IMPACTS ANALYSIS OF A REVISED FEDERAL LIGHT-DUTY ON-ROAD PARTICULATE MATTER STANDARD

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1. Executive Summary

This report presents the environmental impact assessment of a theoretical revision to the US federal particulate matter (PM) standard for light-duty on-road motor vehicles – covering chassis certified vehicles up to 14,000 lbs. GVWR. Emission benefits for both PM of 2.5 microns or less (PM2.5) and black carbon (BC) through 2060 were estimated along with the health benefits and valuation through 2050. Elevated ambient PM2.5 concentrations are associated with increased morbidity from lung and circulatory disease; BC is the second most significant pollutant impacting climate change. [1, 2]* The impact analysis demonstrated that internal combustion engine (ICE) vehicles will continue to be environmentally significant until 2060 – independent of the underlying electrification rate scenario. Moreover, the cumulative benefits, estimated through 2050, would be as follows:

- 58 to 112 thousand tons of PM2.5 exhaust eliminated,
- 42 to 81 thousand tons of BC eliminated, and
- 18 to 163 billion dollars of health care cost savings.

The US regulatory framework for the control of light-duty PM exhaust has fallen behind the EU, China and India where Euro 6, China 6 and BS 6 standards (respectively) have resulted in the incorporation of high-pressure fuel injection and gasoline particulate filter (GPF) control technology in currently sold light-duty on-road vehicles. In fact, nearly every European GDI engine car and every Chinese GDI and PFI engine car is currently certified with a GPF. Furthermore, LDVs in Europe have been required to meet the approximate equivalent of a 0.5 mg/mile standard since 2017 and in China since 2023 due to the implementation of a particle number standard of $6x10^{11}$ per km. This standard applies to nearly all driving conditions and cycles. In addition, future Euro 7 standards are expected to further tighten the particle number limit to $1x10^{11}$ per km, regulate solid ultrafine particles down to 10 nm in diameter, and expand the operating window to include lower temperature operation, higher altitude and towing. The CLOVE consortium concluded that these tighter limits over expanded operating conditions are feasible with the latest generation control technologies. [3, 4]

Compliance with current and planned US regulations – specifically the 3 mg/mi federal Tier 3 PM standard and the California ARB 1 mg/mi LEV III PM standard – will likely be achieved with in-cylinder controls only. [5] Moreover, gasoline direct injection (GDI) technology has been increasing in US light-duty sales penetration since model year 2010 – representing over 50 percent market share in MY2022 light-duty sales. [6] GDI fuel delivery results in both higher fuel economy and higher PM emissions over the port fuel injection (PFI) technology it replaces. [7] Combining both GDI, with high pressure injectors, and GPF represents the preferred engineering solution for both higher fuel economy and lower PM emissions from light-duty vehicles.

* Bracketed numbers denote References (see Section 5).

The modeled federal PM certification standards were defined to facilitate the implementation of PM emission control technology (e.g., GPF and high-pressure fuel injection) in the North America fleet. Included were PM limits for the federal test procedure (FTP) at standard and cold temperatures and the supplemental federal test procedure (SFTP) as summarized in Table 1 (see green shaded cells). The modeled FTP limits (at standard temperature) represent a 90 percent reduction over the current EPA Tier 3 requirements; the modeled SFTP standards represent a 67 percent reduction over the ARB Advanced Clean Car II (ACC II) standards for model years 2026 and later.

Table 1. On-road PM Standards (mg/mile), Chassis Certification ≤ 14,000 lbs.

Agency, Standard	LDV, LDT, MDPV			Class 2b Trucks			Class 3 Trucks		
	FTP Limit	SFTP Limit	SFTP Cycle	FTP Limit	SFTP Limit	SFTP Cycle	FTP Limit	SFTP Limit	SFTP Cycle
EPA Tier 3 (2017+ MY)	3	6	US06	8	7 or 10	Mix	10	7	Mix
ARB LEV III (2025+ MY) *	1								
ARB ACC II (2026+ MY) *		3	US06		6	US06		5	Unified Cycle
Modeled EPA (2027+ MY) *	0.3/0.6†	1.0	US06	0.8/1.6†	2.0	US06	1.0/2.0†	1.7	Unified Cycle

The environmental impact of the modeled standards was evaluated for the 49-state plus District of Columbia modeling domain using EPA references and tools. The domain was divided into separate certification regions of seventeen Section 177 states (i.e., those that have adopted California standards) and thirty-two states plus DC subject solely to federal certification requirements.‡ Importantly, the magnitude of the emission inventory impact of the modeled standards is significantly influenced by the degree to which the light-duty fleet becomes electrified. The rate of future-year electrification, an uncertain modeling variable, was handled as a range by defining the following 3 scenarios.

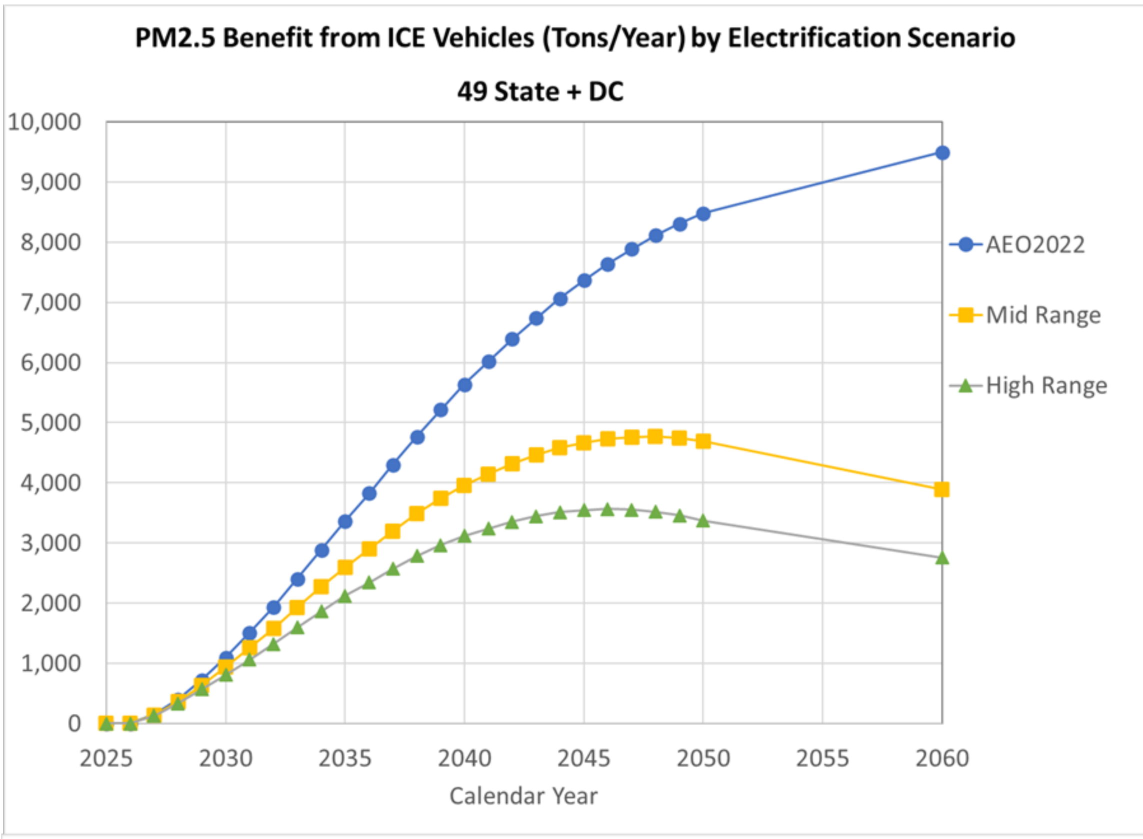
1. *Low range electrification* was defined by the electrification forecast of new vehicle sales as completed in the Energy Information Agency (EIA) *Annual Energy Outlook 2022* (AEO2022). [8] This represents approximately 13% new light-duty vehicle sales in 2050.
2. *Mid range electrification* was defined by a 10 to 15-year delay in achieving the high range scenario targets (by sector) with 100 percent electrification of all on-road sales by model year 2060.§

