Pathways to Rapid Reductions in Virginia's Transportation Emissions

Prepared for: Georgetown Climate Center
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Date: May 25, 2021

Introduction and Contents

- Virginia Context
  - Vehicles
  - Transportation Emissions

- A variety of low-carbon transportation policy scenarios were modeled, recognizing uncertainties regarding future policy pathways – with different degrees of protectiveness – through 2040.
  - Clean Car Standards
  - Advanced Clean Truck Rule
  - Cap-and-Invest
  - Combinations of clean car standards and cap-and-invest

- Multi-Impact Perspective for each Scenario
  - Pollution, Health, and Mortality
  - Economic Benefits and Costs

- Methodology

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Background: On-Road Vehicles

	Electric Vehicles (EVs)	Light-Duty Vehicles (LDVs)	Medium- and Heavy-Duty Vehicles (MDHDs)
2018 Baseline Estimates	6,375	7.5 Million	177,000
2020-2040 Cumulative New Purchases (Business As Usual)	1.3 Million	6.4 Million	200,000

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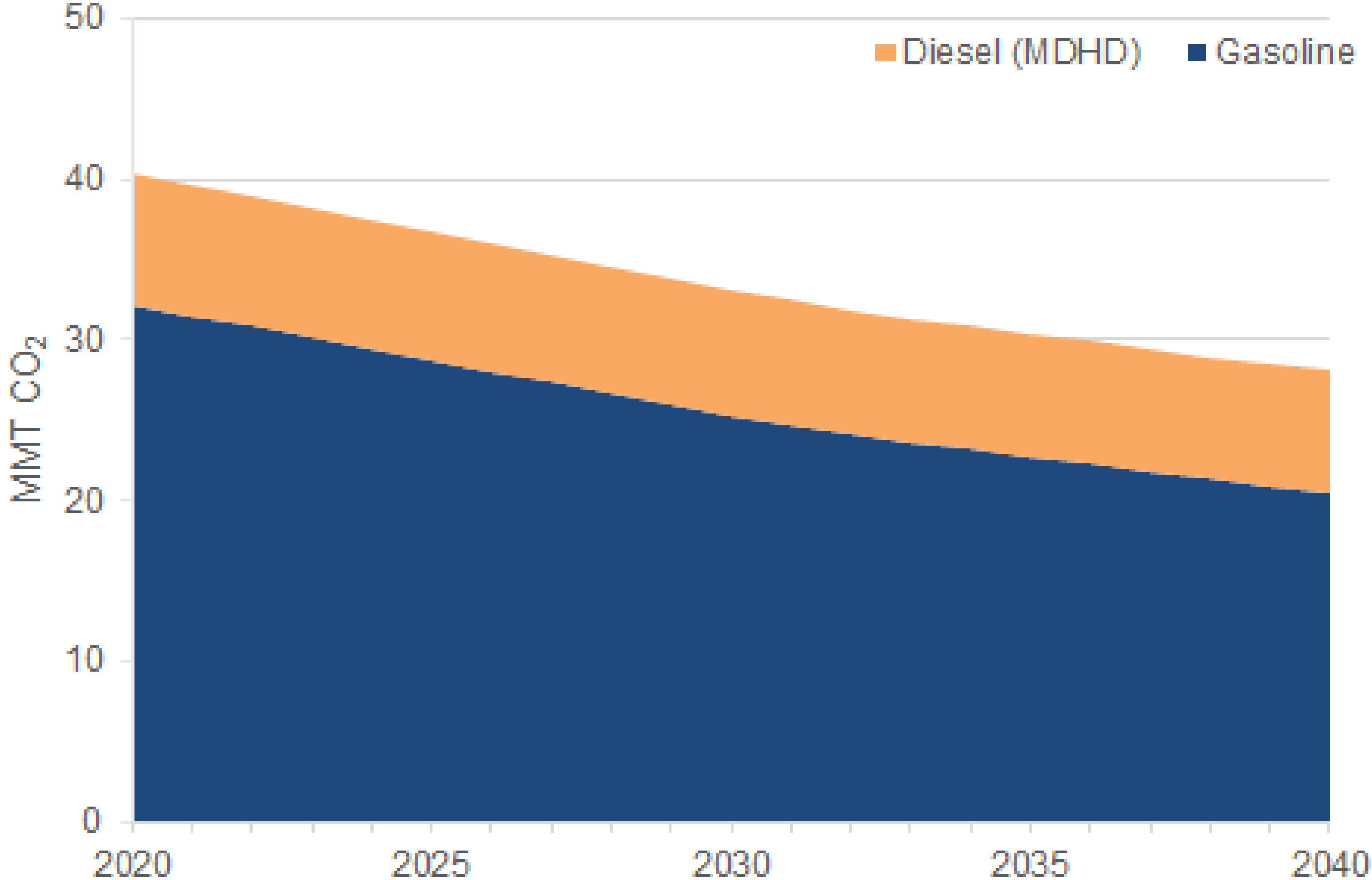
Projected Business as Usual CO_2 Pollution from Cars & Trucks in VA



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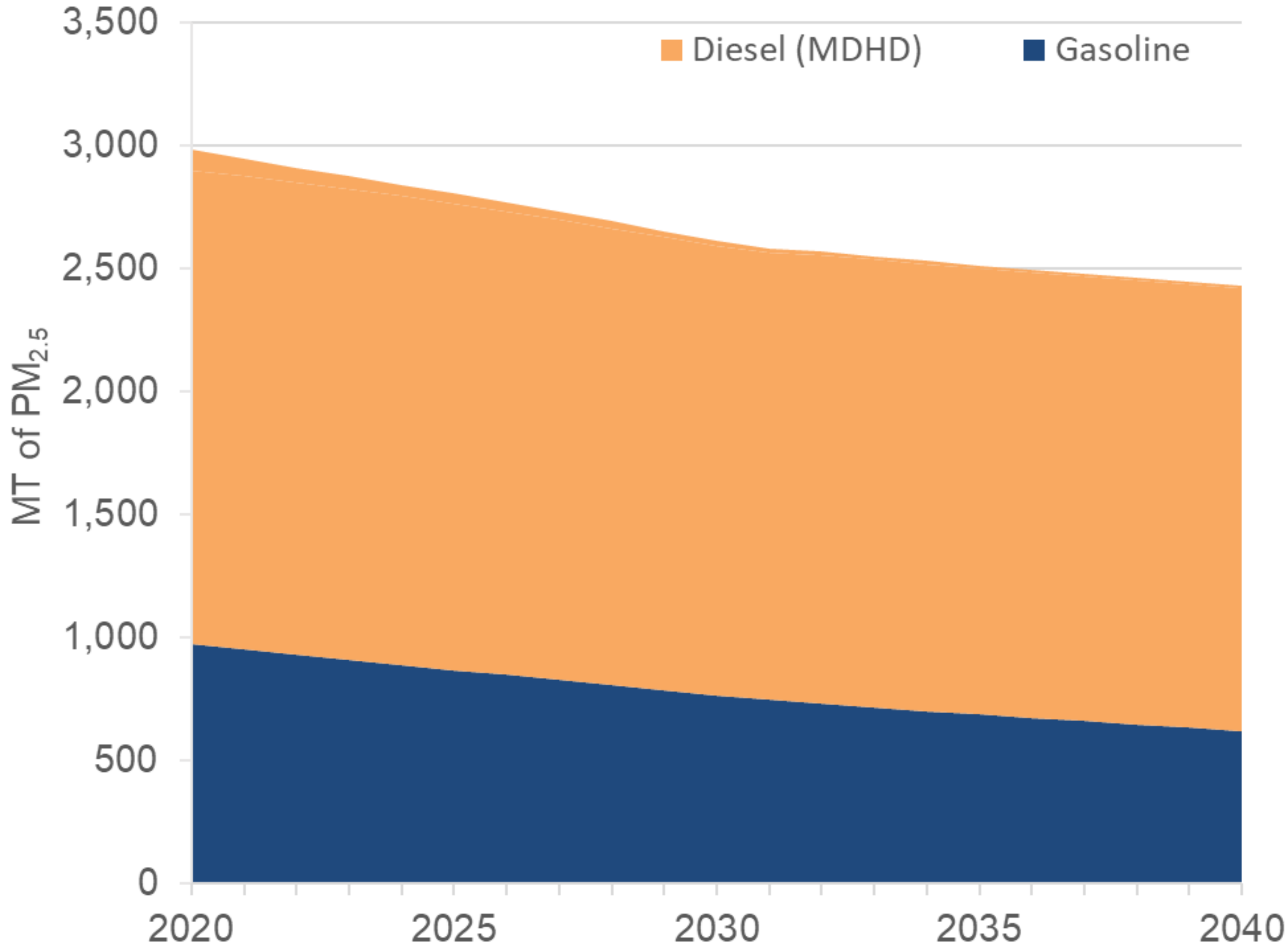
Projected Business as Usual $PM_{2.5}$ Pollution from Cars & Trucks in VA



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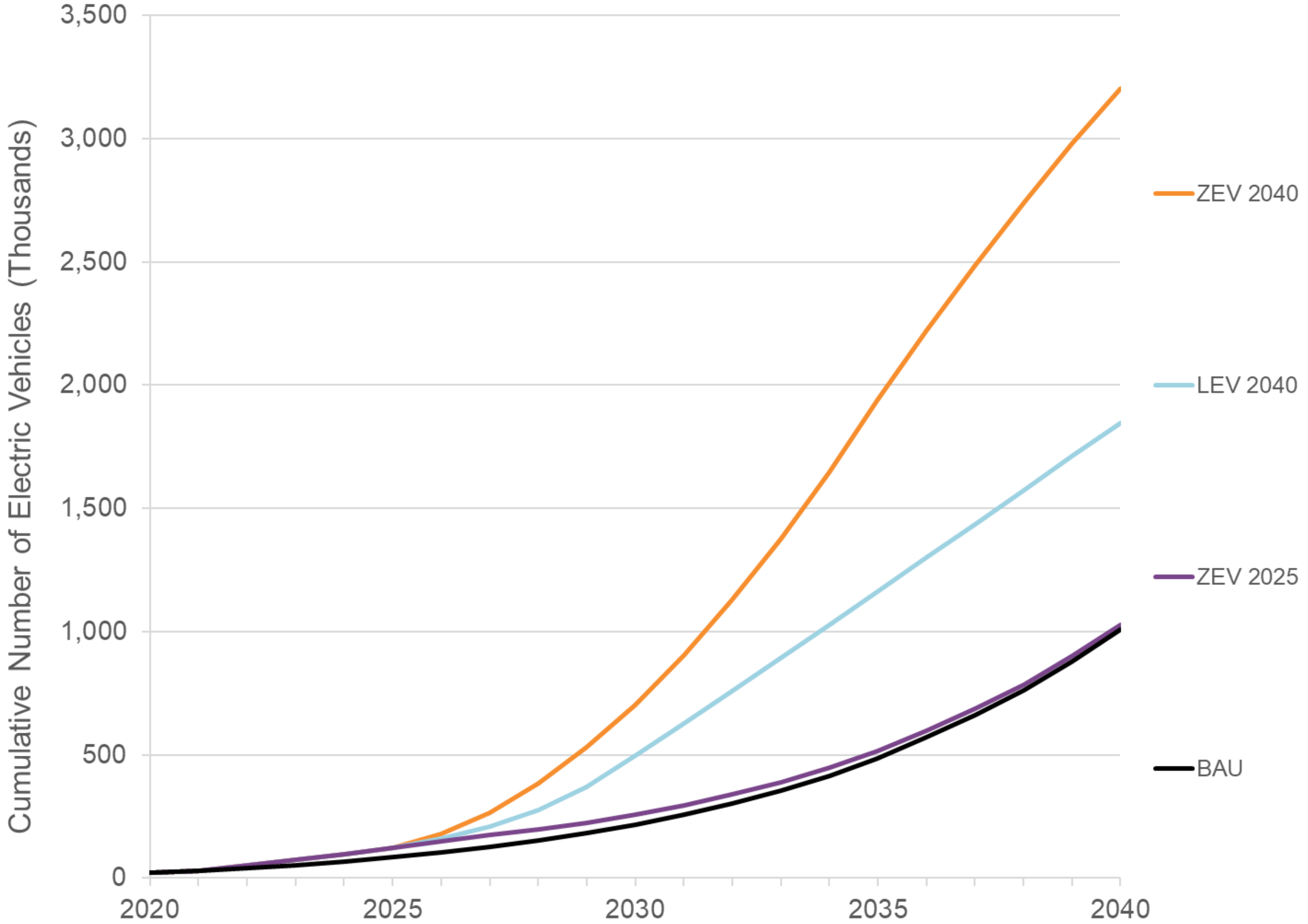
RESULTS

Impact of Clean Car Standards

In February 2021, the Virginia General Assembly passed HB 1965, which directs the State Air Pollution Control Board to implement a low-emissions and zero-emissions vehicle program for motor vehicles (i.e., clean car standards) with a model year of 2025 and later.

To help inform policy deliberations among Virginia stakeholders, this section summarizes results from analysis that was conducted at the end of 2020 and published in January 2021. The scenarios modeled (described on slide 46) illustrate a range of possible outcomes for a variety of policy pathways, including LEV and ZEV standards implemented through 2040.

Clean Car Standards Projected to Drive Light-duty EV Deployment 2-3x Greater Than BAU



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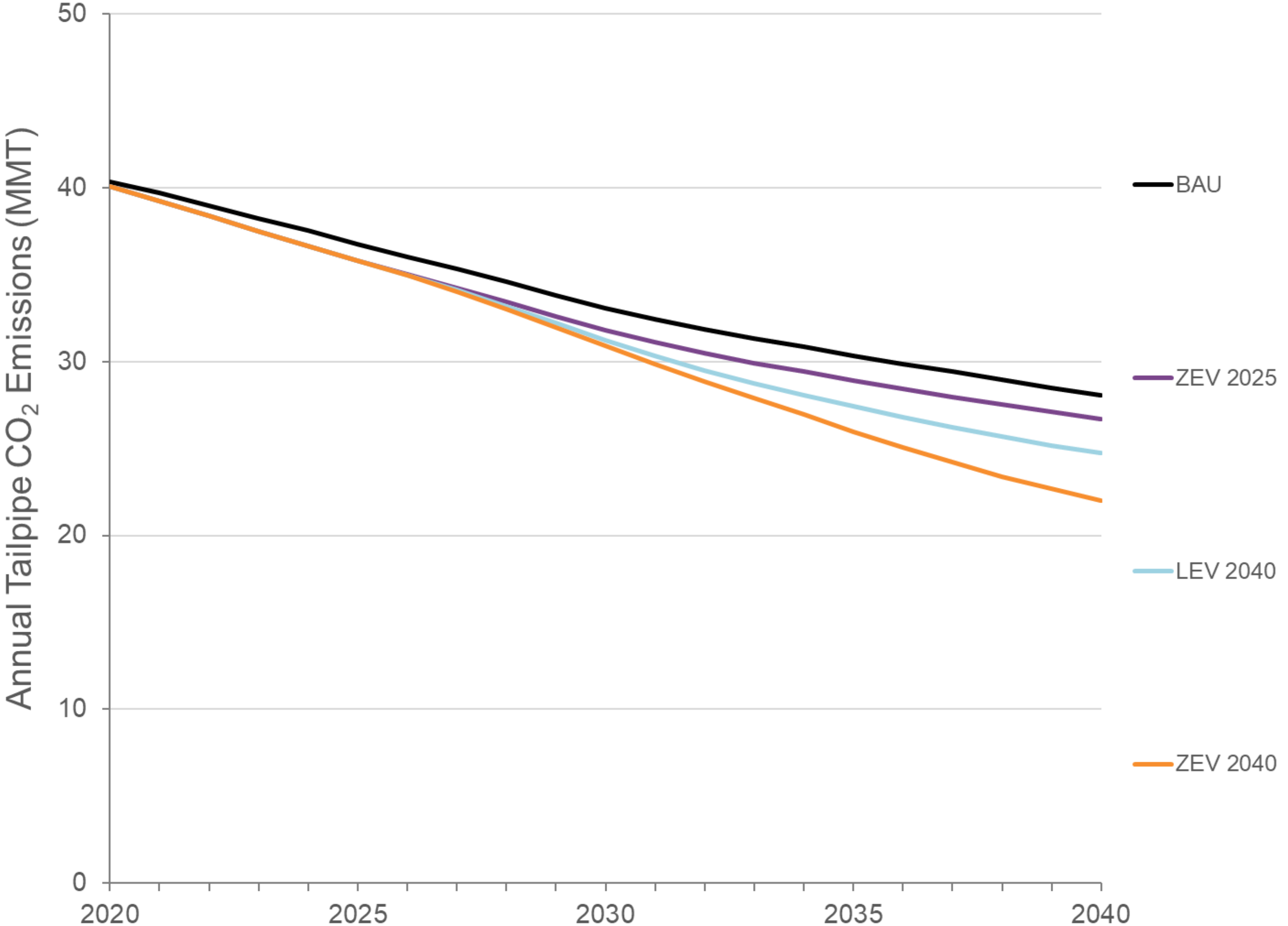
CO_2 Pollution Reduction Larger with More Protective Clean Car Standards



