

Energy Research and Development Division  
**FINAL PROJECT REPORT**

# **Air Quality Implications of an Energy Scenario for California Using High Levels of Electrification**

**California Energy Commission**

Gavin Newsom, Governor

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## PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Air Quality Implications of an Energy Scenario for California involving High Levels of Electrification is the final report for the Real World Electrification Options of Energy Services and Environmental Justice Considerations project (EPC-15-028) conducted by the Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at [www.energy.ca.gov/research/](http://www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

## ABSTRACT

Electrification replaces local combustion of fossil fuels with electric devices while maintaining the same services, such as replacing furnaces with heat pumps and gasoline vehicles with electric vehicles. Combined with non-emitting generation, electrification has previously been shown to significantly reduce greenhouse gas emissions. This analysis extends previous work to investigate the effects of electrification on air quality. The results show that there are significant improvements in air quality due to electrification, which lead to substantial health benefits. This report also discusses the potential for electrification to be applied in environmental justice communities which are most heavily affected by pollution.

Keywords: *Electrification, Air quality, Environmental Justice, Modeling*

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# EXECUTIVE SUMMARY

## Introduction

Electrification is the use of electricity in roles traditionally powered by fossil fuels, such as replacing furnaces with heat pumps and gasoline vehicles with electric vehicles. This replaces local combustion of fossil fuels with electric devices while maintaining the same services. Combined with non-emitting generation such as solar and wind generation, electrification has previously been shown to significantly reduce greenhouse gas emissions. A previous California Energy Commission project, *Long-Term Energy Scenarios in California* (EPC-14-069; Mahone et al., 2018), showed that electrification is a potential path to achieve California's 2050 climate goals, which at the time included a reduction to 1990 levels by 2020, a reduction of 40 percent below 1990 levels by 2030, and an 80 percent reduction below 1990 levels by 2050 (these goals have since been extended to include zero carbon electricity and economy-wide net-zero emissions by 2045).

## Project Purpose

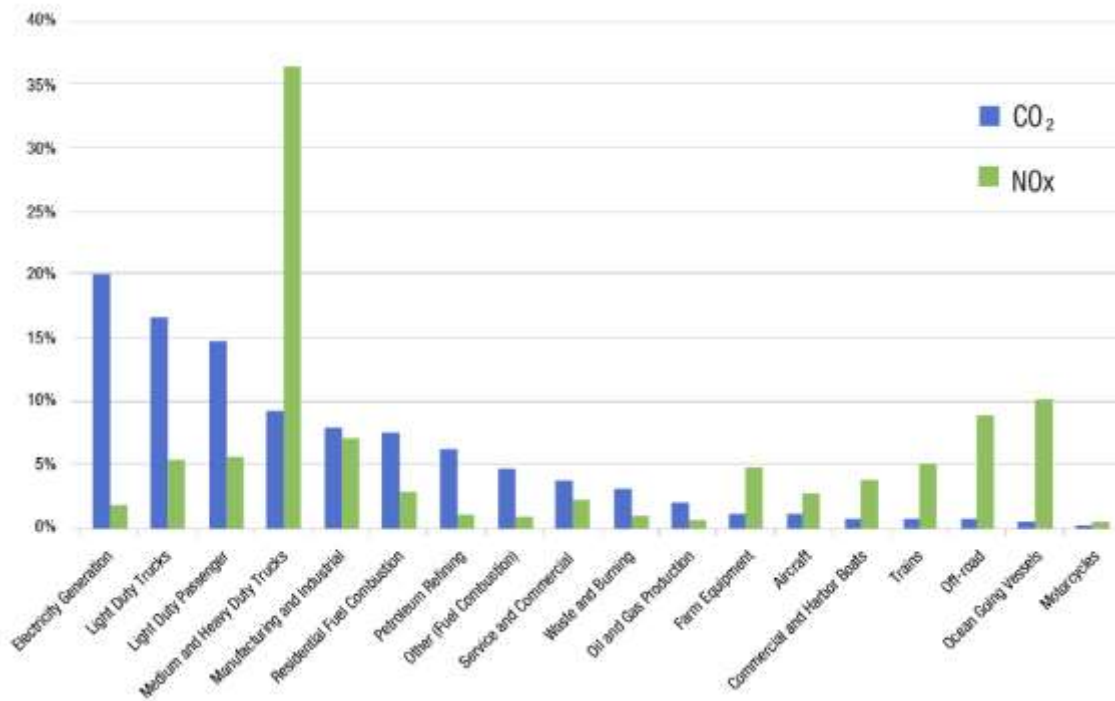
This analysis extends this previous work to investigate the effects of electrification on air quality. This report also discusses the potential for electrification to be applied in disadvantaged communities, which are areas most affected by the combination of economic, health, and economic burdens. These communities are typically low-income and suffer from high unemployment, air and water pollution, and health conditions like asthma. Understanding these benefits will help to direct public efforts to clean the air while reducing greenhouse gas emissions.

## Project Approach

The primary technical focus of this project was air quality modeling. The air quality modeling work for this project required extensive input assumptions regarding the potential for electrification primarily sourced from the *Long-Term Energy Scenarios in California* study (EPC-14-069; Mahone et al., 2018). This report investigated potential pathways to achieve California's greenhouse gas emissions goals. The "in-state biomass" scenario from that study was used since it emphasized electrification strategies. In addition to assumptions provided by this study, more assumptions were necessary since there are many emissions sources that are important for air quality but are not modeled in greenhouse gas emissions models. Figure ES-1 shows the share of carbon dioxide (CO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) emissions for a variety of source categories in California, some of which have large gaps between the two types of pollutants (IEPR, 2015). Assumptions for sources not included in the primary study were derived from other sources, including input from the technical advisory committee for this project. This group reviewed the analysis approach and advised the researchers on potential gaps.

Based on the assumed levels of electrification for different sources, air quality modeling and health effects analysis was performed. This modeling extended current emissions inventories to 2050 and investigated the effects of electrification on the concentration of pollution and the effects of this pollution on human health.

**Figure ES-1: Share of Current Emissions of CO<sub>2</sub> and NO<sub>x</sub> in California for Each Source Category**



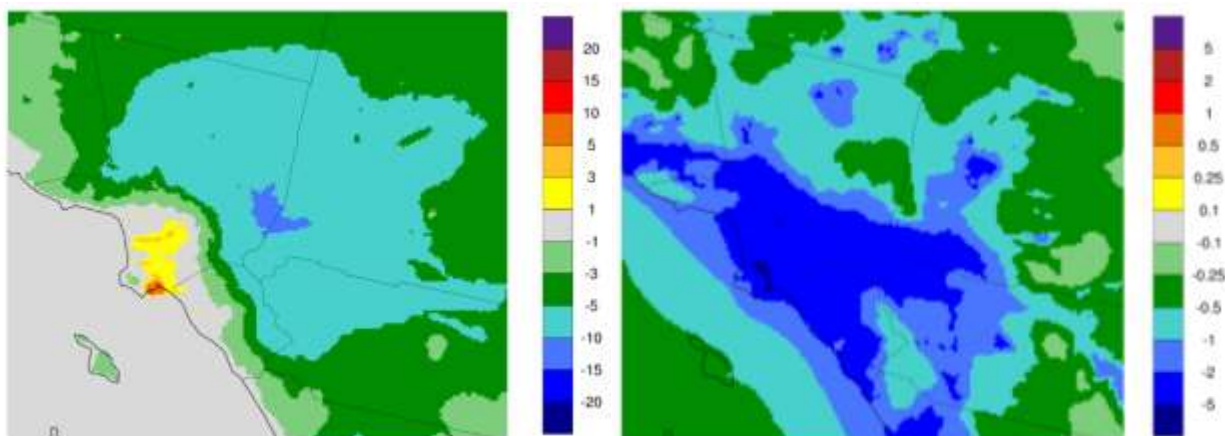
Source: IEPR, 2015

In addition to this technical work, the team collected information on how disadvantaged communities could be engaged to increase the availability of electrification in these communities and ensure the benefits of electrification were shared equitably. This effort included interviews with stakeholders in the environmental justice advocacy community and a meeting to discuss the results. Environmental justice is the fair treatment and meaningful involvement of all groups in environmental policymaking and implementation, and attempts to eliminate inequities like those that lead to disadvantaged communities.

## Project Results

The project showed that electrification would significantly reduce emissions, resulting in improved air quality and reducing mortality rates from pollution. The reductions in pollutant concentrations are shown in Figure ES-2 for the South Coast Basin and Figure ES-3 for California. Electrification results in widespread decreases in concentrations of ozone and particulate matter with a diameter of less than 2.5 micrometers (PM<sub>2.5</sub>). The monetized health benefits for combined changes in ozone and PM<sub>2.5</sub> for California and the South Coast Basin shows significant health benefits throughout the state (Figure ES-4). The total benefits were estimated at \$108 billion per year in 2050 for California, including \$56 billion in benefits for the South Coast Basin.

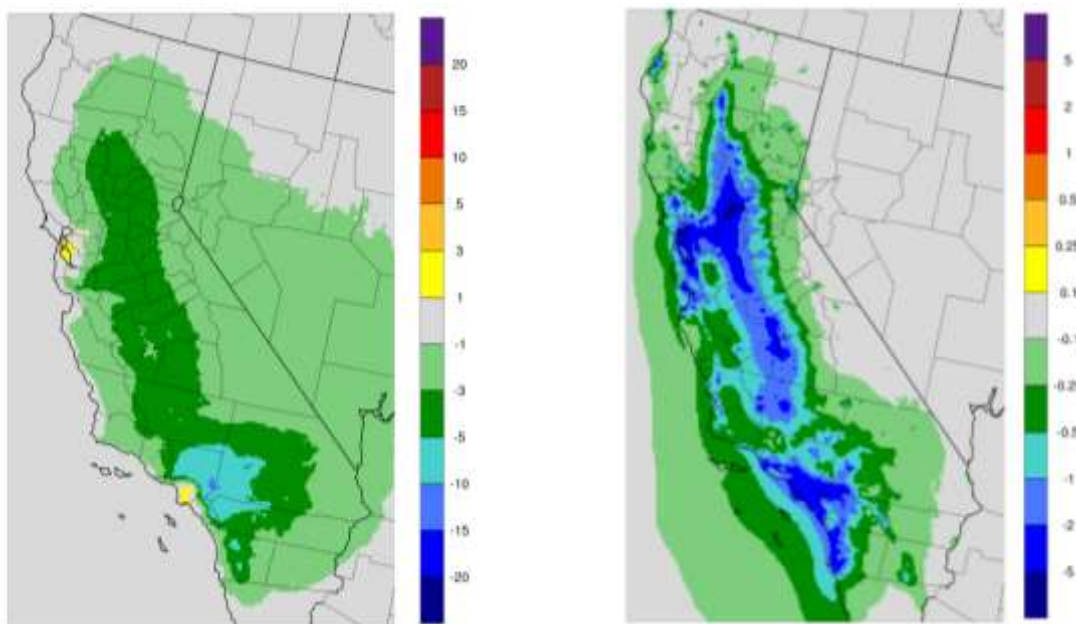
**Figure ES-2: Changes from Electrification for Summer Maximum Daily Average 8-hour-Ozone (left) and Annual  $PM_{2.5}$  for the South Coast Basin (right)**



Eight-hour (ppb; left) and annual  $PM_{2.5}$  ( $\mu\text{g}/\text{m}^3$ ; right). Ppb is parts per billion, a measure of concentration, and  $\mu\text{g}/\text{m}^3$  is micrograms per cubic meter, a measure of density.

Source: EPRI

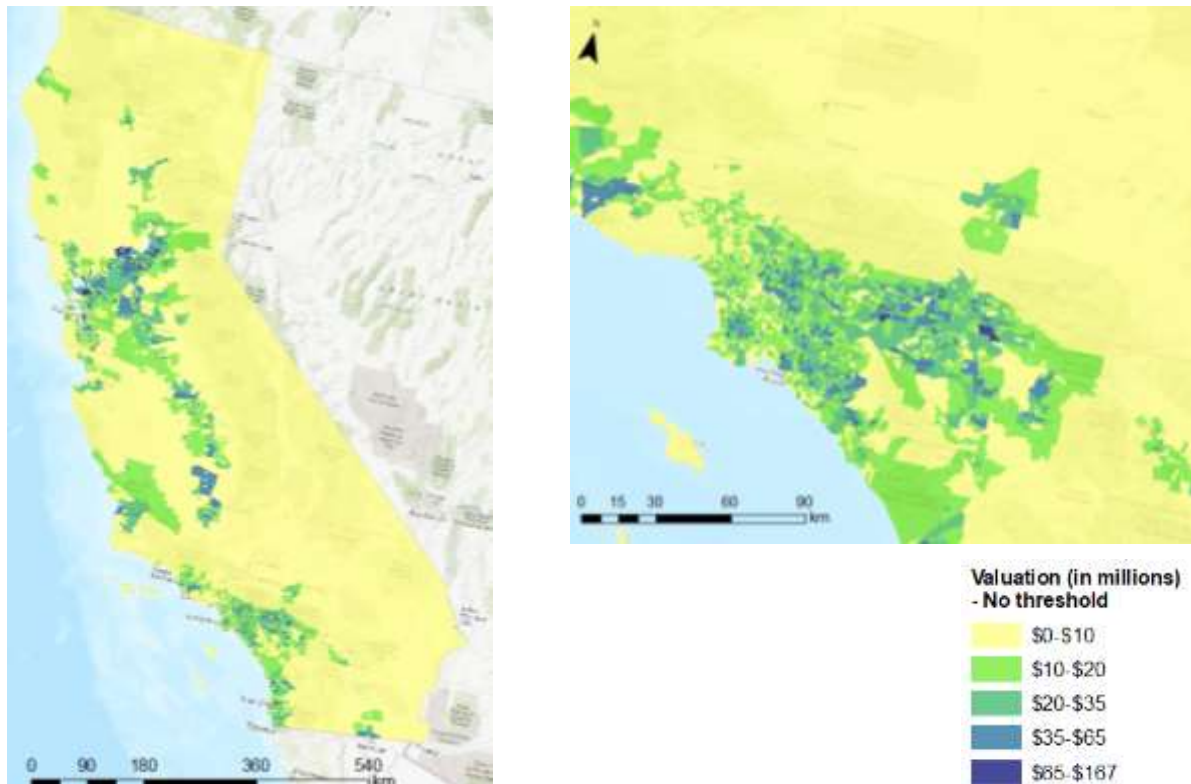
**Figure ES-3: Changes from Electrification for Summer Maximum Daily average 8-hour-Ozone (left) and Annual  $PM_{2.5}$  (right) for California**



Eight-hour (ppb; left) and annual  $PM_{2.5}$  ( $\mu\text{g}/\text{m}^3$ ; right). Ppb is parts per billion, a measure of concentration, and  $\mu\text{g}/\text{m}^3$  is micrograms per cubic meter, a measure of density.

Source: EPRI

**Figure ES-4: Valuation of Health Benefits from Ozone and PM<sub>2.5</sub> Reductions for California (left) and the South Coast Basin (right)**



Source: EPRI

The widespread extent and magnitude of benefits is important since it can help significantly in California's efforts to meet air quality standards. Additionally, the analysis found high effects from emissions from wood-fired heating on winter particulate concentrations. Wood burning is considered an important emissions source and is illegal in some areas during times when atmospheric conditions are particularly sensitive to additional emissions. However, this analysis found that reductions in winter PM<sub>2.5</sub> from residential wood burning is approximately as impactful as emissions from all other sources in the 2050 scenario. This suggests that electrification efforts should be focused on reducing wood combustion where possible, including increasing education about the effects of wood combustion and incentivizing installation of heat pumps as a replacement for wood heating.

Although the health benefits of electrification were shared broadly, the analysis indicated that benefits were slightly higher in disadvantaged areas than they were in non-disadvantaged areas, indicating that electrification generally reduced pollution in an equitable manner. The analysis includes a discussion of recommendations to ensure that disadvantaged communities directly benefit from electrification through higher in-community adoption.

Finally, the analysis included a summary of analyses of the costs of electrification. Although there are multiple ways that costs can be measured, the analysis indicates that even with unfavorable assumptions, *total* net costs for electrification are equivalent to a few years of *annual* health cost benefits, estimated in this analysis as \$108 billion per year in 2050. This



means that there is relatively rapid “payback” for investments from air quality benefits. Additionally, with more favorable assumptions the net benefits of electrification from fuel savings and other operational savings may exceed costs, so these health benefits are additive.

### **Sharing Technology/Knowledge**

The knowledge produced through this study is being transferred in several ways. First, this report discusses the methodology and results in detail.

The team presented the project results in a panel at the Electric Power Research Institute (EPRI) Electrification 2018 conference held August 2018 in Long Beach. This conference provided an opportunity for stakeholders to meet and discuss electrification technologies, the effects of electrification on customers and the environment, and ways to increase electrification and improve air quality. EPRI will continue presenting the projects results in various electrification stakeholder meetings, including the EPRI International Electrification Conference set for Paris, France in mid-October 2019 and the EPRI Electrification Conference in Raleigh, North Carolina in April 2020

Additionally, the technical advisory committee for this project included stakeholders from utilities, air quality management districts, and academia. Through their participation in this project they have participated in the development of assumptions and have reviewed the results as they were developed and in their final form. This will ensure that they understand the benefits of electrification for air quality and that the results can be used to direct future programs and studies.

Finally, EPRI anticipates publishing the results of this analysis in a trade journal.

### **Benefits to California**

This study benefits ratepayers by showing the potential for electrification to address the negative health impacts of bad air quality, which have widespread social impacts. This report quantifies these benefits to help clarify the large opportunity increased electrification provides. This will help to direct future studies and implementation funding.

# CHAPTER 1:

## Introduction

---

California has extensive legislative and regulatory programs to improve air quality and reduce greenhouse gas emissions, while also improving equity and ensuring that air quality improvement benefits are widely shared. This project is part of an effort by the California Energy Commission to understand the benefits of ongoing changes to the energy system on air quality, with a focus on analyzing the impacts on environmental justice communities.

### Previous Related Work

The effects of greenhouse gas reduction on air quality has been analyzed before. Adoption of measures to reduce greenhouse gas emissions is expected to produce substantial co-benefits from reduced co-emitted air pollutants. The California Fourth Climate Change Assessment group in its *2019 Statewide Report* evaluated climate change scenarios and impacts on several areas: economic, land use and development, wildlife, sea-level rise, public health, tribal and indigenous communities, climate justice, energy, water supply, delta levees and infrastructure, agriculture and oceans (Bedsworth et al., 2018). The report indicates that the most plausible and cost-effective way to reduce greenhouse gas emissions and avoid negative air quality impacts involves deep decarbonization of the electricity-generating sector, electrification of energy services where feasible (for example, electric heat pumps for space heating, water heating, electric vehicles for transportation), and substantial increases in energy efficiency.

Ebrahimi et al. (2018) estimate that end-use electrification coupled with decarbonization strategies such as increased renewable energy production and energy efficiency will produce a reduction in greenhouse gas emissions of 21.3 percent by 2030 in California with respect to 1990 vs only 2 percent in the base case scenario when only decarbonization measures are taken such as 50 percent renewable energy penetration. Greenhouse gas reductions are led by the electrification of the transportation sector. However, the authors estimate that a fraction of these reductions are offset by evening charging of electric and hybrid vehicles, when solar and wind energy hit their lowest generation level. In this analysis, industrial electrification does not produce significant benefits in greenhouse gas emissions owing to their flat load that penalizes the use of variable renewable energy resources, but does show significant benefits in air quality from industrial electrification. With respect to ozone, transportation scenario electrification lowers ozone levels in most areas of California, except those close to natural gas generators responding to higher electricity load.

Zapata et al. (2018a, 2018b) consider a scenario leading to 80 percent reduction in greenhouse gas from 1990 levels by 2050 in California, through changes in several economic sectors. They find a significant decrease in mortality of 24-26 percent relative to the Reference scenario, mostly lead by reductions in PM<sub>2.5</sub> concentrations (the Reference scenario achieves the goals outlined in California Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006), the Global Warming Solutions Act of 2006, and includes additional reductions to achieve an 80 percent

reduction). Given the important impacts on mortality of particulate matter (PM<sub>2.5</sub>) emissions, this leads to a drop by 54-56 percent in number of deaths per 100,000 people relative to 2010 levels, providing public health benefits equivalent to \$11.4-\$20.4 billion per year relative to the Reference scenario. These benefits are larger than those from any other program and make a compelling case for the shift to a low-carbon energy system in California. The benefits are especially important for ultrafine particulate (PM<sub>0.1</sub>), an emerging pollutant of concern for public health, with a 36 percent reduction in emissions with respect to the reference case vs only a 3.6 percent reduction in PM<sub>2.5</sub> with respect to the reference case. However, the benefits are not uniform across the state, especially for ozone, with an overall 3.9 percent increase in population-weighted effects due to the increases focused in highly populated urban areas of the San Francisco Bay Area, Los Angeles and San Diego. This is because the extent of nitrogen oxides (NO<sub>x</sub>) reductions is insufficient to shift the chemical regime in those urbanized areas to one in which decreases in NO<sub>x</sub> lead to ozone reductions. On the other hand, the study shows that nearly all (19 out of 23) of the counties exceeding the ozone National Ambient Air Quality Standard (NAAQS) in 2010 would achieve attainment under the 80 percent reduction in greenhouse gas in California scenario. Notwithstanding, most of the premature mortality (about 90 percent) is associated with PM<sub>2.5</sub>, while only 2.0-4.4 percent is attributed to ozone. As a result, benefits associated with PM<sub>2.5</sub> reductions in the 80 percent reduction of greenhouse gas scenario greatly outweigh any damages associated with ozone increases.

Wei et al (2019) investigated the effects of several long-term energy scenarios for California to understand the best ways of achieving greenhouse gas emissions reductions from 1990 levels of 40 percent in 2030 and 80 percent in 2050 (the study was related to the Mahone et al. (2019) analysis used as a basis for many of the assumptions in this report). The analysis included many parts to investigate different aspects of meeting these goals. An analysis of the electricity sector shows that greenhouse gas reductions greater than 80 percent are possible throughout the western grid and California, mainly through the use of renewable generation. Costs were minimized by optimizing over the full timeframe to 2050 or adopting aggressive targets for 2030. Load flexibility decreases capacity requirements. The study also shows that solar resources in California's Central Valley greatly exceed 2025 demand for California, even if deployment is limited to the built environment, salt-affected land, contaminated land, and floating solar farms on reservoirs to ensure that this development is synergetic with other uses. Buildings, industry, and transportation are analyzed in detail, showing high potential for emissions reductions, although with significant challenges. Finally, air quality impacts are analyzed, showing that 2016 health damages from criteria emissions are about \$25 billion, mostly from PM<sub>2.5</sub>.

On a global scale, Van Dyck et al. (2018) find that the transformation of the energy system implied by the Paris Agreement will prevent, due to air quality co-benefits, about 71,000 to 99,000 premature deaths annually around the world by 2030 with respect to 2010, and 178,000-346,000 in 2030 and up to 0.7-1.5 million in year 2050 if a more ambitious 2°C pathway is adopted (with at least 75 percent probability of limiting the average rise of global temperature to 2°C). The value of co-benefits differs widely across regions but outweighs the costs of reducing greenhouse gases on a global level in most scenarios.

Shindell et al. (2018) evaluate the adoption of low- to zero-carbon technologies, by increasing 21st-century carbon dioxide (CO<sub>2</sub>) reductions by 180 gigatonnes carbon, an amount that would shift a “standard” 2°C scenario to 1.5°C or could achieve 2°C without negative emission technologies and practices (for example, bio-energy with carbon capture and storage). This would lead to the reduction of co-emitted air pollutants that would help prevent 153±45 million deaths worldwide over 2020-2100, with ~40 percent of those occurring during the next 40 years. About 93±41 million deaths would be attributable to PM<sub>2.5</sub> reductions and 60±18 million to ozone reductions. Most of the benefits would concentrate on large and heavily polluted urban areas around the world, such as South Asia, Indonesia, China and Nigeria.

A study by Zhang et al. (2017) estimates that with global greenhouse gas mitigation efforts 16,000 premature deaths will be avoided annually in the United States in 2050 due to PM<sub>2.5</sub> decreases and by 8,000 for ozone. Of those, greenhouse gas reductions in foreign countries account for 15 and 62 percent of total deaths for PM<sub>2.5</sub> and ozone (O<sub>3</sub>). Although the reductions are different than those calculated in other studies, this points to the importance of worldwide implementation of greenhouse gas reduction measures on local ozone levels owing to ozone transport aloft.

Cooper et al. (2015) reviews the transport of ozone across boundaries, both from other countries and “aged” ozone from the United States that circles the globe and reenters the United States. The authors find that this ozone is becoming increasingly important to ozone levels in the United States, particularly in rural areas. The authors assert that lowering the National Ambient Air Quality Standard (NAAQS) for ozone in the United States may incentivize regulators to invest more resources to investigate background ozone levels and separate out the contributions from United States and international emissions since action outside of a given area may be necessary to achieve attainment within the area. This may lead to discussion that also address the hemispheric transport of air pollution in addition to international efforts to decrease greenhouse emissions and therefore the development of synergistic strategies.

Finally, Saari et al. (2019) found in their analysis, using a multidecade, multiple initial condition ensemble of annual simulations, that natural climate variability is also an important factor that may obscure potential future climate benefits and health risks. They found that using a sufficiently large number of annual simulations, spurious negative impacts of greenhouse gas reductions disappear. The most typical approach of using 5-year annual simulation averages at least reduces the negative impacts to 10 percent of the simulations. Natural climate variability is an important source of uncertainty by mid-century and health-related uncertainties dominates by the end of the century (these health-related uncertainties are mostly related to the choice of concentration-response function that estimates the effects on human health of a given change in pollution concentration levels).

Notwithstanding uncertainties and the variability of potential co-benefits from greenhouse gas emissions strategies in California and in a global scale, an increasing amount of studies indicated that end-use electrification coupled with electric sector decarbonization strategies can play a significant role in air quality management strategies, along with other measures to decrease emissions from activities not easily electrified.

## Construction of the Current Analysis

This report continues previous work by focusing on analyzing the benefits of high levels of electrification in improved air quality. Electrification eliminates emissions from direct combustion of fossil fuels, including emissions of greenhouse gas emissions, direct pollution, and pollution precursors. These benefits may be offset by increased power plant emissions to generate the required electricity, but the emissions of California's rapidly improving grid are quite low and result in a large net improvement.

The starting point for the electrification scenario was Energy Commission project EPC-14-069, which was an effort to model potential scenarios to achieve California's 2050 climate goals (Mahone et al., 2018). At the time, these goals included a reduction to 1990 levels by 2020, a reduction of 40 percent below 1990 levels by 2030 (SB 32), and an 80 percent reduction below 1990 levels by 2050 (Executive Order S-03-05). These goals have since been extended to include zero carbon electricity (SB 100) and economy-wide net-zero emissions by 2045 (Executive Order B-55-1), although this level of reduction is not represented below and will require further analysis. These goals do not directly target air quality improvement, but the energy systems changes required to achieve these goals are anticipated to reduce emissions of pollution-forming gases and provide air quality co-benefits.

An additional focus of this report is understanding the effects of this energy transformation on the burdens that many disadvantaged communities experience today. This will require efforts at many levels. First, improvements must be available to low-income communities to reduce poverty and ensure that state goals are met. 33 percent of California households are considered low income (Scavo et al., 2016), so large reductions – and especially net-zero emissions will not be possible unless improvements occur at all income levels. Second, improvements should be targeted at sources of pollution that currently affect many communities. For example, many households and schools are located next to freeways with relatively heavy vehicle traffic, which creates high concentrations of air pollution. Traffic-related air pollution has been associated with increased risk of many adverse health outcomes, including mortality, respiratory diseases such as asthma, and cardiovascular diseases. These communities – and particularly the children affected – do not own or control these vehicles, but they do suffer the burden from their use (Cone, 2011). Involving these communities in regulation efforts and ensuring benefits are widespread will help to improve “environmental justice.”

Finally, this report will discuss methods to overcome implementation challenges. The benefits of electrification have long been recognized in work by EPRI and others (EPRI, 1992), but efficient electric alternatives typically have higher up-front costs than fossil-fueled vehicles and devices. This higher up-front cost particularly impacts those in low-income communities, where financing is challenging, home ownership is low, and distrust and language barriers can prevent communication of benefits. Overcoming these challenges will be necessary to meet California's goals.

# CHAPTER 2:

## Project Approach

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This section describes the approach to understanding air quality impacts and barriers to electrification in environmental justice communities.

### Air Quality and Health Effects Modeling

The air quality modeling was performed to understand the impacts of electrification on air quality. Air quality was modeled using a 4-kilometer (km) grid for California as a whole, and a nested 1.33 km grid for the South Coast Basin, as shown in Figure 1. This allowed for increased resolution in the highly populated and heavily impacted Southern California region. Results will be shown for both the larger California domain and the South Coast Basin domain. Health effects were also analyzed to quantify the benefits of electrification through monetization of improvements on human health. The air quality and health effects modeling occurred in four main steps, described in the following sub-sections:

- Creating Reference scenario emissions inventory for 2050.
- Creating 2050 Electrification scenario.
- Modeling air quality for the reference and electrification scenarios.
- Analyzing air quality changes on health.

**Figure 1: Air Quality Modeling Domains**



Source: EPRI

### Creating Reference Scenario Emissions Inventory for 2050

The 2050 base case emission inventory was developed based on the EPA modeling platform 2025 future year inventory and 2025 to 2050 emission scaling factors (Modeling platform 2011 v6.2 (EPA, 2015)). The modeling platform 2025 future year emission inventory is based on

California Air Resources Board (CARB) submitted emissions for on-road vehicles, non-road equipment, marine, and rail sources. 2025 to 2050 scaling factors were estimated based on 2025 and 2035 emission inventories from the CARB California Emission Projection Analysis Model: 2016 SIP - Standard Emission Tool. The detailed method is described.

## California

- Non-road<sup>1</sup> and stationary<sup>2</sup> sources: These were forecasted using EPA modeling platform (2011 v6.2) 2025 emissions to 2050 based on the extension of 2025 to 2035 emission inventory trends available from CARB (CEPAM: 2016 SIP - Standard Emission Tool<sup>3</sup>). For a relatively small number of source categories (for example, diesel-fueled non-road equipment), substantial emission reductions were observed prior to 2025, but emission reductions after 2025 were nominal. These source categories are subject to rapid fleet turnover to lower polluting technologies prior to 2025 because of CARB regulations and/or agreements (for example, In-Use Off-Road Diesel Vehicle Regulation; CARB, 2017). 2050 emissions from such source categories were set to 2025 levels. Ammonia emissions across all categories are assumed unchanged from 2025 which is reasonable considering that CARB estimated only a 3 percent change in ammonia emissions from 2025 to 2035.<sup>3</sup>
- On-road vehicles: On-road vehicle emissions were developed using the SMOKE-MOVES processing tool.<sup>4</sup> Consistent with 2011v6.2 EPA modeling platform methodology, California on-road emissions output for 2050 were adjusted to match CARB 2050 annual emission inventory estimates (source EMFAC2014 (v1.0.7) model output). This approach allows the inventory to reflect the unique vehicle emission rules in California, while leveraging the more detailed source classification codes (SCCs) and the highly resolved spatial and temporal patterns from SMOKE-MOVES.
- Power Sector: Emissions from Electrical Generating Units (EGUs) were estimated with a bottom-up-approach using EPRI's United States Regional Economy, Greenhouse Gas, and Energy Model (US-REGEN<sup>5</sup>). The US-REGEN model is an optimization tool combining a detailed power dispatch and capacity expansion model of the electric sector with a United States economic model covering transactions among suppliers and consumers and forecasted economic growth. This modeling is described in more detail in Appendix A. The US-REGEN model provides hourly NO<sub>x</sub> and SO<sub>2</sub> power plant emissions by plant type and fuel type. These are used to map emissions to plant identification numbers

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1 Includes rail, aircraft, marine vessels, and other non-road equipment such as lawn mowers, forklifts, excavators, pleasure craft, and all-terrain vehicles.

2 Includes industrial facilities that report emissions as point sources such as chemical plants and refineries, but not power plants; and nonpoint industrial, commercial, and residential sources that are not reported as point sources such as consumer products, architectural coatings, and smaller-scale fuel combustion sources.

3 For more information on CEPAM, please visit <https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php>.

4 Sparse Matrix Operator Kerner Emissions - Motor Vehicle Emission Simulator; SMOKE-MOVES and the Emissions Modeling Framework. For more information, please visit [https://www.cmascenter.org/emf/internal/smoke\\_moves/](https://www.cmascenter.org/emf/internal/smoke_moves/).

5 For more information on US-REGEN, please visit <http://eea.epri.com/models.html>.

based on the location of current similar plants. These emissions were then located using the positions of existing units based on plant identification number in the EPA's 2011v6.3 modeling database.

- Fire and natural: Consistent with EPA Modeling Platform methodology fire and natural emissions were assumed unchanged from the base year.

### **Neighboring States**

For other states within the 4-km air quality modeling domain (Oregon, Nevada, Idaho, and Arizona), the team based 2050 Reference scenario emissions on 2025 EPA Modeling Platform estimates with 2050 projections for on-road vehicles, non-road equipment, rail, and commercial marine vessels. The EPA's MOVES<sup>6</sup> (version 2014a) model was used to develop nationwide 2050 scalars for on-road vehicles and non-road equipment. For rail and commercial marine vessels that are not categorized as ocean-going vessels (for example, harbor craft, fishing vessels, dredgers, ferries), 2050 scalars were developed based on the ratio of 2040 (farthest future year available) to 2025 emissions in the 2008 EPA Regulatory Impact Analysis (EPA, 2008). 2025 Modeling Platform estimates were used directly for all other source categories.

### **Outside the United States**

The effects of changes in emissions outside the United States to meet global greenhouse gas emissions targets were not modeled. Previous work has shown that this can provide additional health benefits on the same order of magnitude as local changes (Zhang et al, 2017).

### **Creating 2050 Electrification Scenario**

California Reference scenario emissions were adjusted for the Electrification scenario based on the fraction of emissions reduced by electrification. Electrification fractions were assigned to relevant source classification codes to estimate emission reductions. The Electrification scenario was designed to be aggressive to ensure that the modeling "signal" was high and to show the possible improvements from broad electrification. However, even though this scenario is aggressive, it is likely less aggressive than would be required to meet then-Governor Edmund G. Brown Jr.'s Executive Order B-55-18, which sets a goal of economy-wide carbon neutrality by 2045. Note that the overall air quality indicators in each scenario are interesting, but the difference between these scenarios is more useful in showing the incremental air quality benefit of electrification due to the high degree of uncertainty concerning future emissions and climatic conditions.

The development of the Electrification scenario is described in detail in Appendix B and primarily based on the "Long-Term Energy Scenarios in California" study performed by Energy and Environmental Economics (E3) for Energy Commission project EPC-14-069. This study was intended to show potential pathways to a 2050 reduction in greenhouse gas emissions of 80 percent relative to 1990 levels. The results from the "In-State Biomass" scenario in this report were used for this analysis. The presence of biofuels is incidental to this analysis, but this scenario included the following additional mitigation strategies that matched the objectives of

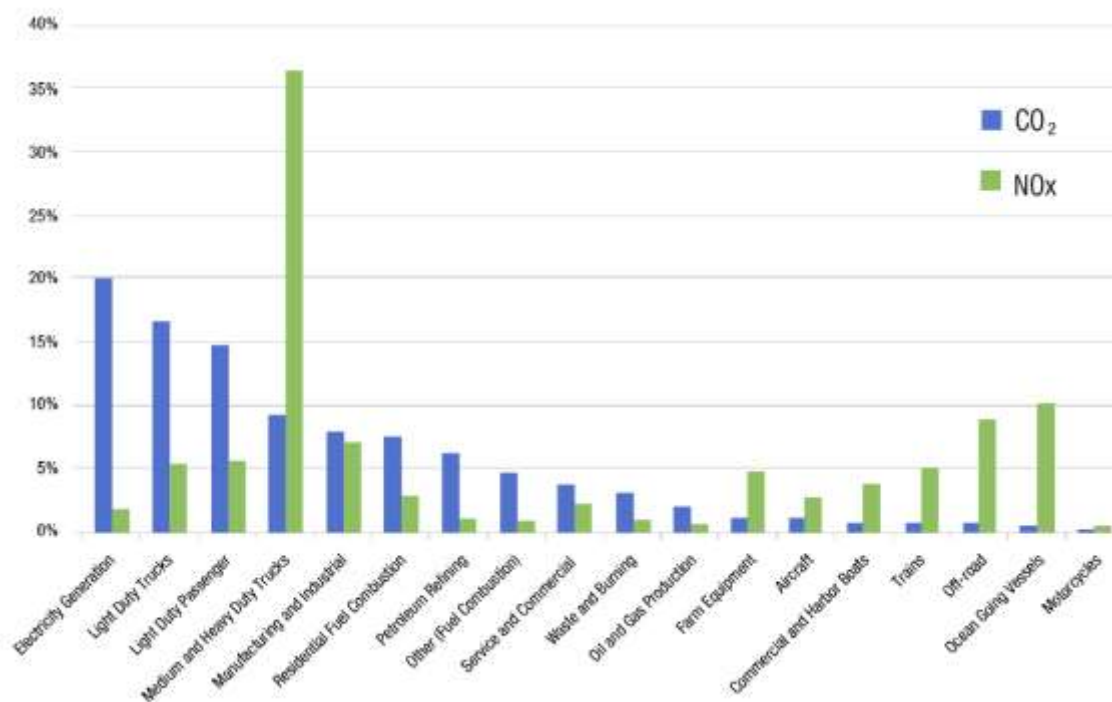
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<sup>6</sup> For more information on MOVES, please visit <https://www.epa.gov/moves>.



the current effort: “Increased reliance on: Industrial electrification, more ZEV trucks, renewables.” The application-specific electrification results formed the basis for most of the transportation and heating categories. Unfortunately, though, there are a large number of emissions categories that are important for air quality effects but have very low greenhouse gas emissions, as shown in Figure 2. These categories are generally not represented in models like E3’s PATHWAYS model, so separate assumptions had to be created for these sources. EPRI filled in these gaps based on expert judgement and input from technical advisory committee members, with a focus on representing aggressive electrification. Grid emissions were also modeled by EPRI even though they were available in the source report since additional detail was required on the precise timing and location of emissions. This modeling used load and load shapes from the E3 analysis, as described in Appendix A.

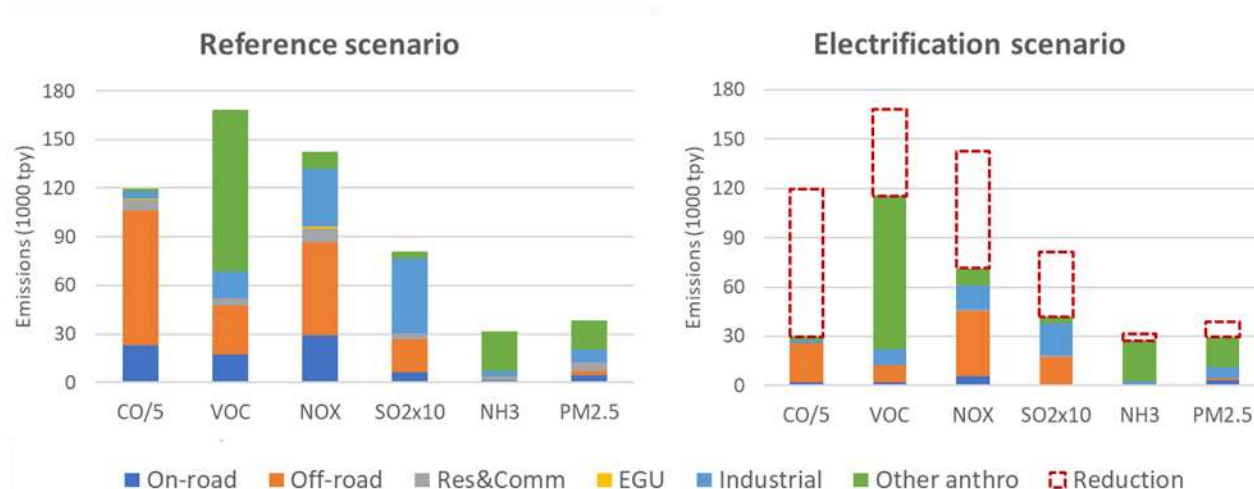
**Figure 2: Share of Current Emissions of CO<sub>2</sub> and NO<sub>x</sub> in California for Each Source Category**



Source: IEPR, 2015

Figure 3 shows estimated 2050 emission reductions for the Electrification scenario in the 1.33-km modeling domain, which includes the South Coast Air Basin. Emission reductions from the Reference scenario to the Electrification scenario are 72 percent for CO, 18 percent for volatile organic compounds (VOC), 49 percent for NO<sub>x</sub>, 47 percent for sulfur dioxide (SO<sub>2</sub>), 14 percent for ammonia (NH<sub>3</sub>), and 23 percent for primary PM<sub>2.5</sub>. The largest contributors to NO<sub>x</sub> emission reductions are on-road vehicles (33 percent), industrial stationary sources (30 percent), and off-road sources (25 percent). The largest contributors to VOC emission reductions are off-road sources (38 percent) and on-road vehicles (28 percent). Residential and commercial stationary sources are the largest contributor to primary PM<sub>2.5</sub> emission reductions, accounting for 61 percent of primary PM<sub>2.5</sub> emission reductions.

**Figure 3: Reference (left) and Electrification (right) Scenario Annual Anthropogenic Emissions for the South Coast Basin in Thousand Tons per Year for 2050**



CO is divided by 5 and SO<sub>2</sub> is multiplied by 10 to achieve similar scales

Source: EPRI

## Modeling Air Quality for the Reference and Electrification Scenarios

The Comprehensive Air Quality Model with Extensions (CAMx) model was used to quantify expected ozone and PM<sub>2.5</sub> impacts of electrification in 2050. The CAMx domains cover California at 4-km grid resolution and the South Coast Basin at 1.33-km resolution. The meteorology is for calendar year 2011 because modelling a historical year is the conventional approach. CAMx performance for 2011 was evaluated by comparing the 2011 baseline simulation to observed air quality (see Appendix C for more information on the baseline comparison). Two future-year annual simulations were performed, the 2050 Reference scenario and 2050 Electrification scenario. Each scenario used CAMx source tagging to quantify contributions to ozone and PM<sub>2.5</sub> from several emissions sectors, including on-road transportation, non-road transportation, residential and commercial, electricity generation, industrial, and other anthropogenic. The analysis of the electrification impacts summarizes changes in ozone and PM<sub>2.5</sub> concentrations and the associated health risk changes.

Modeling studies have uncertainties. The largest uncertainty is the estimation of future year (2050) emissions, which depends on projecting future baseline activity and electrification levels. Future introduction of new regulations could alter the projections of air quality.

