Complex Air Quality Implications from Low Carbon Energy Scenarios for California in 2050

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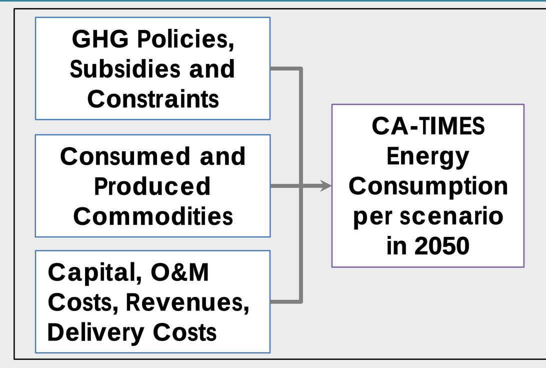
Energy Scenarios

Introduction

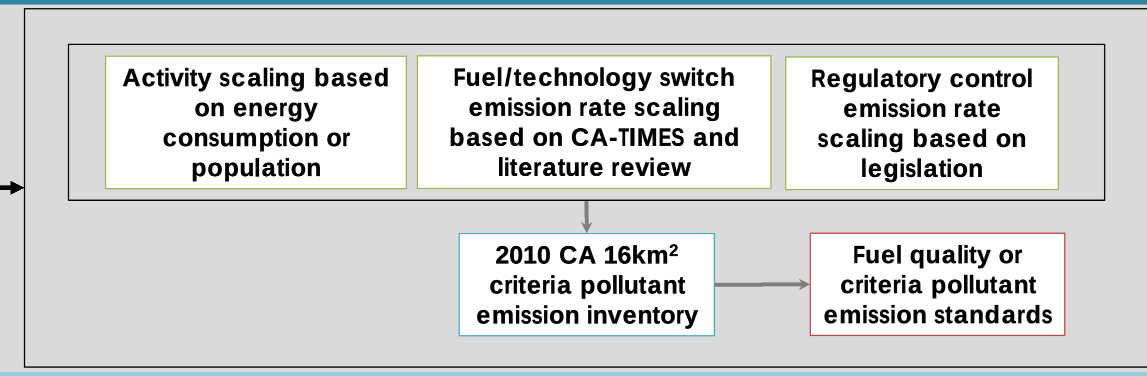
- California's Governor's Executive Order S-3-05 calls for California to reduce GHG levels 80% below 1990 levels by the year 2050.
- The CA-TIMES model has been run with multiple scenarios set to evaluate possible transformative lower carbon energy resources and technologies to meet the carbon target via a constraint.
- Since criteria pollutant emissions are coupled with carbon dioxide emissions from the same energy intensive sources, potentially large changes in air pollution may occur.
- Additional federal ambient air quality standards can be reviewed for current non-attainment basins based on these changes

CA-TIMES Model

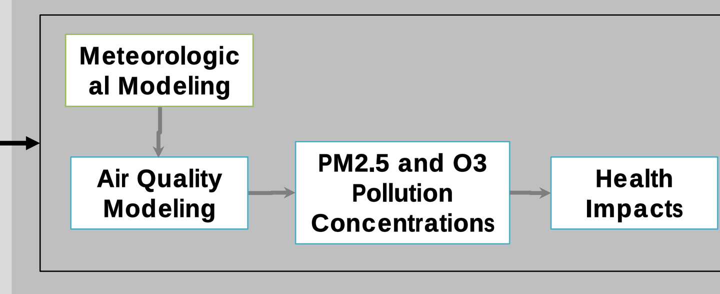
- Bottom-up, technology-rich, cost-minimization energy economic optimization model
- Two scenarios
  - BAU: current GHG policy
  - GHGAi (aka GHG-Step): 80% below 1990 GHG level constraint in 2050.