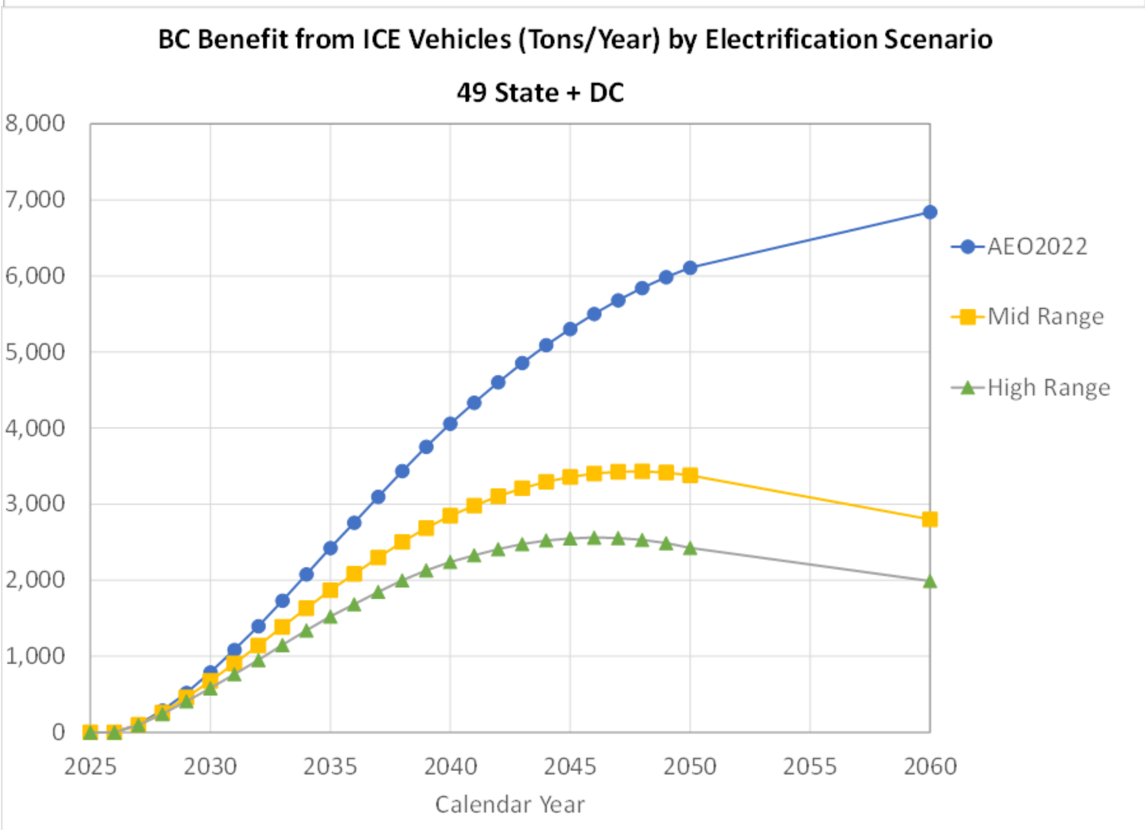
* 25, 50, and 75 percent phase in for first 3 model years, 100 percent compliance thereafter.
† Dual values represent FTP standards at 75 and 20 degrees Fahrenheit, respectively.
‡ DC enacted California standards by December 2022, after the impact assessment had commenced.
§ Both the high and mid range scenarios include a 20 percent set aside for plug-in hybrid electric vehicles (PHEVs) – meaning that 100 percent electrification equals 80 percent battery electric or fuel cell vehicles and 20 percent PHEVs.

3. *High range electrification* was defined by the electrification rate if all California zero emission vehicle regulations as well as all federal executive orders and memoranda of understanding were achieved. This scenario achieves 100 percent electrification of all on-road sales by model year 2050 with key sector sales becoming fully electrified as early as model year 2035 (i.e., light-duty vehicles sold in the California certification region).

Figure 1 summarizes the annual PM2.5 and BC inventory impacts for the modeling domain for the years 2025 to 2060. Up to an estimated 7 and 10 thousand tons/year of BC and PM2.5 exhaust from internal combustion engine (ICE) vehicles would be eliminated in each year. In the fully phased-in fleet (i.e., CY2060), the pollutant benefits are equal to reductions in the light-duty fleet of 91 and 85 percent for exhaust BC and PM2.5, respectively. Moreover, the continuation of benefits to CY2060 results indicate that the environmental impact of internal combustion engines will be significant well into the future – independent of the electrification rate scenario.

Figure 1 Annual Emission Inventory Impact





Cumulative heath impact valuations, based on recently updated EPA data from the 2012 PM National Ambient Air Quality Standards (NAAQS) revision, are summarized in Figures 2, 3 and 4 for the low, mid and high electrification scenarios, respectively. The total health valuation, due to the reduced frequency of health incidences under the modeled regulatory case, results in estimated health cost savings of between 18 billion and 163 billion dollars (cumulative through 2050). The range in total valuation is due to (1) incidence rates defined as a range, (2) the discount rate defined as a range, (3) monetary benefits by incidence defined as a range, and (4) the range in PM2.5 benefit realized by electrification rate scenario. These health cost savings come from the estimated 58 to 112 thousand tons of cumulative PM2.5 benefits under the modeled regulatory case. Within these PM2.5 benefits, an estimated 42 to 81 thousand tons of black carbon would be eliminated.