## Analyzing Air Quality Changes on Health

Changed to health outcome due to decreases in air pollution from electrification were analyzed using the EPA Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP combines an air pollutant's health impact functions (concentration-response functions; CRFs) with population data and baseline health incidence rates (for example, mortality rates) to estimate changes in health outcomes from changes in ambient ozone and PM<sub>2.5</sub> concentrations. The model assesses effects for each grid cell assuming a consistent single-pollutant response function, so it does not include the movement of people between grid cells or the cumulative

impacts of exposure to different pollutants or economic stressors. This analysis used the ozone CRF from Jerrett et al. (2009) and the PM<sub>2.5</sub> CRF from Krewski et al. (2009), both used by the EPA to establish the NAAQS for these pollutants. The main analyses assume no evidence of a threshold – or level below which no health effect would be expected – in the CRFs. This analysis focused on long-term exposure related mortality since this represents the majority of benefits. Morbidity, or effects like asthma that have negative health effects but do not result immediately in death, is important but the valuation of mortality is much higher. Aggregated health benefits were converted to monetary terms using EPA’s Value of a Statistical Life (VSL) of \$8.7 million in 2015 dollars. This value is constant for all deaths avoided, regardless of location or income.

Although the primary analysis assumed no threshold, the potential existence of a threshold in the CRF is a key source of uncertainty inherent in the estimates of avoided health outcomes due to reduced pollutant levels. Understanding effects relative to a threshold could be important since preindustrial pollutant concentrations were above zero, as discussed in Fang et al. (2013) and Horowitz (2006), so there is a minimum level that could be achieved even if all anthropogenic emissions were eliminated. Although no specific minimum level is suggested in this work, it is possible that valuation should be evaluated relative to this level. Building on the main analyses, sensitivity analyses were conducted to investigate the impact of different threshold locations in the ozone and PM<sub>2.5</sub> CRFs on avoided mortality and resultant valuation estimates. For ozone, sensitivity analyses were conducted assuming thresholds of 40, 50, 60, and 70 parts per billion (ppb); for PM<sub>2.5</sub>, the thresholds used were 6, 8, 10, and 12 µg/m<sup>3</sup>. The highest respective thresholds used are the current NAAQS for 8-hour ozone and annual PM<sub>2.5</sub>.

## **Analysis of Barriers to Electrification in Environmental Justice Communities**

The analysis of barriers to electrification in environmental justice communities consisted of a literature review and interviews with stakeholders in the environmental justice advocacy community and interested parties. The papers used are cited in the relevant sections, and the list of interviewees and discussions of their responses are presented in Appendix D.

When the analysis for the project was complete, a stakeholder meeting was held to discuss the results and to create recommendations for increasing engagement in environmental justice communities. The notes from this meeting are provided in Appendix E and have been included in the discussion below.

The input from these stakeholders was invaluable in understanding the diverse set of issues involved in implementing electrification within these communities.

# CHAPTER 3:

## Project Results

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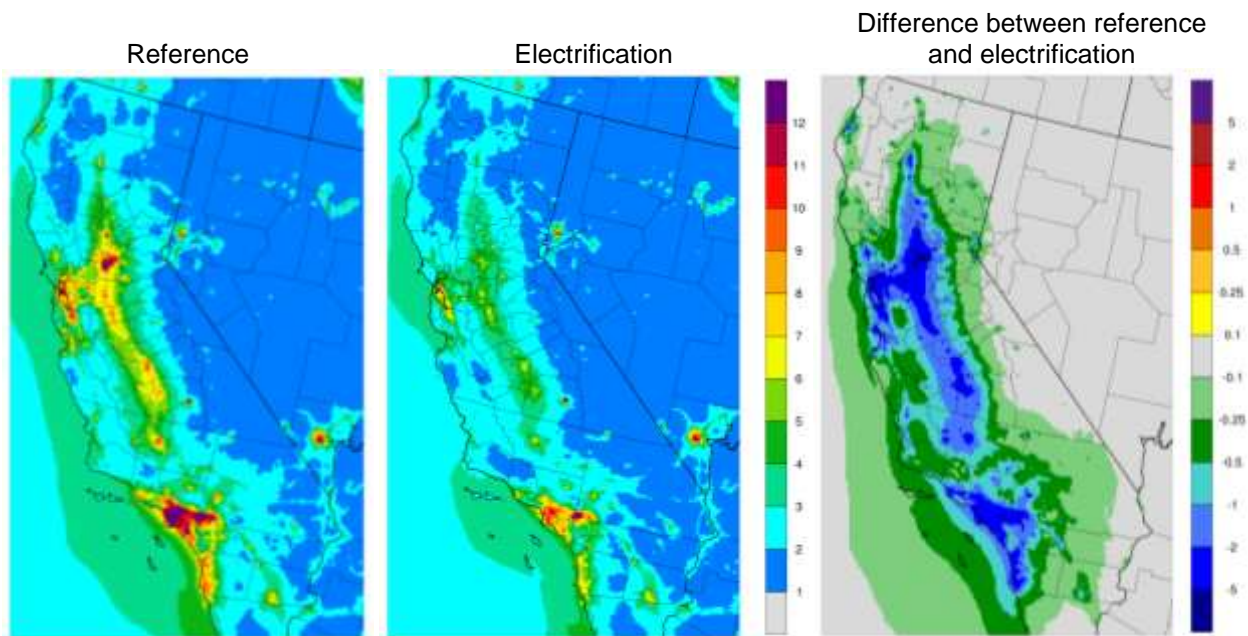
The following sections will discuss the air quality modeling results, health impacts, the costs of electrification, and the effects of air quality changes on environmental justice communities.

### Overall Air Quality Changes

#### Particulate Matter 2.5 Concentrations

Figure 4 through Figure 7 show the air quality modeling results for ground-level PM<sub>2.5</sub>, first for California as a whole and then for the South Coast Basin. In each figure group, the first figure shows the PM<sub>2.5</sub> concentration for each area in the Reference scenario, in the Electrification scenario, and for the difference between them, and the following figure shows the sectoral contribution towards this difference. PM<sub>2.5</sub> concentrations are characterized by the average annual contribution in micrograms per cubic meter (µg/m<sup>3</sup>), where lower values generally lead to better health outcomes. The maximum for each grid point may occur on different days, and the maximum for the Reference and Electrification scenarios may occur on different days. Later sections will show differences between winter and summer, which are important with respect to heating in particular.

**Figure 4: Average Annual PM<sub>2.5</sub> Concentration for California in the Reference and Electrification Scenarios**

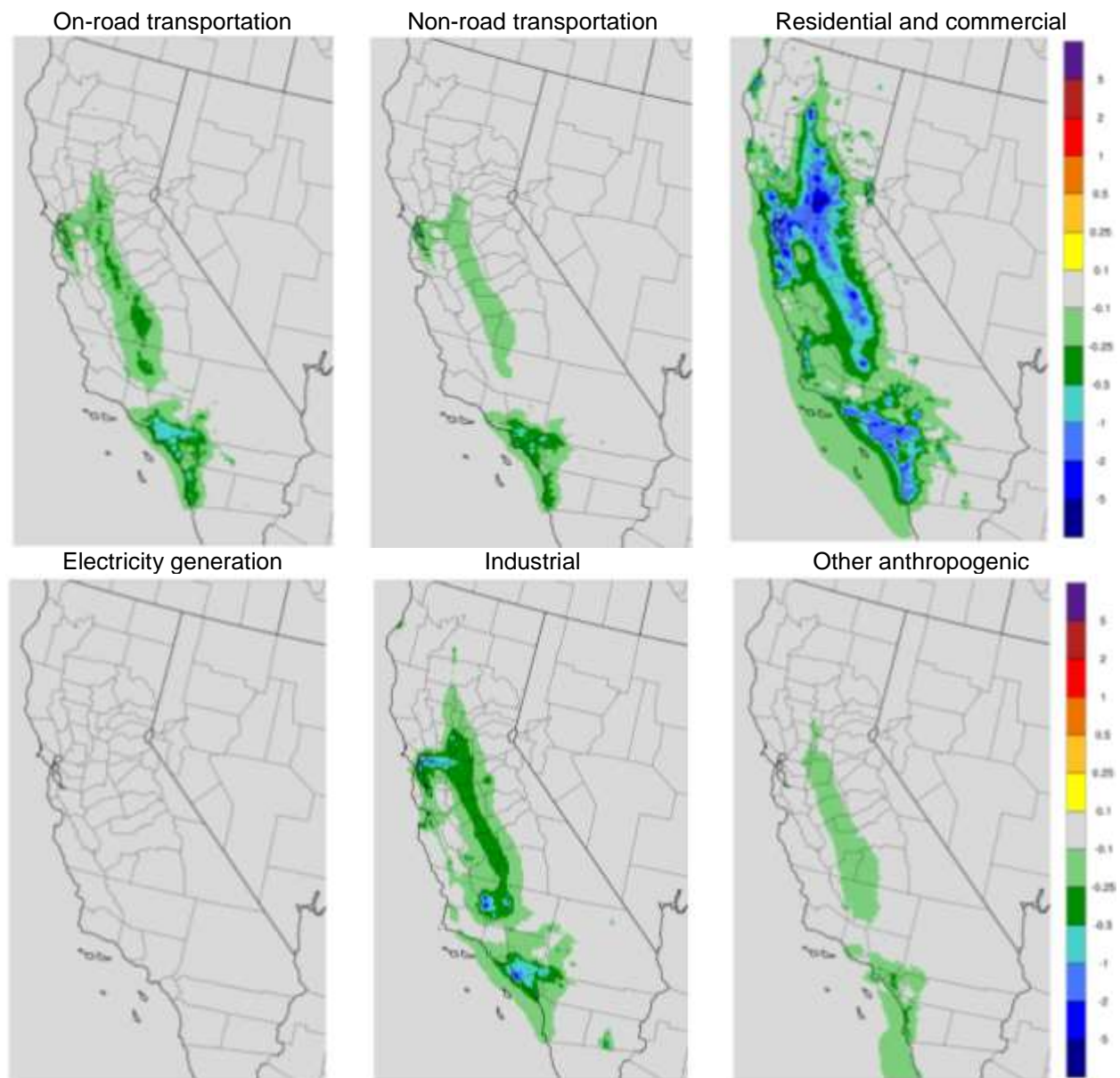


µg/m<sup>3</sup>; lower is better.

Source: EPRI

Electrification results in widespread reductions in PM<sub>2.5</sub> concentrations, both for California as a whole and in the South Coast Basin. Reductions occur in highly populated areas and areas where concentrations are high in the Reference scenario, so these reductions should lead to substantial health benefits. Reductions are particularly pronounced in the Central Valley, due primarily to residential and commercial electrification. As discussed, this is primarily due to the assumption that residential wood combustion is assumed to be eliminated by 2050.

**Figure 5: Sector Contributions to Differences in Annual PM<sub>2.5</sub> Concentration for California**



µg/m<sup>3</sup>; lower is better.

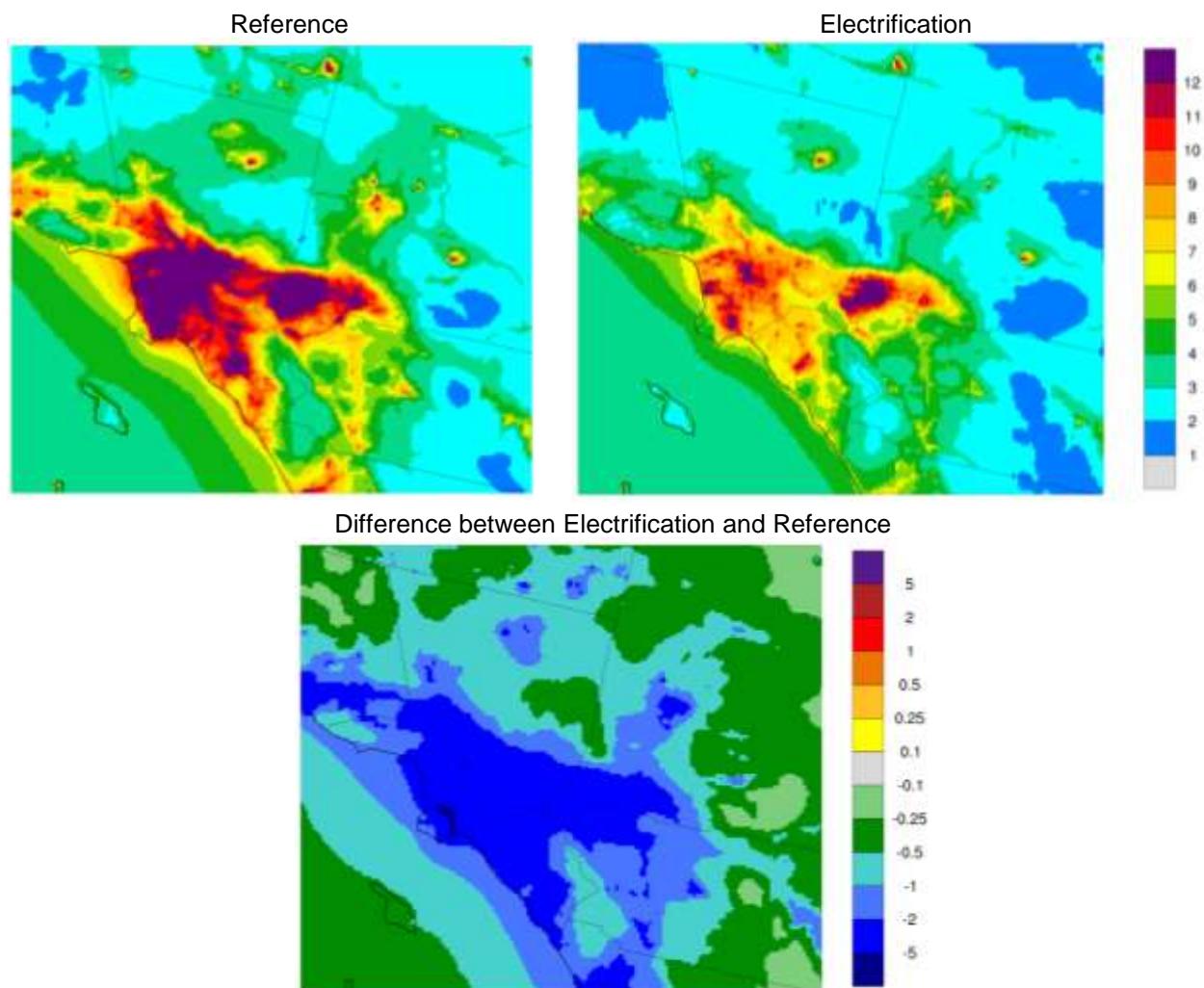
Source: EPRI

Additional PM<sub>2.5</sub> reductions come from on-road transportation, non-road transportation, industrial and “other anthropogenic.” All of these reductions are from replacing gasoline and



diesel use with electricity, which reduced emissions of nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds from vehicle refueling and exhaust and reduces the amount of petroleum produced, refined, stored, and transported. Petroleum production and refining is categorized in the “industrial” sector while petroleum product storage and sea-borne transportation is categorized as “other anthropogenic” activity. Petroleum production is concentrated in Southern California, particularly the southern Central Valley while refining is concentrated in the north east of San Francisco Bay, the southern Central Valley, and the mid-coastal area of the South Coast Basin. Both of these activities are reduced indirectly by transportation electrification, which reduced demand for petroleum products. Emissions from refining activity is typically transported over long distances due to prevailing winds and tall smokestacks designed to aid dispersion to reduce local concentrations. Reductions in on-road vehicles and non-road devices occur near the highways and facilities where these activities take place.

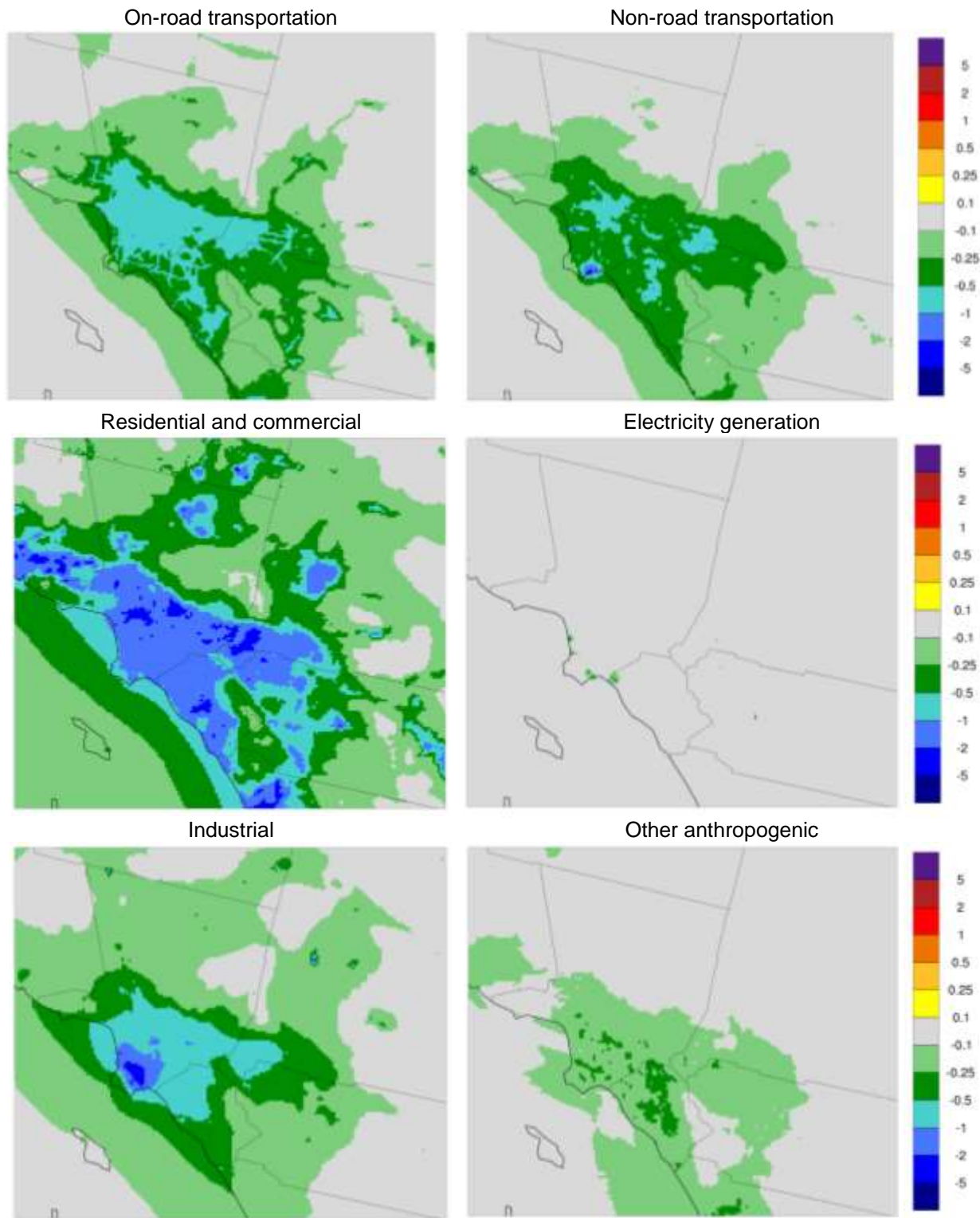
**Figure 6: Average Annual PM<sub>2.5</sub> Concentration for the South Coast Basin in the Reference and Electrification Scenarios**



µg/m<sup>3</sup>; lower is better.

Source: EPRI

**Figure 7: Sector Contributions to Differences in Annual PM<sub>2.5</sub> Concentration for the South Coast Basin**



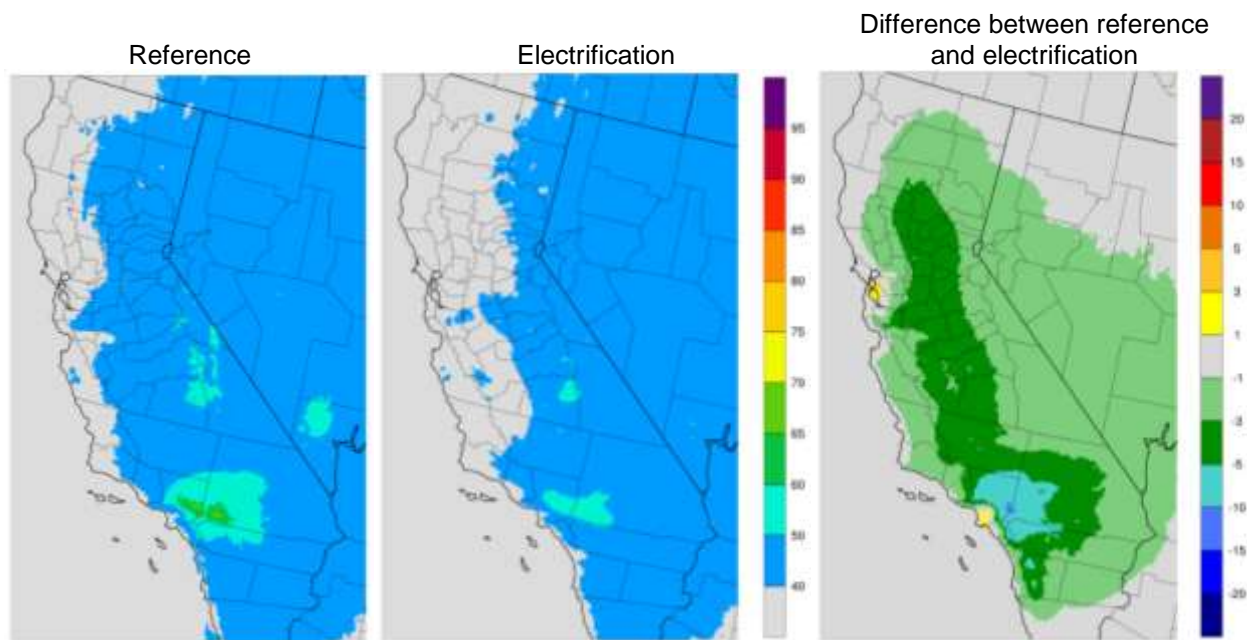
µg/m<sup>3</sup>; lower is better.

Source: EPRI

## Ozone Concentrations

Figure 8 through Figure 11 show the air quality modeling results for ground-level ozone, first for California as a whole and then for the South Coast Basin. In each figure group, the first figure shows the ozone concentration for each area in the Reference scenario, in the Electrification scenario, and for the difference between them, and the following figure shows the sectoral contribution towards this difference. Ozone concentrations are characterized by the maximum daily 8-hour average in ppb, where lower values generally lead to better health outcomes. The maximum for each grid point may occur on different days, and the maximum for the Reference and Electrification scenarios may occur on different days.<sup>7</sup>

**Figure 8: Ozone Concentration for the California in the Reference and Electrification Scenarios**



**Maximum daily 8-hour average; ppb; lower is better.**

Source: EPRI

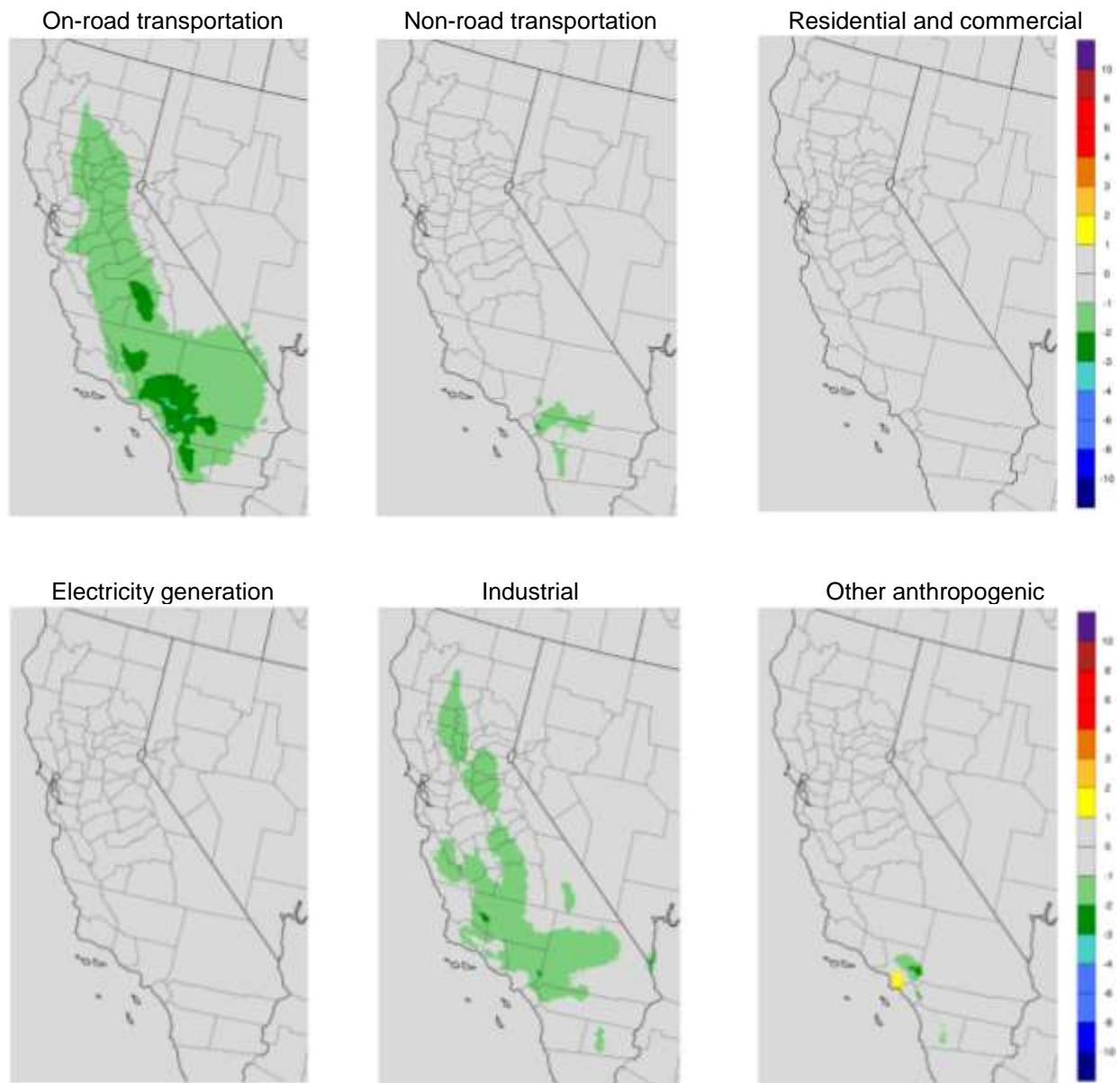
Electrification generally results in reductions in ozone concentration, but there are some increases in the San Francisco Bay Area and near the mid-coastal area of the South Coast Basin. This increase is a result of an effect called “NO<sub>x</sub> titration.” In the Reference scenario very high nitrogen oxide emissions (NO<sub>x</sub>) levels shift the air chemistry into a regime where NO<sub>x</sub> causes local ozone levels to decrease (however, ozone levels are increased further downwind). Electrification decreases NO<sub>x</sub> emissions due to reduced shipping of petroleum products, and although this is generally beneficial, it decreases the NO<sub>x</sub> titration effect and results in higher concentrations locally. A similar effect was seen in Zapata et al. (2018b) and Ebrahimi et al. (2018) for scenarios that greatly reduced greenhouse gas emissions in California. Ozone

<sup>7</sup> Note that the measure used here is related to but different from the standard used for compliance with National Ambient Air Quality Standards, which is based on the three-year average of the annual fourth-highest daily maximum 8-hour average ozone concentration for a discrete set of air quality monitors. However, reductions in the maximum 8-hour average should result in reductions in the NAAQS measure.



concentrations in this area are relatively low in the Reference scenario. Although any increase in concentration is unfortunate, this local increase occurs in an area with low reference-level ozone, so concentrations are not increased to high levels (the increase expands the area with concentrations between 40-50 ppb but does not result in elevation above 50 ppb). Meanwhile, these NO<sub>x</sub> reductions contribute to reductions in highly impacted inland areas and are part of the chemical regime that results in lower PM<sub>2.5</sub> levels in this area, which provide substantial health benefits.

**Figure 9: Sector Contributions to Differences in Ozone Concentration for California**

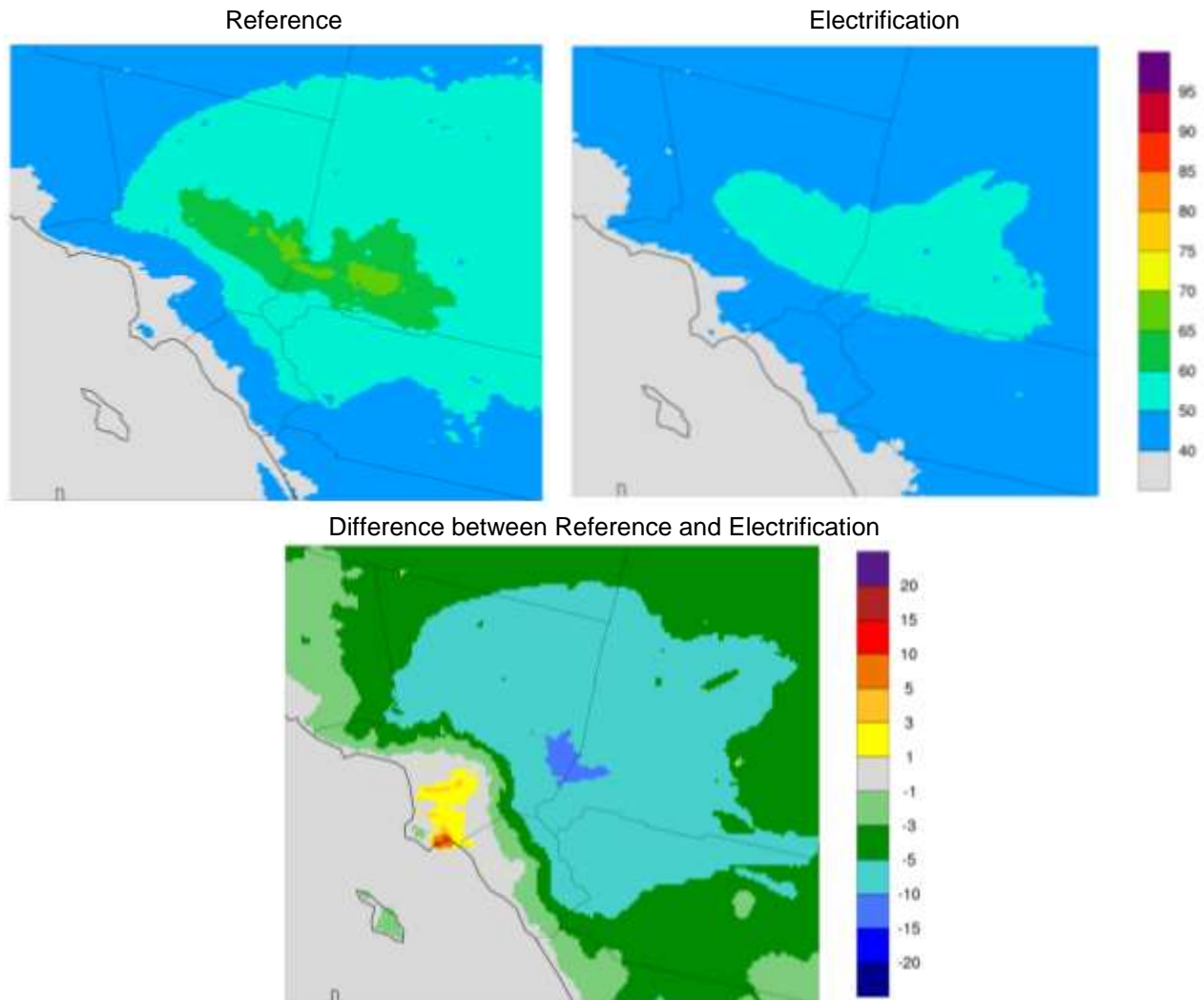


Maximum daily 8-hour average; ppb; lower is better.

Source: EPRI

The largest sectoral contributions to ozone reductions come from on-road transportation and industrial activity. The on-road contribution is due to the reduction in combustion emissions from light-, medium-, and heavy-duty vehicle traffic due to high levels of electrification. These reductions occur near where driving intensity is high, so they generally occur in highly populated areas and contribute to substantial improvements in health. Transportation electrification also results indirectly in reductions in industrial ozone due to a reduction in demand for petroleum products, which reduces extraction and refining activities. Much of the industrial contribution occurs near highly populated areas, although it is less focused.

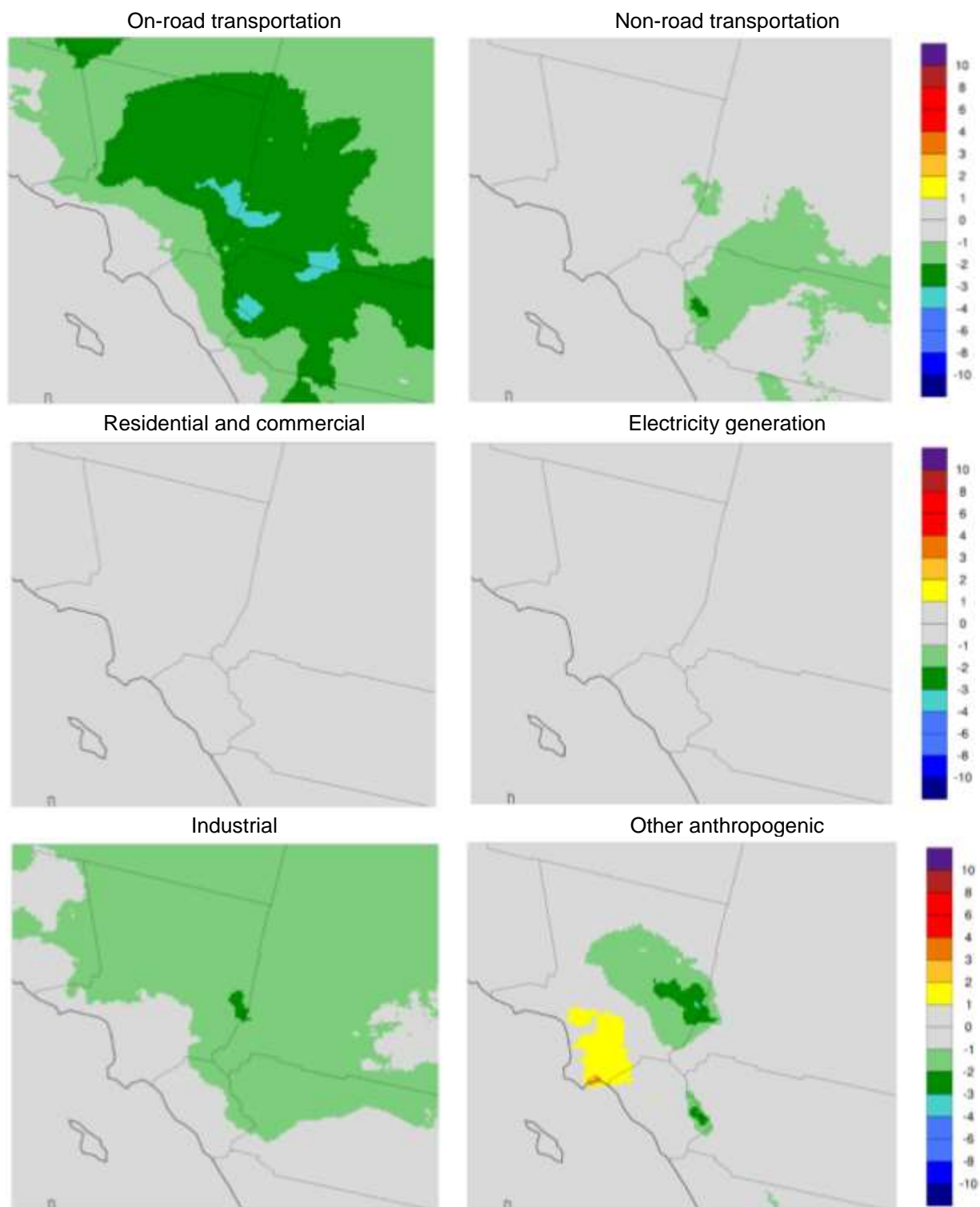
**Figure 10: Ozone Pollution for the South Coast Basin in the Reference and Electrification Scenarios**



Maximum daily 8-hour average; ppb; lower is better.

Source: EPRI

**Figure 11: Sector Contributions to Differences in Ozone Concentration for the South Coast Basin**



Maximum daily 8-hour average; ppb; lower is better.

Source: EPRI

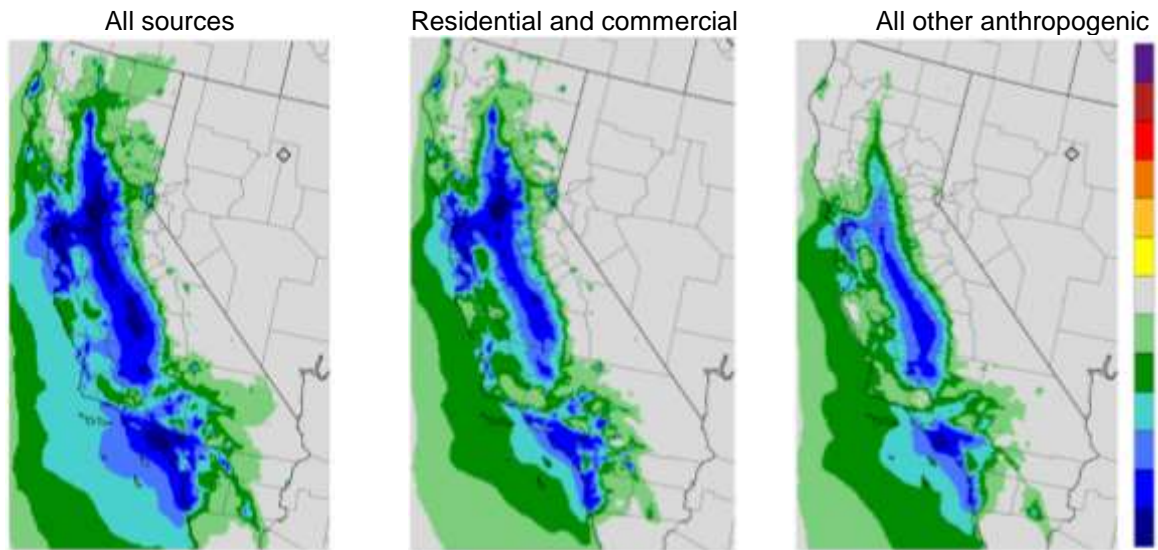
## Effects of Residential Wood Combustion on Winter PM<sub>2.5</sub>

Emissions from wood combustion have been recognized as a source of significant air quality effects, including efforts to reduce wood-fired emissions on days where particulate concentrations are already high (Vainshtein, 2019). This analysis also found that wood combustion was a significant source of emissions, as discussed in this section. Figure 9 and Figure 11 show that the residential and commercial sectors have almost no effect on ozone concentrations, but Figure 5 and Figure 7 show that they have a substantial contribution to reducing annual PM<sub>2.5</sub> concentrations. Given the large effects, it was important to understand why this effect was occurring. Further analysis was performed to understand the specific source for this contribution.

One indication for this source is the difference between winter and summer effects. Figure 12 and Figure 13 show the changes in PM<sub>2.5</sub> concentration for winter (represented by the January average), for California and the South Coast Basin respectively. These figures show that the combined residential and commercial group contributes as much to PM<sub>2.5</sub> concentrations as all other anthropogenic sources, and in many areas are responsible for the majority of PM<sub>2.5</sub>. However, in the summer results shown in Figure 14 there is a much lower effect (summer is represented by the July average). The emissions for almost all residential and commercial activities are the same throughout the year, except for heating, where 95 percent of emissions occur in the winter vs. 5 percent in the summer. Figure 15 shows that the majority of the annual difference in the South Coast Basin comes from organic aerosol (represented by the organic carbon mass), and Figure 16 shows that this organic carbon is almost exclusively due to primary emissions, and are not due to chemical reactions in the atmosphere that form secondary organic aerosol. Together, these results show that the PM<sub>2.5</sub> benefit due to residential and commercial electrification come primarily from the reduction in directly emitted organic aerosol, which is almost exclusively from residential wood combustion.

As noted in Table 7, this analysis assumed 100 percent electrification of residential wood combustion. This selection was made based on the assumption that since most space heating was electrified, that electrification programs would be focused on wood combustion, which causes the most intensive emissions per unit of heating. However, in addition to the use of wood as a low-cost form of heating, wood fires are also used for ornamental purposes and it is unclear how much activity is attributable to each of these uses. Since completely banning indoor wood combustion is likely infeasible, the proposed 100 percent reduction is unrealistic. However, given the high importance of this source of emissions, this topic should be studied in more detail to create a more representative assumption for likely adoption levels and programs required to achieve high adoption.

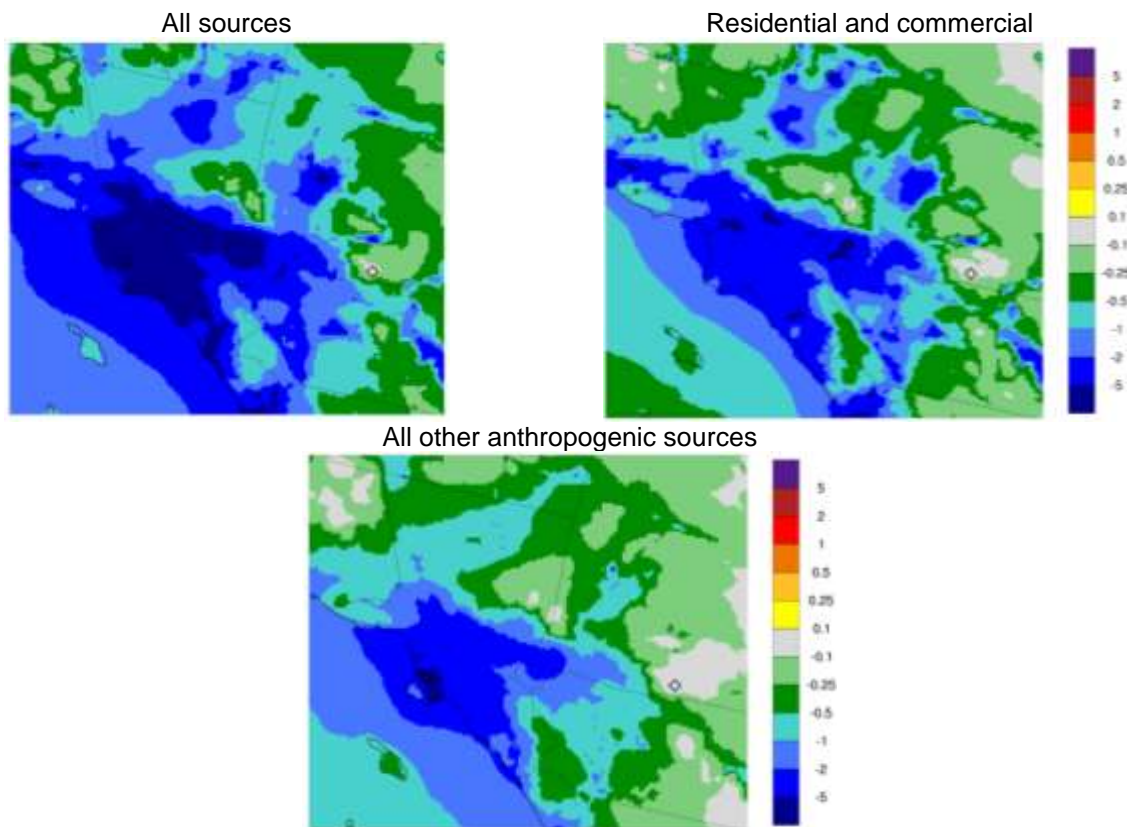
**Figure 12: Contributions to Reductions in Winter PM<sub>2.5</sub> Concentrations for California**



Average for January;  $\mu\text{g}/\text{m}^3$ ; lower is better.