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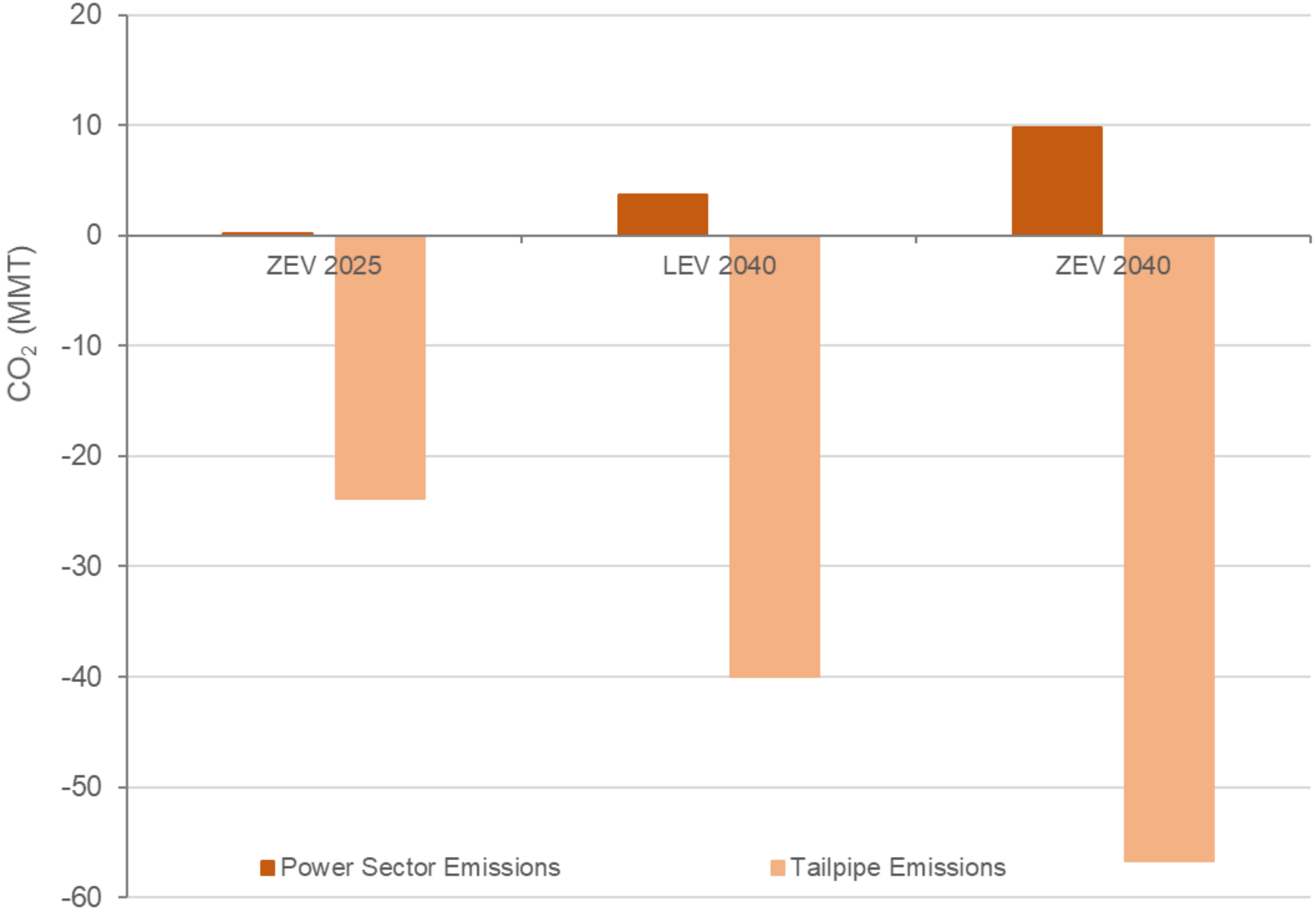
CO_2 Pollution Changes from Clean Car Standards:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



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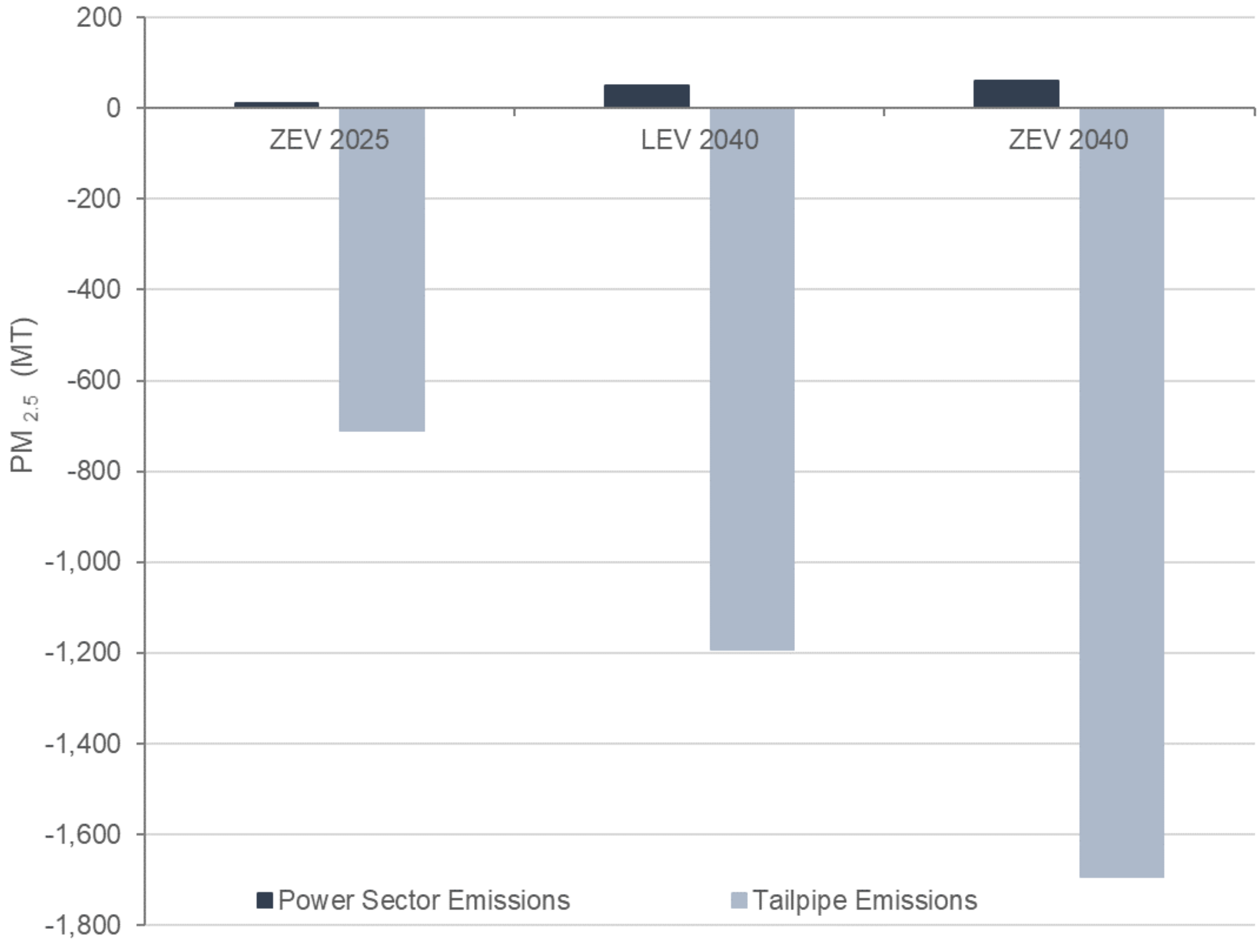
$PM_{2.5}$ Pollution Changes from Clean Car Standards:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

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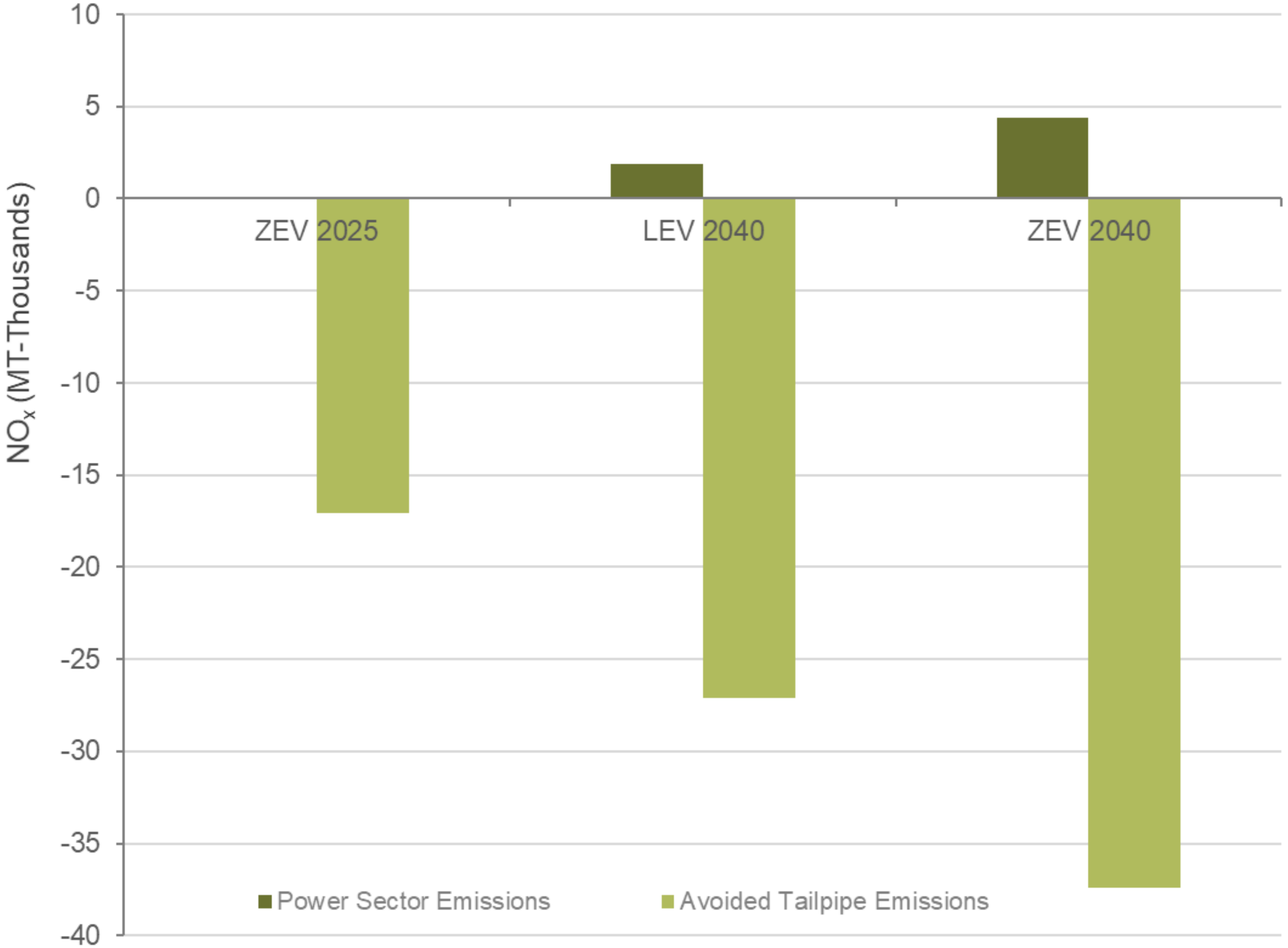
NO_x Pollution Changes from Clean Car Standards:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

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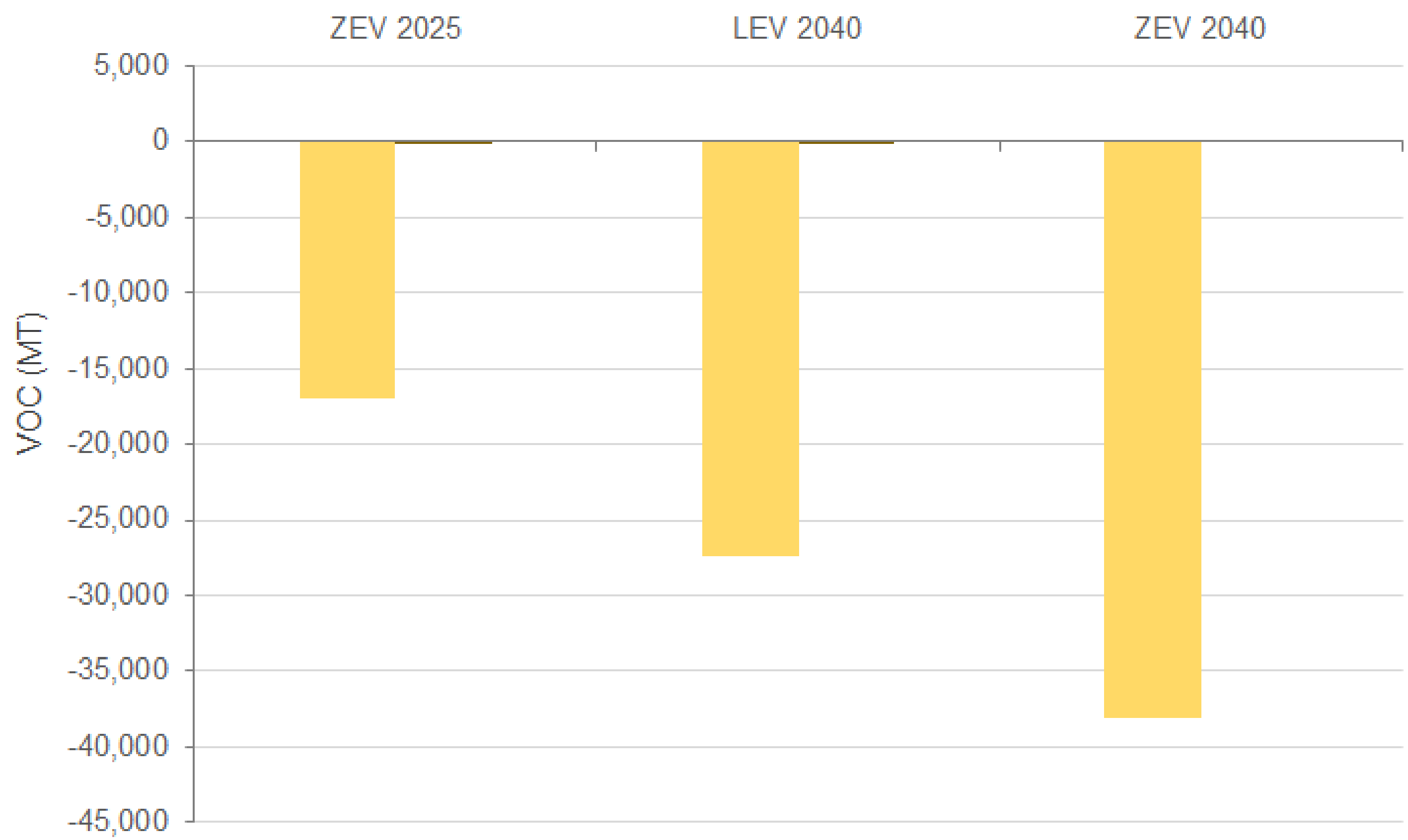
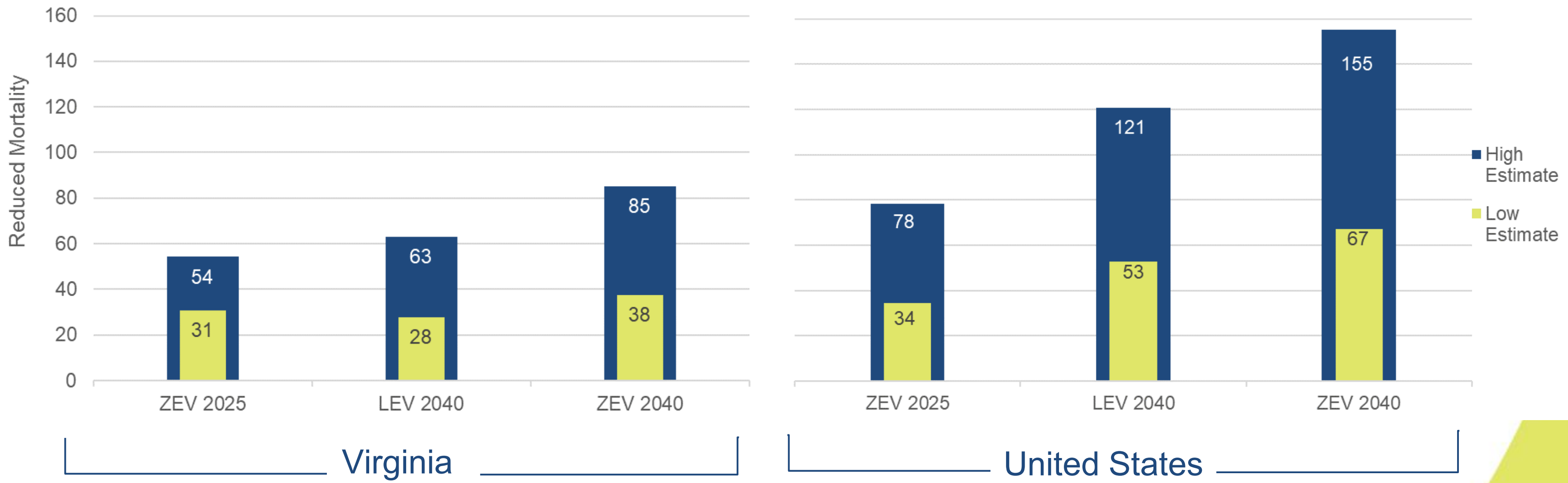
VOC Pollution Changes from Clean Car Standards:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