Figure 2. Cumulative Impact, Low Range Electrification

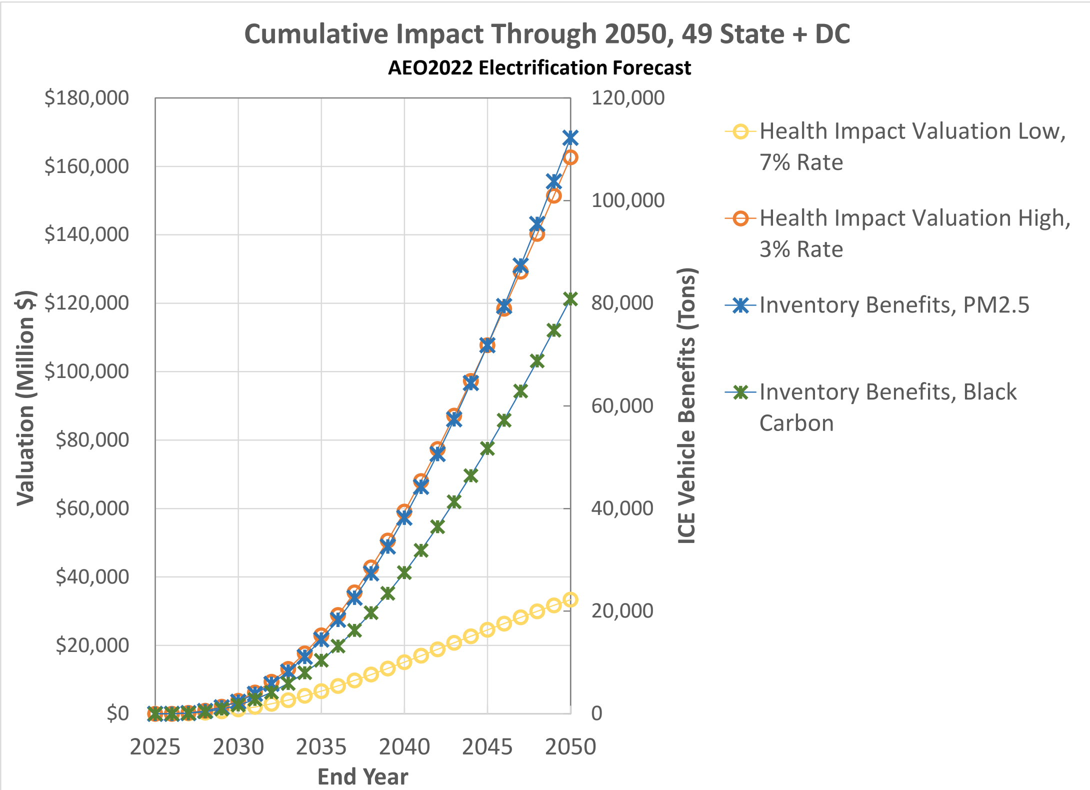


Figure 3. Cumulative Impact, Mid Range Electrification

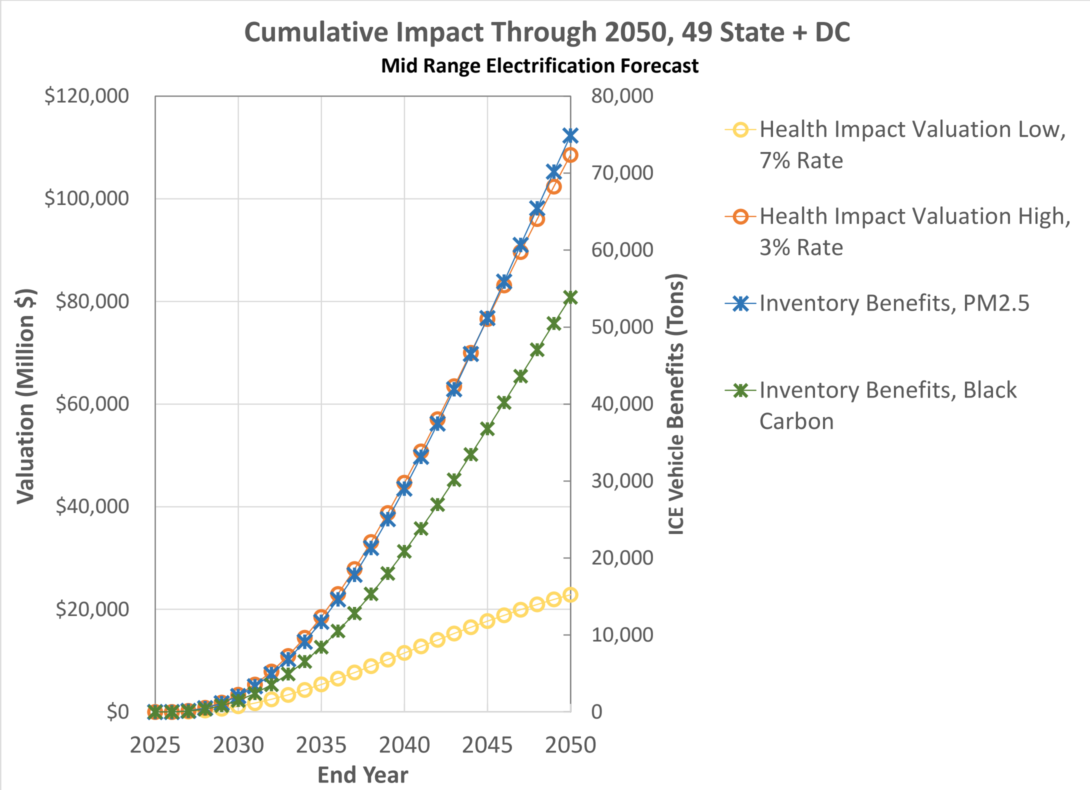
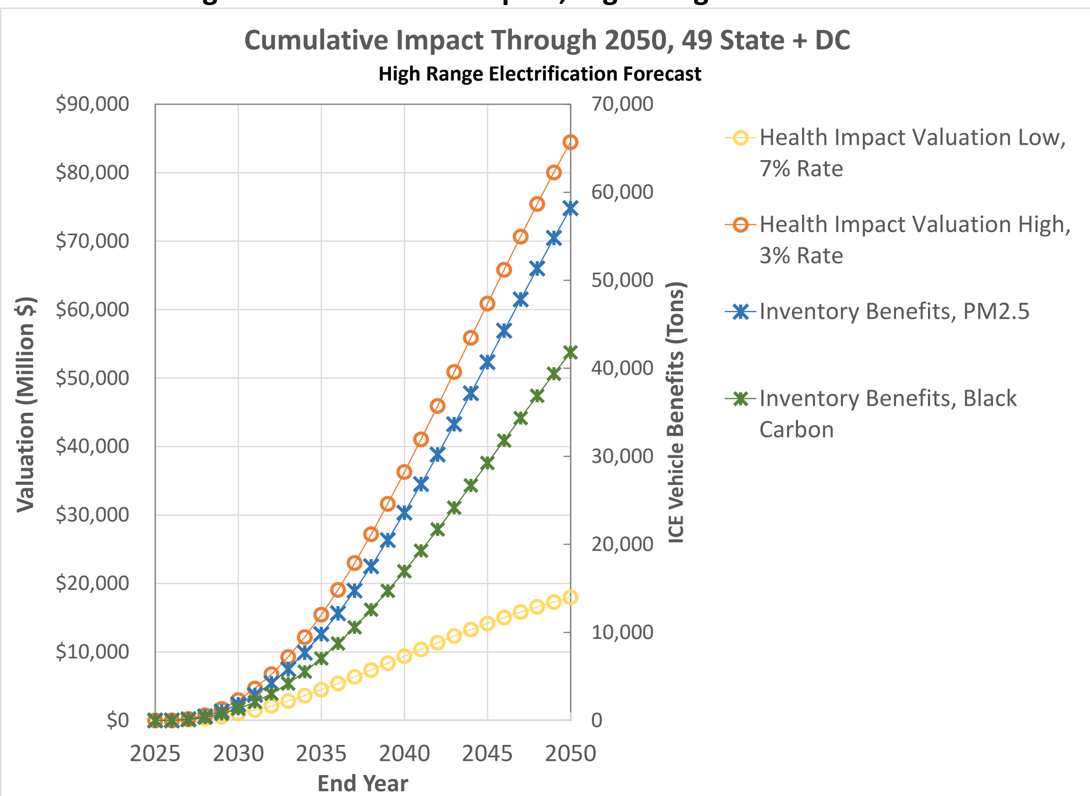


Figure 4. Cumulative Impact, High Range Electrification



2. Key Resources

Key data resources and modeling tools were incorporated into this assessment as shown below. The use of each is discussed individually.

- National Emissions Inventory
- MOVES3 Model
- Health Incidence and Benefit Factors
- Annual Energy Outlook 2022 (AEO2022)
- Ambient PM Measurements
- GPF Test Record

2.1. National Emissions Inventory (NEI)

EPA's triennial effort known as the National Emissions Inventory (NEI) represents the best estimate of national emissions inventories from which this assessment's analyses were built. The 2016v2 Platform version of the NEI released in September 2021 was recently updated based on MOVES3 modeling.[*] The 2016v2 platform includes emissions for the years 2016, 2023, 2026, and 2032.[†]

The 2016v2 modeling platform provided the basis for mass PM2.5 emissions resolved by county. Absolute emissions from the NEI form the foundation of this assessment; all adjustments to the NEI inventory were completed on a "relative" basis to maintain integrity with the absolute estimates of the resource. Moreover, key fleet characteristics were reviewed and utilized from the NEI to support the additional MOVES3 modeling completed to meet the overall objective of modeling the impact of the theoretical regulatory change.

2.2. MOVES3 Model

The MOtor Vehicle Emission Simulator (MOVES) is a periodically updated model that is required for use in official US on-road emission inventory assessments.[‡] The current version, MOVES3, was used to develop the NEI's 2016v2 platform as well as in this impact analysis.[§] The uses of MOVES3 included interpolation to years not covered by the NEI, adjustments to the base case inventory (i.e., the current regulatory context), estimating BC from PM2.5,[**] and updates to the activity levels for consistency with AEO2022 (see Section 2.4).[††]

[*] The 2016v2 modeling platform is a subset of the agency efforts carried out under the 2017 NEI. Dates of the on-road inventory files were October 2021.
[†] Data and documentation of the NEI are available here: https://www.epa.gov/air-emissions-modeling/2016v2-platform.
[‡] With the exception of California as USEPA currently permits the use of a California-developed model (known as EMFAC) for official inventory submissions for that state. EMFAC modeling was not completed in this analysis and thereby inventories for the State of California were not estimated.
[§] MOVES modeling to support the impact analysis was completed with version 3.04 dated August 2022.
[**] MOVES3 estimates for elemental carbon (EC) were used as a surrogate for BC.
[††] The model and technical support documents are located here: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

2.3. Health Incidence and Benefit Factors

Health incidence per ton (IPT) and valuation benefits per ton (BPT) rates relied on EPA modeling and development using the BenMAP Community Edition model version 1.5.0.4. Values represent national air quality impacts per ton of emissions reduced for years 2020, 2025, 2030, 2035, 2040, 2045 based on data sets from the 2012 PM NAAQS revision and updated estimates on future income growth. These data, published in January 2020, were used to translate control case PM2.5 benefits into reductions in health incidences and the estimated valuation.[*]

2.4. Annual Energy Outlook 2022 (AEO2022)

The Energy Information Agency's (EIA's) annual publication *Annual Energy Outlook* (AEO) is the preferred federal on-road fleet forecast. AEO data are part of both MOVES3 and the NEI 2016v2 platform development. NEI 2016v2 relied on AEO2021; this analysis updated the fleet forecast for consistency with AEO2022. AE02022 provided vehicle populations, VMT and electrification forecast through CY2050.[†] Note that AEO2023, released in March 2023, became available after the completion of the impact analysis).

2.5. Ambient PM Measurements

EPA's Air Quality System (AQS) contains ambient air pollution measurement data – including, more recently, data from the agency's near roadway monitoring program. Co-located ambient measurements of near-roadway PM concentrations and urban background PM concentrations were analyzed to determine the incremental emissions from the local roadway. This assessment included an evaluation of the impact of the regulatory change on near-roadway PM concentrations for 5 locations (Denver, Indianapolis, Louisville, Milwaukee, and Providence).[‡]

2.6. GPF Test Record

The GPF test record reviewed included recent demonstration projects of GPF technology operating on US vehicles and non-public emissions data from commercially sold EU vehicles. The US demonstration projects included joint MECA Clean Mobility (MECA) programs with Environment Canada and the University of California Riverside. [9, 10, 11, 12, 13, 14] Additional demonstration data were those of the California ARB testing in support of the Advanced Clean Cars Midterm Review.[§] The demonstration data provided estimates of GPF control effectiveness across multiple test cycles, temperatures and engine warmup conditions. The non-public emissions data on

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[*] The EPA data are available here: https://www.epa.gov/benmap/mobile-sector-source-apportionment-air-quality-and-benefits-ton.
[†] This work was completed prior to the release of AEO2023 in March 2024. AEO2022 is located here: https://www.eia.gov/outlooks/aeo/.
[‡] Background on the near roadway monitoring program can be found here: https://www.epa.gov/amtic/near-road-monitoring and the AQS data depository is here: https://www.epa.gov/aqs.
[§] Data are here: https://ww2.arb.ca.gov/sites/default/files/2020-01/appendix_k_pm_test_results_ac.pdf.

commercially sold vehicles included overall control effectiveness on OEM installed systems and effectiveness as a function of accumulated mileage.

3. Methods

The scope of the impact analysis of a revision to the US federal PM standards for light-duty on-road motor vehicles is summarized in Table 2. PM2.5 and BC emission inventory benefits were estimated for the period of 2025 to 2050 and 2060. CY2060 represents the furthest out year of MOVES3. The proposed standards would apply only to the non-electrified fleet, and the rate of future year electrification of new vehicle sales is uncertain. Therefore, future year electrification is handled as a range defined by 3 scenarios. The methods of the impacts analysis are described in the following three subsections.

- Base Case Inventory Development
- Control Case Inventory Development and Health Impact Assessment
- Near-Roadway Impact Analysis

Table 2. Impact Analysis Scope

Evaluation Years	2025 – 2050, 2060
Pollutants	PM2.5, Black Carbon *
Domain	49-States + District of Columbia †
Temporal Basis	Annual ‡
Base Case Regulatory Context	Federal certification region (32 states + DC); California certification region, Section 177 states (17 states)
Control Case Fleet Coverage	Proposed standards apply to automobiles and trucks up to 14,000 lbs. GVWR, complete vehicle certifications only.
Future Electrification	3 scenarios of electrification rates/targets modeled

3.1. Base Case Inventory Development

The Base Case inventory (i.e., the current regulatory context) was developed from the NEI and multiple inventory adjustments with the MOVES3 model. Figure 5 presents an overview of the steps of the Base Case inventory development with key elements as follows.