Source: EPRI

**Figure 13: Contributions to Reductions in Winter PM<sub>2.5</sub> Concentrations in the South Coast Basin**

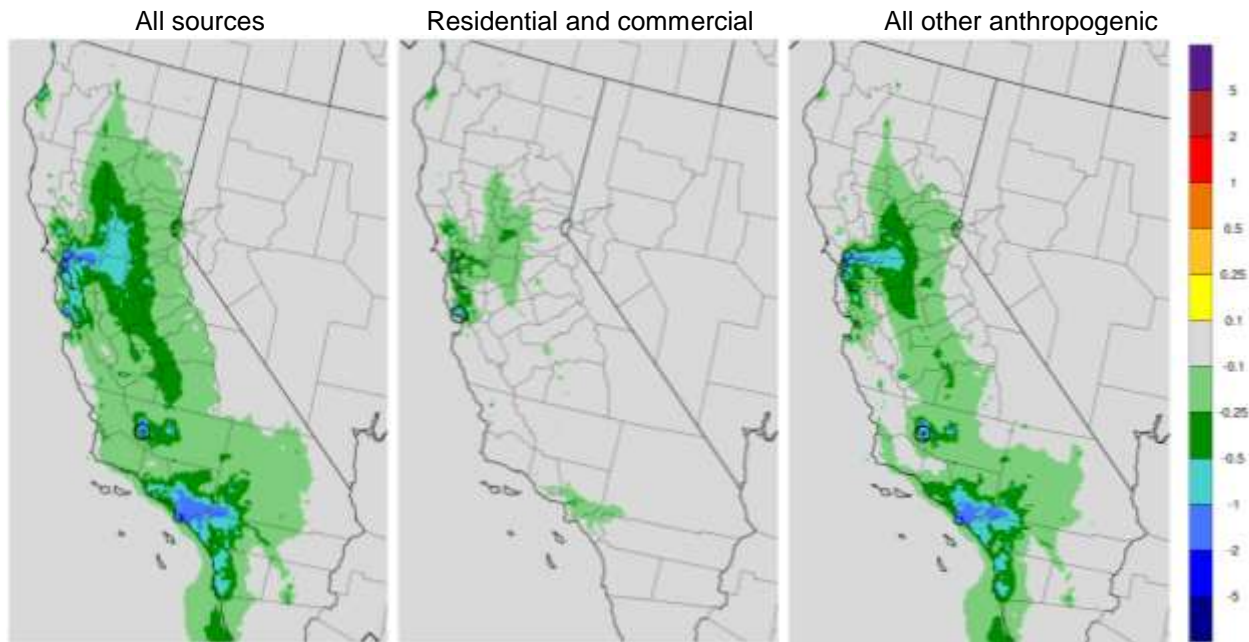


Average for January;  $\mu\text{g}/\text{m}^3$ ; lower is better.

Source: EPRI



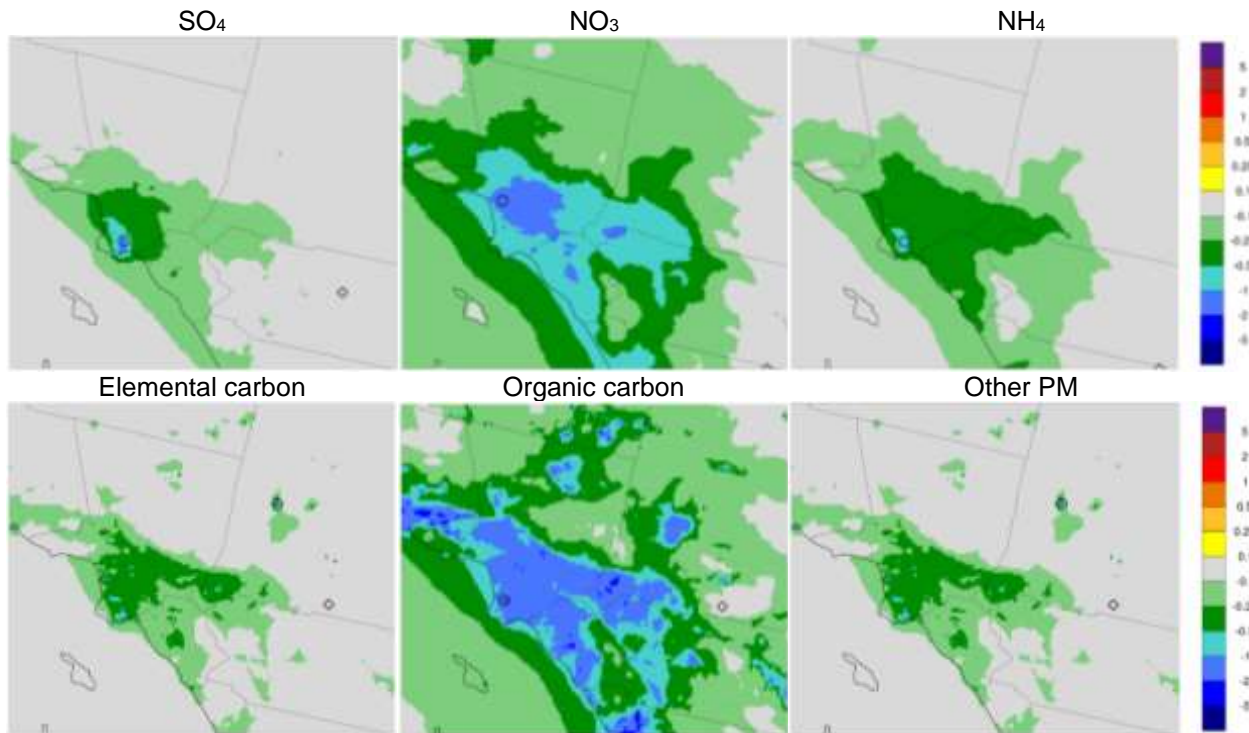
**Figure 14: Contributions to Reductions in Summer Average PM<sub>2.5</sub> Concentrations for California**



Average for July;  $\mu\text{g}/\text{m}^3$ ; lower is better.

Source: EPRI

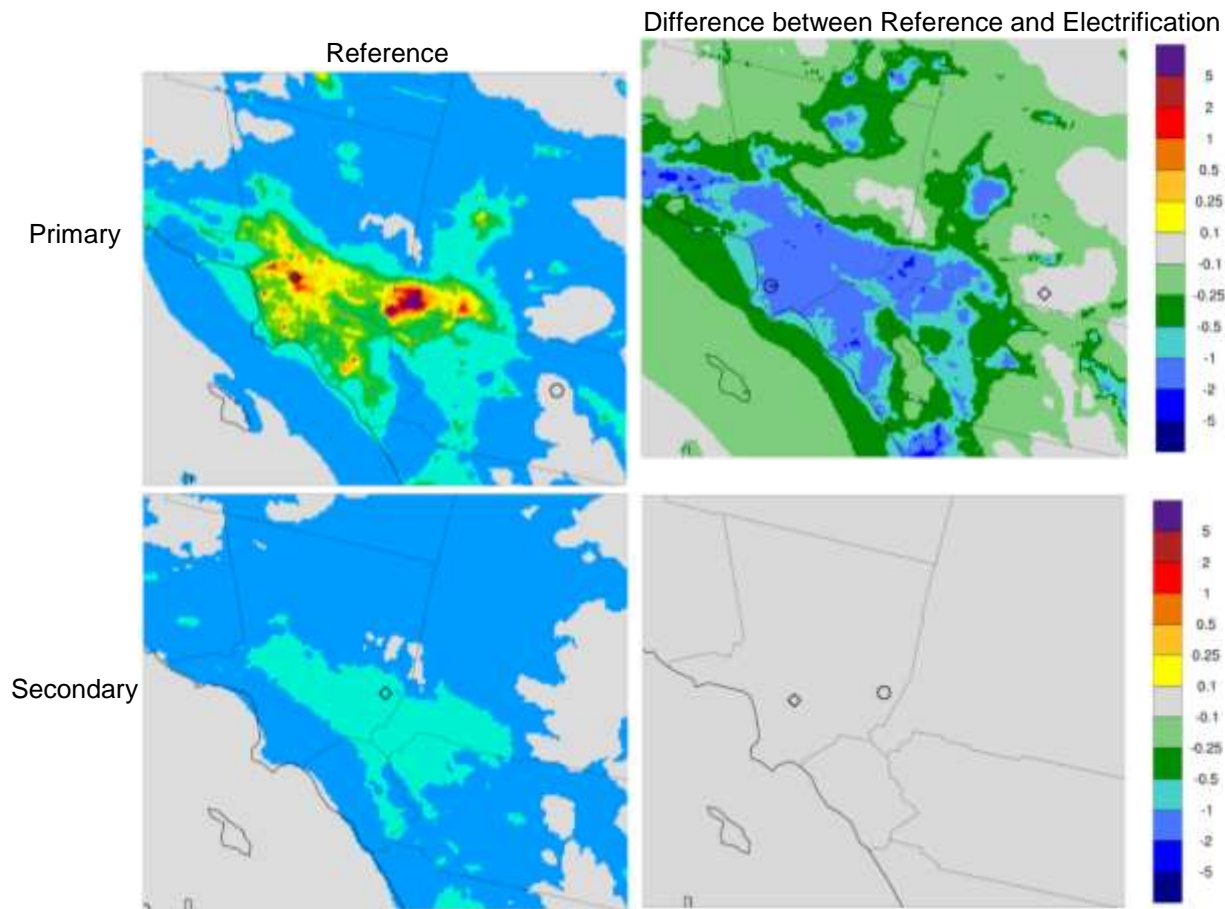
**Figure 15: PM<sub>2.5</sub> Concentrations Separated by Species for South Coast Basin**



Average for year;  $\mu\text{g}/\text{m}^3$ ; lower is better.

Source: EPRI

**Figure 16: Primary vs. Secondary PM<sub>2.5</sub> Contributions in the South Coast Basin for Organic Carbon**



Includes absolute values in the Reference scenario and differences between the Electrification and Reference scenarios (average for year;  $\mu\text{g organic carbon}/\text{m}^3$ ; lower is better).

Source: EPRI

## Health Impacts from Electrification

The pollutant concentrations summarized in the previous section were also processed using the procedure described in Chapter 2. The primary analysis assumed no threshold, but sensitivity analyses assumed varying thresholds for ozone and PM<sub>2.5</sub>. This resulted in the avoided mortality and valuation described in Table 1 and Figure 17 through Figure 20, which show the results for PM<sub>2.5</sub> and ozone, for both California as a whole and for the South Coast Basin. The results parallel the findings for pollutant concentrations described above. The main results, assuming no threshold, indicate an estimated net health benefit of about 6,400 avoided mortalities per year in the South Coast Basin and about 12,300 avoided mortalities per year for California as a whole. This reduction in mortality leads to an estimated net benefit of \$56 billion per year in the South Coast Basin and \$108 billion per year for California as a whole. These benefits do not include changes due to reductions in local emission concentrations (below the 1.33km or 4km grid), so effects for some communities may be higher. The estimated avoided number of deaths due to PM<sub>2.5</sub> reductions are approximately 30 times higher than those from ozone reductions.

The negative health effects from increases in ozone in the mid-coast area of the South Coast Basin are more than balanced by positive benefits from PM<sub>2.5</sub> reductions in all census tracts. The combined effects of ozone and PM<sub>2.5</sub> were shown in Figure ES-4 in the Executive Summary.

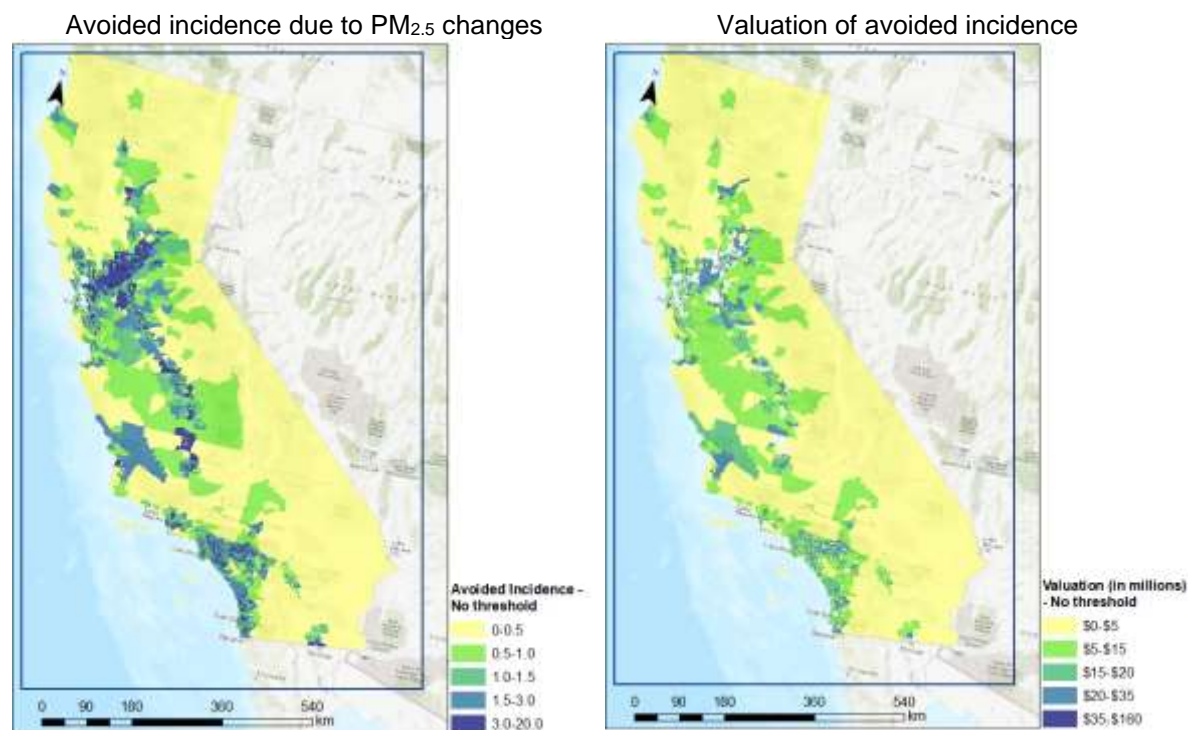
**Table 1: Avoided Mortalities and Associated Valuation from Reduced Ambient PM<sub>2.5</sub> and Ozone Concentrations Resulting from Electrification (Costs in Billions of 2015\$ per Year)**

	South Coast Basin		Rest of California		Total for California	
	Avoided mortalities	Valuation	Avoided mortalities	Valuation	Avoided mortalities	Valuation
PM <sub>2.5</sub>	6,242	\$54.3B	5,746	\$50.1B	11,988	\$104.4B
Ozone	179	\$1.6B	179	\$1.5B	358	\$3.1B
Total	6,421	\$55.9B	5,925	\$51.6B	12,346	\$107.5B

Assumes no threshold.

Source: EPRI

**Figure 17: Avoided Incidence and Valuation of Avoided Incidence from PM<sub>2.5</sub> Concentration Changes for California**

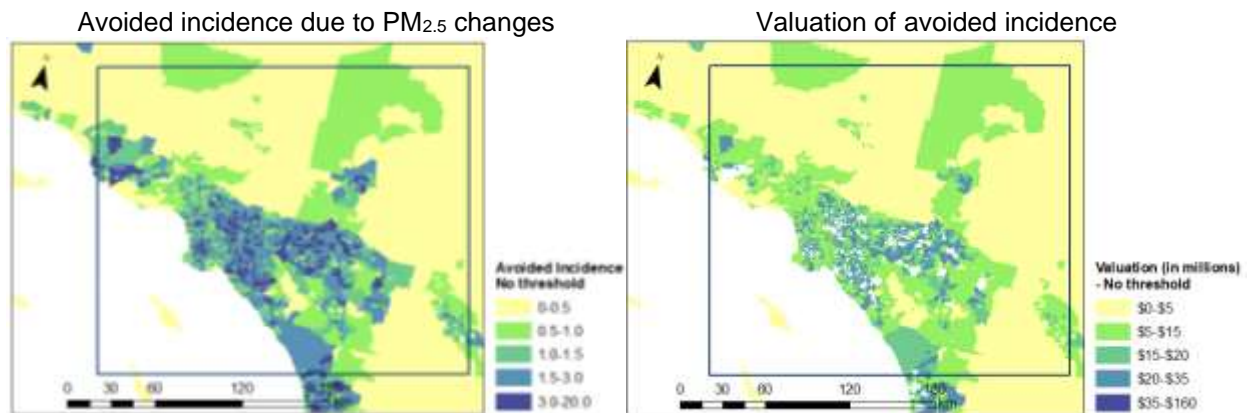


Assuming no threshold. Left: avoided mortalities per year; right: valuation in millions of dollars.

Source: EPRI



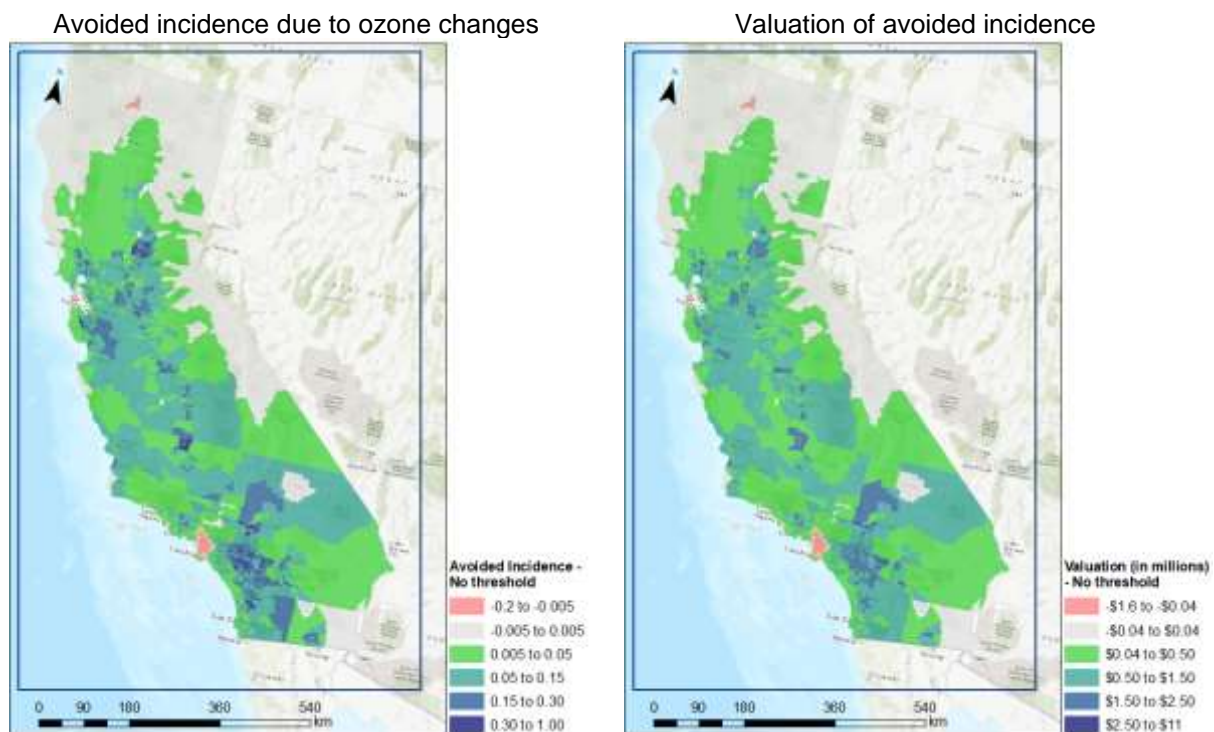
**Figure 18: Avoided Incidence and Valuation of Avoided Incidence from PM<sub>2.5</sub> Concentration Changes for the South Coast Basin (In Millions of Dollars)**



Assuming no threshold. Left: avoided mortalities per year; right: valuation in millions of dollars.

Source: EPRI

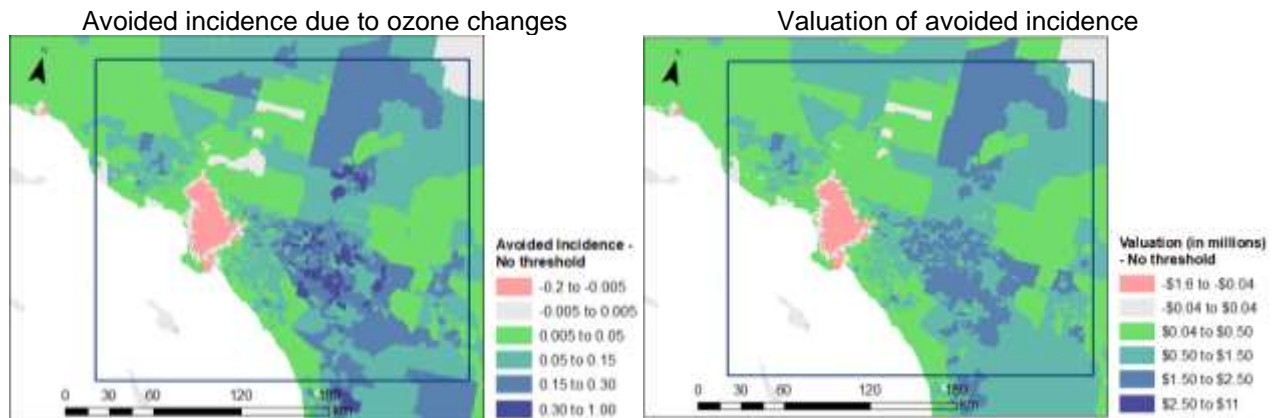
**Figure 19: Avoided Incidence and Valuation of Avoided Incidence from Ozone Concentration Changes for California (In Millions of Dollars)**



Assuming no threshold. Left: avoided mortalities per year; right: valuation in millions of dollars.

Source: EPRI

**Figure 20: Avoided Incidence and Valuation of Avoided Incidence from Ozone Concentration Changes for South Coast Basin (In Millions of Dollars)**

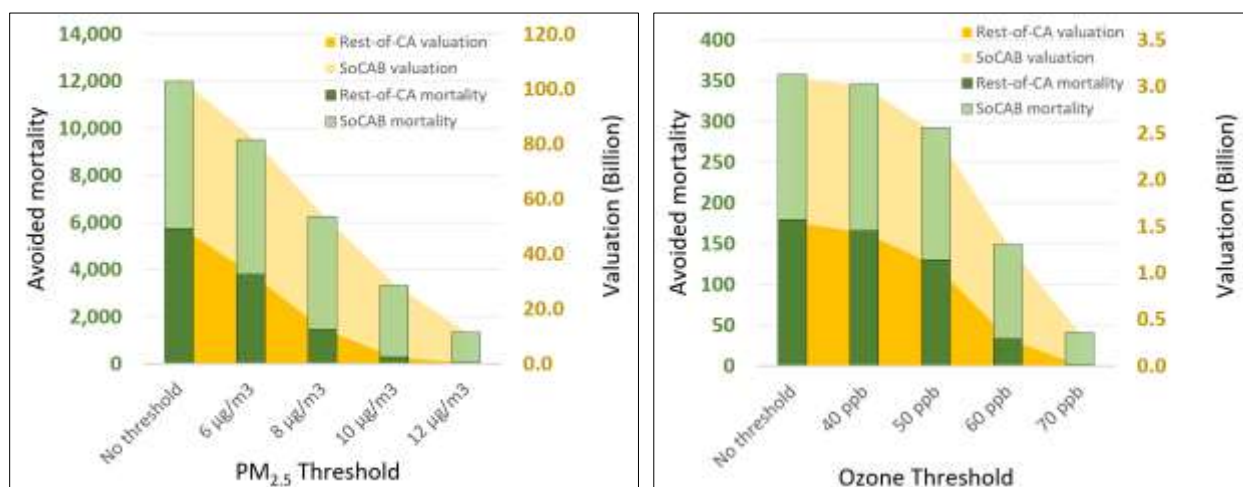


Assuming no threshold. Left: avoided mortalities per year; right: valuation in millions of dollars.

Source: EPRI

Sensitivity analyses were conducted assuming different thresholds for health effects from ozone and PM<sub>2.5</sub>. With higher thresholds for health effects the estimated avoided mortalities changed substantially, as summarized in Figure 21 and shown with details for each pollutant and each threshold in Appendix F. Using the highest threshold for each pollutant can result in a 5 – 9 times lower estimates in avoided mortality or valuation compared to the assumption of no threshold. For example, about 1,300 total deaths might be avoided in California if PM<sub>2.5</sub> has a threshold of 12 µg/m<sup>3</sup>, as opposed to 12,000 deaths when assuming no threshold.

**Figure 21: Avoided Mortality and Associated Valuation from Reduced Long-term PM<sub>2.5</sub> (left) and Ozone Exposure (right)**



Assuming different threshold levels, in the South Coast Basin and the rest of California; the overall height of the bars represents the values for all of California

Source: EPRI

The overall results indicate that PM<sub>2.5</sub> effects are the primary driver of health benefits from reductions in long-term PM<sub>2.5</sub> and ozone concentrations. However, a key observation is the wide variation in benefits estimates that occurs depending on threshold. Additional sensitivity analyses and uncertainty assessment could be conducted; for example, the results use only one concentration-response function for each pollutant, while many others exist and would generate different results.

## Costs of Electrification

To understand the benefits of electrification, it was also important to understand the costs of electrification. These costs depend significantly on assumptions for future fuel costs, greenhouse gas benefits, and transition costs. The study that was the basis for many of the assumptions in this study, Mahone et al. (2018), calculated net electrification costs with a range of assumptions for fuel costs and greenhouse gas benefits. This analysis found that costs span from a net benefit of \$700B if costs are low and benefits are maximum to a cost of \$250B if the opposite is true, with a central estimate of \$25B. This *total* cost is lower than the *annual* air quality benefit of \$108B, and even in the worst case would represent approximately two and a half years of air quality health benefits. More recent work from the same authors (Mahone et al., 2019) indicates that electrification provides a net cost reduction for most single-family and most new low-rise multifamily households. About half of retrofit low-rise multifamily had a lifetime cost increase of \$100 or less per year, and newer technology would decrease costs. Overall, these comparisons indicate that air quality benefits are greater than total costs in benefits, so even high estimations of the cost of electrification are “paid back” quickly.

## Effects on Environmental Justice Communities

Previous work has shown that there is significant inequity between groups that create emissions and groups that experience negative air quality (Tessum et al., 2019; Reichmuth, 2019). This inequity is increased due to differences in income that mean that affected communities are usually unable to move to cleaner areas, have less access to health care, and have less political power to advocate for change. To begin to address this challenge, California created legislation and regulations to measure the effects of pollution and inequality to designate “disadvantaged” communities that should be the focus of particular attention and funding to improve environmental justice. This is currently measured and implemented using CalEnviroScreen 3.0, which uses a variety of pollution and income criteria to identify census tracts that are disadvantaged communities (CalEPA, 2019). To understand the potential benefits of electrification for disadvantaged communities, the monetized air quality benefits analyzed separately for disadvantaged census tracts as identified in CalEnviroScreen 3.0. As shown in Table 2, benefits are approximately in line with population, with fewer benefits from ozone reductions and more benefit from PM<sub>2.5</sub> reductions. Due to the larger effects of PM<sub>2.5</sub>, the total benefits in disadvantaged communities are approximately 28 percent of the total, relative to 25 percent of the population who currently live in disadvantaged census tracts based on CalEnviroScreen. Figure 22 shows the health benefits from the analysis above, but for disadvantaged census tracts only. Notably, all disadvantaged census tracts experience some

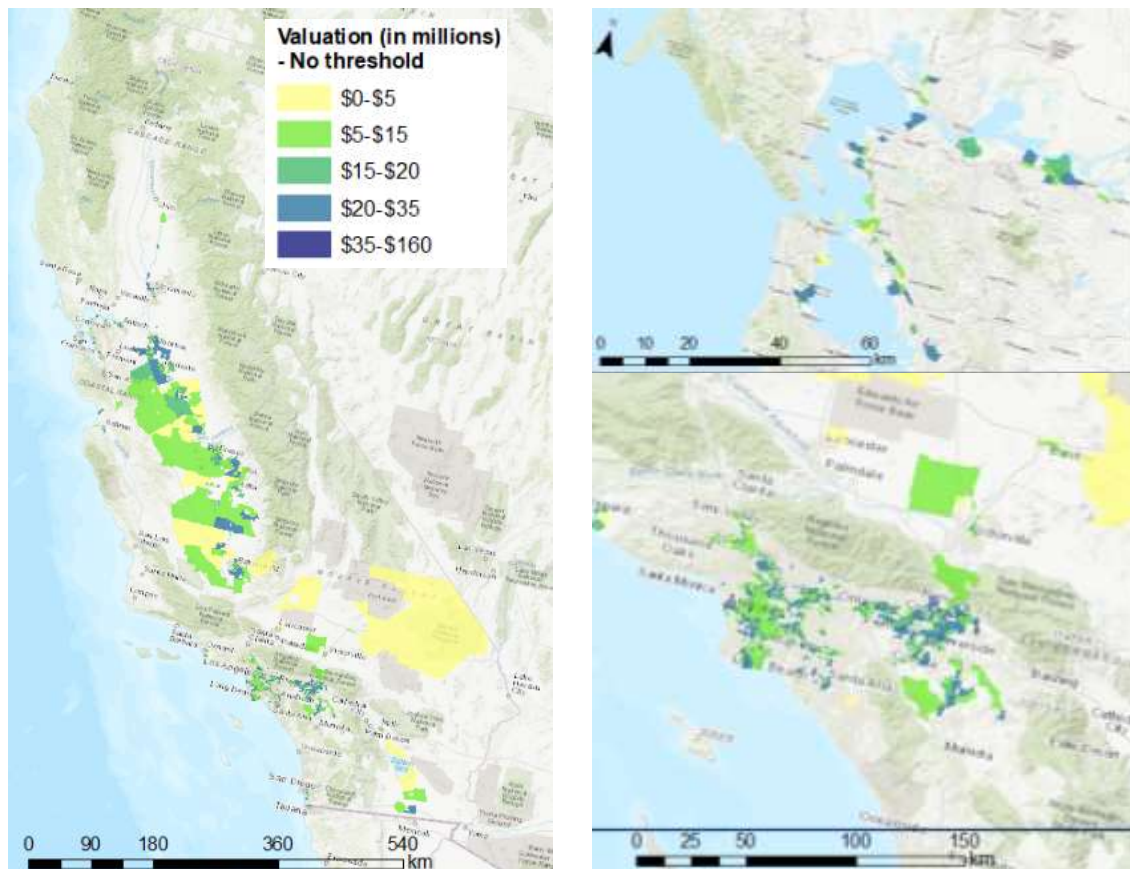
benefit. Table 3 shows the monetized benefits for PM<sub>2.5</sub>, by sector and by threshold for disadvantaged communities, and Table 4 shows the share for disadvantaged communities. These indicate that since disadvantaged communities tend to start with higher pollution levels, if a threshold was used the benefits would concentrate in these communities. Additionally, the benefits from the on-road transportation, non-road transportation, industrial, and other anthropogenic sectors are higher in disadvantaged communities than the population share (25 percent), but are offset by the residential and commercial sector, which has a lower disadvantaged share.

**Table 2: Air Quality Benefits for Disadvantaged Communities**

	Population	Ozone benefits	PM <sub>2.5</sub> benefits	Total benefits
Disadvantaged	9.4M	\$0.6B/year	\$30B/year	\$31B/year
Total	37.3M	\$3B/year	\$104B/year	\$108B/year
% disadvantaged	25%	20%	29%	28%

Source: EPRI

**Figure 22: Valuation of Health Effects for Disadvantaged Census Tracts for California (left), the Bay Area (right upper), and the South Coast Basin (right lower)**



Source: EPRI

**Table 3: Monetized PM<sub>2.5</sub> Effects for Disadvantaged Communities, for Selected Sectors and Thresholds**

	<b>Total</b>	<b>On-road transport</b>	<b>Non-road transport</b>	<b>Residential and comm.</b>	<b>Industrial</b>	<b>Other anthropogenic</b>
No threshold	\$29.9B	\$4.3B	\$3.2B	\$15.0B	\$5.5B	\$1.4B
6ug/m3	\$27.4B	\$4.0B	\$3.0B	\$13.5B	\$5.1B	\$1.3B
8ug/m3	\$22.0B	\$3.4B	\$2.6B	\$10.3B	\$4.4B	\$1.0B
10ug/m3	\$15.0B	\$2.4B	\$1.8B	\$6.5B	\$3.3B	\$0.7B
12ug/m3	\$7.1B	\$1.2B	\$0.9B	\$3.0B	\$1.7B	\$0.3B

Monetary benefits are per year in 2050

Source: EPRI

**Table 4: Share of PM<sub>2.5</sub> Effects for Disadvantaged Communities Relative to All Communities, for Selected Sectors and Thresholds**

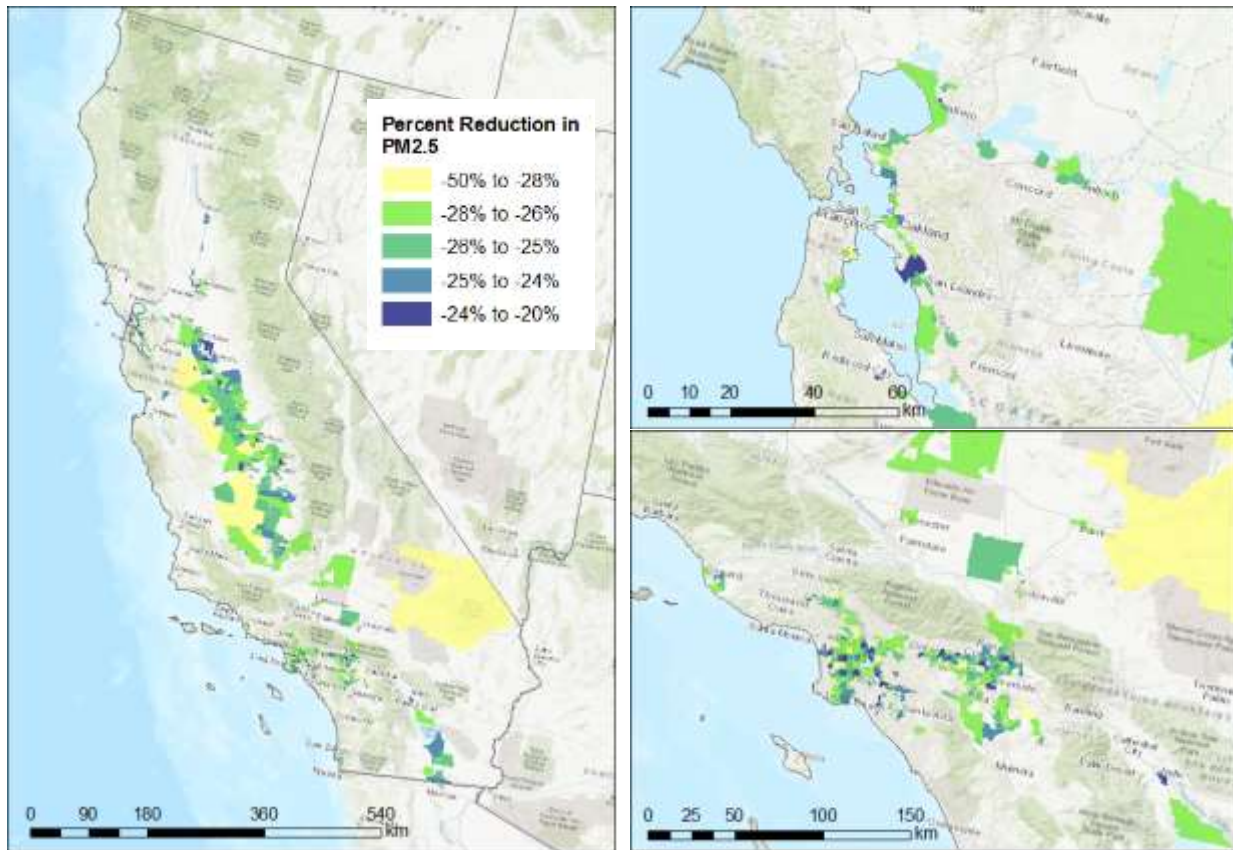
	<b>Total</b>	<b>On-road transport</b>	<b>Non-road transport</b>	<b>Residential and comm.</b>	<b>Industrial</b>	<b>Other anthropogenic</b>
No threshold	<b>29%</b>	33%	33%	25%	36%	31%
6ug/m3	<b>33%</b>	36%	36%	30%	40%	34%
8ug/m3	<b>40%</b>	43%	43%	37%	46%	41%
10ug/m3	<b>52%</b>	53%	54%	48%	56%	53%
12ug/m3	<b>61%</b>	62%	62%	59%	66%	64%

Source: EPRI

An additional air quality concern in disadvantaged communities is the level of PM emissions from on-road vehicles, particularly diesel engines. Although Table 4 shows large-scale transportation PM<sub>2.5</sub> effects, these direct emissions from vehicles tend to concentrate locally, so have effects beyond those seen in large-scale air quality modeling. Figure 23 shows the effects of electrification on on-road PM<sub>2.5</sub> emissions in disadvantaged census tracts. All disadvantaged census tracts experience some reductions, with typical reductions of 20-28 percent.



**Figure 23: Percentage Change in On-road PM<sub>2.5</sub> Emissions for Disadvantaged Census Tracts for California (left), the Bay Area (right upper), and the South Coast Basin (right lower)**



Source: EPRI

## Overcoming Barriers to Electrification

### Barriers to Electrification of On-road Transportation

On-road transportation is a broad category that includes personally owned cars, delivery trucks, buses, and semi-trailer trucks. In California, the on-road transportation sector is the largest source of greenhouse gas emissions, at 40 percent in 2016 (CARB, 2018a), and the third largest source of NO<sub>x</sub> for California in this analysis, with 23 percent share in 2050. The electrification potential for light-duty vehicles is quite high, and the potential even for heavier vehicles is promising based on current trends, so high levels of electrification were assumed, as shown in Table 5 (development of these assumptions is discussed in Appendix C). As discussed, reductions in emissions from on-road transportation has the potential to provide substantial reductions in air quality and improvements in health.

**Table 5: 2050 Adoption Levels for Each On-road Transportation Fuel Use Category**

Fuel use category	Electrification share	Fuel use category	Electrification share
Combination long-haul	80%	Passenger truck	93%
Combination short-haul	80%	Transit bus	88%
Intercity bus	88%	Refuse truck	80%
Light commercial truck	85%	School bus	88%
Motor home	80%	Single unit long-haul	66%
Motorcycle	93%	Single unit short-haul	66%
Passenger car	93%		

Source: EPRI

This discussion will focus on medium- and heavy-duty trucks. Light-duty vehicles are currently the largest source of greenhouse gas emissions, but California has a suite of policies in place, including the Zero Emissions Vehicle Mandate, greenhouse gas vehicle fleet limits (AB1493, commonly called “Pavley”; currently implemented as part of the National Plan), and a variety of incentives for PEV purchases and supporting infrastructure. Although there is still much work to do to ensure the success of light-duty electrification, it is assumed that these efforts will be successful within the 2050 timeframe due to the widespread focus on this vehicle category. In other vehicle categories, the situation is more complex. This section will focus on overcoming barriers to medium- and heavy-duty electrification.

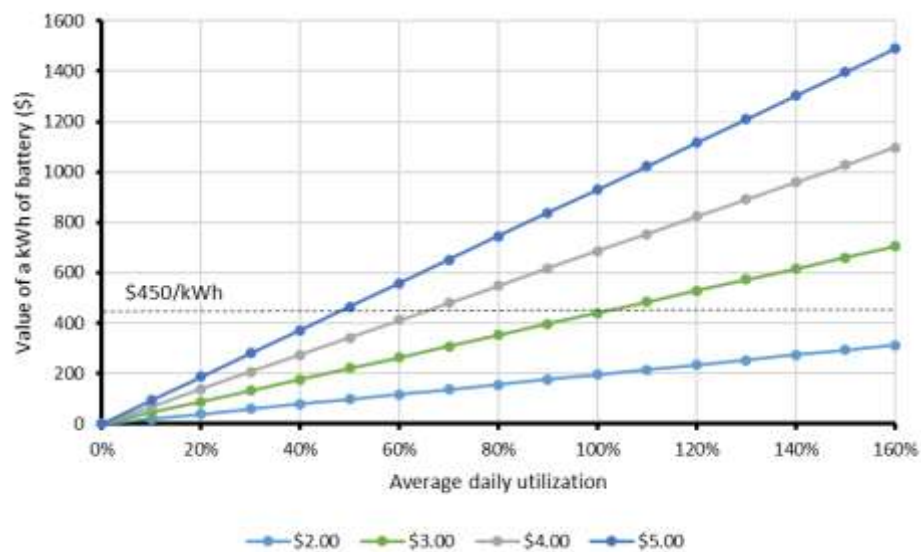
Medium- and heavy-duty vehicles are typically purchased by governments or business for use in fleets. Fleets have a variety of purposes, including passenger transport, cargo delivery, and to transport or act as on-site tools (for example a utility bucket truck, which is equipped to facilitate access to an elevated power line and transports the required parts for repair). In each case, the vehicles are generally mission-critical, so it is important for these vehicles to meet power and energy requirements. This can be an advantage or a disadvantage – transit buses have high loads, but a relatively regular driving pattern. Other vehicle types may have less load, but highly variable driving patterns. The primary barrier to electrification for these vehicles is the lifecycle costs of batteries that will meet the full mission profile.

