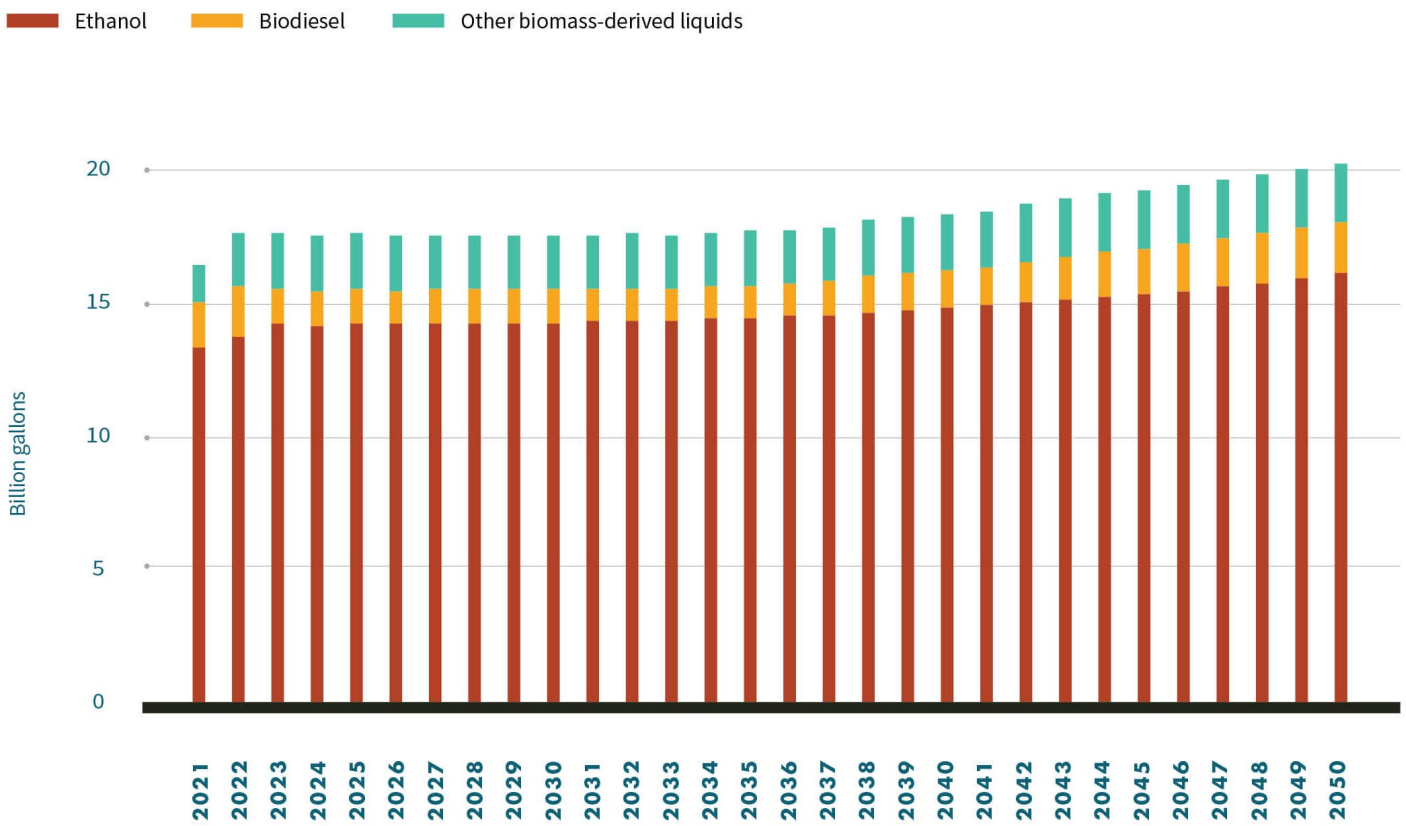
(Pages 51-54)

Feedstock availability for additional biofuels

The U.S. has potential to produce over a billion tons of biomass annually.

1. Steady **improvements in per-acre yields** for corn and soybeans
2. Use of inedible tallow, used cooking oil and distillers corn oil for biofuel production
3. **Nonfood feedstocks** such as oilseeds from cover crops like pennycress, carinata and camelina
4. Half of the cellulosic biofuel target of the RFS could be met by harvesting **agricultural residues**
5. The other half could be met by producing **energy crops**, like miscanthus, on marginal land without diverting productive cropland. (Certain economic and regulatory conditions would be required for such energy crops to be viable.)