- NEI Review and Use – The NEI's 2016v2 modeling platform (Section 2.1) served as the PM2.5 inventory starting point for the years 2016, 2023, 2026, and 2032. County-level estimates were aggregated to the state total. Review of NEI MOVES3 modeling assumptions was completed for consistency with project's objectives. Activity data related to vehicles, VMT, age distribution and electrification rates were pulled for consistency with project's MOVES3 inventory modeling.

- MOVES3 Base Case Emission Rates – MOVES3 emission rates were reviewed and modifications to the emission rates of Class 2b/3 gasoline trucks for Base Case

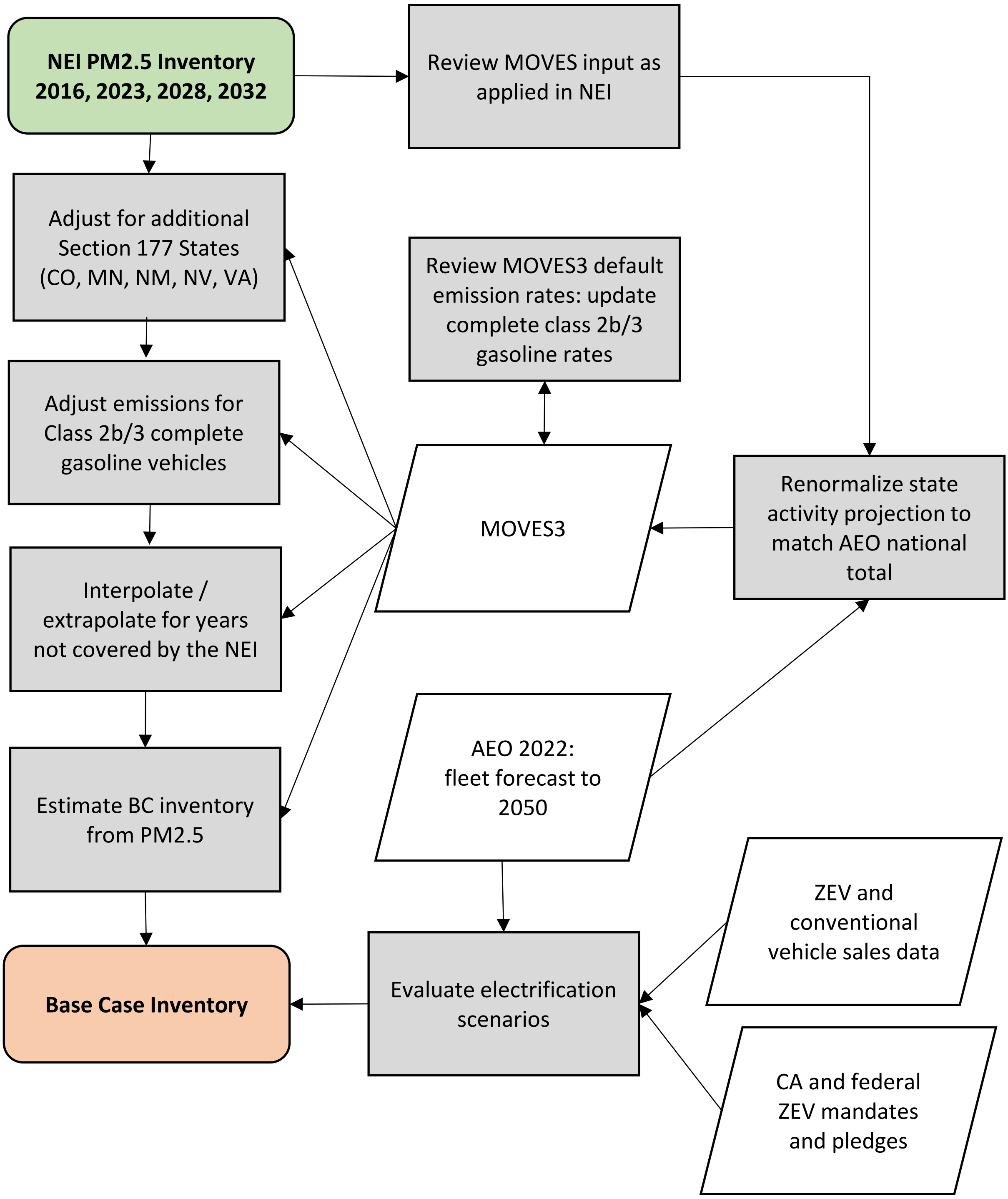
* Black Carbon (BC) not directly reported by MOVES; Elemental Carbon (EC) was used as a surrogate for BC.
† EMFAC is the official inventory model for California; EMFAC was not applied in this project and thereby CA was omitted from the study domain.
‡ Monthly modeling aggregated to an annual basis.

inventory modeling. To cover a data gap in the PM emission rate data tables, EPA utilized diesel PM emission rates from equivalent regulatory weight class diesel powered vehicles. This diesel rate substitution applied to 2010-and-newer model years. These rates included impacts from DPF and a decline in PM emission rates since MY2010 that is not representative of gasoline engines. New Base Case PM emission rates were based on scaling up from similar technology light-duty gasoline trucks (under 8,500 lbs. GVWR) using the factor of 1.4 that EPA utilized to approximate PM emission rates from Class 2b/3 gasoline trucks for 2009-and-older model years. [15]

- <u>AEO2022 Use</u> – AEO2022 (Section 2.4) provided update national total VMT and vehicles through CY2050. These data were extrapolated to CY2060. The impact analysis rescaled the NEI state-level VMT and vehicle projections such that the national total matched that of AEO2022. AEO2022 also served as the basis of the low range electrification scenario as described below.
- <u>Electrification Scenarios</u> - The rate of future-year electrification, an uncertain modeling variable, was handled as a range by defining low, mid and high range electrification scenarios as described below. For mid and high range scenarios, a 20 percent set aside for plug-in hybrid electric vehicles (PHEVs) was assumed, as well as an assumption that passenger car penetration would occur about twice as fast as light-duty trucks. Inventory adjustments for electrification rates were completed relative to the electrification assumptions of the NEI. Moreover, within each scenario, distinct electrification rates were defined for the federal and California certification regions. Appendix A to this report provides additional detail on the development of the electrification scenarios.
    - *Low range electrification* was defined by the electrification forecast of new vehicle sales of AEO2022. [8] AEO2022 represents a national forecast. It was assumed that 85 percent of future growth in electrification rates would occur in the California certification region due to regulatory mandates.[*]
    - *Mid range electrification* was defined by a 10 to 15-year delay in achieving the high range scenario targets (by sector) with 100 percent electrification of all on-road sales by model year 2060.
    - *High range electrification* was defined by the electrification rate if all California zero emission vehicle regulations as well as all federal executive orders and memoranda of understanding were achieved. This scenario achieves 100 percent electrification of all on-road sales by model year 2050 with key sector sales becoming fully electrified as early as model year 2035 (i.e., light-duty vehicles sold in the California certification region).

[*] State-level sales data for model year 2019 showed about two thirds of BEVs and PHEVs were sold in the California certification region.