Emissions



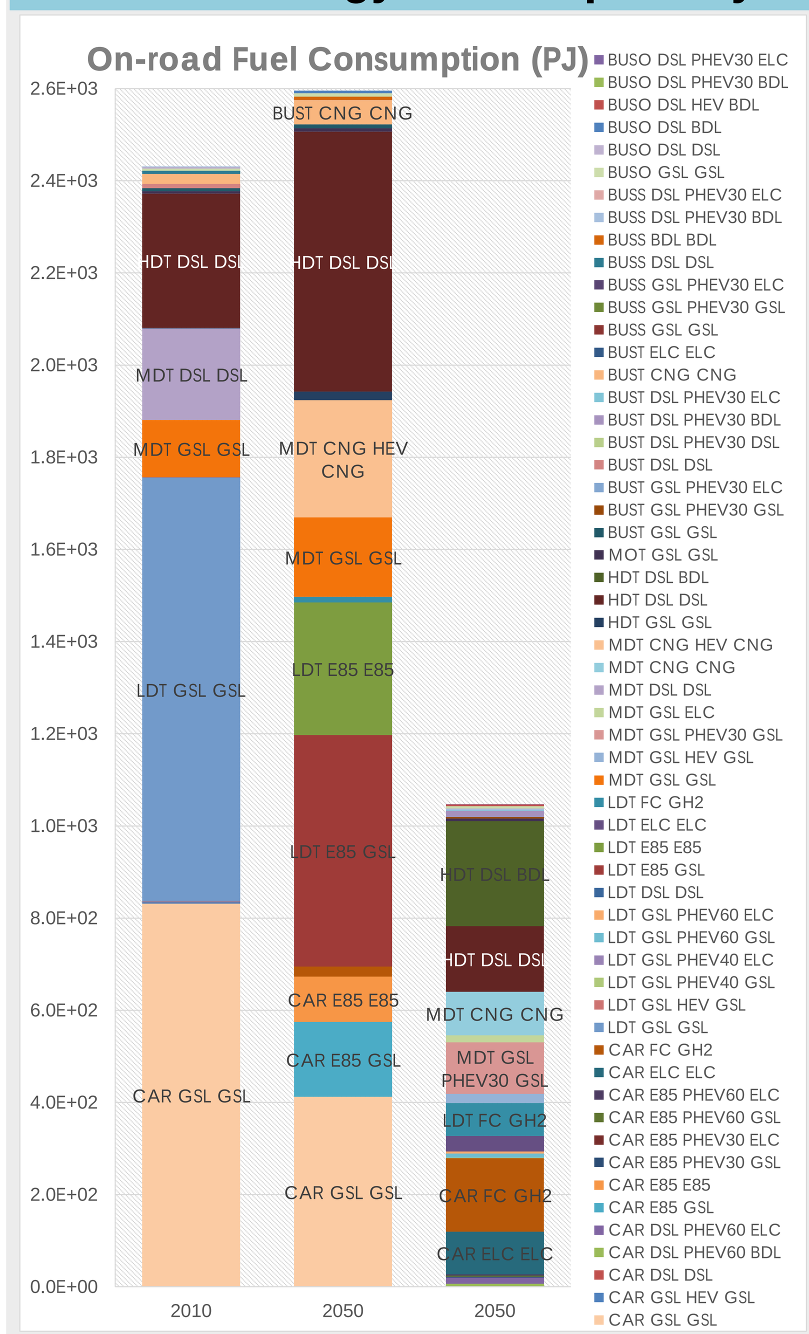
Air Quality



Air Quality Modeling

- Meteorological fields dynamically downscaled from CESM climate model with RCP8.5 scenario using Weather Research Forecasting (WRF) model
- Stagnation events of August 2047 and December 2051 selected based on population weighted average concentrations for air quality simulations that used these meteorology monthly episodes with a current 2010 emission inventory
- A 24km resolution statewide mother domain along with two nested higher resolution 4km domains of the San Joaquin Valley and the South Coast Air Basins were simulated.

Mobile Energy Consumption by Sector, Technology, Energy Resource



On-road Differences between Scenarios

Vehicle Class Share Differences

- BAU Scenario displays decreases in the CAR vehicle class and increases in the HDT and the MDT vehicle classes for an overall increase in fuel consumption relative to 2010
- GHG scenario has fuel/energy consumption reduced by over half relative to 2010 levels.

Fuel, Energy and Electrification Changes and Differences

- BAU scenario has substantial increase E85 substituting gasoline in the light duty for light duty vehicles CAR and LDT. CNG for medium duty truck along with hybridization consumes a larger consumption than gasoline MDT.
- GHG scenario has nearly completely zero-emission or electrified (hydrogen and battery electric) light duty vehicles displacing gasoline in 2050. Gasoline and diesel MDT switch to CNG and PHEV gasoline. Biodiesel is also heavily consumed by HDT but diesel still accounts for a third of the HDT fuel consumption.

