The National Academies of SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

TRB Webinar: Air Quality Impact Models for Electric Vehicle Fleets

October 21, 2021

2:00- 3:30 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

•1.5 Professional Development Hours (PDH) – see follow-up email for instructions

•You must attend the entire webinar to be eligible to receive PDH credits

•Questions? Contact Beth Ewoldsen at Bewoldsen@nas.edu

#TRBwebinar

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

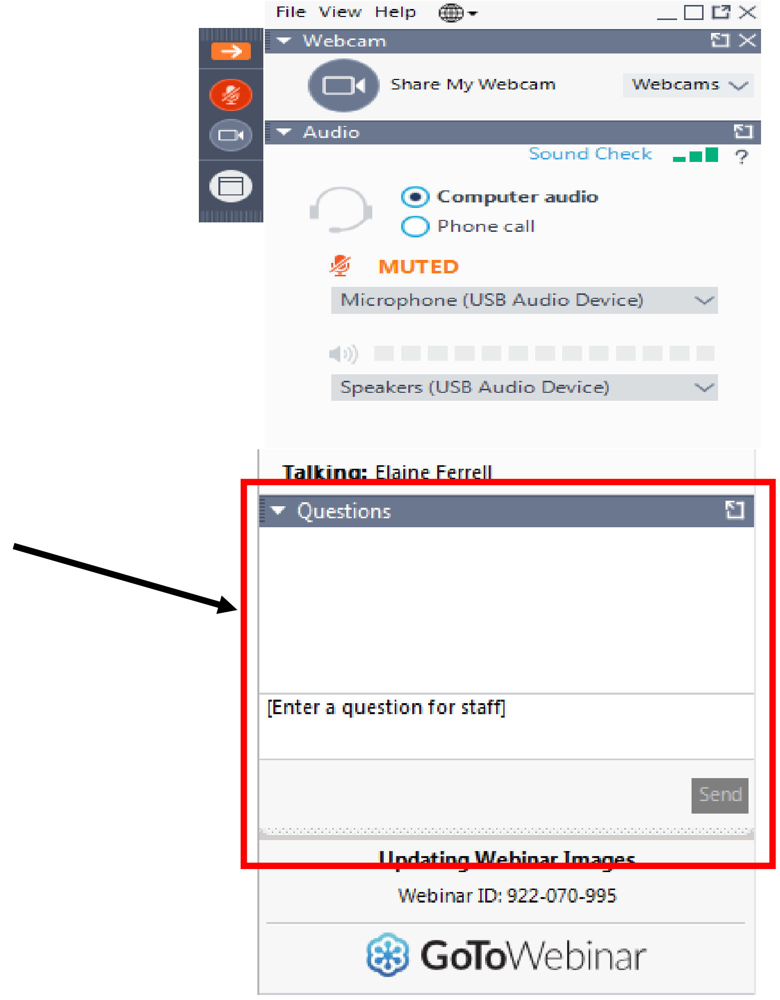
REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

- Determine modeling load requirements and energy consumption of EVs with varying driving behavior
- Identify renewable and non-renewable generation of electricity and supplying to grids

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



#TRBwebinar

Thomas Bradley
thomas.bradley@colostate.edu
Colorado State University

Marcus Alexander
malexander@epri.com
Electric Power Research Institute

Uarporn Nopmongcol
unopmongcol@ramboll.com
Ramboll

Eladio Knipping
eknipping@epri.com
Electric Power Research Institute

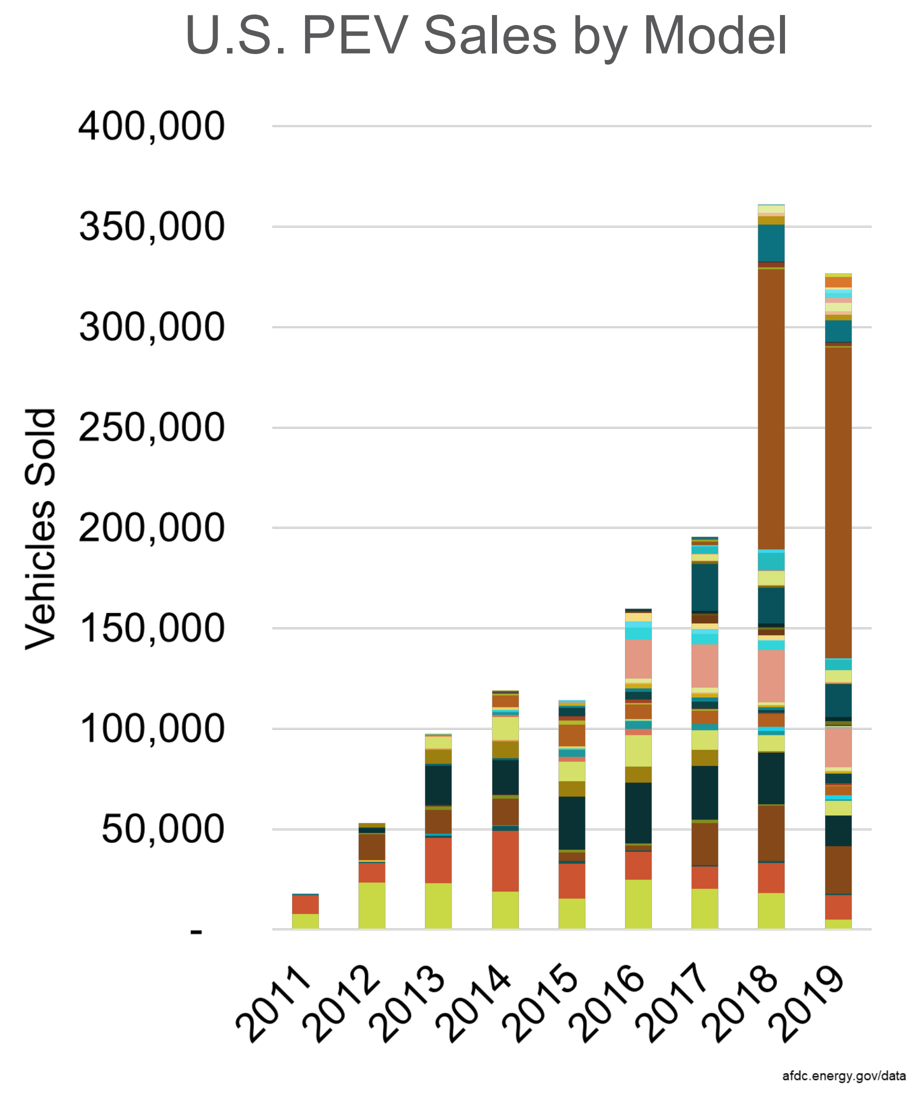
Understanding electric vehicle operation for air quality modeling

Thomas Bradley, thb@colostate.edu

www.engr.colostate.edu/se

Background on Electric Vehicles

- The US is undergoing a transition towards a full electrification of the personal and commercial transportation fleet
- Driven by:
  - Consumer Preference
  - Supply-side Policy (driven by Air Quality and GHG Emissions consideration)
  - Personal and Commercial Economics
  - Sustainability



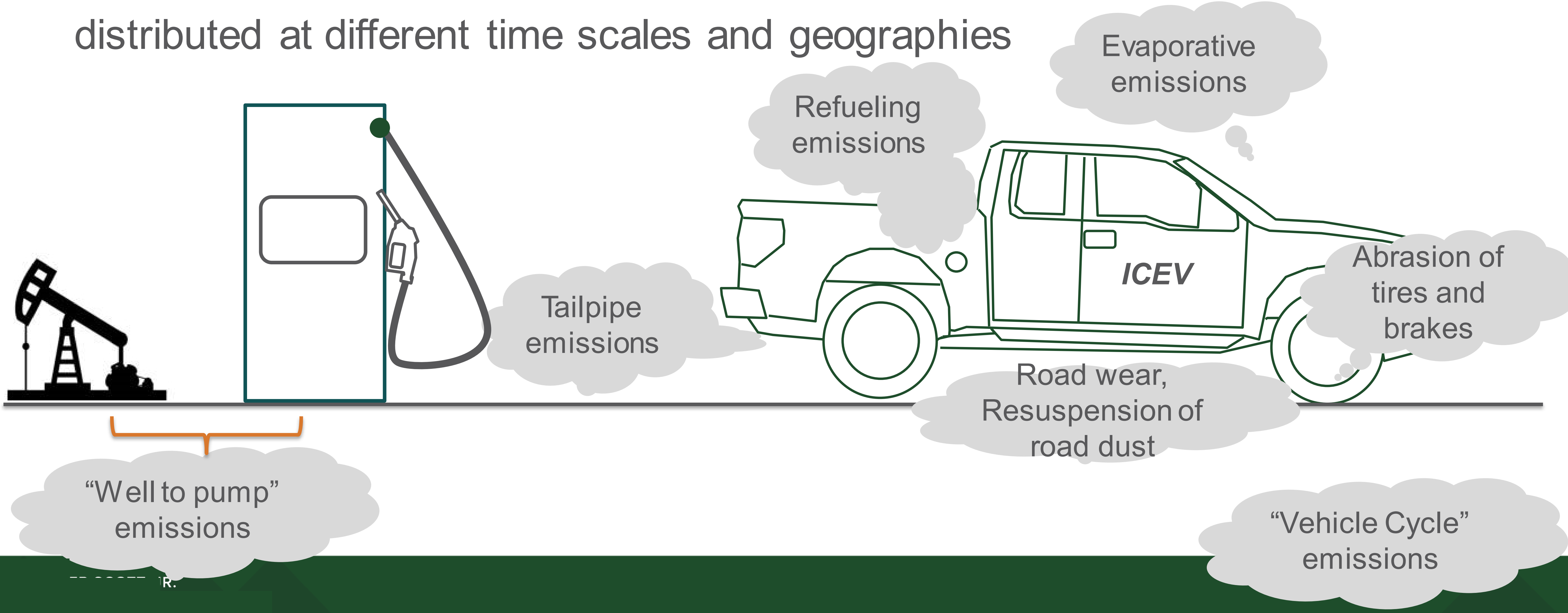
Understanding electric vehicle operation for air quality modeling

Discussion points for this presentation:

- Characterizing Battery Electric Vehicle and Plug-in Hybrid Electric Vehicle operational emissions
- The personal and commercial fleet makeup limits the rate and "end-state" of the transportation system transition

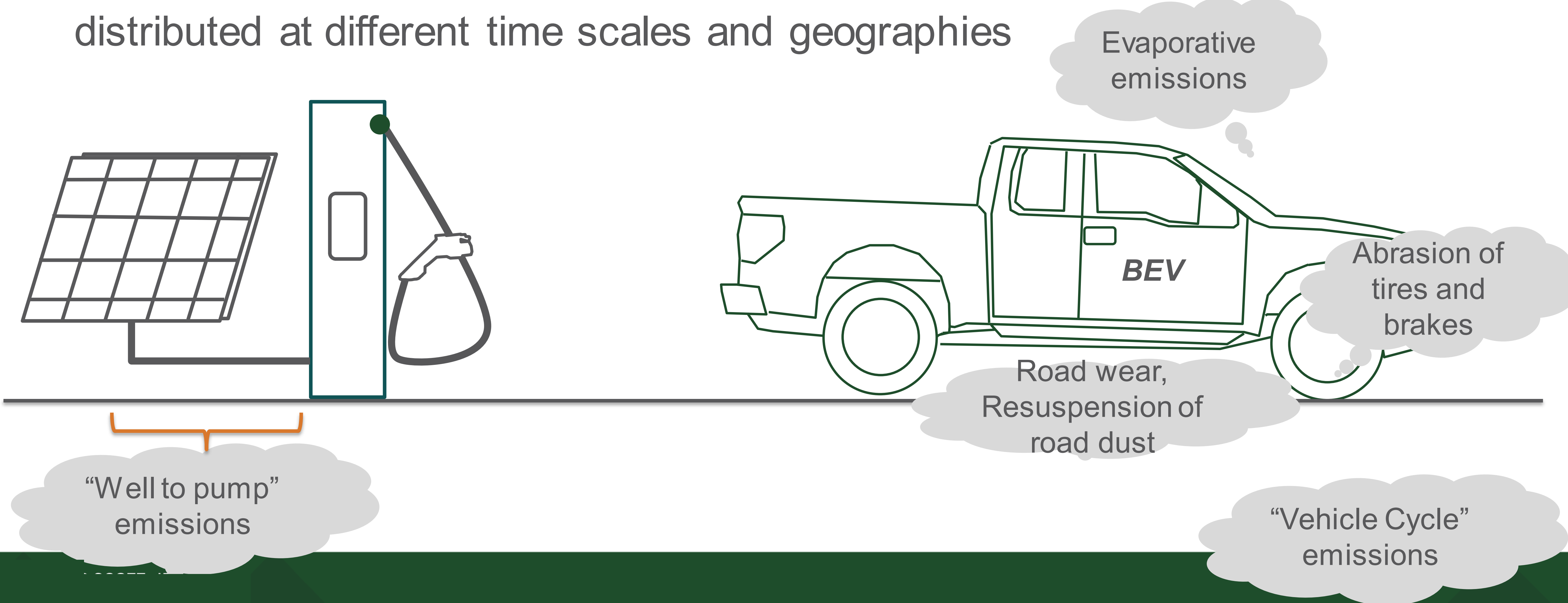
Characterizing BEV and PHEV emissions in operation

- ICEVs have operational and upstream emissions, generated and distributed at different time scales and geographies



Characterizing BEV and PHEV emissions in operation

- BEVs also have operational and upstream emissions, generated and distributed at different time scales and geographies



Characterizing BEV and PHEV emissions in operation

- *Later talks will emphasize the impacts of the electricity fuel-cycle
- Many of the sources of operational emissions are controlled and modeled by regulatory limits
  - Tailpipe emissions, evaporative emissions, refueling emissions
- Vehicle cycle emissions are the subject of considerable debate, especially in modeling many of the novel and lower-quantity components of BEVs (batteries, motors)
  - https://doi.org/10.1007/978-3-319-48768-7_11 , https://doi.org/10.3390/batteries5020048