Figure 5. Base Case Inventory Schematic



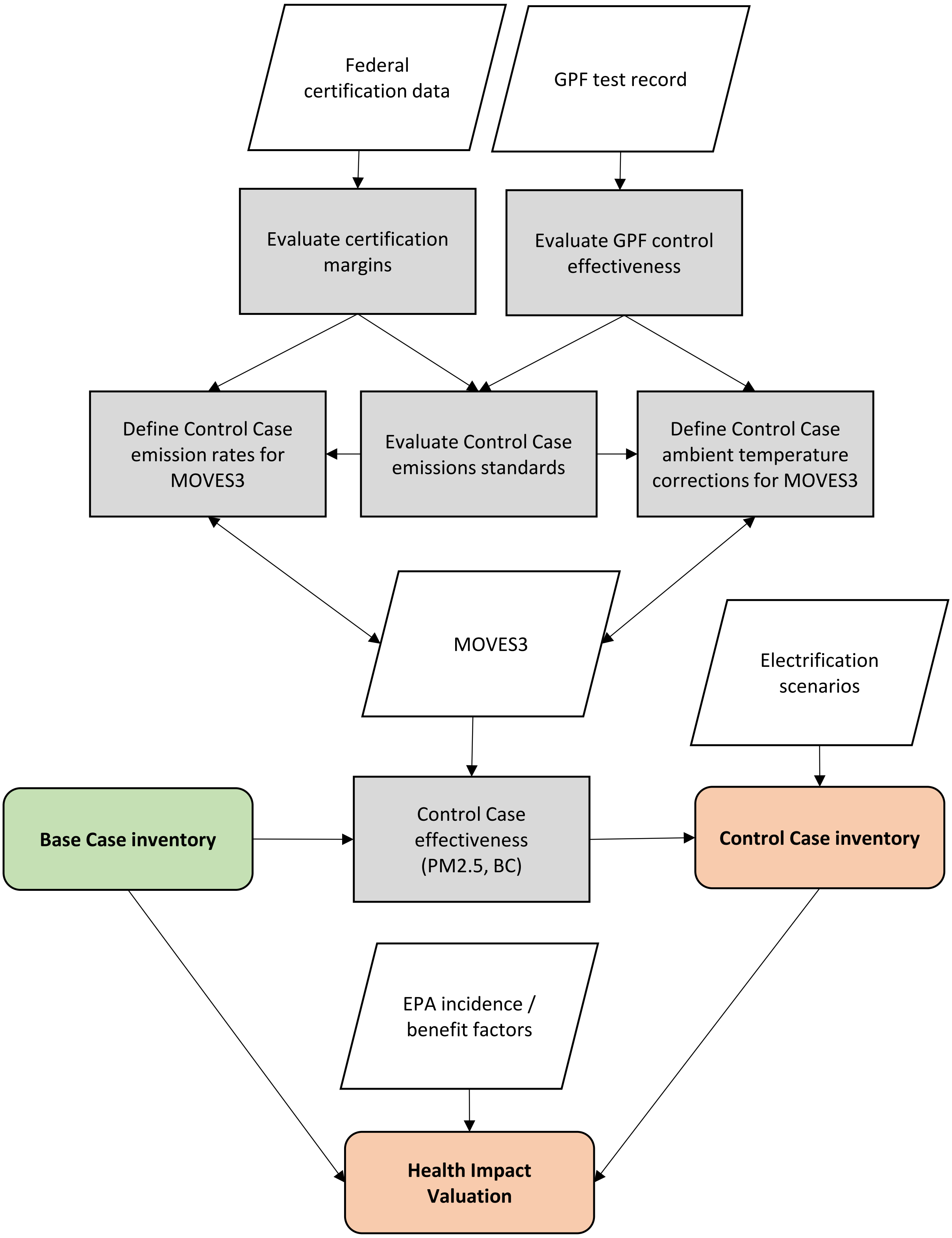
- OVES3 Adjustments – state-level modeling was completed to apply a series of adjustments to the NEI PM2.5 inventory as shown in Figure 5. The modeling relied on key activity data from the NEI (age distribution, VMT and vehicles) while relying on model default input for the remainder of input. Inventory processing was completed at the model year level so that electrification rates could be incorporated as a post-model adjustment. State level VMT and vehicle populations were renormalized to match the latest national growth projection of AEO2022.
    - MOVES was applied to adjust PM2.5 inventory for 5 additional Section 177 states (CO, MN, NM, NV, and VA) beyond the 12 states subject to California certification requirements as assumed in the NEI. Section 177 state inventories included the LEV III 1 mg/mi standard (see Table 3) using MOVES3 emission rate assumptions as developed by EPA. [7]
    - MOVES was applied to adjust Class 2b/3 PM2.5 inventory for updated Base Case PM emission rates as described above, to interpolate PM2.5 inventory for calendar years not quantified in the NEI, and to estimate the BC inventory from PM2.5 inventory.

3.2. Control Case Inventory Development and Health Impact Assessment

The Control Case inventory and health impact valuation were developed from the Base Case inventory and a series of analytical steps as shown in Figure 6. Overall, the process of setting the modeled standards and the respective MOVES modeling input for the Control Case was completed by reviewing GPF control effectiveness, existing manufacturer certification to current standards and existing emission rates of the MOVES3 model. The MOVES3 model was applied to estimate the Control Case effectiveness on PM2.5 and BC emissions, and the Control Case inventory was estimated from the Base Case inventory. The electrification scenarios, unchanged from the Base Case, were applied. The health impact assessment was estimated by the combination of PM2.5 benefits achieved and EPA incidence-per-ton and benefit-per-ton factors.

Within this overall approach, additional details related to (1) modeled Control Case standards, (2) development of Control Case MOVES3 input and (3) the health impact assessment are presented in the following.

Figure 6. Control Case Inventory and Health Impact Valuation Schematic



Control Case Standards

The modeled federal standards regime is summarized in Table 3 – alongside current or upcoming standards of the EPA and ARB. The modeled standards, highlighted in green, include PM limits for the federal test procedure (FTP) at standard and cold temperatures and the supplemental federal test procedure (SFTP). The modeled FTP limits (at standard temperature) represent a 90 percent reduction over the current EPA requirement. The modeled cold temperature FTP limits would be the first cold temperature standards for PM. The modeled SFTP standards represent a 67 percent reduction over the planned ARB Advanced Clean Car II (ACC II) standards for model years 2026 and later – and would be based on the same SFTP cycles of the ARB requirements. Similar to Tier 3, the modeled standards would phase in over the first 3 model years at 25, 50 and 75 percent.

Table 3. On-road PM Standards (mg/mile), Chassis Certification ≤ 14,000 lbs.

Agency, Standard	LDV, LDT, MDPV			Class 2b Trucks			Class 3 Trucks		
	FTP Limit	SFTP Limit	SFTP Cycle	FTP Limit	SFTP Limit	SFTP Cycle	FTP Limit	SFTP Limit	SFTP Cycle
EPA Tier 3: 2017+ MY	3	6	US06	8	7 or 10	Mix	10	7	Mix
ARB LEV III: 2025+ MY	1								
ARB ACC II: 2026+ MY		3	US06		6	US06		5	Unified Cycle
Modeled EPA (2027+ MY)	0.3/0.6*	1.0	US06	0.8/1.6*	2.0	US06	1.0/2.0*	1.7	Unified Cycle

The 90 percent reduction in the federal FTP PM limit is achievable given the following.

- GPF control technology is based on that already used on diesel vehicle exhaust (i.e., diesel particulate filters or DPF) which achieves a greater than 90 percent PM control level. [15]
- The demonstration projects of the GPF test record (Section 2.6) produce benefits up to and exceeding 90 percent. These project results also support a cold temperature limit (20 ^{o}F) at 2 times the standard temperature limit (75 ^{o}F).
- The emissions data from commercially sold EU vehicles (Section 2.6) have US06 tests results sufficiently below the modeled SFTP standards of Table 3.
- Median certification margins of current federal FTP limits of 3, 8 and 10 mg/mi are 73, 80 and 86 percent, respectively.†
- Compliance with the California ARB 1 mg/mi LEV III PM standard will be achieved with in-cylinder controls which indicates that further engine-out PM exhaust reductions may be realized. [5]

* Dual values represent FTP standards at 75 and 20 degrees Fahrenheit, respectively.
† Values are based on a snapshot of 2021 to 2023 model year federal certification data as of June 2022.

Development of Control Case MOVES3 Input

The development of MOVES3 Control Case input – consisting of emission rates and gasoline ambient temperature adjustment equations – was completed in parallel with defining the Control Case standards (Table 3).

MOVES3 modal emission rates were defined consistently with the "effective" FTP PM rates shown in Table 4 – for passenger cars and LDT (≤ 8,500 lbs. GVWR).[*] [7] The Control Case FTP limit of 0.3 mg/mile was assumed to have a margin within MOVES3 similar to that of the LEV III 1 mg/mile limit (i.e., 25 percent). The net control level of the modeled limit – including the assumed margin – equated to an 85 percent reduction in PM exhaust for a new vehicle (i.e., Age = 0) and standard temperature of 75 °F. The 85 percent reduction formed the basis of developing modal PM emission rates for the Control Case from existing modal PM emission rates of GDI vehicles meeting Tier 3 standards.

Table 4. Effective FTP Composite PM Rates for Current and Modeled Limits

Vehicle Class	Standard, Fuel Metering	FTP PM Limit (mg/mi)	MOVES3 Effective FTP Composite for Age = 0 (mg/mi)	Effective Margin in MOVES3 for Age = 0
PC / LDT	Tier 3, GDI	3	1.5	50%
	LEV III, GDI	1	0.75	25%
	Modeled FTP, GDI	0.3	0.23	25%

Additional assumptions in the development of Control Case MOVES3 modeling input were as follows.

- The demonstration projects of the GPF test record (Section 2.6) showed that PM2.5 control effectiveness over high-power cycles (e.g., the US06) was statistically similar to that of the FTP. The control effectiveness was applied to all exhaust power bins equivalently. Moreover, control effectiveness was statistically similar for both running exhaust and startup exhaust; equivalent reductions to both running and startup exhaust were applied.
- The GPF test record (Section 2.6) showed GPF technology results in higher BC control relative to PM2.5 control. BC control effectiveness was modeled through modifications to BC/PM2.5 ratios, which decreased by 38 percent in the presence of GPF. The Control Case BC/PM2.5 ratios of 0.43 and 0.42 for running and startup exhaust were applied, which compare to existing MOVES3 BC/PM2.5 ratios of 0.70 and 0.67 for running and startup exhaust, respectively.[†] [7] These ratios equated to an approximate 91 percent reduction in BC exhaust for the Control Case for new vehicles at standard temperature.

[*] The FTP limit itself is not a MOVES3 input parameter and is thereby labeled "effective".
[†] BC/PM2.5 ratios of 0.70 and 0.67 represent exhaust from GDI fuel delivery in the absence of GPFs.

- A deterioration of the control effectiveness of GPF versus vehicle age was assumed by using equivalent MOVES3 assumptions applied to DPF effectiveness, which included both filter leaks and filter disablement. [15]
    - Filter leaks were modeled as a 35 percent loss of control effectiveness with a frequency = 0% new and 5% at end of regulatory useful life (linear interpolation). These assumptions were held constant until the end of service life.
    - Filter disablements were modeled as a 100 percent loss of control effectiveness with a frequency = 0% new and 2% at end of regulatory useful life (linear interpolation). These assumptions were held constant until the end of service life.
- The modeled cold temperature FTP limit of twice that of the FTP limit at standard temperature (Table 3) was modeled through a modification of the ambient temperature corrections for the Control Case. The ambient temperature adjustment, which only applies to the startup exhaust component, was rescaled to results in a 250 percent increase in PM emissions between 75 and 20 degrees for the Control Case.[*] The Control Case PM2.5 control increases with declining temperatures below 75 degrees, which is consistent with the GPF test record (Section 2.6).

