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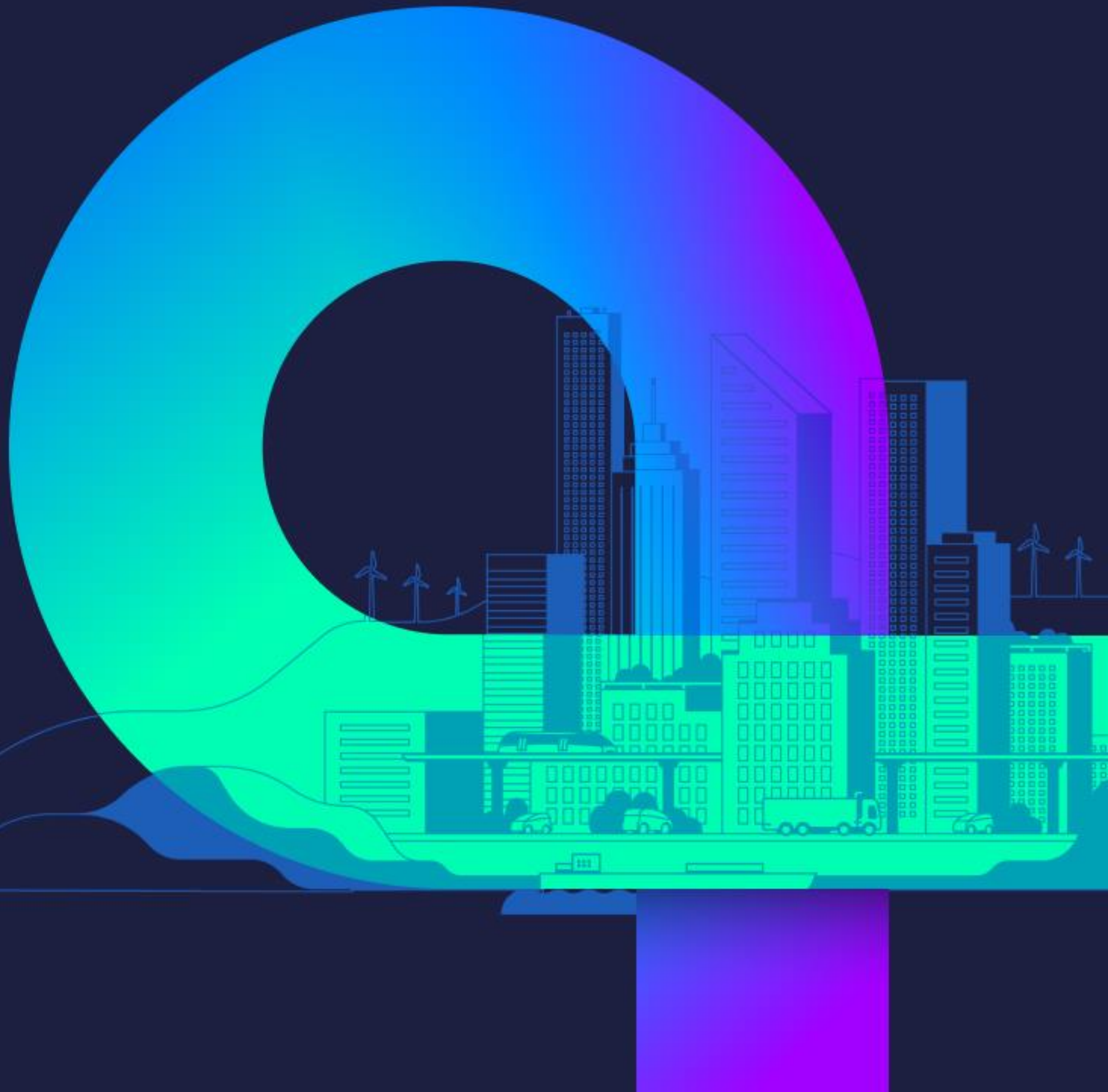
The Realities of Achieving True Net Zero

Jim Arthurs

TTP Industry Conference

June 26, 2024 Nashville



Disclaimer

This analysis includes data from multiple sources plus many estimates. It is intended to provide information that is directionally correct, but actual outcomes in the development of heavy duty truck* transportation may vary.

** For purposes of this presentation, unless otherwise indicated, heavy duty truck is defined as Class 8 (33,001 lb GVWR and up).*

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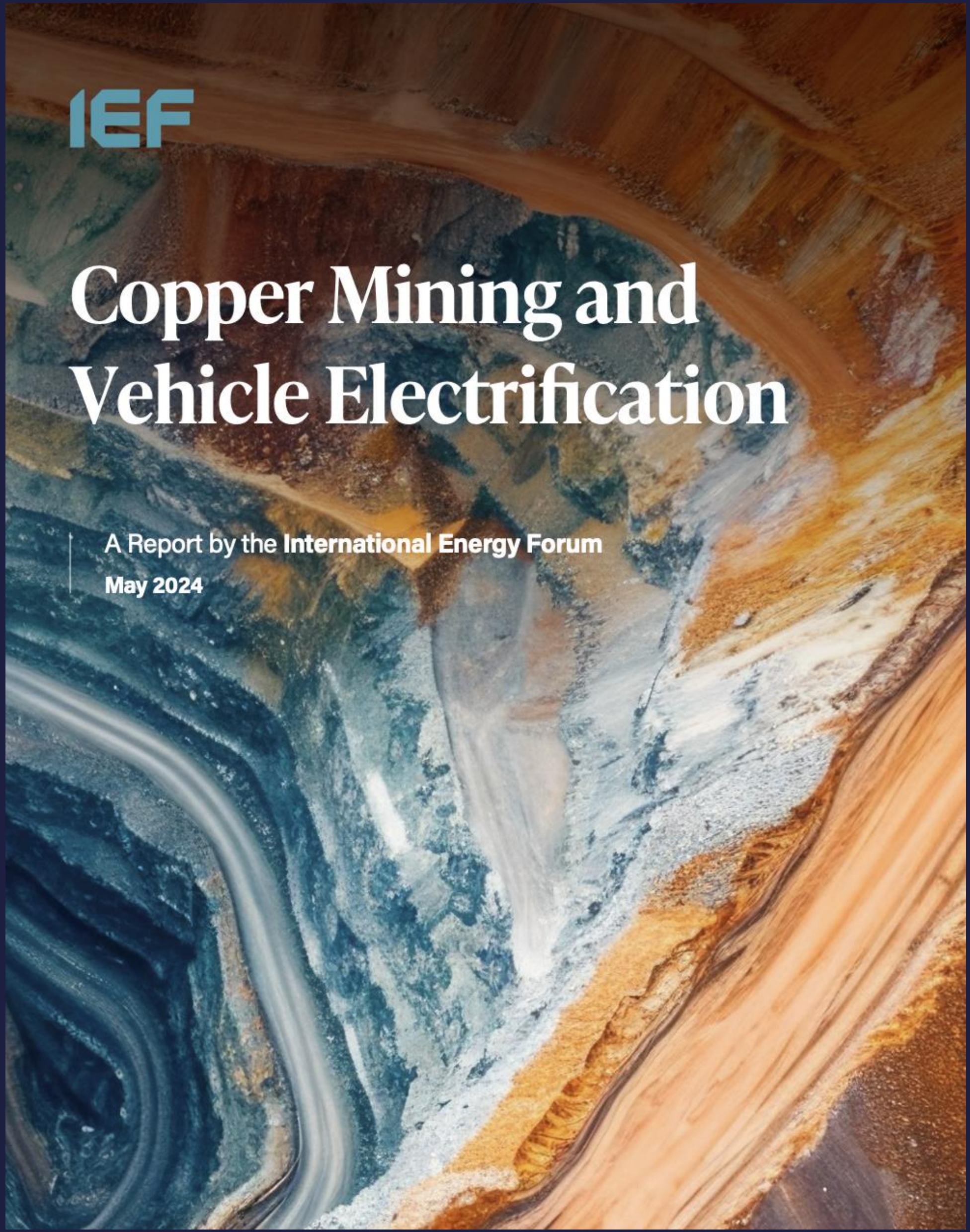
US regulatory authorities are mandating rapid expansion of zero emission vehicles, including heavy duty trucks

In order to successfully deploy zero emission heavy duty trucks, several things need to be in place:

- The supply chain of minerals to support vehicle electrification
- Expansion of the electric grid and charging capacity, or expansion of hydrogen fueling capacity
- Trucks that effectively do the work required

Let’s start by looking at minerals…

Critical minerals for electrification



Copper is required throughout the electric vehicle ecosystem, from batteries to vehicles to electricity distribution to chargers.

The International Energy Forum has recently released a detailed study of copper mining and vehicle electrification, which says in part:

- "To meet business-as-usual needs, 115% more copper must be mined in the next 30 years than in all prior human history"
- "New copper mining needed to replace fossil fuel with renewable energy sources is 4.6 times the baseline demand"
  - 194 new copper mines are needed to produce an additional 91 megatons per year by 2050
  - 6 new large-scale mines per year
- The report raises substantial doubt that this increase in copper production is achievable

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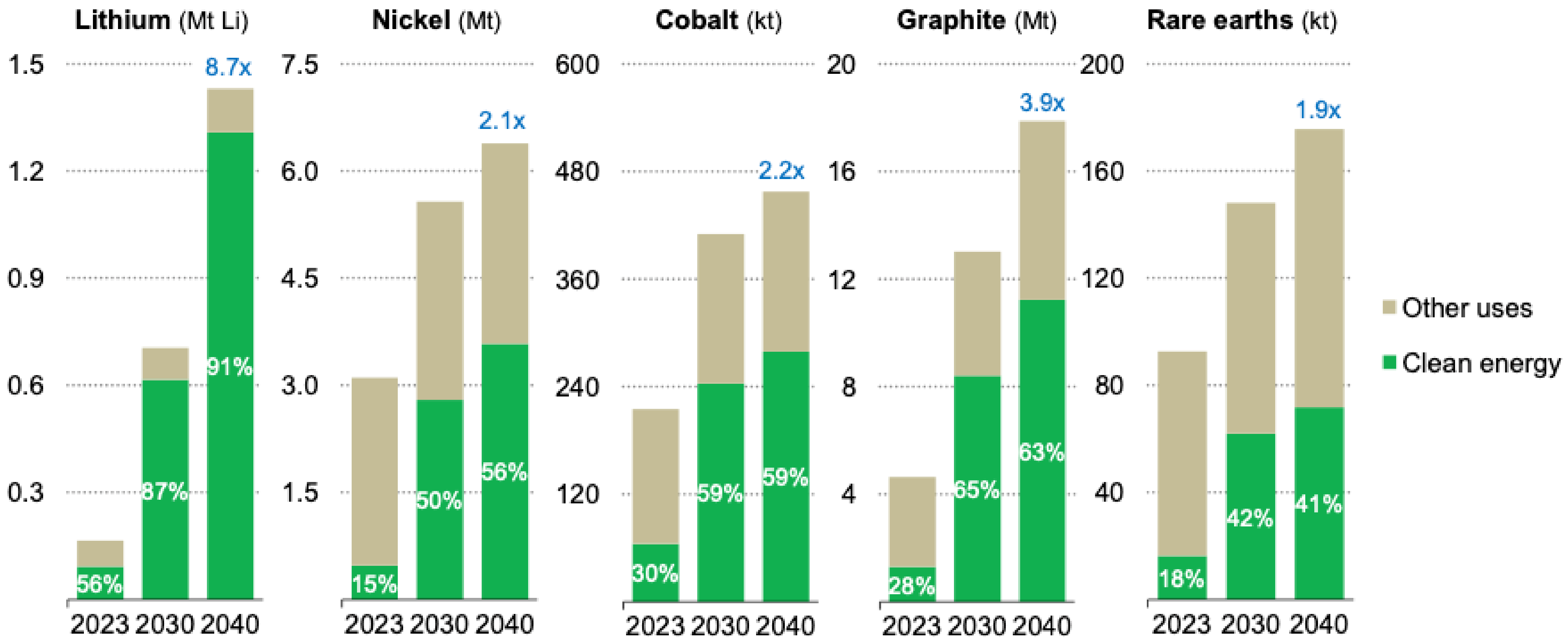
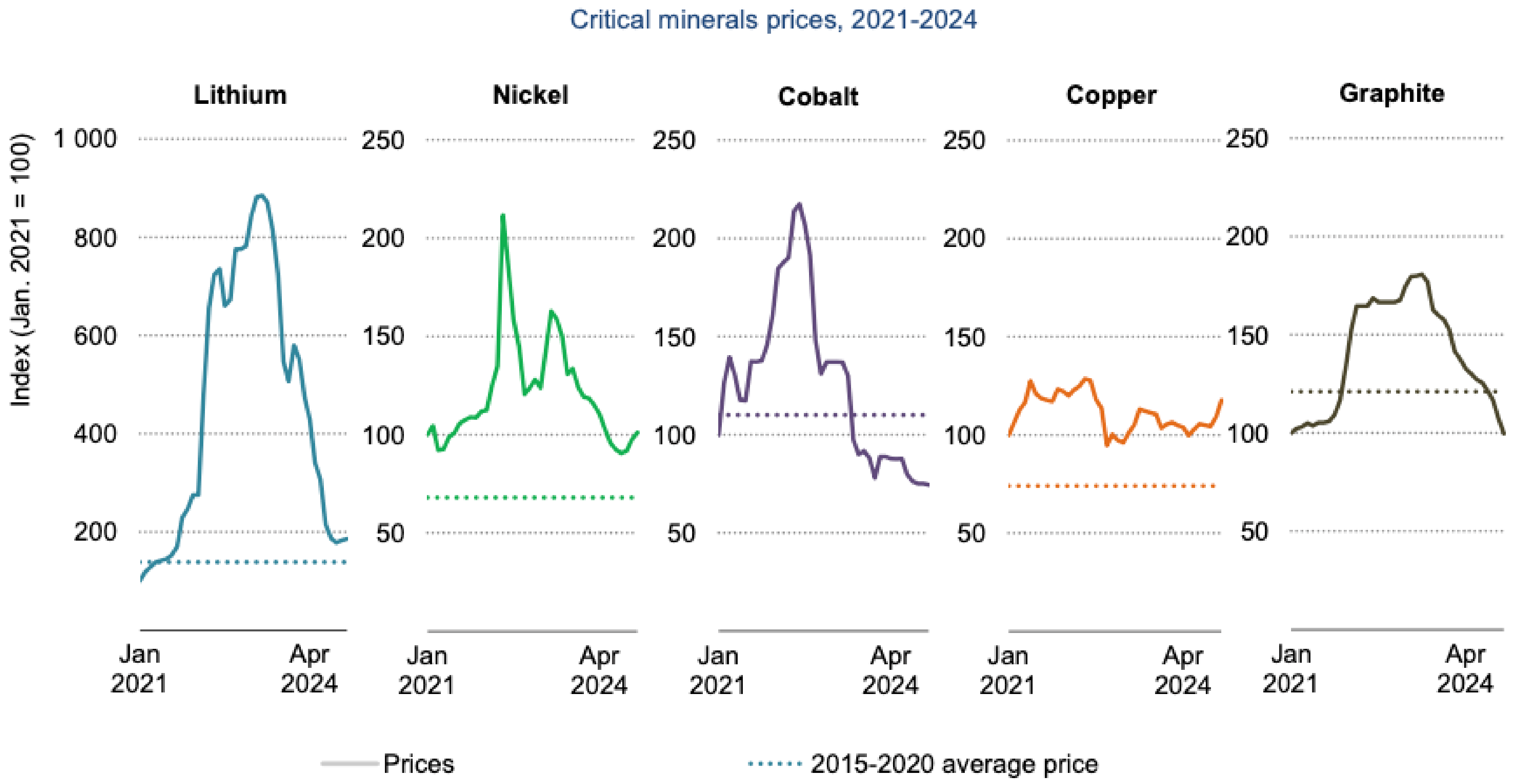
To support global vehicle electrification, rapid growth of other critical mineral supplies is required