Figure 24 shows how this variation in use can affect the relative economics of electrification. The horizontal axis represents the variation in daily utilization; a battery with 0 percent use is never economic, while a battery that is 100 percent used each day is economic even with relatively high battery prices.<sup>8</sup> Note that with mid-day charging, 100 percent “utilization” could be exceeded. Currently diesel in California is about \$4/gallon (EIA, 2018) and the marginal cost

<sup>8</sup> The analysis assumes electric drive is 3.5 times more efficient than diesel drive, electricity is \$0.10/kWh, charging efficiency is 90%, there are 300 work days in a year, battery life is 12 years (regardless of cycles), and the discount rate is 5%.

of batteries in this segment are about \$450/kWh (NYSEV-VIF, 2018; based on the price difference between the 330 kWh and 440 kWh Proterra buses), so an average daily use of about 65 percent would be required to break even. However, even costs higher than this marginal rate can be accommodated in full vehicles since BEV powertrains without battery are generally cheaper than comparable conventional powertrains. For example, a recently released electric delivery vehicle with a range of 100 miles is expected to have “comparable” up-front costs to conventional vehicles (Hanley, 2018). With decreased fueling costs and maintenance costs, the lifecycle costs of this vehicle should be much lower than a comparable conventional vehicle. In this example, the unknowns are how wide the application is for delivery vehicles with 100 miles of range, and how this will change in the future.

**Figure 24: Marginal Value of a kWh of Battery vs. Average Daily Use and the Cost of a Gallon of Diesel**



Source: EPRI

This cost tradeoff indicates that the barriers to on-road electrification will largely be addressed through reduced battery prices, which are occurring gradually (BNEF, 2019). In addition to economics, there is significant policy pressure to reduce emissions from these vehicles. For example, the California Air Resources Board has recently set a statewide goal of 100 percent electrification of bus fleets by 2040 (CARB, 2018b), and is pursuing reductions in other medium-duty and heavy-duty categories.<sup>9</sup>

## Barriers to Electrification of Non-road Transportation

Non-road transportation includes a variety of mobile devices or devices related to transportation, including ships, rail, airplanes, forklifts, truck anti-idling devices, and lawn and garden equipment. In California, the non-road transportation sector is responsible for

<sup>9</sup> For example, please visit <https://www.arb.ca.gov/msprog/ict/ict.htm> and <https://ww2.arb.ca.gov/our-work/programs/zero-emission-airport-shuttle> for discussion of ongoing programs



approximately 3 percent of 2016 greenhouse gas emissions (CARB, 2018a) and is the largest source of NO<sub>x</sub> in California in this analysis with 36 percent share in 2050. The electrification potential for non-road devices varies substantially between devices types, from 100 percent for some categories to 0 percent for others. The assumptions for electrification levels in this study are shown in Table 6 below (the development of these assumptions is discussed in Appendix C). There have been additional developments since this analysis was started which indicate that some of the categories previously considered “out of reach” may have much more potential than previously estimated. For example, one manufacturer of construction equipment has recently announced that they plan to stop development of new diesel engine-based versions of some models of equipment and will power them with electricity instead (Lambert, 2019).

**Table 6: 2050 Adoption Levels for Each Non-road Transportation Fuel Use Category**

Fuel use category	Electrification share	Fuel use category	Electrification share
Agricultural	15%	Other non-road	0%
Aviation	10%	Rail	0%
Construction and mining	0%	Rail (yard)	100%
Forklift	100%	Recreational equipment	0%
Ground support equipment	100%	Recreational marine	25%
Lawn and garden	100%	Refrigeration	100%
Marine	10%	Terminal tractor	100%
Marine (port)	100%	Truck auxiliary power unit	100%

Source: EPRI

Achieving non-road electrification will require a combination of new products, education, incentives, and regulation. Forklifts are an example of an application where this combination has been successful and should be instructive for development of future implementation programs.

Electric forklifts have existed for a long time and found applications within cargo handling even without a focus on emissions or energy use as the economics and performance exceed that of liquid-fueled forklifts (EPRI, 2017). Electric forklifts have no direct emissions, so they can be used indoors without special air handling, and forklifts generally require weight for counterbalance, so low-technology batteries and motors were sufficient for a wide variety of low-weight-capacity and low-use applications. The development over time has been towards higher weight capacities and higher utilization. This occurred first through battery swapping

and fast charging of older-technology batteries and more recently through the introduction of high-technology batteries and high-quality motor drives. These improved products have enabled high degrees of market adoption, to the point where all forklift applications will be electrifiable in the near future.

Even though electric forklifts have been available for a wide array of applications for decades, there are still misunderstandings about the capabilities and costs of electric forklifts, so education efforts continue to be necessary. For one thing, the upfront costs of electric forklifts are in general higher than for internal combustion units, even though savings occur over time through reduced maintenance and fuel costs. To educate the customer on this tradeoff, EPRI created tools to help customers determine the total cost of ownership, or life-cycle costs, for the various options.<sup>10</sup> This tool shows that in some cases payback for the electric option occurs within a year, so even customers that have relatively low tolerance for capital expenditure should consider electrifying.

In addition to education, incentives and financing can be important tools to increase adoption. Incentives can come from a variety of sources, including utilities. A variety of electric forklift incentive programs have been implemented by electric utilities, ranging from hundreds to thousands of dollars per forklift, depending on the size of the forklift and expected load over time. For example, the Sacramento Municipal Utility District has an electric forklift purchase incentive of \$2,000 for the customer and \$1,000 for the vendor (SMUD, 2019a). In Southern California, the South Coast Air Quality Management District has a program to incentivize electrification of commercial and residential lawn and garden equipment (South Coast AQMD, 2019). In addition to direct incentives, financing programs like leases can reduce the up-front cost hurdle, reduce the level of commitment necessary to try electric options, and can include costs like maintenance and repair to create a more stable monthly cost.

Finally, regulation can be an important tool in reducing overall emissions. The California Air Resources Board has created a program that assigns emissions scores to different ages and capacities of forklifts and requires forklift operators to achieve a fleet average score (CARB, 2016). Electric forklifts have a score of 0.0 regardless of size, so electrifying at least part of a fleet can contribute substantially towards compliance.

## **Barriers to Residential Electrification**

Electrification of homes will be an important part of achieving low greenhouse gas emissions in California. The residential sector accounts for 6 percent of statewide 2016 greenhouse gas emissions in 2017 due mainly to natural gas combustion (CARB, 2018a; in this discussion “natural gas” includes homes supplied with propane). Residential emissions are a substantial source of PM<sub>2.5</sub>, as discussed in detail above. Additionally, combustion of all fuels within a house can cause indoor air quality problems. Indoor air quality is not analyzed in this report, but previous work has shown that natural gas cooking can significantly degrade indoor air quality compared to use of electric cooktops, particularly for smaller houses (Mullen et al., 2015). Further, using inefficient heating appliances in poorly insulated homes can lead to high

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<sup>10</sup> EPRI electric forklift tools, available at: <http://et.epri.com/Calculators.html> (accessed 3/19/2019).

energy expenses, which can mean that members of low-income communities spend a high share of their income on heating or need to forgo heating to afford other expenses. Table 7 shows the electrification assumptions used in this report.

**Table 7: 2050 Adoption Levels for Residential Electrification Categories**

Residential	Heating	99%
Residential	Space heating	83%
Residential	Wood heating	100%

Source: EPRI

The primary uses of natural gas or propane is space heating and water heating, with some households also using wood for space heating. Houses that have natural gas these fuels for cooking, clothes drying, and other miscellaneous uses like outdoor grills. Electrified alternatives exist for each of these appliances, as shown in Table 8. Many of the less efficient appliances already have widespread deployment, but high-efficiency appliances are increasingly available to replace both natural gas appliances and less efficient electric appliances.

**Table 8: Electric Appliances for Residential Applications**

Application	Less efficient electric appliance	More efficient electric appliance
Space heating	Resistance strip heaters	Heat pumps
Water heating	Resistance water heaters	Heat pump water heaters
Cooking	Resistance cooktops and ovens	Induction cooktops and convection ovens
Clothes drying	Resistance clothes dryers	Heat pump driers and ultrasonic driers
Miscellaneous	<i>Application-dependent</i>	<i>Application-dependent</i>

Source: EPRI

Although these high-efficiency electric appliances generally have low operating costs and no direct emissions, they often have higher up-front costs than comparable natural gas appliances. However, the service costs for plumbing natural gas in a home and installing exhausts are substantial, so for new construction recent analyses indicate that a fully electrified house will have lower overall costs than a house with gas appliances (Billimoria et al., 2018). These households will also have lower operating costs, resulting in a win-win. There are still substantial informational barriers to be overcome so that homebuyers understand the benefits of electrification and the performance of electric options will have to be demonstrated to change customer preferences for natural gas in some applications like cooking, but given the costs benefits there is the potential for widespread electrification of new-construction housing. Unfortunately, the costs for retrofits are substantially higher.

These costs are reflected in the electrification incentives for Sacramento Municipal Utility District, which are \$11,750 if all appliances are replaced, a panel upgrade is performed, and efficiency improvements are implemented (SMUD, 2019b, 2019c). Activity is increasing to reduce statewide building emissions, including forming the Building Decarbonization Coalition, a joint collaboration between government, environmental organizations, and industry. For example, the Natural Resources Defense Council (NRDC) and the Building Decarbonization Coalition have jointly created a specification for “retrofit-ready” heat pump water heater that can be plugged into a shared 120V outlet, reducing the need for conduit or a panel upgrade to support electrification of water heating (Larson, 2019).

## **Barriers to Industrial Electrification**

There are many opportunities for industrial electrification, but the diversity and proprietary nature of industrial processes means that many different technologies will have to be developed to address this sector. A recent EPRI study explored nationally the major industrial fossil-fueled processes with commercially viable electric technology alternatives (this analysis was used internally for opportunity assessment but was not published). A total of 34 electric process technologies were identified along with their applicable markets, process end-uses, energy and non-energy benefits and hurdles for adoption. Appendix G discusses the application of these technologies to electrification in California in more detail.

Electrifying the industrial sector will require understanding the potential barriers to adoption. Adoption of electric technologies within the industrial and agriculture sectors is typically not predicated on the energy cost savings benefits unless those savings are substantial and energy is a relatively high constituent cost of production. Even the best business case can be stymied by misconceptions or a lack of accurate information needed to overcome these potential roadblocks:

- Process or business risks and uncertainties
- Skepticism about whether the technology will deliver the promised benefits
- Cost of development/introduction/implementation
- Lack of knowledge or expertise
- Uncertain demand for products that will rely upon the technology
- Limited access to capital
- Customer decision-making
- Competing investments with better perceived returns
- Reluctance to change existing processes
- Gaps in labor skills
- Compliance requirements or uncertainties

Overcoming these barriers will require considerable industry-specific efforts. In addition to economics, the potential for improved productivity and other non-energy benefits are important. Examples of potential non-energy benefits are:

- Reduced raw materials and feedstock requirements
- Reduced production waste and rejects
- Improved product quality
- Reduced facility expenses (floor space, HVAC)
- Improved health and safety
- Reduced waste management and treatment costs/risk
- Improved throughput, yield or productivity
- Improved labor use (and training)
- Reduced energy use and costs
- Reduced environmental footprint
- Support of LEAN manufacturing objectives
- Reduced inventory investment
- Reduced downtime

Targeted electrification can help to address each of these, while reducing greenhouse gas emissions and improving air quality.

# **CHAPTER 4:**

## **Technology/Knowledge/Market Transfer Activities**

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As the project concludes in 2019, sharing the results will be of utmost importance. The knowledge gained during the project will be contained in a publicly available EPRI technical report. First, the final report, complete with a readable executive summary, will be published. Second, EPRI plans to publish the results in a trade journal. Further, the knowledge also will be summarized in a presentation that is technically deep as well as easy to understand by a layperson. This latter point is important since many of the stakeholders may not have the same background or training as the report's authors. Both the report and the presentation will be shared with all key stakeholders in California via direct presentation, webinar, or other method at no cost.

As part of its public mission, EPRI hosts international, national, state, and regional Electrification conferences and symposia. These events are also an opportunity for EPRI to share the results of this project to a broad audience.

### **Key Stakeholders**

The following key stakeholders will be informed of the results of this work and will be briefed if requested. Government stakeholders include California Energy Commission, the California Public Utility Commission, and the State of California Governor's office as well as state legislators and their staff.

Second, the air quality management districts such as the Bay Area AQMD, the South Coast AQMD, the San Joaquin AQMD, as well as other AQMDs (for example North Coast) are an important group of stakeholders. These stakeholders will also be contacted to inquire about their interest for an individualized presentation, either in-person or via webcast.

Next, the electric utilities such as Pacific Gas and Electric Company, San Diego Gas & Electric, Southern California Edison, Sacramento Municipal Utility District, Los Angeles Department of Water and Power, Burbank Water and Power, the myriad of municipal irrigation districts, and other public municipal utility groups.

In addition, key non-governmental organizations play a vital role in transportation electrification. Some examples include the (former) California EV Collaborative (now known as Veloz), NRDC, Union of Concerned Scientists, the Sierra Club, and Clean Cities. Other key non-governmental organizations include the various environmental justice organizations in Northern, Southern, and Central California.

Finally, automotive original equipment manufacturers will also receive the report and an offer to join a webcast or presentation. This includes General Motors, Ford, FCA, BMW, VW Group (including Porsche and Audi), Mercedes-Benz, Hyundai/KIA, Honda, Toyota, and Nissan.

## Type of Briefings

A combination of briefings will be available starting with individual (to the agency) in-person briefings for the government departments and agencies. In addition, an in-person presentation at a meeting of Veloz, formerly known as the California PEV Collaborative. The Collaborative includes about 40 of the primary stakeholders in the EV industry.<sup>11</sup> EPRI will offer at such presentations to do follow-on individual presentations, either in-person or via webcast.

Further, there are more than 10 public events hosted by EPRI from 2019-2020, each of which provides an opportunity for EPRI to present these results. These include a California Electrification workshop to be held in Berkeley in June 2019, a New York workshop scheduled for late August 2019, and a Texas workshop in San Antonio scheduled for early October 2019, as well as the EPRI International Electrification Conference set for Paris in mid-October 2019 and the EPRI Electrification Conference to be held in Raleigh in April 2020. In addition, for most of the past three decades, EPRI's Electric Transportation group hosts three public working councils: The Electric Vehicle Infrastructure Working Council (IWC). Electric utilities, automakers, charging station companies, electric bus and truck companies, hardware manufacturers, national labs, and government representatives all have previously attended this public meeting.

## Use

The end users will be able to incorporate the results of the Energy Commission-EPRI Electrification study in key discussions in California. Some of the events mentioned above will be held outside of California, but this education benefits California as it helps increase knowledge of the project's results and hence increases the potential to scale, speeding up implementation, and driving down prices over time.

## Publication

EPRI will release the report via its normal media channels including posting to the [www.epri.com](http://www.epri.com) website, as well as Twitter and other social media accounts. EPRI will highlight the report on its public website and publish a summary and link to the report in the bi-monthly Electric Transportation newsletter. In addition, downloads will be tracked monthly. Public requests for project results will also be tracked. Lastly, EPRI is completely open to communicating with additional stakeholders and/or in additional methods and medium as determined by the Energy Commission. Since the report and presentation will both be publicly available at no cost, any stakeholder – whether an individual or a large organization – can easily download the results, review them, and apply them.

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<sup>11</sup> For more information on Veloz, please see: <http://www.pevcollaborative.org/members>.

# CHAPTER 5:

## Conclusions/Recommendations

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This chapter discusses the primary conclusions of this analysis and recommendations for accelerating electrification in California.

### Conclusions

At a high level, this analysis shows:

- Electrification has the potential to significantly improve air quality, which will benefit health.
- Wood-fired heating has an outsized impact on winter air quality.

These will be discussed in more detail in the following subsections.

### Electrification Has the Potential to Significantly Improve Air Quality Benefitting Health

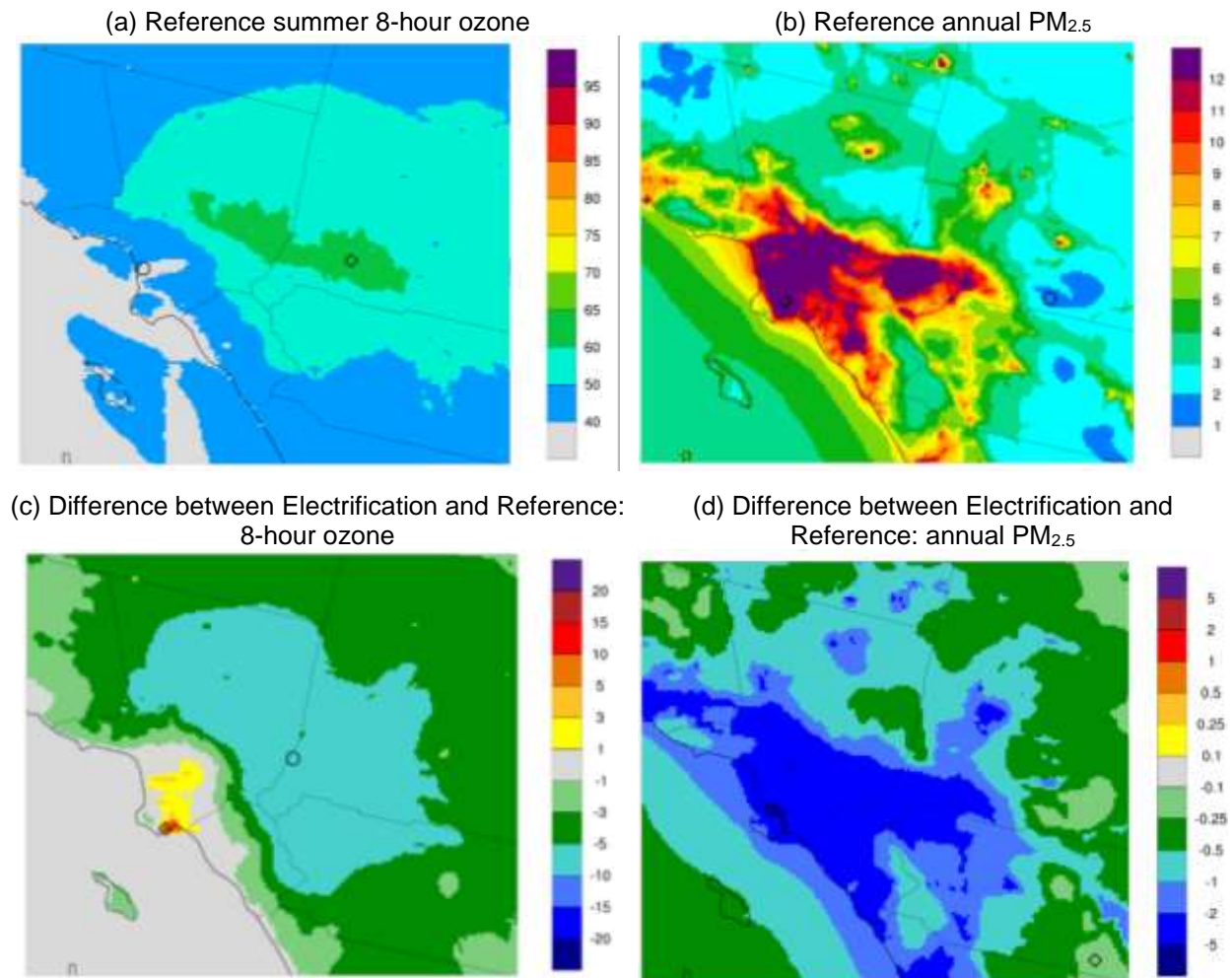
The 2050 Reference scenario shows summer average maximum daily 8-hour average (MDA8) ozone below 65 ppb in the South Coast Basin and mostly below 50 ppb in the rest of California (the current 8-hour ozone standard is 70 ppb; this is based on a different metric but provides a reference level). Ozone reductions due to electrification exceed 5 ppb in most of the South Coast Basin and reach 10 ppb in Pomona (Figure 25). Other areas of California also see ozone reductions, about 3-5 ppb in central California and less than 3 ppb elsewhere, but they are widespread. Decreases in on-road sector emissions drive most of these ozone reductions. Ozone increases occur in an area near Long Beach and central Los Angeles where ozone is suppressed by high NO<sub>x</sub> emissions in the Reference scenario and consequently reductions in NO<sub>x</sub> emissions causes ozone to increase. These increases are mostly lower than 3 ppb but increases of more than 10 ppb are predicted in a few grid cells near Long Beach where the Reference scenario summer MDA8 ozone is below 40 ppb, that is, ozone increases occurred in areas with low ozone levels in the Reference scenario.

The 2050 Reference scenario shows annual average PM<sub>2.5</sub> above 12 µg/m<sup>3</sup> in the South Coast Basin and other urban areas (this is the current primary PM<sub>2.5</sub> standard). PM<sub>2.5</sub> in these areas is mostly comprised of primary organic aerosol and crustal material with additional contributions from nitrate. Electrification reduces PM<sub>2.5</sub> (Figure 25 and Figure 26) everywhere in California, by more than 2 µg/m<sup>3</sup> in large areas of South Coast Basin and up to 14.7 µg/m<sup>3</sup> near Long Beach. In winter months, electrification of residential and commercial sources (for example, replacing fireplaces and wood stoves) dominates PM<sub>2.5</sub> benefits, up to 8 µg/m<sup>3</sup> annual average reduction in Sacramento, by reducing primary organic aerosol emissions. Electrification of industrial sources offers widespread PM<sub>2.5</sub> reductions of more than 0.5 µg/m<sup>3</sup> in the South Coast Basin, San Francisco Bay Area, and Bakersfield areas. Electrification benefits from reduced on-road and off-road emissions are seen in urban areas and mostly are lower than 1 µg/m<sup>3</sup>.



These air quality improvements lead to \$108 billion in annual health benefits in 2050.

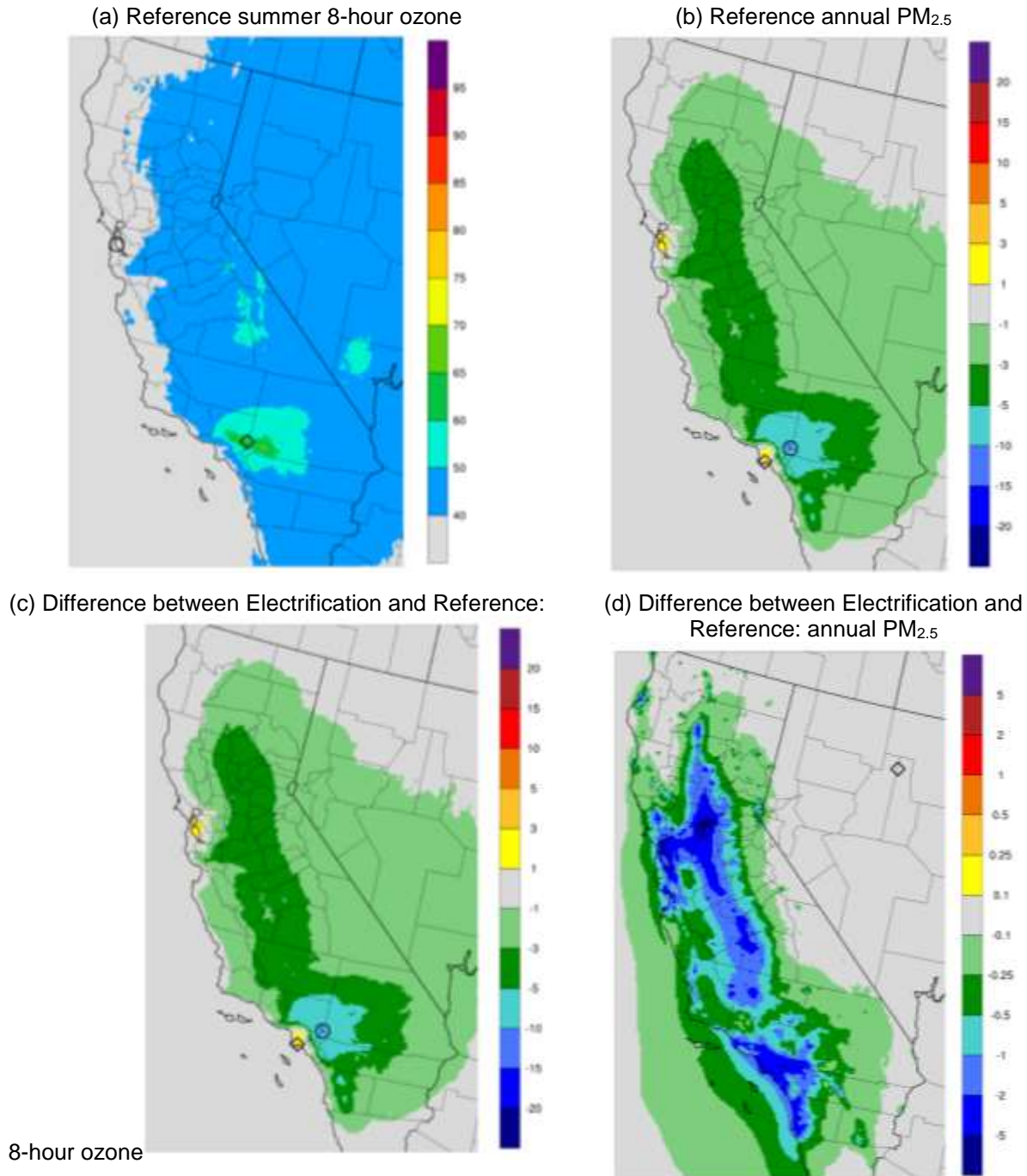
**Figure 25: Summer Maximum Daily Average 8-hour-Ozone (ppb) and Annual PM<sub>2.5</sub> (µg/m<sup>3</sup>) for Different Scenarios in South Coast Basin**



Reference scenario (a and b) and difference between Electrification scenario and Reference scenario (c and d) in South Coast Basin.

Source: EPRI

**Figure 26: Summer Maximum Daily Average 8-hour-Ozone (ppb) and Annual PM<sub>2.5</sub> (µg/m<sup>3</sup>) for Different Scenarios in California**



Reference scenario (a and b) and difference between Electrification scenario and Reference scenario (c and d) in California

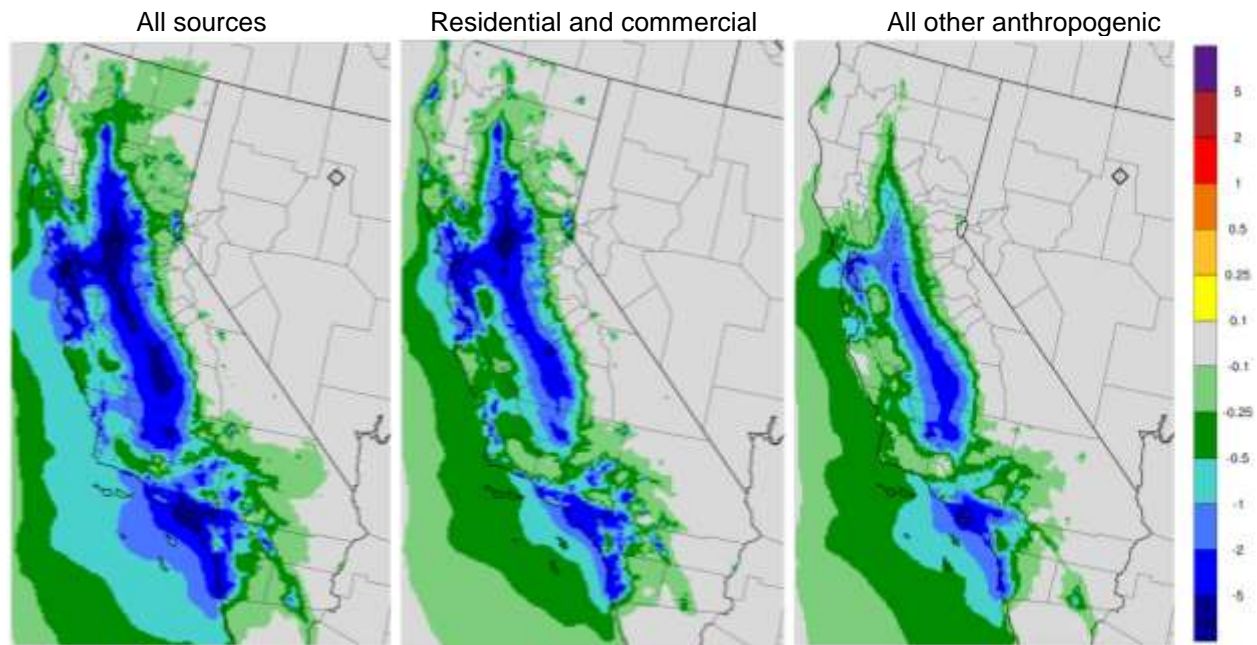
Source: EPRI

### Wood-fired Heating Has an Outsized Impact on Winter Air Quality

Wood-fired heating has approximately as much effect on winter PM<sub>2.5</sub> concentrations as all other anthropogenic sources put together, as shown in Figure 27. Although the effects of wood-fired

heating on ozone and summer PM<sub>2.5</sub> are much lower, this is significant and should be analyzed in more detail in future work.

**Figure 27: Contributions to Reductions in Average Winter PM<sub>2.5</sub> Concentrations for California**



Average for January;  $\mu\text{g}/\text{m}^3$ ; lower is better.

Source: EPRI

## Recommendations and Considerations for Acceleration of Electrification

The analysis of the potential for electrification and barriers to electrification led to the creation of recommendations and considerations for increasing electrification, particularly in environmental justice communities.

### Transportation

California already has a set of aggressive transportation electrification policies. These policies include the light-duty Zero Emissions Vehicle (ZEV) Mandate, the Low Carbon Fuel Standard (LCFS), light-duty vehicle efficiency standards, and Public Utility Commission proceedings to encourage installation of infrastructure for light-duty vehicles and heavier vehicle classes. Many of these policies can be met with non-electric options, but electric vehicles and electricity as a fuel are generally quite competitive. This analysis suggests other areas where policies could be effective in decreasing emissions and improving air quality:

- Increase efforts to electrify medium- and heavy-duty vehicles: Medium- and heavy-duty vehicles generally have higher emissions than light-duty vehicles, so an increased focus on heavier vehicles will be beneficial. These vehicles are also a source of higher pollutant concentrations for environmental justice communities, so improvements will

also help to improve equity. As an example, the CARB's recent targets for moving towards ZEV transit buses will reduce emissions from these vehicles significantly.

- Increase efforts to electrify non-road vehicles and devices: Non-road vehicles and devices are a diverse set of end uses that span from lawn and garden equipment, to cargo-handling equipment, to ships, trains, and airplanes. The electrification potential of these different vehicles and devices and the best electrification approach varies widely, but emissions from these sources is typically much higher than from other activities, so electrification will have a significant impact on air quality. Currently some promising device classes such as forklifts and airport ground support equipment are being electrified, but there are many additional opportunities. As devices become available it will be important to support adoption through pilot programs, incentives, and infrastructure installation to reduce risk and to demonstrate the capabilities of electrified options. It is important to ensure that the benefits from the efforts are recognized and rewarded.

## **Housing**

Retrofits are generally expensive, so the authors worked with domain experts and advocates for environmental justice communities to identify opportunities to overcome barriers, especially for low-income customers. Structural barriers that occur in low-income communities are discussed in Scavo et al. (2016), but EPRI projects have also found that there are costs in electrical system upgrades that occur in all communities. One of the main challenges in California is that the distribution and transmission infrastructure is not designed for an all-electric future due to a focus on air conditioning load rather than heating, which can have much higher loads in many situations. Additionally, some areas in California have very low air conditioning adoption due to cooler climates, so the design load per household is low relative to the demands that would come from full household electrification. Other areas of the United States and the world were designed around electric heating and water heating options and have different design practices for distribution networks. For example, in the Southeast United States where electric space and water heating has high adoption, a standard pole-top 50-kVA transformer is installed to handle three homes, while that same transformer handles nine similarly sized homes in California (Narayanamurthy, 2016).

Studies on newer electrified zero net energy homes illustrate this difference between previous practices and loads that are likely in the future. In these homes there is a significant reduction in energy usage (annual kWh), but a significant increase in connected load (peak kW), especially if adding electric vehicles to electrified heating systems. Adding heating, water heating, and plug-in electric vehicles takes the connected load of a home from the traditional 6 kW to closer to 20 kW (Narayanamurthy, 2016). These loads have greater diversity between homes and buildings, which can reduce the load on a neighborhood transformer, but current planning tools have insufficient data to account for this diversity and assume that all loads occur simultaneously. Although these design practices could be modified, extensive data and analysis would be required.

Based on current practices upgrades would be required, and any cost of upgrades to existing infrastructure attached to customer property have to be covered by the customer due to the allocation formula in Rule 15 (Pacific Gas and Electric, 2003). In one instance, the cost of the system upgrade for enabling heat pump water heating in a low-income community in Southern California was upwards of \$1 million for 80 apartments. This occurred since panel upgrades triggered upgrades at the meter socket, wiring to the house meter, and community transformer (Narayanamurthy, 2016). This is expected to be a recurring problem in many parts of California. One avenue to address these challenges could be to rate base the upgrades to customer specific utility infrastructure as is being piloted by the California Public Utility Commission for electric vehicles (Southern California Edison, 2018).

The work on this project led to the following suggestions to address these hurdles:

- **Plan for full electrification:** One of the difficulties in electrifying a household is the costs due to incremental electrification. For example, if a household installs a heat pump space heater, and then an electric water heater, and then later a vehicle charger, and finally a photovoltaic system, each of these upgrades could independently require permits, wiring, panel upgrades, and even service upgrades, greatly increasing expense. This would generally not be intentional, but household tend to replace appliances like space heaters and water heaters when they fail, and these failures do not occur simultaneously. As an alternative, many experts suggested doing an “electrification ready” upgrade with the first appliance. This would entail evaluating the household wiring to determine whether preparation could be cost-effectively done to ensure that future appliance replacements would be cheaper. For example, most of the cost of a panel upgrade is due to labor and overhead, so depending on the potential load for a household the panel may be increased by two sizes instead of one. If wiring changes were going to be required for one appliance, prewiring for other appliances would also be done. This would increase the cost for a single upgrade but would substantially decrease overall costs. Policy would have to be developed to determine how this increased cost would be paid for and what preemptive upgrades would be “cost effective” for an external source to supply, rather than being paid for by the household themselves.
- **Integrate low-income electrification programs with other building envelope and water efficiency measures programs:** In addition to general cost barriers, low-income customers often have the additional difficulty that the houses have existing maintenance problems or effects from old age that make any change difficult. For example, some program implementers have stated that at the start of an energy efficiency retrofit it was discovered that the target house had severe roofing problems that resulted in leaks. These leaks would result in immediate damage to the proposed retrofit and since the program had no allowance for roof repair, the project had to be abandoned. Additionally, less efficient houses can incur additional capital and electricity costs when electrified. Today’s heat pump units use electric resistance as backup when heating load are high, which greatly increases load and cost. When efficiency of the building shell is increased, it reduces the heating loads at peak winter conditions and

reduces electric resistance operation, thus reducing the required size of the system and the cost to operate it. Similarly, introducing water savings measures can reduce the load on the heat pump water heater, reduce operation of electric resistance, and reduce energy use and thus cost. Future electrification programs will have to be holistic to ensure that similar problems with the existing housing stock do not prevent successful completion of upgrades.

- Create programs to incentivize third-party financing: Careful policy can leverage public incentives and financing to increase third-party financing. For example, the Connecticut Green Bank was the first “green bank” which leverages limited public dollars to attract private capital for clean energy investment. This is particularly important for property owners with large portfolios of affordable housing properties.
- Automated time of use management: As California customer transition to time of use rates, adaptive intelligence in heating systems, both water and space heating, will reduce customer costs by reducing operation during high cost times. Manufacturers of heat pump water heaters are developing these types of adaptive algorithms for a PG&E pilot as part of AB 2868 deployment, while smart thermostat manufacturers have similar capability developed for demand management programs (CPUC, 2017).
- Evaluate potential for changes to distribution planning standards: As described above, current standards for distribution planning are designed to ensure adequate capacity in worst-case conditions. In actual operation, usage is generally less than these standardized estimates due to load diversity. As electrification increases, this type of neighborhood-level constraint will be encountered more often. These standards should be evaluated to see whether the assumed load factors are appropriate for the projects that are current occurring. Further, load management should be evaluated to see if it could provide adequate constraints to allow planning standards to be changed. For example, loads with low time sensitivity, such as plug-in electric vehicle charging or water heating, could be automatically delayed when a local distribution asset is highly loaded to ensure that operating constraints can always be maintained.
- Advanced refrigeration systems and demonstration of back-up free heat pumps: For most California climates, modern heat pumps do not require resistance backup for heating, significantly reducing the power levels that need to be designed into houses and distribution systems. However, most heat pumps on the market are designed for use in any climate, so new systems without backups would have to be designed for mild climates. Further, new heat pump systems with carbon dioxide and other advanced refrigerants have even higher coefficients of performance in heating, which can reduce the energy use and energy cost of operating electric heating systems and increase cost effectiveness.
- Study how rates are paid in affordable housing: Many affordable housing properties, especially multifamily, are master metered for gas, but tenant metered on electric. This means that electrification would shift costs from the property owners to tenants, which

would discourage adoption. The effects of rate payment should be analyzed to understand the personal impacts of electrification.

- Reform building standards: Getting to widespread electrification will require more stringent building codes that carry stronger incentives for low carbon technologies. At present, the Title 24 building code does not incentivize electrification technologies to meet zero-net-energy building codes. Builders have a choice to use an electric or natural gas baseline, but the natural gas baseline is more cost effective for builders today. Title 24 is also applicable to retrofits and rehabs, so they have the same challenges with cost effectiveness.



## CHAPTER 6:

# Benefits to Ratepayers

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This study analyzes the potential air quality benefits from an aggressive electrification scenario that achieves dramatic greenhouse gas reductions by 2050, including the benefits for Environmental Justice communities. The results from this project will help to direct future studies and efforts to achieve these goals. The results suggest the need for future research on:

- **Wood fired heating:** Although wood-fired heating has been previously identified as an important source of emissions, this analysis indicates that the effects of these emissions is very significant, especially as other sources of emissions are reduced. Electrification has high potential to address parts of this problem since wood is often used where natural gas is not available. This problem and potential mitigation options should be studied in more detail.
- **Additional effects of indoor air quality:** This study did not address indoor air quality, but electrification also eliminates emissions due to indoor combustion of natural gas, wood, and other fuels. This reduction would directly benefit customers and would be in addition to the large-scale pollution reduction benefits analyzed in this study.
- **Effects of reduced fuel demand on in-state petroleum production:** The potential co-benefits of reduced petroleum production and refining are due to electrification of transportation, which reduced demand for petroleum products. Given that transportation is currently entirely dependent on petroleum, refineries have relatively high emissions, and refineries and petroleum production are often adjacent to environmental justice communities, the change to petroleum demand could have significant secondary effects.

## LIST OF ACRONYMS

Acronym	Definition
CARB	California Air Resources Board
CAMx	The Comprehensive Air Quality Model with Extensions was used to calculate air quality impacts from emissions
CEPAM	California Emission Projection Analysis Model
CO	Carbon monoxide, a pollutant
$\mu\text{g}/\text{m}^3$	Micrograms per cubic meter, as measure of density
NAAQS	National Ambient Air Quality Standard
$\text{NO}_3$	Ammonia, which is considered a pollutant when it is in the air
$\text{NO}_x$	Nitrogen oxides, which are a category of pollutants which include nitrogen and oxygen in various combinations
$\text{PM}_{2.5}$	Particulate matter below 2.5 micrometers in size; these can be solids or liquids
$\text{PM}_{10}$	Particulate matter below 10 micrometers in size, which includes $\text{PM}_{2.5}$ ; these can be solids or liquids
ppb	Parts per billion, a measure of density
$\text{SO}_2$	Sulfur dioxide, a pollutant
VOC	Volatile organic compounds, a category of pollutants

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# APPENDIX A:

## Grid Modeling

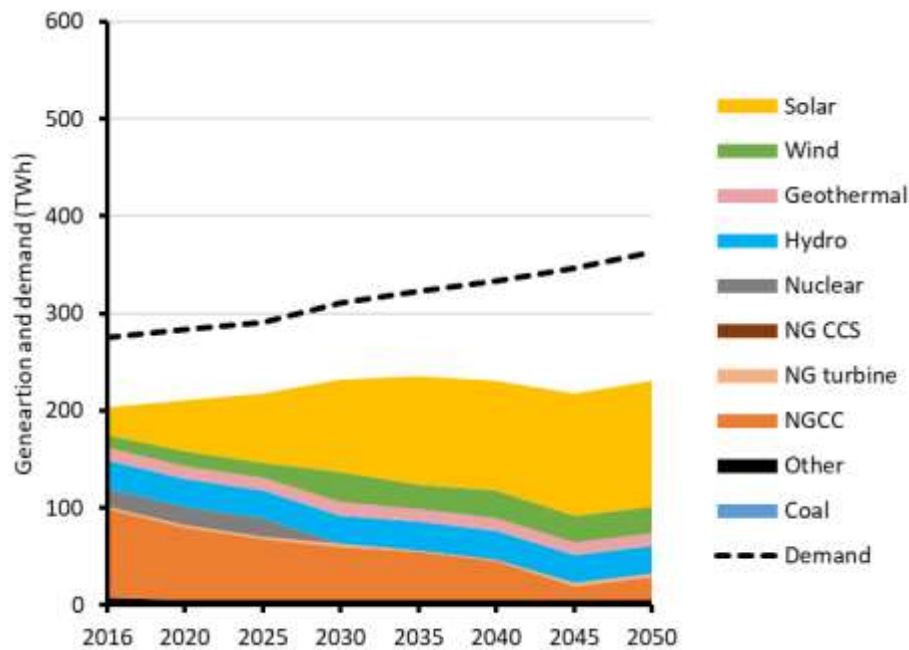
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This appendix describes the results of the EPRI grid modeling. Most of the electrification assumptions for the final scenario come from an associated California Energy Commission effort, “Long-Term Energy Scenarios in California,” performed by Energy and Environmental Economics (E3) (the project was EPC-14-069). However, for this analysis the load and load shape from that report was used with EPRI’s own grid model, US-REGEN, to investigate the effects of electrification on the electricity sector. US-REGEN also allowed a more spatially and temporally detailed representation of non-greenhouse gas emissions, which was important for the grid modeling effort.

### Reference Scenario Generation Trends

Figure A-1 shows the generation trends in the scenario without electrification for 2015-2050. The air quality analysis depends only on the effects of generation in 2050, but due to the importance of investments over time, it is necessary to model the grid for the full timeframe. The Reference scenario results show that renewables grow from their current level to cover most generation – only 14 percent of 2050 generation is not renewable, and most of this is combined cycle natural gas. Additionally, 36 percent of electricity demand is imported from surrounding states, up from 26 percent today.