Health Impact Assessment

EPA published health incidence per ton (IPT) and valuation benefits per ton (BPT) data, as described in Section 2.3, were applied to the PM2.5 benefits of the Control Case. Published values for the years 2020, 2025, 2030, 2035, 2040, 2045 were interpolated to cover all years from 2025 to 2050. The original source valuations, in expressed in 2017 dollars, were converted to 2022 dollars using health care inflation data.[†] Valuations were estimated with two bounding discount rate assumptions of 3 and 7 percent. Monetary benefits are those realized from a reduction in annual average PM2.5 concentrations based on reductions in the annual PM2.5 inventories under the Control Case. Health incidences covered the following, mutually-exclusive events.

- Mortality[‡]
- Acute Myocardial Infarction[†]
- Hospital Admissions, Respiratory
- Hospital Admissions, Cardiovascular
- Emergency Room Visits, Respiratory
- Acute Bronchitis
- Asthma Exacerbation
- Work Loss Days

[*] The 2.5 factor applied to startup PM exhaust equates to a factor of 2 increase in the FTP composite PM exhaust. The 2.5 factor compares to nearly a 7-fold increase in startup PM2.5 exhaust estimated by MOVES for comparable vehicles without GPF technology. Accordingly, the Control Case benefits increase with decreasing temperature below 75 degrees.
[†] https://www.usinflationcalculator.com/inflation/health-care-inflation-in-the-united-states/.
[‡] Incidences of mortality and acute myocardial infarction (i.e., heart attack) were defined as a range.

- Acute Respiratory Symptoms
- Upper Respiratory Symptoms
- Lower Respiratory Symptoms

3.3. Near-Roadway Impacts

The near-roadway impact analysis was based on EPA's multi-pollutant near-roadway and NAAQS monitoring networks (Section 2.5) for CY2017 and extrapolated into the future. CY2017 was selected as this year was extensively analyzed by Sonoma Technology (STI) and thereby the correctness of annualized results was corroborated by STI published results. [16] Of the 20 locations identified by STI with technically suitable co-located near-roadway and NAAQS monitors, 5 were selected to represent a range of conditions and were used to assess how the proposed regulation would impact localized PM2.5 concentrations. The analysis focused on the incremental PM2.5 concentrations occurring proximate to roadways – defined as the difference in measured concentrations between near-roadway and NAAQS PM air quality monitors. Updated assumptions were applied to identify the non-exhaust portion of PM2.5 and the underlying state-level inventories (both Base and Control Cases) were used to estimate future year reductions in near-roadway incremental PM2.5 concentrations due to the standards assumed in this study.

4. Results

The results of the impact analysis are presented for the emissions and health impacts followed by the near-roadway impacts.

4.1. Emissions and Health Impacts

Appendix B to this report is the detailed repository of the emissions and health impacts of the proposed regulatory change. Appendix B summarizes key results in 7 charts and 15 tables. The 15 tables included are as follows.

- Base Case PM2.5 Exhaust Inventory (Tons/Year)
- Control Case PM2.5 Exhaust Inventory (Tons/Year)
- PM2.5 Benefit of Control Case (Tons/Year)
- PM2.5 Benefit of Control Case (Percent Reduction)
- Base Case Black Carbon Exhaust Inventory (Tons/Year)
- Control Case Black Carbon Exhaust Inventory (Tons/Year)
- Black Carbon Benefit of Control Case (Tons/Year)
- Black Carbon Benefit of Control Case (Percent Reduction)
- Health Impact Valuation (Annual), AEO2022 Electrification Forecast
- Annual Reduction of Health Incidences Under Control Case, AEO2022 Electrification Forecast
- Health Impact Valuation (Annual), Mid Range Electrification Forecast
- Annual Reduction of Health Incidences Under Control Case, Mid Range Electrification Forecast
- Health Impact Valuation (Annual), High Range Electrification Forecast
- Annual Reduction of Health Incidences Under Control Case, High Range Electrification Forecast
- Cumulative Impact Through 2050, Emissions (Tons), Benefits ($)

The domain covered within these results can be modified to any of the individual states or the District of Columbia. Or the domain can be set to 3 regions: 49 States + DC, Federal Certification Region, or California Certification Region.* The 7 charts for the collective "49 States + DC" domain are discussed and presented below.

Figure 7 presents two charts of the PM2.5 inventory (Base and Control Cases) and the Control Case PM2.5 inventory benefits for years 2025 to 2060 for on-road vehicles ≤14,000 lbs. GVWR. Annual PM2.5 inventory results are presented for each of the electrification scenarios where "AEO2022" represents the low range scenario. PM2.5 benefits continuously increase to 9.5 thousand tons/year by 2060 in the AEO2022 scenario. PM2.5 benefits peak at 4.8 and 3.6 thousand tons/year for the mid and high range scenarios, respectively. The control level achieved by 2060 is between 84 and 85 percent for the 3 scenarios.†

* The pulldown list in Cell C2 of the worksheet "DOMAIN & CONTENTS" sets the geographic domain, and all tables and charts refresh automatically. Note that the "California Certification Region" excludes the State of California which was not evaluated in this assessment.

† The PM2.5 control level achieved by 2060 varies by state based on ambient conditions, the proportions of cars and trucks, and other modelling variables. A range of between 78 and 90 percent reduction in PM2.5 exhaust in 2060 is observed (see Appendix B).