Source: IEA Global Critical Minerals Outlook 2024

Prices of these minerals have been extremely volatile, increasing risks to ROI on mining investments



Source: IEA Global Critical Minerals Outlook 2024

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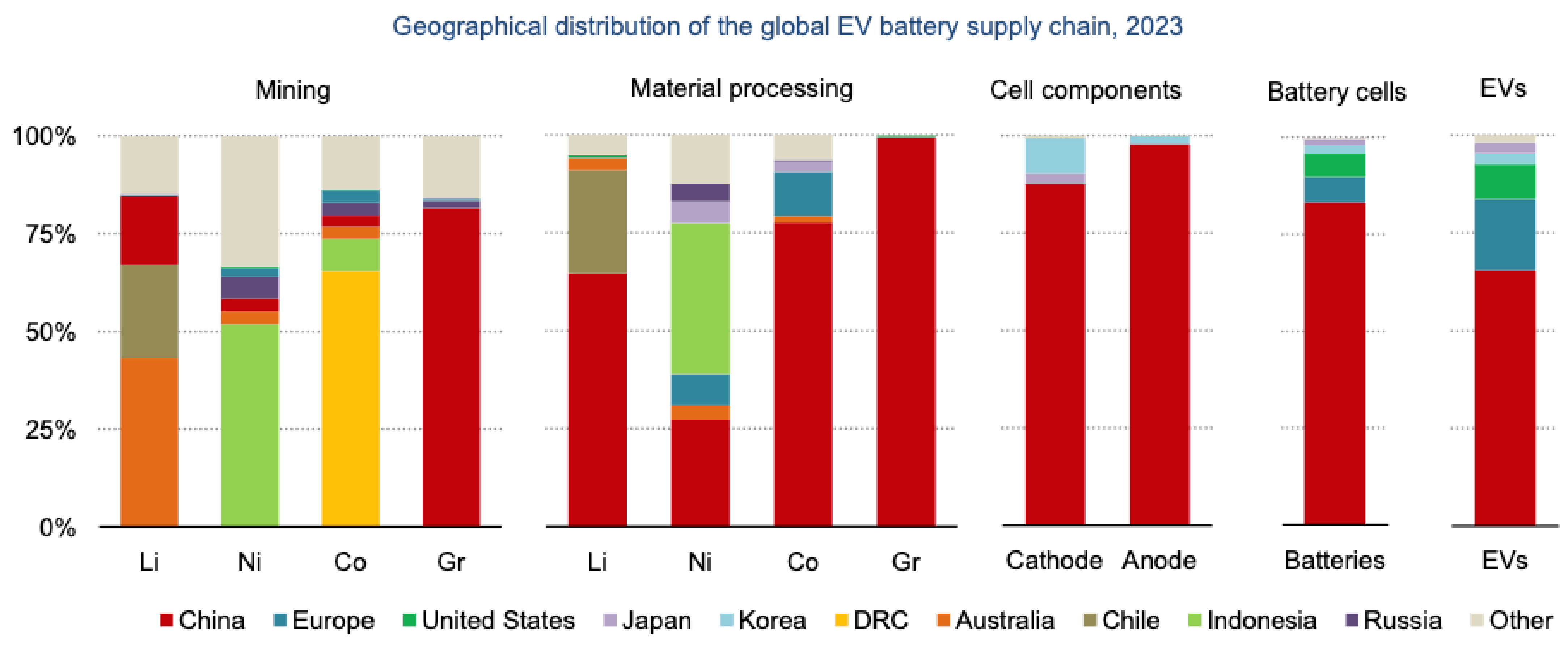
While mineral mining is geographically diversified, China controls most downstream production

China dominates the downstream and midstream global EV battery supply chain



Source: IEA Global Critical Minerals Outlook 2024

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A Key Question:

Given the current state of the mineral supply chain, how likely is it that the US will secure an adequate and dependable supply of all required critical minerals to support mass vehicle electrification in the next 15 years? In the next 25 years?

Current state of ZEV trucks

While progress has been made in the light duty EV segment, heavy duty trucks are very different

US Vehicle Population	Millions of Vehicles	Average Annual Fuel Consumption (gallons/vehicle)
Light duty	257.6	481
Commercial	11.6	1,603
Heavy duty	3.1	9,686

Heavy duty trucks:

- Are ~1% of the vehicle fleet
- Consume 20X the fuel per vehicle as light duty
- Are purely for commercial use
- Vehicle priorities are economics and reliability

- Are hard to electrify:
    - Battery cost and weight
    - Limited range
    - Long time to charge
    - Electric power availability

Source: US Department of Transport Bureau of Transportation Statistics

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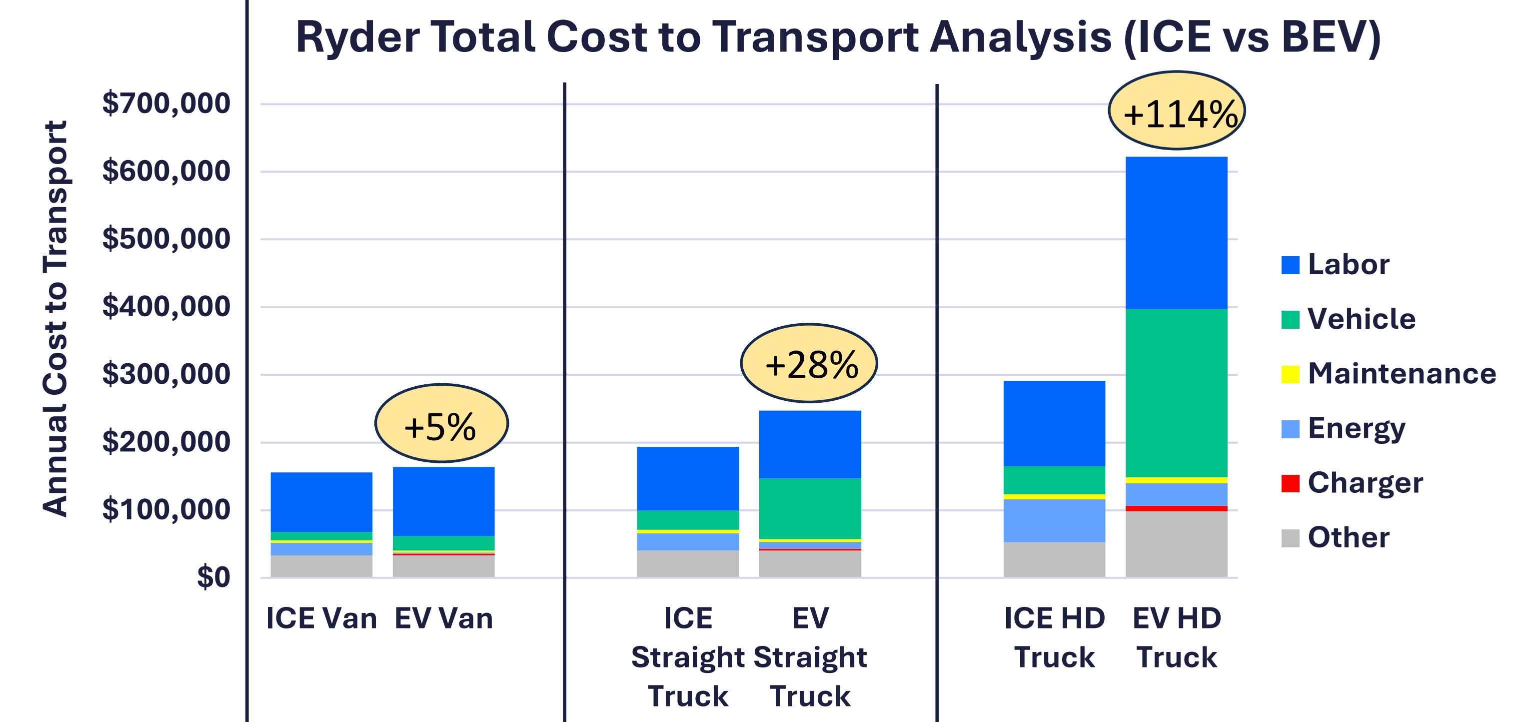
Heavy-duty electric trucks are available, but they do not meet the needs of most truck fleets



	ICE Van	EV Van	ICE Straight Truck	EV Straight Truck	ICE HD Truck	EV HD Truck
Annual miles	40,000		55,000		109,000	
Vehicles	1		1		1	1.9
Payload lbs	2,500		11,000		29,000	22,000
Drivers	1		1		1.2	2.1
Hours/week	48	55	48	51	58	97
Cost / mile	$3.90	$4.10	$3.52	$4.49	**$2.67**	$5.71

Ryder System Inc. manages a fleet of nearly 260,000 commercial vehicles. They did a head-to-head comparison of their diesel and electric truck costs:

- Electric vans were competitive, with only 5% higher cost
- Electric medium duty trucks were productive, but had a 28% higher cost to operate
- Heavy duty electric trucks were unproductive, **requiring 1.9 trucks and 2.1 drivers to do the work of one diesel.** This resulted in operating costs more than double their diesel costs

Source: Ryder Electric Vehicle Total Cost to Transport Analysis May 2024

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What about fuel cell electric trucks?

- Heavy duty fuel cell electric trucks are still in their infancy, with very few trucks in operation
  - Nikola reported that it sold 35 FCEV trucks in 2023
  - Total HD FCEV trucks in operation are probably less than 100

- No public information regarding FCEV operations, efficiency, performance and operating costs has been released

- While there is significant interest in FCEV trucks and emerging interest in hydrogen internal combustion trucks, a critical issue is the cost and availability of hydrogen fuel
  - To be competitive with diesel, 1 kg of hydrogen (energy equivalent to 9/10ths of a gallon of diesel) needs to be in the $4 to $5 range. The current price of hydrogen ranges from about $16 to $30 per kg and fueling infrastructure is sparse

- It seems unlikely that FCEV trucks will capture any significant market share in the 3 to 5 year timeframe.

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Another Key Question:

Given the current performance of battery electric heavy duty trucks, and only a small number of fuel cell electric heavy duty trucks in operation, how likely is it that these vehicles will improve to the point where they make operational and economic sense for truck fleets so they can begin large scale adoption within the next three or four years (e.g. by 2027 or 2028)?

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There are many obstacles and risks to large scale vehicle electrification timing and feasibility. None have been solved.