Clean Car Standards Save Lives in Virginia and Nationally (High and Low estimates, cumulative 20 years)



Clean Car Standards Reduce Emergency Room Visits and Workdays Lost

Statewide and Nationally (Cumulative 20 years, relative to BAU)

Scenario	Geography	Reduced Emergency Room Visits from Asthma	Reduced Work Loss Days
ZEV 2025	Virginia	11	2,600
	United States	22	4,900
LEV 2040	Virginia	19	4,300
	United States	33	7,700
ZEV 2040	Virginia	25	5,900
	United States	42	10,000

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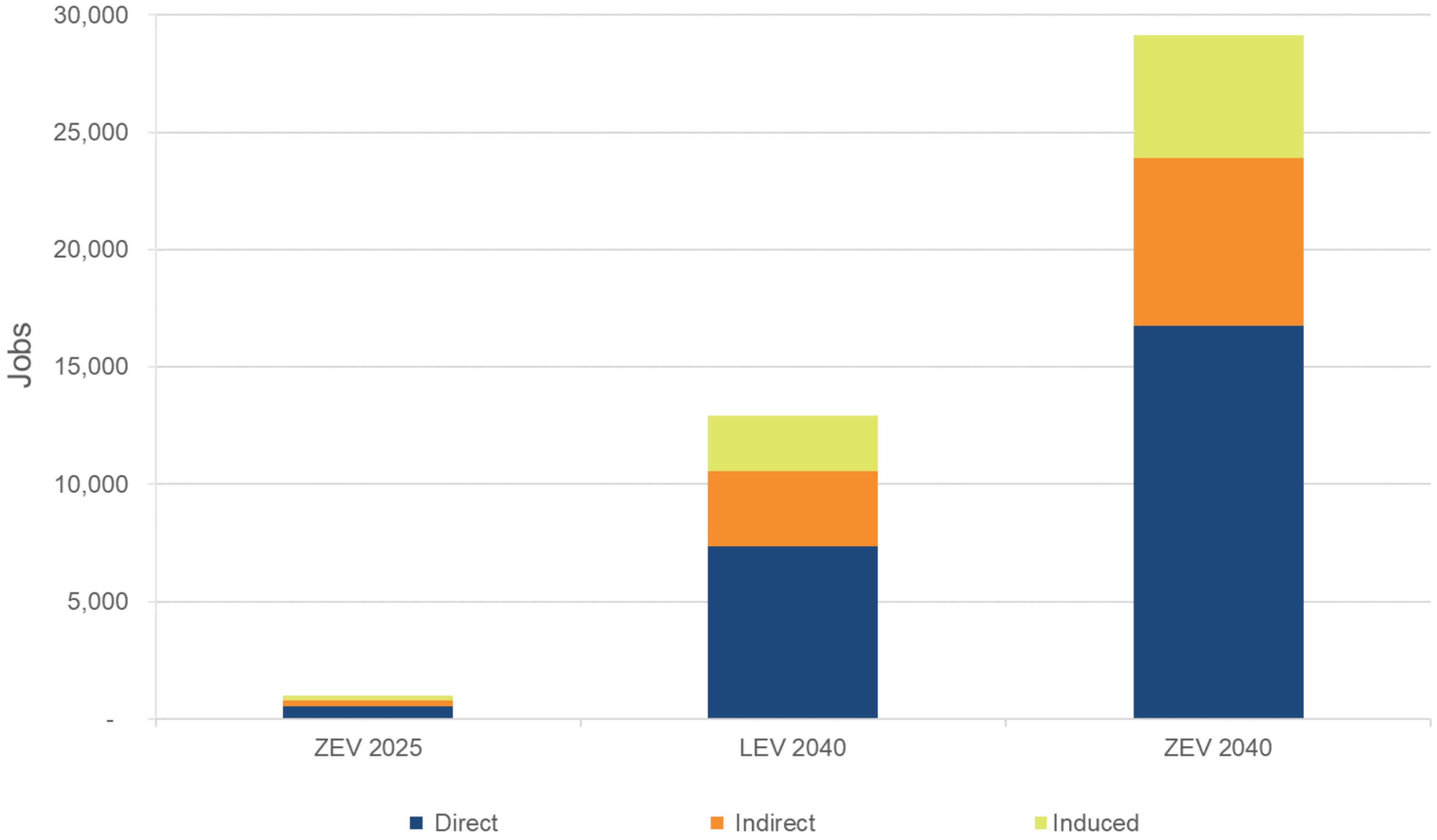
Net VA Jobs Growth Projected from Clean Car Standards (cumulative)



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Clean Car Standards Produce Net Benefits

Scenario	Total Benefits ($B)	Total Costs ($B)	Net Benefits ($B)	Benefit Cost Ratio
ZEV 2025	2.6	0.34	2.2	**7.5**
LEV 2040	14	3.9	10	3.6
ZEV 2040	**30**	**8.9**	**21**	3.4

All dollars are 2017-$

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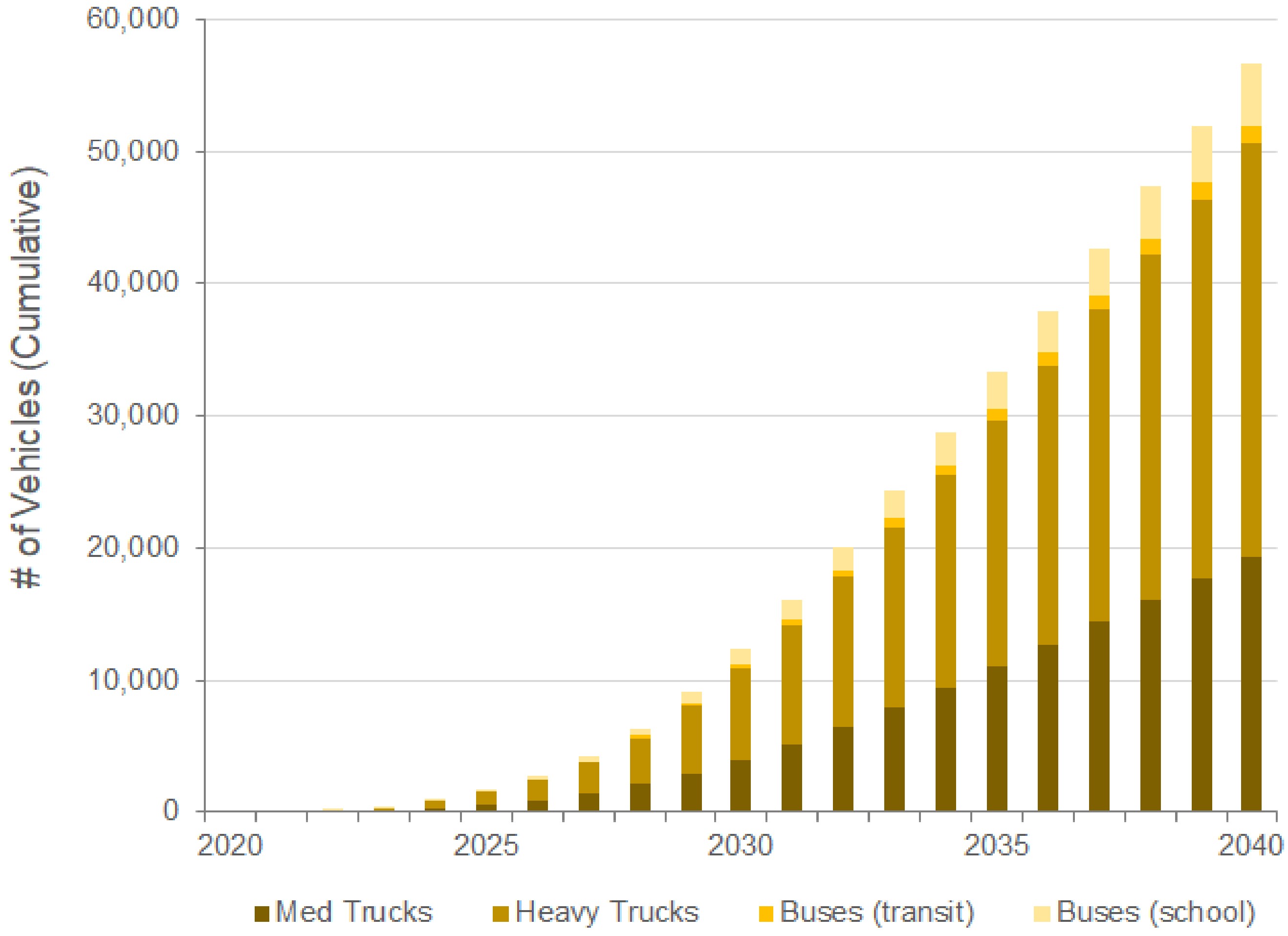
Advanced Clean Trucks Rule

This section summarizes results from analysis (described on slide 46) to illustrate possible outcomes if Virginia were to implement an Advanced Clean Trucks rule consistent with the California Air Resources Board Advanced Clean Trucks Rule

Advanced Clean Trucks Rule Leads to Growth of New Medium- and Heavy-Duty EVs



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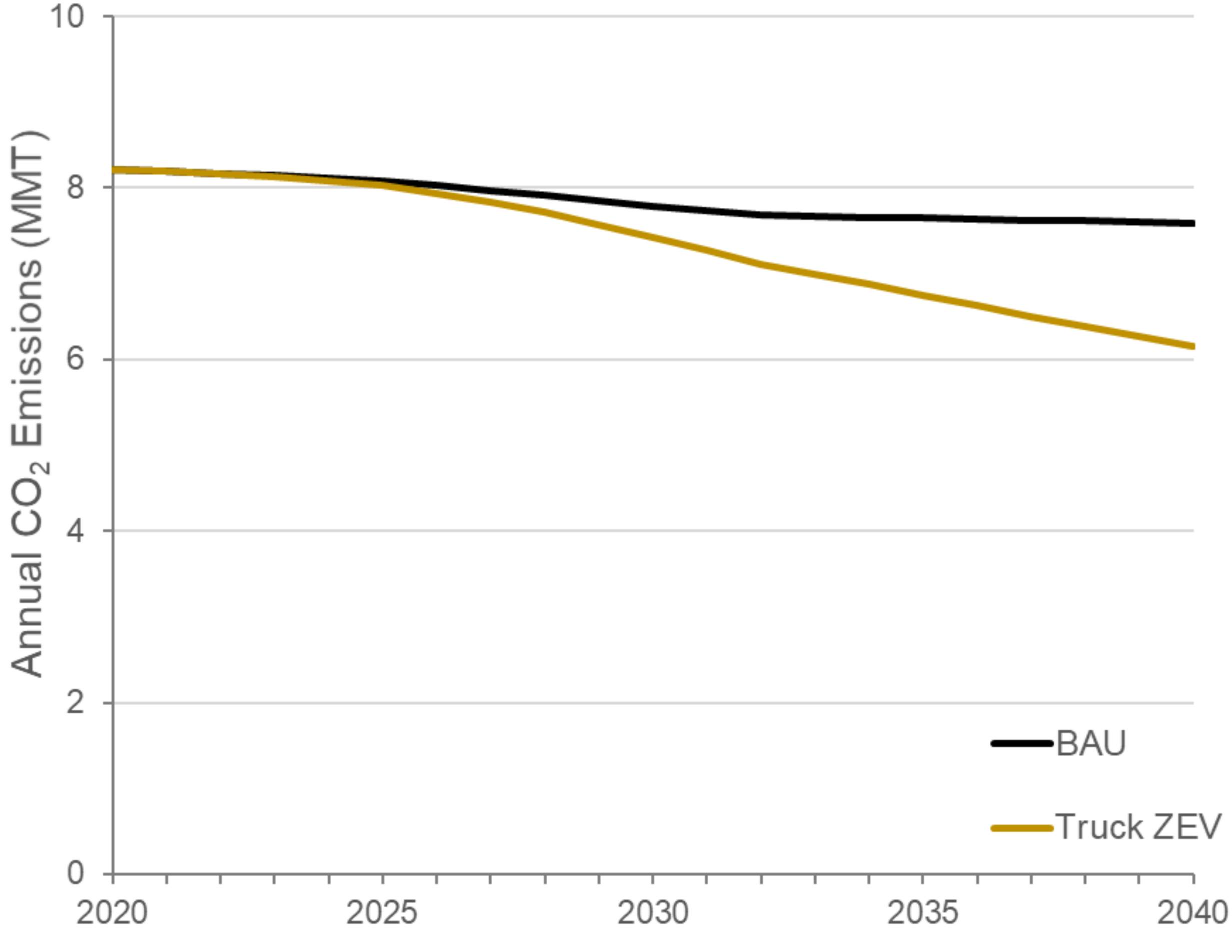
Advanced Clean Trucks Rule Projected to Cut Annual Diesel CO_2 Emissions ~ 5% by 2030 and 19% by 2040



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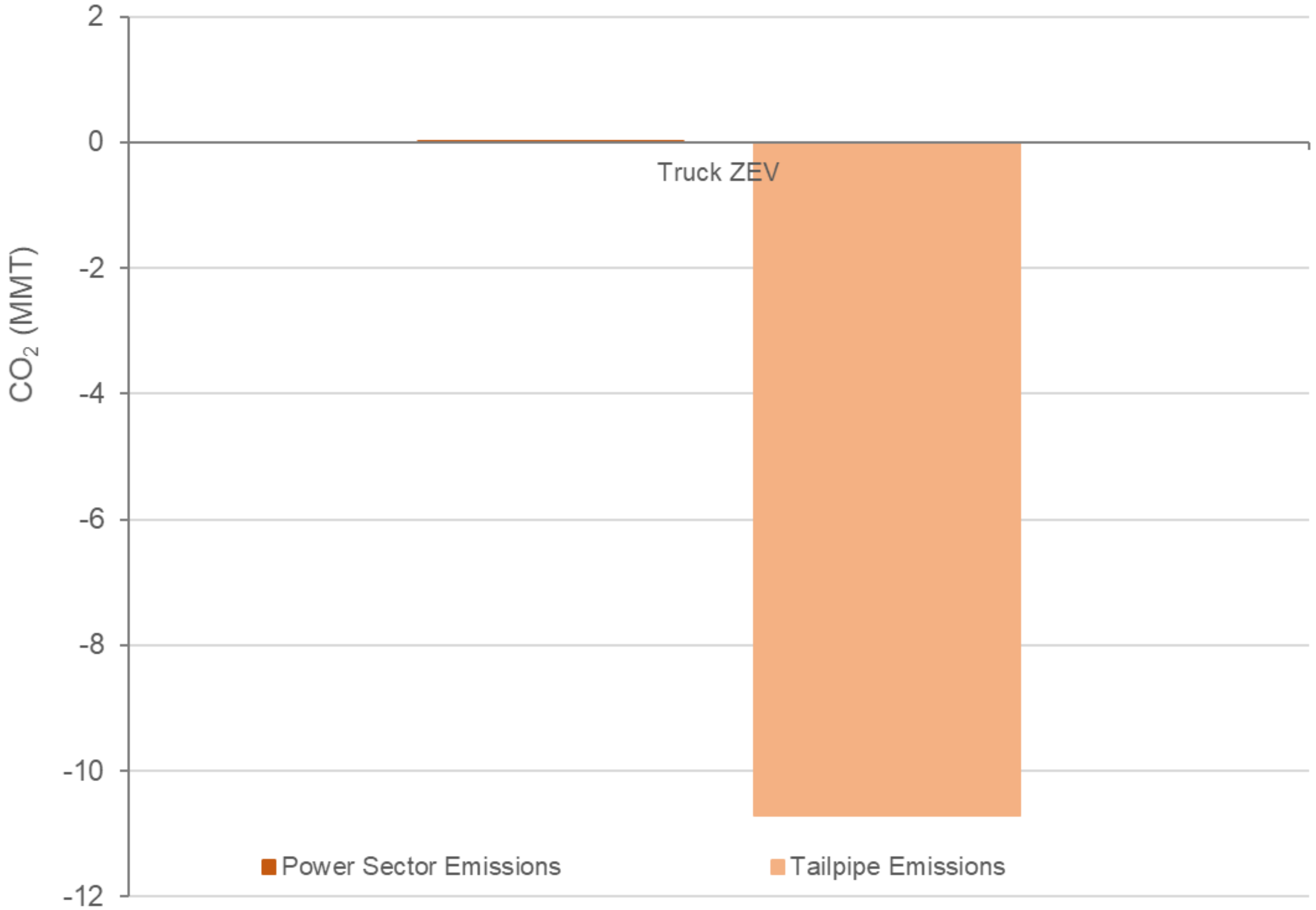
CO_2 Pollution Changes from Advanced Clean Trucks Rule:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: The Power Sector increase is less than 1% of the Avoided Tailpipe reduction