Figure 7. Annual PM2.5 Inventory, 49 State + DC

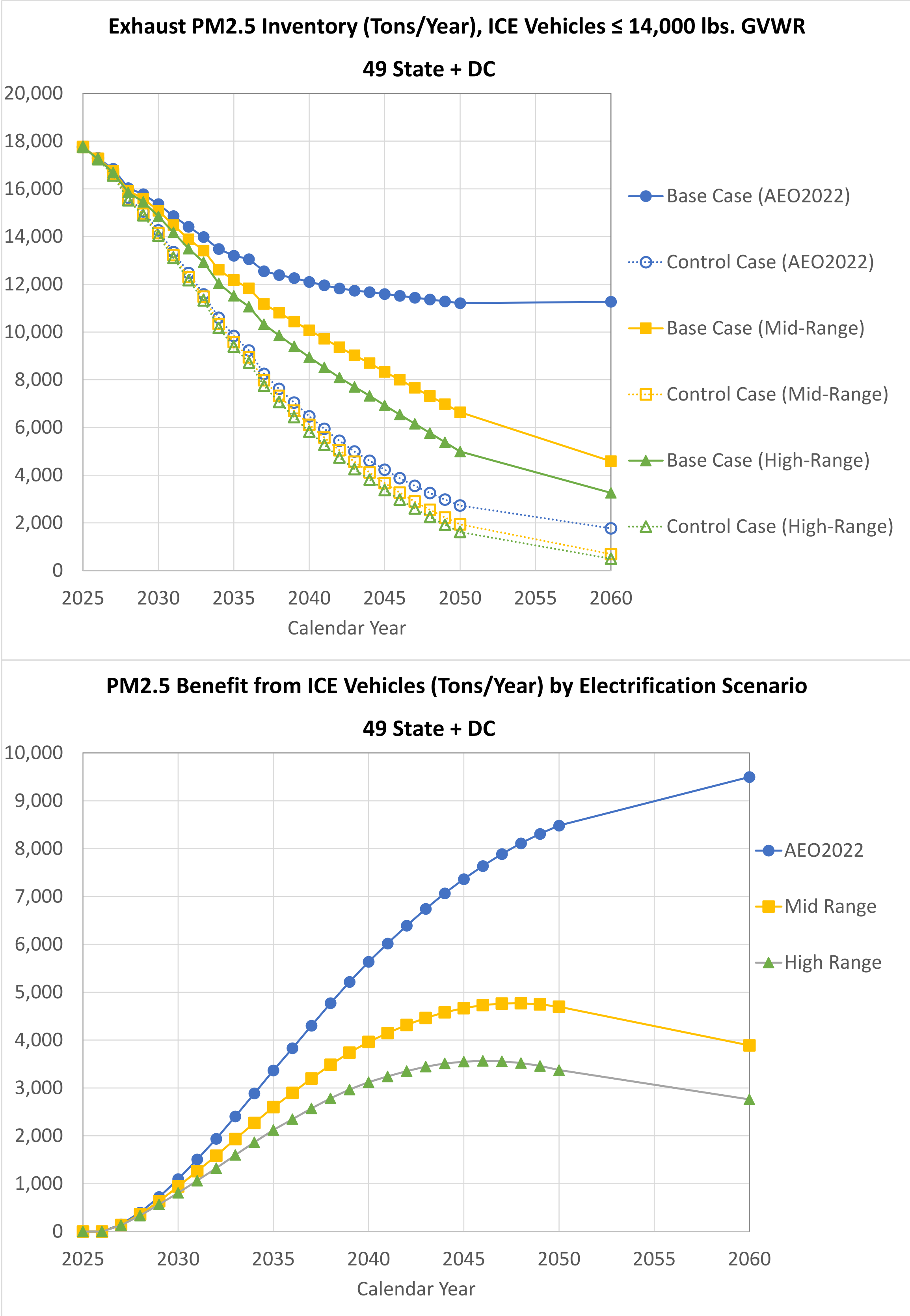
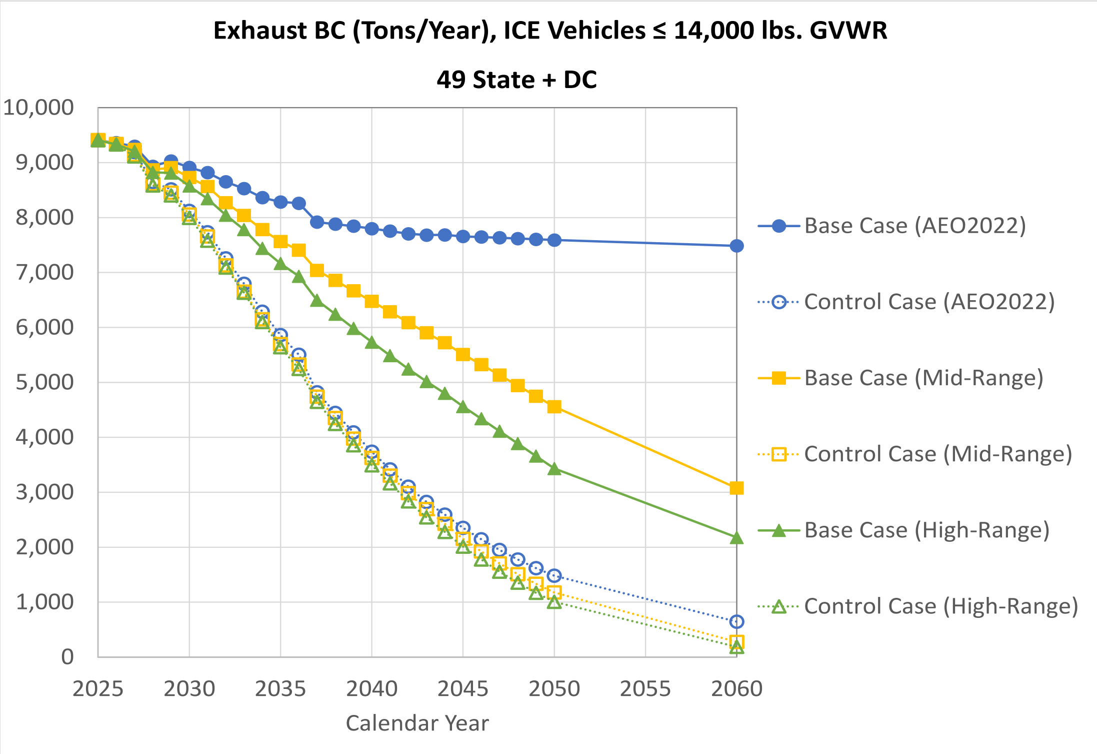
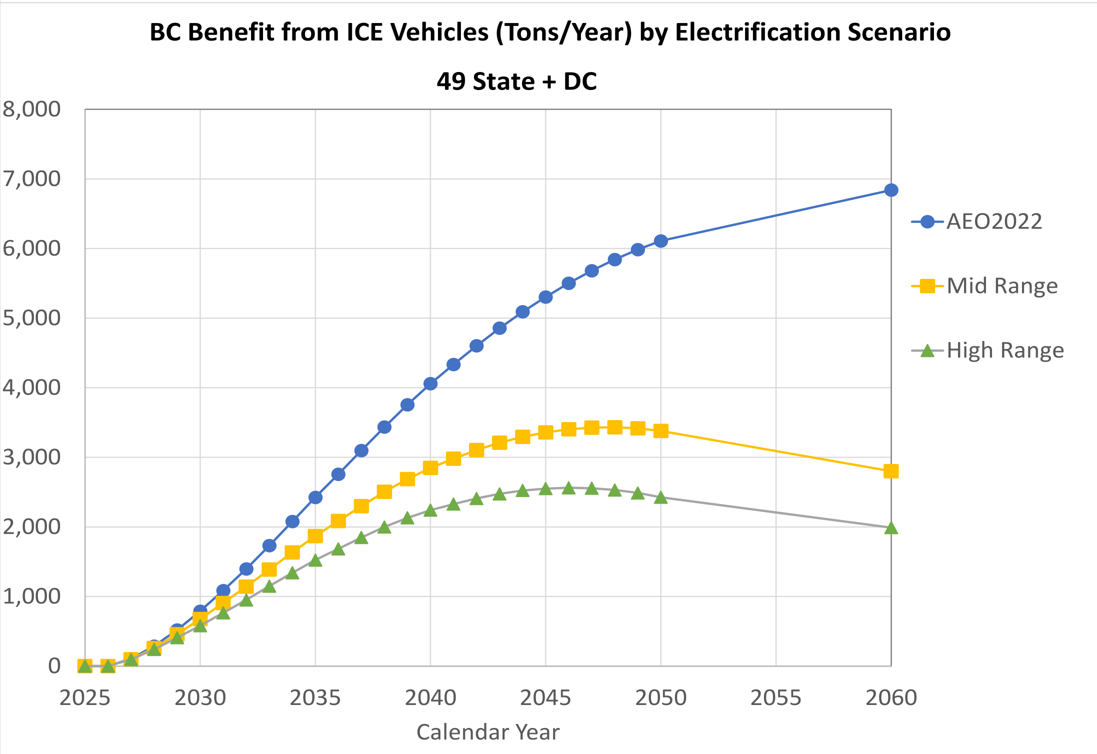


Figure 8 presents two charts of the black carbon (BC) inventory (Base and Control Cases) and the Control Case BC inventory benefits for years 2025 to 2060. BC benefits continuously increase to 6.8 thousand tons/year by 2060 in the AEO2022 scenario. BC benefits peak at 3.4 and 2.6 thousand tons/year for the mid and high range scenarios, respectively. The control level achieved by 2060 is 91 percent for the collective 49 State + DC domain.

Figure 8. Annual Black Carbon Inventory, 49 State + DC





Figures 9, 10 and 11 present the cumulative impacts through 2050 for the 3 electrification scenarios. Within a given electrification scenario, the total health impact valuation is reported as a range. That range comes from health incidences defined as a range (i.e., mortality and acute myocardial infarction), the discount rate defined as a range (3 and 7 percent) and monetary benefits of reduced incidences reported as a range. Accordingly, when examined across all 3 scenarios, there is considerable range in the total estimated health cost savings due to the range of underlying PM2.5 benefits by electrification scenario. Overall, the impact analysis of proposed regulation achieves a net health cost savings estimated between 18 and 163 billion dollars for the 49 State + DC domain. These health cost savings come from the estimated 58 to 112 thousand tons of cumulative PM2.5 benefits under the proposed regulatory case. Within these PM2.5 benefits, an estimated 42 to 81 thousand tons of BC would be eliminated.