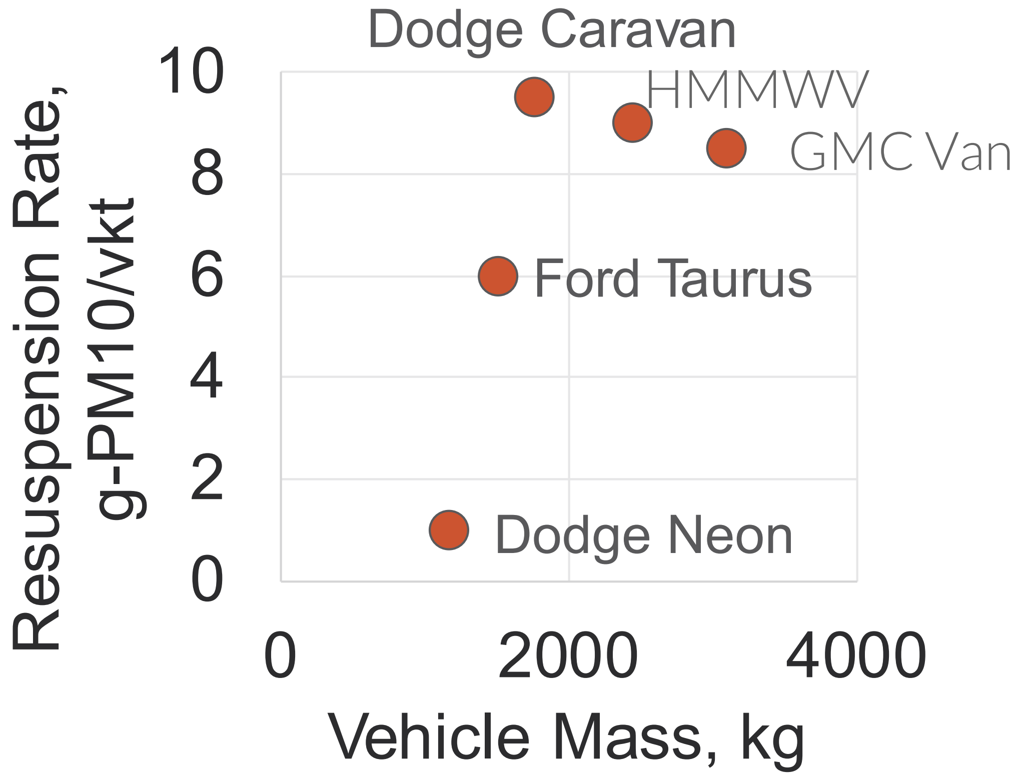
Characterizing BEV and PHEV emissions in operation

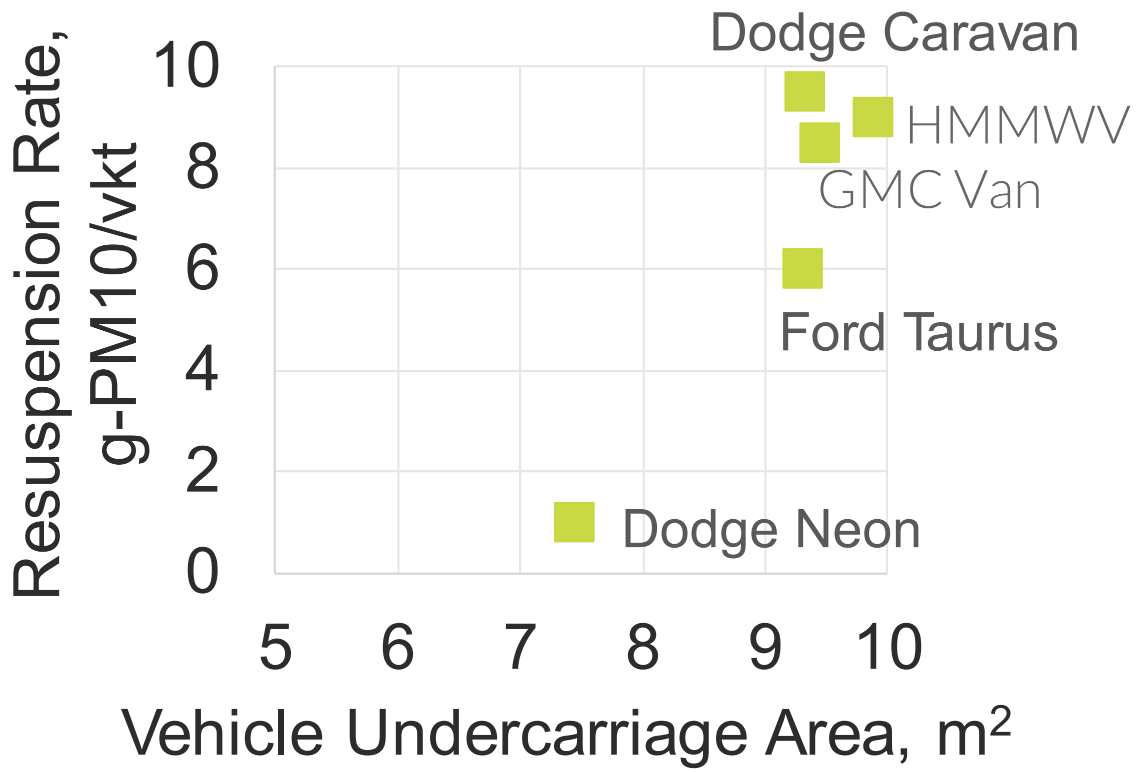
- Brake abrasion is a source of PM2.5, PM10
  - BEVs and PHEVs both have two sources of braking on board the vehicle, regenerative braking and friction braking
  - All data available today are estimates, but typical estimates are that BEV/HEV brakes wear at 35% - 50% of the rate of ICEVs link, link
- Tire/road abrasion is a source of PM2.5, PM10
  - Tire/Road abrasion emissions are driven by vehicle mass, link
  - Early PHEVs/BEVs were heavier than ICEV analogues
  - Weight difference will reduce with XEV-centric platforms
    - MachE is only 15% heavier than Mustang

BEV conversions are 25% heavier (curb weight)

Characterizing BEV and PHEV emissions in operation

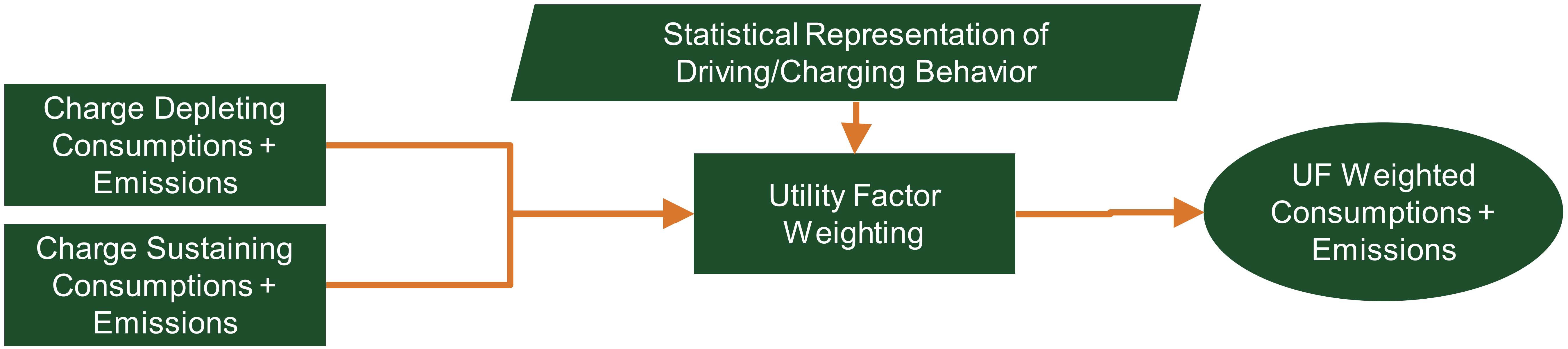
- Resuspension
  - BEVs are often allocated increased resuspension emissions due to increased mass, but cited relations are weak within relevant ranges of mass (data from link)





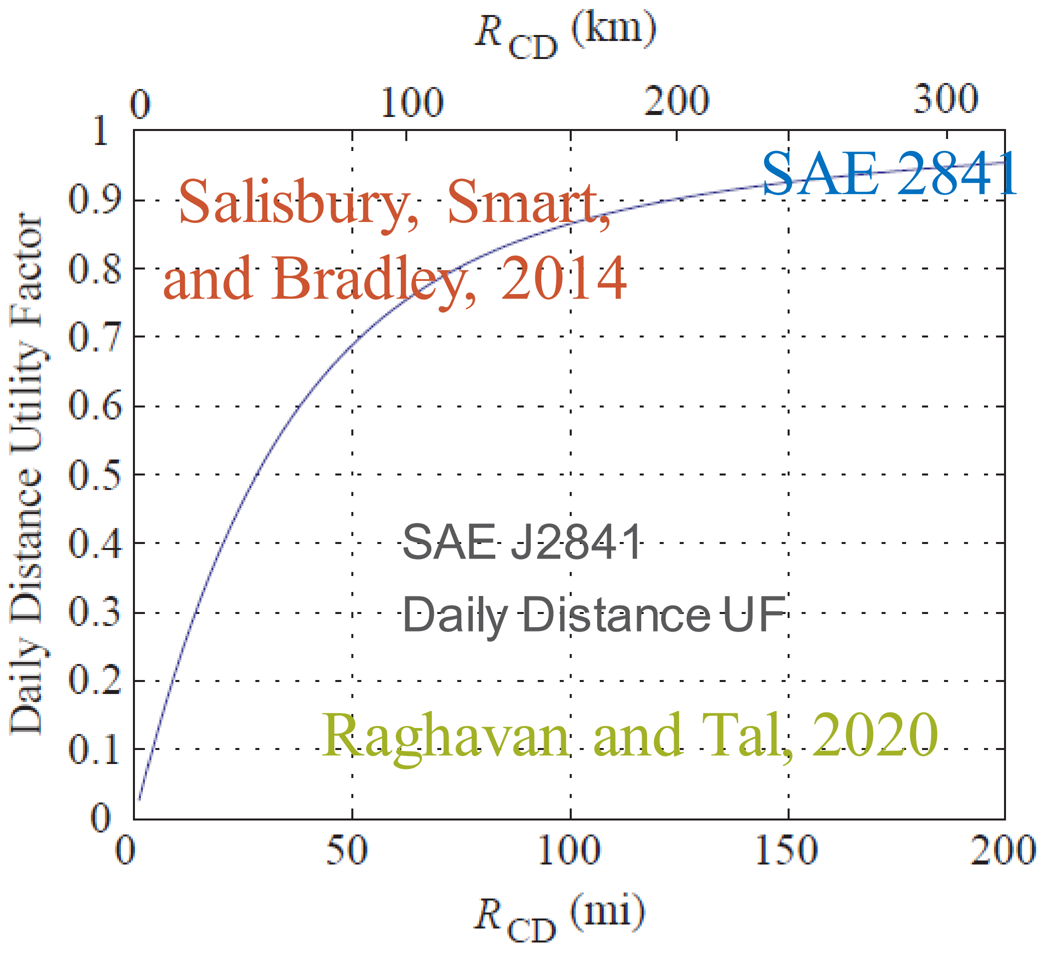
Characterizing BEV and PHEV emissions in operation

- PHEVs projected to make up to ~20% of the PEV vehicle fleet until 2035
- PHEVs are plug in electric vehicles that can operate in both an all-electric mode for a limited distance (R_{CD}), or as a hybrid (ICE-powered mode)



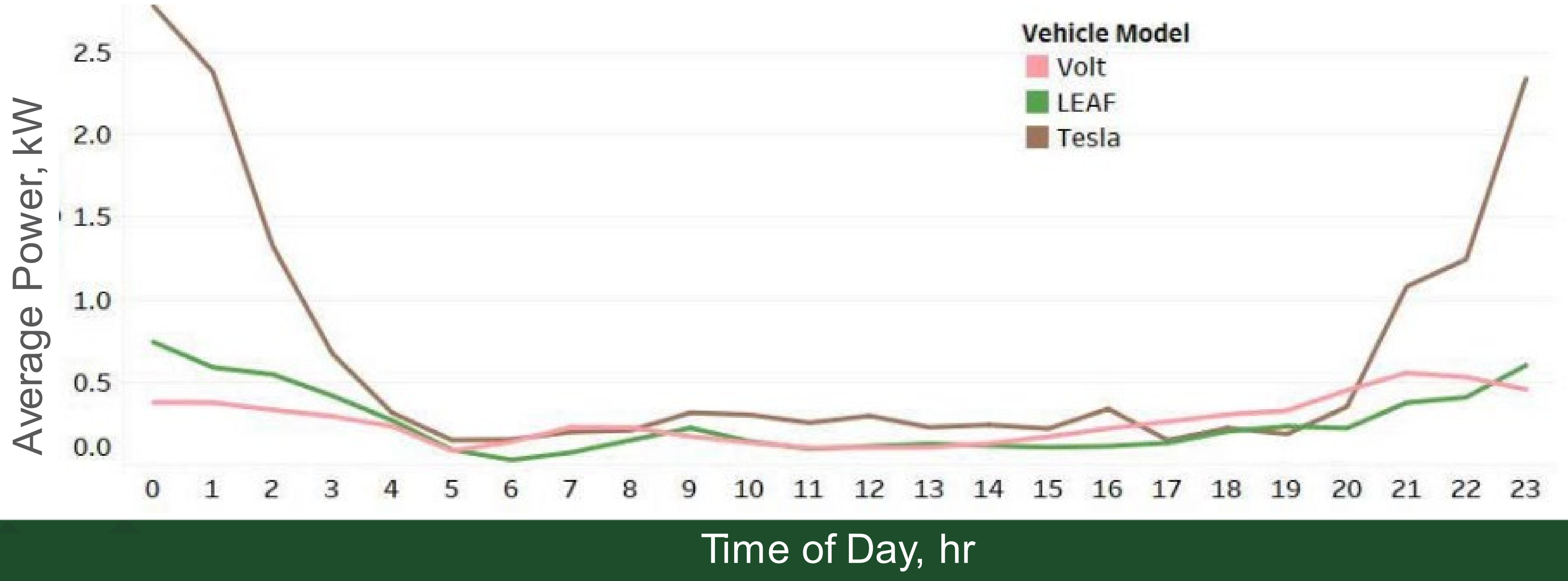
Characterizing BEV and PHEV emissions in operation

- There are standards for UF weighting based on survey
- There are UFs calculatable from real-world operation data
  - UFs (and thereby PHEV emissions and consumptions) are sensitive to assumptions of
    - Charging, vehicle age, number of vehicles in the household, etc.