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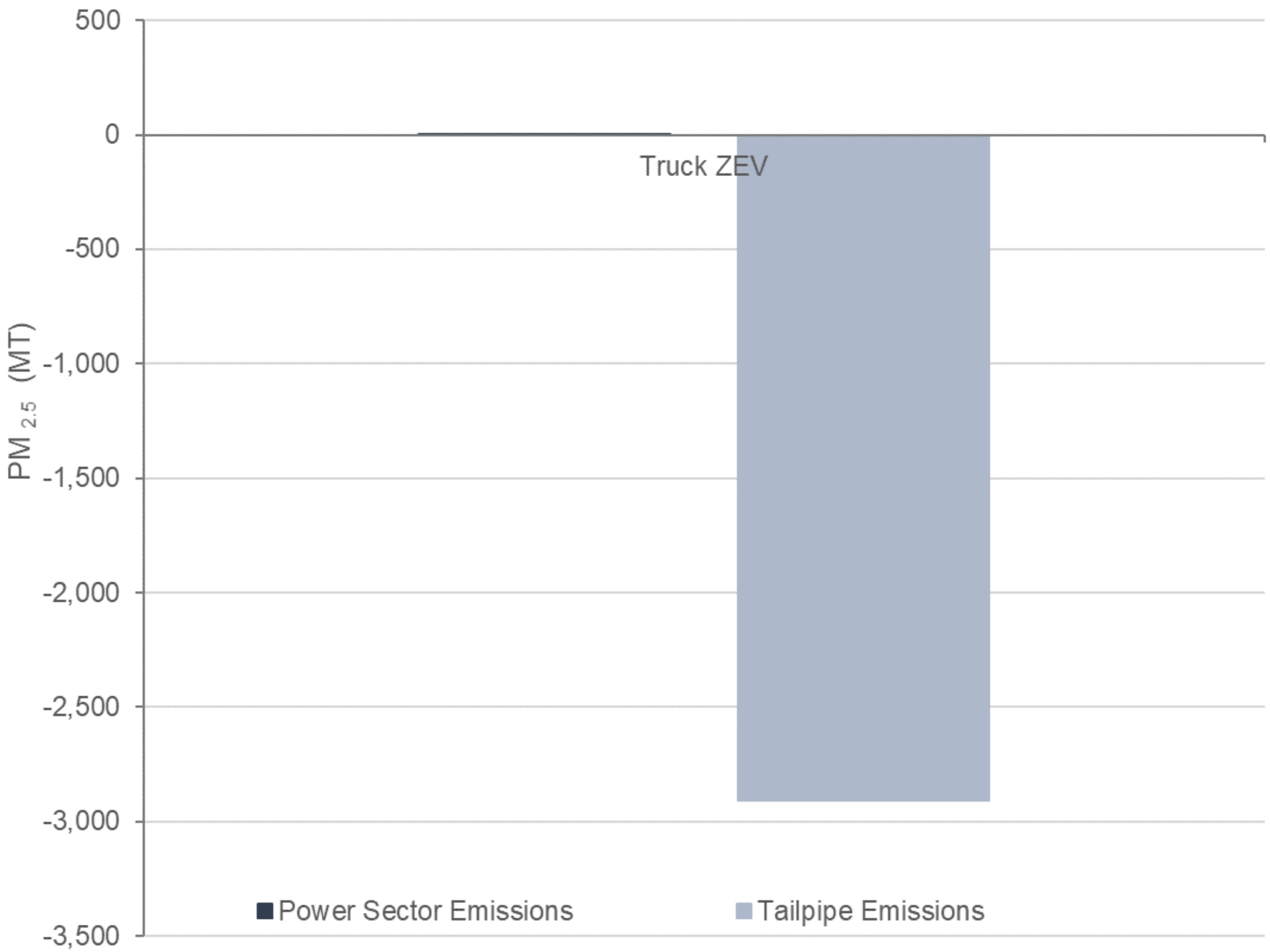
$PM_{2.5}$ Pollution Changes from Advanced Clean Trucks Rule:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: The Power Sector increase is less than 0.1% of the Avoided Tailpipe reduction

Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

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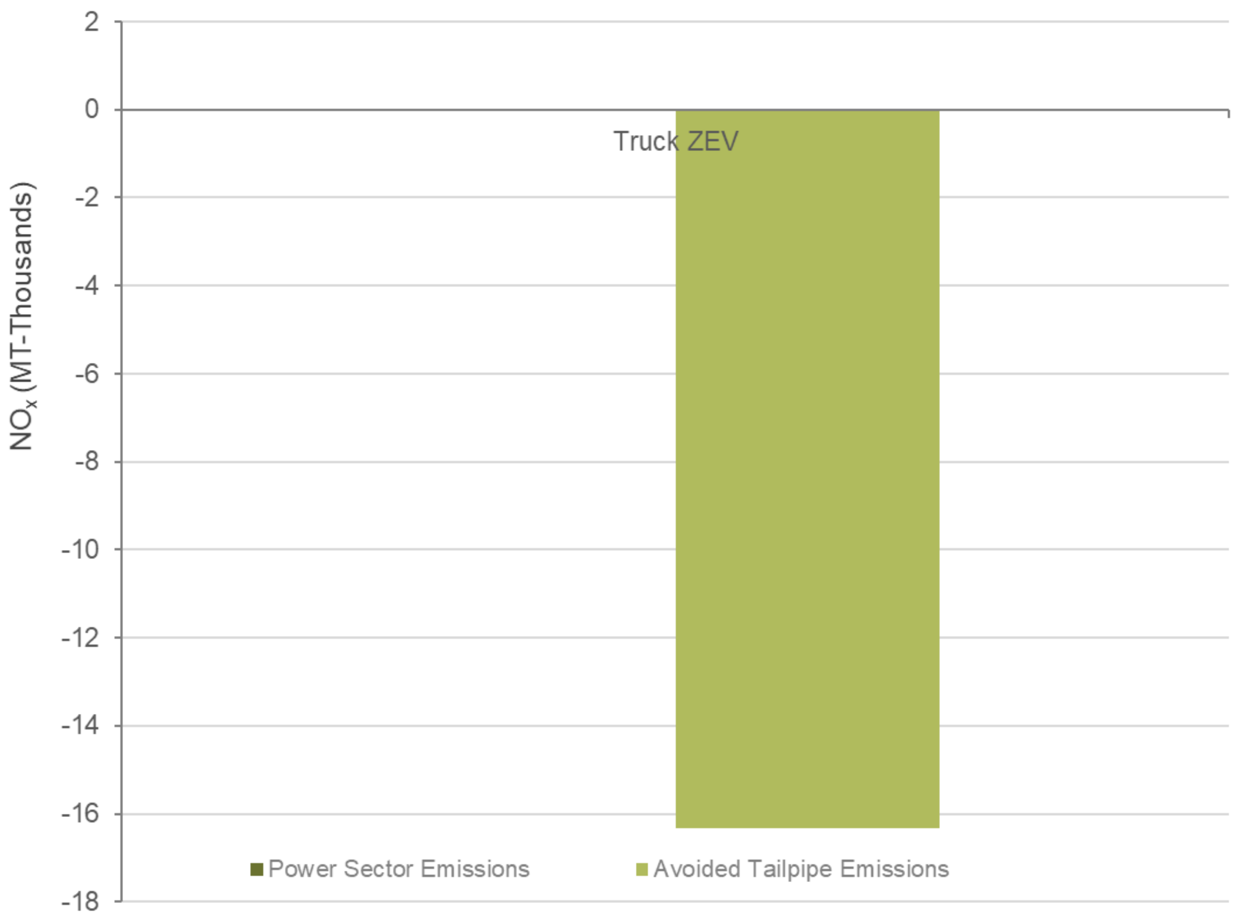
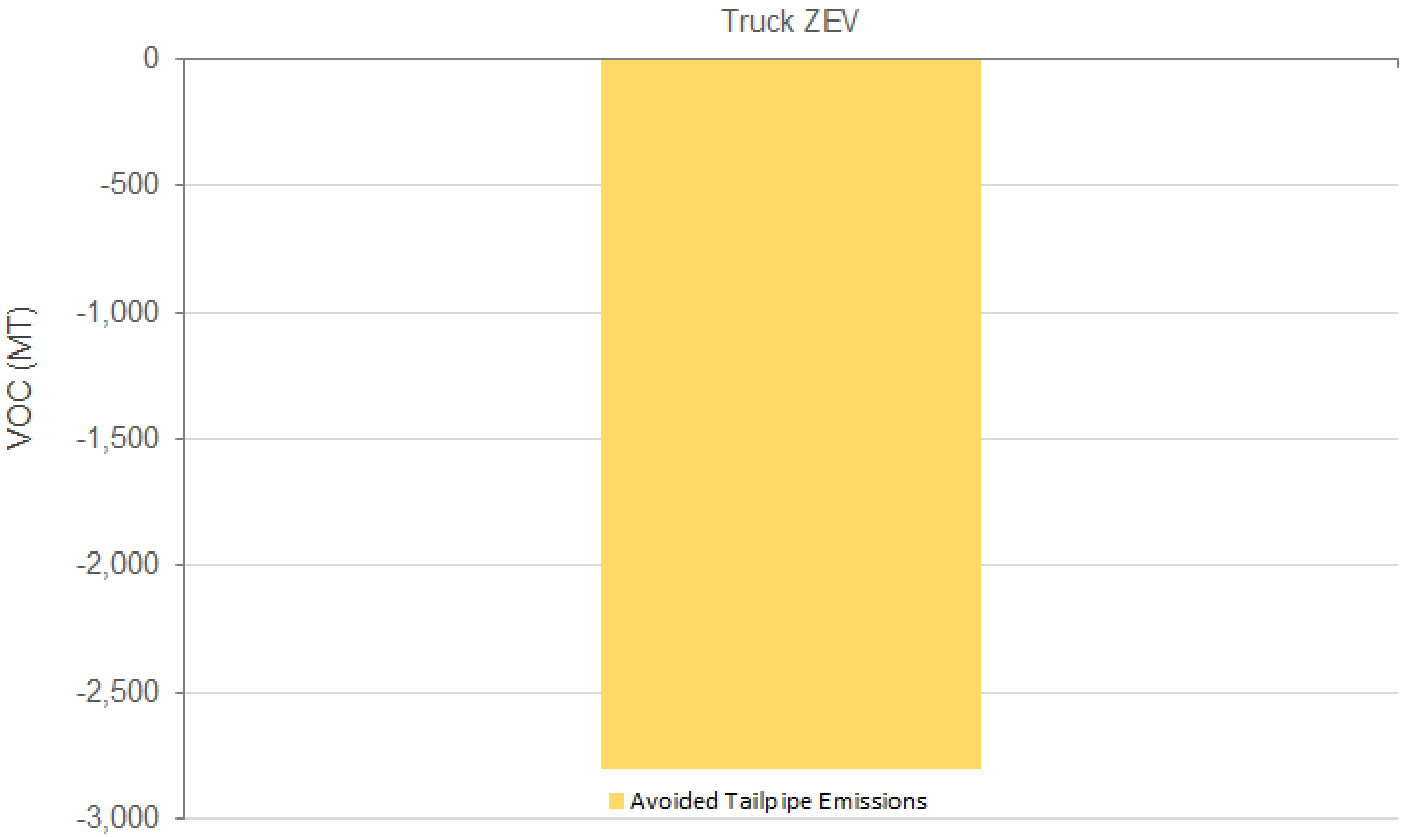
NO_x Pollution Changes from Advanced Clean Trucks Rule:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: The Power Sector increase is less than 0.1% of the Avoided Tailpipe reduction

Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

VOC Pollution Changes from Advanced Clean Trucks Rule:
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: The Power Sector increase is less than 0.001% of the Avoided Tailpipe reduction

Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

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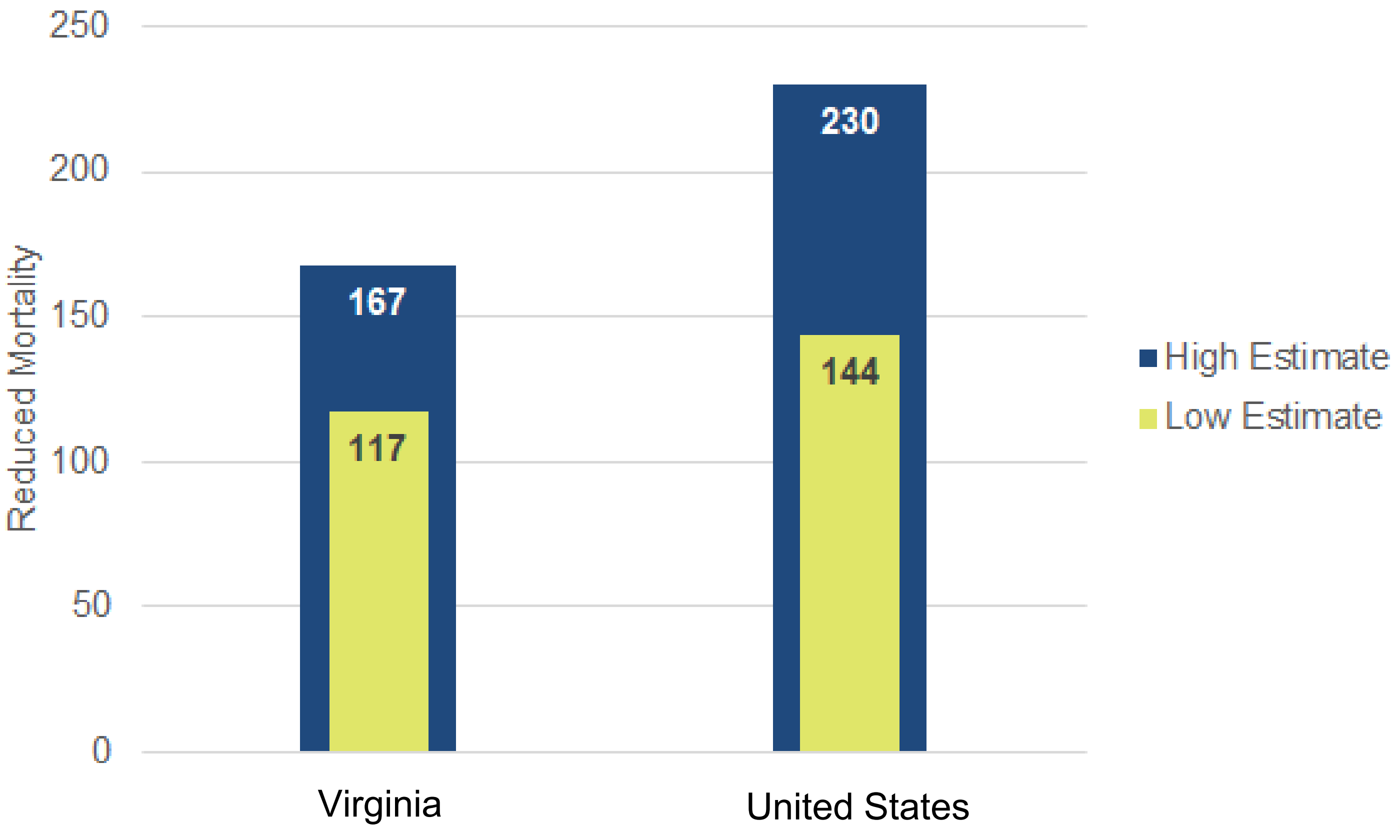
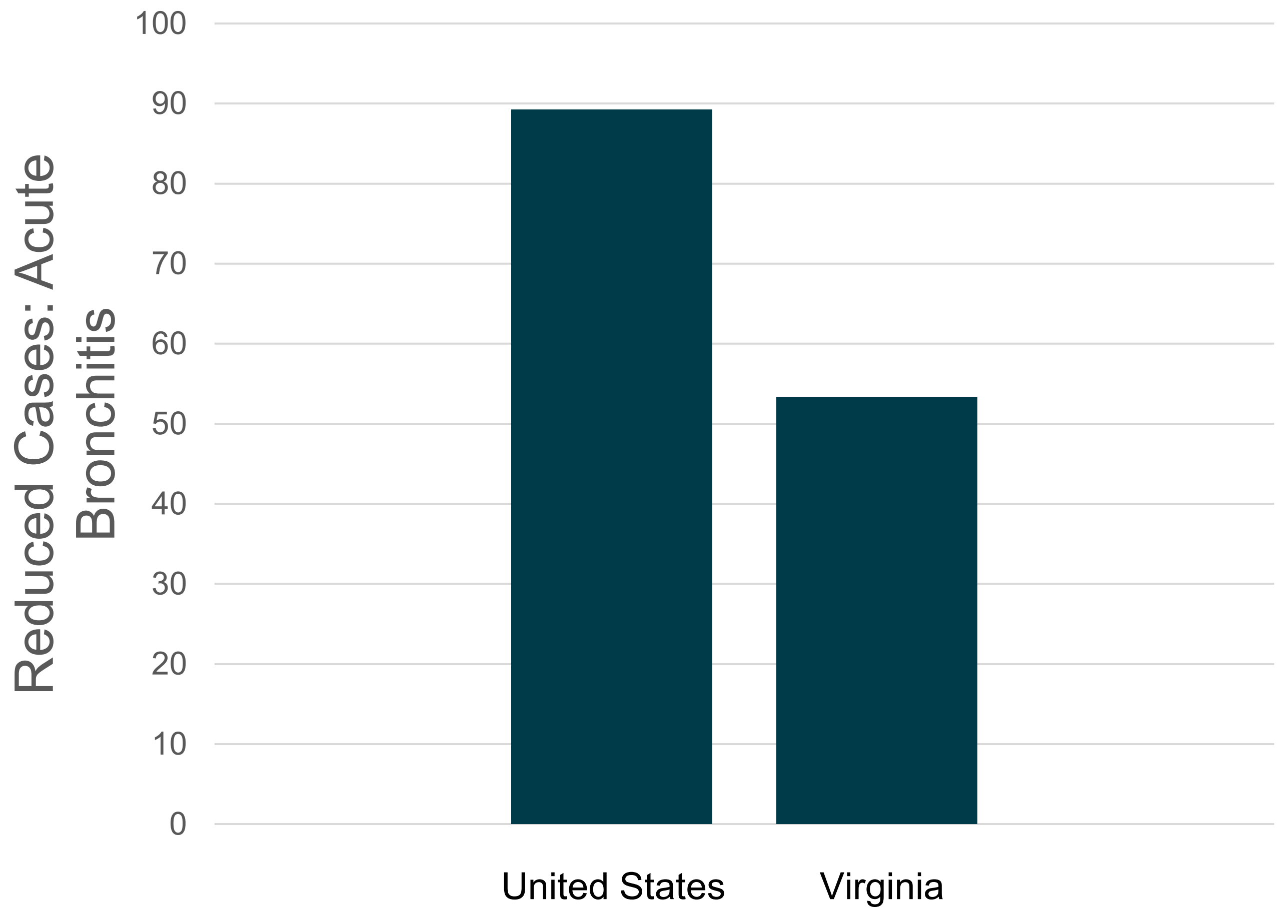
Advanced Clean Trucks Rule Saves Lives in Virginia and Nationally