Mineral supply chains

Geopolitical security

Availability of investment capital

Improved battery technology to enable better range and payload

Environmental impact of mining

Truck collision and fire safety

Availability of land and rights of way for electric grid expansion

Price stability on required materials

"Real world" experience with battery and fuel cell vehicles

Truck longevity

"Last mile" electrification

Impact of heavier trucks on road and bridge infrastructure

Massive increase in clean electricity generation

Truck range and productivity

Truck reliability

Permits and licenses for mining and grid expansion

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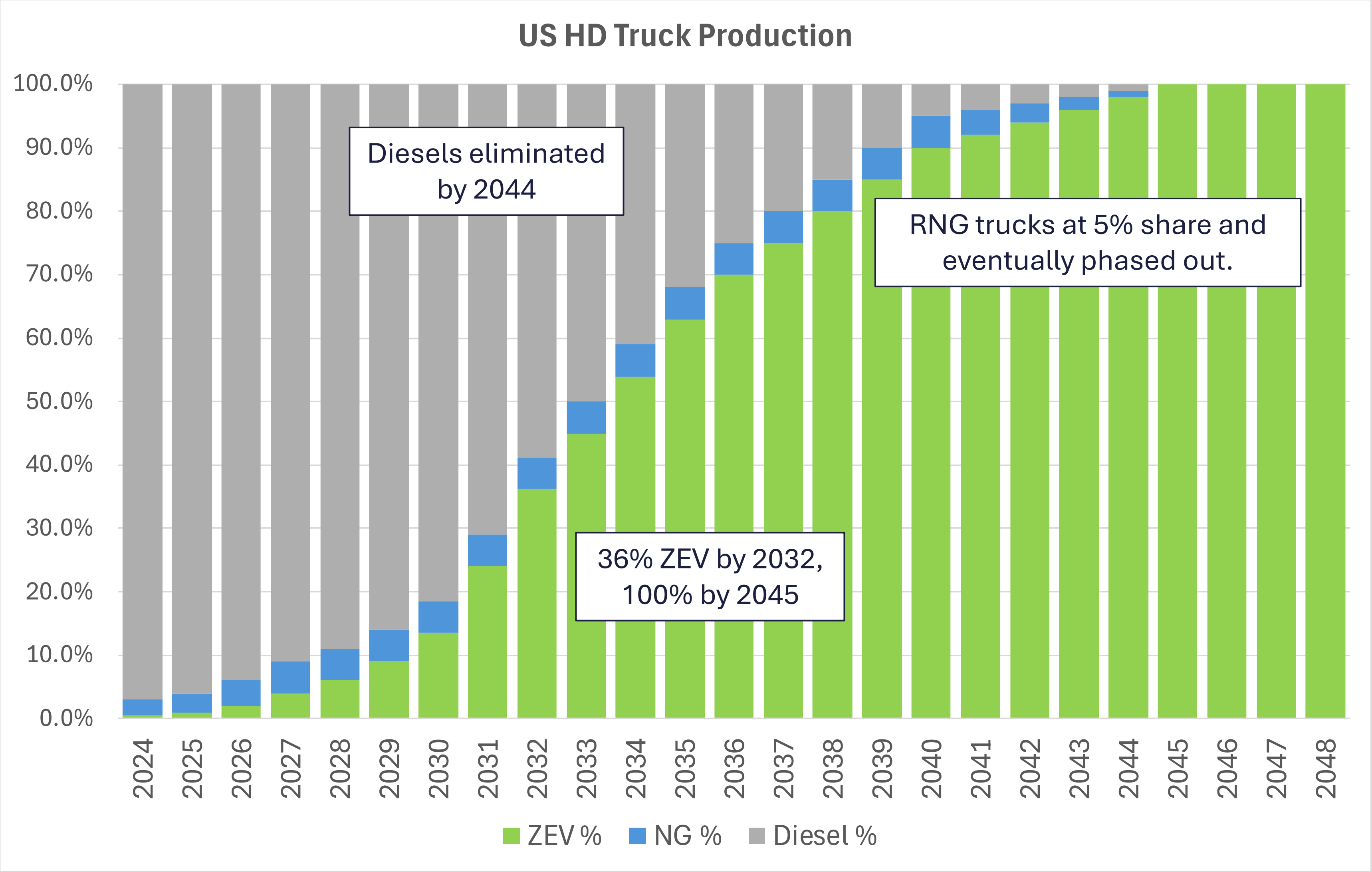
A ZEV adoption and emission reduction scenario

EPA ZEV path for HD trucks in the US *One of the scenarios*



Source: The Transport Project analysis

The EPA's Phase 3 greenhouse gas standards mandate the reduction of CO2 emissions from vehicle tailpipes. They do not specify a particular combination of technologies to achieve the mandated reductions. They do mandate that by 2032, CO2 emissions from daycab tractors must be reduced 40% from the Phase 2 standard, and sleeper cabs must be reduced by 25%.

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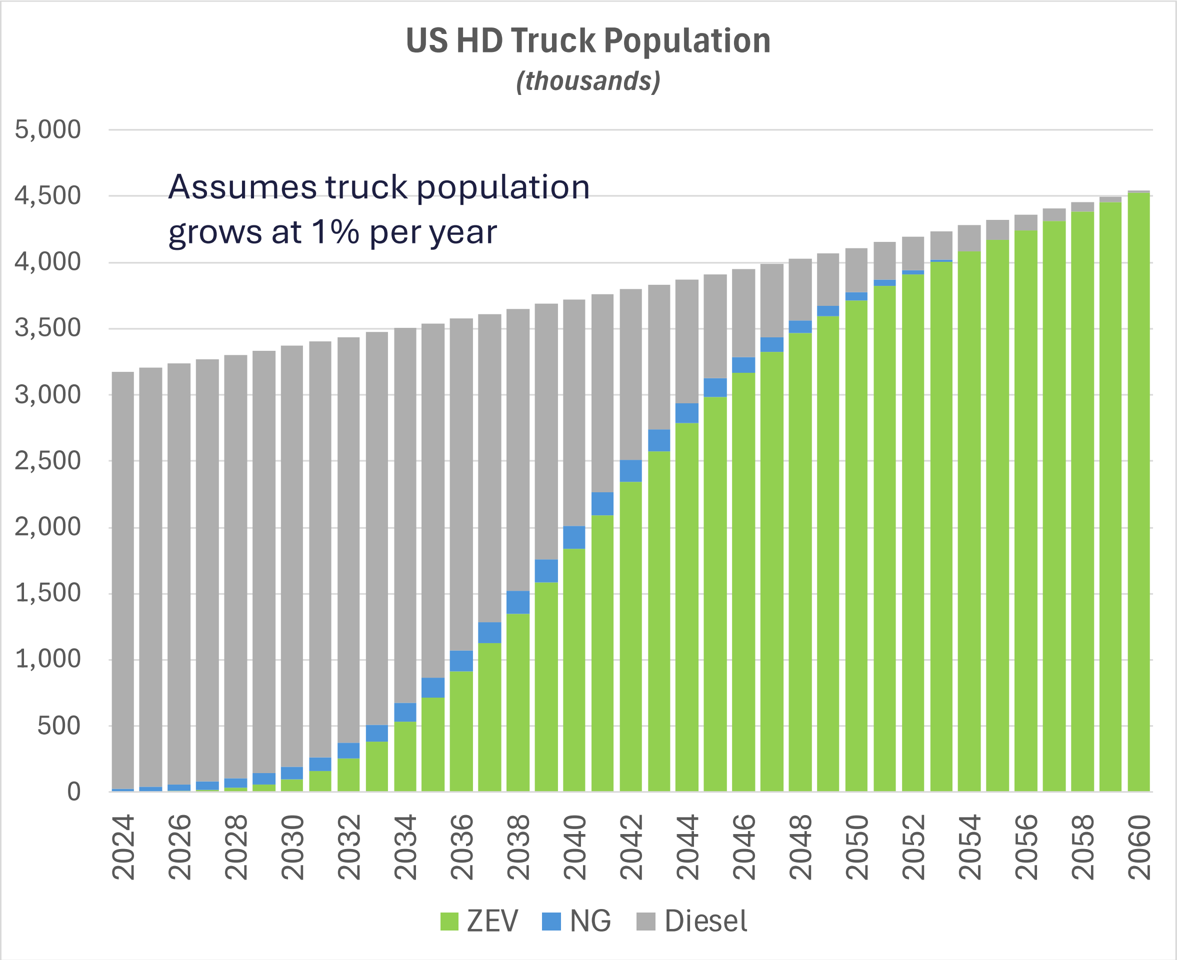
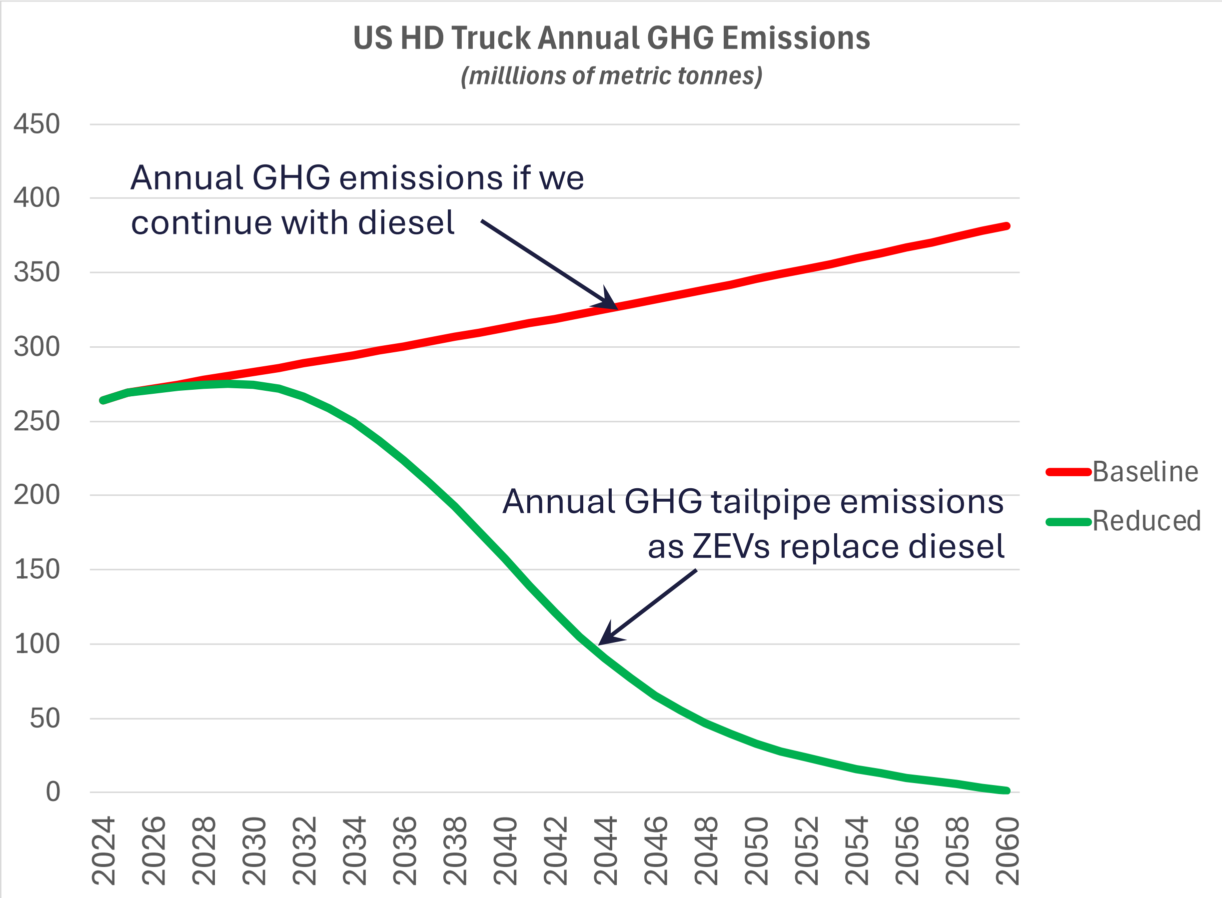
EPA ZEV path for HD trucks in the US: desired outcome





As new ZEV trucks replace older diesels, the US fleet is fully ZEV by 2060, and almost 400 million metric tonnes of annual GHG emissions are eliminated

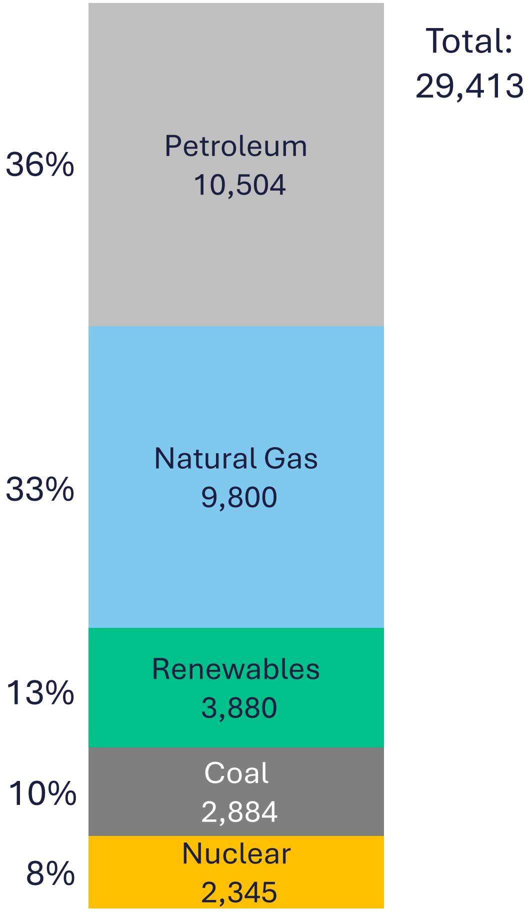
Source: The Transport Project analysis

Electricity requirements to support broad ZEV adoption

US energy production and consumption in 2022

Electricity units in terawatt-hours (TWh)

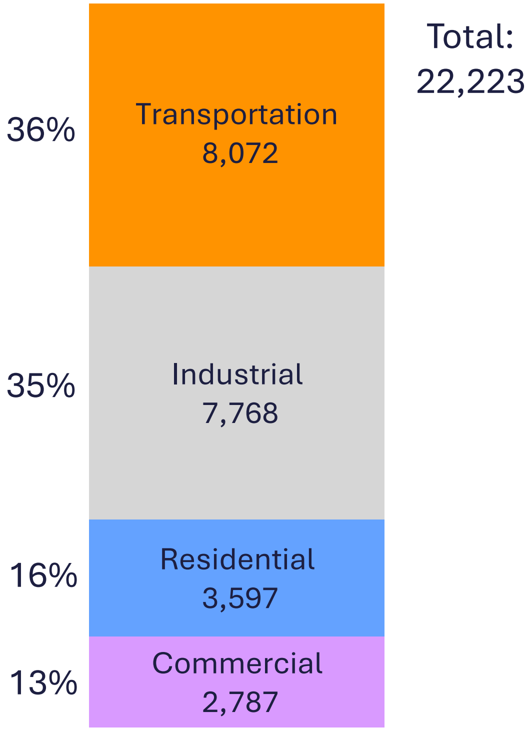
US Annual Energy Production



Energy consumption is 24% lower than energy production.