**Figure A-1: Reference Scenario Generation Trends**



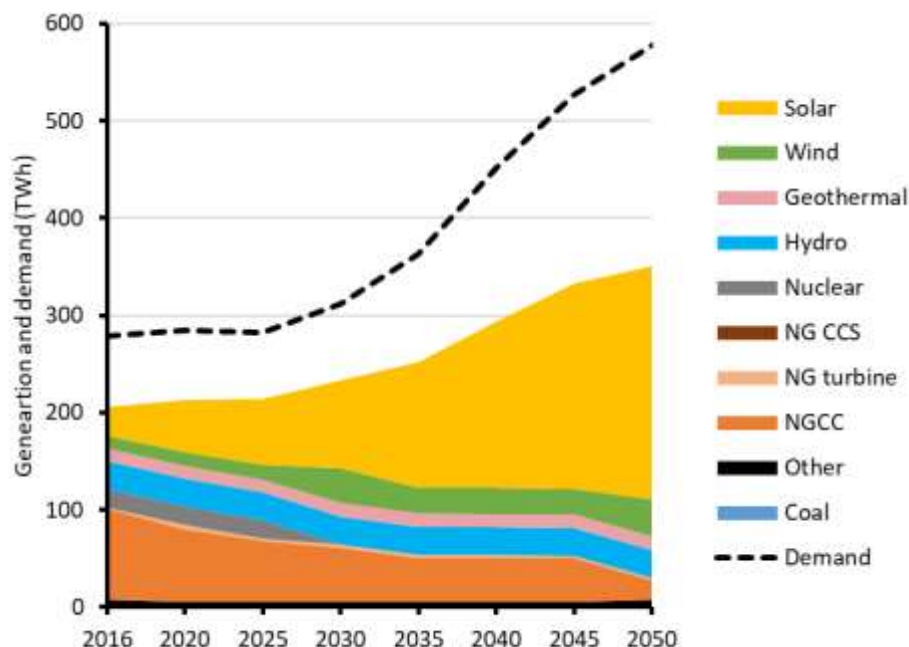
Source: The authors of this report



## Electrification Scenario Generation Trends

Figure A-2 shows the generation trends in the Electrification scenario for 2015-2050. The demand for electricity increases by 60 percent, so substantially more generation is required. In this scenario renewable generation continues to play a large role – there is more solar, wind, and geothermal generation in this scenario than in the Reference scenario. Only 9 percent of generation is non-renewable, mostly from combined-cycle natural gas. 39 percent of electricity demand is imported, slightly higher than in the reference case.

**Figure A-2: Electrification Scenario Generation Trends**



Source: The authors of this report

## Carbon Dioxide Emissions for Generation Scenarios

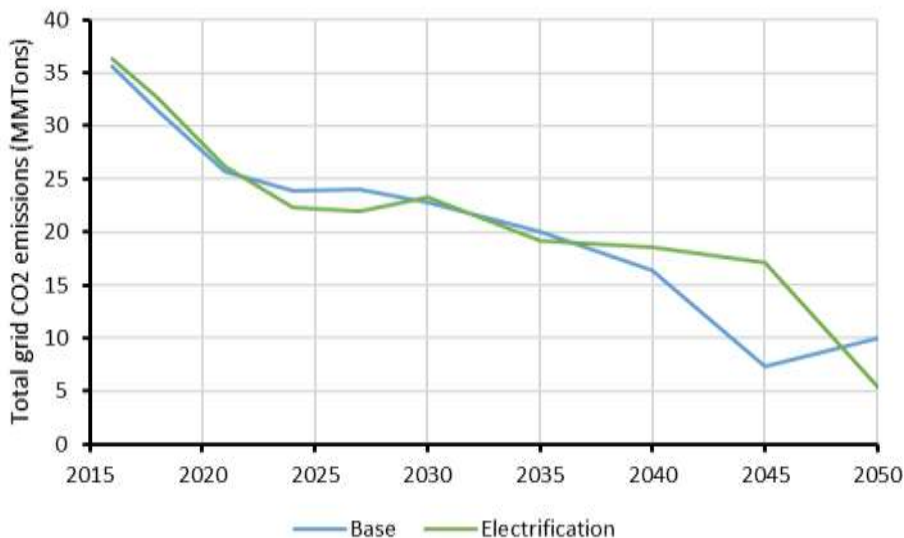
Figure A-3 shows the total grid CO<sub>2</sub> emissions for the two scenarios. In terms of total emissions, the Electrification scenario has similar 2050 CO<sub>2</sub> emissions to the Electrification scenario, but generation is 52 percent higher. In terms of the emissions rate, Figure A-4 shows that the two scenarios are comparable. The emissions rates for the Electrification scenario are about half those of the Reference scenario for 2050, but there is enough year-to-year fluctuation that this is not true in 2045 and may not be true in 2055 or other potential comparison years.

Importantly, though, the emissions rates are low in both scenarios. Figure A-4 also shows the marginal emissions for these two scenarios, based on the difference in emissions divided by the difference in generation. As discussed in Volume 1 of EPRI's 2015 Environmental Assessment performed with the Natural Resources Defense Council (EPRI-NRDC 2015<sup>12</sup>), this scenario generally meets the requirements for large-scale marginal emissions. This estimate of marginal emissions is unfortunately unstable with high deviations above and below the marginal

<sup>12</sup> <https://membercenter.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006875>.

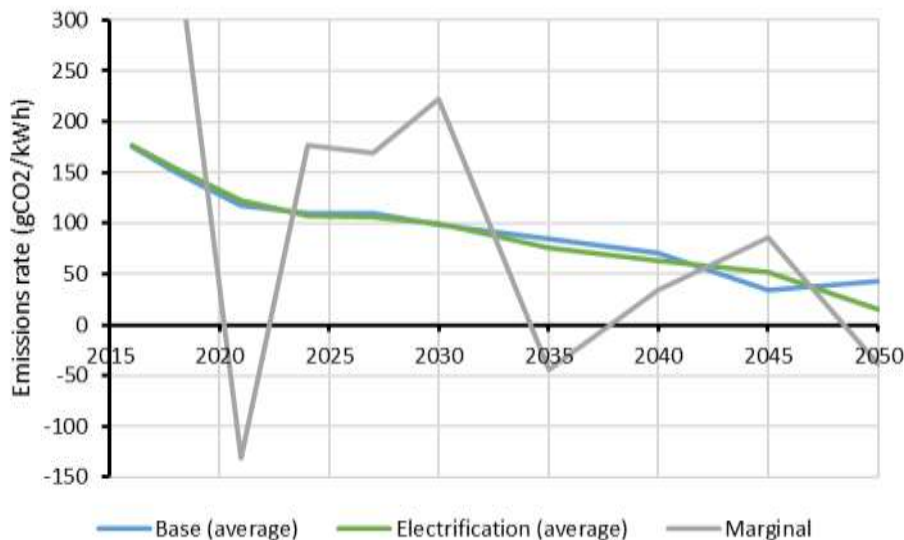
emissions, and the marginal 2050 emissions rate is negative, which is conceptually possible but practically incorrect. This is likely due to the large amount of trade in electricity between California and surrounding states, so calculating a stable marginal emissions would require inclusion of the surrounding regions.<sup>13</sup> In addition, the increase in generation is large enough that it no longer seems appropriate to define it as “marginal

**Figure A-3: Total Grid Emissions for the Two Grid Scenarios**



Source: EPRI

**Figure A-4: Emissions rates for the two grid scenarios**



Source: EPRI

<sup>13</sup> It should be noted that the air quality analysis will include the changes for all plants in the surrounding regions, so all emission attributable to electricity use in California will be included.

# **APPENDIX B:**

## **Final Electrification Scenario for Air Quality Modeling**

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This appendix discusses the assumptions for the penetration of electrification technologies for transportation technologies.

### **Objective and Approach**

One of the most important objectives of the overall work is to estimate the value of air quality improvements due to electrification. The output will focus on the effects of individual technologies, but to properly model air quality impacts it is necessary to understand the context of a high-electrification scenario. For example, the sensitivity of the atmosphere to an incremental ton of nitrogen oxides (NO<sub>x</sub>) will depend on the concentration of NO<sub>x</sub>, volatile organic compounds (VOC), particulate matter (PM) and other chemical constituents. This means that the best results will be obtained by specifying the adoption levels of all vehicles and devices – not just those selected for detailed study.

Studying the potential adoption of every technology is an expansive effort, so for this analysis the decision was made to use adoption levels from an associated California Energy Commission effort, “Long-Term Energy Scenarios In California,” (abbreviated below as LTES) performed by Energy and Environmental Economics (E3) (the project was EPC-14-069). This project studied potential greenhouse gas mitigation scenarios for 2015-2050. The project team for this analysis selected the results from an alternative scenario, the “In-State Biomass” scenario. The presence of biofuels is incidental to this analysis, but this scenario included the following additional mitigation strategies that matched the objectives of the current effort: “Increased reliance on: Industrial electrification, more ZEV trucks, renewables.” In many cases, the breakdown of individual technologies did not match the needs of the air quality model, so modeler judgement was used instead. The following sections discuss the 2050 total adoption levels and then the assumptions that informed these outputs.

### **2050 Adoption Levels**

The degree of electrification for each technology category is shown in the following three tables; Table B-1 for non-transportation categories, Table B-2 for non-road vehicles and devices and Table B-3 for on-road vehicles. The sources of the assumptions are shown in the tables and discussed in more detail below. The air quality modeling will be performed for 2050 only and will compare a baseline with 0 percent electrification in all categories and an electrification scenario with the electrification shares shown in the table. For each on-road transportation category there are separate sub-categories for exhaust particulate matter (PM) and brake-and-tire PM emissions. Brake and tire PM emissions are assumed to be reduced by ¼ the extent of

electrification share to represent reductions in friction brake usage, so an electrification share of 80 percent would result in a brake and tire PM reduction of 20 percent.<sup>14</sup>

**Table B-1: 2050 Adoption Levels for Each Fuel Use Category**

Sector	Fuel use category	Electrification share	Source
Agriculture	heat	0%	No electrification assumed
Agriculture	other	0%	No electrification assumed
Electricity	generation	*	Specified elsewhere
Industrial	boiler	98%	LTES commercial water heating adoption
Industrial	chemical manufacturing	0%	No electrification assumed
Industrial	heat	60%	EPRI assumption
Industrial	motion	100%	Very high adoption assumed
Industrial	other	0%	No electrification assumed
Industrial	solvents	0%	No electrification assumed
Industrial	space heat	80%	LTES commercial space heating adoption
Other	fires	0%	No electrification assumed
Other	other	0%	No electrification assumed
Other	roads	0%	No electrification assumed
Other	solvents	0%	No electrification assumed
Other	waste disposal	0%	No electrification assumed
Petroleum	boiler	90%	Petroleum use reduction
Petroleum	heat	90%	Petroleum use reduction
Petroleum	other	90%	Petroleum use reduction
Residential	heating	99%	LTES residential water heating adoption
Residential	space heating	83%	LTES residential space heating adoption
Residential	wood heating	100%	Complete replacement of wood heating assumed

Source: EPRI

<sup>14</sup> Victor R.J.H. Timmers, Peter A.J. Achten. Non-exhaust PM emissions from electric vehicles. Atmospheric Environment, Volume 134, 2016. <https://www.sciencedirect.com/science/article/pii/S135223101630187X>.

**Table B-2: 2050 Adoption Levels for Each Non-road Transportation Fuel Use Category**

Fuel use category	Electrification share	Source
Agricultural	15%	TAC suggestion
Aviation	10%	TAC suggestion
Construction and mining	0%	
Forklift	100%	Assume aggressive adoption
Ground support equipment	100%	Assume aggressive adoption
Lawn and garden	100%	Assume aggressive adoption
Marine	10%	TAC suggestion
Marine (port)	100%	Assume aggressive adoption
Other non-road	0%	
Rail	0%	
Rail (yard)	100%	Assume aggressive adoption
Recreational equipment	0%	
Recreational marine	25%	TAC suggestion
Refrigeration	100%	Assume aggressive adoption
Terminal tractor	100%	Assume aggressive adoption
Truck apu	100%	Assume aggressive adoption

Source: EPRI

**Table B-3: 2050 Adoption Levels for Each On-road Transportation Fuel Use Category**

Fuel use category	Electrification share	Source
Combination long-haul	80%	LTES heavy duty adoption
Combination short-haul	80%	LTES heavy duty adoption
Intercity bus	88%	LTES bus adoption
Light commercial truck	85%	TAC suggestion
Motor home	80%	LTES heavy duty adoption
Motorcycle	93%	LTES light duty adoption
Passenger car	93%	LTES light duty adoption
Passenger truck	93%	LTES light duty adoption
Transit bus	88%	LTES bus adoption
Refuse truck	80%	LTES heavy duty adoption
School bus	88%	LTES bus adoption
Single unit long-haul	66%	LTES medium duty adoption
Single unit short-haul	66%	LTES medium duty adoption

Source: EPRI

## Derivation of Share for Each Fuel Use Category

### Agriculture: Heat and Other

Electrification was not assumed for agricultural applications. Agriculture is a small segment of total emissions with the exception of ammonia (which is very substantial) and primary particulate matter, but these are due to fertilization and tilling so are not generally subject to electrification (indoor agriculture could potentially reduce these emissions while increasing electricity use, but was out of scope).

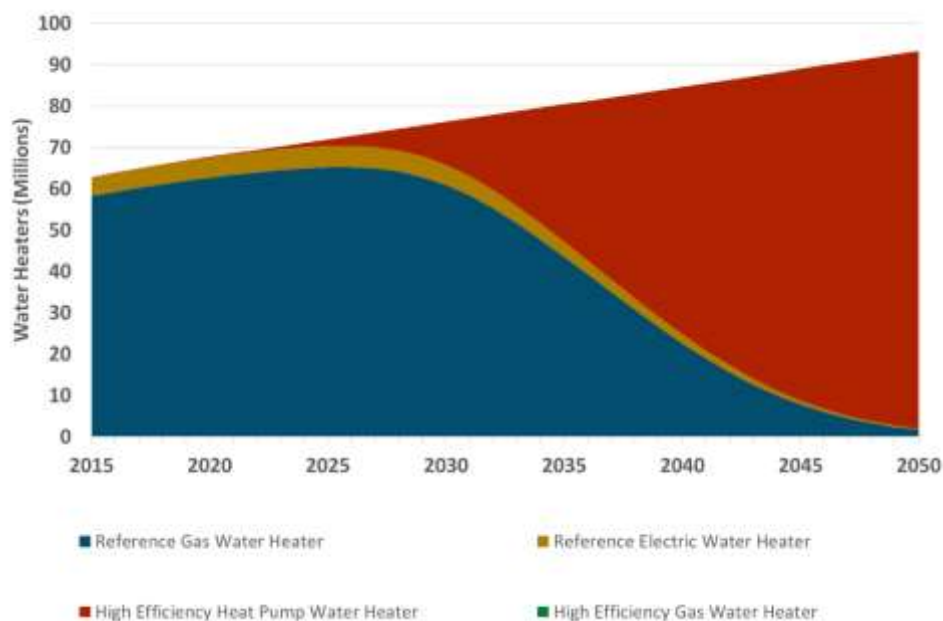
### Electricity: Generation

In this analysis, the load from electrification was run through US-REGEN to calculate the emissions of each power plant in the US. Electricity-sector emissions will generally increase due to increased electrification, but net emissions will in most cases be lower.

### Industrial: Boiler

The air quality emissions inventory used did not distinguish between industrial emissions and commercial emissions, and the LTES data used did not have stock data for industrial equipment. To align these, the decision was made to assume that industrial boiler emissions followed the electrification trajectory for the LTES commercial water heating, and an LTES scenario with increased industrial energy use was selected. The resulting stock forecast is shown in Figure B-1. It should be noted that electric industrial and commercial boilers are a mature technology and can be cost-effective today depending on relative fuel costs. It is likely that an increased focus on criteria and greenhouse gas emissions will increase the cost competitiveness of electric water heating.

**Figure B-1: Commercial Water Heating Stock from LTES "In-state biofuels" Scenario**



Source: Mahone et al., 2018 (unpublished)

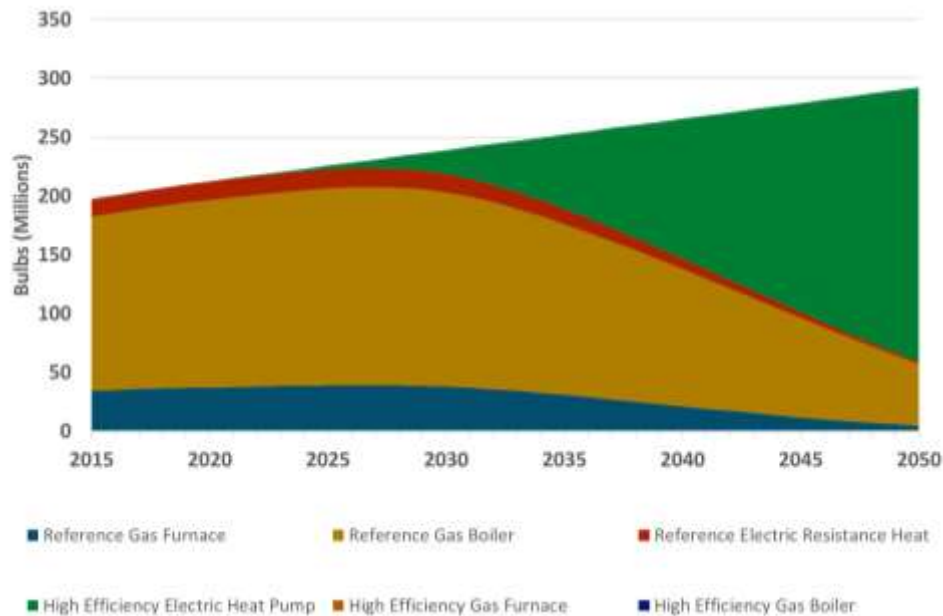
## Industrial: Heat

Industrial heat is a complex category due to the diverse set of use cases. Unlike applications like space heating, industrial heating encompasses a wide range of potential temperature ranges, heat flux requirements, and other application-specific characteristics. This means that a given electrification technology such as infrared LEDs may be very well-suited for one application, but completely unable to meet the needs for another since it is unable to apply enough heat or reach a high enough temperature. EPRI's electrification group estimates that 10-12 percent of current industrial heating requirements are met through electric technologies, and that available electric technologies could meet 75 percent of remaining applications. An electrification share of 60 percent is assumed, implying high uptake but not total capture of the technical potential.

## Industrial: Space Heat

As described above, there was a mismatch between the air quality emissions inventory and LTES. The decision was made to use the LTES stock data for commercial space heating for combined industrial/commercial space heating in the emissions inventory combined with the use of an LTES scenario with high industrial electrification. The commercial space heating energy use forecast from the LTES is shown in Figure B-2.

**Figure B-2: Commercial Space Heating Energy Use from LTES "In-state biofuels" Scenario**



Source: Mahone et al., 2018 (unpublished)

## Industrial: Chemical Manufacturing, Other, and Solvents

These categories were generally considered to be out of the scope of electrification. Most “other” emissions categories involved mining and manufacturing which could only be reduced with a change in the quantities of products required. Although electrification will likely change



the types of products demanded and may potentially change the net quantities of demand, this was not modeled.

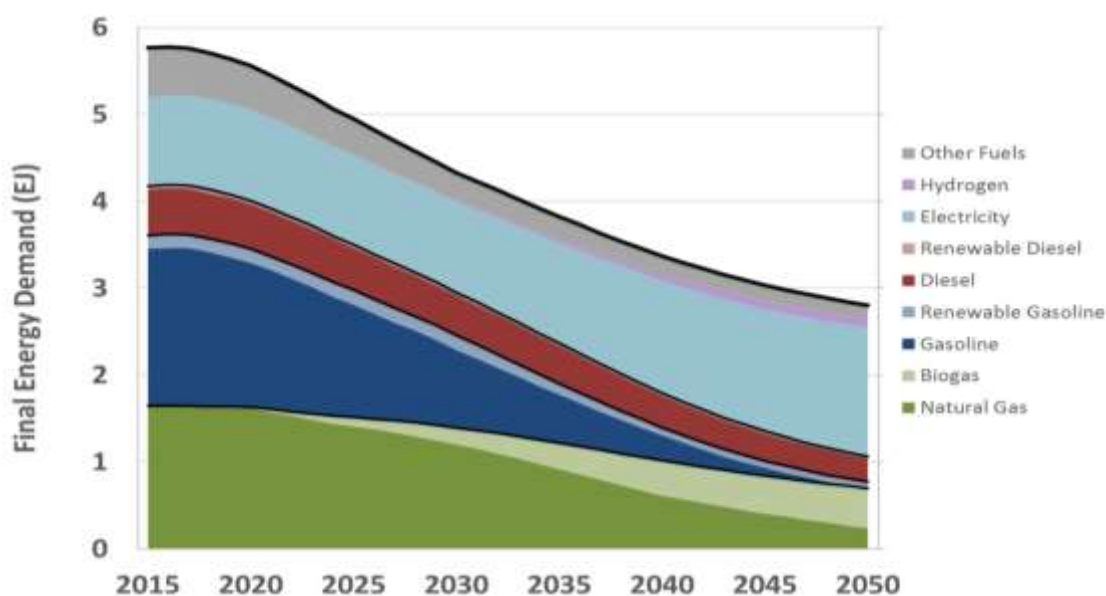
### Other: Fires, Other, Roads, Solvents, and Waste Disposal

All of the categories in the Other “sector” were considered to be outside the scope of electrification, since emissions are due to factors that are unlikely to be electrified with current technology. This is unfortunate – solvents represent about half of VOC emissions and roads represent 20-40 percent of primary PM emissions in this inventory, but addressing these emissions will require changes in practices aside from electrification (such as increased paving and road sweeping or decreased solvent use).

### Petroleum: Boiler, Heat, Other

The Petroleum sector was broken out from the Industrial sector because the total quantity of petroleum use is particularly sensitive to electrification. In the LTES, diesel use is substantially reduced and gasoline use is almost entirely reduced. Transportation of final petroleum products out of California is relatively expensive, so in-state use and in-state refining are closely balanced.<sup>15,16</sup> It is therefore assumed that this reduction in petroleum use will result in proportional a decrease in in-state criteria emissions, resulting in a 90 percent reduction in Petroleum sector emissions, as shown in Figure B-3.

Figure B-3: Changes in Energy Use in the LTES



Source: Mahone et al., 2018 (unpublished)

Further reductions due to electrification are possible, but are not assumed due to the complex nature of refineries. It should be noted that the imbalance between 2050 diesel use and

<sup>15</sup> <https://www.eia.gov/todayinenergy/detail.php?id=23312>.

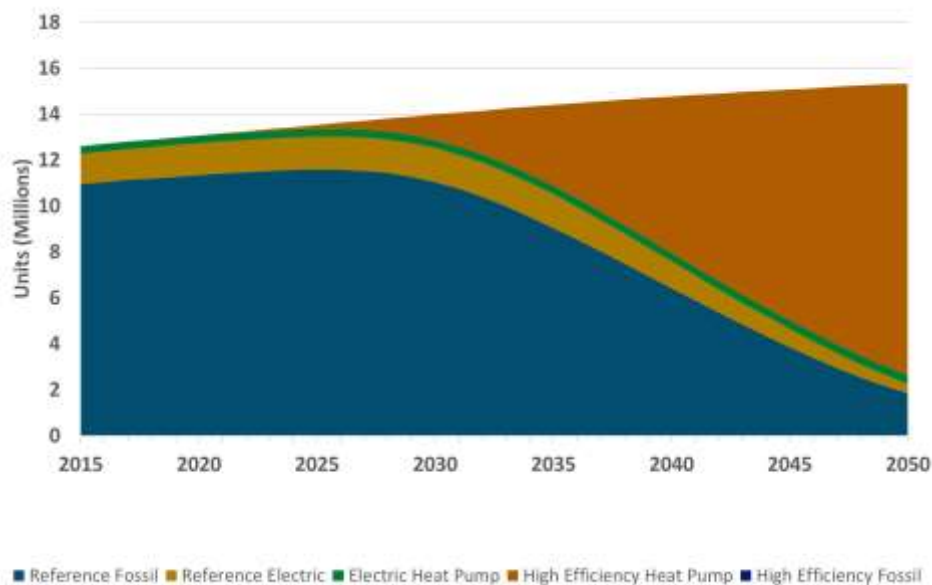
<sup>16</sup> [https://www.eia.gov/analysis/transportationfuels/padd5/pdf/transportation\\_fuels.pdf](https://www.eia.gov/analysis/transportationfuels/padd5/pdf/transportation_fuels.pdf).

gasoline use would likely cause further changes to the sector due to the product balance of refineries, but these effects are not modeled here.

### Residential: Heating and Wood Heating

The assumption for residential space heating was taken directly from the LTES. It was further assumed that wood heating would be preferentially electrified due to the high criteria emissions impact and relative expense of wood heating. The adoption levels are shown in Figure B-4.

**Figure B-4: Residential Space Heating Adoption from LTES "In-state biofuels" Scenario**

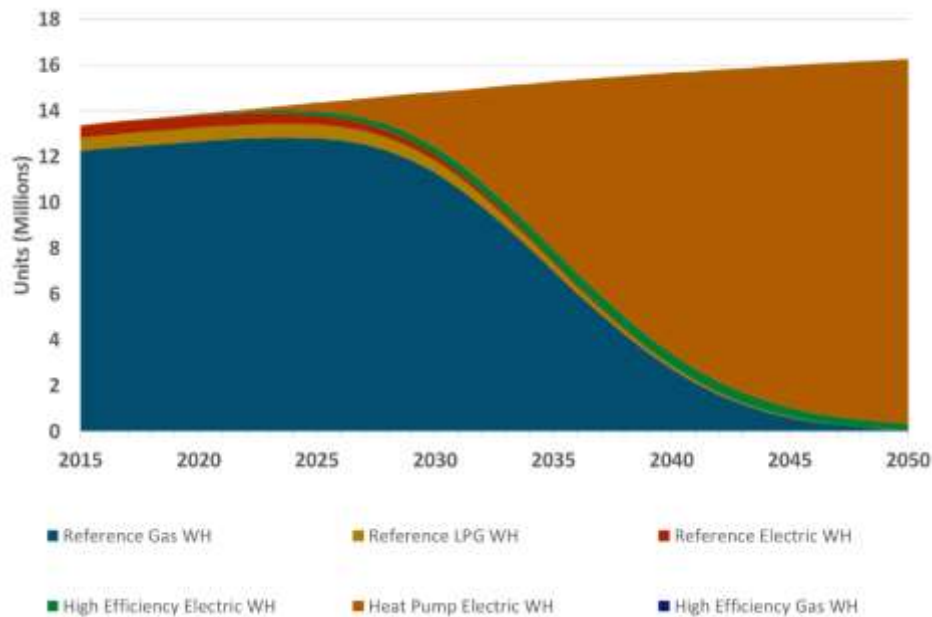


Source: Mahone et al., 2018 (unpublished)

### Residential: Heating

In the air quality emissions inventory, “heating” includes all heating not otherwise specified as a furnace. This includes water heaters, stoves, and non-natural-gas space heating. It is assumed that most of the emissions for this category will be due to water heating, so the water heating penetration in the LTES is used to represent the category as a whole. The adoption levels are shown in Figure B-5.

**Figure B-5: Residential Water Heating Adoption from LTES "In-state biofuels" Scenario**



Source: Mahone et al., 2018 (unpublished)

## **Derivation of Share for Each Non-road Fuel Use Category**

### **Agricultural, Aviation, Marine and Recreational Marine**

These categories were initially assumed to have no electrification due to the energy-intensity of the activities involved and the relative remoteness from grid power. Based on Technical Advisory Committee member input, a small amount of electrification was assumed in each category. Note that each category has some experimental/prototype activity, but commercial expansion is limited.

### **Construction and Mining, and Recreational Equipment**

These categories are assumed to operate in remote locations or on a temporary basis and are therefore not electrified.

### **Rail**

Electrified rail is a mature technology, but it is capital intensive and requires long construction times. Given the limited momentum in rail electrification at the current time, no electrification is assumed. High-speed passenger rail will be electrified, but it will be a new application, so will only reduce inventoried emissions to the extent that it displaces current passenger rail and current short-range flights. However, these displacement effects were not modeled.

### **Forklift and Ground Support Equipment**

These categories already have competitive electric options for some equipment categories, and market expansion is very likely. Full electrification is assumed.

## **Lawn and Garden**

Lawn and garden equipment represent a relatively small fraction of energy and expenditure, but a high fraction of unburnt hydrocarbons and carbon monoxide (7 percent and 20 percent respectively). Due to the need to reduce emissions and the increasing availability of electric alternatives, full electrification is assumed by 2050.

## **Marine (Port)**

Marine (port) emissions primarily include emissions of ships in port being loaded and unloaded. Although limited electrification is assumed while underway, there is an intense focus on port emissions and cold ironing is a mature technology, so full electrification of in-port emissions is assumed.

## **Other Non-road**

These emissions were not individually categorized but include applications like emergency water pumping and generators. Due to the temporary nature of these applications, no electrification is assumed.

## **Rail (Yard) and Terminal Tractor**

For these two categories, these emissions are associated with loading and unloading of cargo or otherwise transferring cargo within a facility. Due to the focus on reducing emissions for facilities and the relatively limited area of operation, full electrification is assumed.

## **Refrigeration and Truck apu**

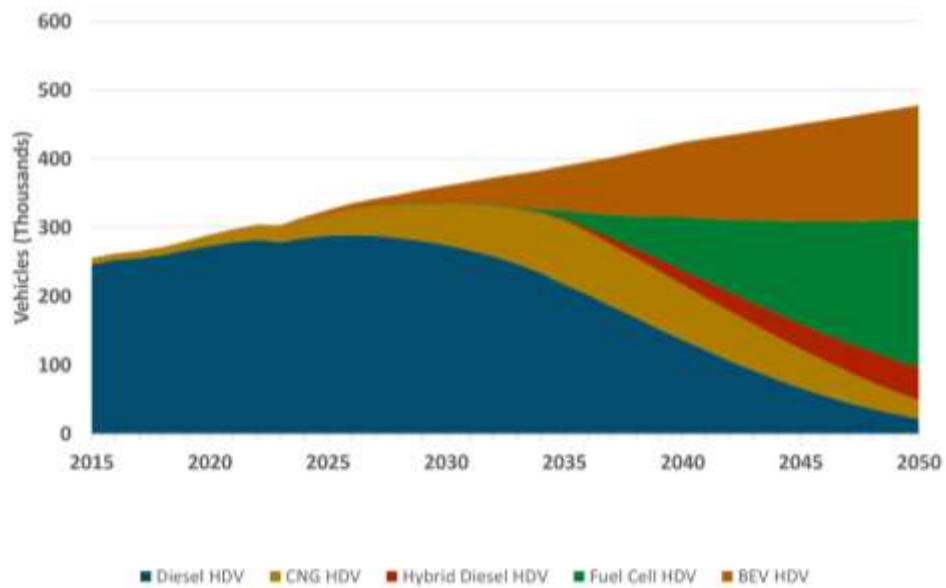
These categories are associated with emissions from trucks while not underway and refrigeration of cargo. Due to the high electrification of trucks, a focus on small-engine emissions, and availability of electric replacements, full electrification is assumed.

## **Derivation of Share for Each On-road Fuel Use Category**

### **Combination Long-haul, Combination Short-haul, Motor Home, and Refuse Truck**

Each of these categories is a heavy-duty on-road application, so the heavy-duty adoption from the LTES is assumed. This is shown in Figure B-6.

**Figure B-6: Heavy-duty Truck Stock from LTES "In-state biofuels" Scenario**

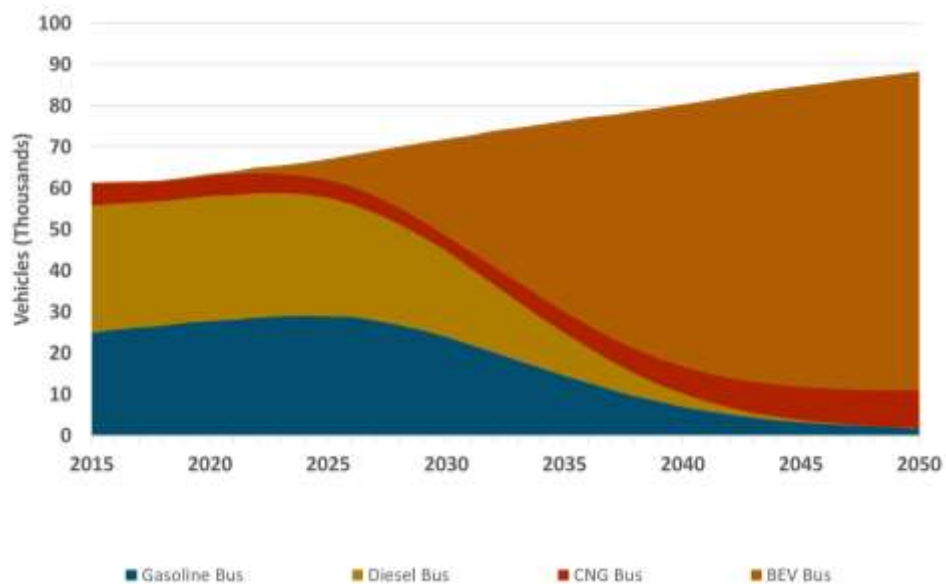


Source: Mahone et al., 2018 (unpublished)

## Intercity Bus, Transit Bus, and School Bus

Each of these categories is a bus application, so the bus adoption from the LTES is assumed. This is shown in Figure B-7.

**Figure B-7: Bus Stock from LTES "In-state biofuels" Scenario**

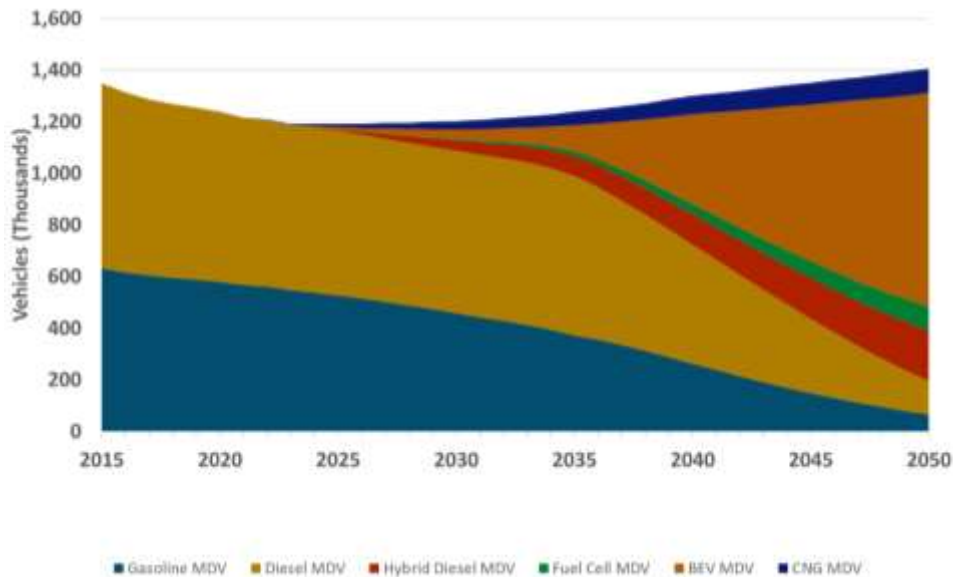


Source: Mahone et al., 2018 (unpublished)

## Single Unit Long-haul, Single Unit Short-haul

Each of these categories is a medium-duty application, so the medium-duty adoption from the LTES is assumed. This is shown in Figure B-8.

**Figure B-8: Medium-duty Stock from LTES "In-state biofuels" Scenario**



Source: Mahone et al., 2018 (unpublished)

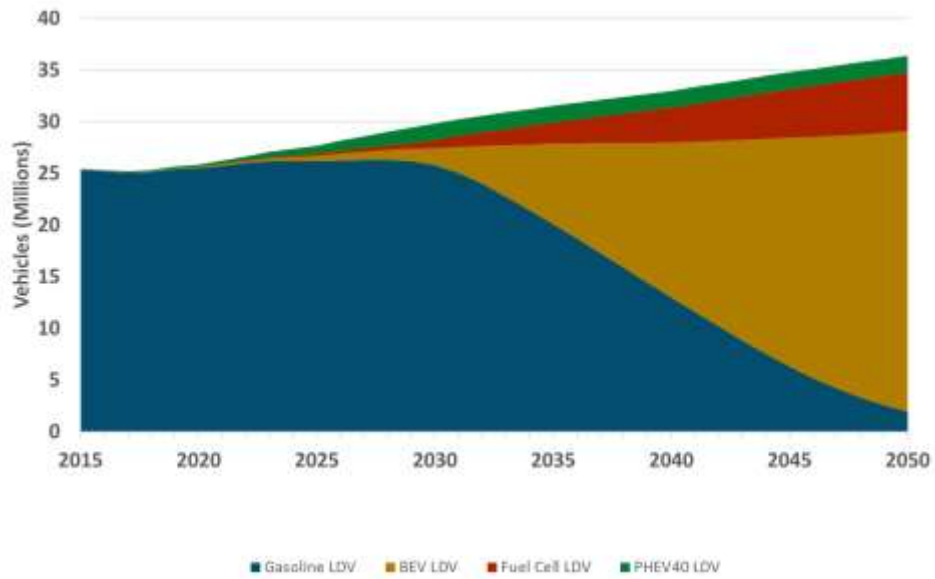
## Light Commercial Truck

This category primarily includes last-mile delivery. Based on input from a Technical Advisory Committee member a high level of electrification is assumed, approximately midway between the LTES medium-duty assumption and the LTES light-duty assumption.

## Motorcycle, Passenger Car, and Passenger Truck

Each of these categories is a light-duty application, so the light-duty adoption from the LTES is assumed. This is shown in Figure B-9.

**Figure B-9: Light-duty Stock from LTES "In-state biofuels" Scenario**



Source: Mahone et al., 2018 (unpublished)



# APPENDIX C:

## Air Quality Results

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### 2011 Baseline Modeling

An evaluation of the air quality model performance is important to support conclusions drawn from the future-year scenarios. CAMx baseline modelling was conducted using 2011 emissions and meteorological input data. The 2011 emissions are from the NEI inventory (<http://www.epa.gov/ttn/chief/net/2011inventory.html>)<sup>17</sup> except for on-road vehicle and biogenic emissions developed for this study. Specifically, California on-road emissions were from the California Air Resources Board (CARB)'s EMFAC2014 estimates and processed through EPA's SMOKE-MOVES model to capture temporal and spatial patterns of highly resolved meteorology. Natural emissions are meteorology-dependent and are held constant between the 2050 Reference scenario and Electrification scenario. The WRF meteorological model version 3.8 (latest available) was run to provide required meteorological inputs for CAMx.

The initial CAMx 2011 baseline simulation shows reasonable performance for both ozone and PM<sub>2.5</sub>. The maximum daily 8-hour average (MDA8) ozone tend toward underprediction, notably for downwind locations such as Riverside. Normalized mean biases (NMB) for MDA8 ozone meet the recommended bias criteria of  $\pm 15$  percent (Emery et al., 2017). Normalized mean errors (NME) are below 20 percent across all quarters, well within the error criteria of less than 25 percent.

PM<sub>2.5</sub> performance in the first and fourth quarters shows NMB lower than 5 percent and NME lower than 40 percent, (compared to  $\pm 30$  percent and 50 percent criteria). We find weaker performance in the second and third quarters due mainly to underestimation of nitrate (NO<sub>3</sub><sup>-</sup>) and organic carbon (OC). We performed several sensitivity tests and selected three options that enhance the baseline model performance including: 1) updating the on-road ammonia emissions following the recent measurement study (Sun et al., 2014), 2) adjusting ammonia surface resistance in CAMx, and 3) updating secondary organic aerosol processor in CAMx.

### Analysis of Ozone/Particulate Matter Source Contribution Results

The CAMx model has mass-tracking algorithms to explicitly simulate the fate of emissions from specific sources accounting for chemical transformations, transport and pollutant removal. This study utilizes the CAMx Ozone Source Apportionment Technology (OSAT) and the Particulate Source Apportionment Technology (PSAT). Both source apportionment techniques use reactive tracers (also called tagged species) that run in parallel to the host model to

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<sup>17</sup> 2011v6.2 Emissions Modeling Platform Technical Support Document for 2011, 2017, and 2025 (8/18/15), [http://www.epa.gov/ttn/chief/emch/2011v6/2011v6\\_2\\_2017\\_2025\\_EmisMod\\_TSD\\_aug2015.pdf](http://www.epa.gov/ttn/chief/emch/2011v6/2011v6_2_2017_2025_EmisMod_TSD_aug2015.pdf).

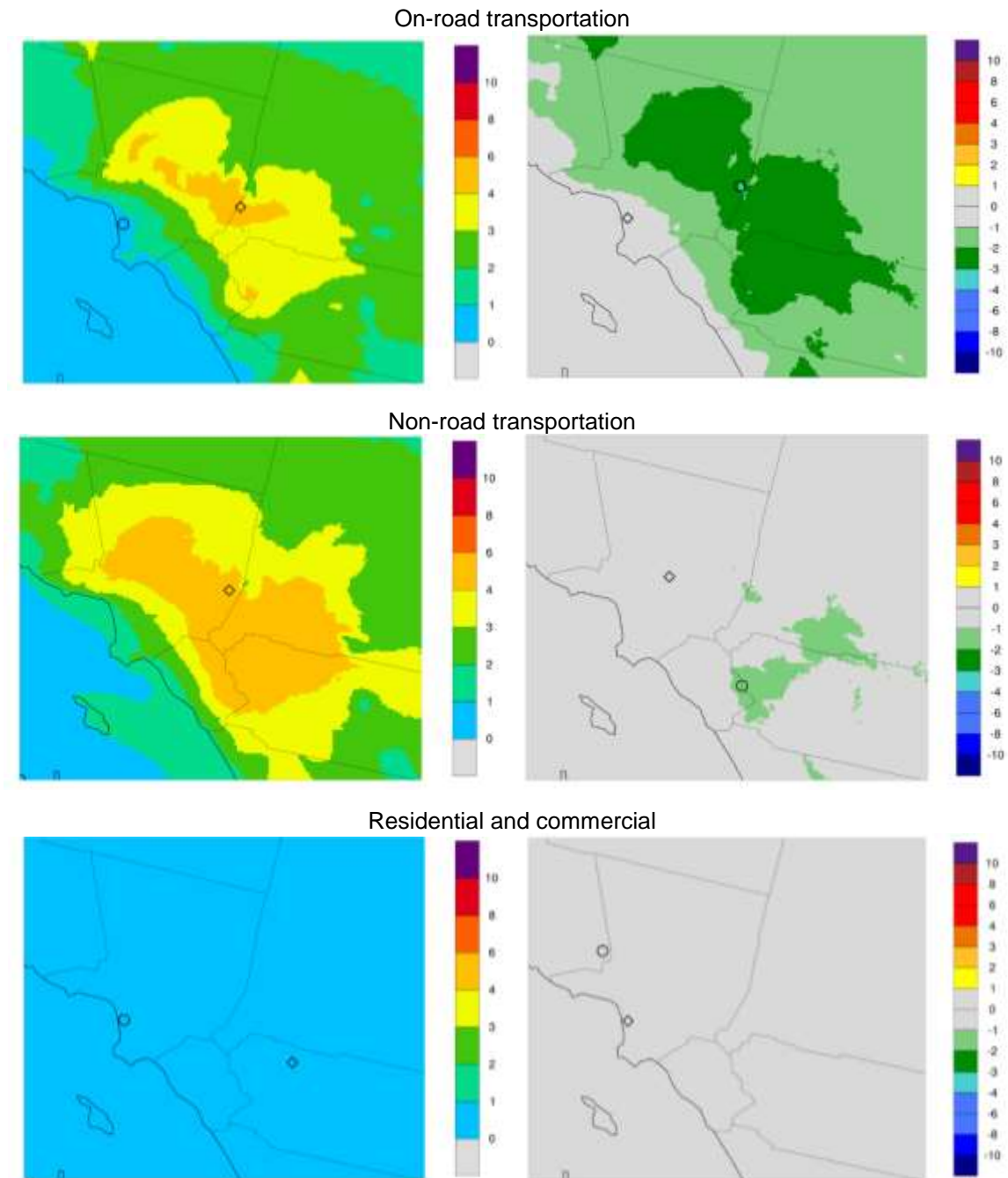
determine the contributions to ozone and PM from individual user selected Source Groups. The analysis of the electrification impacts by source group are shown below.