(High and Low estimates, cumulative 20 years)



Advanced Clean Trucks Rule Reduces Cases of Acute Bronchitis Statewide and Nationally

(cumulative 20 years)



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Advanced Clean Trucks Rule Reduces Emergency Room Visits and Workdays Lost

Statewide and Nationally (cumulative 20 years)

Scenario	Geography	Reduced Emergency Room Visits from Asthma	Reduced Work Loss Days
Truck ZEV	Virginia	60	5,300
	United States	76	8,900

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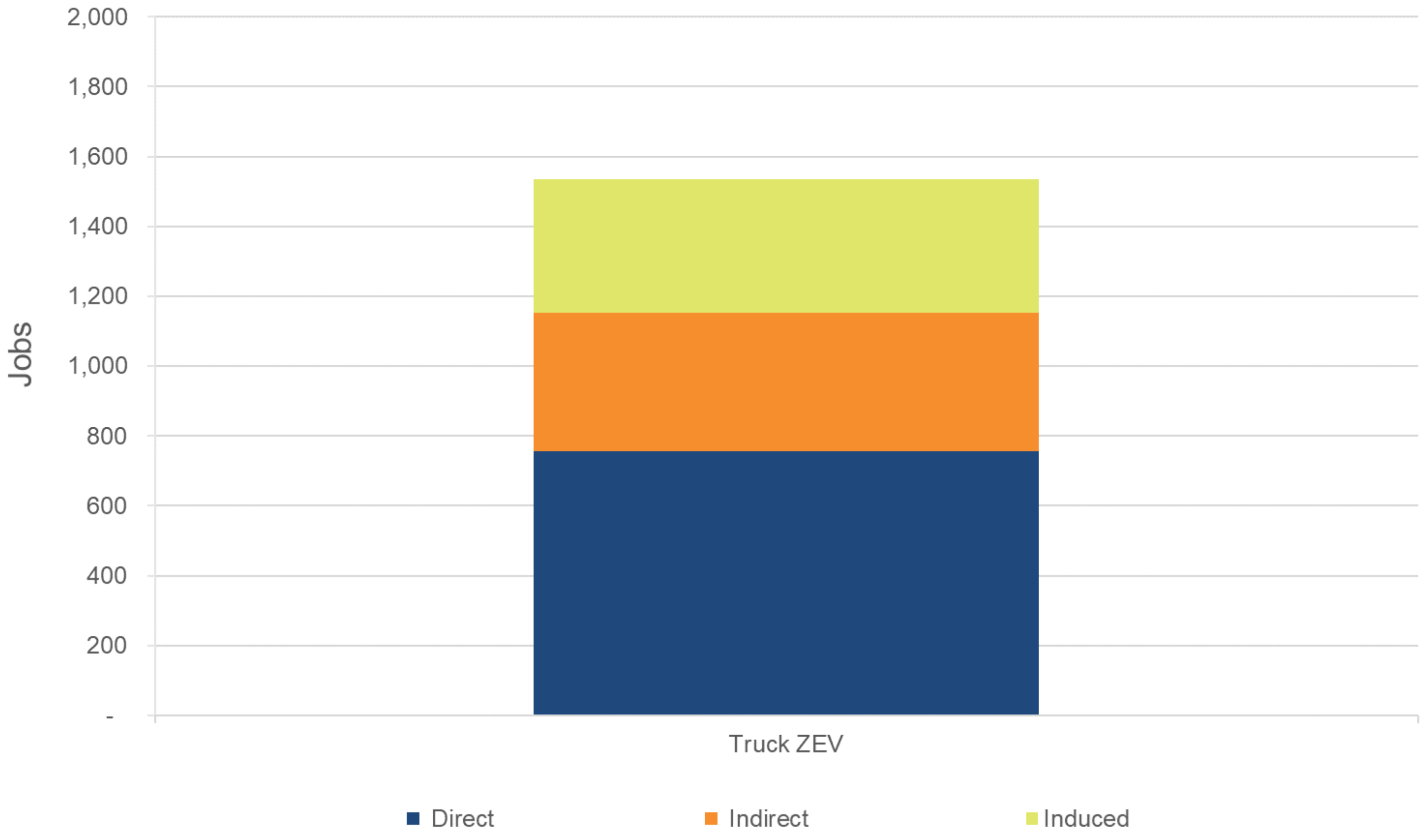
Net VA Jobs Growth Projected from Advanced Clean Trucks Rule

(Cumulative through 2040)



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Advanced Clean Trucks Rule Produces Net Benefits for Virginia

Scenario	Total Benefits ($B)	Total Costs ($B)	Net Benefits ($B)	Benefit Cost Ratio
Truck ZEV	1.62	0.095	1.5	**17.1**

All dollars are 2017-$

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Transportation Climate Initiative (TCI) Program Impacts

This section summarizes results from analysis (described on slide 46) that illustrates a range of possible outcomes for a variety of policy pathways, including LEV and ZEV standards *in addition to* different cap-and-invest scenarios that are implemented through 2040.

The two cap-and-invest scenarios are largely based on modeling that was conducted in 2019 to inform the Transportation and Climate Initiative, illustrating that a range of outcomes are possible depending on future program ambition, which is subject to review and revision on a periodic basis between 2022 and 2040.

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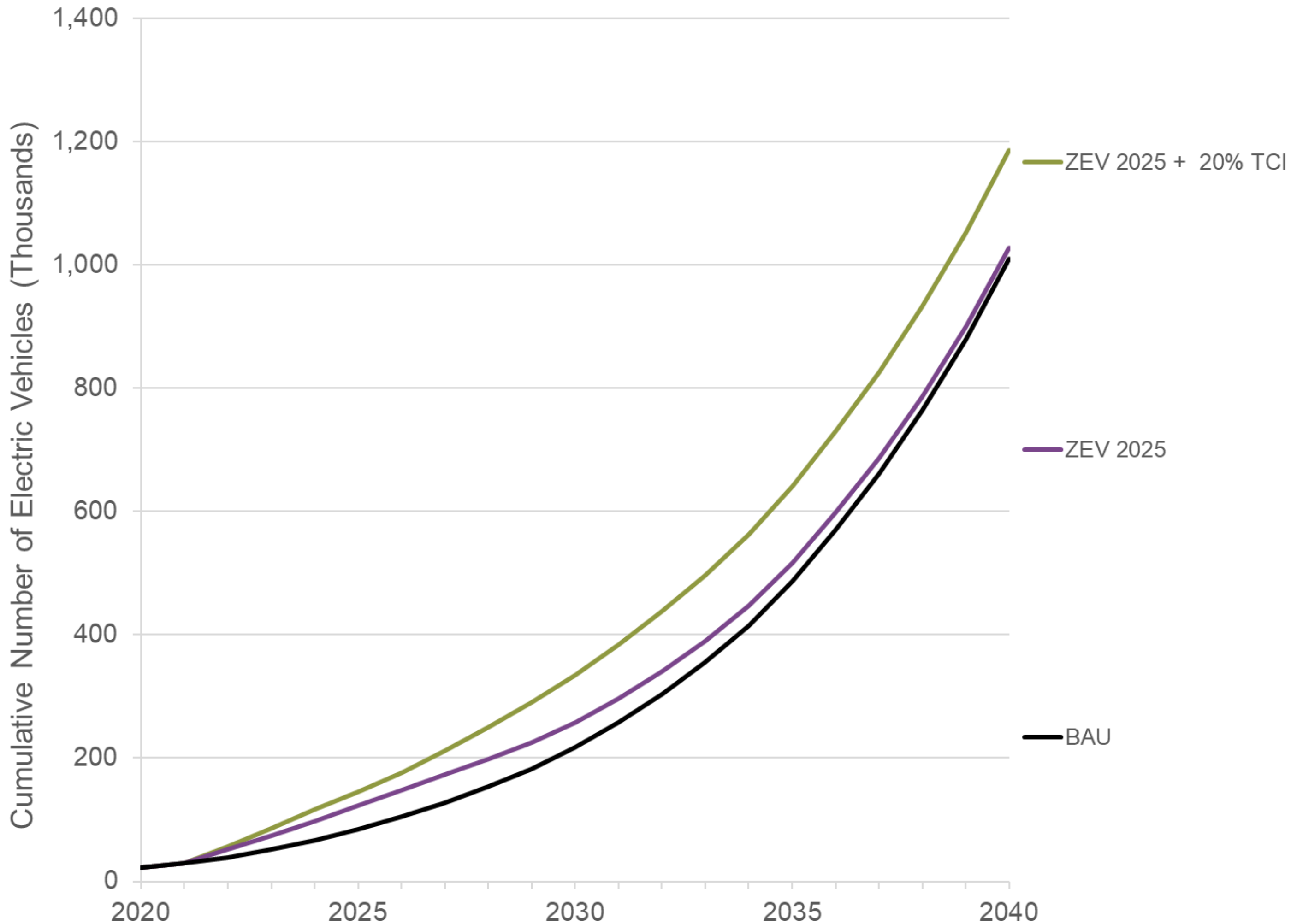
TCI Policy Boosts and Sustains Growth in EV Adoption



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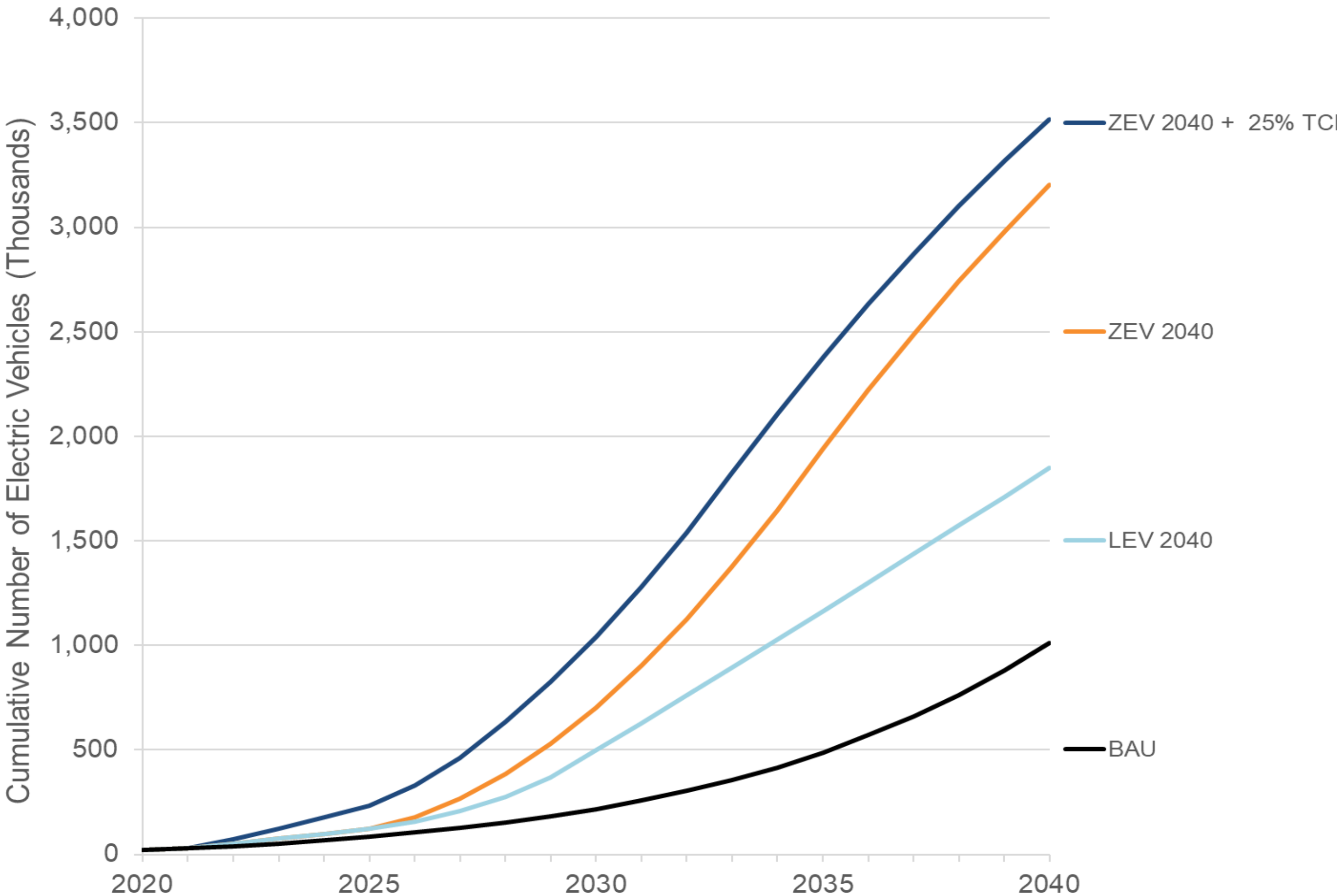
Adding TCI Program Produces Greater Cumulative Benefits Than Clean Car Standards Alone



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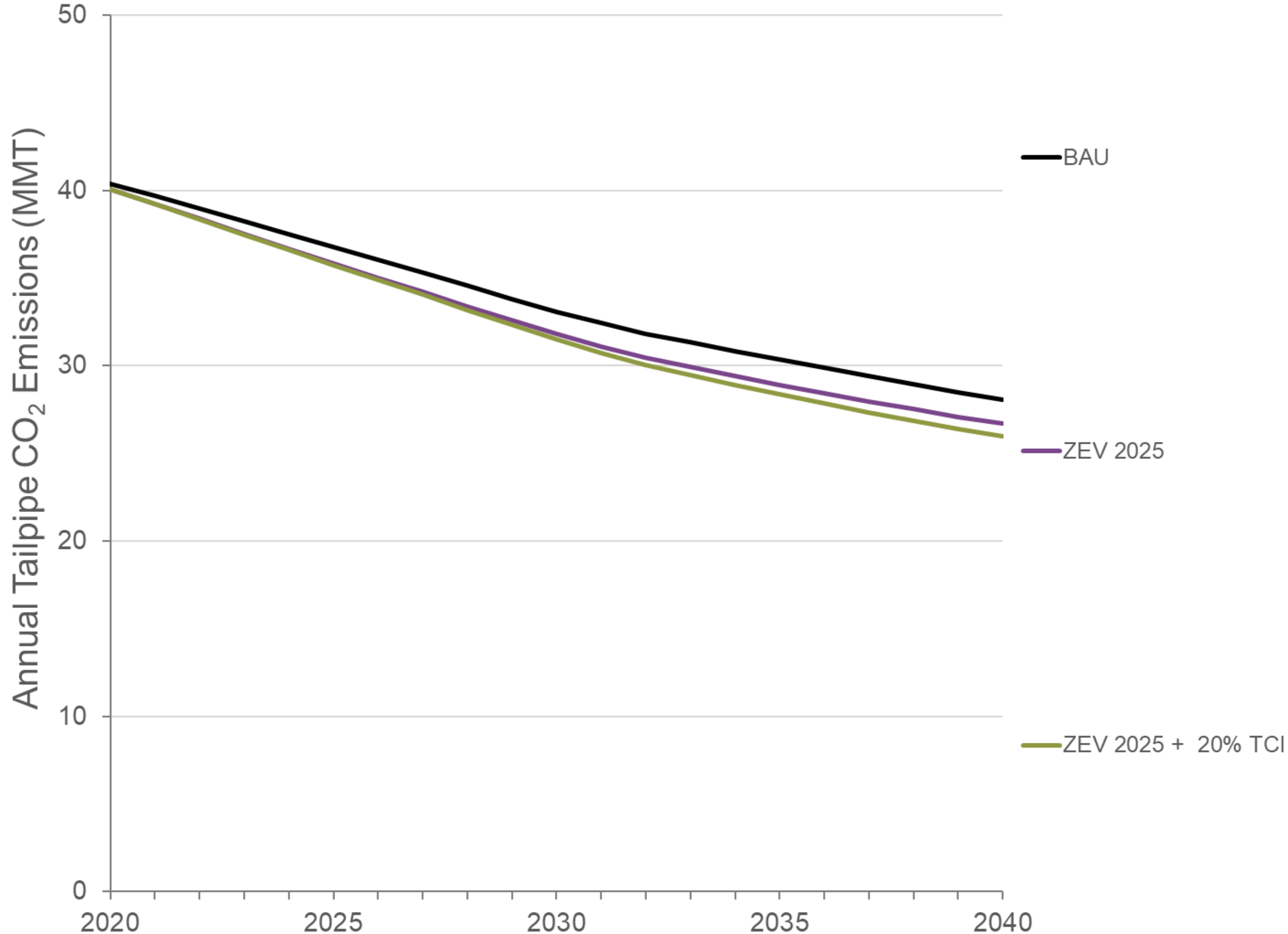
TCI 20% Cap Reduction Scenario Contributes to additional CO_2 Reductions