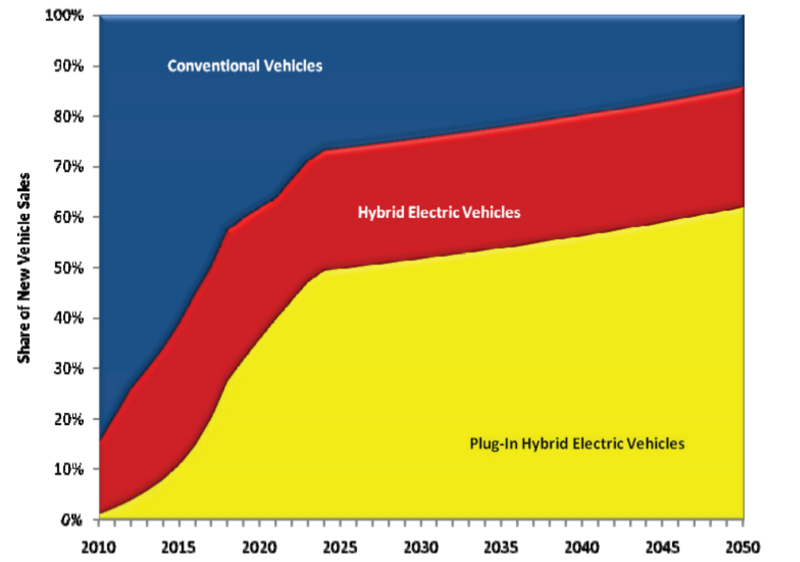
Characterizing BEV and PHEV emissions in operation

- The result is that uncontrolled BEVs and PHEVs use electricity at particular times of the day, times of the week (link)
  - Might be controllable through TOU rates, managed charging, education, etc.

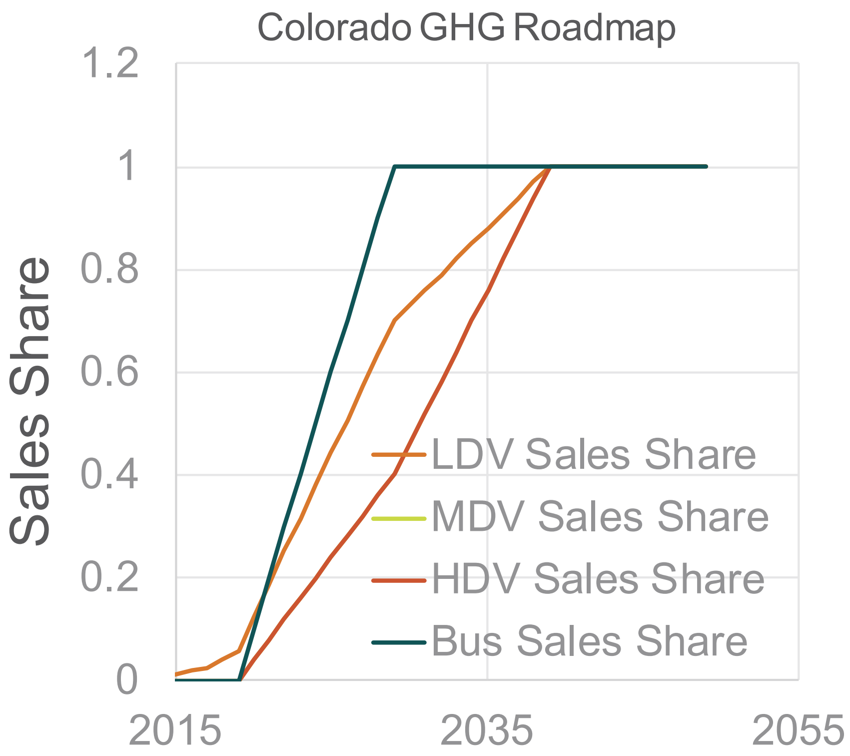


The Transitions to PEVs

- We often think about transportation's transition to electrification as being "a" transition (link, link)
- In reality, it is going to be a series of transitions that will occur:
  - in all sectors of the transportation fleet, and
  - at different times for different parts of the US



Assumed new car market share for the Medium PHEV scenario for conventional vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles for each vehicle category



The Transitions to PEVs

- Electric vehicle sales are not evenly distributed geographically across the US (link)
- Regions with policy incentives, charging infrastructure investments, education and awareness programs are early adopters
- Customers with roof-top solar, or energy storage are early adopters

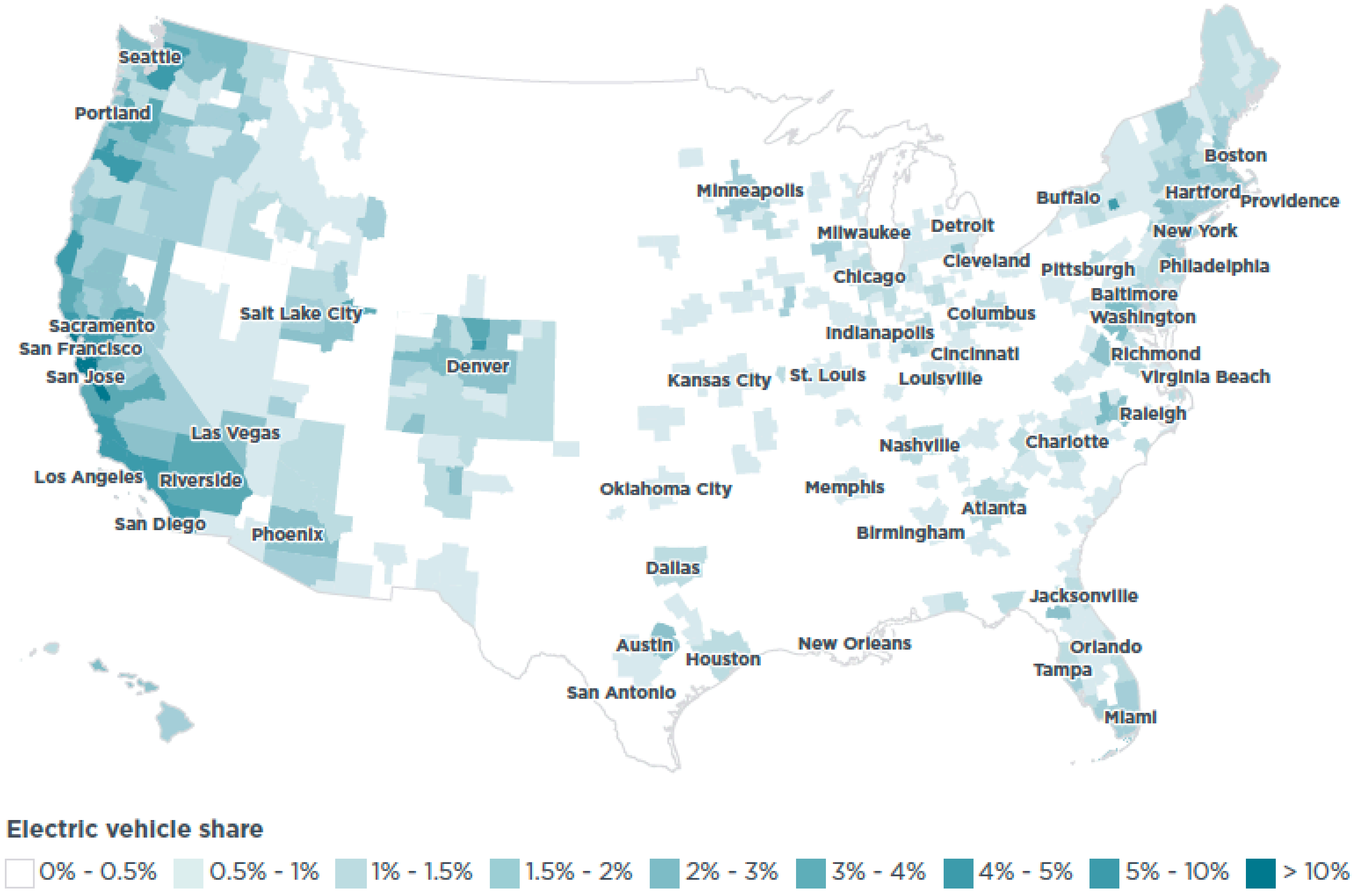
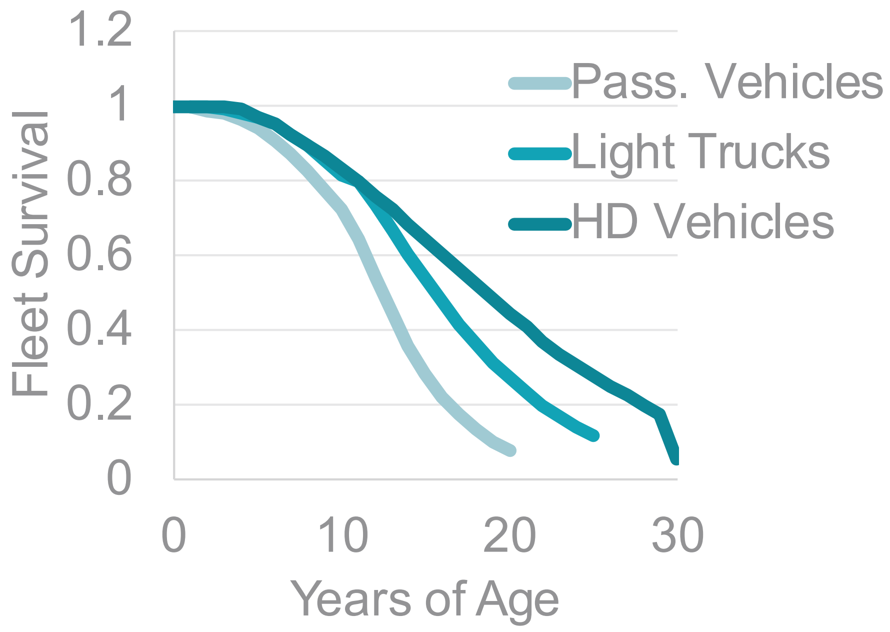


Figure 3. Electric vehicle shares of new 2019 vehicle registrations by metropolitan area. New vehicle registration data are from IHS Markit.

The Transitions to PEVs

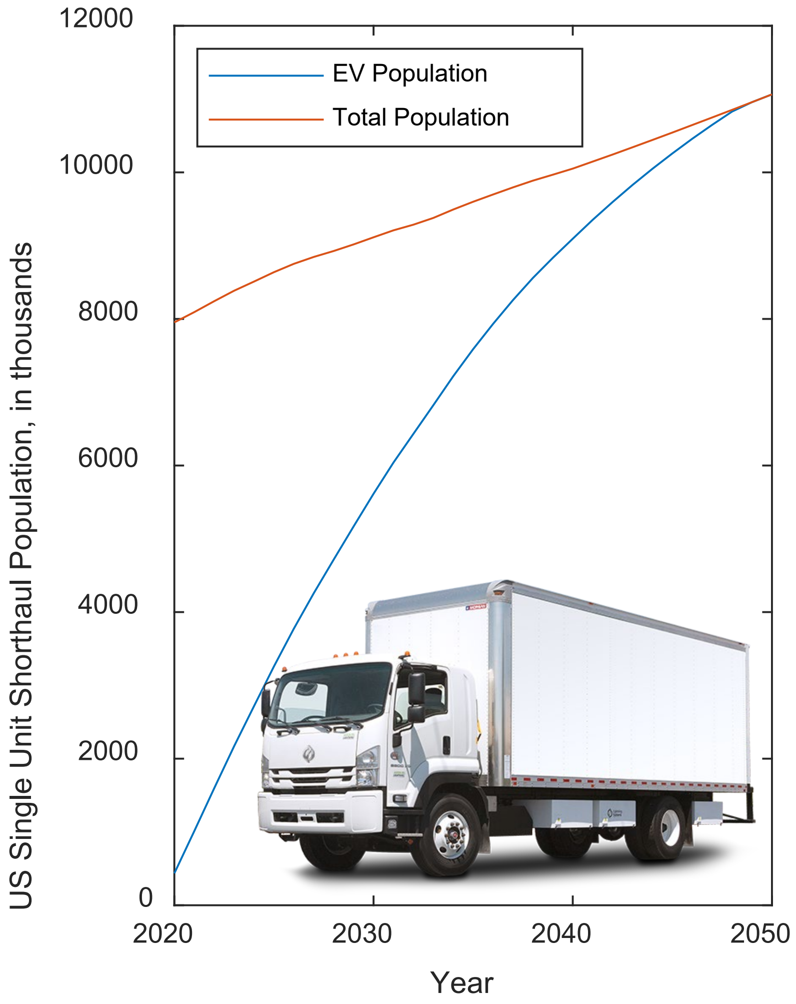


- PEV transition is limited by the rate of retirement of the vehicles in the fleet
  - In 2021, 10% of vehicles sold in CA are PEVs, but less than 2% of the fleet are PEVs
  - Trucks and HD Vehicles last even longer (link, link)
- 50% of today's passenger vehicles will be on the road in 2031
- 50% of today's HDVs will be on the road in 2040

https://freightliner.com/why-freightliner/industry-leading-results/introducing-the-freightliner-inspiration-truck/

The Transitions to PEVs

- Consider the example of the Short Haul Combination Truck
  - A near-term application for HD BEVs
  - 150 mi Range can perform 95% of trips now
  - <5 year payback period in 2020 with incentives
- If sales are 100% of a growing market, it still takes till 2040 to achieve 90% electrification



https://lightningemotors.com/lightningelectric-chevrolet-6500xd/

Understanding electric vehicle operation for air quality modeling

Discussion points for this presentation:

- Characterizing Battery Electric Vehicle and Plug-in Hybrid Electric Vehicle operational emissions
- The personal and commercial fleet makeup limits the rate and "end-state" of the transportation system transition