## **Appendix References**

- Emery, C., Liu, Z., Russell, A.G., Odman, M.T., Yarwood, G. and Kumar, N., 2017. Recommendations on statistics and benchmarks to assess photochemical model performance. *Journal of the Air & Waste Management Association*, 67(5), pp.582-598.
- Sun, K., Tao, L., Miller, D.J., Khan, M.A. and Zondlo, M.A. 2014. On-road ammonia emissions characterized by mobile, open-path measurements. *Environmental science & technology*, 48(7), pp.3943-3950.

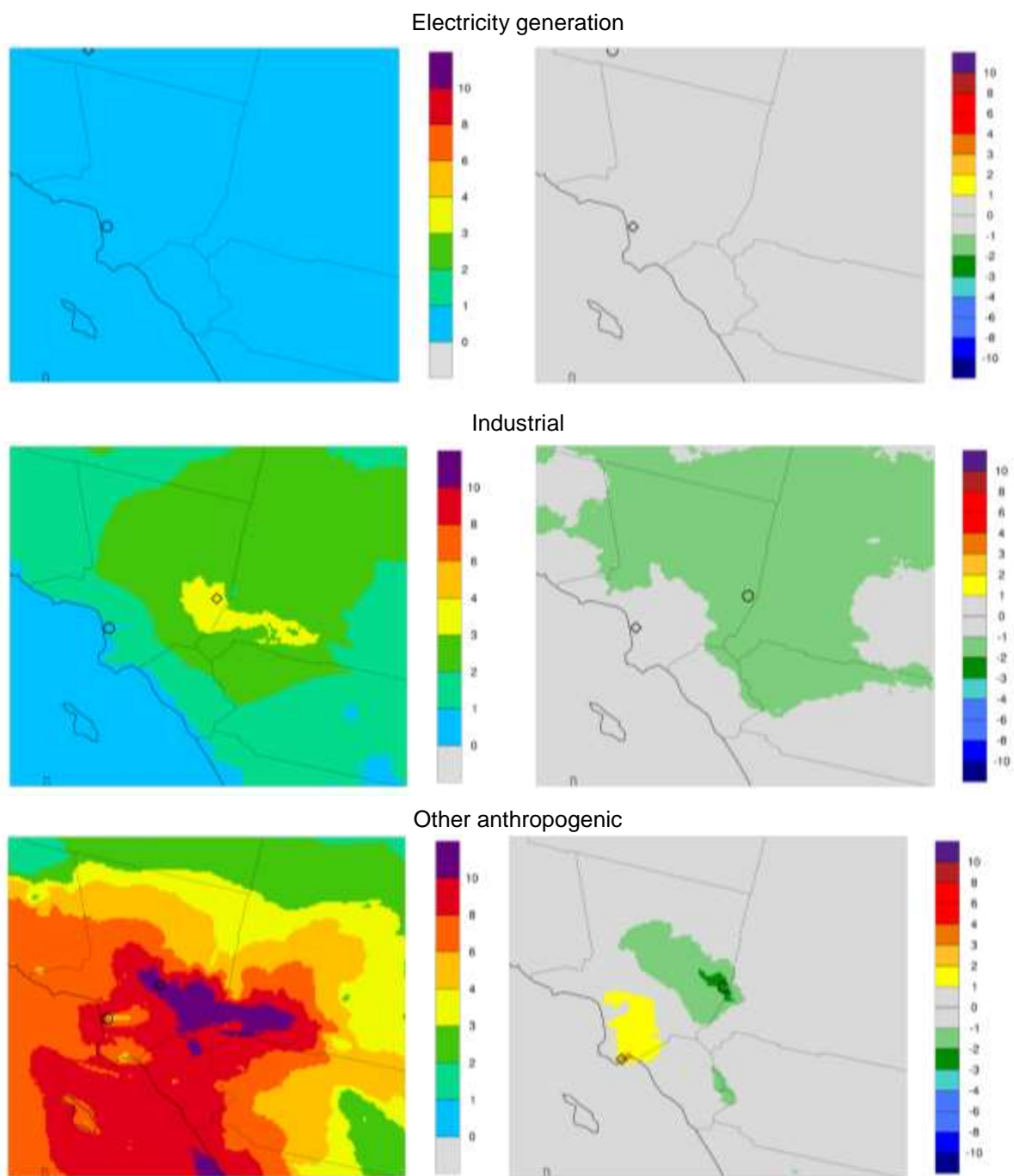
## South Coast Air Basin Domain

**Figure C-1: Source Contributions to Summer Average Daily Maximum 8-hour Average Ozone Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right)**



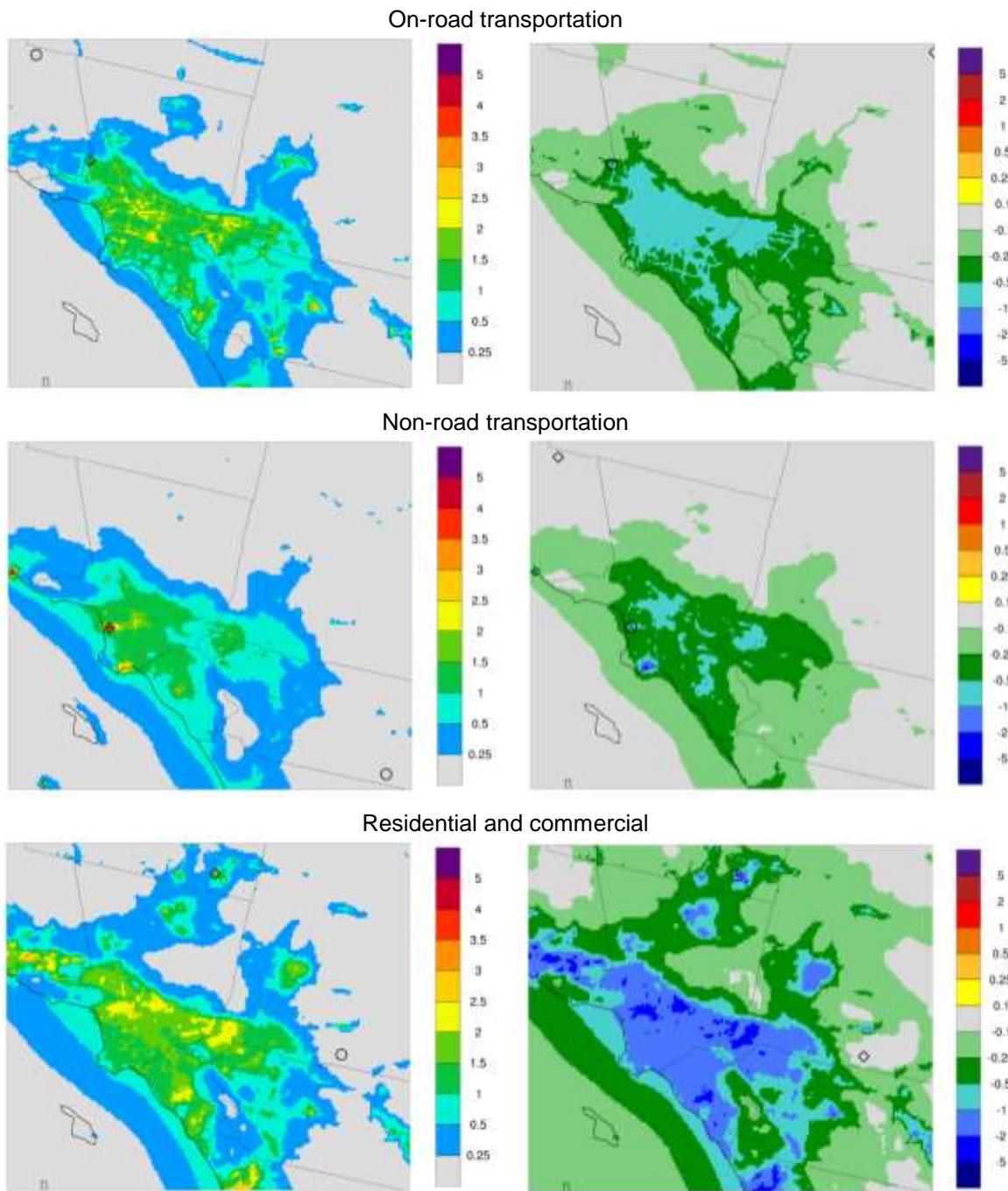
Source: EPRI

**Figure C-2: Source Contributions to Summer Average Daily Maximum 8-hour Average Ozone Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right) (continued from previous page)**



Source: EPRI

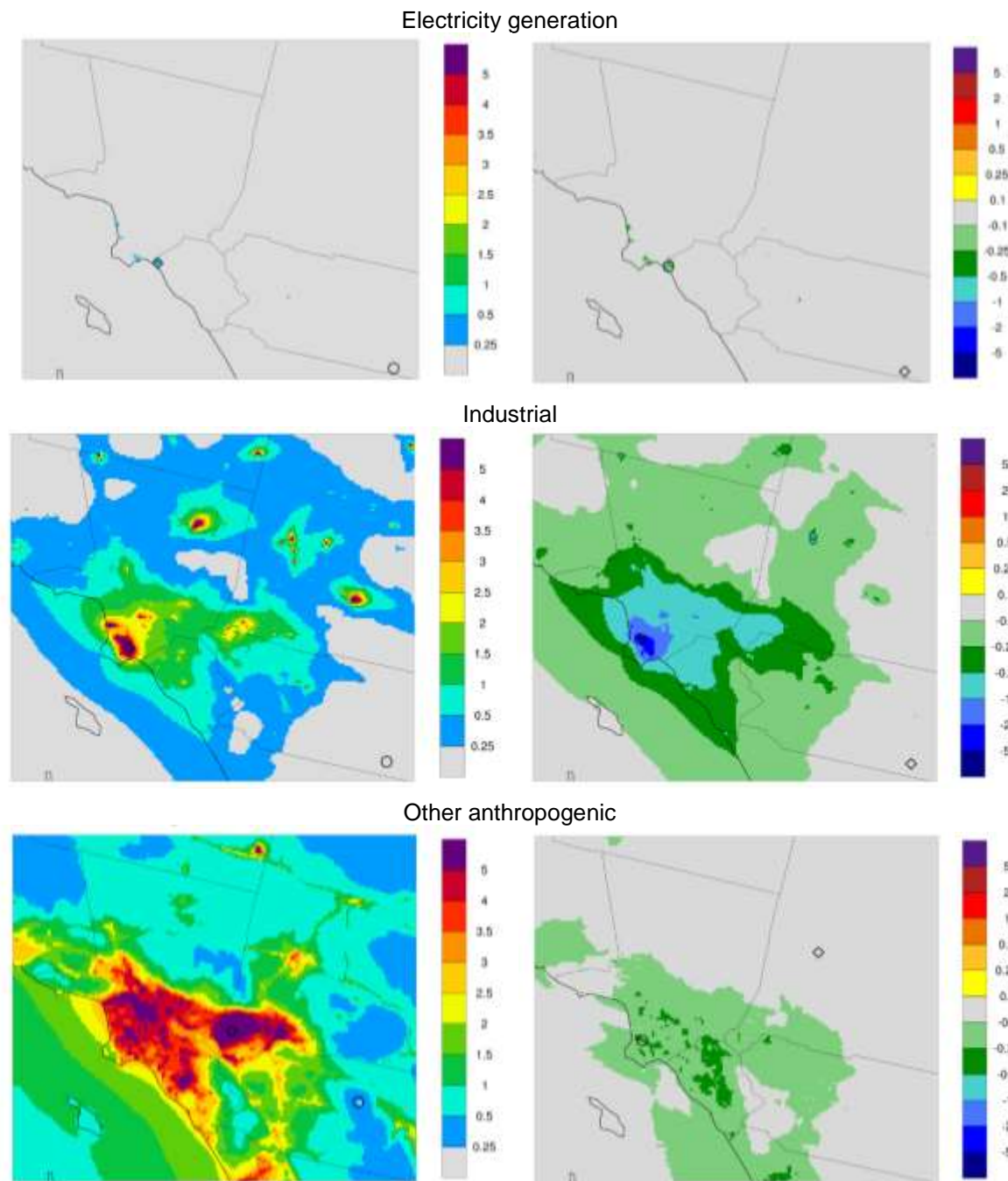
**Figure C-3: Source Contributions to Annual Average PM<sub>2.5</sub> Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right)**



Source: EPRI



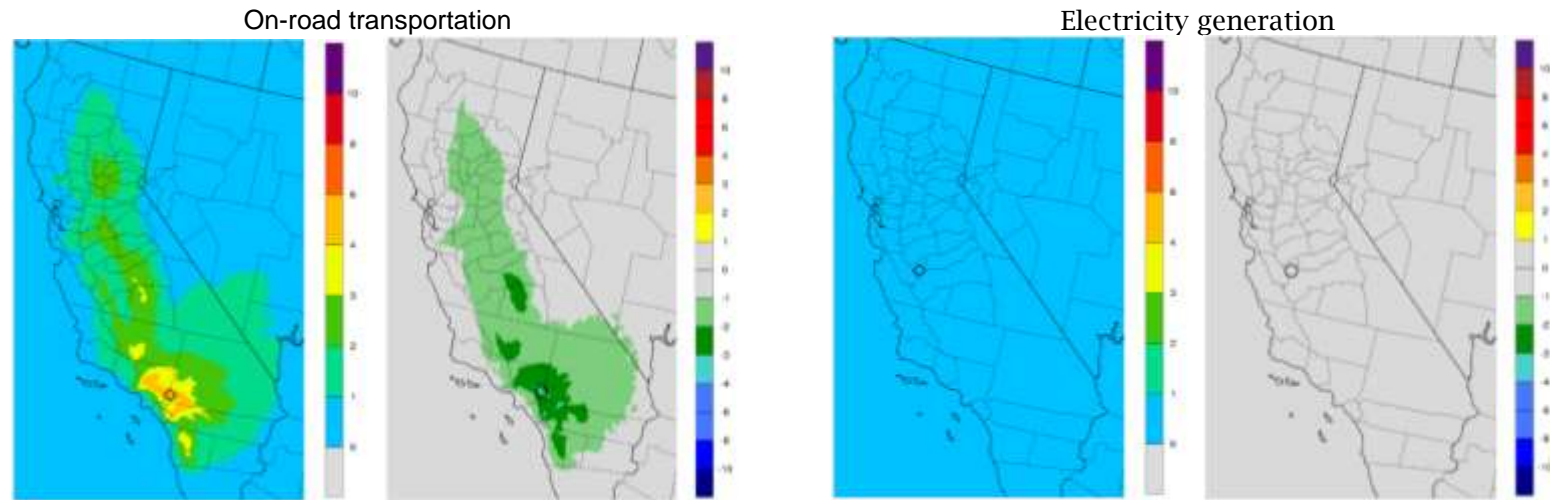
**Figure C-4: Source Contributions to Annual Average PM<sub>2.5</sub> Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right) (continued from previous page)**



Source: EPRI

## California Domain

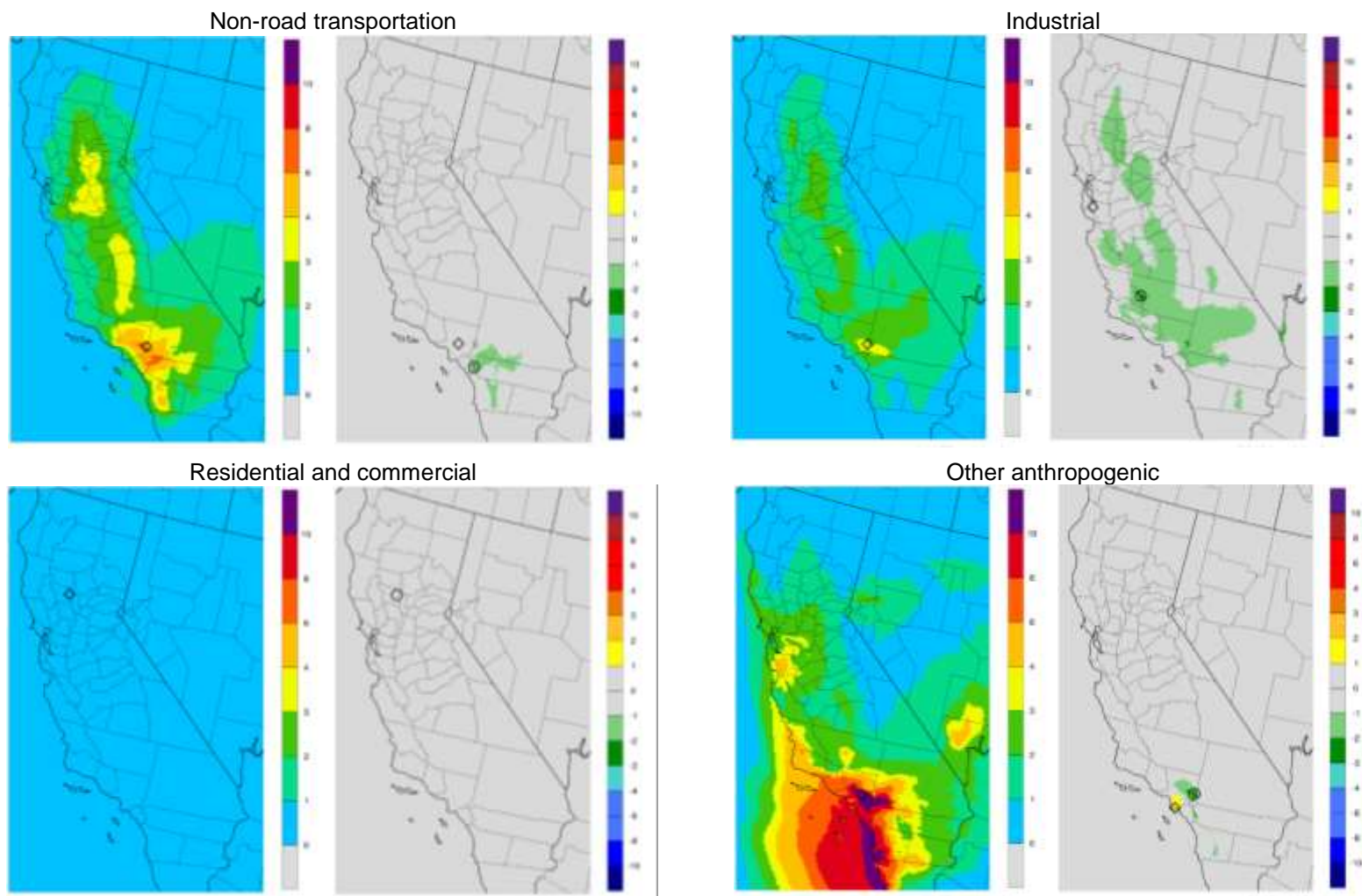
**Figure C-5: Source Contributions to Summer Average Daily Maximum 8-hour Ozone Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right)**



Source: EPRI

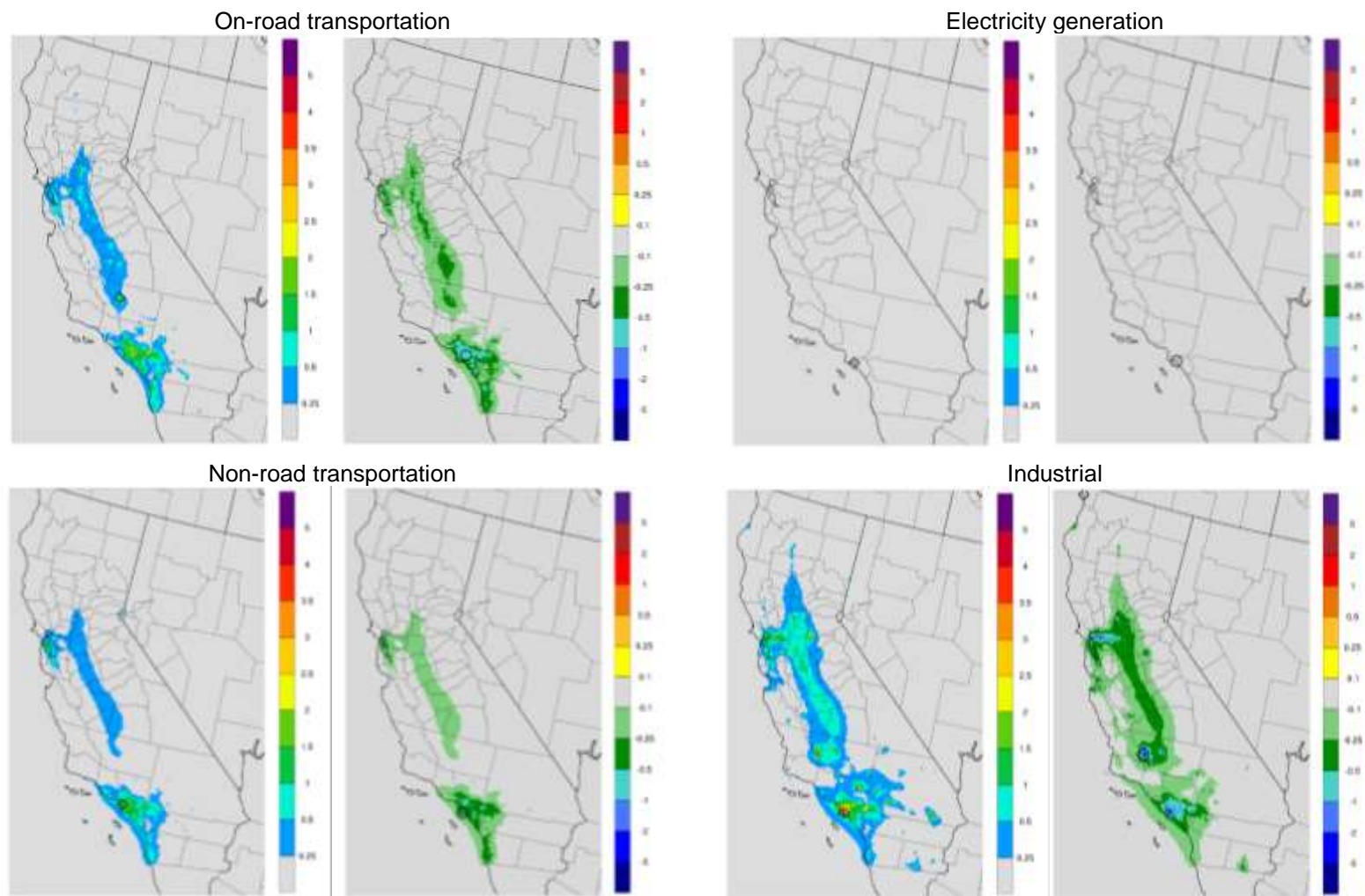


**Figure C-6: Source Contributions to Summer Average Daily Maximum 8-hour Ozone Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right) (continued from previous page)**



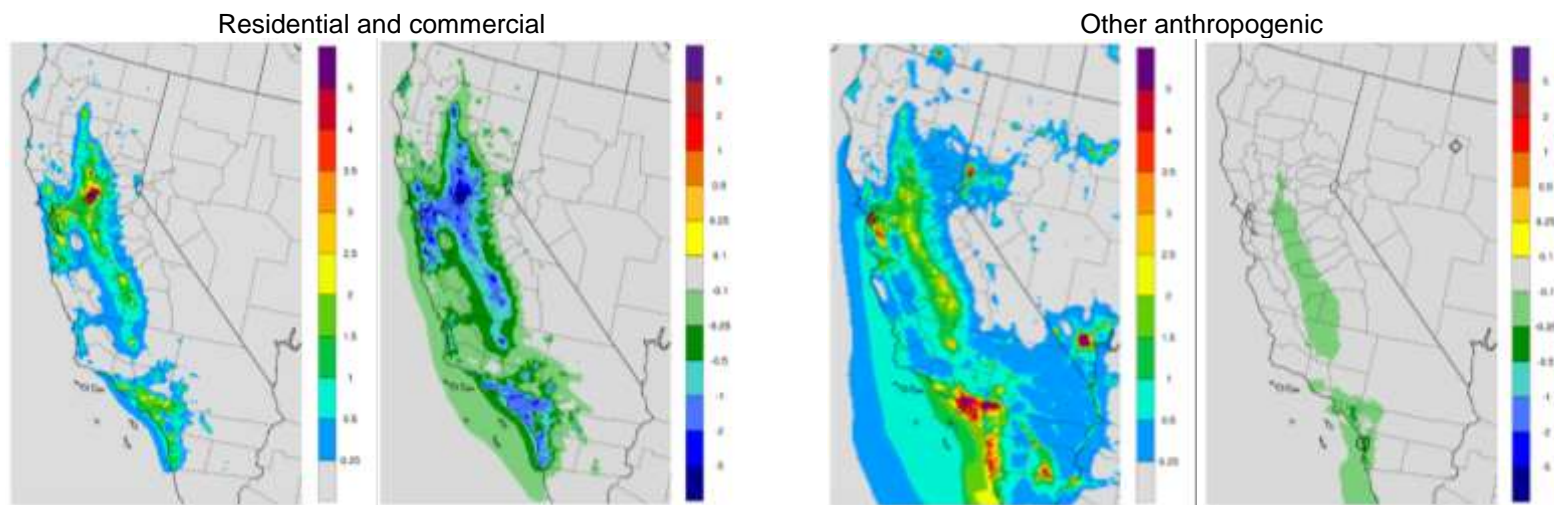
Source: EPRI

**Figure C-7: Source Contributions to Annual Average PM<sub>2.5</sub> Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right)**



Source: EPRI

**Figure C-8: Source Contributions to Annual Average PM<sub>2.5</sub> Concentrations for the Reference Scenario (left) and Difference Between Electrification Scenario and Reference Scenario (right) (continued from previous page)**



Source: EPRI

# **APPENDIX D:**

## **Discussion of Environmental Justice issues interviews**

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### **Introduction**

EPRI conducted a series of interviews with environmental justice groups and supporting departments at the electric utilities throughout the state. Non-profits as well as other stakeholders suggested including these groups. The following list of organizations was contacted for their input on environmental justice and electrification:

- Association for Energy Affordability
- California Public Utilities Commission (CPUC)
- California State University Long Beach
- Center for Community Action and Environmental Justice
- Central California Environmental Justice Network (CCA EJ)
- Coalition for a Safe Environment
- Communities for a Better Environment
- Earthjustice
- East Yard Communities for Environmental Justice (EYCEJ)
- Evergreen Economics
- Green Education
- Greenlining
- Liberty Hill
- Long Beach Alliance for Children with Asthma (LBACA)
- Natural Resources Defense Council (NRDC)
- Pacific Gas and Electric (PG&E)
- San Joaquin Valley Air Pollution Control District
- Sierra Club
- Sacramento Municipal Utility District (SMUD)
- Southern California Edison (SCE)
- Southwest Energy Efficiency Project (Sweep)
- Valley Improvement Projects

Lengthy interviews were conducted with the groups listed in Table D-1. This consists of both environmental justice groups as well as other stakeholders and interested parties who focus on

low income/environmental justice areas. Each interviewee was also asked for their recommendation of who else to speak with.

**Table D-1: Listing of Primary Stakeholders for Environmental Justice Issues Interviews**

Name	Location	Focus/Goals
Center for Community Action and Environmental Justice	Primarily in the Riverside area	Advances the goals of the environmental health and justice movements in California
Communities for a Better Environment	Statewide	Combines grassroots organizing with research and legal work to challenge large-scale industries and policies to achieve environmental justice.
Earthjustice	Statewide	Earthjustice is a non-profit public-interest environmental law organization
Evergreen Economics	Statewide	Performs research using rigorous economic analysis to address public policy questions.
Greenlining	Statewide	Advances economic opportunity and empowerment for people of color through advocacy, community and coalition building, research, and leadership development.
Pacific Gas and Electric Company	Northern California	Works with the San Joaquin Valley disadvantaged communities (DC) to explore affordable electrification.
San Diego Gas & Electric	San Diego County	Provides customer-assistance programs to encourage energy efficiency and demand response adoption.
Sacramento Municipal Utility District	Sacramento area	Evaluates electrification opportunities from SMUD's perspective.

Source: EPRI

## Electrification and Environmental Justice Interview Summary

This section summarizes the key points made by participants in these interviews.

Overall points:

- Some communities are so disconnected they have no electric or gas service, and some not even running water.
- The cost to electrify some remote locations where very-low income households are located can be over \$100,000 per household.

- Each organization and local AQMD has different opinions on electrification ranging from relatively neutral to aggressively opposing electrification. Some local AQMD executive officers support natural gas trucking due to lower costs.
- Providing charging infrastructure to HDV helps incentivize electric HDVs to reduce emissions and other impacts that in many cases predominantly affect low-income communities. Rate basing the infrastructure has been a great solution in an environment where we don't have a tax base to fund these types of policies. Cap and trade funds can help reduce emissions in EJ communities.
- Access to transportation/mobility is the top indicator for getting out of poverty.
- EV car sharing could be an option. Any low-income incentives for EVs should be for both the EV and the EVSE because both are needed.
- Low-income customer awareness of billing alerts (that notify them of higher usage during a billing period) is low. Such customers are very happy to learn about these programs and find them very useful.
- Non-English disadvantaged communities often use radio or newspapers to obtain information.
- Programs with a dynamic rate encourage customers to charge at the right times and impact the system in a positive way.

Identified barriers to electrification:

- Propane and natural gas interests. Natural gas at the present time reduces emissions and some technologies such as natural gas trucks have lower cost than electric alternatives. Fuzzy messaging with "renewable natural gas."
- To achieve California's goals for GHG reduction and EV adoption requires a huge amount of investment and remapping of entire programs beyond what has been done so far. The goals will not be achieved with the policies in place.
- The price of carbon (in California's cap and trade program), doesn't adequately represent the social cost of carbon.
- Installing EVSE in existing buildings, particularly multi-unit dwellings, is one of the largest challenges to transportation electrification. Also, the cost of panel upgrades.
- The CPUC three-prong test is outdated and unclear, which has been a barrier to electrification.
- Barriers to disadvantaged households having greater access to EVs include physical access to EVs and infrastructure; there are financial, informational, and cultural barriers.
- Electrification becomes a non-starter for very-low income households when any kind of up-front cost would be required.
- There needs to be sufficient mobile internet access to disadvantaged folks, so they can locate charging.

- Disadvantaged communities often don't trust government or "pseudo-government" such as utilities and large corporations.
- It is very difficult to get good information on usage of certain fuels, such as propane or wood, that are used in very-low income areas. For wood-burning households there is no information available on how much wood they burn or what (if anything) they pay for it.
- Potential conflict with gas utilities. Since electrification takes service away from gas utilities, they have had discussions with other utilities on how to address this issue. The gas companies would like the electric side to either completely electrify a customer or do nothing, so the gas companies are not left having to supply a very small amount of gas. However, cooking is the most difficult to justify in terms of cost-effectiveness.
- Heat-pump water heaters are still too expensive. Almost no specialized contractors are willing to perform a complete installation of heat-pump water heaters because it is a cross between electrical, plumbing, and HVAC. That leaves general contractors.

#### Recommendations or other comments:

- It is extremely important to keep in mind the socioeconomic status of constituents and their working conditions, for example inside a hot, polluted warehouse. How can the recently passed AQMD indirect source rule be most effective? Clean transportation options, for example CNG buses are being sold as the clean tech today, but that locks the region into a 40-year investment.
- Prioritize incentives to and programs within lower-income communities to electrify transportation.
- Utilities should be interested in bringing their muscle and resources to bear at the Energy Commission convincing them that they need to take building electrification, building codes and appliance standards seriously for all the reasons that are already obvious. In addition, the bad options need to be taken away from landlords for them to choose the right options, ones that make sense from a societal perspective in the long-term.
- Consider utility rate basing to provide electric upgrades to enable appliance upgrades, similar to make ready funding for electric transportation.
- Other western states use on-bill financing to enable conversion from gas to electric water heating, for example. This helps disadvantaged individuals who have less opportunity to take time off work or find childcare.
- Consider using demand response incentives to help pay for deploying electric appliances, especially in low-income communities.
- We need to get off the gas lines and have people going all electric and stop investment into gas infrastructure.
- Perform consumer research to test approaches through interviews or focus groups. "You need to find out what's sexy about it or what's really appealing about it for the



facility folks or building owners and building managers. I think it needs to go a different path than the promotions that we use for energy efficiency upgrades.”

- As a short-term solution to EV infrastructure in MUDs: locate DCFC near MUDs.
- Shedding car ownership is a huge benefit to a DC family’s budget. Look to a bottoms-up approach to provide incentives for mobility. Do not push EV ownership on DC families if they do not need it. Determine what electrification action makes sense to fit the individual’s mobility need.
- Offer on-bill financing for energy efficiency programs. These could be similarly successful with electrification as well as reduced interest rates through bank loans.
- It is justifiable to amortize initial electrification costs over 50-100 years because the change will continue to pay off for a period longer than the appliance’s lifetime.
- The PUCs should ensure that electrification incentives are set such that if a panel upgrade is done, then it’s a requirement to specify the upgraded panel to cover all anticipated electrification loads.
- An approach in low-income communities is to retrofit entire subdivisions at the same time.

# **APPENDIX E:**

## **Summary of Environmental Justice Stakeholder Meeting**

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The Natural Resources Defense Council and EPRI held a stakeholder meeting on March 28, 2019, to discuss issues related to electrification of environmental justice communities, including the effects of poor outdoor air quality on these communities, the effects of poor indoor air quality, and increasing engagement within these communities. The list of participating organizations was:

- Active San Gabriel Valley
- California Air Resources Board
- California Energy Commission
- Electric Power Research Institute
- Energy Coalition
- Greenlining Institute
- Los Angeles County
- Natural Resources Defense Council
- Ohm Connect
- Ramboll Environ
- Southern California Edison
- Strategic Growth Council, California
- University of California, Irvine
- University of California, Los Angeles
- USC Sol Price School of Public Policy

This appendix provides a summary of this meeting.

### **Effects of Outdoor Air Quality**

The results from this study were discussed. This resulted in feedback in a number of areas. First, the meaning of the threshold in analysis of health impacts was questioned and addressed by multiple experts. The discussion indicated that there is no scientific evidence for the existence of a threshold for particulate matter – even in areas with very clean air incremental decreases in emissions appear to result in health benefits. However, regulatory agencies have typically used a threshold because there have been limited studies of effects at low concentrations, so benefits can only be proven at higher levels. An additional factor in including a threshold is that some level of particulate concentration would exist even if there were no anthropogenic emissions, so there is a practical lower limit to health effects. This

implies that emissions reductions should not be valued relative to a hypothetical world where there are no health effects, since there will always be some effect. However, the potential presence of a lower limit does not suggest a specific threshold to be used for analysis. This discussion was used to modify the section above to discuss the potential for a lower limit.

Another important observation is that a constant exposure function was used. The exposure function is used to convert pollutant concentrations into health effects, in this study the number of additional premature deaths that occur with a given amount of pollution. Using a constant exposure function implies that each subpopulation has the same effect from a given pollution level and is generally done in the interest of “fairness” on the assumption that all populations should be treated equally. Although this is a common assumption, a concern was raised that this likely underrepresents the effects in environmental justice communities. The populations in these communities typically have less access to health care and lower means to seek out health care when problems occur. This means that these populations are likely to have preexisting health conditions that increase the effects from a given amount of pollution and are less likely to seek medical help until symptoms are severe. Both factors would result in higher levels of mortality from the same pollution concentration. This suggests that additional study should be performed on using a location-varying or demographic-varying exposure function to capture the more severe effects of pollution on environmental justice communities. Note that this is additional to the higher pollution concentrations experienced by these communities.

## **Effects of Indoor Air Quality**

Just as concentrations of pollutants in outdoor settings result in negative health effects, concentrations of pollutants indoor can also cause negative health effects. There is limited study on the different effects of indoor versus outdoor air quality, but the average person spends 90 percent of their time indoors, 68 percent of it at home, so there are potentially larger effects due to increased time exposure. Although poor indoor air quality would affect all populations, low-income populations in environmental justice communities are more likely to have indoor air quality problems due to poor quality and ill-maintained natural gas stoves, inefficient or inadequate ventilation, and the presence of older appliances with pilot burners, including stoves and floor or wall furnaces. Additionally, environmental justice communities are more likely to have higher levels of crowding which may increase cooking time, which is a significant contributor to indoor air quality problems. Initial results from a study that measured indoor air quality in environmental justice communities were discussed. The study found that mean concentrations were below the standards for outdoor air quality, but there were a number of homes that were much higher than the standard, likely resulting in health impacts. The reasons for these high levels was unclear but will be analyzed. This analysis also suggests that indoor air quality can be improved through electrification of stoves, ventilation hood usage with higher flow rates, and the use of air purifiers.

## **Creating Projects that Focus Benefits on Environmental Justice Communities**

There are a number of projects to retrofit affordable housing and will likely be more in the future. 80 percent of affordable housing was built before efficiency standards were introduced in 1978, so their energy use is high relative to other homes. Retrofitting these houses will reduce emissions and reduce utility bills for residents. Additionally, Los Angeles has a target to electrify 80 percent of buildings by 2030, which will require an increased focus on electrification retrofits in the future, including in environmental justice communities. One important aspect of this work in environmental justice communities is that it will have to be done with a holistic approach. First, one concern within these communities is displacement, that after upgrades are performed the current residents will be kicked out so that the housing can be rented for more. Addressing this means that a sense of security will have to be provided. Second, it is important that the workforce needed to perform these upgrades be recruited from within the community so that they can benefit from these jobs and training. Finally, it is important that this work be well designed, since energy efficiency upgrades typically increase sealing and “tighten” the envelope of a house. This means that volatile organic compounds and PM from sources within the house cannot escape, making indoor air quality worse. Pilots are proceeding and will provide a foundation for future work to ensure that this range of needs is met.

## **Measuring Inequity**

Multiple California government agencies are working on measuring inequity and adverse environmental impacts so that funding can be directed towards improving the most affected communities. This stakeholder meeting included a wide-ranging discussion of an upcoming change to one aspect of this, Energy Commission’s Energy Equity Indicators work, and potential changes and data sources that could be used to improve the indicators. The discussion indicated the tensions between different ways of interpreting the data and the effects this may have on funding. As one example, one measure of health effects currently used is the level of hospital admittances for asthma. Although these are correlated with poor air quality, it was suggested that asthma is a controllable disease, so this measure is more related to a lack of access to health care rather than a direct effect of pollution. It is important to address both of these factors but doing so will require different approaches. As a second example, the measures used are often biased towards urban areas, so there are some areas like the Imperial Valley that score relatively low on the indicators but have severe pollution levels that are not being addressed. One reason for this is that some communities are within regions that are relatively clean but have hotspots that are quite polluted.