Why?

US Annual Energy Consumption



Source: US Energy Information Administration

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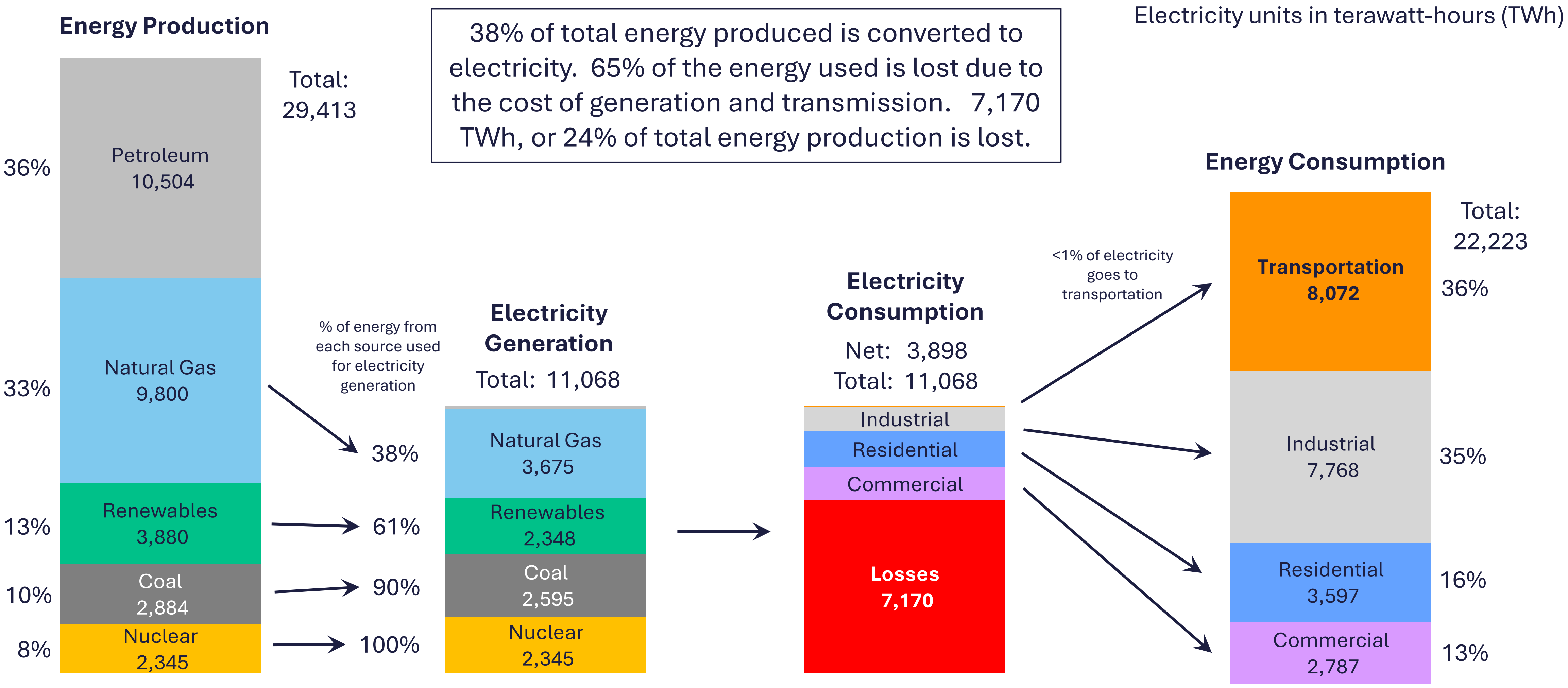
US energy production and consumption in 2022

38% of total energy produced is converted to electricity. 65% of the energy used is lost due to the cost of generation and transmission. 7,170 TWh, or 24% of total energy production is lost.



Source: US Energy Information Administration

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Energy consumption for transportation: 2022 and when fully electrified

	Energy Efficiency (US DOT)	Average Energy Efficiency	Energy Input Required to Transfer 100 Units of Energy to the Road
ICE Vehicle	12% to 30%	21%	488
BE Vehicle	64% to 73% (including regen)	69%	145

BEV requires ~70% less energy input vs ICE

	2022	2050 (with 1% annual fleet growth)	2050 fully electrified
Vehicles (thousands)	282,215	365,540	365,540
Transportation Energy Required	8,072 TWh*	10,560 TWh	**3,168 TWh**
	* Including <1% for current EVs	Assuming no electrification	30% of 10,560 TWh

Source: US Department of Transportation, The Transport Project analysis

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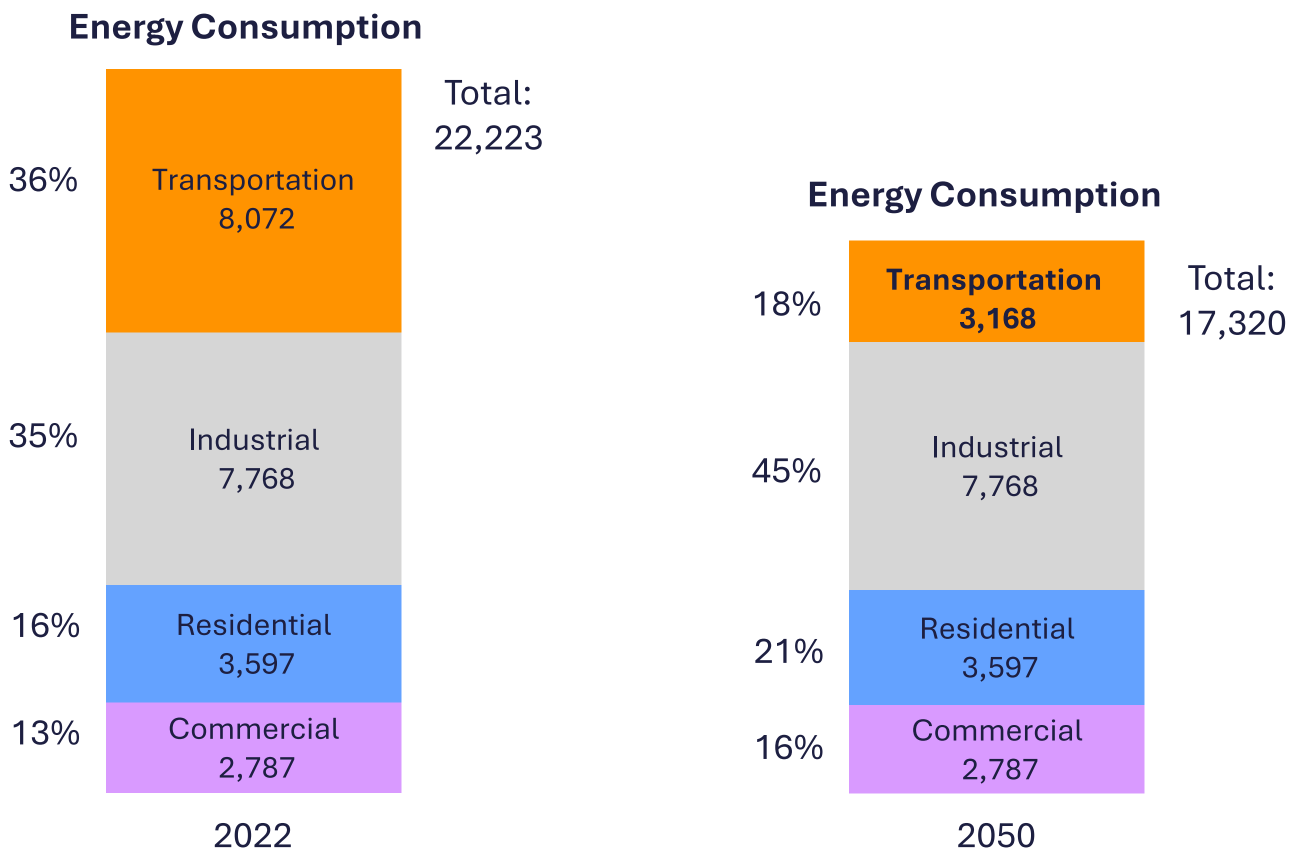
US annual energy consumption: 2022 vs 2050 if transportation is fully electrified

Electricity units in terawatt-hours (TWh)



For this analysis, we assume no changes in energy consumption in Industrial, Residential and Commercial segments.

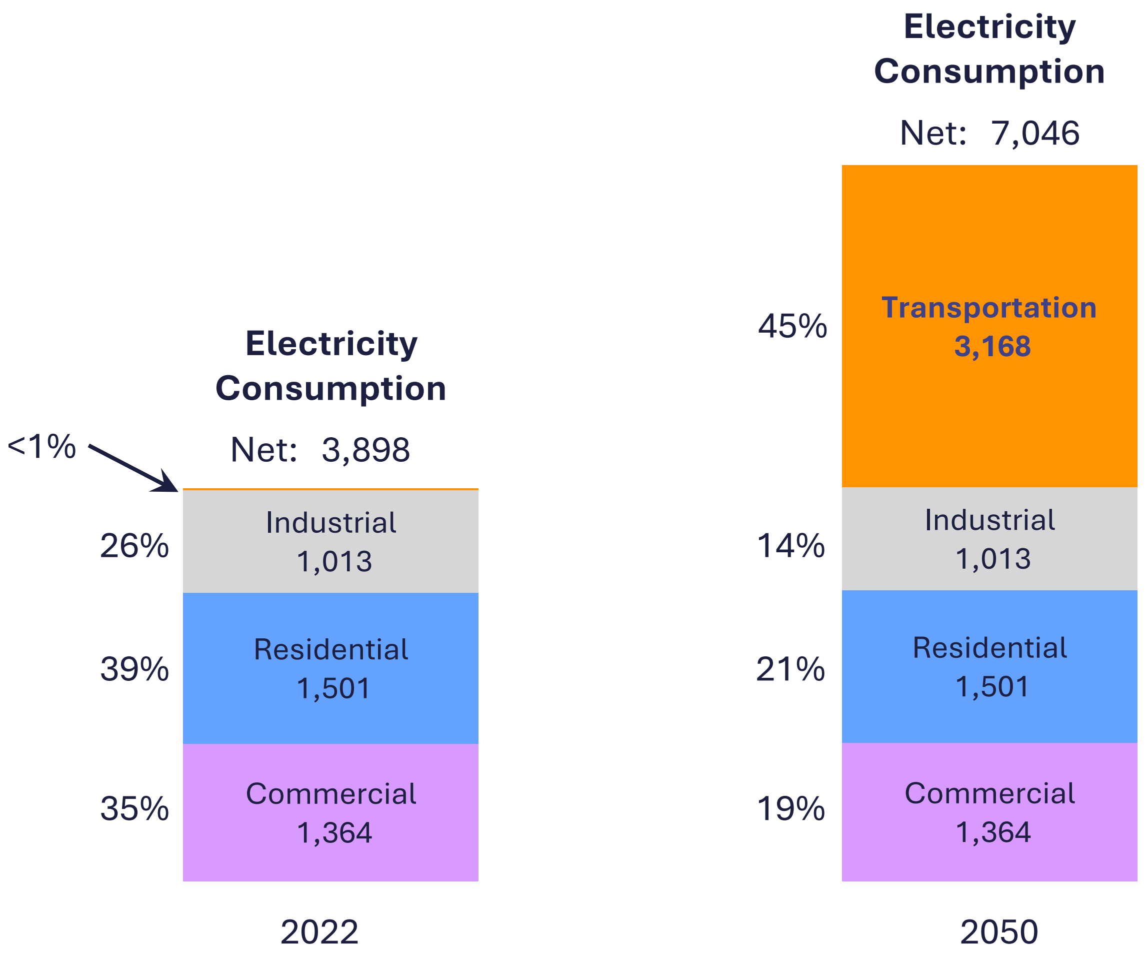
Transport energy consumption declines 61% from 8,072 TWh to 3,168 TWh due to EV efficiency

Overall energy consumption declines 22% from 22,223 TWh to 17,320 TWh

Source: US Energy Information Administration, The Transport Project analysis

US annual net electricity consumption: 2022 vs 2050 if transportation is fully electrified

Electricity units in terawatt-hours (TWh)