Thank you

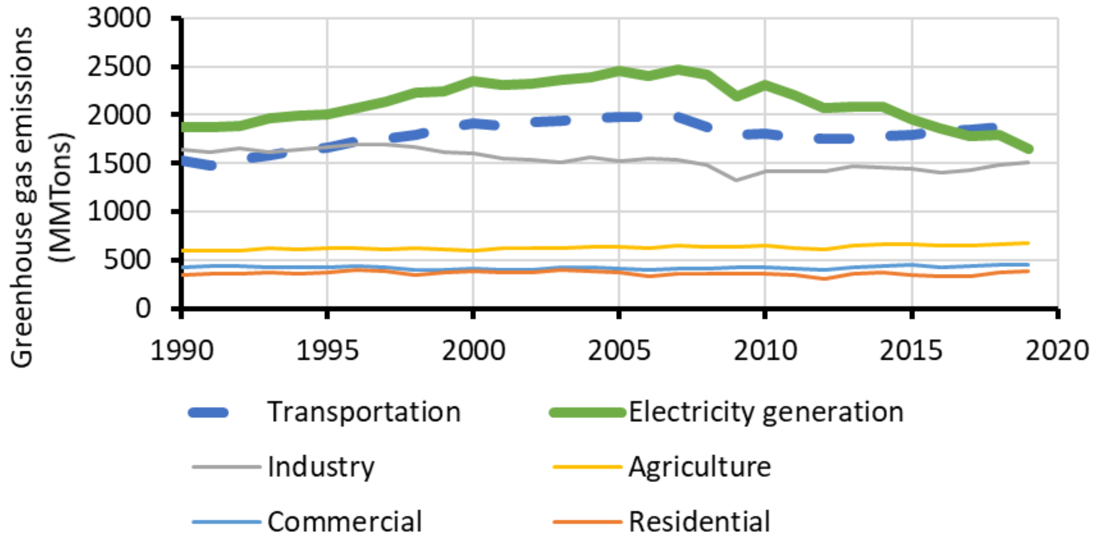
Modeling the effects of added load to the grid

Marcus Alexander

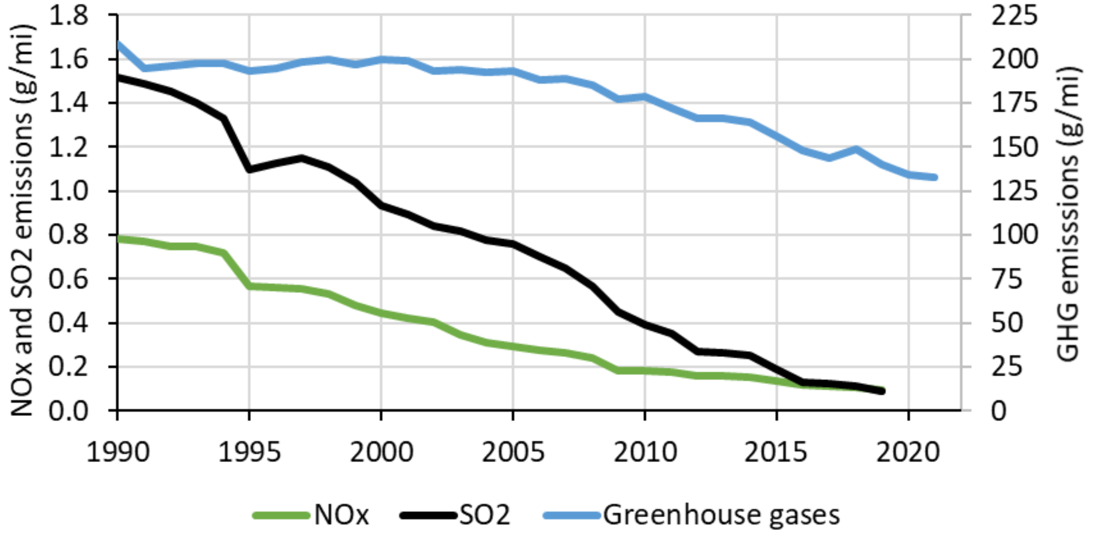
Electric Power Research Institute

Overview

- Electricity has tremendous potential as a low greenhouse gas emitting fuel
- Also has potential for air quality co-benefits due to the lack of local emissions
- However, exactly what the benefits are requires careful analysis
- This presentation discusses work done by EPRI, NRDC, and Ramboll for a previous investigation of transportation electrification



Source: EPRI analysis of EPA data



Source: EPRI analysis of EPA and EIA data

How are the transportation and electricity sectors different?

Emissions regulation regimes

Transportation

- Emissions regulations typically only apply to new vehicles (although there are usually checks to ensure continued compliance)
- Fleet emissions improve through turnover as older vehicles retire

Emissions regulation regimes

Transportation

- Emissions regulations typically only apply to new vehicles (although there are usually checks to ensure continued compliance)
- Fleet emissions improve through turnover as older vehicles retire

Electricity generators

- Emissions regulations apply to both new plants and older plants
- Emissions are often regulated based on the *total quantity* of pollutants; these caps can be at the plant, state, or region level
- There are often additional regulations on the grid mix, such as renewable portfolio standards
- Fleet emissions improve through both turnover and in-service reductions

Emissions regulation regimes

- All of this means that to a first approximation additional miles in existing vehicles will result in additional emissions, but additional generation may not lead to more emissions at the *system level*
- Regulations like renewable portfolio standards will have to be complied with regardless of load

How should we calculate grid emissions?

How should we calculate grid emissions?

- There are at least three major ways:
  - Average
  - Small-scale marginal (intensive marginal)
  - Large-scale marginal

How should we calculate grid emissions?

- Average
  - Emissions intensity for new loads is (implicitly) assumed to be proportional to the current emissions intensity

$$Rate = \frac{\sum emissions}{\sum generation}$$

How should we calculate grid emissions?

- Small-scale marginal
  - Emissions intensity for new loads is calculated from the emissions for a small amount of new load

$$Rate = rate\ for\ very\ small\ increase\ in\ generation$$

How should we calculate grid emissions?

- Large-scale marginal
  - Emissions intensity for new loads is modeled based on adding new load to the system in a high-fidelity grid model

$$Rate = \int \sum \prod it's\ complicated$$

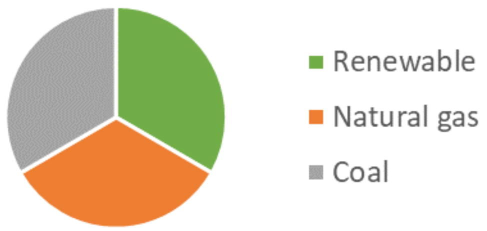
Large-scale marginal

- Run a full grid model over the applicable timeframe for the base case
- Add electric transportation load
- Run the full grid model again with the new combined load
- Subtract the differences in emissions and the differences in load

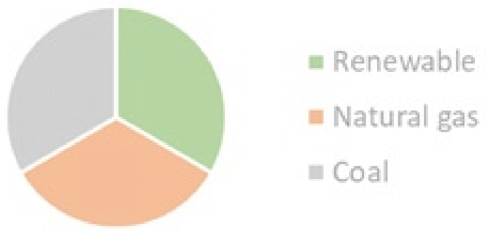
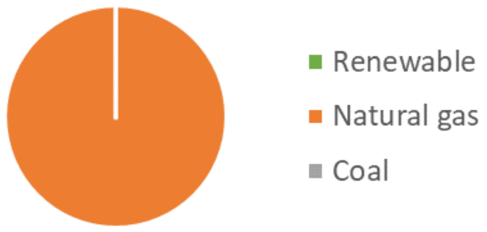
Example

- Let’s say that we have a simplified system with the following characteristics:
  - Renewable Portfolio Standard of 33%, so 33% of energy served must come from renewable generation
  - Coal is the lowest-cost dispatchable resource, and there is enough to serve 33% of the load
  - Natural gas meets the remaining load
- What’s the grid mix?

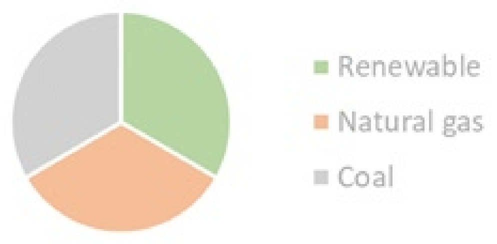
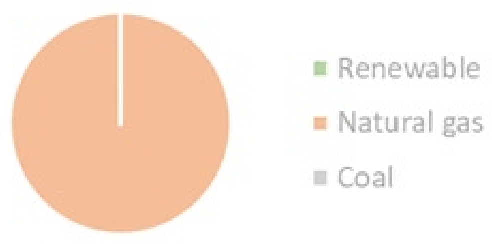
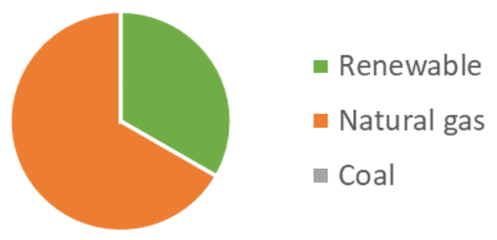
Example

Average	1/3 renewable (by policy) 1/3 coal (lowest cost) 1/3 natural gas (remainder)	

Example

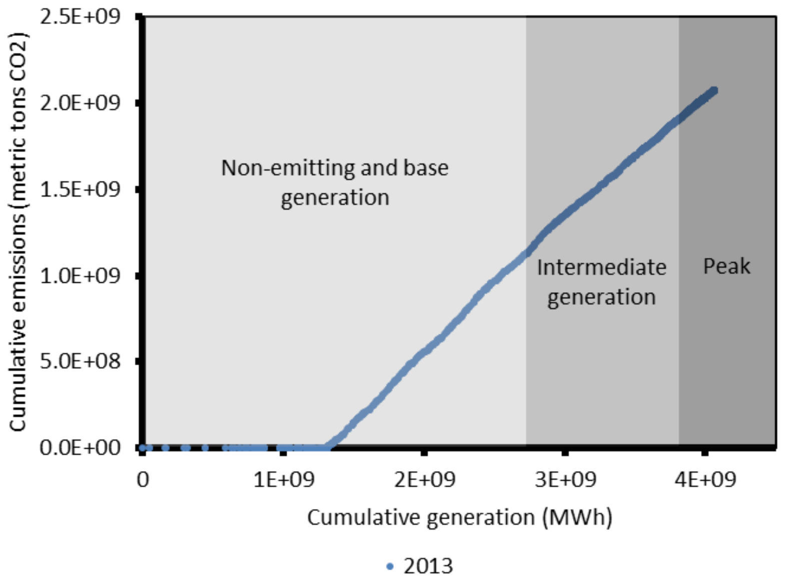
Average	1/3 renewable (by policy) 1/3 coal (lowest cost) 1/3 natural gas (remainder)	
Small-scale marginal	All natural gas (meets remaining load)	

Example

Average	1/3 renewable (by policy) 1/3 coal (lowest cost) 1/3 natural gas (remainder)	
Small-scale marginal	All natural gas (meets remaining load)	
Large-scale marginal	1/3 renewable (by policy) 2/3 natural gas (meets remaining load)	

What does real life look like?

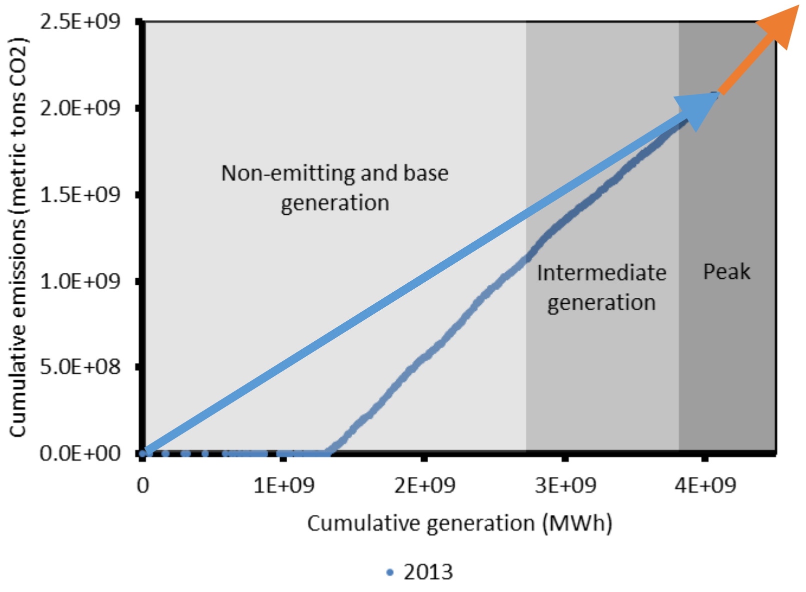
- The top chart shows cumulative emissions relative to cumulative generation for all plants in the US for 2013, ordered by CO_2 emissions intensity



Source: EPRI analysis of EPA and EIA data

What does real life look like?

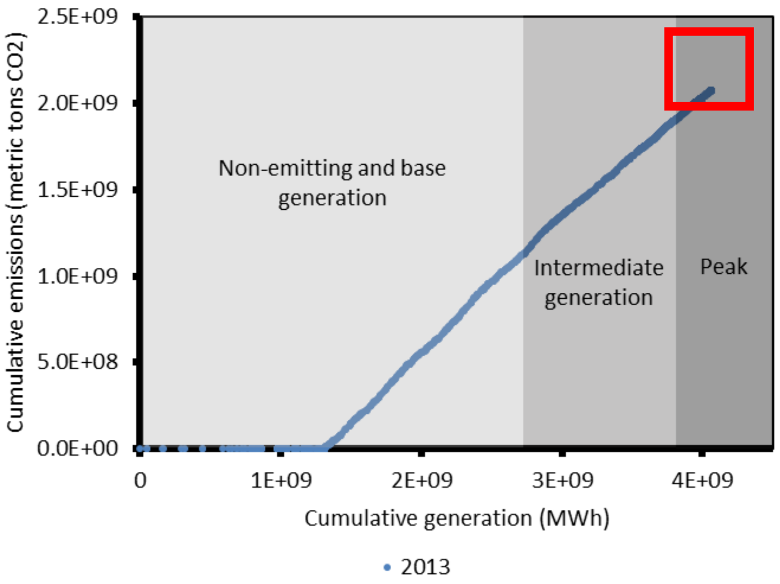
- The top chart shows cumulative emissions relative to cumulative generation for all plants in the US for 2013, ordered by CO_2 emissions intensity



Source: EPRI analysis of EPA and EIA data

What does real life look like?