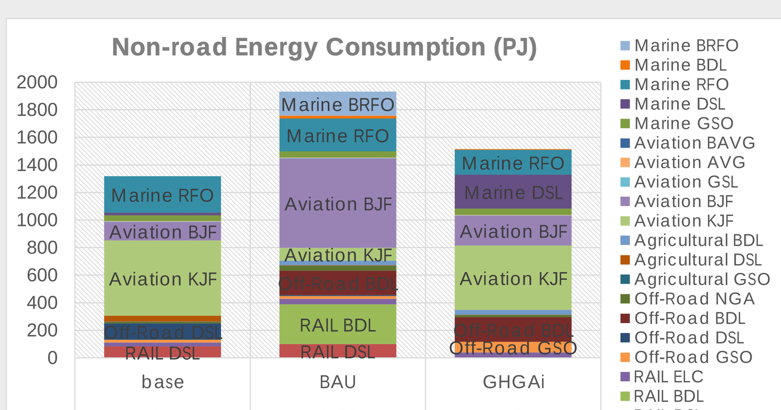
Other Mobile Differences between Scenarios

Mode Activity Differences

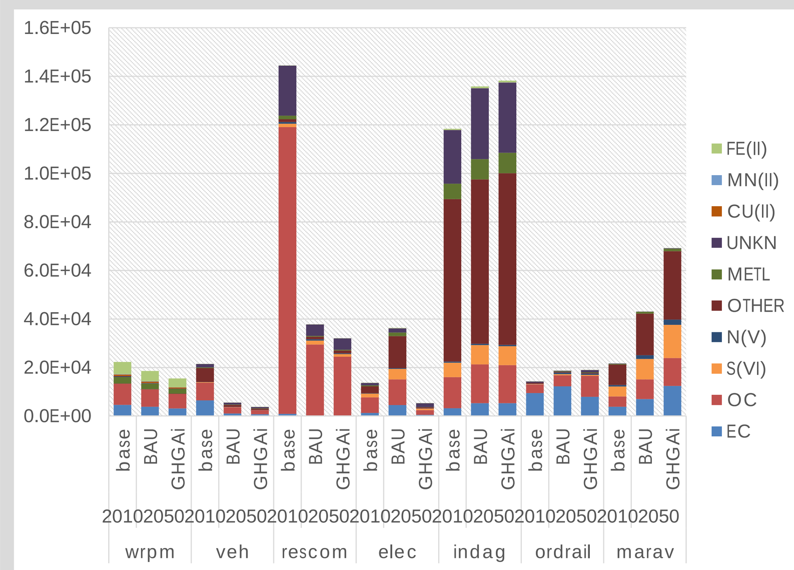
- BAU scenario displays roughly 3 fold growth in rail, 2 fold growth in marine, and nearly 2 fold growth in off-road activity.
- GHG scenario shows similar growth in off-road, marine, and aviation, but displays a decline in rail instead of a growth.

Fuel, Energy and Electrification Changes and Differences

- BAU scenario shows substantial biodiesel used in rail accounts for 3/4ths consumption, biodiesel instead of diesel is consumed in off-road applications, biojetfuel also displaces a majority of the aviation fuel consumption, and biomass based residual fuel oil takes roughly half of the marine fuel consumption.
- GHG scenario displays all rail becomes electrified, biodiesel instead of diesel is consumed by off-road, biojetfuel constitutes only a third of aviation fuel consumption and marine diesel instead of biomass-based residual fuel oil is used by marine vessels.