Figure 9. Cumulative Impact, Low Range Electrification

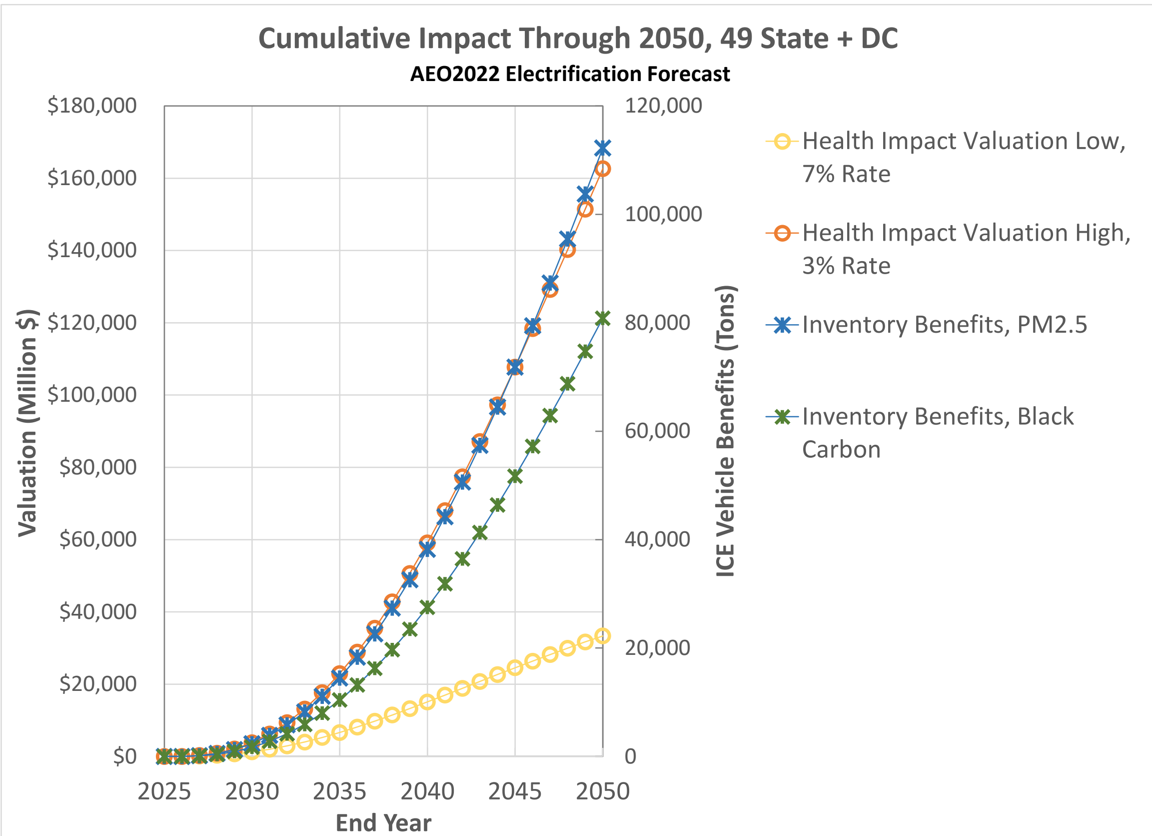


Figure 10. Cumulative Impact, Mid Range Electrification

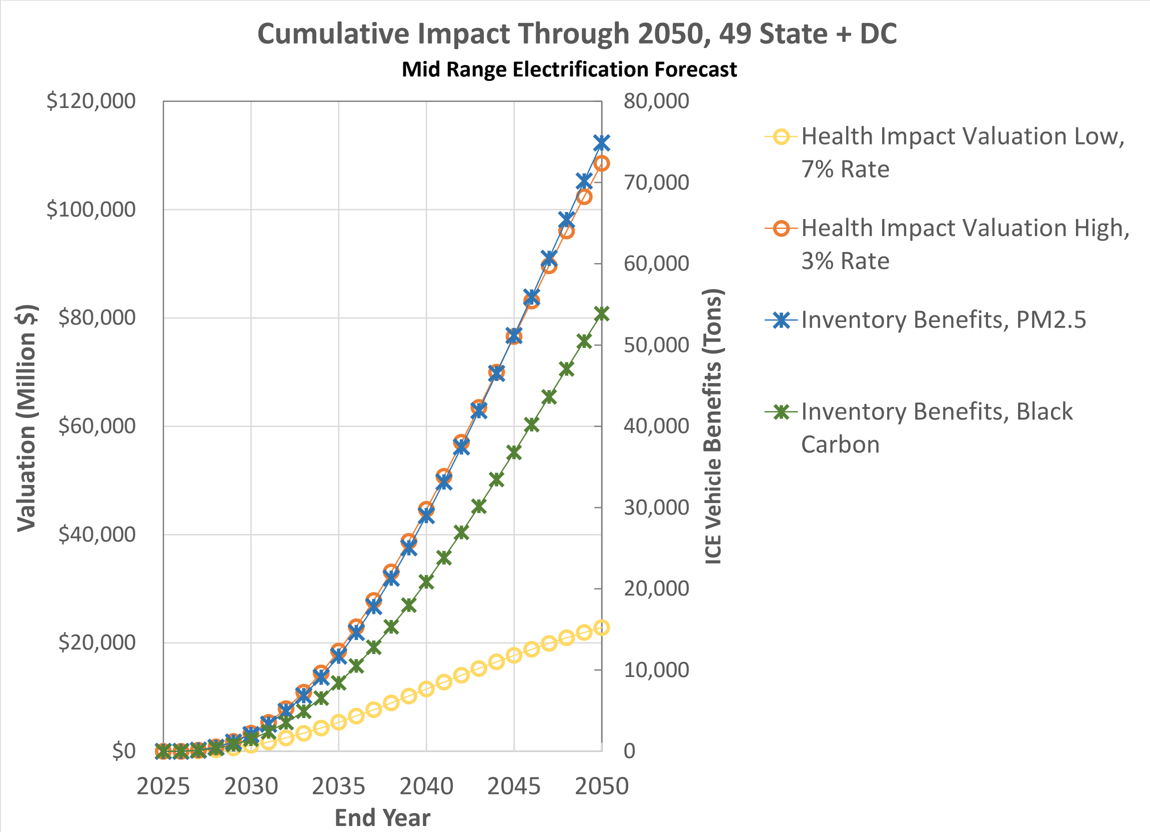
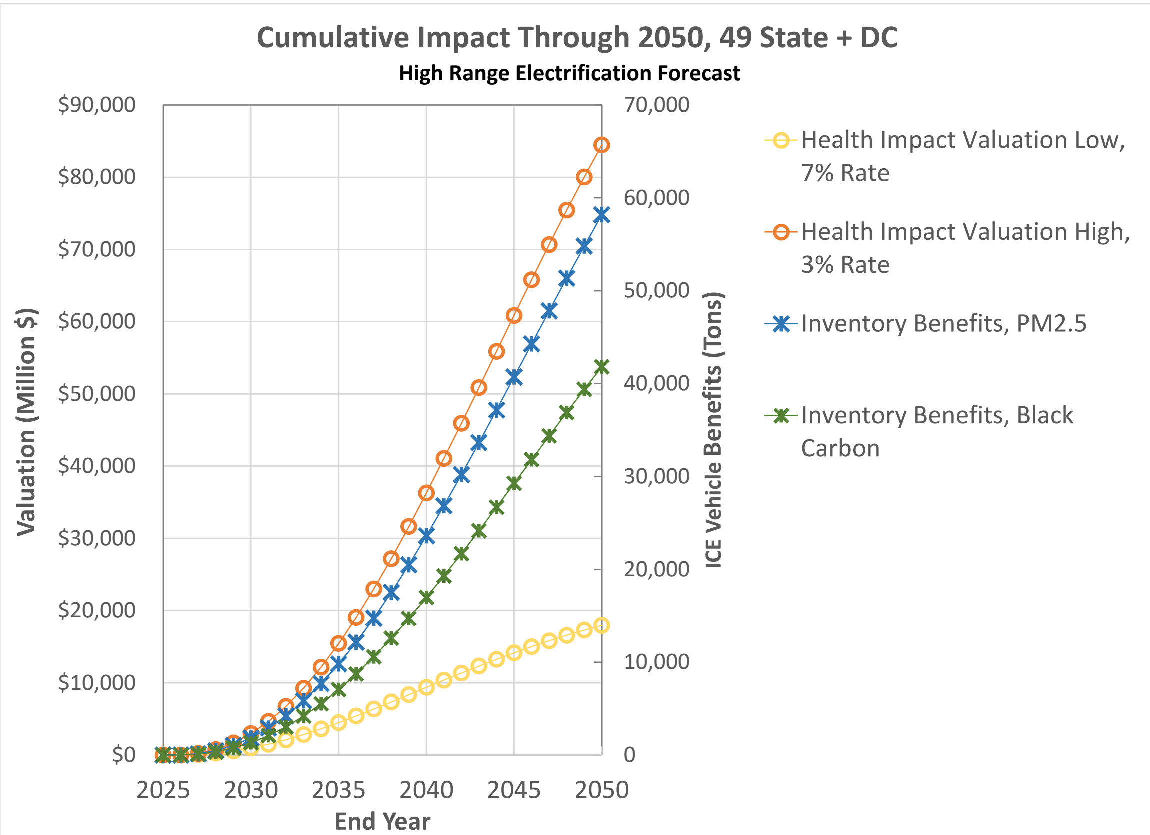


Figure 9. Cumulative Impact, High Range Electrification



4.2. Near-Roadway Impacts

Living close to roadways has been shown to result in adverse health impacts including incidence of COPD, asthma, and heart attack – health events indicative of elevated PM2.5 concentrations – as documented in the comprehensive and systematic review completed by the Health Effects Institute in 2010.[*] "Close" is most commonly defined as either within 300 or 500 meters of a major roadway.[†,‡]

The incremental PM2.5 concentrations near roadways was examined for 5 locations of Denver, Indianapolis, Louisville, Milwaukee, and Providence. "Incremental PM2.5" is defined by the excess PM2.5 concentrations measured near roadways relative to urban-scale measurements at NAAQS monitors. The 5 locations were chosen to represent a range of underlying conditions.

The estimated reduction in incremental PM2.5 concentration due to the modeled regulation was quantified and is summarized in Table 5 by calendar year. These results indicate that meaningful improvements in near-roadway PM air quality would be realized by the Control Case. By 2050, between a 7 and 46 percent reduction in incremental PM2.5 could be realized.

Table 5. Reduction in Near-roadway Incremental PM2.5 Achieved by the Proposed Regulatory Case

Location	Electrification Scenario	Reduction in Near-Roadway PM2.5 Increment				
		2030	2035	2040	2045	2050
Denver	Low-Range	3%	10%	15%	21%	23%
	High-Range	2%	5%	7%	9%	9%
Indianapolis	Low-Range	4%	13%	22%	30%	32%
	High-Range	3%	10%	14%	19%	19%
Louisville	Low-Range	4%	15%	23%	32%	35%
	High-Range	3%	10%	15%	21%	20%
Milwaukee	Low-Range	6%	20%	31%	43%	46%
	High-Range	5%	14%	20%	28%	27%
Providence	Low-Range	2%	7%	10%	14%	15%
	High-Range	1%	3%	5%	6%	7%

These results are more illustrative than definitive. Guidance methods and tools for future-year extrapolation of near-roadway PM air quality have not been defined. Within the data analyzed, it showed that high near-roadway PM concentration events were seasonal (late fall and early winter) indicating a predominance of either seasonal and/or episodic conditions. For this reason, the values of Table 5 should be considered

[*] https://www.healtheffects.org/publication/traffic-related-air-pollution-critical-review-literature-emissions-exposure-and-health.

[†] https://www.lung.org/clean-air/outdoors/who-is-at-risk/highways.

[‡] https://www.sciencedirect.com/science/article/pii/S1361920920306295.

approximate. Appendix C to this report contains additional details of both methods and results of the near-roadway PM air quality analysis completed.

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