FIGURE 47. PROJECTED BIOFUEL PRODUCTION IN THE U.S. IN THE AEO REFERENCE CASE



Source: AEO 2022

(Figure 47, page 99)

Portfolio of low-carbon ICEV fuels

1. Each option faces challenges and no option is a silver bullet solution for all applications.
2. However, with key adjustments to regulations or market developments, each may have an opportunity to contribute to a lower carbon transportation sector.

CURRENTLY AVAILABLE FOR ICEVS	CURRENTLY AVAILABLE FOR AFVS	POTENTIAL FUELS
Ethanol	Renewable Natural Gas	Pyrolysis Fuels
Biodiesel	Renewable Propane	Biomass to Liquids
Renewable Diesel	E85	E-fuels
Renewable Gasoline		Hydrogen
Fischer-Tropsch Diesel		

Each low CI option was evaluated

TABLE 16. COMPARISON OF ALTERNATIVES TO DECARBONIZE ICEVs

OPTION	PAIRED VEHICLE TECH-NOLOGY	STATUS/ POTENTIAL OF FUEL PRODUCTION	COMPATIBLE WITH CURRENT FUEL DELIVERY LOGISTICS?	COMPATIBLE WITH CURRENT FUEL DISPENSING SYSTEM?	CONSUMER ACCEPTANCE	SHORTEST TIME TO FULL MATURITY	RELATIVE UNSUBSIDIZED COST OF TRANSITION	CARBON EMISSIONS REDUCTION VS. CURRENT FLEET & FUELS
Current ULSD & E10 Gasoline	Current Gas ICEV	Current	Yes	Yes	Yes	Current	None	base
Reduced CI Gasoline & Diesel	Current Gas ICEVs	Current	Yes	Yes	Yes	Mid-Term	Low-Med	5-15%
Ethanol (E15)	Current Gas ICEV	50% ethanol increase	Yes, mostly	Yes	Yes	Near-Term	Low	3%
Ethanol (E15)	Plug-in Hybrids (PHEVs)	50% ethanol increase	Yes	Yes	Yes	Mid-Term	Low-Med	20%
Biodiesel (B5)	Current Diesel ICEV	Requires ~100% increase over current production	Yes	Yes	Yes	Near-Term	Low-Med	<5%

** Excerpt from full table **

(Table 16, page 176)

High-Level Conclusions from Fuels Evaluation

Feasibility	Low Carbon Options	Benefits	Barriers
Available Today	E10/E15/E85 B20 RD100 RNG	Drop-in solutions for existing vehicles	Declining FFV population E15/E85 fueling infrastructure BD/RD feedstocks Limited NGV population
Near-Term Potential	Higher ethanol blends Non-food feedstocks Carbon capture and storage Advanced ICEV technologies	Deeper decarbonization with near-to-market technologies	New vehicles and fuel infrastructure required Support for growers of non-food feedstocks Regulatory certainty
Longer-Term Potential	Cellulosic ethanol FT diesel E-Fuels	Increased volume potential Deeper decarbonization Greater variability in the liquid fuel mix	Technological development to make economic Surplus low-carbon power

Summary

1. Decarbonizing ICEVs is required to address climate change
   a. Transportation is largest source of U.S. GHG emissions
   b. GHGs have long atmospheric lifetimes – prompt action is prudent
   c. ICEVs will comprise the bulk of the U.S. fleet for many years even with policies promoting EV adoption
2. Many options exist to decarbonize ICEVs
   a. Biofuels are and will continue to be the lowest-hanging fruit
   b. Expanding beyond current options requires a policy environment which supports investment in growing existing and near-commercial options

Thank you.

Questions?