Statewide Total Emission Rate



Emission Changes by Emission Source Type

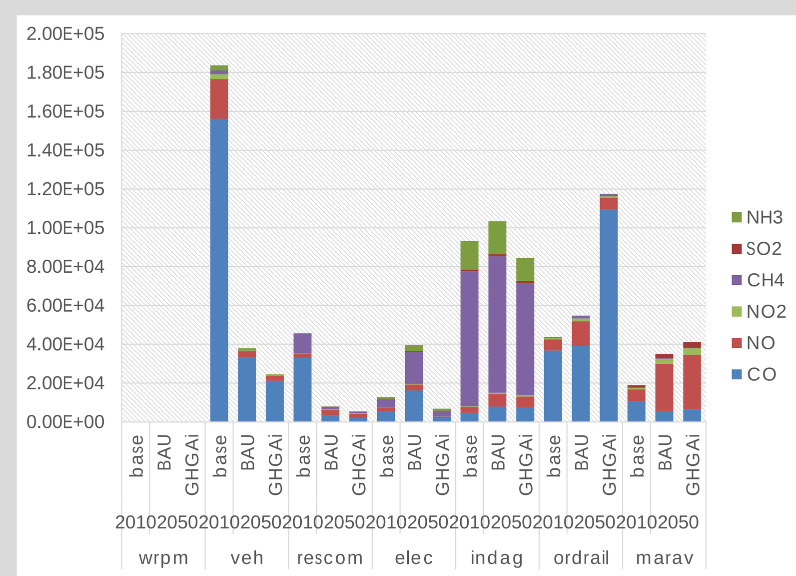
Particulate Matter Emissions

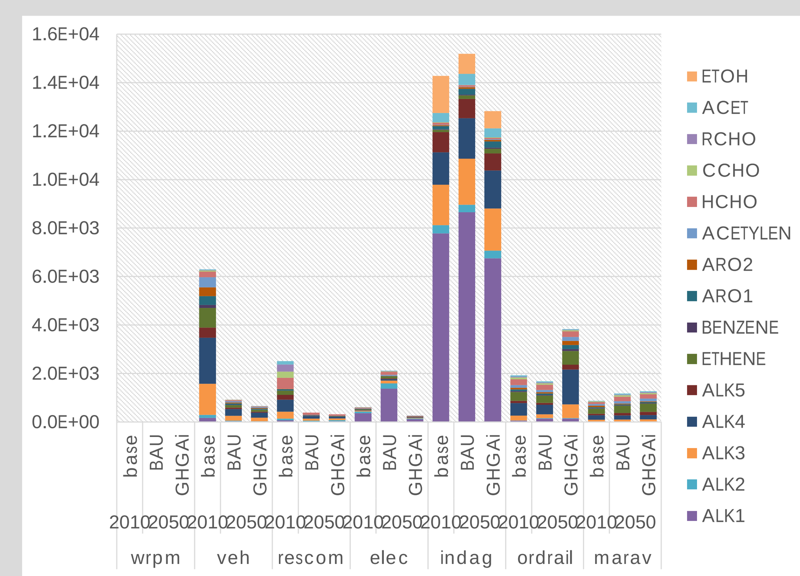
- Large reductions in organic carbon due to the decrease in residential woodburning
- Brake and tire wear decrease due to brake wear reduction
- Deeper Zero Emission Vehicle penetration and activity reductions reduce PM emissions significantly
- Increase production of biofuels, and hydrogen and decrease in petroleum leads to net increase in PM emissions in industrial sector. Growing marine and less biofuels used in GHG scenario shows marine emissions accelerating.

Gaseous emissions

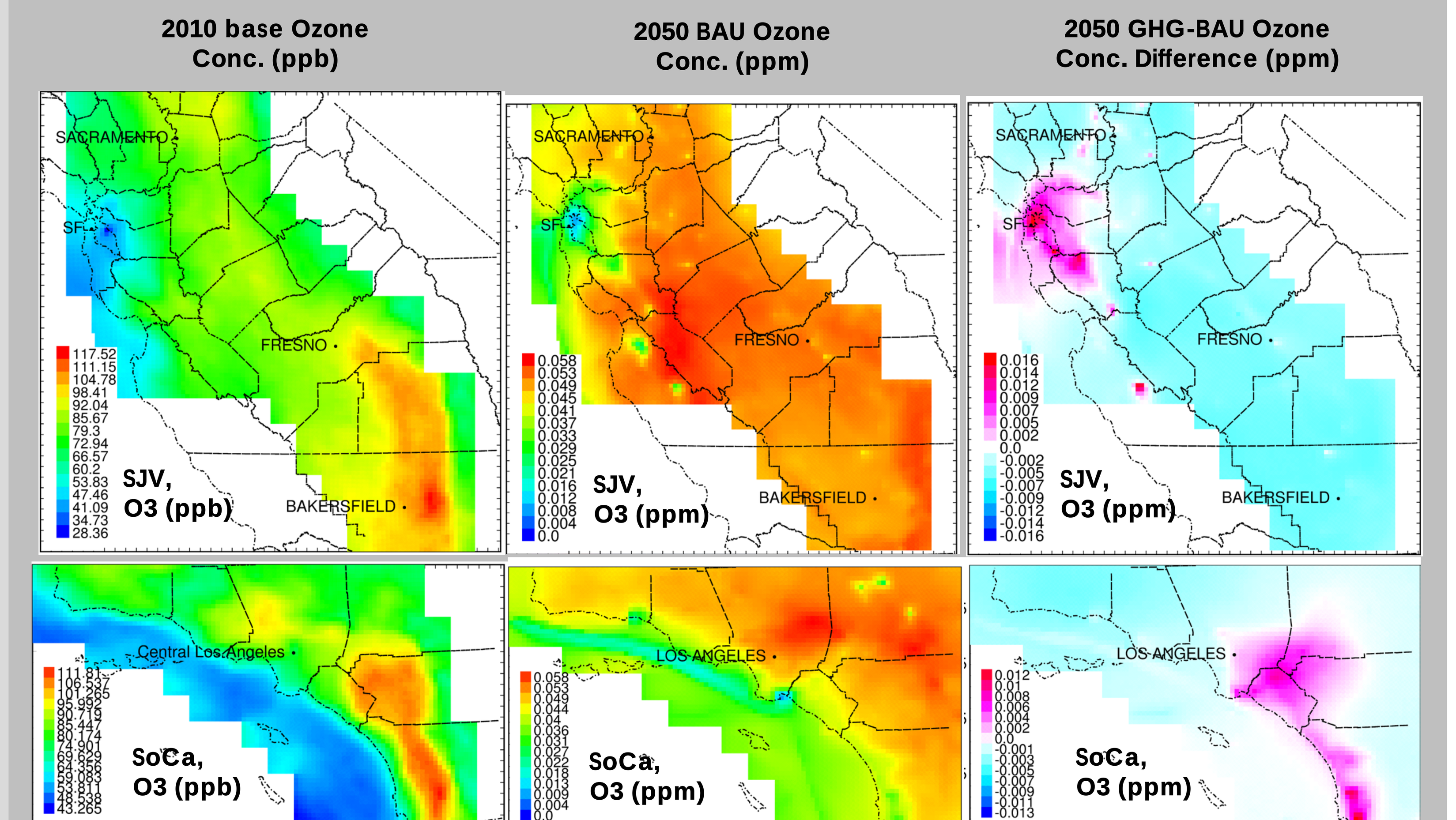
- Co and SO2 emissions decline substantially with zero emission vehicles
- An increase in regulated pollutant emissions from biomass use in the electricity sector emissions are prevented through non-carbon based energy resources.
- An increase in CO from off-road is due to the switch from diesel to biodiesel and gasoline in off-road engines
- NO increases in marine are due to the increase of biomarine fuels.
- The GHG scenario has higher H2 production and is associated with less VOC and regulated pollutant changes but higher PM changes.