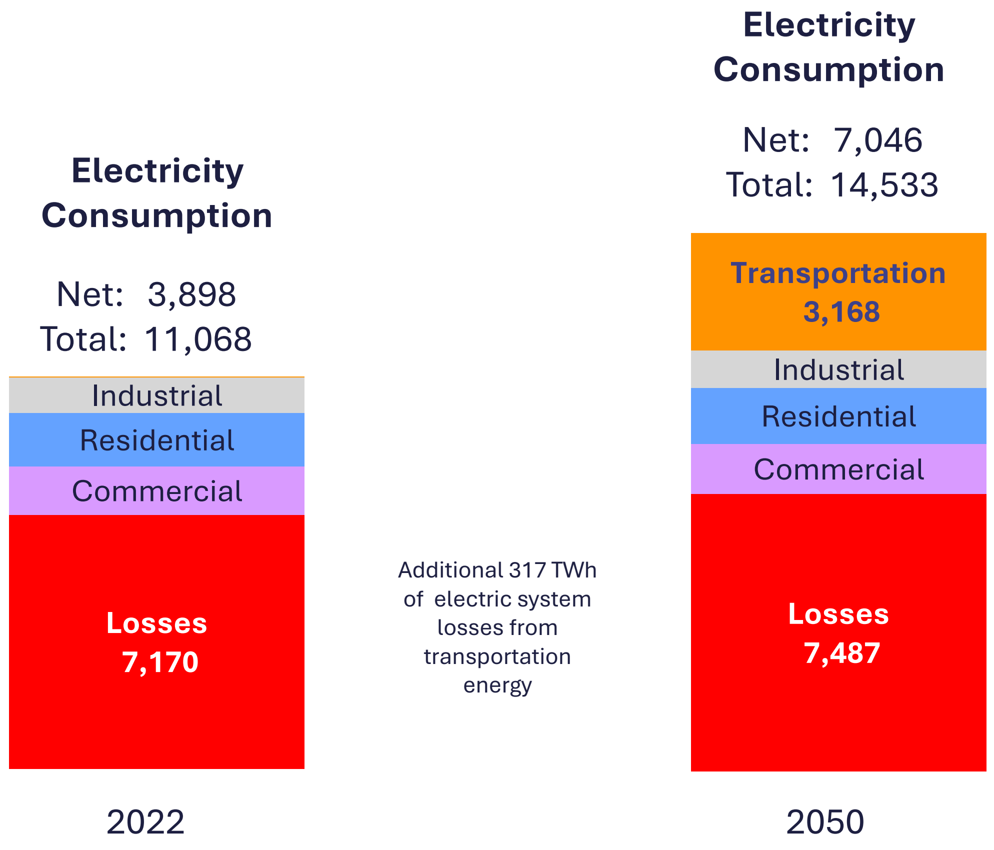


With electricity consumption for transportation increasing to 3,168 TWh, and assuming no change in other segments, overall electricity consumption increases 81% to 7,046 TWh

Source: US Energy Information Administration, The Transport Project analysis

US annual gross electricity consumption: 2022 vs 2050 if transportation is fully electrified

Electricity units in terawatt-hours (TWh)



If all the electricity required to provide 3,168 TWh for transportation is from solar and wind, losses will be low as there is no fuel combustion with these technologies. We assume 10% losses, with 5% from transmission and 5% from other operating losses.

Total electricity consumption including losses increases 31% to 14,453 TWh

Source: US Energy Information Administration, The Transport Project analysis

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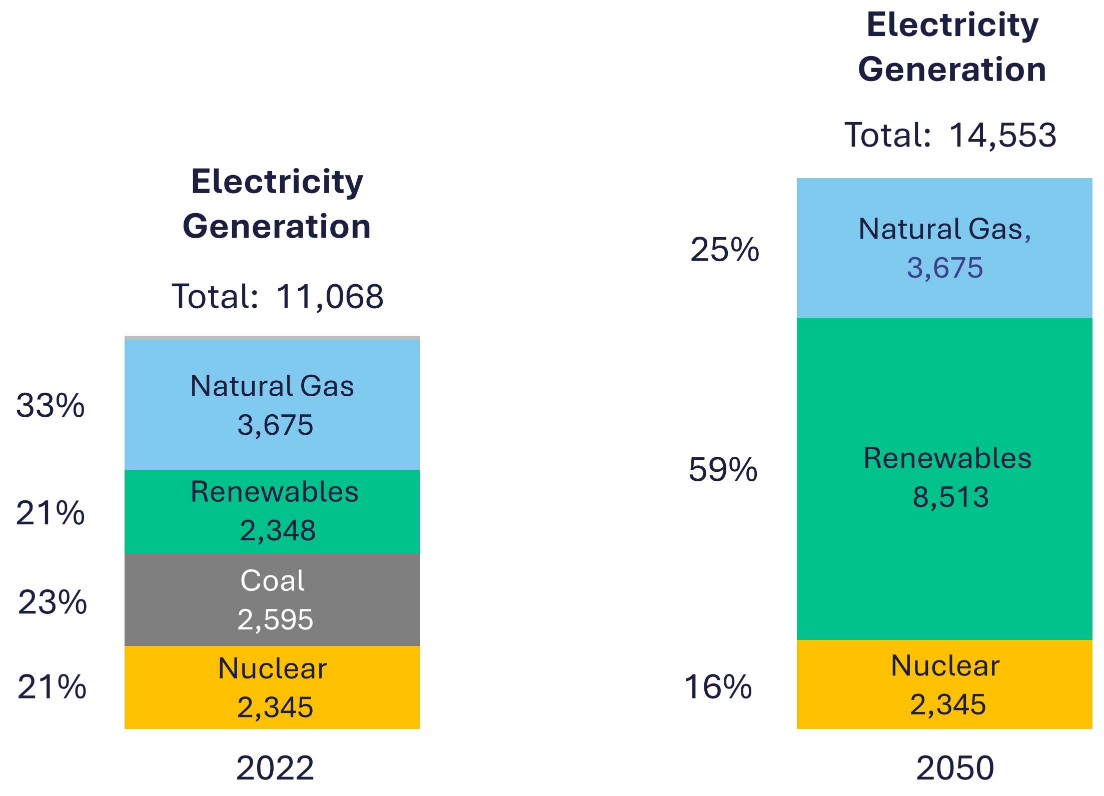
US annual electricity generation: 2022 vs 2050 if transportation is fully electrified using clean electricity

Electricity units in terawatt-hours (TWh)



With gross electricity consumption increasing to 14,533 TWh to support vehicle electrification, and assuming only solar and wind power for transportation plus the elimination of coal in generation, electricity generation from renewables must increase 3.6 times to 8,513 TWh.

Source: US Energy Information Administration, The Transport Project analysis

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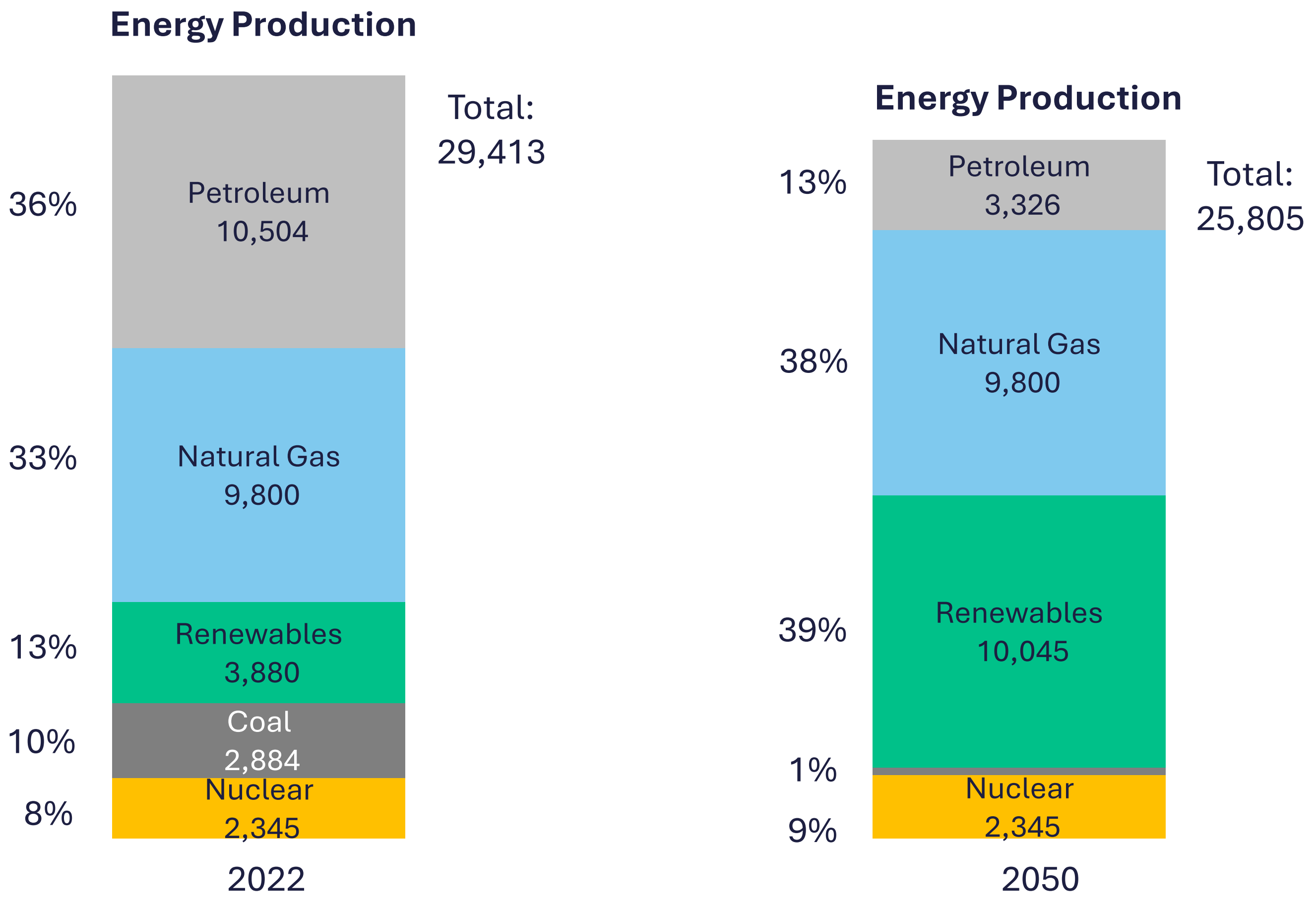
US annual energy production: 2022 vs 2050 if transportation is fully electrified using clean electricity

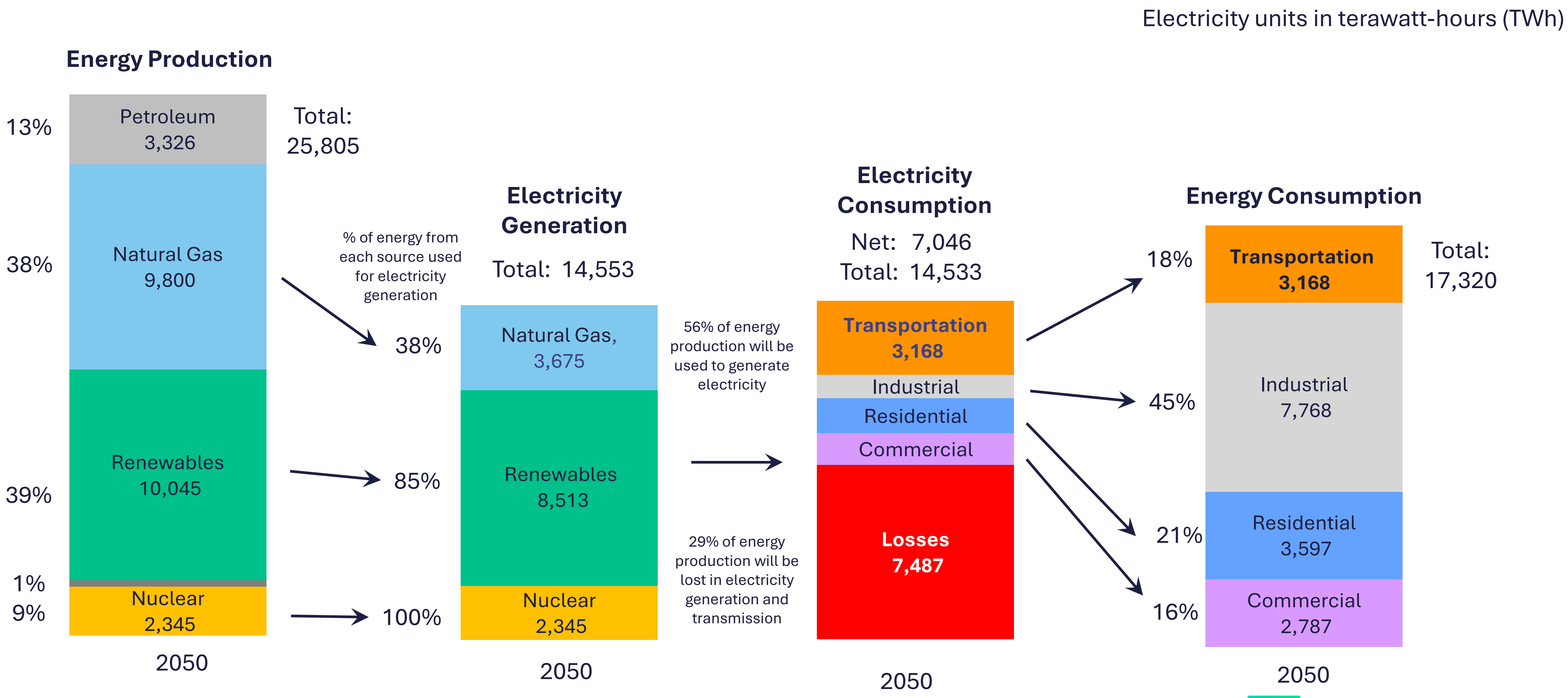
Electricity units in terawatt-hours (TWh)



To support vehicle electrification with clean electricity, overall energy production decreases 12% to 25,805 TWh. This assumes non-transportation use of petroleum, natural gas and coal continues unchanged. If they are to be displaced, increases in renewable energy will be required.