## **Including Environmental Justice Communities in Studies and Projects**

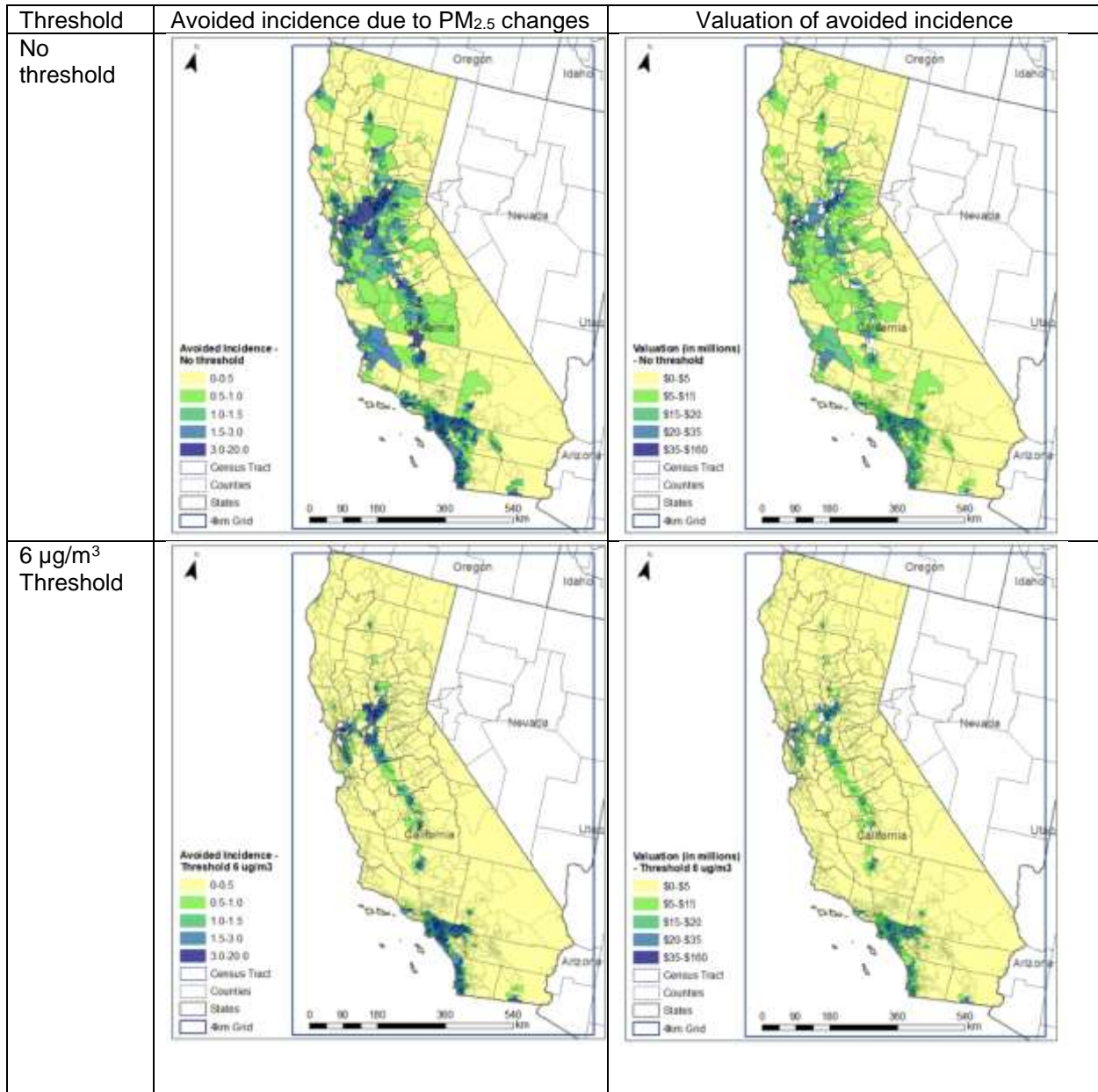
The final session discussed inclusion of environmental justice communities in studies and projects. Working towards environmental justices is an increased focus for California, so many funding opportunities from California government agencies include an environmental justice

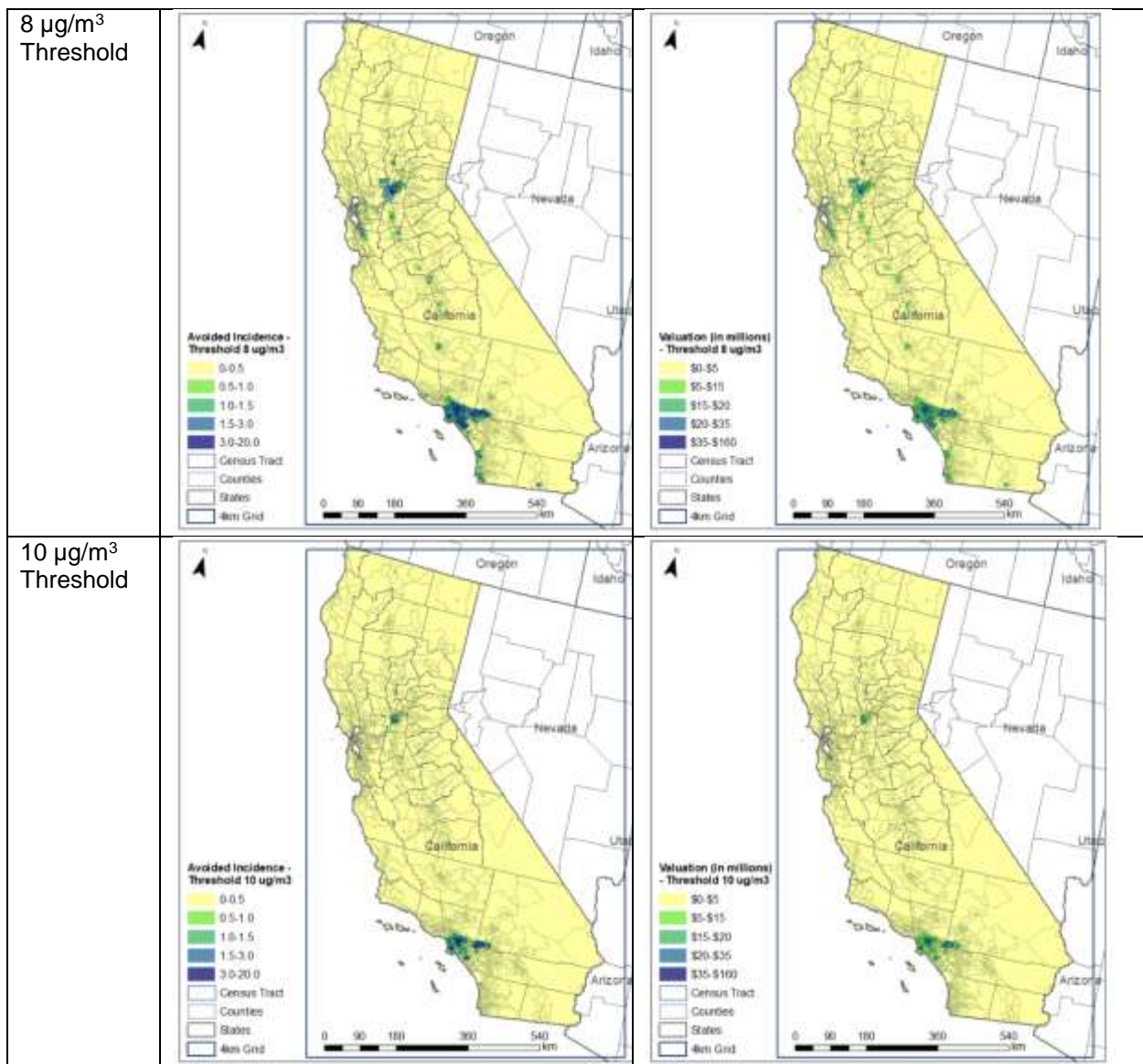
component, and environmental justice communities have not been engaged well and feel more like a “box to check” than a group with a seat at the table. This session suggests that a best practices document should be developed to help project developers meaningfully engage with environmental justice communities. Some important items to consider are:

- Reserve a meaningful portion of project funding for community engagement. The precise funding level will design on the project, but it is important to recognize that project managers are not working for free and should not expect the community to either. This does not mean that everyone must be paid directly, but consideration should be made for the needs of the participants. If a focus group is held, funding should be provided for transportation, water, food, and childcare to reduce barriers to participation. If labor like door-to-door surveying is required, the surveyors should be paid.
- Communities should be engaged in a way that works well for them. For example, focus groups can work much better than large community meetings so that people are heard. Project managers should not just present a blizzard of data and expect understanding; they should speak in terms of why this work is important for community members. Given language barriers, communities should be engaged in their own language, with fluent speakers or translators if necessary. The promotora model, in which community members are paid directly to perform surveys and work with other members of the community to understand their needs, was suggested as one promising approach.
- Plan to spend a lot of time working with the community. In the past, the amount of time needed to engage communities has been badly underestimated. This has resulted in “community listening” efforts that did not really listen and did not make community members feel heard. This misses the opportunity to really understand the problem and develop solutions that will actually work.

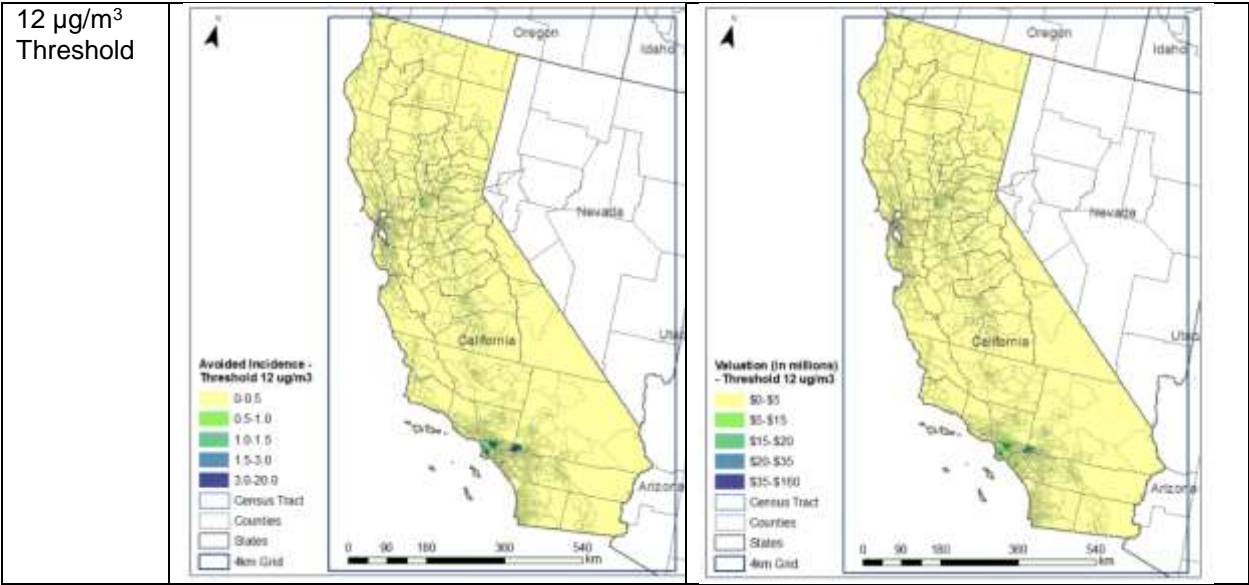
# APPENDIX F: Additional Charts on Health Impacts from Electrification

**Figure F-1: Avoided Incidence and Valuation of Avoided Incidence from PM<sub>2.5</sub> Concentration Changes for California by Census Tract, Assuming Different Thresholds (left: avoided mortalities per year; right: valuation in millions of dollars)**



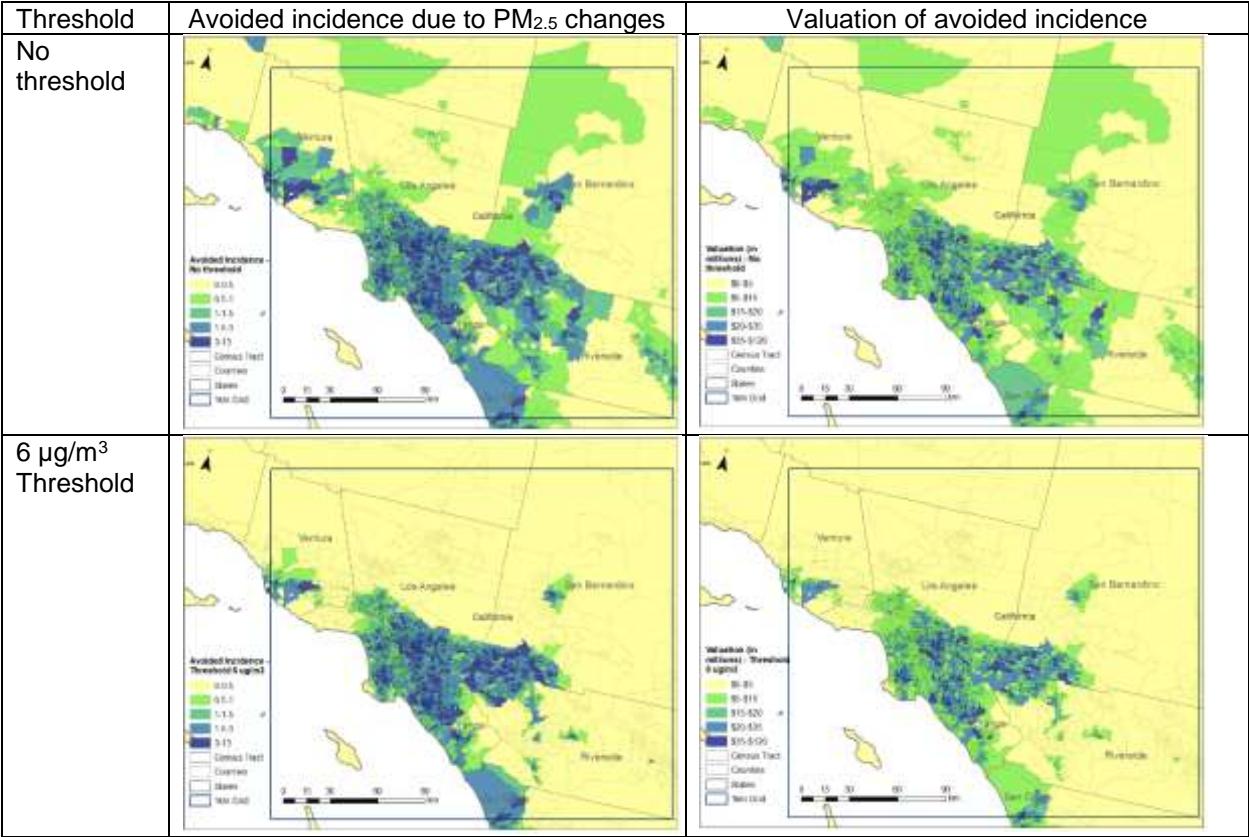


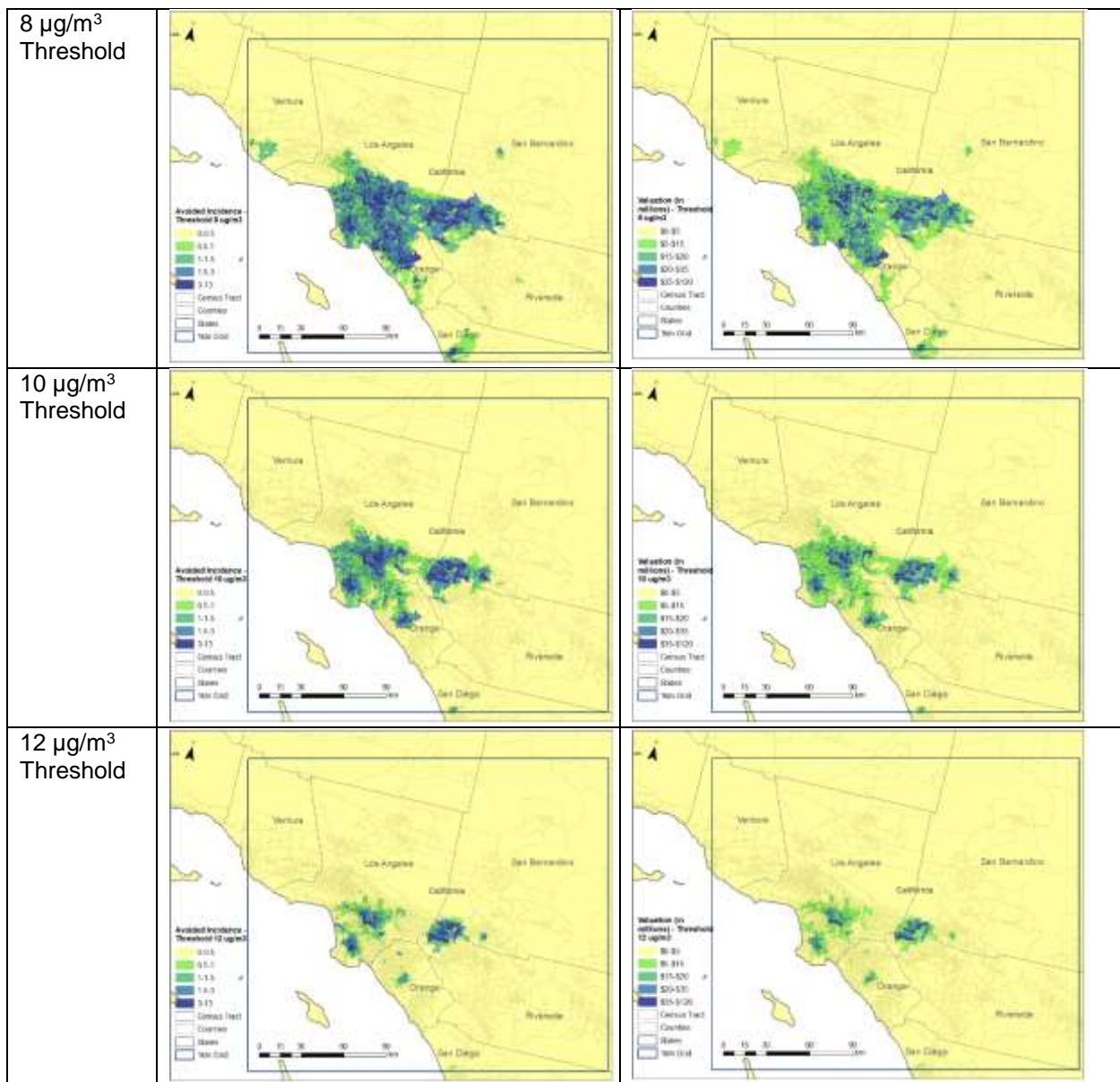




Source: EPRI

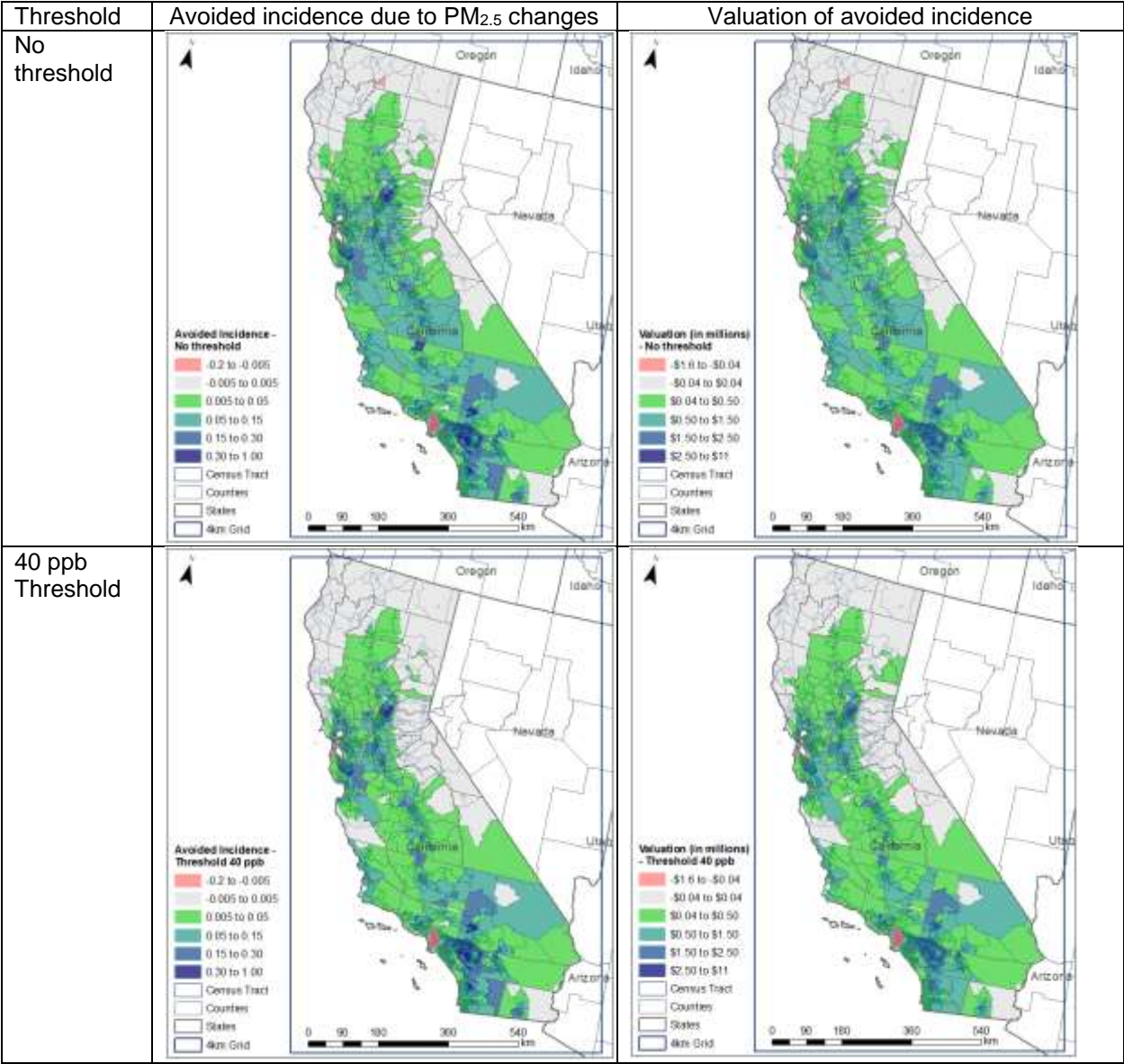
**Figure F-2: Avoided Incidence and Valuation of Avoided Incidence from PM<sub>2.5</sub> Concentration Changes for the South Coast Basin by Census Tract, Assuming Different Thresholds (left: avoided mortalities per year; right: valuation in millions of dollars)**



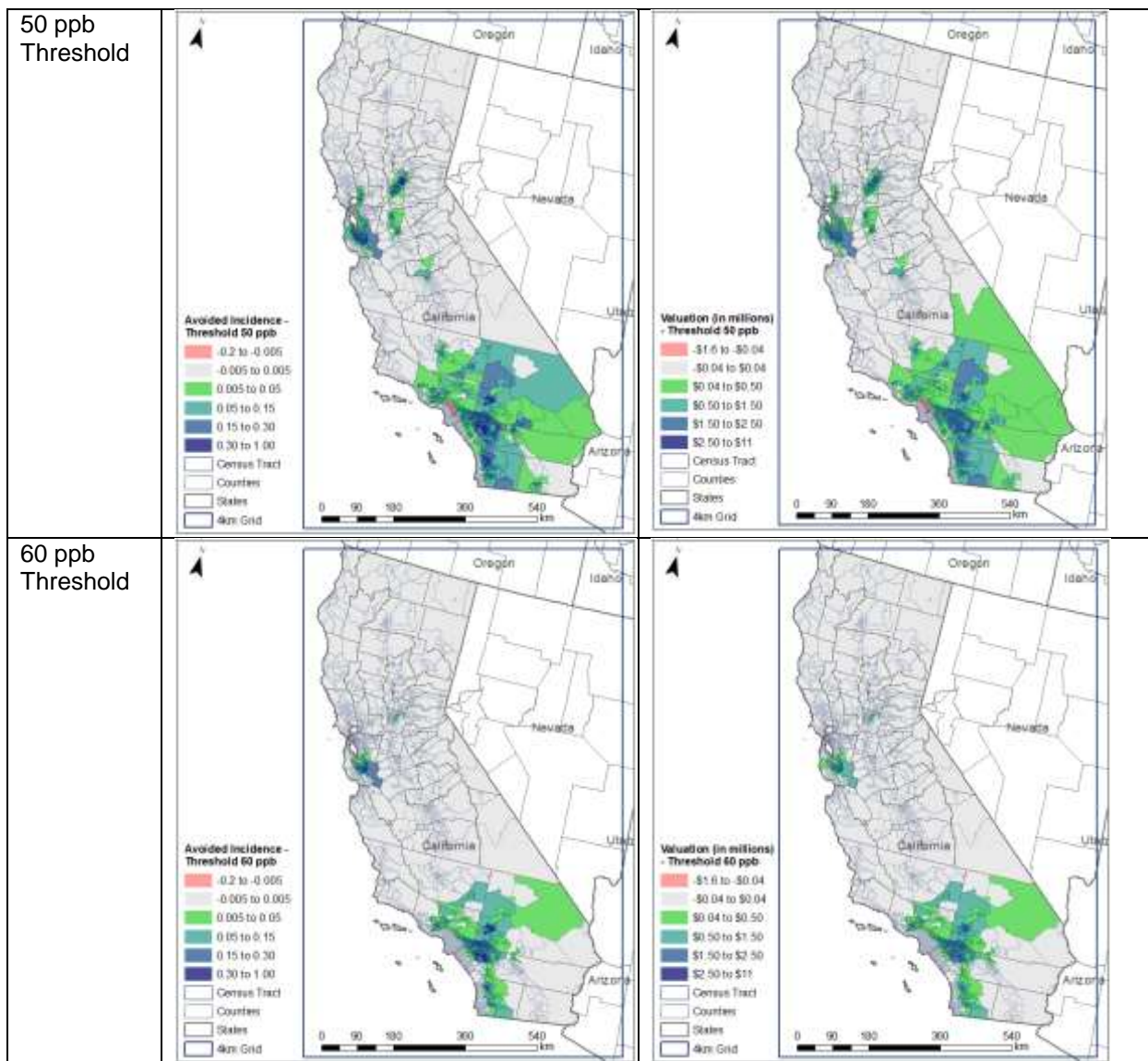


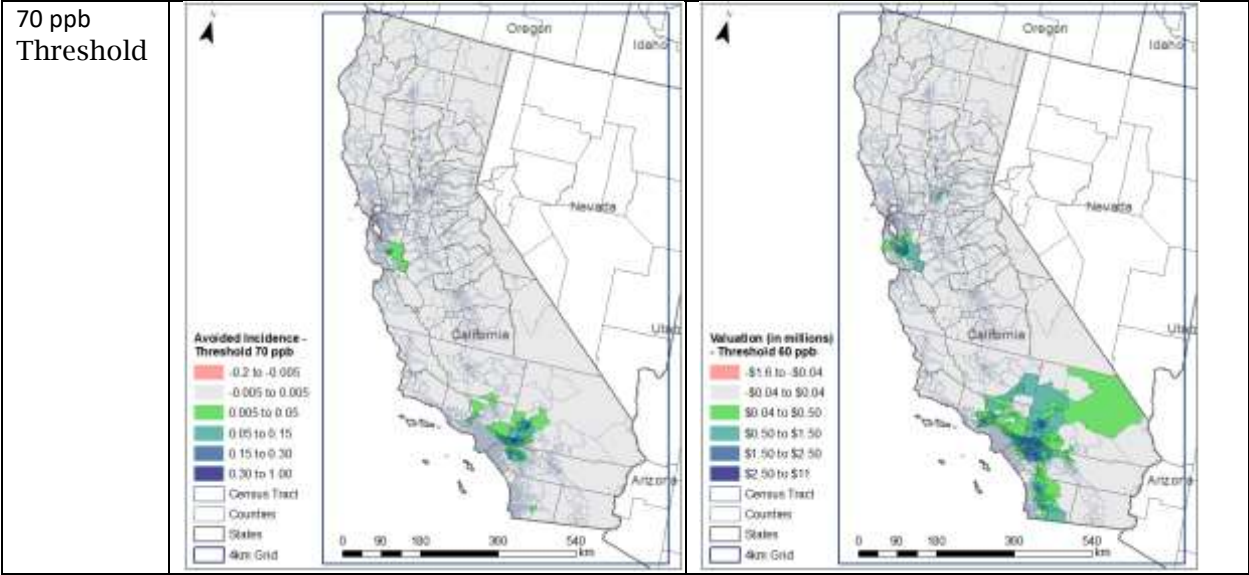
Source: EPRI

**Figure F-3: Avoided Incidence and Valuation of Avoided Incidence from Ozone Concentration Changes for California by Census Tract, Assuming Different Thresholds (left: avoided mortalities per year; right: valuation in millions of dollars)**



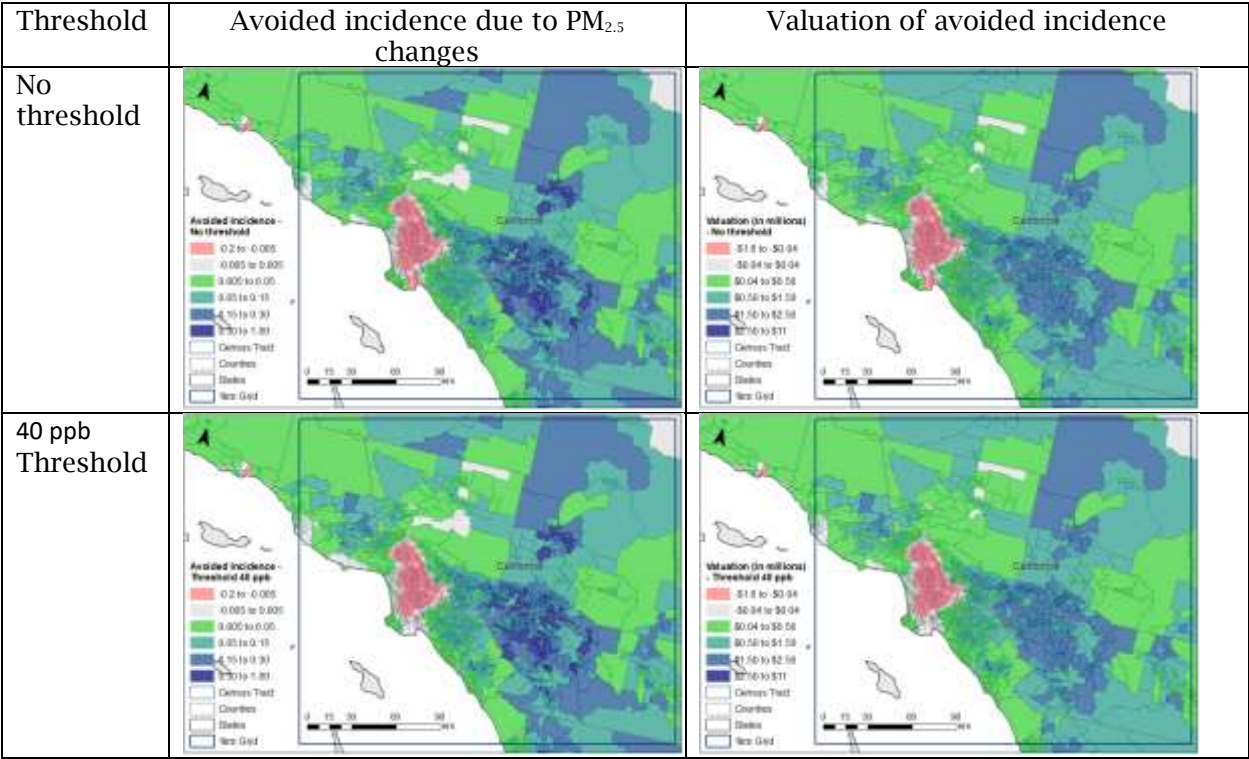


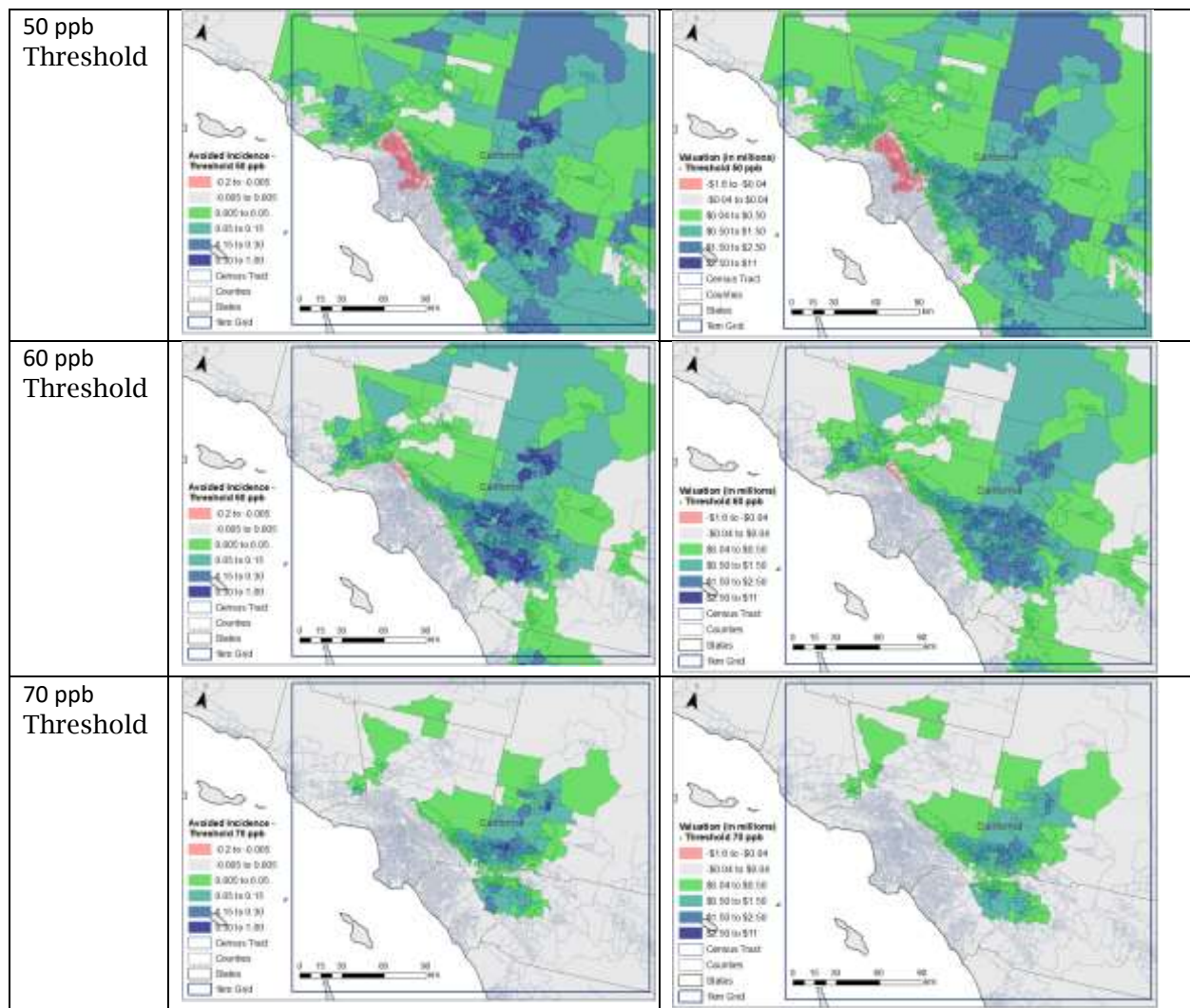




Source: EPRI

**Figure F-4: Avoided Incidence and Valuation of Avoided Incidence from Ozone Concentration Changes for the South Coast Basin by Census Tract, Assuming Different Thresholds (left: avoided mortalities per year; right: valuation in millions of dollars)**





Source: EPRI

# APPENDIX G:

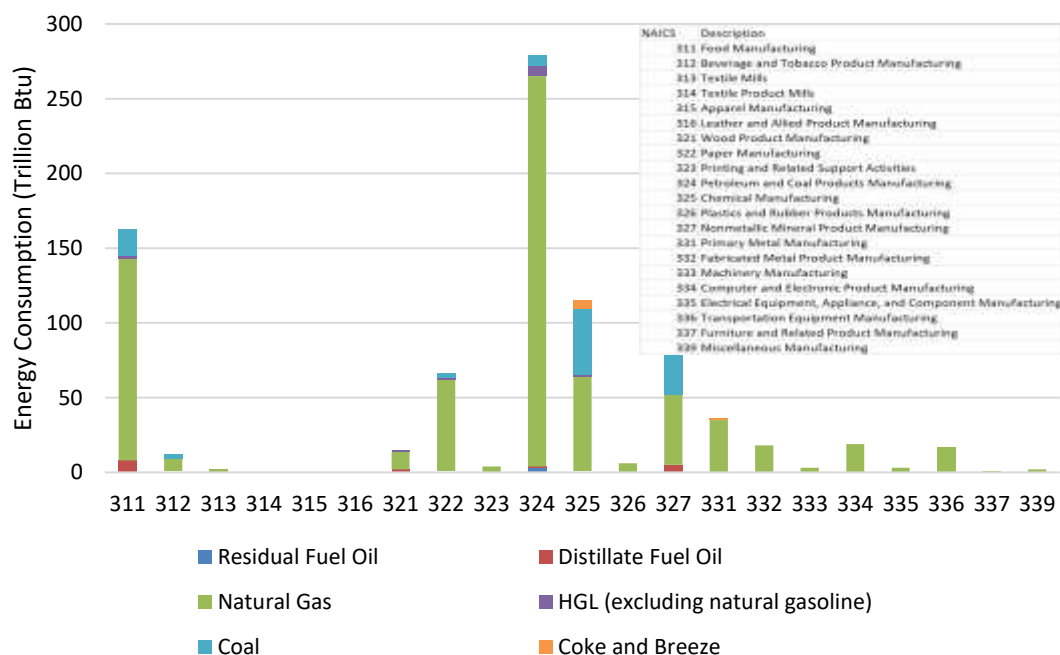
## Target Fossil Fuel Intensive Industrial Segments and Potential Applications of Electrification Technologies

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The United States Department of Energy's 2017 Manufacturing Energy Consumption Survey (MECS) provides primary energy consumption data by industrial NAICS code broken down to the census region level.<sup>18</sup> California is part of the West census region that is dominated in terms of population and industrial activity by the Pacific Zone that includes California, Oregon and Washington. As such, the West Region of the MECS survey is used as a reasonable proxy for identifying and targeting the most impactful California industries for electrification. In this region industrial and agriculture/forestry activities consume 877 trillion British thermal units (Tbtu) and 65 Tbtu respectively of fossil fuels annually.

The following sections describe the activities for a selection of segments of the industrial sector with particularly high emissions impacts. Figure G-1 and Figure G-2 show the industries that are the largest consumers of various fossil primary energy resources in the west census region and for specific California industries.

**Figure G-1: Industrial Fossil Fuel Combustion (West census region)**

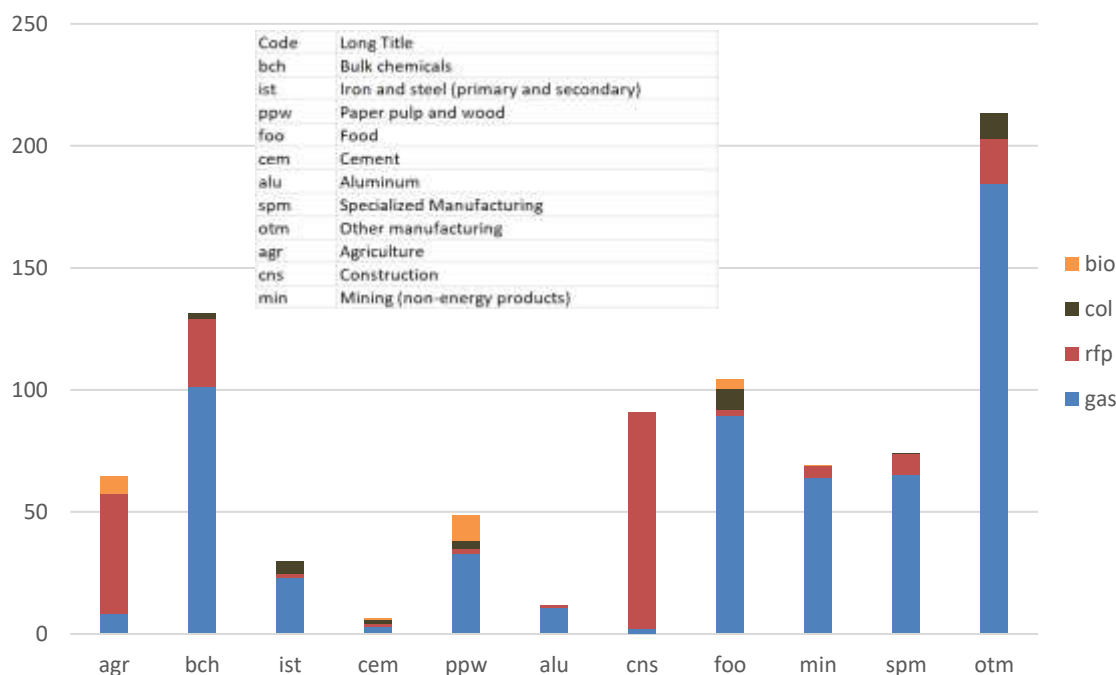


Source: United States Department of Energy 2017 Manufacturing Energy Consumption Survey (MECS)

<sup>18</sup> <https://www.eia.gov/consumption/manufacturing/>.



**Figure G-2: Selected California Industrial Fossil Fuel Consumption (end use fuels are biomass (bio), coal (col), petroleum products (rfp), and natural gas (gas))**



Source: EPRI (data from US-REGEN)

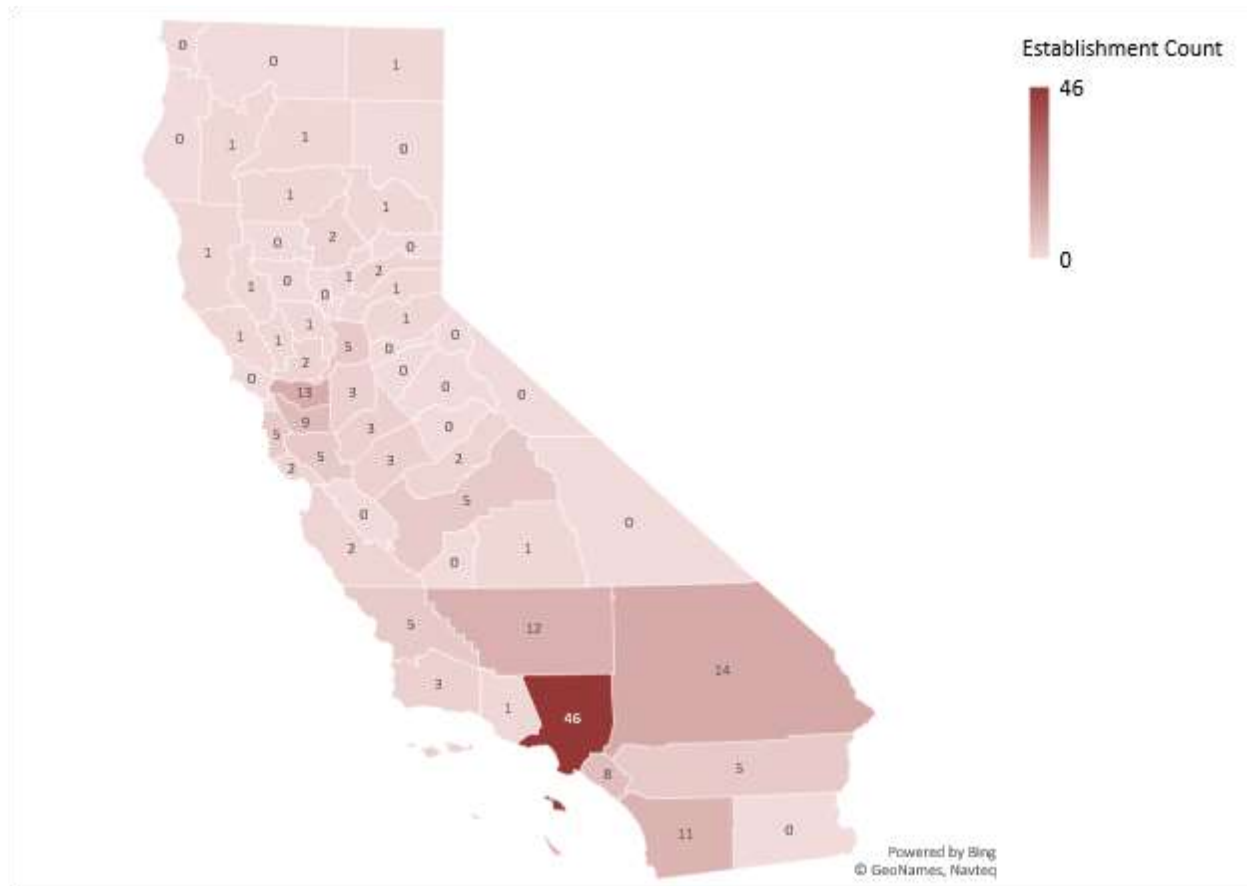
## Petroleum Refining

The petroleum refining industry is by far the largest consumer of fossil fuels in the west region combusting more than 279 TBtu of natural gas, coal, gasoline and residual fuel oil. California is home to two substantial centers of oil refining operations; one in Los Angeles County in the Long Beach and Port of Los Angeles coastal area; with additional sites in nearby San Bernardino, Kern, San Diego and Orange counties and the second just inland east of Oakland along the eastern San Francisco Bay and San Pablo Bay coasts in Contra Costa and Alameda counties. The combustion of primarily natural gas is necessary for heating and generating the pressures needed in reactor vessels for the various cracking, distilling and reforming processes as well as to produce steam in massive quantities as an input for hydrogen generation used in downstream production of high energy, high value fuels such as gasoline, diesel and jet fuel. These refineries are optimized to generate the most profitable mix of distillate fuels in a highly competitive and volatile commodity market. As such, great attention is paid to maximizing process yield while also optimizing process efficiency and costs. Capital investments are immense and there is strong motivation to extend their useful life for decades through process improvements and modifications to improve yield, reduce cost or to come into compliance with tightening environmental regulations. Interaction of process variables is profound and minor variations can have substantial downstream impacts on yield, product quality and profitability. Several electrification options exist for this industry, but few have the potential payback in terms of energy costs, productivity improvements or environmental compliance to justify the process risk under current economic and regulatory regimes. Near term and long-term opportunities will be discussed in subsequent sections

Oil refineries are sources of ozone precursors through the emissions of volatile organic compounds (VOCs) and nitrogen oxides (NO<sub>x</sub>). The most important of these are the NO<sub>x</sub> emissions that combine with VOCs not only from anthropogenic sources, but also from abundant natural sources at ground level in the presence of sunlight to produce ozone. Other products of combustion are associated with fine particulate matter (PM<sub>2.5</sub>). In response to regulatory pressure, the industry has sought to improve refinery performance in terms of productivity and pollution abatement, however, the primary strategy has been to ensure sufficient stack height and effluent velocity to achieve dispersion of combustion products to avoid exceeding state and federal air quality standards. Furthermore, the California oil refineries contribute an estimated 29,610,000 metric tons per year of CO<sub>2</sub> emissions while the related oil and gas production and transportation activities in state contribute an additional 17,930,000 metric tons. Combined the activities associated with petroleum products account for 53 percent of the total industrial contribution to state greenhouse gas emissions.