Gaseous Pollutant Emission Rate (kmol/day)





August 2047 Ozone Monthly Average Stagnation Event



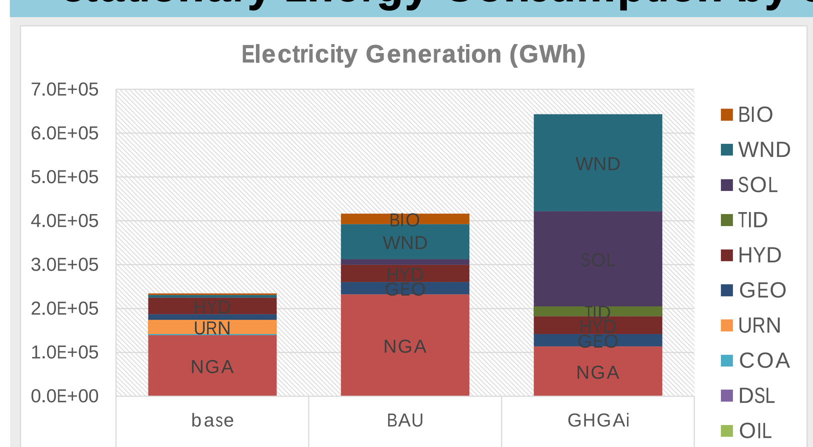
San Joaquin Valley Air Basin Ozone Changes

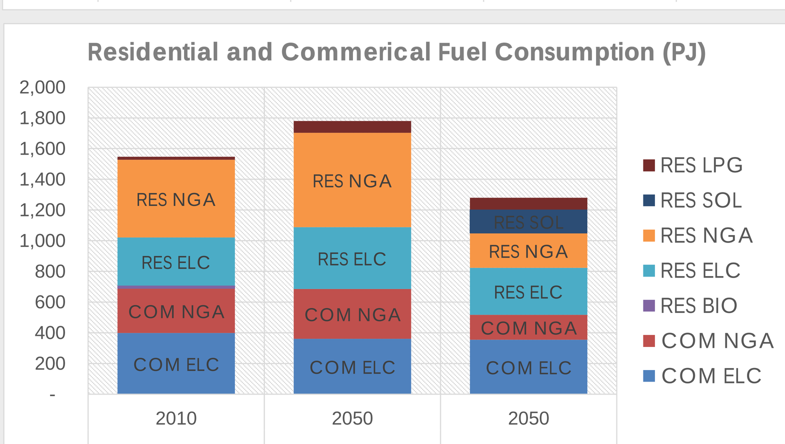
- The BAU scenario displays dramatic drops by half from 117ppb to 58ppb, where the maximum shifts from Bakersfield to west of Fresno.
- The GHG scenario has slightly higher ozone concentrations of about 16ppb in the San Francisco Bay area due to increases in emissions from the industrial sector and marine. However, since the Bay Area already had very low ozone concentrations, it does not increase it to levels higher than the concentrations in 2010.