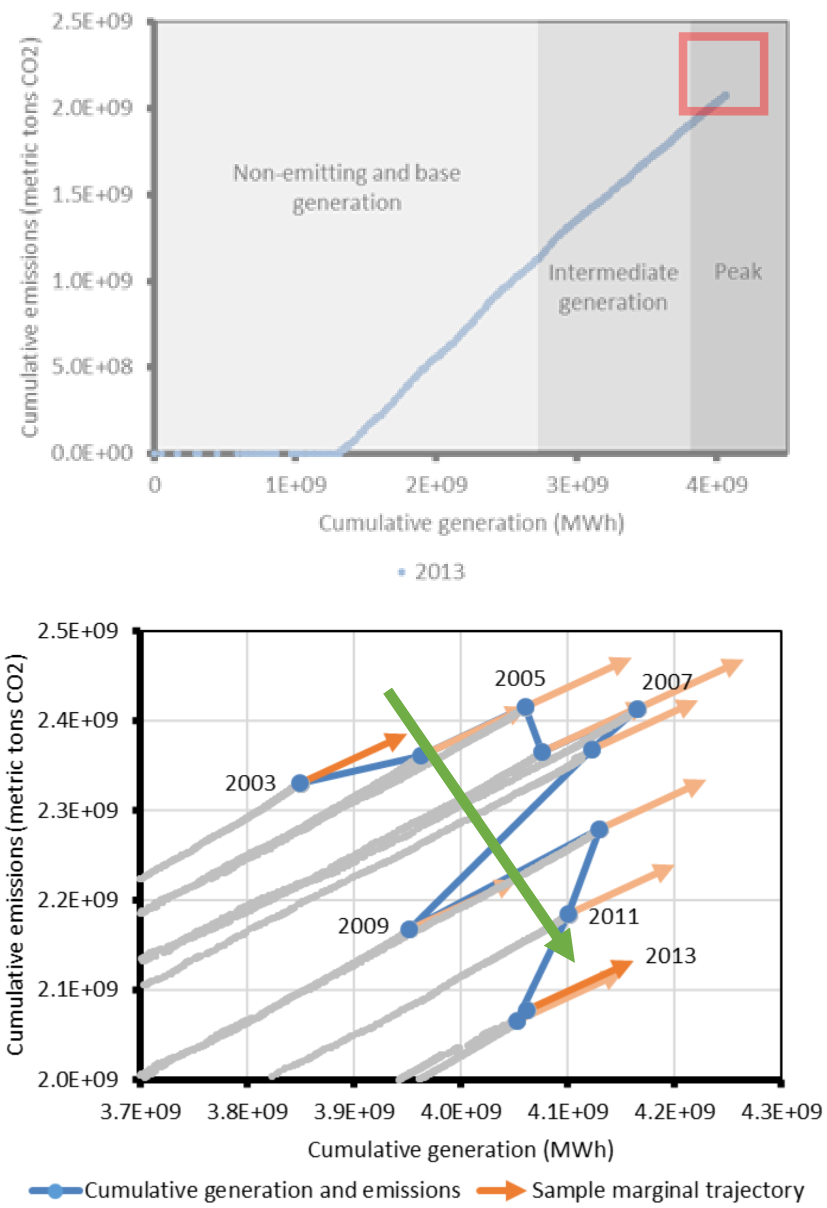
- The top chart shows cumulative emissions relative to cumulative generation for all plants in the US for 2013, ordered by CO_2 emissions intensity



Source: EPRI analysis of EPA and EIA data

What does real life look like?

- The top chart shows cumulative emissions relative to cumulative generation for all plants in the US for 2013, ordered by CO_2 emissions intensity
- The bottom chart shows the zoomed in red area, but for many years
- The trend does not follow a simple linear extrapolation; policy appears to be more important



Source: EPRI analysis of EPA and EIA data

Best practices for modeling grid emissions for electric transportation

EPRI grid modeling

- EPRI uses the US-REGEN model for grid modeling; it:
  - Is economy wide
  - Has high spatial and temporal resolution
  - Has a comprehensive set of policies affecting grid emissions
  - Has endogenous capacity expansion and retirement
  - Projects capacity and generation over time using EPRI's understanding of generation costs
  - Allows for exploration of a variety of policy and resource scenarios
- https://eea.epri.com/models.html#us-regen for more information

Rate of load introduction

- High enough to cause a real response to the system
- Low enough to be realistic

Rate of load introduction

- High enough to cause a real response to the system
- Low enough to be realistic
- The 2 million vehicles placed on the road in the last decade require about **6 TWh/year** of electricity

Rate of load introduction

- High enough to cause a real response to the system
- Low enough to be realistic
- The 2 million vehicles placed on the road in the U.S. the last decade require about **6 TWh/year** of electricity
- Total U.S. electricity use is about **4000 TWh/year**

Emissions scope

- To the extent possible, all emissions related to fuel acquisition and processing should be included
- Non-exhaust vehicle emissions are becoming increasingly important and should be included

More information

More information

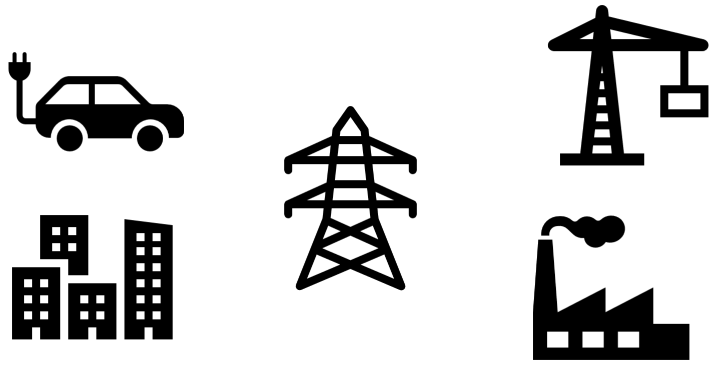
- **Environmental Assessment of a Full Electric Transportation Portfolio, Volume 1: Background, Methodology, and Best Practices**
  - **https://www.epri.com/research/products/000000003002006875**
- Volume 2: Greenhouse Gas Emissions
  - https://www.epri.com/research/products/000000003002006876
- Volume 3: Air Quality Impacts
  - https://www.epri.com/research/products/000000003002006880

- Marcus Alexander; malexander@epri.com

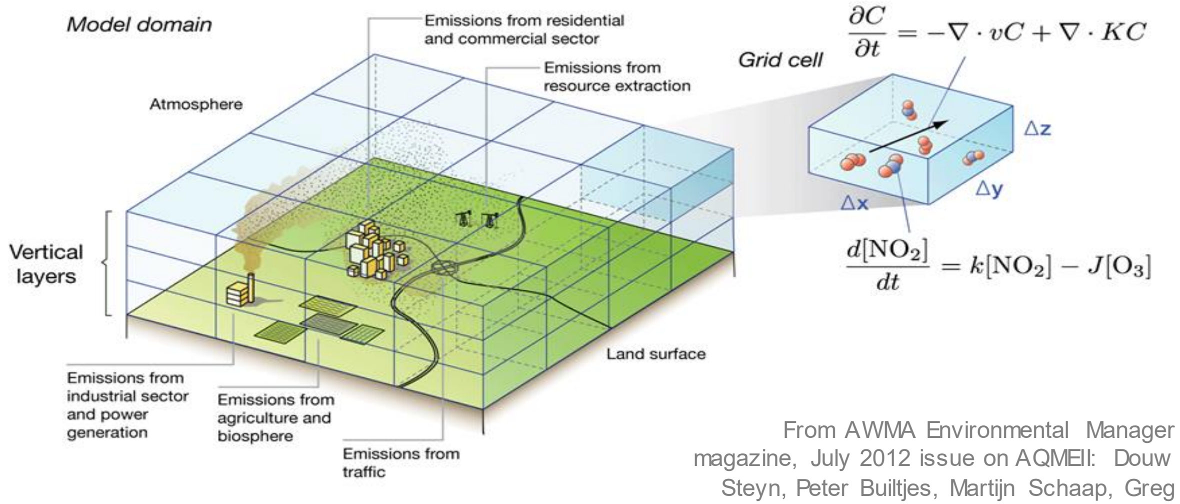
Air Quality Modeling for Electric Vehicle Fleets

Uarporn (Ou) Nopmongcol
Ramboll

Assessing Emission Impacts through Air Quality Modeling



Use a Photochemical Grid Model for Ozone and $PM_{2.5}$

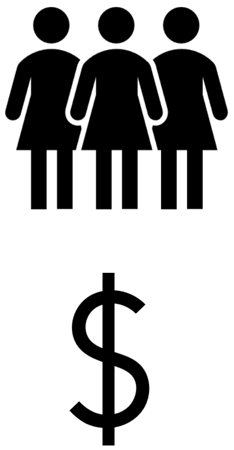


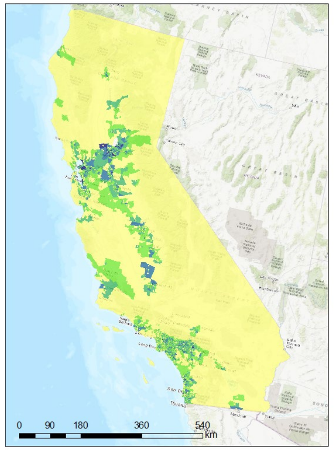
From AWMA Environmental Manager magazine, July 2012 issue on AQMEII: Douw Steyn, Peter Builtjes, Martijn Schaap, Greg Yarwood

Ozone, $PM_{2.5}$

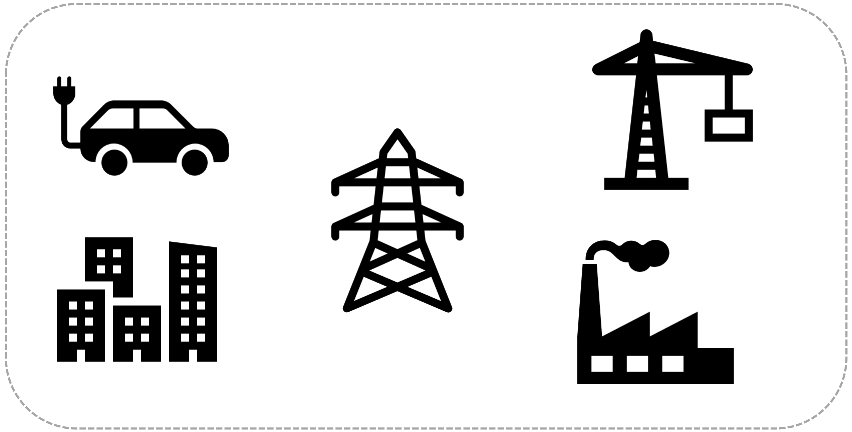
Mortality

Valuation





Holistic look across all Emitting sources



Changes from direct and indirect sources

- Direct (electrifiable sources and electric grids)
  - Transportation, off-road
  - Residential & commercial
  - Industrial boilers
- Indirect (impacted by changes in demand)
  - Petroleum upstream (exploration, production, and shipping)
- Increasing emission from economic and activity growth
  - Industrial sectors
  - Dust from more activities, e.g., miles traveled
- Carbon pricing also a key factor

Recent Continental US study: Model and Scenarios

US-REGEN Economic/Energy Emission Inventory

- Criteria air pollutants from all anthropogenic emission sources
- Continental US (CONUS)
- 2015–2050 period in 5-year increments

Basis

- Baseline emissions: EPA's 2014 National Emission Inventory
- Forecast: Economic activity, technology, and emissions controls

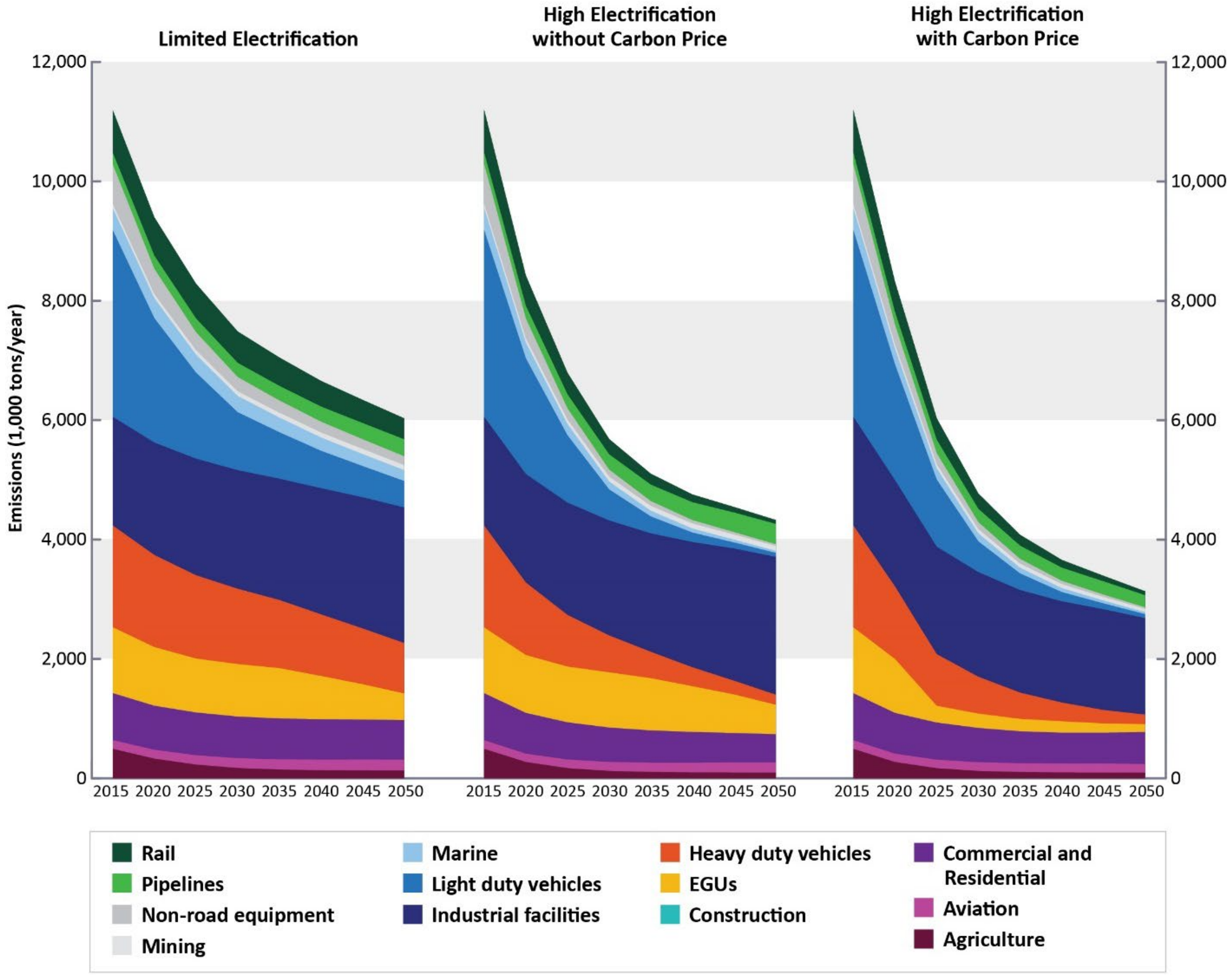
Scenarios

- Limited Electrification (Reference case)
- High Electrification without Carbon price
- High Electrification with Carbon price