Oil refineries have been historically sited where factors of production are most readily available. Access to large volumes of crude oil from gathering fields through pipelines or via import terminals from ocean going tankers is essential; as well as availability of water, large tracts of land and skilled workforce. Equally important is proximity to the end markets for the most valuable and highly consumed refined products. Thus, it is not uncommon to see refineries situated near large population centers to minimize distribution costs for fuels (gasoline, diesel, jet fuel, propane) supporting transportation in its various forms. While there has been some historical attempt to secure the large tracts of land needed in less populated regions, urban sprawl has tended to envelop centers of refining activity in California. In addition, those siting of refineries decades before the advent of sound environmental and health science and the resulting regulation were ill equipped to predict or model health and environmental impacts on what would become surrounding communities. These surrounding communities have tended to emerge as some of the more economically disadvantaged, bearing a disproportionate burden of exposure to ground level ozone and PM<sub>2.5</sub> and their attendant negative health impacts. Figure G-3 shows the relative density of oil refining operations in California. Strategies and policies to address aggregate state impacts of the petroleum industry on ozone and PM<sub>2.5</sub> may also need to pay specific attention to local concentrated impacts in these nearby environmental justice communities.

**Figure G-3: Location of Petroleum Refining Sites in California**



Source: EPRI

## Chemicals and Plastics

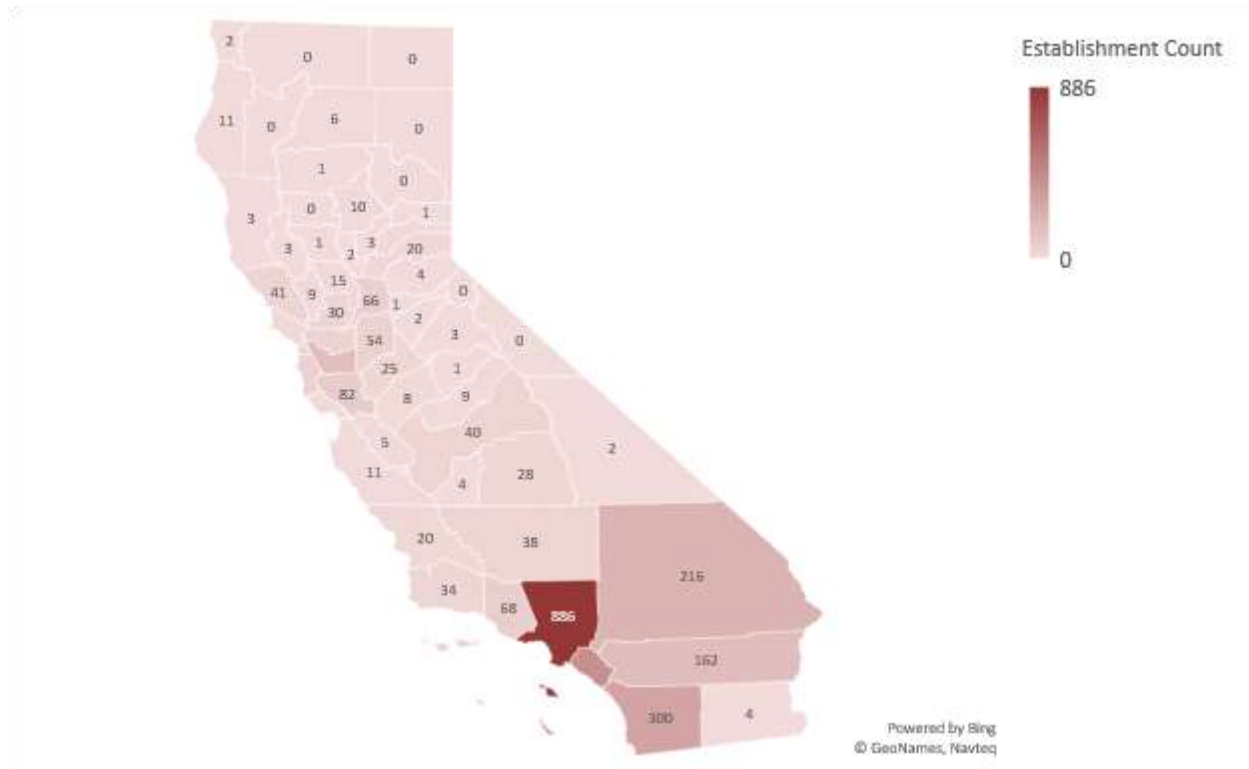
Chemical process industries comprise a diverse swath of products from bulk organic and inorganic materials such as rubber, polyethylene or ammonia to semi-finished and finished goods such as tires, discrete plastic parts and pharmaceuticals. Chemical goods are typically constituents, reagents or sub-components for other finished goods although some, like pharmaceuticals and fertilizers, are sold directly for end-use. The chemical and plastics industry is the third largest consumer of fossil fuels in the west census region consuming 121 TBtu and second largest in California. Fuel is consumed largely for similar purposes as in the petroleum industry to initiate and provide energy to sustain chemical and biological reactions; however, additional thermal inputs are needed in the rubber and plastics sub-segments for mixing, extrusion and molding processes. This industry relies a bit more heavily on bituminous fuels to drive steam generation from central boiler rooms for distribution to processes where the thermal energy is needed.

Environmental impacts of the energy consuming activities of the chemicals and plastics industry are virtually identical in nature to those associated with the petroleum industry.  $\text{NO}_x$  and primary  $\text{PM}_{2.5}$  from natural gas fired process would be proportionate to that of the petroleum industry, however a higher reliance on coal, coke and breeze fuels are likely to elevate ozone, particulate matter and  $\text{CO}_2$  contributions. The chemical industry also generates additional environmental impacts in their

surrounding communities arising from fugitive emissions of the chemicals produced and process by-products. These impacts can contribute additional hazardous air pollutants (HAPs), particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) in local and regional environments and highly impact greenhouse gas emissions. Chemical facilities, in particular, plastics and rubber component production, tend to be smaller scale and much more numerous than petroleum refining works. These facilities contribute 6,347,000 metric tons of CO<sub>2</sub> emissions including fugitive CO<sub>2</sub> equivalents yielding an average chemical facility footprint of 2,141 metric tons per year compared with 260,769 metric tons per year of CO<sub>2</sub> for an average California petroleum refinery. It is noteworthy that this industry, along with petroleum operations and the pulp and paper industry are the major participants in the operation of industrial combined heat and power facilities that contribute an additional 11,080,000 metric tons of CO<sub>2</sub> emissions in the state

Figure G-4 shows the locations of facilities for production of chemicals and plastics in California. Since the chemical industry utilizes products and by-products from the petroleum industry as feedstocks and given the fact that they require many of the same important factors of production, it is not surprising that these facilities tend to be co-located in regions alongside petroleum operations. As such, their impacts on surrounding communities can be assumed to be proportionate to their contribution from their fossil fuel combustion plus any fugitive and exhausted process emissions. Strategies for addressing this industry's environmental and carbon footprint could easily be combined through implementation of similar electric technologies into a single petrochemical electrification roadmap. Although creating awareness and promoting electric solutions into the chemical and plastics facilities may present challenges due to greater fragmentation and thus dilution of financial resources within the market. The combined petrochemical industry accounts for about 41-45 percent of California's fossil fuel consumption and 54 percent of CO<sub>2</sub> emissions.

**Figure G-4: Locations of Sites for Production of Chemicals and Plastics**



Source: EPRI

## Food, Beverage and Tobacco

The production food, beverage and tobacco products for human and animal consumption comprise the second largest electrification target market in terms of fossil fuel consumption in the west census region and third overall in California. Roughly 20 percent of the fossil fuel consumption in the region occurs in this segment. A majority of the fuel consumed is natural gas used for direct fired cooking, direct and radiant baking, boiling, blanching and to produce steam for cooking and sterilization. In addition, a small amount of residual fuel oil is used to produce steam for similar applications. An exception is sugar production, which still employs a substantial fleet of coal-fired boilers supplemented by natural gas and fuel oil boilers to produce process steam. In aggregate, the industry consumes about 175 TBtu of fossil fuels annually within the region.

The environmental impacts of the energy intensive processes within the California food, beverage and tobacco industry (100.4 TBtu) are only slightly less in magnitude than that of the chemical industry (131.2 TBtu) in terms of fossil fuel consumption. These industries tend to require heavy net water withdrawals for steam systems, produce cleaning, boiling and blanching processes and for aqueous and steam process cleanup driven by stringent food safety regulations. Clean sterile water and heavy post process wastewater treatment to reduce biological oxygen demand (BOD) loading before discharge to publicly owned treatment works (POTW) is common. Influent and effluent water treatment can add an additional level of energy intensity that should be considered part and parcel to the industry's direct impacts.

Figure G-5 shows the locations of facilities for food, beverage and tobacco. These locations roughly correspond geographically to localities with higher densities of agricultural activity, namely costal and San Joaquin Valley counties with slightly heavier concentrations in Los Angeles, San Diego and Orange counties in the south and in the northern wine region including Sonoma, Napa and Alameda counties. Consequently, the air quality, water quality and usage impacts can be considered somewhat additive to those described for the agriculture markets in subsequent sections. Effectively reaching and promoting electric technologies into this industry could prove challenging given that there are more than 5600 establishments in California engaged in food, beverage and tobacco processing. It will be necessary to develop a clear strategy on the few technologies that are most impactful and advance them to the industry participants with customer characteristics that indicate the highest potential to adopt.



## Stone, Clay, Glass and Cement Products

generated through the chemical conversion of clay and limestone feedstocks) is formed then introduced into a grinding operation for conversion into Portland cement. In aggregate, the industry consumes 106 TBtu of fossil fuel in the western census region. In California, however the cement industry is not a large consumer of fossil fuel accounting for just over 6.5 TBtu of usage through the combustion of an array of natural gas, coal, petroleum distillate oil and biofuels. This represents only about 0.7 percent of the state's fossil fuel consumption.

The massive volumes of cement produced for the concrete industry and the extreme temperatures required to reach the sintering state where partial liquification is necessary to produce clinker (1,450 °C, 2,640 °F), are factors in cement production's contribution of 8 percent of global carbon emissions. In California, the small relatively low consumption of fossil fuel consumption offers a clue about the ultimate source of the industry's contribution to greenhouse gas emissions. Substantial process emissions of CO<sub>2</sub> occur as result of chemical reactions during sintering in the production of cement clinker due to the decomposition of limestone in the kiln. Tackling this element of greenhouse gas emissions from the industry requires a re-thinking of the processes used to produce Portland cement. Other glass and clay production operations add further to the segment's air emissions and carbon footprint. As a result, this industry contributes 8,446,000 metric tons of emissions annually; 25 percent more than the chemical industry.

Figure G-6 shows the locations for facilities producing stone, clay, glass, and concrete. These non-metal mineral based products are generally manufactured in facilities within and surrounding counties with the highest population densities. They are among the heaviest payloads that must be transported to end markets where residential commercial and industrial buildings, road and other civil engineering projects take place. Consequently, to minimize transportation costs these facilities tend to be in heavy industrial areas near population centers or otherwise near mine mouth locations. While stone, clay, glass and cement production contribute substantially to greenhouse gas emissions, the impact of operations on surrounding California communities in terms of ozone and secondary PM<sub>2.5</sub> is somewhat muted due to relatively low volumes of non-renewable fuel combustion involved. A greater concern is the primary particulate matter associated with rock and clinker crushing and grinding operations. While there is some potential to electrify these processes, that action will have little impact on the resulting fugitive emissions of stone dust.



**Figure G-6: Locations of Facilities for Stone, Clay, Glass, and Concrete Production**



Source: EPRI

## Wood Products, Pulp and Paper

The wood pulp and paper industry includes not only the manufacture of wood cellulose fiber based paper products from virgin forest feedstock, but also recycled paper and paperboard products, structural, engineered and finishing wood products for building construction, furniture manufacture and paper printing processes. Production of wood pulp or re-pulping of recycled material to produce paper, paperboard and corrugated structural products are the more energy intensive processes. In the west census region, this industry consumes about 85 TBtu of fossil fuel with 78 percent of this total attributed to pulp and paper production. California alone accounts for 48.5 TBtu of total annual fuel consumption within the segment, which is comprised mostly of natural gas with small amounts of supplemental coal and fuel oil. This industry has a long history of taking advantage of available forestry and construction clearing waste, lumber mill by-products and black liquor as renewable fuels to fire boilers for the generation of steam. The steam in turn is used to provide the necessary thermal inputs for pulping operations and paper mill carding steam drums as well as steam turbine drives to mechanically power the massive mill machinery complex. Often these are configured in combined heat and power (CHP) facilities that generate electricity to partially offset plant power requirements or sold as excess to the grid under purchase power agreements (PPA).

The operational characteristics and favorable economics of these inexpensive renewable fuel sources are deeply embedded in the industry making it difficult to replace them with electric technology alternatives. Nonetheless, the expense and risk associated environmental air quality

regulation compliance, reliability of biofuel supplies, maintenance of certified staff to operate the massive steam plants, safety and maintenance issues associated with steam turbine and jack-shaft/gearbox mechanical drive trains that operate the mills and lack of precise operational controls available through modern electric servo-drive technologies are leading the industry to consider direct electric powered alternatives. In California, the industry contributes a mere 486,000 metric tons of CO<sub>2</sub> emissions or just 0.12 percent of the state's carbon footprint. If it were possible to convert pulping, mill drives and the remaining steam for calendaring drums to electric energy sources the entire carbon footprint of the industry could be electrified. The cost competitiveness of an all-electric paper mill is a difficult bar to reach under the current conditions however it is possible to begin taking steps in that direction with the application of targeted electric technologies to solve operational issues while reducing fossil fuel consumption

Given the minimal in-state fossil fuel consumption, negligible carbon footprint and the inferred low contribution of NO<sub>x</sub> emissions and use of renewable fuels it would be tempting to declare this industry as a *de minimis* source if local community impacts. However, regardless of its renewable nature, fuel is combusted in the boilers of these facilities producing NO<sub>x</sub> leading to ozone and secondary PM<sub>2.5</sub> formation that is exacerbated by noxious fugitive process emissions with some VOC content. These factors continue to drive the need for cleaner electric powered solutions in the industry to reduce local community exposures. Figure G-7 shows the locations of facilities for wood, pulp, and paper production. As expected, these facilities tend to be located in regions associated with forestry activities with some additional concentrations in industrial centers in Los Angeles, Orange and San Diego counties and east of San Francisco Bay. Addressing the energy requirements of this industry through electrification would positively impact the surrounding down-wind environmental justice communities to their east.

**Figure G-7: Location of Facilities for Wood, Pulp, and Paper Production**



Source: EPRI

## Primary Metals, Fabricated Metals and Machinery

The primary and fabricated metals and machinery industry in California consumes about 57 TBtu of fossil fuels. This fuel is used primarily in the smelting of iron and aluminum from base ore feedstocks, subsequent refining, alloying and re-melting of recycled metal to produce iron, steel and aluminum billets which in turn become feedstock to produce bars, tubing, structural beam and channel shapes, flat plates, sheets and coil strip, castings and forgings. These serve as raw materials for an astonishing array of fabricated, machined and otherwise converted components and assembled machinery. Each of these stages of production typically require some amount of thermal inputs for changing the chemistry, form, shape, microstructure and engineering properties of the material. Due to the need for increased precision and quality control to meet ever-increasing performance specification and to control costs of production in highly, globally competitive markets for these commodities and to reduce environmental, health, and safety risks; precision advanced electric process heating technologies have been supplanting fossil fuels in these industries.

Among the primary environmental concerns for the family of metals industries is compliance with various air quality regulations. All phases of production that rely on fossil fuel thermal inputs are exposed to costs and risks associated with point source air permits. This includes not only the products of fuel combustion but also process emissions that contain hazardous vapors and particulate matter, smoke and VOC. In terms of greenhouse gas emissions, the industry contributes

1,037,000 metric tons of CO<sub>2</sub> emissions to the state's carbon footprint, split roughly equally between primary metals and subsequent processing industries.

Figure G-8 shows facilities for primary and fabricated metals and machine production. Metals processing is highly concentrated in the Los Angeles to San Diego coastal strip and near Oakland east of San Francisco Bay. A wide array of productive and competitive electric technologies exists for improving the air emissions from these industrial sources. With the exception of primary metals smelting, there are viable and competitive electric alternatives for most metals thermal processes offering the potential to minimize air quality impacts on surrounding environmental justice communities. On the primary metals side longer-range low-impact processes are in stages of research and development that could further reduce these impacts.

**Figure G-8: Locations of Facilities for Primary and Fabricated Metals and Machine Production**



Source: EPRI

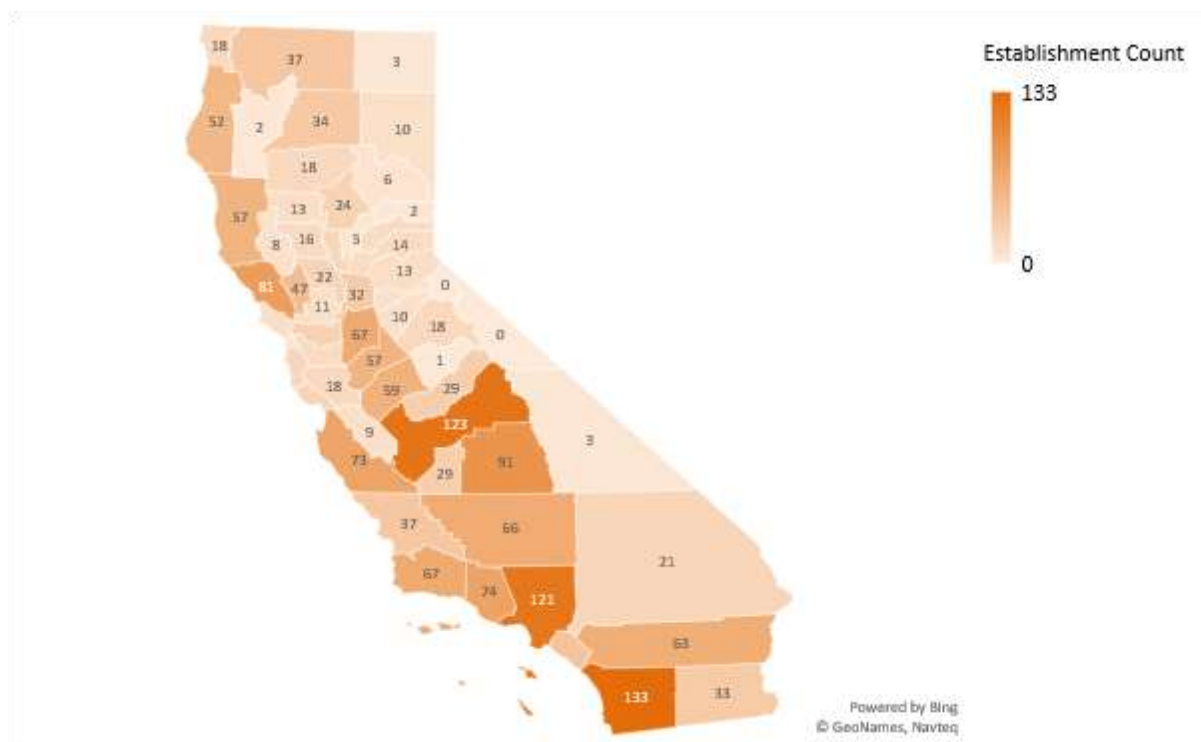
## Agriculture and Forestry

The agriculture and forestry industries provide the primary raw materials and feedstocks into other major industrial sectors described above including food and beverage, wood, pulp and paper, chemical products (pharmaceuticals, bio-fuels, fibers, and so on) and construction. Distillate fuel is the dominant fuel for direct energy consumption for livestock and crop and forestry operations. Distillate (primarily diesel, gasoline and propane) is used for crop tilling, harvesting, weed control, and other operations that require heavy machinery. Crop drying is another fuel-intensive farm activity, and the amount of fuel used varies by the type of crop and its moisture content. High-temperature dryers are powered by either electricity or propane. Supplying water can also be an

energy-intensive task. Although some farms have access to public water supplies, most farms pump water from wells and groundwater sources. Most pumping is done with electricity, but pumps in remote locations may use diesel or propane.<sup>19</sup>

Agriculture in California consumes in aggregate 64.88 TBtu of fossil fuel. The predominant fuel types consumed are distillates (diesel, gasoline and propane) used for crop field operations machinery, irrigation pumping and seasonal produce drying. Additional amounts of natural gas are consumed for crop drying as well as the use of certain renewable bio fuels (primarily bio diesel) in internal combustion engines powering tractors, pumps, and so on. The non-renewable fossil fuel consumption of 57.46 TBtu annually is a potential target for electrification. Agricultural and forestry activities occur broadly through all latitudes of the state concentrated however from the central valley to the pacific coast. Figure G-9 shows the locations of agricultural facilities in California. All coastal counties as well all counties with any part of their geography in the San Joaquin Valley support higher densities of agricultural activities. Lower elevation regions across the southern tier of counties also possess favorable climates for agriculture. Forestry activity occurs essentially where agriculture does not, as shown in Figure G-10. The consumption of diesel fuel and gasoline by mostly mobile tree harvesting platforms is not conducive to electrification due to the remoteness of operations, rugged terrain and mobility of the work sites.

**Figure G-9: Locations of Agricultural Facilities**



Source: EPRI

<sup>19</sup> Today In Energy, October 17, 2014, Energy for growing and harvesting crops is a large component of farm operating costs: <https://www.eia.gov/todayinenergy/detail.php?id=18431#>.

**Figure G-10: Location of Forestry-related Facilities**



Source: EPRI

The most substantial air quality impacts of the fossil fuel powered activities associated with farming and forestry are the likely localized effects on primary  $PM_{2.5}$  from incomplete fuel combustion and cultivation dust and  $NO_x$  leading to ground level ozone formation. These emissions occur and remain very close to ground level and therefore are direct exposure risks. Ground level  $NO_x$ , associated with summer season activities, particularly in the San Joaquin Valley, are held in place by climatic strata along with transport  $NO_x$  from upwind industrial sources. These react throughout the long summer days with VOC to generate ground level ozone. Because total fuel combustion is relatively small compared to the aggregate of other industrial sources of  $CO_2$ , greenhouse gas contribution is less of a concern from agricultural activities, however, fuel leakage and evaporation consequences should be considered due to the substantially higher greenhouse gas potential. Another important consideration is the impact of these emissions and other releases on water resources. The severely stressed California watersheds and aquifers, particularly during prolonged drought conditions linked to climate change, can ill-afford further compromise from surface discharges and contaminated precipitation. These factors place additional economic risk and pressure on populations and businesses that are highly dependent on the state's water resources.

The impact of emissions and discharges associated with agricultural and forestry activities in the state are much more dispersed by the very nature of the activities. They are spread across vast swaths of tilled farmlands, pastures, ranches and forests and therefore do not have persistent, severe and geographically concentrated impacts except as described above. These emissions do however serve to raise the baseline concentrations upon which transported pollutants are added. As

stated above this would be most prevalent where certain geographic and climate conditions exist such as the California central valley, during atmospheric temperature inversions that can trap pollutants.

## **Electrification Opportunities**

Within each industrial market described above there are certain near term and longer-term electric technology options that hold the greatest potential to be adopted by offering substantial energy and non-energy benefits to industry participants. Table G-1 shows the expected potential for electrification in 2020, and the sections below describe the electrification technologies in detail.



**Table G-1: Expected Impacts of Electrification Technologies in 2020**

Summary: Electricity Use and Projections					
(Million kWh)					
Electrotechnology	ERG V4 (note 1)		RDC 2015		
	2010	2020	2015	2020	Growth
<b>Process Industries</b>					
1 - Electrochemical Synthesis	1,500	1,900	900	970	70
2 - Electrolytic Separation	29,000	46,000	36,209	39,810	3,601
3 - Freeze Concentration	32	39	68	104	37
4 - Industrial Process Heat Pumps	4,400	5,000	6,230	6,842	612
5 - Membrane Processes	1,200	1,400	2,184	2,787	603
6 - Electric Boilers	10,000	23,000	12,875	15,380	2,504
7 - Pulsed Power	900	4,100	6	7	1
<b>Total Process Industries</b>	<b>47,032</b>	<b>81,439</b>	<b>58,472</b>	<b>65,900</b>	<b>7,429</b>
<b>Materials Production</b>					
8 - Direct Arc Melting	13,000	21,000	32,595	36,326	3,731
9 - Electrorefining	400	480	963	1,074	111
10 - Electrolytic Reduction	27,000	53,000	24,618	26,589	1,971
11 - Electroslag Processing	480	1,300	502	626	124
12 - Resistance Heating And Melting	21,000	30,000	37,317	40,168	2,851
13 - Induction Melting	1,200	1,500	2,946	3,622	676
14 - Ladle Refining	510	430	1,631	1,958	327
15 - Plasma Processing	210	200	139	147	8
16 - Vacuum Melting	100	180	1,239	1,507	268
<b>Total Materials Production</b>	<b>63,900</b>	<b>108,090</b>	<b>101,949</b>	<b>112,017</b>	<b>10,068</b>
<b>Materials Fabrication (Metals and Non-metals)</b>					
17 - Electric Discharge Machining	140	150	560	681	121
18 - Electrochemical Machining	101	115	122	136	14
19 - Electrofinishing	2,300	2,600	2,068	2,329	260
20 - Electroforming	1	1	9	14	4
21 - Electron Beam Processing	63	72	419	486	67
22 - Flexible Manufacturing Systems/Automation (note 2)	340	410	*	*	-
23 - Induction Heating	62,000	86,000	21,147	24,280	3,132
24 - Infrared Processing	4,600	5,700	5,925	7,929	2,004
25 - Laser Processing	100	120	481	751	270
26 - Microwave Heating And Drying (note 3)	240	320	338	368	30
27 - Radio-Frequency Heating And Drying (note 3)	3,800	4,900			
28 - Ultraviolet Curing	4,200	5,800	7,722	9,856	2,133
29 - Acoustics/Ultrasound	150	180	791	917	126
30 - Process Measurement, Control, and Integration (note 2)	190	270	*	*	-
31 - Cryogenics	640	790	15,471	19,710	4,239
<b>Total Materials Fabrication</b>	<b>78,865</b>	<b>107,428</b>	<b>55,054</b>	<b>67,455</b>	<b>12,401</b>
<b>Municipal Water/Wastewater Treatment</b>					
32 - Water Supply Ozonation	110	290	649	868	219
33 - Water Supply Reverse Osmosis (Desalination)	71	270	2,265	3,157	892
34 - Wastewater Ultraviolet Disinfection	8	25	944	1,324	380
<b>Total Water/Wastewater</b>	<b>189</b>	<b>585</b>	<b>3,858</b>	<b>5,349</b>	<b>1,491</b>
<b>TOTAL</b>	<b>189,986</b>	<b>297,542</b>	<b>219,333</b>	<b>250,722</b>	<b>31,389</b>
Notes:					
1. ERG V4 data presented here for information only. Several technology categories are defined differently between ERG V4 and the current analysis, and for most categories, the current analysis relies upon different data sources and/or estimating methodologies.					
2. Flexible Manufacturing Systems/Automation and Industrial Process Measurement, Control and Integration are combined into a new category of Innovative (Lean) Manufacturing, treated as a strategic category to improve customer competitiveness, and are not associated with specific electric energy impacts estimates.)					
3. Microwave Heating & Drying and Radio-Frequency Heating and Drying are combined into one category of Dielectric Heating & Drying, with the impacts and estimates combined.					

Source: EPRI

## **Petrochemical Industries**

- Mature electric technologies
  - Advanced membrane technologies hold the potential to allow separation various hydrocarbons with little or no thermal energy input requirements.
  - Advanced industrial heat pumps can improve the quality of pressure and temperature regimes in sections of refining process towers. These would essentially utilize electric powered technologies to reduce or eliminate process-heating stages of the process.
  - Biosynthetic fibers
  - Graphene nanoparticles and membranes
- Electrode boilers for steam generation
  - Additive manufacturing
  - Plasma oxidation carbon fibers
  - Emerging or developing electric technologies
  - Power to hydrogen techniques could convert the hydrogen plant to electrolysis or advanced membrane options
  - Gliding arc plasma reforming
  - Power 2 chemicals for direct chemical synthesis

## **Food, Beverage and Tobacco**

- Mature electric technologies
  - Indirect induction methods are applicable to cooking processes that involve boiling, blanching or otherwise cooking food.
  - Electric infrared and resistance heating technology is applicable to baking and drying processes
  - Microwave techniques can be applied to rapid heating or preheating products and for surface sterilization.
  - Ultraviolet surface and waste water sterilization
  - Electric boilers can provide process and sterilization steam needs
  - Electric refrigeration transportation units
- Emerging or developing electric technologies
  - Robotic systems can be applied to material movements and cold storage and retrieval.
  - Low charge ammonia refrigeration
  - Synthetic food production

## **Stone, Clay, Glass and Cement Products**

- Mature electric technologies
  - Industrial Heat pumps can be applied to various heat recovery uses reducing fossil fuel consumption.
  - Infrared technologies can be applied to drying applications
  - Advanced electric stone crushing
  - Electrode boilers
- Emerging or developing electric technologies
  - Carbon dioxide cured concrete
  - Power to hydrogen for kiln thermal inputs
  - Syngas kiln fuel

## **Wood Products, Pulp and Paper**

- Mature electric technologies
  - Electrode boilers for steam generation
  - Electro-servo motor mill drives.
  - Infrared pocket dryers.
  - Infrared and radio frequency wood and paper drying
  - Industrial heat pumps and heat recovery chillers
  - Microwave print curing
- Emerging or developing electric technologies
  - Indirect induction vessel and drum heating

## **Primary Metals, Fabricated Metals and Machinery**

- Mature electric technologies
  - Induction melting
  - Induction ladle pre-heating
  - Induction bulk and skin hardening and tempering
  - Infrared surface preheating and curing
  - Microwave coating curing
  - Plasma surface preparation
  - Robotics handling and logistics
  - Electric arc Melting
  - Industrial heat pumps and heat recovery chillers
  - Electric resistance ovens

- Emerging or developing electric technologies
  - Electrolysis Smelting
  - Power to hydrogen replacing carbon in smelting
  - Direct reduction iron
  - Flash Bainite induction
  - Isothermal melting
  - Magnetic field induction
  - Fast boriding
  - Electro-coagulation and ultra violet waste water treatment

## **Agriculture and Forestry**

- Mature electric technologies
  - Electric single-phase written pole motors for irrigation pumping
  - Radio frequency grain drying
  - Indoor agriculture for high value crops
- Emerging or developing electric technologies
  - Robotic milking and livestock tending
  - Robotic crop harvesting
  - Robotic tractors and field crop cultivation equipment

## **Electrification Technologies and Potential Applications Areas**

This section discusses the most promising electrification technologies, along with their potential application areas. The potential application areas are identified by North American Industry Classification System (NAICS) code, a standard way of classifying industrial applications.<sup>20</sup>

### **Cryogenics**

Cryogenic technology is the mainstay of the industrial air gases industry production processes -- compressing, purifying, cooling and separating air into its constituents (for example, nitrogen, oxygen, and argon). This technology is used whether the product is shipped as a liquid (about 10-20 percent of the product) or as compressed gas. Selective adsorption and membrane process are also used, but primarily when the product purity and production rate requirements are lower. These gases and liquids are used across a broad spectrum of industrial applications – oxygen might be used to enhance a combustion or oxidation process and nitrogen and argon used for their inert properties. The liquid products are used for their cooling properties or as state for transporting and storing the gases for other uses. The industry structure supports a number of potential opportunities, as it invests beyond the major plants and builds smaller plant at industrial customer

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<sup>20</sup> <https://www.census.gov/eos/www/naics/>.

sites and develops and markets industrial equipment that relies upon the cryogenically produced products.

#### **Cryogenics Industries/NAICS**

- Chemical Manufacturing /325
- Transportation Equipment/336
- Food and Beverage/ 311&312

#### **Direct Arc Melting**

Direct arc melting has become the most important steelmaking process in the U. S. and is expected to grow from its substantial base of 60 percent of U. S. steel production. One area of key growth is expected to be the development of direct reduced iron. Traditionally, electric arc furnace steel production has been constrained by availability of scrap steel, as arc furnaces cannot directly use iron ore in the process. However, the industry has started investing in direct reduced iron processes, which can be used in arc furnaces, and this is expected to remove the limits on direct arc melting from availability of steel scrap. In addition, one key U. S. steelmaker that has resisted investment in arc furnace technology has just announced plans to invest in its first arc furnace.

#### **Direct Arc Melting Industries/NAICS**

- Primary Metals/331

#### **Induction Heating**

Induction heating is a proven cost effective non-contact method of heating electrically conductive materials, with no other combustion materials involved. It is used throughout industry sectors for melting, heating, annealing, hardening, joining, and sintering. While generally considered a mature technology, there is substantial room for growth in its use, reflecting both general economic expansion of the industries in which it is applied and increased adoption across industries in new applications. The relative benefits compared with gas fired approaches (for example, fast, controlled, efficient and cost-effective heating) along with advances in control technologies favor induction technologies.

#### **Induction Heating Industries/NAICS**

- Fabricated Metals/332
- Primary Metals/331
- Transportation Equipment/336
- Machinery/333
- Electrical Equipment, Appliances, Components/335

#### **Resistance Heating and Melting**

Resistance heating is one of the most prevalent electric technologies, used for a number of heating and melting applications throughout several different industries. Indirect resistance heating furnaces are commonly used for heating plastics, liquid chemicals, semiconductors, mineral

products, and various applications for the heat treatment of metals and metal products. There are several advantages over gas furnaces, including faster startup time, ease of control/automation, and minimal product contamination. These advantages are most prevalent in vacuum furnace heat-treating applications. Direct resistance technologies, which directly heat work pieces with strategically placed electrodes, are prominent in glass melting operations for wool fiber furnaces and electric boosting applications for container glass and textile fiber applications. Direct resistance also has several advantages for metalworking applications like surface heating and seam welding.

### **Resistance Heating and Melting Industries/NAICS**

- Non-Metallic Mineral Products/327
- Plastics and Rubber/326
- Chemicals/325
- Computers and Electronics/334
- Food and Beverage/311&312
- Petroleum/324
- Transportation Equipment/336
- Fabricated Metals/332
- Miscellaneous/ 339
- Primary Metals/ 331
- Paper; Printing/ 322,323
- Electrical Equipment, Appliances, Components / 335
- Machinery/333

### **Ultraviolet Curing**

Ultraviolet (UV) curing is a photochemical process in which high-intensity ultraviolet light is used to instantly cure or “dry” inks, coatings or adhesives. UV curing is not actually drying but is a polymerization process that hardens the material. The technology is widely adopted in automotive, telecommunications, electronics, graphic arts, converting and metal, glass and plastic decorating industries. Constituting about 4 percent of the industrial coatings market, UV curing has been growing rapidly, displacing conventional water and solvent-based thermal drying processes due to its increased productivity, improvement of product quality and performance, and environmentally friendly characteristics. The capital costs of both UV and other drying technologies are becoming more competitive and UV systems require substantially less floor space, offer higher productivity rates, and can potentially lower energy costs. Additive manufacturing processes using UV curable resins present additional potential growth opportunities. These developments offer potential new applications and represent an additional area of growth potential. Rapid growth in UV curing is expected to continue and may be supported by the adoption of the newer solid-state UV LED technology that could replace older, or displace new sales of, more electricity-intensive UV curing systems.

### **Ultraviolet Curing Industries/NAICS**

- Printing/323
- Electronics/334
- Transportation Equipment/336
- Fabricated Metals/332
- Machinery/333
- Electrical Equipment, Appliances, Components/335
- Non-Metal Mineral Products/327
- Wood Products, Furniture /321
- Textiles/314
- Paper/322
- Plastic/Rubber/326
- Leather/316
- Miscellaneous/339

### **Infrared Processing**

Infrared (IR) heating has been used in industrial applications since the 1930s, when commercial light bulbs with special reflectors were used to cure the paint on automobile bodies. Since then, the technologies for producing IR radiation have become more sophisticated and are being applied in a wide range of industrial applications, such as: curing metal finishers and protective coatings; fusing thermoset and thermoplastic powder coatings; forming molded plastics; bonding adhesives and metals; drying papers, inks and fabrics, and; processing foods. Electric IR is widely used in industry because it offers many operational control, efficiency and environmental benefits compared to conventional (for example, fossil-fueled oven methods). Gas catalytic IR also offers advantages over the conventional ovens and is receiving much attention in the market. The terms of competition between electric and gas catalytic IR technologies center on the specific process requirements that might favor one over the other (for example, related to wavelength), in addition to costs and availability of the electric service or gas supply.

### **Infrared Processing Industries/NAICS**

- Transportation Equipment/336
- Plastics and Rubber/326
- Electrical Equipment, Appliances and Components/335
- Fabricated Metals/332
- Food and Beverage/311,312
- Textiles/314
- Paper/322
- Non-Metal Mineral Products/327



- Miscellaneous/339

## **Water Supply Reverse Osmosis**

Reverse Osmosis (RO) systems use a semi-permeable membrane to separate and remove dissolved solids, submicrometer colloidal sized particles/matter, organics, viruses, and bacteria from water. In parts of the county – California, Florida and the Gulf Coast, clean water supplies are under substantial pressure from: water quality concerns and regulations; salt water incursion into ground water sources; and drought, for example. With the decreasing costs of RO, the technology is becoming more competitive with evaporation and distillation, which require thermal energy. Lengthy development processes involving many stakeholders, in addition to the costs, present challenges for municipal projects. Nevertheless, in water-stressed areas, RO is increasingly being developed or considered by municipal water utilities. In addition to desalination for drinking water supply systems, RO systems are used to process power plant boiler feed water, in pharmaceutical processes, and reclaiming produced water in oil and gas operations.

### **Water Supply Reverse Osmosis Industries/NAICS**

- Municipal Water Supply/2213
- Chemicals/325
- Food and Beverage/311,312
- Utilities/22

## **Induction Melting**

Iron and steel foundries in the U. S. are realizing that induction melting has substantial advantages over cupola and other processes. Induction melting continues to gain market share and is the technology of choice for most new foundry melting furnaces. While the cupola process has some advantages, the high cost of coke, environmental concerns, and the need for specialized labor to control the melt process has led to increased investment in induction melting.

### **Induction Melting Industries/NAICS**

- Primary Metals/331
- Fabricated Metals/332
- Machinery/333
- Electronics/334
- Transportation Equipment/336

## **Membrane Processes**

Membrane processes use a barrier layer that allows water or other materials up to a certain size, shape or character to permeate (that is, pass through), but rejects or slows the other components from moving with that filtrate. The membranes' ability to remove water from a process stream or effluent is an effective way to concentrate the valuable components of the stream, or to remove the undesirable components – either way, the membrane is providing a valuable separation function. Membranes accomplish this separation without a phase change (for example, evaporation or

freezing), providing two distinct process characteristics: a) the principal energy required is typically for pumping the material stream instead of heating or cooling it and b) without the need for heat, the components in the process are less likely to suffer thermal degradation. These characteristics support applications in a wide range of industries, including food and beverage, biochemical processing, petroleum refining, chemicals, and semiconductors among others. Within these sectors, applications include process water treatment, wastewater treatment and reuse, metal and catalyst recovery, solvent recovery, gas separation, and concentration of heat sensitive biological macromolecules and proteins.

*Membrane Processing Industries/NAICS*

- Food and Beverage/311, 312
- Chemicals/334
- Petroleum/324

**Electric Technologies for Specialty Alloys – Electroslag Processing, Vacuum Arc Melting and Plasma Cold Hearth Refining**

United States aerospace, automotive, and energy technology industries are growing fast in the U. S. with increasing exports and are becoming more reliant on specialty steel and titanium alloys. Many of these alloys cannot be produced by conventional means but must use special atmospheres and techniques that require high tech electric technologies such as electroslag processing, vacuum arc melting, and plasma cold hearth refining. These industries have become highly selective of their material specifications and are increasingly requiring not only more precise alloy content but also the specifying the process that must be used and calling for electrotechnology-produced alloys in their material acquisition approaches.

**Electroslag Processing, Vacuum Arc Melting and Plasma Cold Hearth Refining Industries/NAICS**

- Primary Metals/33