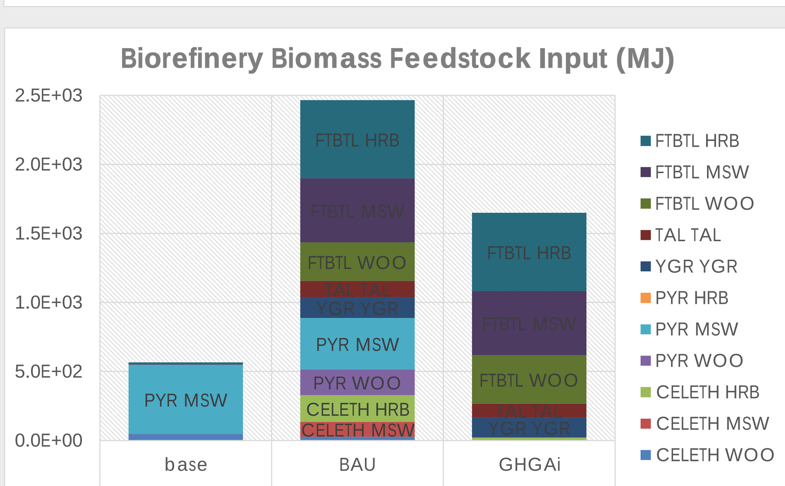
Los Angeles Air Basin Ozone Changes

- The BAU scenario displays dramatic drops by half from 117ppb to 58ppb, where the maximum shifts from Bakersfield to west of Fresno.
- The GHG scenario has slightly higher ozone concentrations of about 16ppb in the San Francisco Bay area due to increases in emissions from the industrial sector and marine. However, since the Bay Area already had very low ozone concentrations, it does not increase it to levels higher than the concentrations in 2010.

Stationary Energy Consumption by Sector, Technology, Energy Resource







Electricity Generation

- BAU scenario would require a roughly 1/3 increase in natural gas to meet the population growth and electricity demand in 2050. Substantial wind and the increase in biomass/biogas and geothermal is also noticeable in the BAU scenario. The BAU scenario shows slightly less than half of the electricity generation mix to be renewable, and the remainder natural gas. No nuclear is present in this scenario.
- The GHGAi scenario shows electricity generation from natural gas to be less than that used for electricity generation in 2010. Roughly 70% of the mix is renewable, with 1/3[rd] of electricity generation from wind, another 1/3[rd] from solar, and maximum hydropower, geothermal and even tidal resources are used alternative from natural gas.

Residential and Commercial

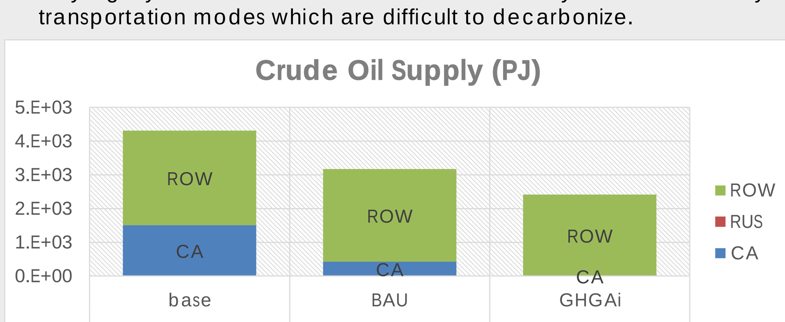
- BAU scenario shows very comparable energy consumption relative to 2010, except there is slight growth in residential natural gas, electricity and liquid petroleum gas consumption.
- GHG scenario has significant reductions in natural gas consumption, where commercial natural gas is reduced by half relative to 2010 and BAU 2050 levels and residential natural gas is half of 2010 levels and roughly a third of 2050 BAU scenario levels. There is also a large increase in residential solar, nearly equal to the energy consumption of natural gas in the GHGAi scenario.