Source: US Energy Information Administration, The Transport Project analysis

2050 US annual energy production and consumption summary



Source: US Energy Information Administration, The Transport Project analysis

What share of transportation energy is used by heavy duty trucks?

Net transportation energy in 2050 = 3,168 TWh

Gross transportation energy in 2050, including transmission and other losses = **3,485** TWh

Less than 1% of transportation energy is currently electric, so assume all growth must be from renewable sources

2022 total vehicle fuel consumption:

	Million Gallons	
HD trucks	30,439	17%
All other vehicles	143,691	83%
Total	174,131	

Heavy duty truck share of transportation energy:

	TWh	
HD trucks	**610**	**17%**
All other vehicles	2,875	83%
Total	**3,485**	

Source: US Department of Transportation Bureau of Transportation Statistics, The Transport Project analysis

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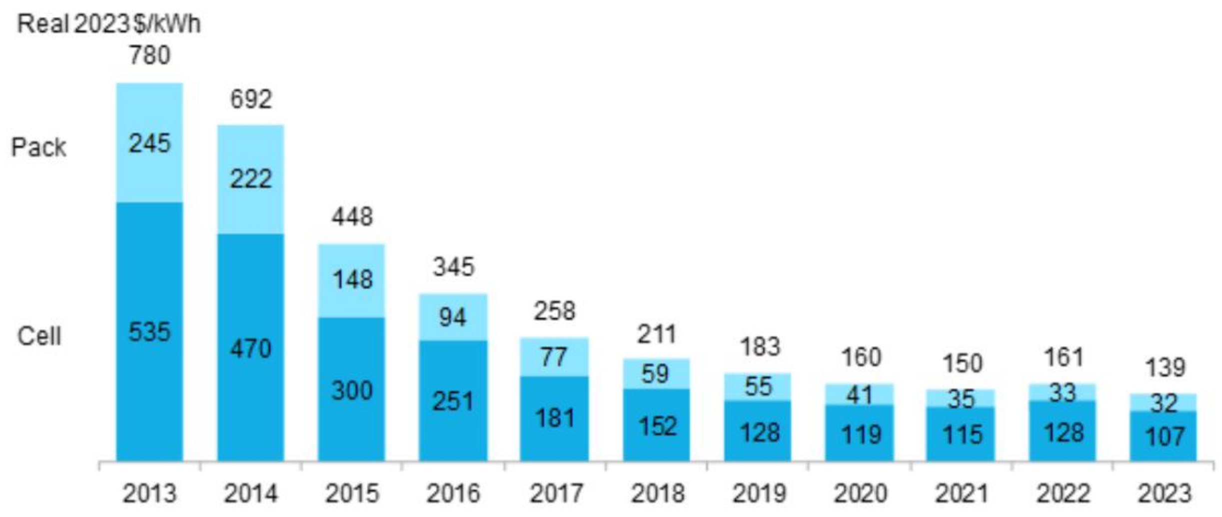
How would truck productivity affect electricity requirements for heavy duty trucks?

610 TWh of electricity is needed to power heavy duty trucks, assuming 1:1 substitution with diesel

But current experience is 2:1 substitution is needed today. How quickly can BEV trucks improve?

Figure 1: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: BloombergNEF. Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles, and stationary storage.

Battery cost reduction is flattening, indicating maturity of current battery technology

Is battery energy density on a similar curve?

Current battery energy density is ~500 WH/kg. Diesel is 12,500 WH/kg, 25X higher

It is possible that BEV trucks will never achieve 1:1 parity with diesel trucks because of significantly lower energy density

Source: Ryder Systems Inc., Bloomberg New Energy Finance, The Transport Project analysis

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What share of transportation energy is used by heavy duty trucks?

Heavy duty truck share of transportation energy:

	TWh	
HD trucks	610	17%
All other vehicles	2,875	83%
Total	3,485	

- 610 TWh assumes 1:1 substitution with diesel
- This is not assured
- Cold weather and hill climbs significantly impact BEV energy consumption and productivity
- It is reasonable to assume, to be conservative, a 1.5:1 substitution of BEVs for diesel

Assuming 1.5:1 substitution of BEV for diesel

Heavy duty truck share of transportation energy, revised for productivity:

	TWh	
HD trucks	915	**24%**
All other vehicles	2,875	76%
Total	**3,790**	

Source: US Department of Transportation Bureau of Transportation Statistics, The Transport Project analysis

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What infrastructure do we need to fully electrify on-road transportation using clean, renewable electricity?

3,790 TWh of clean electricity … equals a 34% increase in generation and grid capacity.

755 square miles of solar panels
at 30 watts/sq ft and 3,000 solar hours per year

+

253,000 wind turbines taking up 4,800 square miles
at 3 MW per turbine and 2,500 wind hours per year

+

5,200 GWh of battery storage

* Assuming 50/50 mix of solar and wind generation. 1,895 TWh each.

35,000 miles of high voltage transmission lines
22% of current infrastructure**

+

1,200,000 miles of local electricity distribution lines
22% of current infrastructure**

+

200,000,000 L2 home chargers
4,700,000 DC fast chargers
70%/30% mix of home and public charging

+

690,000 DC fast chargers
8 chargers per HD truck

** Assuming 33% of incremental electricity can use the existing grid for transmission

Source: The Transport Project analysis

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What would the infrastructure we need to fully electrify on-road transportation cost?

755 square miles of solar panels	@ $30.00 / sf	$632 Billion
253,000 wind turbines	@ $3.9M / unit	$987
5,200 GWh of battery storage	@ $250 / kWh	$1,298
35,000 miles of high voltage transmission lines	@ $1.7M / mile	$60
1,200,000 miles of local electricity distribution lines	@ $290K / mile	$351
200,000,000 L2 home chargers	@ $1,000 / unit	$200
5,390,000 DC fast chargers	@ $250K / unit	$1,348
		$4,876 Billion

Total: $4.9 TRILLION

Plus 6,300 square miles of land for wind and solar

- Not included in costs

HD: $1.2 TRILLION

Heavy duty truck share at 24% of total demand

- $211K per truck for infrastructure investment
- Plus 1,500 square miles of land for wind and solar
- 7,500 square feet per truck

Source: The Transport Project estimates and analysis

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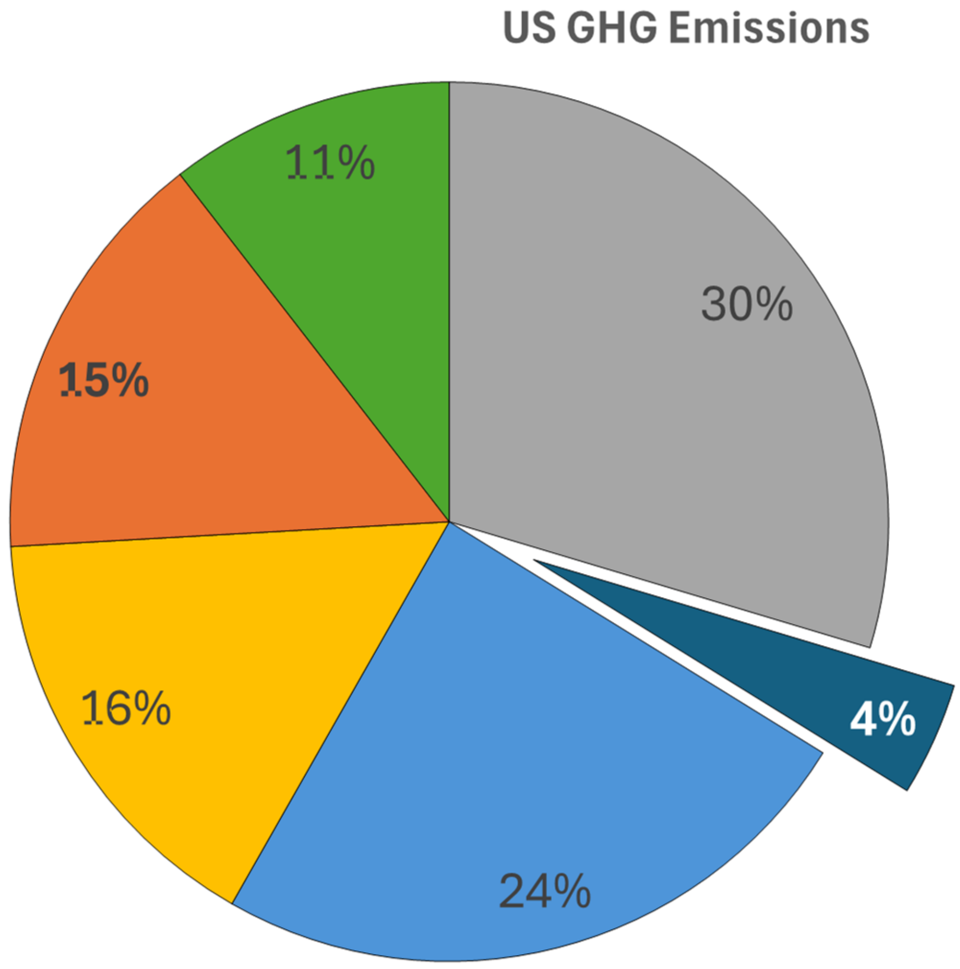
What is the impact of electrifying US HD trucks?



- 2022 GHG emissions from HD trucks were 264 million metric tons annually
- Reducing HD truck emissions to zero would reduce 4.2% of total 6,320 million metric tons from all US sources
- It would reduce 0.7% of the total of 36,800 million metric tons of GHGs emitted globally

A relatively small reduction at a massive economic cost.

HD Trucks:	$1.2T to reduce 4% = $300B per % reduced
All other transport:	$3.7T to reduce 24% = $154B per % reduced

Source: US EPA Inventory of Greenhouse Gas Emissions 2022, IEA CO2 Emissions in 2022

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The challenge facing truck fleets

The challenge faced by HD truck fleets

	Available and Works Today?	Allowed Tomorrow? *
Diesel	Yes	No
Biodiesel	Yes	No
LNG	Yes	No
Bio LNG	Yes	No
CNG	Yes	No
RNG	Yes	No
Battery Electric	No	Yes
Fuel Cell Electric	No	Yes
Hydrogen ICE	No	Yes

* Allowed tomorrow under EPA / CARB regulations for HD trucks

- **No viable, low risk option to fully decarbonize heavy duty truck transportation works today and will be allowed in the future.**
- Truck technology is a business-critical decision – CAN NOT make the wrong choice
- Transitions are disruptive and expensive. Don't want to do more than one.
- 11 years after the introduction of HD natural gas engines in the US, natural gas HD trucks have less than 3% market share. BEV and FCEV trucks are far less. While some truck fleets have made significant commitments to low emission trucks, the majority have not.
- **Most fleet customers are frozen – they don't have a good long-term choice. So, they wait and see, and for now continue to run diesels.**

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The challenge faced by HD truck fleets

“We have pressures that we’re all facing, and those pressures are affecting our businesses, our decisions, and the future of our industry. The reason we’re feeling this tension is because there’s a misalignment of sustainable technology, policies to regulate emissions, and an economic case for incorporating emerging technology.”
Shelley Simpson, President, JB Hunt Transport Services   ACT Expo, May 2024

“EV mandates for the trucking industry are disconnected from reality. It stands to reason that the best approach to decarbonization would provide the greatest environmental benefit at the lowest possible cost. Current regulations do neither while unleashing inflationary consequences that will be felt for decades to come.”
American Trucking Associations   ACT Expo, May 2024

Issues with the new EPA GHG standards for HD trucks

- Tailpipe emissions are the only consideration
- Upstream emissions from electricity generation are not included
- Methane emission reductions from renewable natural gas are not included
- Natural gas trucks are inaccurately assumed to have a 6% GHG emission reduction vs diesel
- Cost and benefit assumptions are unrealistic
- Timeframes are unrealistic

The opportunity with RNG

Comparison of the energy consumption of natural gas and battery electric trucks on today's grid

	300 Mile Highway Trip	Energy System Losses
Battery Electric Truck 	@ 1.7 kWh/mile = 510 kWh X 1.5 trucks* = 765 kWh	Electric grid: 65% Need 2,186 kWh generated
CNG Truck 	@ 6.0 miles/DGE = 50 DGE = 1,853 kWh	Gas pipeline: 10% Need 2,059 kWh before transport

* Based on productivity penalty of battery electric trucks due to range and payload limitations

Including the productivity impact, BEV trucks running on grid electricity use more energy than CNG trucks running on pipeline gas.

This is a highway example. Urban vocational vehicles would have higher energy consumption with both BEV and CNG trucks..