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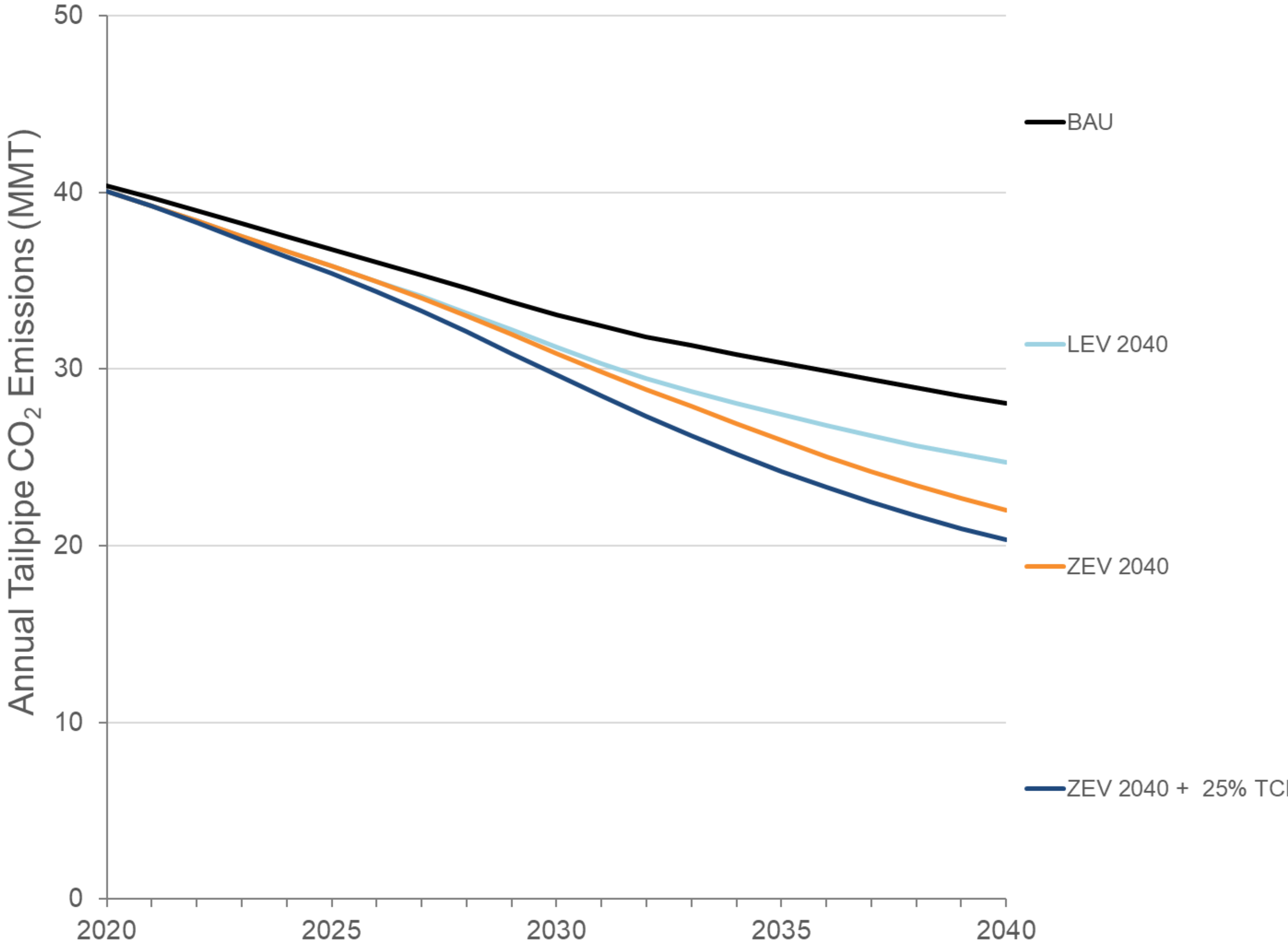
More Ambitious Policies Lead to Greater CO_2 Emission Reductions



2040 emissions drop 12%-28% relative to BAU

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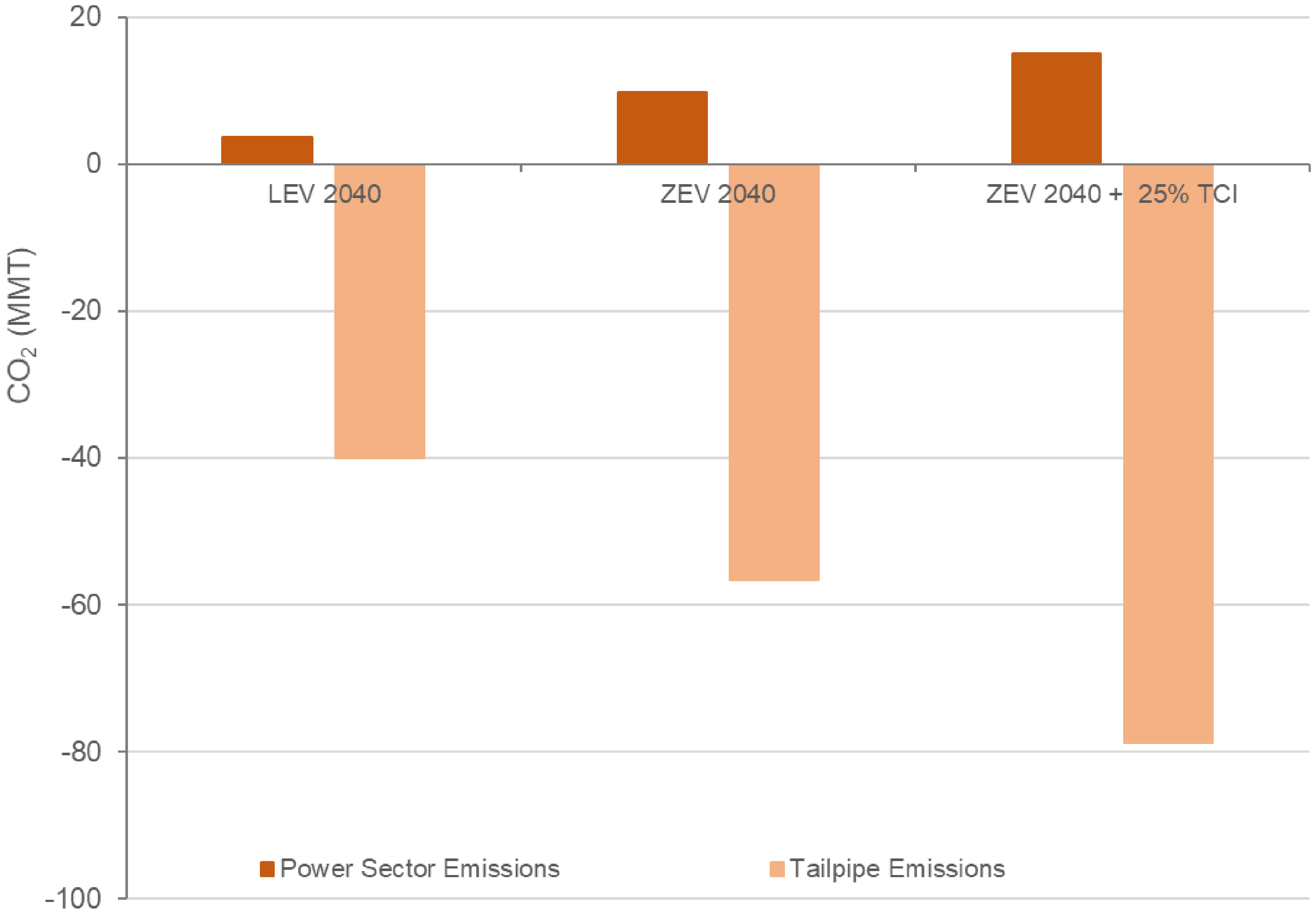
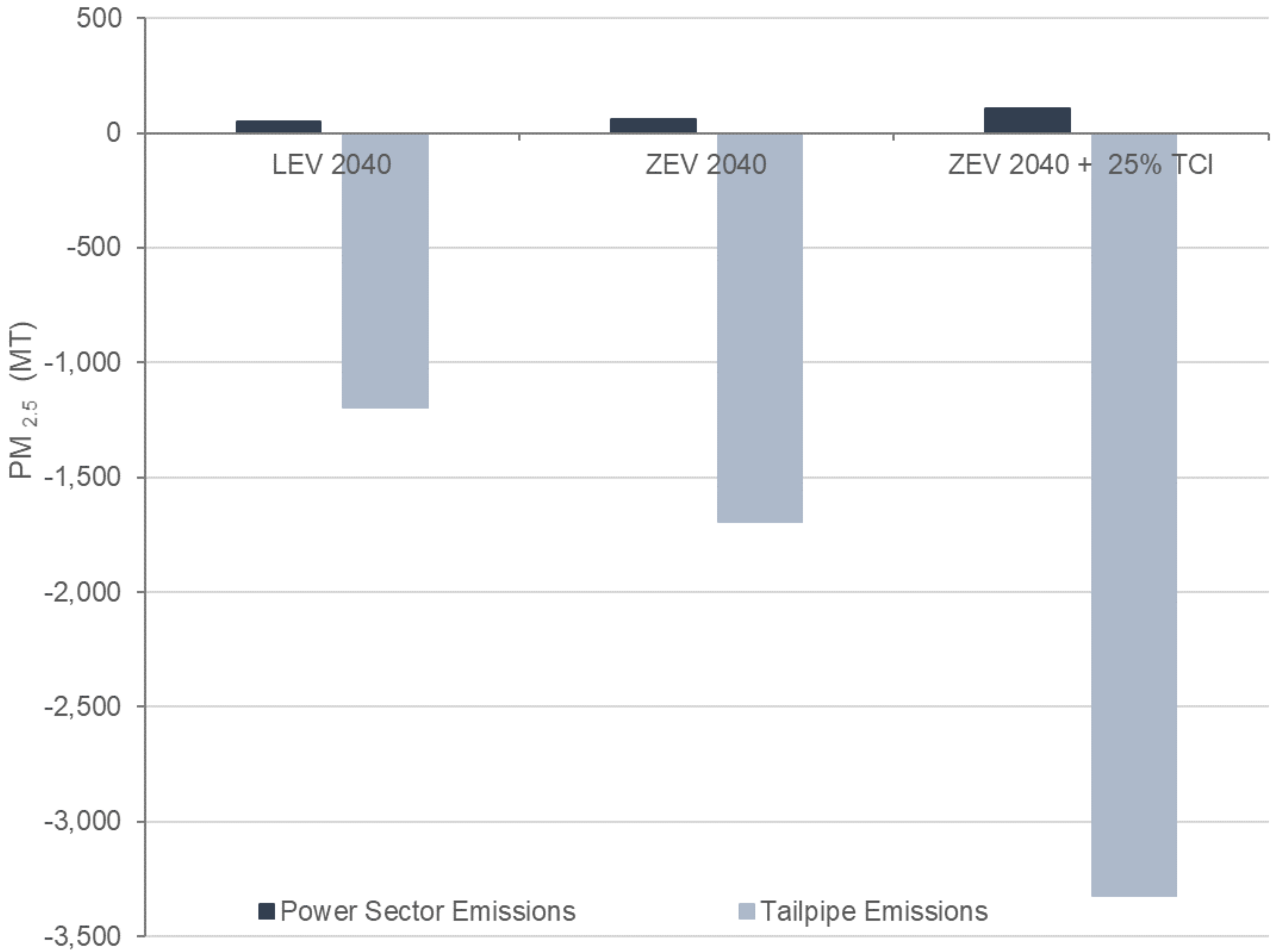
CO_2 Pollution Changes:

(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



$PM_{2.5}$ Pollution Changes:

(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

NO_x Pollution Changes:

(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)

Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

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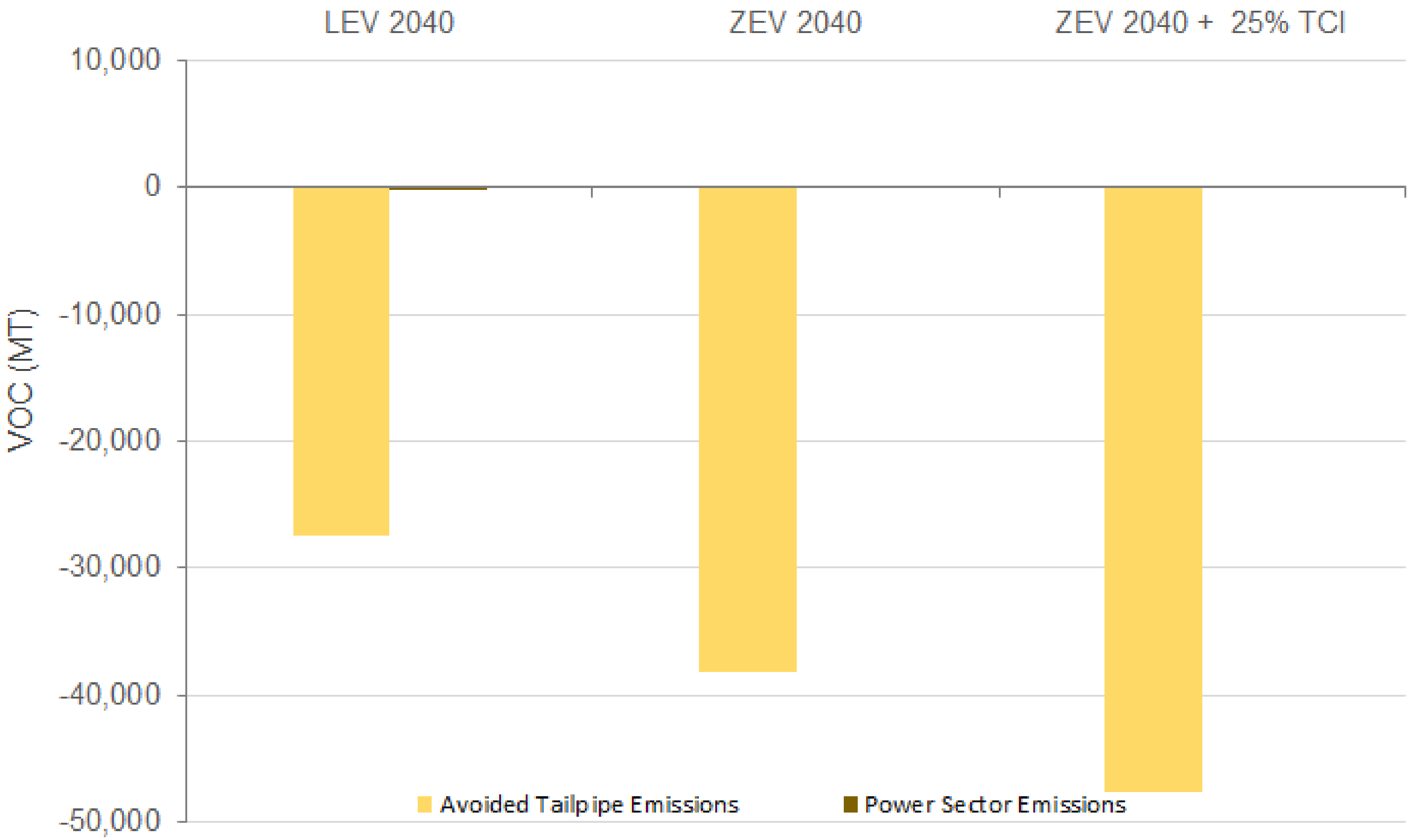
VOC Pollution Changes:

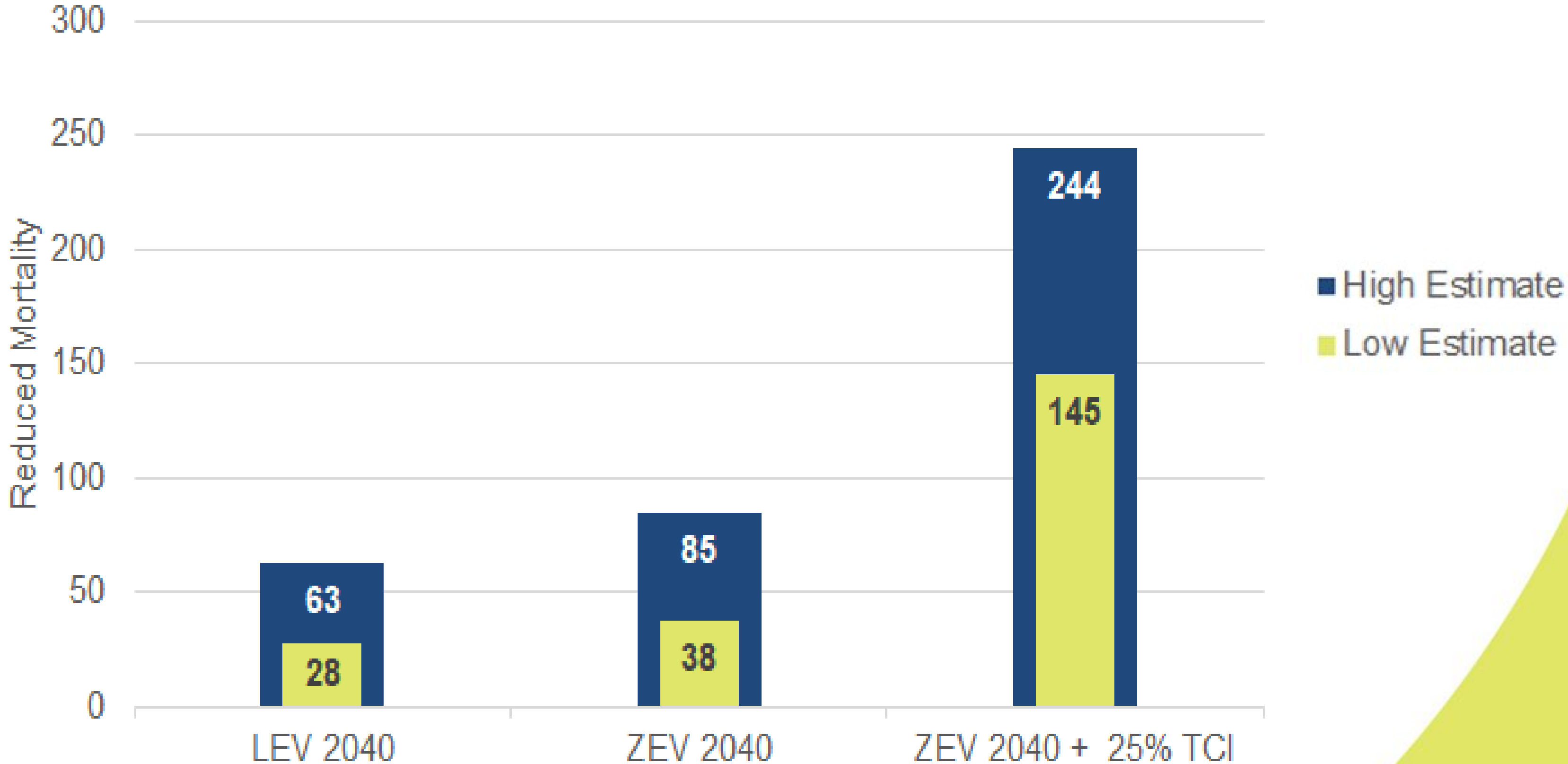
(Power sector & tailpipe emissions, relative to BAU, cumulative through 2040)



Note: Power Sector Emissions are less than 1% of the Avoided Tailpipe Emissions

Note: This analysis was performed at a state-wide level. Community-level impacts were not analyzed.

Clean Car Standards + TCI Program Save Lives in Virginia: Cumulative Benefits Greater Than Individual Policies



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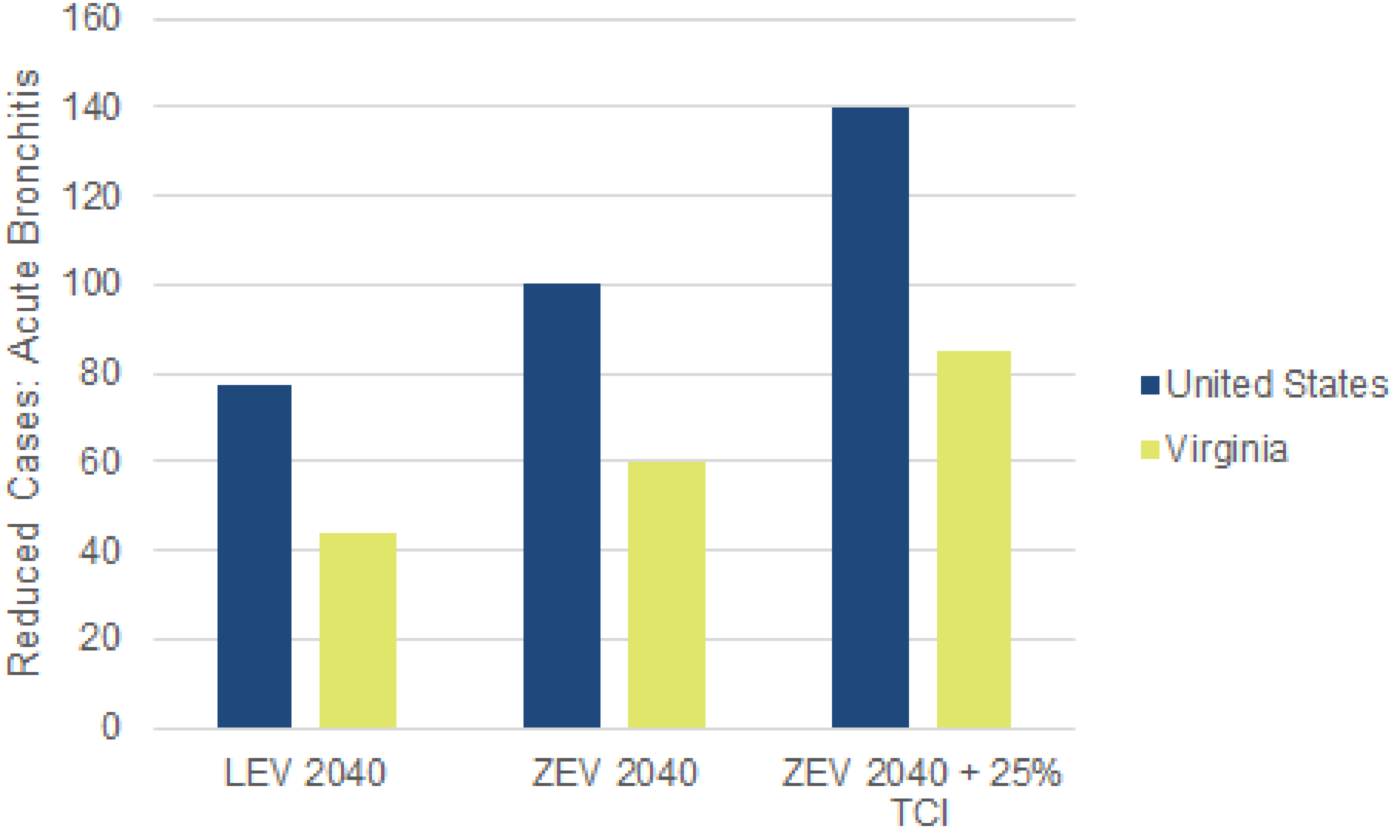
Clean Car Standards + TCI Program Reduce Cases of Acute Bronchitis Statewide and Nationally
(cumulative 20 years)



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Clean Car Standards + TCI Program Reduces Emergency Room Visits and Workdays Lost

(cumulative 20 years)

Scenario	Geography	Reduced Emergency Room Visits from Asthma	Reduced Work Loss Days
LEV 2040	Virginia	19	4,300
	United States	33	7,700
ZEV 2040	Virginia	25	5,900
	United States	42	10,000
ZEV 2040 + 25% TCI	Virginia	36	8,300
	United States	47	16,000

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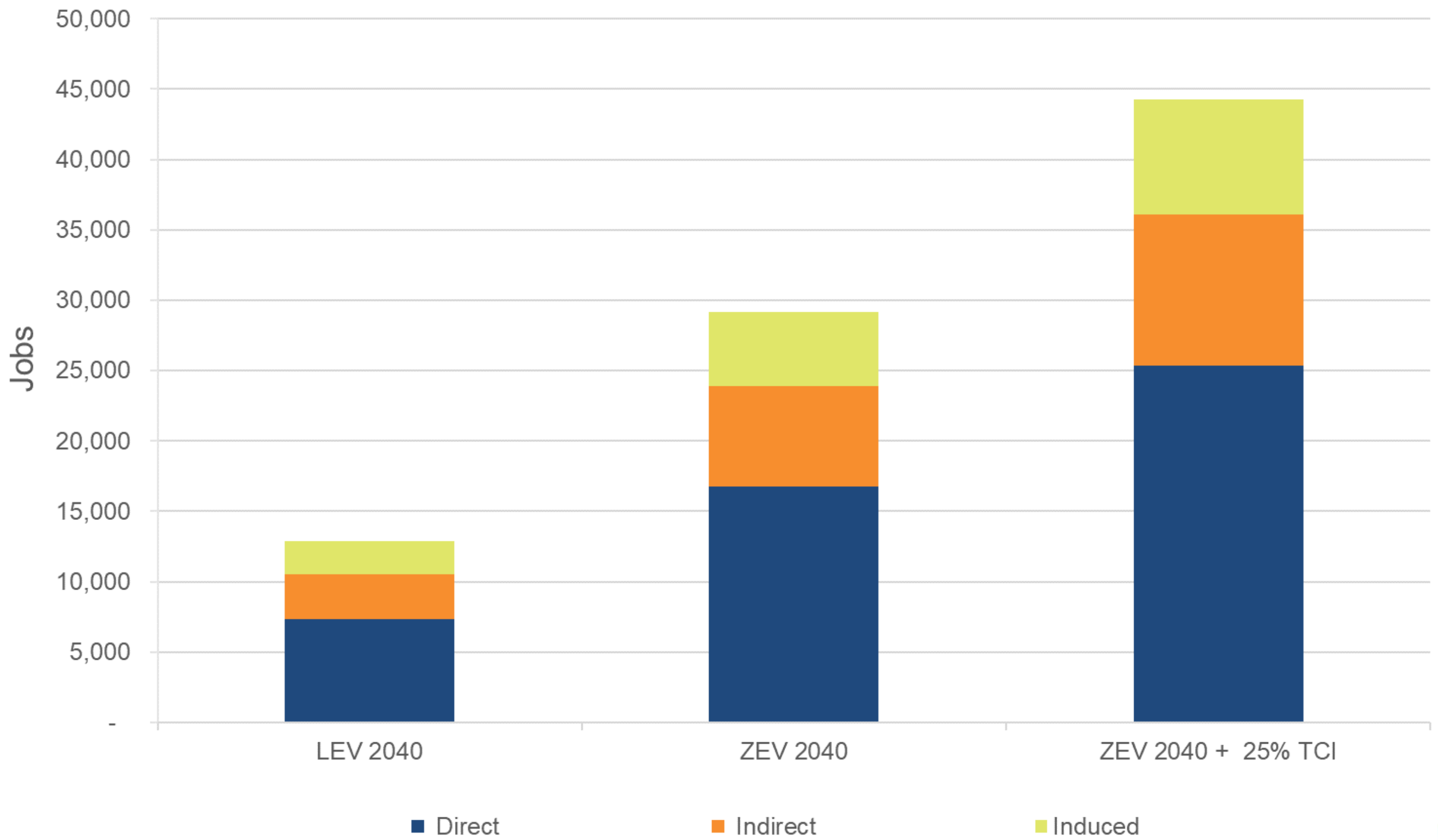
Clean Car Standards + TCI Program Create Net Virginia Jobs Growth (Cumulative through 2040)



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Clean Car Standards and TCI Program Produce Net Benefits for Virginia

Scenario	Total Benefits ($B)	Total Costs ($B)	Net Benefits ($B)	Benefit Cost Ratio
LEV 2040	14	3.9	10	3.6
ZEV 2040	30	8.9	21	3.4
ZEV 2040 + 25% TCI	**39**	**9.7**	**30**	**4.1**

All dollars are 2017-$

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Conclusions

- More ambitious vehicle standards that accelerate EV purchases result in greater net benefits
  - Lower emissions
  - More jobs
  - Better health outcomes
- Combining TCI-P with Clean Cars Standards achieves deeper reductions and maximizes co-benefits.
- Slow fleet turnover rates mean that immediate policy actions are needed to achieve long-term goals.
- Power sector emissions increase slightly due to EV charging, but are dwarfed by transportation emissions improvements from increased EV use and less pollution from vehicles—including less diesel emissions. The result is significant net emissions reductions in Virginia. This analysis was performed at a state-wide level, and additional analysis would be needed assess community-scale emissions impacts.

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Methodology

Policy Scenarios Evaluated

Scenario	Scenario Name	Description
Business As Usual (BAU)	BAU	Using the Virginia EV forecast adopted from Transportation Funding Sustainability report. New light-duty vehicle (LDV) fuel efficiency reflects the 2018 SAFE rule.
LEV & ZEV standard - 2025	ZEV 2025	Introduces both Zero Emissions Vehicle (ZEV) standard and Low Emissions Vehicle (LEV) standards for new LDVs through 2025, with no additional improvements thereafter.
LEV GHG standard - 2040	LEV 2040	Extends the LEV III standards to reduce new LDV emissions per mile by 38% from 2021 levels in 2030, with continued improvements through 2040.
LEV & ZEV standard - 2040	ZEV 2040	LEV 2040 is included. In addition, adds a 100% ZEV standard for LDVs beginning in 2035.
Advanced Clean Trucks - ZEV	Truck ZEV	Follows the California Air Resources Board's Advanced Clean Trucks Regulation for Medium and Heavy-Duty Vehicles
TCI 20% Cap	TCI 20%	TCI 20% Cap Reduction scenario: 2032 Transportation CO_2 emissions are 20% less than in 2022.
ZEV 2025 + TCI 20% Cap	ZEV 2025 + TCI 20%	Combined Scenarios: TCI 20% Cap Reduction + ZEV 2025
TCI 25% Cap	TCI 25%	TCI 25% Cap Reduction scenario: 2032 Transportation CO_2 emissions are 25% less than in 2022.
LEV & ZEV 2040 + TCI 25% Cap	ZEV 2040 + TCI 25%	Combined Scenarios: TCI 25% Cap Reduction + ZEV 2040

Business as Usual (BAU):

Policy Description & Methods

Uses EIA's 2020 Annual Energy Outlook (AEO), modified to reflect the Safer Affordable Fuel Efficient (SAFE) Vehicles Rule standards for cars and light trucks. New vehicles average 42 MPG-e in 2025, and this remains steady through 2040.

For Electric Vehicles, the forecast comes from Virginia's Mid EV forecast, contained in the Transportation Funding Sustainability (2019) report.[1] In this forecast, EVs reach 46% of all new Light-Duty car sales by 2040. For BAU, the on-road inventory includes 84,000 LDV EVs in 2025, and roughly 1,000,000 in 2040.

[1]Report Source: Virginia Secretary of Transportation. (2019). Transportation Funding Sustainability. https://rga.lis.virginia.gov/Published/2020/RD54/PDF

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Assumptions: Vehicle Retirements

Average LDV vehicle lifetime for Virginia is 12 years.* For medium- and heavy-duty vehicles: a 10-year lifetime is assumed for medium-duty trucks,[1] 12 years for buses,[2] and 15 years for heavy-duty trucks.[3]

Average lifetimes were applied in a simple linear manner such that ½ the fleet would retire at the average lifetime for the specific vehicle type. The last vehicles in any cohort would be retired at exactly twice the average lifetime years.

***According to Alliance for Automotive Innovation:**
Auto industry insights: Alliance for automotive innovation. (n.d.). Retrieved January, 2020, from https://www.autosinnovate.org/resources/insights/va

1 Laver, R., Schneck, D., Skorupski, D., Brady, S., & Cham, L. (2007). *Useful Life of Transit Buses and Vans* (Rep.). Washington, DC: U.S. Department of Transportation Federal Transit Administration.
2 Yang, L., Hao, C., & Chai, Y. (2018). Life cycle assessment of commercial delivery Trucks: Diesel, Plug-in electric, AND Battery-Swap Electric. *Sustainability, 10*(12), 4547. doi:10.3390/su10124547
3 Thielen, R. (2020, March 13). 5 quick facts About semi-trucks. Retrieved April 14, 2021, from https://www.commerceexpressinc.com/2020/01/09/5-quick-facts-about-semi-trucks/#:~:text=Engine%20Failure&text=However%2C%20the%20monster%20engineering%20that,%2Dtruck%2015%2D16%20years.%E2%80%8B

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Assumptions: Capital Costs

Incremental Electric Vehicle Costs are taken from TCI-NEMS:[1]

For LDVs in 2020, EVs cost $9500 more than comparable ICE vehicles and this diminishes by 67% to about $3150 by 2030. This relative difference is forecast to stay at roughly the same level through 2040.

MDHD:

School Bus incremental EV costs in 2020 are $163,000.

Transit Bus incremental EV costs in 2020 are almost $260,000.