Biofuel Supply

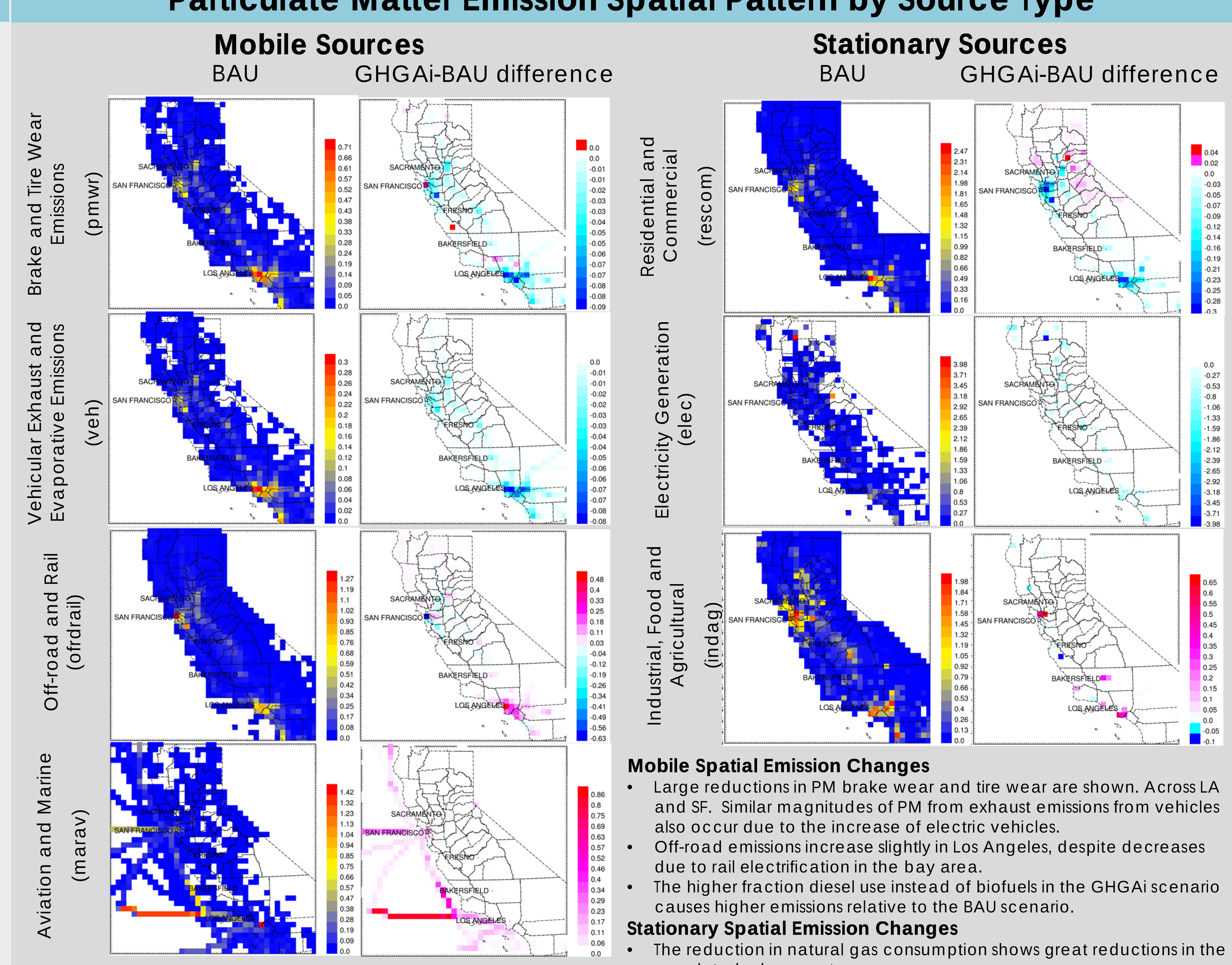
- BAU scenario shows biofuel inputs to increase by nearly 4 fold. Increase in Fischer-Tropsh Biomass to Liquid (FTBTL) as well as biodiesel from yellow grease (YGR) and animal tallow/fat (TAL) also increase. Pyrolysis oil from municipal solid waste and wood residue contributes to a fourth of the feedstock. Cellulosic ethanol is also produced but is small at about 10% of all feedstock.
- GHG scenario has biofuels increase by 2 fold in the GHGAi scenario. There is likely less biofuels produced in order to meet the carbon constraint with zero-emitting renewables. Biodiesel and FT diesel dominates the fuel produced in the GHGAi scenario. Nearly no ethanol nor pyrolysis oil is produced.

Petroleum Supply

- Petroleum supply from California is reduced in both scenarios and is essentially zero in the GHGAi scenario. Oil supply from Rest of World (ROW) remains to be a large share of crude oil supply, and declines only slightly in the GHGAi scenario. These are likely used in the heavy transportation modes which are difficult to decarbonize.



Particulate Matter Emission Spatial Pattern by Source Type



Other Emissions

- Natural emissions such as dust emissions and biogenic emissions were assumed to be the same for both the BAU and GHGAi scenarios and hence their difference is not shown here.