Source: Tesla, The Transport Project analysis

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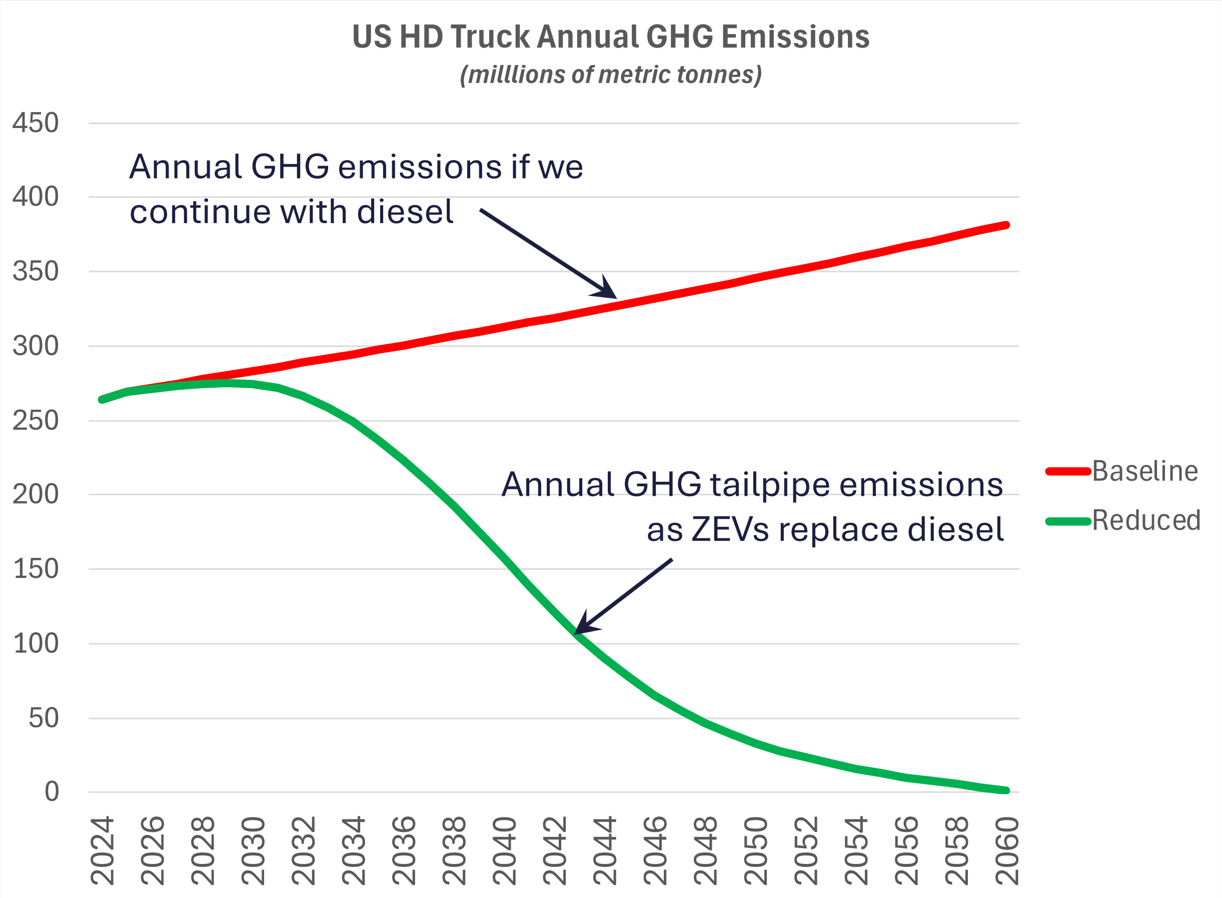
What happens when emission standards only consider tailpipe emissions?

The desired outcome of emission standards:



1. If the mandated vehicles are not cost effective, fleets will keep their old diesels running. We stay on the red line.

or

2. If the electricity that powers the ZEVs is not from clean renewable sources, we are just shifting emissions from the tailpipe to the power plant. There is no net benefit.

To be effective, emission standards must consider full lifecycle emissions.

Source: The Transport Project analysis

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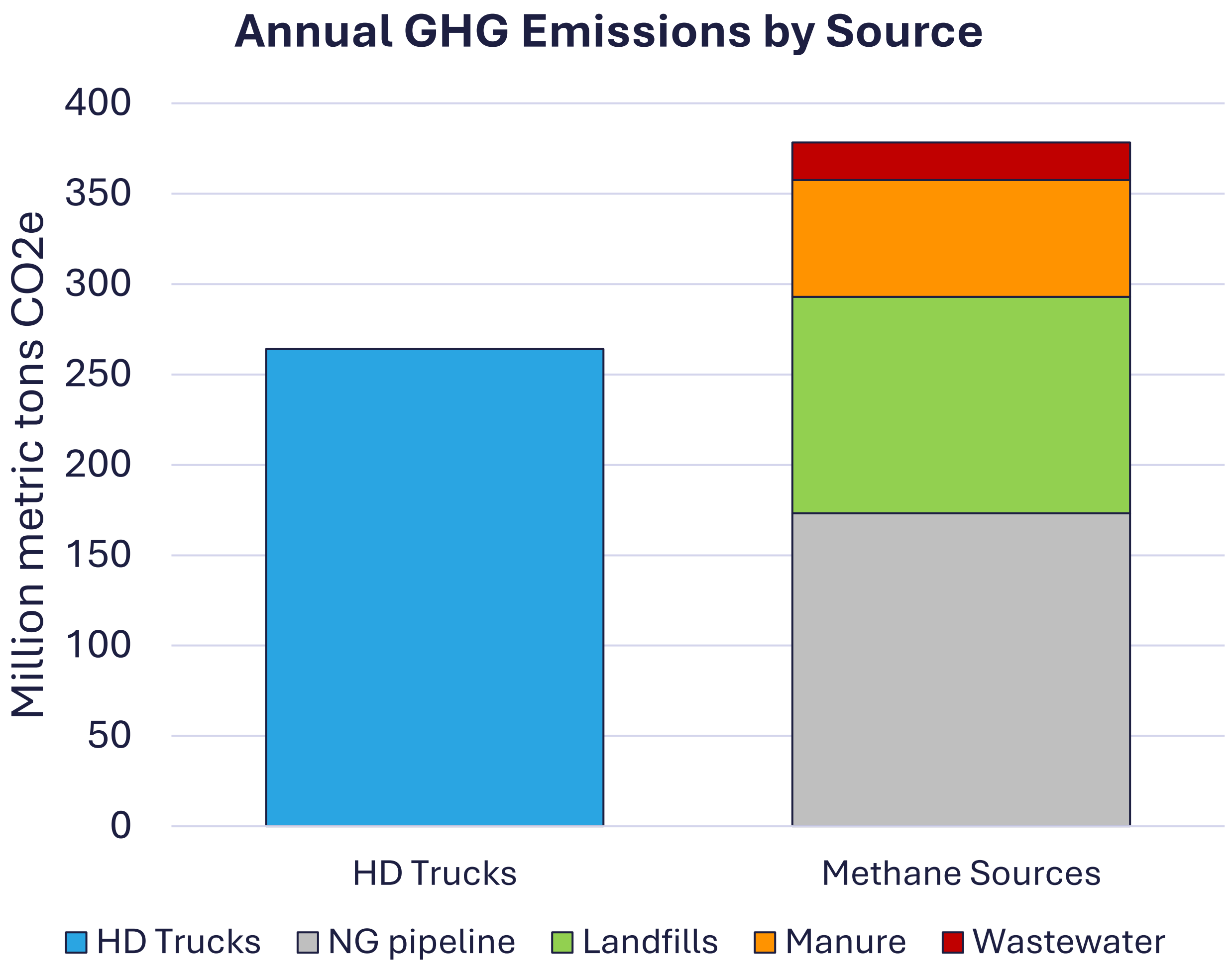
The importance of capturing methane emissions



- Methane emissions from sources that can be captured or reduced exceed current GHG emissions from HD trucks
- Landfill gas emissions reduced by 39% since 1990
- Hexagon Agility study: more than enough RNG capacity in the US to power the HD truck fleet

Source: US EPA Inventory of Greenhouse Gas Emissions 2022

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The ”math” of renewable gas

Diesel Carbon Intensity: 100

Combusting 1 gallon of diesel creates 28.4 lbs of CO_2

RNG Carbon Intensity: -126*

Combusting 1 DGE of RNG reduces 35.8 lbs of CO_2e

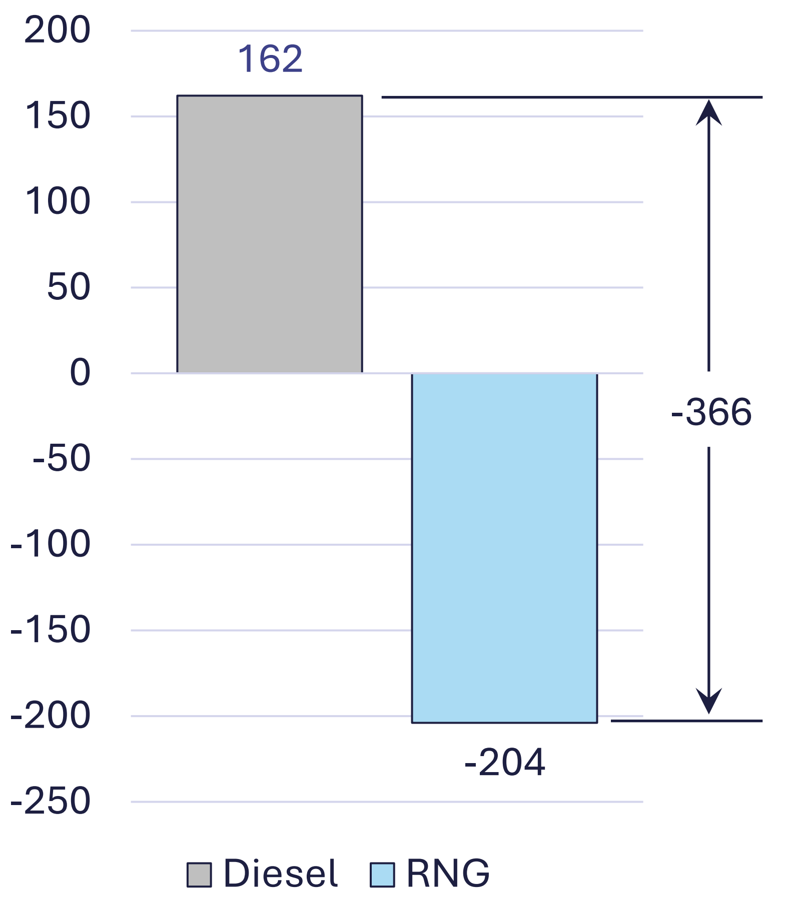
Impact of 1 DGE of RNG vs 1 gallon of diesel is 64.2 lbs of CO_2e reduced

* California LCFS average CI score for bioCNG

** 100,000 miles at 8 mpg = 12,500 gallons consumed
12,500 x 28.4 lbs = 355,000 lbs = 162 metric tonnes

Source: The Transport Project analysis

Tonnes of CO_2e emitted or saved by one truck running 100,000 miles/year**



BEV trucks can be, at best, zero CO_2e emissions, meaning they reduce a maximum of 162 tonnes per truck per year compared to diesel**.

Net reduction with RNG:

366 metric tonnes of CO_2e
per truck, per year

126% more saved than BEV

Cannot be ignored!

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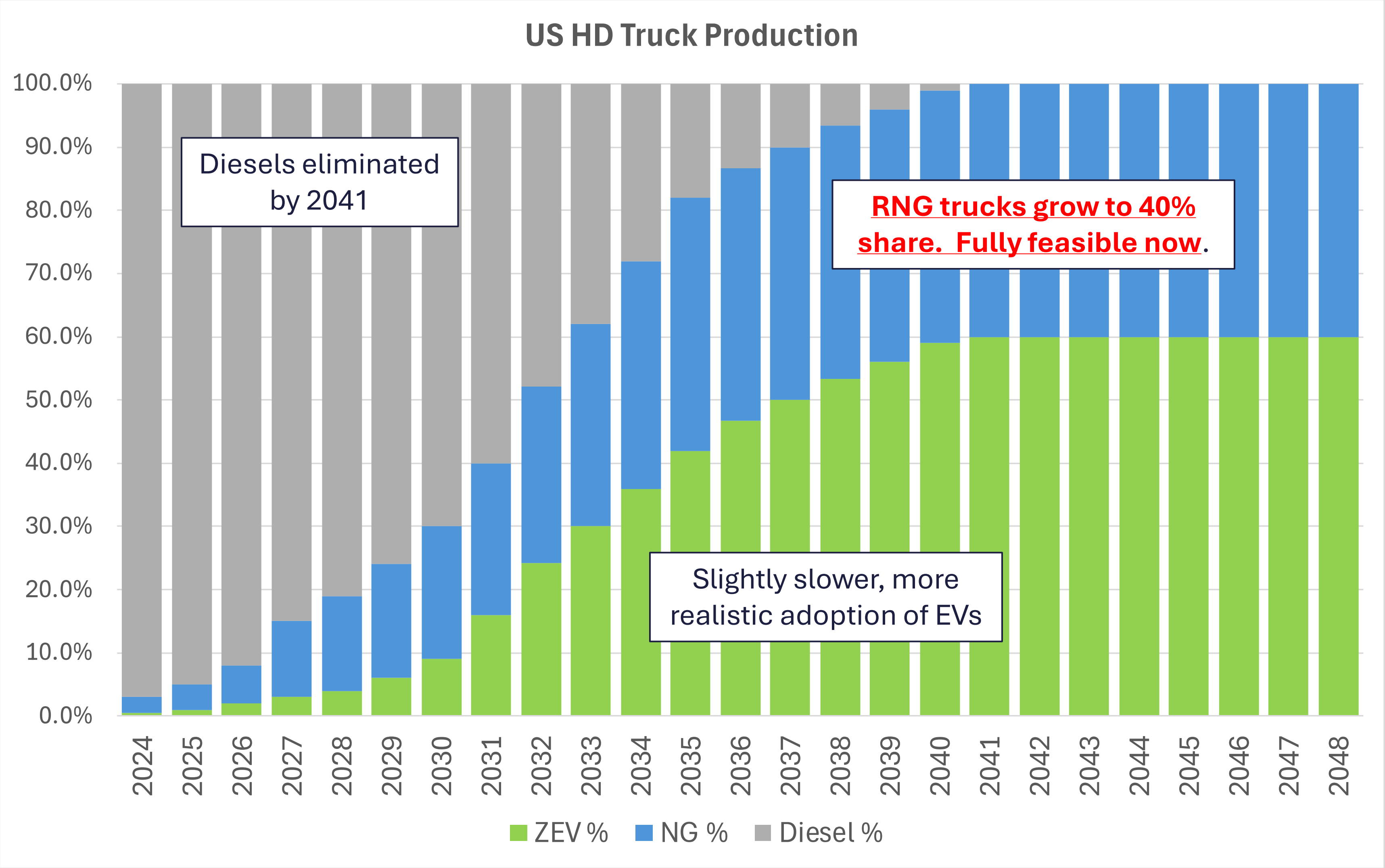
An alternate path for the US, embracing the GHG benefits of RNG and properly including them in the calculations



- **Embrace RNG**
  - Cost effective TODAY
  - Operationally effective TODAY
  - Faster to scale up
  - Negative CO_2e
- Include methane emission abatement in GHG score
- Use RINS system to track.
  79% of natural gas used in transportation in the US in 2023 was from renewable sources and is tracked.