NOx Emissions

High Elec scenarios have substantially greater emission reductions for on-road vehicles, rail, buildings, and non-road equipment

High w/ carbon price scenario has greater emission reductions for industrial facilities, EGUs, and pipelines

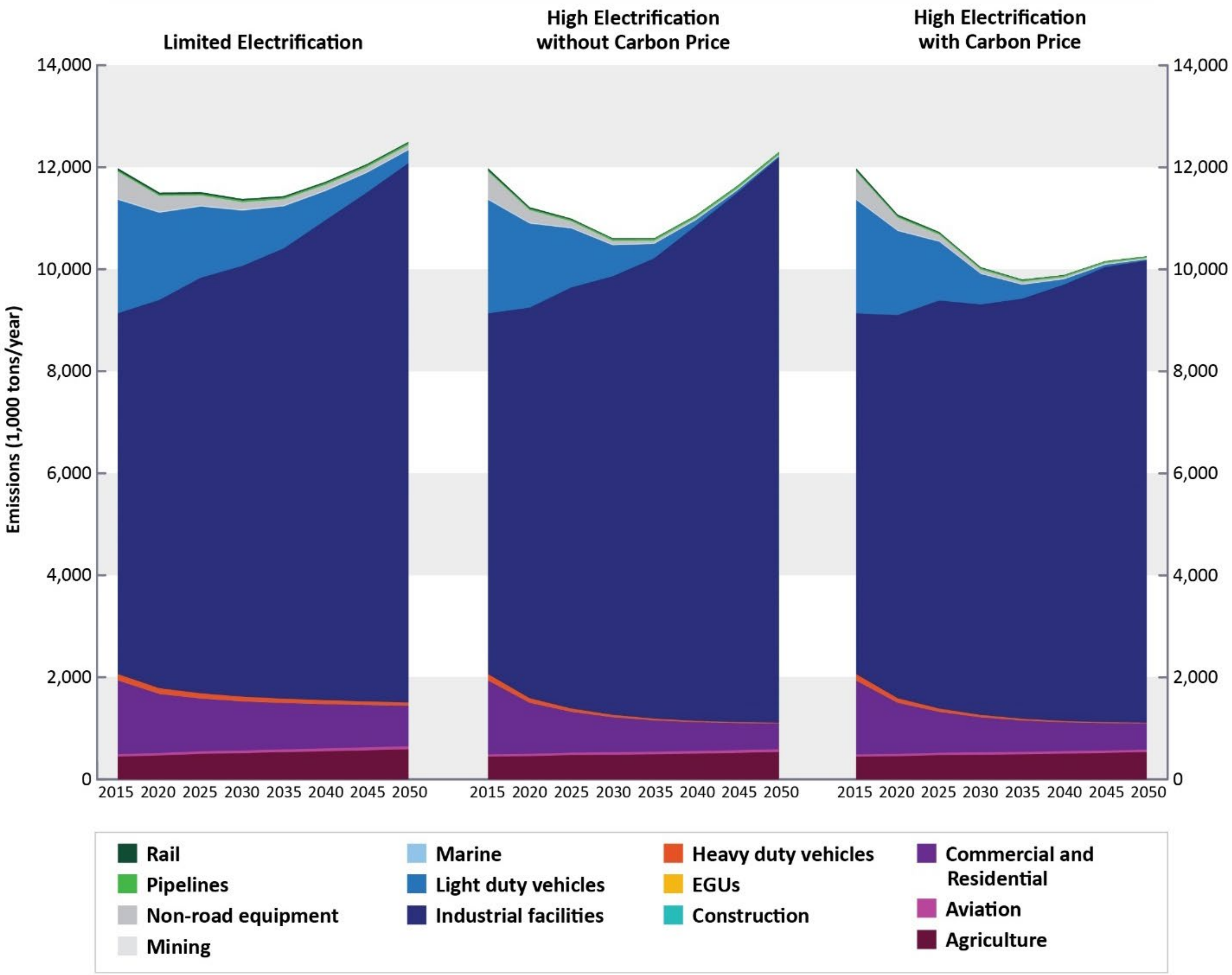


VOC Emissions

Upstream Oil & Gas (industrial facilities) is key driver

- **Upward trend** in Limited and High w/o carbon price scenarios
- **Downward trend** High w/ carbon price scenario

Higher emissions for Limited scenario due to commercial & residential and vehicles



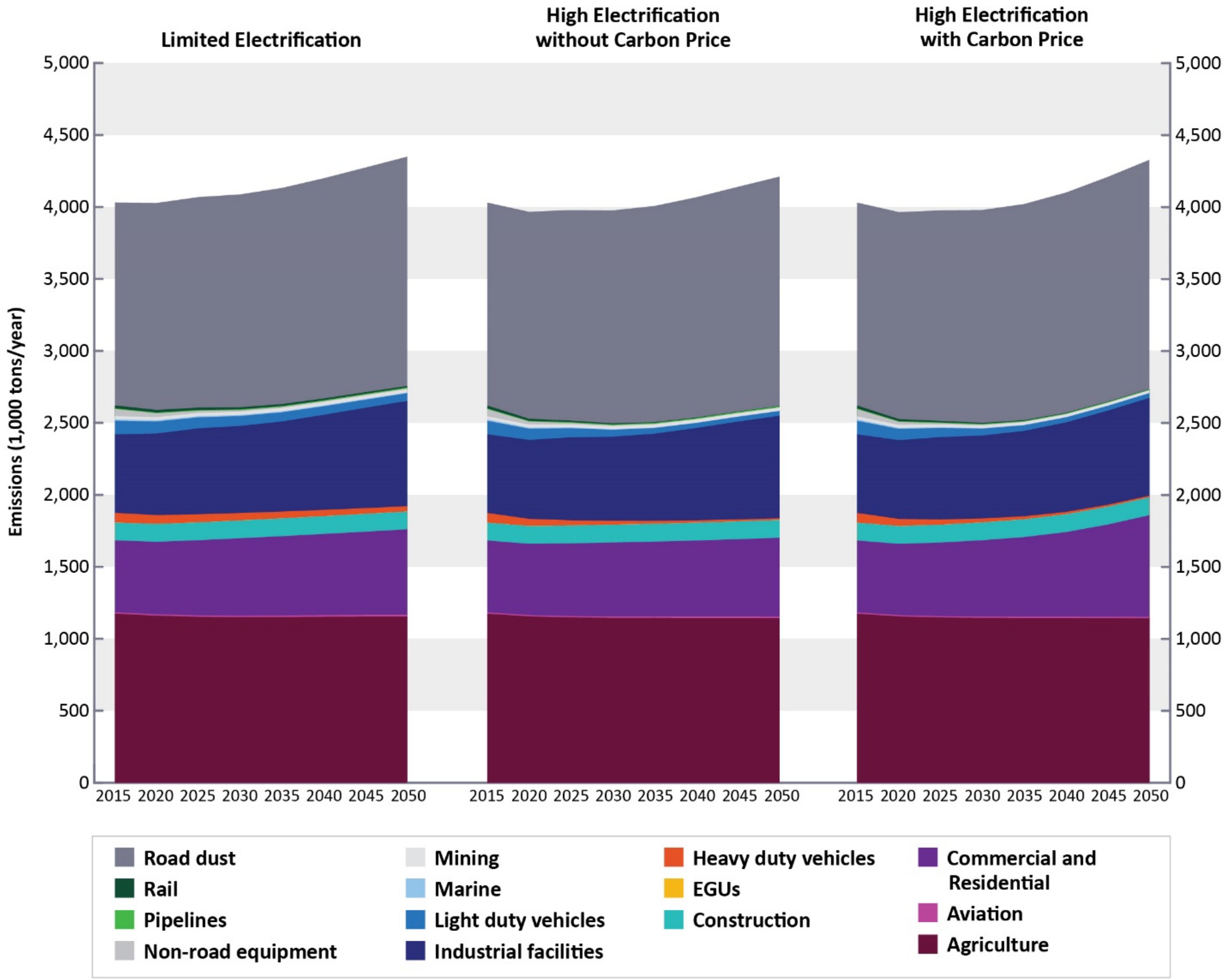
Primary $PM_{2.5}$ Emissions

Fugitive dust dominates

- Agriculture, road, construction

Lower for High Elec due to vehicles and non-road equipment

Slightly higher for High Elec w/ C price due to commercial & residential

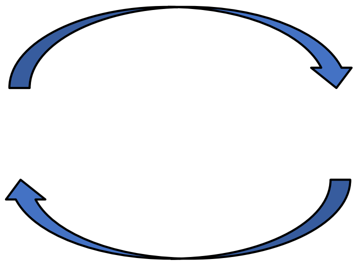


REGEN Emissions Development and Integration into Air Quality Modeling

Typical EPA / Air Quality Modeling Format

- Geographic
  - County (nonpoint)
  - Facility and unit (point)
- Source Classification
  - 5500+ NEI SCCs
  - 1000+ NAICS

REGEN Emission Model Development



REGEN end-use emission output integration into Air Quality Modeling

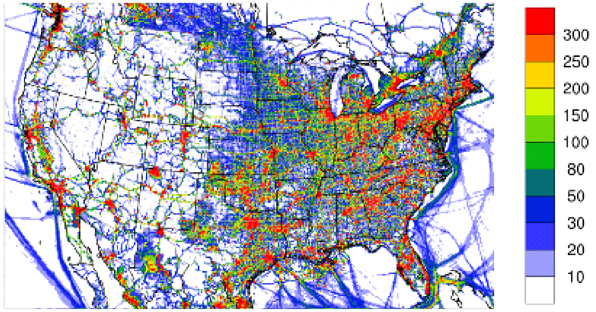
REGEN Format

- Geographic
  - State or multi-state region
- Source Classification
  - 31 Sectors
  - 12 Sources
  - 11 Fuels

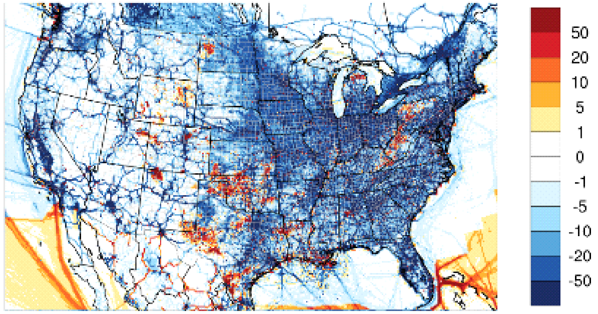
Handshake between REGEN and Air Quality Model

Spatial Distribution of NOx Emissions

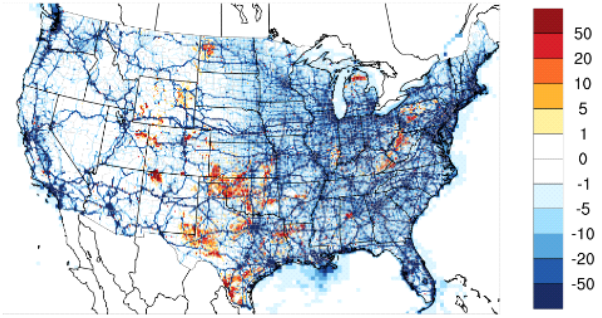
2016 Baseline



Delta
(2035 Limited Elec – 2016 Base)

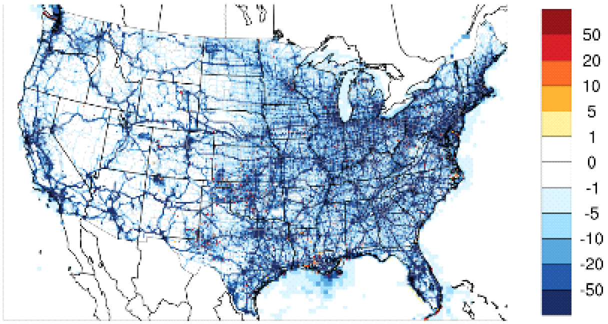


Delta
(2035 High w/o C price - 2035 Limited Elec)

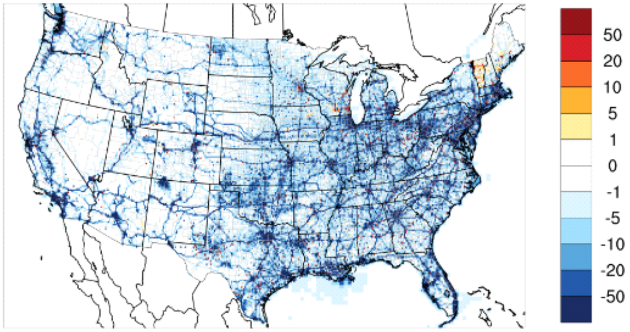


Declining on-road and non-road NOx emissions
but increasing oil & gas NOx emissions

Delta
(2035 High w/ C price - 2035 Limite Elec)



Delta
(2050 High Elec w/ C price - 2035 High Elec w/ C price)

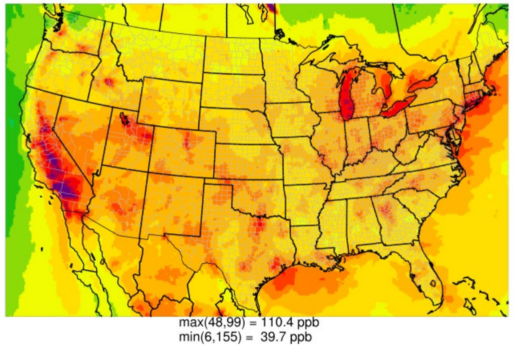


Carbon pricing reduces NOx emissions out to 2050

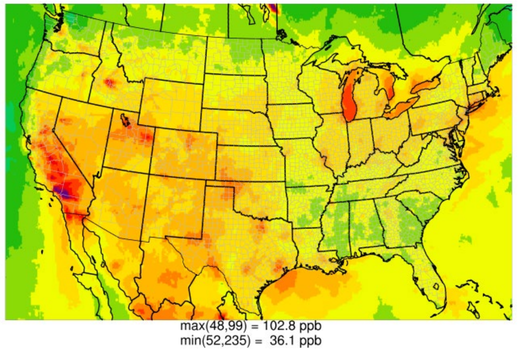
Air Quality Analysis
Ozone and $PM_{2.5}$