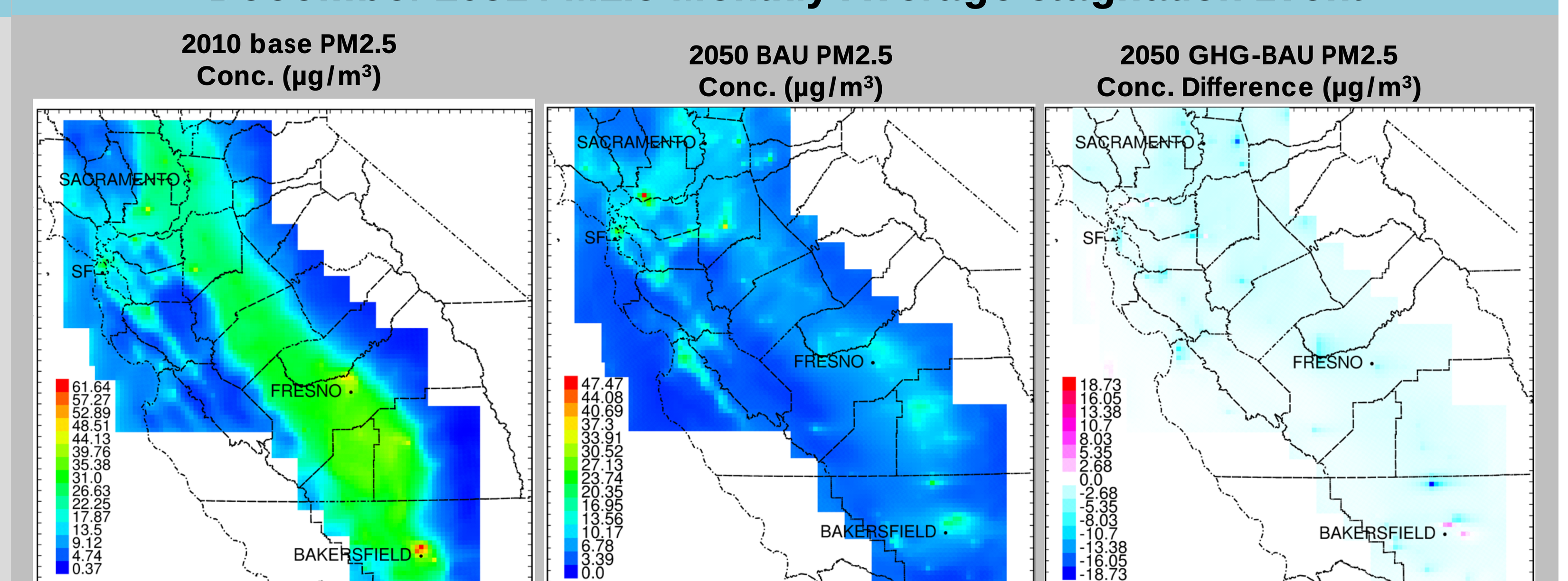
Mobile Spatial Emission Changes

- Large reductions in PM brake wear and tire wear are shown. Across LA and SF. Similar magnitudes of PM from exhaust emissions from vehicles also occur due to the increase of electric vehicles.
- Off-road emissions increase slightly in Los Angeles, despite decreases due to rail electrification in the bay area.
- The higher fraction diesel use instead of biofuels in the GHGAi scenario causes higher emissions relative to the BAU scenario.

Stationary Spatial Emission Changes

- The reduction in natural gas consumption shows great reductions in the populated urban centers.
- The increase in renewable zero-emitting solar and wind electricity generation substituting natural gas and biomass shows reductions in urban centers as well as northern forestry aeas.
- Reduction in petroleum but increases in hydrogen and biofuel production show a slight increase in industrial PM emissions. However, avoidance of dairy emissions for bio-natural gas in electric power plants show reductions in gases not shown here.

December 2051 PM2.5 Monthly Average Stagnation Event



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Conclusions

CA-TIMES Scenario Differences

- Meeting CO2 constraints in 2050 requires activity reduction as well as dramatic fuel/energy switching
- A more stringent CO2 constraint scenario indicates it is more cost effective to decarbonize stationary, lighter modes, or utilize the grid
  - Renewable electricity generation (solar, wind)
  - electric light duty vehicles (hydrogen)
  - Electric rail
- Biofuel production would need to increase to displace fossil fuels in the heavier transportation modes, but its consumption and production would be reduced with an 80% GHG target.

Criteria Pollutant Emissions

2050: GHGAi vs. BAU

- Emission reductions from vehicles and renewable electricity generation are offset by increases in non-road sources due to less biofuel consumption.

$PM_{2.5}$ and O_3 Concentrations

Ozone

- Ozone concentrations in summer stagnation events can drop substantially half, falling from 110-120ppb to 50-70ppb in both the SJV and SoCal basins for both BAU and GHGAi scenarios.
- Increases in ozone near ports and populated urban centers may be experienced if alternative fuel supply production is located here and if biofuels are less utilized.
- Major changes of regulatory, zero-emitting, low-carbon and activity reduction combined results in significant ozone reduction and ozone NAAQS appear to be in attainment for these historically problematic basins.

PM2.5

- PM2.5 is much lower, ranging from 10-20μg/m³ reduction in concentration throughout the central valley.

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