Source: The Transport Project analysis

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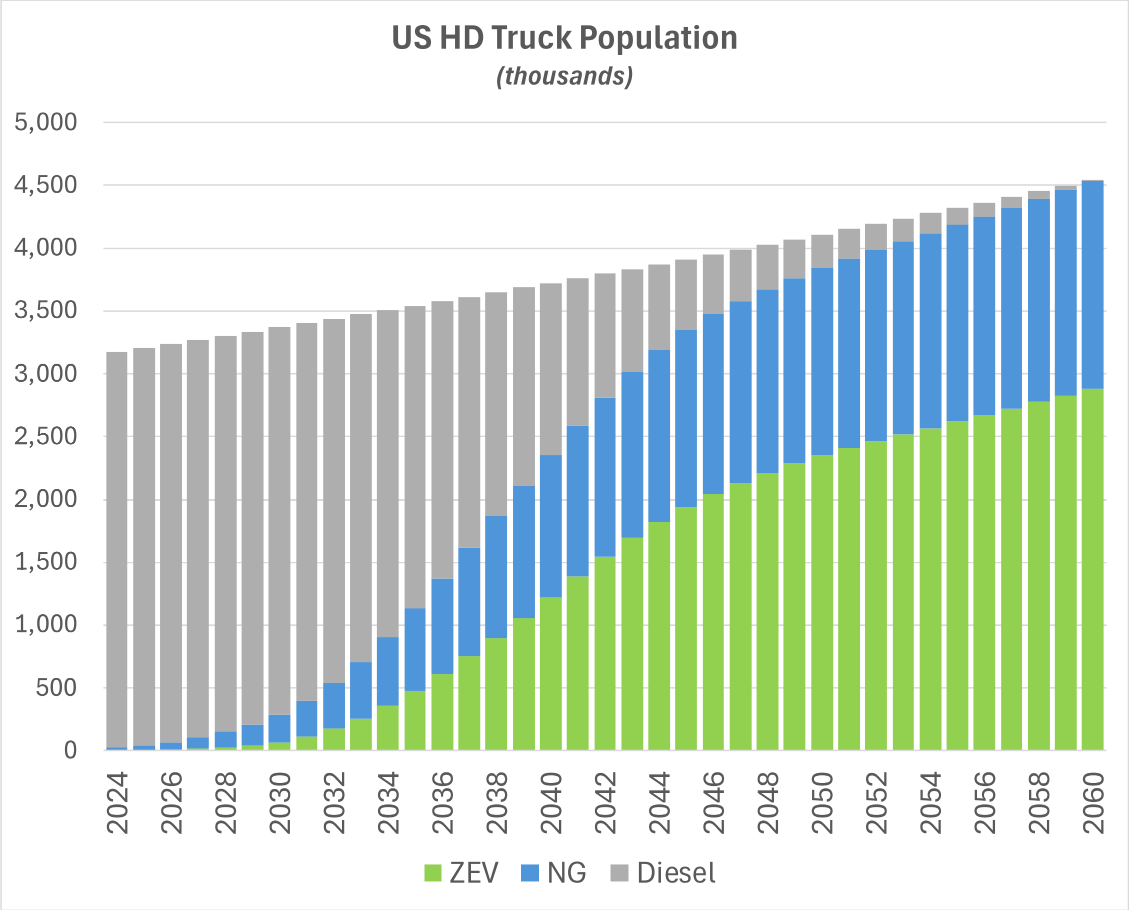
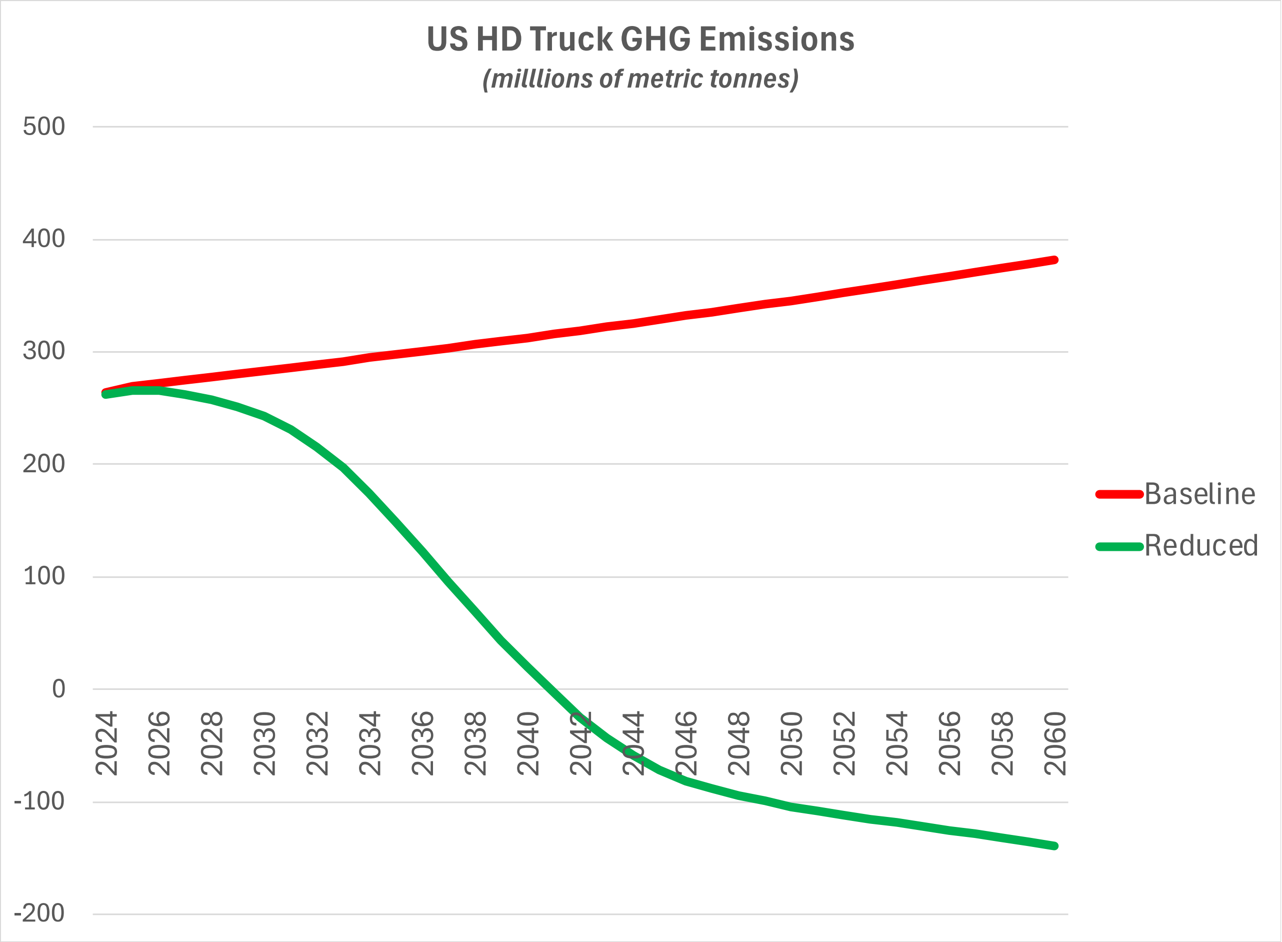
An alternate path for the US: desired outcome





As RNG and new ZEV trucks replace older diesels, about 500 million metric tonnes of annual GHG emissions are eliminated. Zero GHG emissions are achieved by 2041

Source: The Transport Project analysis

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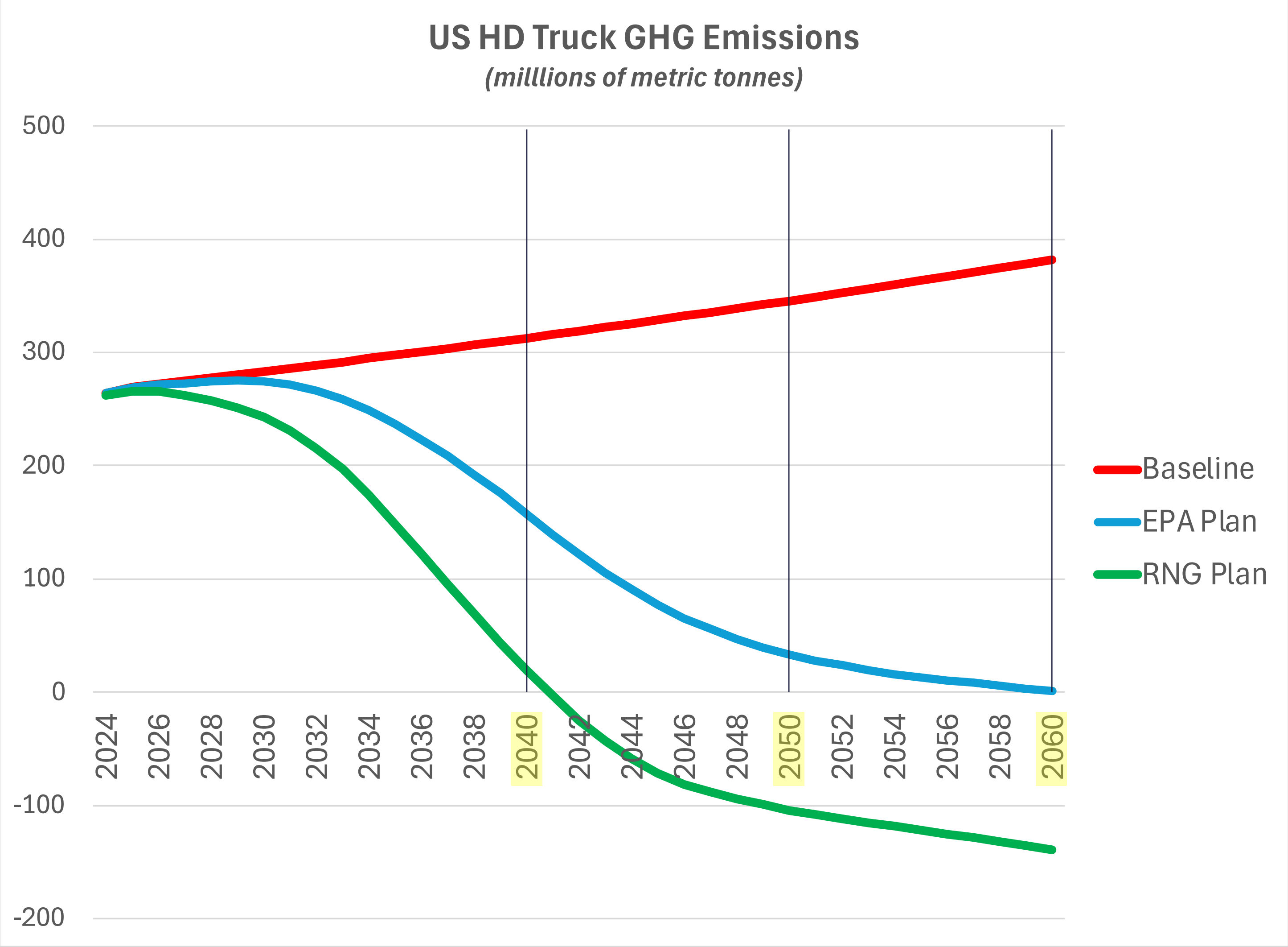
A less risky, more effective path for the US



Cumulative GHG emission reductions
(million metric tons)

By 2040:	EPA	771	
	RNG	1,788	+132%
By 2050:	EPA	3,301	
	RNG	5,763	+75%
By 2060:	EPA	6,824	
	RNG	10,651	+56%

Carbon neutral by 2041
Achieved in 17 years compare to 36 years with EPA scenario

Source: The Transport Project analysis

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Summary and Call to Action

- The realities of achieving true net zero are not likely what is envisioned and prescribed by the rulemaking authorities
  - The prescribed path is unlikely to achieve the desired result
- Embracing RNG as a carbon-reducing technology, *in addition to* electric technologies, provides a lower risk, lower cost, faster path to reducing GHG emissions for HD trucks

Join us in advancing The Transport Project's mission of getting North America's fleets running safely, reliably and effectively on clean, renewable fuels.

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For The Transport Project