Ozone Impacts

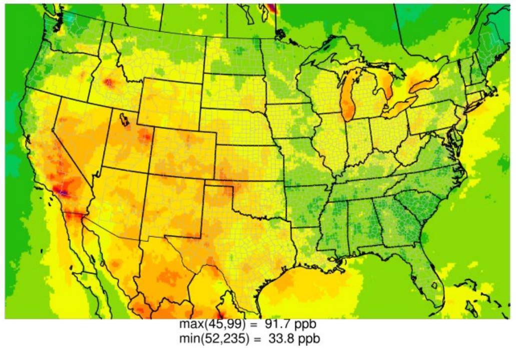
2016

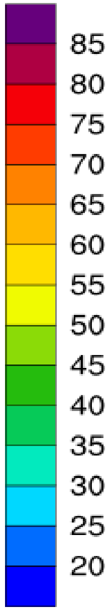


2035 Limited

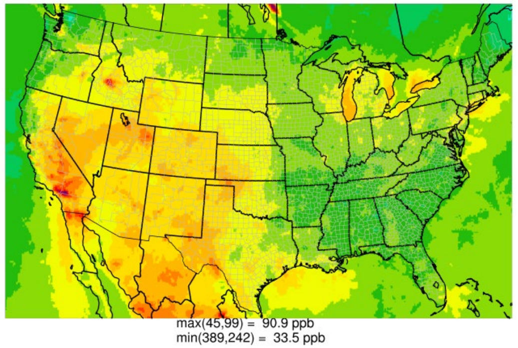


2035 High w/o Carbon Price

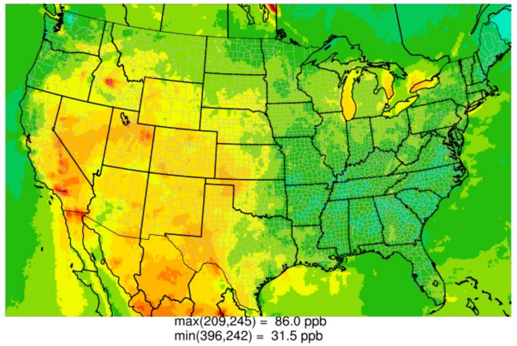




2035 High w Carbon Price

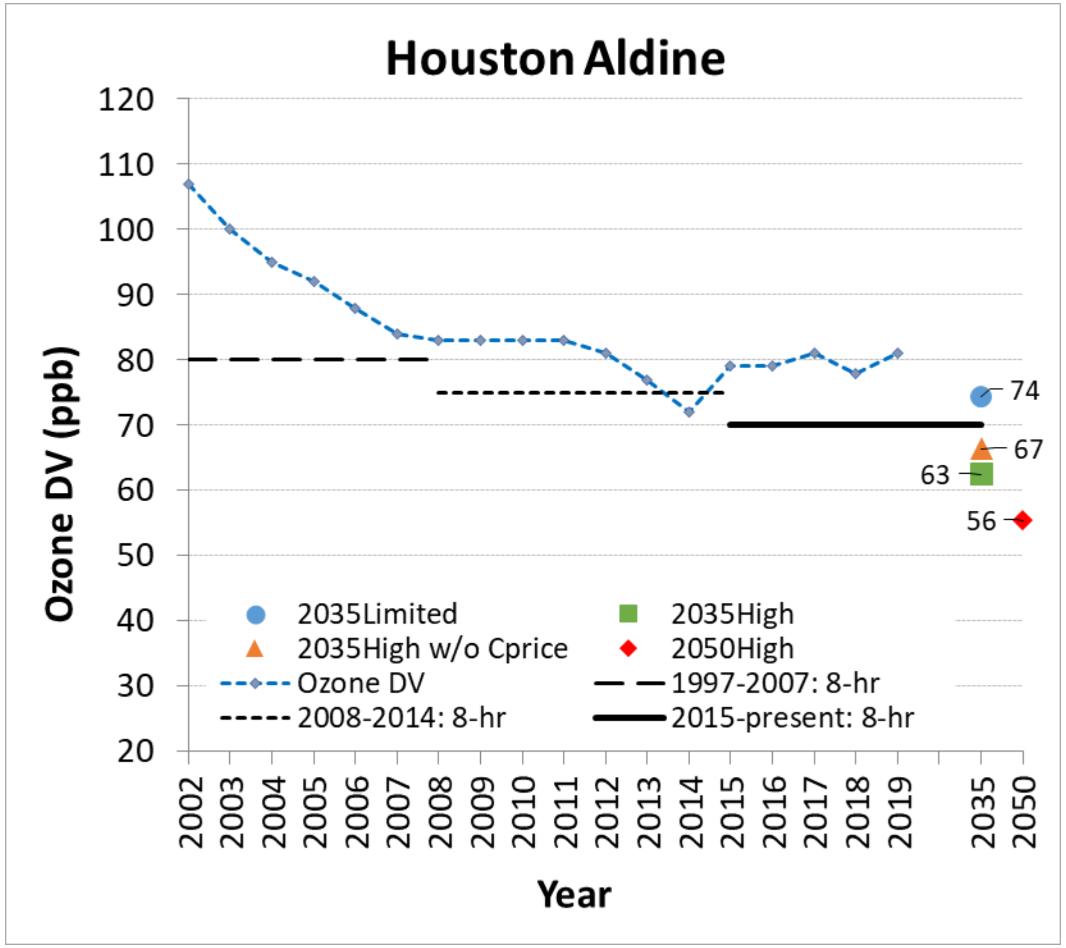


2050 High w Carbon Price



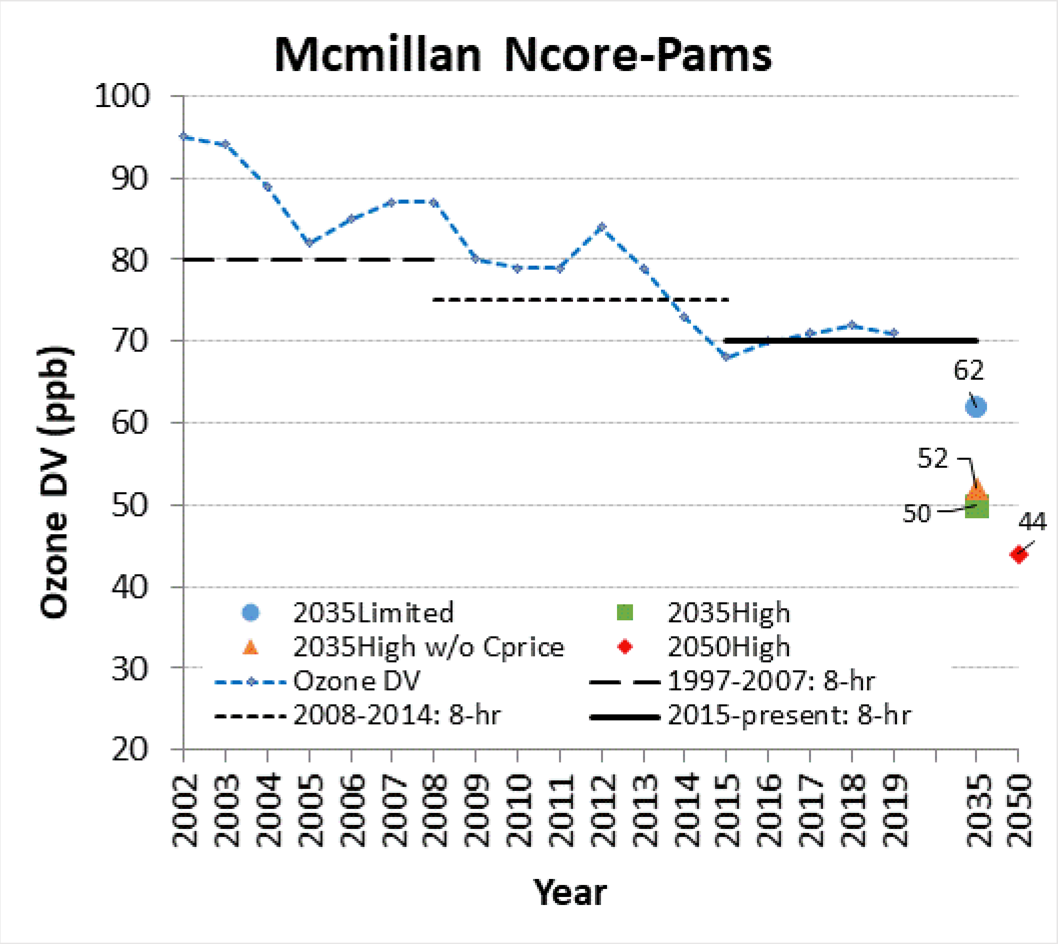
Deep NOx emission reductions lead to striking ozone reduction across the country especially in the eastern US

Case study: Houston Ozone Trend



- 2019 ozone design value (DV) of 81 ppb
- Downward ozone trend until 2014; flat since
- Complex air quality due to mix of pollution sources plus local circulation
- Fleet turnover is not sufficient to meet NAAQS in the 2035 Limited Electrification scenario
- Electrification will help extend downward trend and assure attainment

Case study: DC Ozone Trend



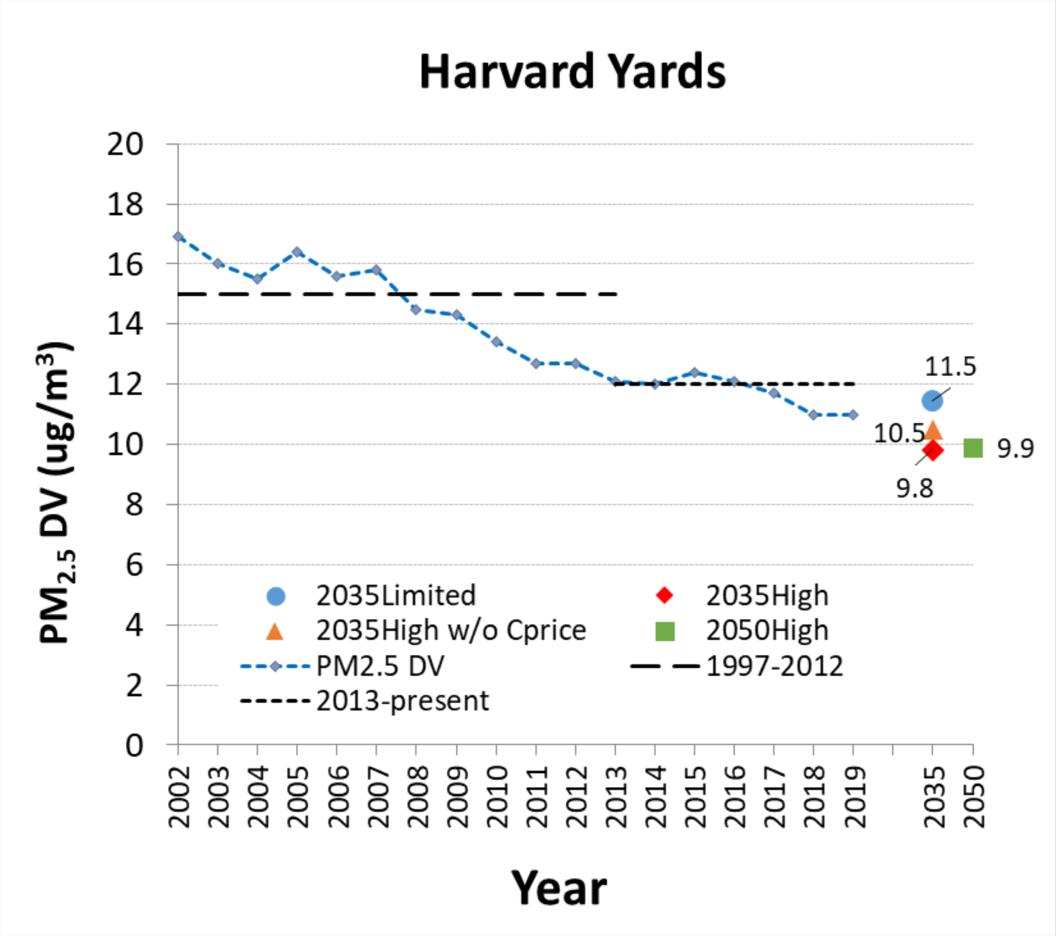
- Multistate metropolitan area

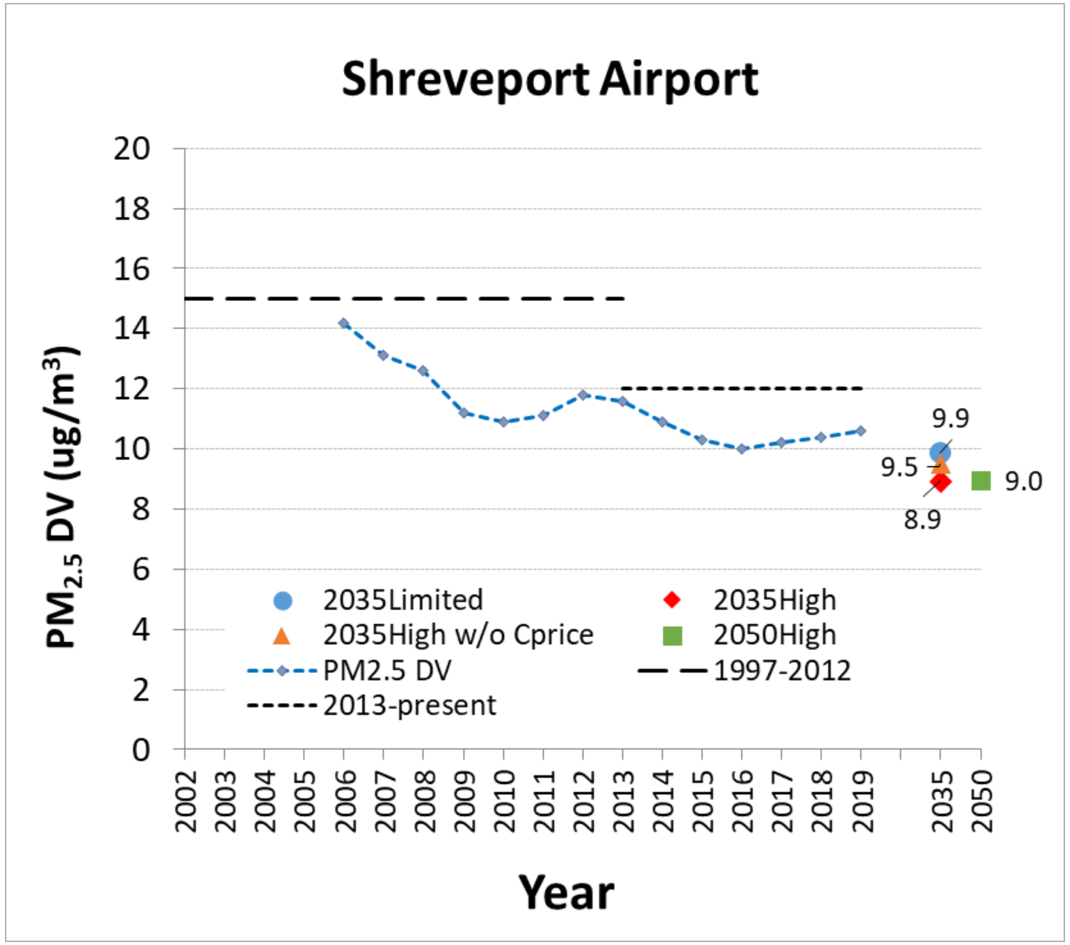
  Washington-Arlington-Alexandria Core Based Statistical Area (CBSA)