Medium & Heavy-Duty truck incremental EV costs in 2020 are almost $90,000.

All MDHD Electric incremental costs fall 33% by 2030 and stay flat afterwards through 2040.

[1] TCI-NEMS is Transportation and Climate Initiative's version of the Department of Energy's NEMS model. Inputs can be found here: https://www.transportationandclimate.org/sites/default/files/Reference%20Inputs.xlsx

Assumptions: Emissions

Tailpipe

- Avoided tailpipe emissions - calculated as a decrease from BAU emissions, applying fuel-specific emissions factors.
- Emissions factors per gallon of fuel for CO_2 comes from TCI-NEMS, while the criteria pollutants factors are from a U.S. EPA MOVES2014 model run for year 2032. For years not reported, a compound annual growth rate was applied to interpolate between years. After 2035, emissions factors are held constant.
- Multiplying the emissions factors by gallons (or the appropriate equivalent) provides annual emissions estimates.

Power Sector

- Emissions factors for each electricity generating unit serving Virginia load is taken from EPA Continuous Emissions Monitoring Systems data.
- Greenlink's ATHENIA neural network architecture was deployed to capture the behavior and dispatch of the power system as required by the Virginia Clean Economy Act.
- Emissions factors are multiplied by generation to derive emissions estimates.

LEV & ZEV Standard 2025 (ZEV 2025):

Policy Description & Methods

The low emission vehicle (LEV) standard portion of this scenario includes an emissions improvement (shown as miles-per-gallon equivalent, or MPG-e) over Business as Usual. In 2025, this leads to a fleet-wide average of 53 MPG-e for new vehicles. This begins phasing in 2022. The average MPG-e for new vehicles stays flat at 53 through 2040.

The ZEV part of this scenario is manufacturer-required ZEV credits. These credits are calculated from the previous three-year average of sales of new LDVs multiplied by credit share through 2025. Credit shares reach 22% in 2025, with each BEV qualifying for 3.4 credits.

EV growth accounts for a portion of the emissions improvement. Annual purchases are defined as Virginia's share* of the Annual Energy Outlook (2020) forecast for South Atlantic EVs through 2028.

These conditions lead to a total of ~123,000 EVs in 2025 and over one million in 2040.

*Virginia represents 27% of new vehicle sales in the South Atlantic according to EIA and the Alliance for Automotive Innovation

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LEV GHG Standard 2040 (LEV 2040):

Policy Description & Methods

This scenario includes an emissions improvement (shown as miles-per-gallon equivalent, or MPG-e) over Business as Usual. In 2025, this requires a fleet-wide average of 53 MPG-e for new vehicles. This begins phasing in over time starting in 2022.

The average MPG-e for new vehicles improves to 56.5 by 2030 and remains there through 2040.

Electric Vehicle growth makes up a portion of the vehicle fleet emissions improvement, with EVs as 27% of the new LDV sales from 2022 through 2025. After 2025, that share grows to become 40% of new sales in 2030 and 60% by 2040. The total number of EV LDVs in Virginia reach 123,000 in 2025 and roughly 1.85 million in 2040.

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LEV & ZEV Standard 2040 (ZEV 2040):

Policy Description & Methods

In addition to the LEV 2040 characterization, this scenario was defined to incorporate a ZEV-style minimum credit requirement.

Manufacturer-required ZEV credits are calculated from the previous three-year average of sales of new LDVs multiplied by credit share through 2025. Credit shares reach 22% in 2025, with each BEV qualifying for 3.4 credits.

After 2025, the credit requirement is linearly increased to hit 100% of all LDV sales by 2035 (approximately an 8% increase per year).

By 2030, ~195,000 new light-duty EVs are purchased and 670,000 are part of Virginia's on-road inventory.

In 2040, 100% of new LDV sales are EVs; 380,000 new LDV EVs are purchased and almost 3,200,000 are forecasted to be on-road.

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Advanced Clean Trucks - ZEV (Truck ZEV):

Policy Description & Methods

This scenario models the effects of the California ARB's Advanced Clean Truck (ACT) Regulation[1] for new Medium and Heavy-Duty Vehicles in Virginia through 2040. This scenario did not evaluate any LDV-oriented changes. The baseline truck forecast comes from VA-specific VMT projections in the TCI Investment Strategy Tool,[2] which estimate ~ 180,000 MDHD vehicles, 60% of which are Heavy-Duty, in 2020. VMT for non-EV MDHD vehicles remains consistent with the TCI Reference Case forecast. MDHD vehicle sales requirements in line with the ACT Regulation result in the MDHD ZEV sales percentage by vehicle type in Virginia shown in the table below. Post- 2035 sale requirements are extended linearly. More conservative sales requirements are used when vehicle classes are aggregated.

EV share of new sales	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040
Medium Duty	1%	2%	5%	7%	10%	15%	20%	25%	30%	55%	70%
Buses	1.5%	3.5%	9%	11%	13%	20%	30%	40%	50%	75%	83%
Heavy Duty	1%	2%	5%	7%	10%	15%	20%	25%	30%	40%	60%

1 https://ww3.arb.ca.gov/board/books/2020/062520/20-6-3pres.pdf?_ga=2.95831900.1740005036.1593070635-1815689003.1593070635
2 See section 3.2: https://www.transportationandclimate.org/sites/default/files/TCI%20Invest-Tool-Documentation_09212020_final.pdf

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TCI 20% Cap (TCI 20%):

Policy Description & Methods

This scenario is based on modeling done to inform the Transportation Climate Initiative (TCI), which Virginia joined in 2018. TCI modeling released in December 2019 included illustrative scenarios of low-carbon transportation investments in transit, cycling, smart growth, zero-emission and alternative fuel vehicles, and other strategies. These investments reduce emissions and result in safety and health benefits.

The “TCI 20% scenario” included in this Virginia modeling estimates the emission reductions and EV sales resulting from TCI investments in the deployment light-duty, medium and heavy-duty electric and alternate fuel vehicles. Emission reduction estimates also accounted for reductions in vehicle miles traveled associated with price effects of the policy, plus TCI investments in transit and various other vehicle travel reduction strategies in the TCI Investment Strategies Tool.

The TCI 20% scenario – based on the TCI 2019 modeling scenarios – reduces CO_2 emissions by 20% below 2022 levels by 2032. To estimate the incremental growth in EVs for Virginia under the TCI 20% scenario, compared to Business As Usual, this study applied the same incremental growth in EV sales levels projected for the VA by TCI-NEMS modeling of the TCI 20% scenario.*

This policy begins in 2022 and leads to a total of ~310,000 EVs on-road in 2030, and almost 1,200,000 in 2040.

*TCI modeled additional EVs through 2032 only, so this study extended that delta for all years beyond 2032.

ZEV 2025 + TCI 20% Cap (ZEV 2025 + TCI 20%):

Policy Description & Methods

This scenario combines the ZEV 2025 elements with TCI 20% characterization.

The additional EVs expected from meeting the 20% TCI cap reduction are considered additive to those purchased to meet the ZEV 2025 requirements. This scenario also includes changes to the fleet consistent with the 2025 LEV standard of 53 MPG-e.

TCI 25% Cap (TCI 25%):

Policy Description & Methods

This scenario is based on modeling done by the Transportation Climate Initiative (TCI), which Virginia joined in 2018. TCI modeling released in December 2019 included illustrative scenarios of low-carbon transportation investments in transit, cycling, smart growth, zero-emission and alternative fuel vehicles, and other strategies. These investments reduce emissions and results in safety and health benefits.

The “TCI 25% scenario” included in this Virginia modeling estimates the emission reductions and EV sales resulting from TCI investments in the deployment light-, medium-, and heavy-duty electric and alternate fuel vehicles. Emission reduction estimates also accounted for reductions in vehicle miles traveled associated with the price effects of the policy, plus TCI investments in transit and various other vehicle travel reduction strategies in the TCI Investment Strategies Tool.

The TCI 25% scenario – based on the TCI 2019 modeling scenarios – reduces CO_2 emissions by 25% below 2022 levels by 2032. To estimate the incremental growth in EVs for Virginia under the TCI 25% scenario, compared to Business As Usual, this study applied the same incremental growth in EV sales levels projected for VA by TCI-NEMS modeling of the TCI 25% scenario.*

This policy begins in 2022 and leads to ~580,000 EVs on road in 2030, and almos[t] 1,700,000 in 2040.

*TCI modeled additional EVs through 2032 only so this study extended that delta for all years beyond 2032.

ZEV 2040 + TCI 25% Cap (ZEV 2040 + TCI 25%):

Policy Description & Methods

This scenario combines the ZEV 2040 requirements with the impacts of the TCI 25% scenario.

The additional EVs expected from meeting the 25% emissions cap (previously described) are considered additive to those purchased to meet the ZEV 2040 requirements. This scenario also includes changes to the fleet consistent with the 2040 LEV standard of 56.5 MPG-e by as well as the aforementioned VMT reductions related to vehicle travel reduction strategies, transit and price effects.

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Assumptions for Future Electricity Rates in Virginia

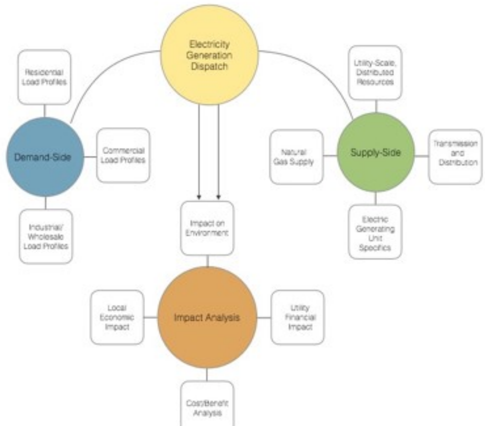
In order to calculate the net costs and savings of more electric vehicles in the fleet, the fuel cost difference between combustion engine vehicle fuel (gasoline and diesel) and electric powered vehicle fuel (electricity) was calculated.

The projection for future Virginia electricity rates were taken from EIA's NEMS forecast and adjusted for VA. The average rate starts at $0.12 / kWh, equivalent to $1.05 per LDV charge.

Power Sector: ATHENIA

Greenlink's AI-driven ATHENIA model assesses energy market operations using 7 modules:

- Demand: Sector-specific electricity demand profiles
- Supply: Historical data on plant and unit operations, generation, emissions, financials, and water usage
- Dispatch: matches supply and demand resources hourly to forecast utility operations
- The model undergoes significant testing and training, learning how the utility system operates with consideration for factors like growth, hourly and seasonal variability, commodity prices, planned and unplanned outages, and other operational considerations
- Other Modules (Utility Financials Module, Economic Development, Environmental, and Cost-Benefit) are detailed on other slides, as relevant.
- ATHENIA achieved an R^2 of 0.91 and averaged less than 8% error in forecasting the hourly output of each electricity generating unit on the power system in its testing



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Assumptions: Miles Per Gallon Equivalent (Electric & ICE Vehicles)

Electric Vehicles: Battery capacity (kWh) was converted to miles-per-gallon equivalent using EPA's formula.[1] This formula was used with NEMS battery capacities and ranges then averaged to represent the efficiency for EVs (93 MPG-e).

ICE Vehicles: Miles per gallon within the BAU scenario for ICE vehicles aligned with the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule. MPG for subsequent scenarios were revised to align with the 2011 CAFE standard.

[1] MPG-e = range (miles/kWh of capacity) where 33.7 kWh is 1 gallon-e of fuel.

Health Impacts and Benefits

Analyzed using ATHENIA and EPA's **CO-Benefits Risk Assessment (COBRA)** Health Impacts Screening and Mapping Tool.[1]

- Estimates the health benefits associated with clean energy policies and programs to compare against program costs.
- Annual NO_x, VOCs, & $PM_{2.5}$ tailpipe emission reductions and power sector emissions due to increased EVs are analyzed against Business as Usual for each scenario.
- Results are expressed in decreased mortality rates, days of missed work, and asthma related emergency room visits.

[1]CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool. (2020, October 27). Retrieved February 01, 2021, from https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool

Economic Impacts: Avoided Social Damages

- Marginal benefits from avoided tailpipe emissions are established at the county level for NO_x, CO_2, $PM_{2.5}$, and VOC,[1] then population-weighted to establish typical state-wide benefit levels per marginal ton of abatement from the transportation sector.

- Marginal costs from increased power sector emissions are established at the stack level for NO_x, SO_2, PM_{10}, $PM_{2.5}$, NH_3, VOC, and CO_2 using the same data sources. Changes in emissions are ATHENIA outputs.

[1]County-level marginal damages are from AP2 https://public.tepper.cmu.edu/nmuller/APModel.aspx, except CO_2, which uses a CPI-adjusted 2016 Social Cost of Carbon trajectory https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

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Economic Development

- Aggregation schemes were used within IMPLAN, input-output macroeconomic software, to create Virginia-specific direct, indirect, and induced job-years and gross regional product (GRP).
  - ***Direct:*** Job-years and GRP directly related to the change in expenditures on electric and ICE vehicles and charging infrastructure (eg: vehicle manufacturing, charger installation).
  - ***Indirect:*** Job-years and GRP indirectly related to the change in expenditures on electric and ICE vehicles (eg: supply chain or parts manufacturing).
  - ***Induced:*** Job-years and GRP that are induced from spending differences. These result from, for example, an EV tax incentive, changed household incomes, or reduced ICE maintenance (eg: increased demand of retail or entertainment jobs).

Economic Development (con't)

Increased EV investments and decreased purchases of ICE vehicles are aggregated with IMPLAN Job and GRP Analysis Multipliers. Investments streams come from:

- ***Vehicle Capital Cost:* Applied to vehicle projections for each scenario**
    - *New ICE light-duty vehicle prices:* Energy Information Administration's (EIA) 2020 Annual Energy Outlook (AEO) Ranging from $30,000 to $35,000 per vehicle.[1]
    - *New EV light-duty vehicle prices:* Annual incremental costs taken from TCI-NEMS.
    - *Medium & Heavy Duty ICE/ EV Trucks*: Reported market prices were used as proxies,[2] annual incremental costs from TCI Investment Strategies Tool.
- ***Fuel Price Projections:* Applied to assumed annual miles driven for each vehicle type**
    - *Fossil Fuel Prices:* EIA's 2018 Annual Energy Outlook (EIA AEO).[3]
    - *Electricity Fuel Projections:* Expressed as dollars per gallon of gas equivalent ($/GGE) on an annual basis, from TCI-NEMS.
- ***Consumer Tax Incentives:* Creates additional induced jobs and GRP within VA's Economy**
    - All scenarios, excluding *TCI 20%, TCI 25%* and the *Advanced Clean Trucks - ZEV* scenarios took advantage of Federal Government tax incentives up to $7,500 for the purchase of qualified electric vehicles, phasing down when manufacturer sales reach 200,000 vehicles.
    - *TCI 20%* and *TCI 25%* scenario tax incentive values are taken from TCI-NEMS, which incorporated vehicle subsidies.
- ***Charging Infrastructure - Continued on next slide***

[1] U.S. Energy Information Administration. 2020. "Light-Duty Vehicle Energy Consumption by Technology Type and Fuel Type". Retrieved January 08, 2021, from https://www.eia.gov/outlooks/aeo/data/browser

[2] New Average Truck Price in the United States. 2020. Retrieved January 11, 2021 from https://www.statista.com/statistics

[3] U.S. Energy Information Administration. 2018. 2018 Annual Energy Outlook. Retrieved January 11, 2021, from https://www.eia.gov/outlooks/aeo/data/browser

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Economic Development - Charging Infrastructure

- Public, workplace and personal charging station needs were determined using the US Department of Energy's Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite.[1]
- Based on the EVI-Pro Lite results, 85% of electric vehicle owners primarily charge at home, with the rest of users charging their vehicles at work or in public.
- Prices of public charging stations ranged from $1.5 to $10 thousand for light duty vehicles; $25 to $145 thousand for heavy duty vehicles and busses.[2]

[1] Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite. (n.d.). Retrieved January 11, 2021, from https://afdc.energy.gov/evi-pro-lite
[2] Smith, M., & Castellano, J. (2015). *Costs Associated With Non-Residential Electric Vehicle Supply Equipment* (Rep.). U.S. Department of Energy.

Cost-Benefit Analysis

The elements used in the benefit-cost analysis are netted beyond the Business as Usual forecast and include:

- **Capital Costs**, net additional expenses of different ICE or EV buying patterns. The compact EV price forecast used for LDVs is from TCI-NEMS; while the MDHD EV price delta comes from the TCI Investment Strategies Tool, The base prices for each category come from different sources.[1]
- **Pollutant Damages**, value of avoided cost of health impacts of pollution. This includes both decreased pollution from tailpipes (noted on previous slide) and changes in pollution from power plants.
- **Fuel Cost Savings**, from lower cost electricity substituted for liquid fuels.

[1] Medium Trucks: https://www.codot.gov/programs/commuterchoices/assets/documents/trandir_transit.pdf
Heavy Trucks: https://www.statista.com/statistics/937418/new-truck-average-price-in-the-united-states/
Transit Buses: https://www.codot.gov/programs/commuterchoices/assets/documents/trandir_transit.pdf and School Buses: https://www.al.com/news/mobile/2014/11/how_much_for_a_brand-new_schoo.html and expert solicitations

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Pathways to Rapid Reductions in Virginia's Vehicle Emissions

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