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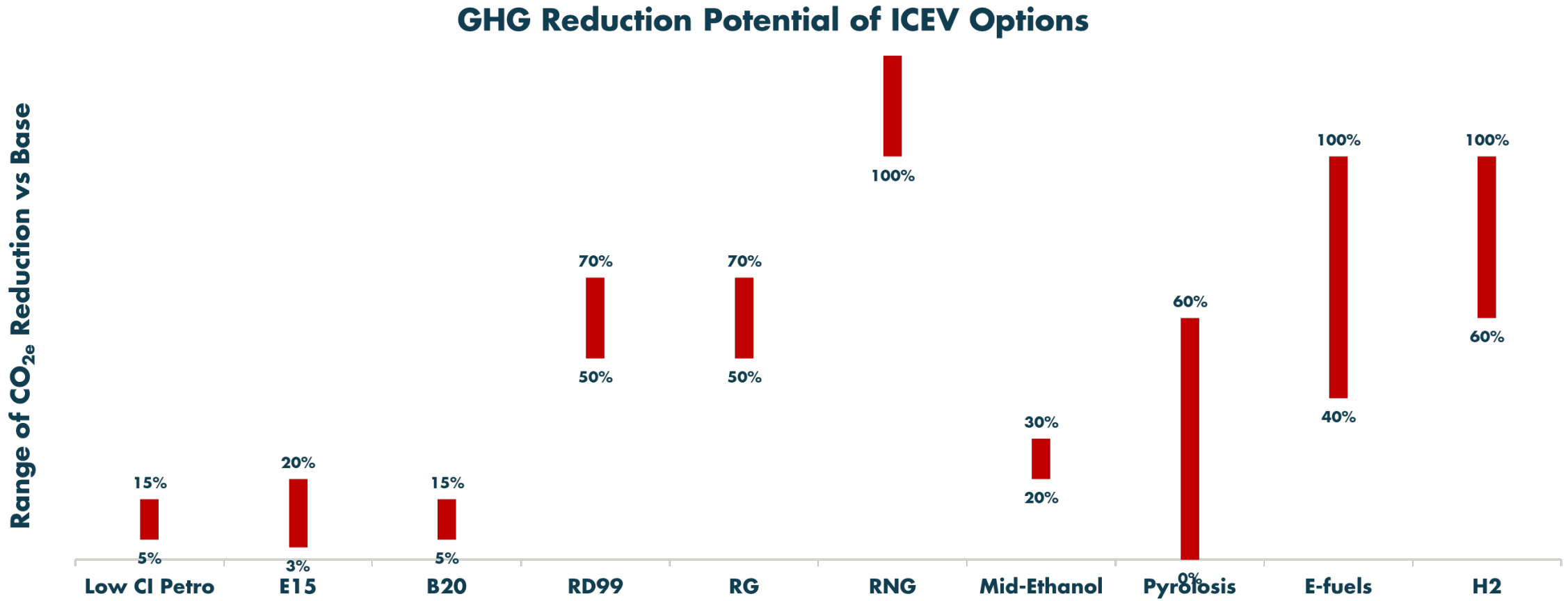
Range of GHG reduction potential

The final tables in the report show the potential GHG reduction of various options. Below is a graphical representation of those ranges, demonstrating that meaningful reductions are available from ICEVs in the near- and mid-term.



(Data drawn from Table 16, page 176)

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Summary and Conclusions

- There is no single solution for decarbonizing the on-road transportation sector
- ICEVs will comprise a significant portion of the fleet well into the future, despite policy efforts to accelerate a transition to new vehicles
- GHG emissions accumulate and remain in the atmosphere for more than 100 years –
    - Early emissions reductions is critical to achieving environmental objectives
    - This necessitates lowering the carbon emissions from ICEVs and not waiting for the market to transition to new vehicles
- Carbon emissions from the current and future fleet of ICEVs can be reduced through a variety of ways, most notably renewable fuels and ICEV technologies. Combining low carbon fuels with higher efficiency ICEVs and hybrids increases the GHG reduction potential
    - There are at least 24 biofuels that can reduce emissions equal to or more than today's EVs charging from the U.S. electricity grid, even when excluding coal power plants from the mix
    - Reducing emissions by up to 15% with existing fuels would remove up to 300 million MT of CO_{2e} emissions each year
- New fuel options being explored and developed today (e.g., pyrolysis, e-fuels, H2-ICE) show tremendous promise in reducing carbon emissions of ICEVs, but need support to overcome technological, cost and market hurdles.
    - Reducing emissions by at least 40% with innovative fuels would remove 800 million MT of CO_{2e} emissions each year
- Given the varying degrees of viability and timing uncertainties, a portfolio approach to ICEV decarbonization is advisable.
    - A portfolio approach for ICE fuels and future vehicle technologies will result in both ICEVs' (near-term) and ZEVs' (longer term) roles in minimizing transportation carbon emissions being realized.

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Questions and discussion