- Downward since 2002 but further emission reduction is necessary
- Electrification can double ozone benefit by 2035

Case study: Ohio and Louisiana $PM_{2.5}$ Trend

Impacts of electrification less dramatic than for ozone

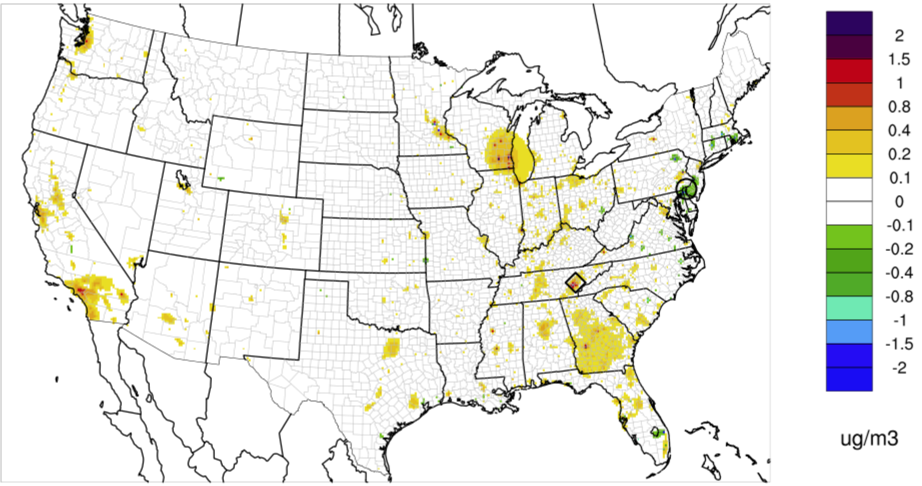




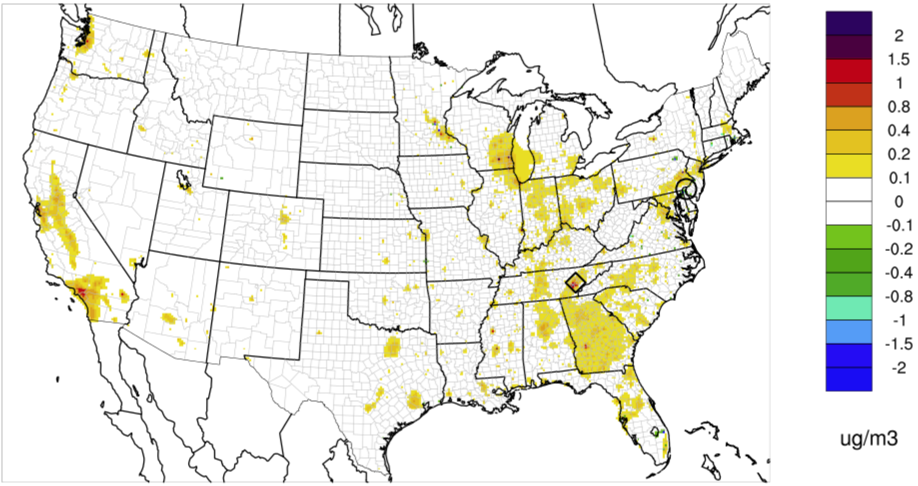
Primary vs Secondary

- Increase total $PM_{2.5}$ in 2050 from 2035 driven by primary $PM_{2.5}$

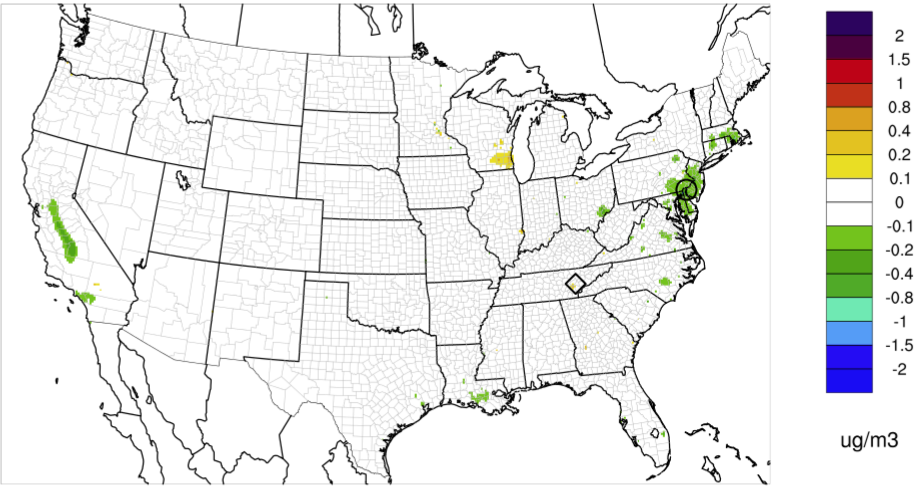
Total $PM_{2.5}$ mass



Primary $PM_{2.5}$: primary organic aerosol, dust



Secondary $PM_{2.5}$: nitrate, sulfate, SOA



Other studies

EPRI-NRDC 2015 Report

EPRI

NRDC NATURAL RESOURCES DEFENSE COUNCIL

Electrifying Transportation Reduces Greenhouse Gases and Improves Air Quality: Executive Summary

The Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) produced the Environmental Assessment of a Full Electric Transportation Portfolio to provide in-depth analysis of the environmental impact of electrifying a range of vehicles, including U.S. light-duty and medium-duty transportation and industrial equipment such as forklifts.

CONUS Vehicles + Equipment (2017)

Environmental Science & Technology

ACS AuthorChoice

Article

pubs.acs.org/est

Air Quality Impacts of Electrifying Vehicles and Equipment Across the United States

Uarporn Nopmongcol,[*,†] John Grant,[†] Eladio Knipping,[‡] Mark Alexander,[*,‡] Rob Schurhoff,[§] David Young,[‡] Jaegun Jung,[†] Tejas Shah,[†] and Greg Yarwood[†]

California focused (CEC, 2019)

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

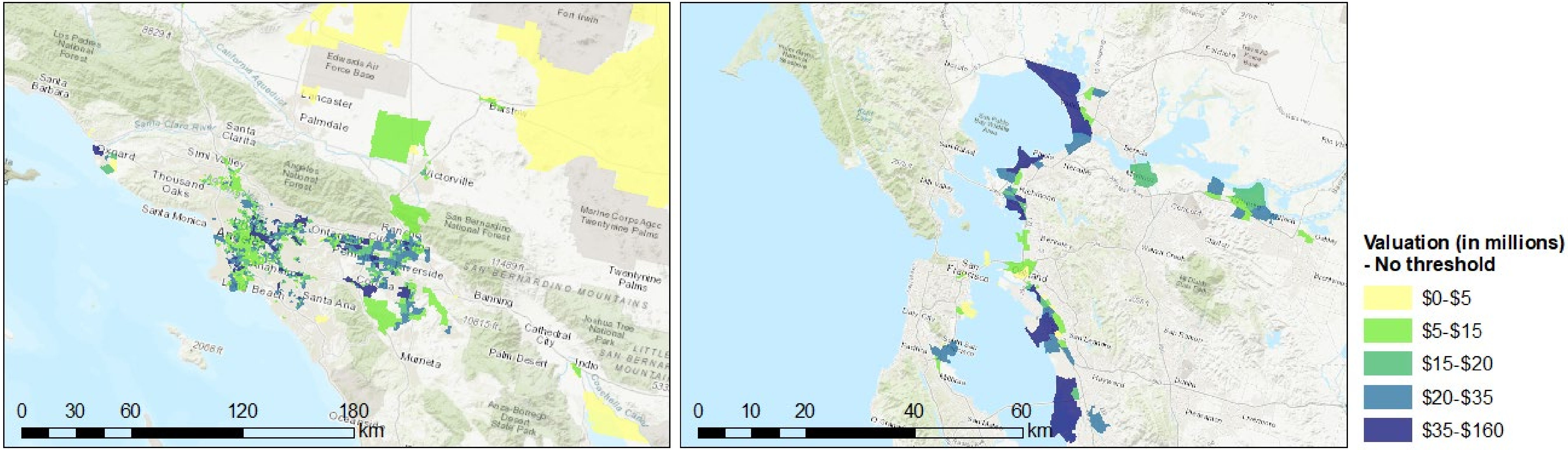
Gavin Newsom, Governor

STATE OF CALIFORNIA ENERGY COMMISSION

June 2019 | CEC-500-2019-049

Valuation of Avoid Mortality from $PM_{2.5}$ changes

California Case Study: Benefits across disadvantaged communities



Key Takeaways

- Downward trends in ozone and $PM_{2.5}$ recently **stalled or even reversed** at important locations
- "On-the-books" strategies may be insufficient for some states to meet the NAAQS
- **Electrification is key** to resuming and extending these downward pollution trends
  - Ozone improvements mostly doubled from 2016 in High Electrification scenarios (approaching background in 2050) due mainly to **lower NOx emissions from on-road and nonroad**
  - $PM_{2.5}$ improvements due mostly to lower NOx and SO_2 emissions from on-road, non-road, and EGUs

Key Takeaways

- $PM_{2.5}$ improvements stall from 2035 to 2050 because secondary $PM_{2.5}$ precursor (NOx, SO_2) emission reductions are offset by growing primary $PM_{2.5}$ emissions

  States may need to consider emissions from several activities that may not be traditionally included in emission mitigation strategy

- Air quality benefits of carbon pricing can be significant near oil & gas sources

- Interstate transport can affect attainment status and may require demonstration of “Good Neighbor” provisions

  Broad adoption of electrification benefits regional as well as local air quality

More information

- EPRI-NRDC, 2015. Environmental Assessment of a Full Electric Transportation Portfolio, Volume 3: Air Quality Impacts
  - https://www.epri.com/research/products/000000003002006880
- EPRI-Ramboll, 2017. Air Quality Impacts of Electrifying Vehicles and Equipment Across the United States. ES&T
  - https://pubs.acs.org/doi/10.1021/acs.est.6b04868
- CEC, 2019. Air Quality Implications of an Energy Scenario for California Using High Levels of Electrification
  - https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-049.pdf

Uarporn (Ou) Nopmongcol
unopmongcol@ramboll.com

Thomas Bradley
thomas.bradley@colostate.edu

Colorado State University

Uarporn Nopmongcol
unopmongcol@ramboll.com

RAMBOLL

EPRI

Marcus Alexander
malexander@epri.com

Eladio Knipping
eknipping@epri.com

#TRBwebinar

Other TRB events for you

- *October 25-28*: **Electric Vehicles Workshop (Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles-Phase 3)**

- *November 1*: **Building Information Modeling for Infrastructure**

https://www.nationalacademies.org/trb/events

TRB Weekly

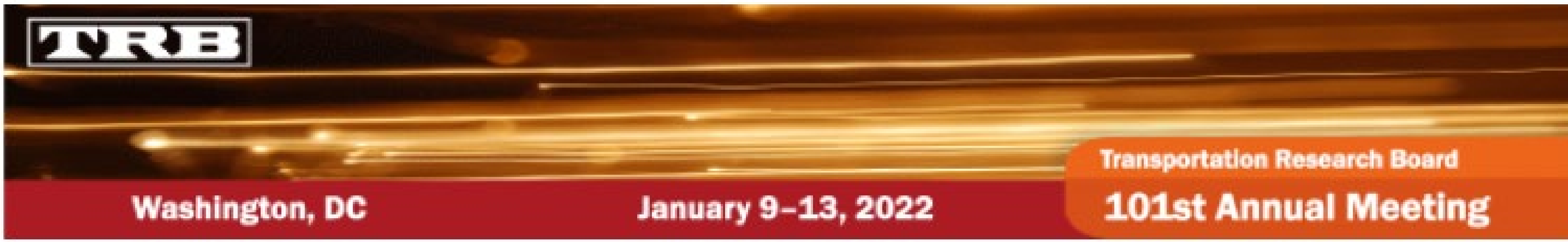
The National Academies of SCIENCES · ENGINEERING · MEDICINE

TRB TRANSPORTATION RESEARCH BOARD

- Subscribe to the newsletter for the most recent TRB news & research

https://bit.ly/ResubscribeTRBWeekly

Register for TRB's Annual Meeting!



Register now for our January meeting! ***There will be no onsite registration this year.***

https://bit.ly/TRBAM2022registration

#TRBAM

TRB's Podcast!

- Have you heard TRB's Transportation Explorers?
- Listen on our website or subscribe wherever you listen to podcasts!

#TRBExplorers

Get involved with TRB

- Receive emails about upcoming webinars: https://mailchi.mp/nas.edu/trbwebinars

- Find upcoming conferences: https://www.nationalacademies.org/trb/events

@NASEMTRB

@NASEMTRB

Transportation Research Board

#TRBWebinar

Get Involved with TRB

Getting involved is free!

Be a Friend of a Committee bit.ly/TRBcommittees

– Networking opportunities

– May provide a path to Standing Committee membership

Join a Standing Committee bit.ly/TRBstandingcommittee

Work with CRP https://bit.ly/TRB-crp

Update your information www.mytrb.org