NextSTEPS (Sustainable Transportation Energy Pathways)

Modeling Optimal Transition Pathways to a Low Carbon Economy in California

Results from CA-TIMES v1.5 Energy System Model and Implications for Policymakers

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Research Seminar

California Air Resources Board

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CA-TIMES Model Goals

- The goal of CA-TIMES is to understand the role of ***technologies***, ***resources*** and ***policies*** for achieving deep reductions in California's energy system GHG emissions by 2050
  - ***Integrated*** model of entire energy system (demand and supply sectors)
  - Understand **cost** trade-offs between different uses of scarce resources
  - Scenario approach varying technology and resource costs and availability
  - Understand the impacts of policies and assumptions on energy resource mix, electricity and fuel supplies, and end-use technologies

CA-TIMES General Modeling Approach

- CA-TIMES is a bottom-up, technologically detailed energy and economic optimization model of California's energy sectors
  - System includes thousands of technologies and hundreds of time periods
  - The model makes technology investments and operations decisions
  - Minimizes total system cost of meeting energy service demands with perfect foresight
    - Scenarios with welfare maximization are examined (elastic demand (ED) scenarios)
  - Model California's energy system under 80% GHG reduction by 2050

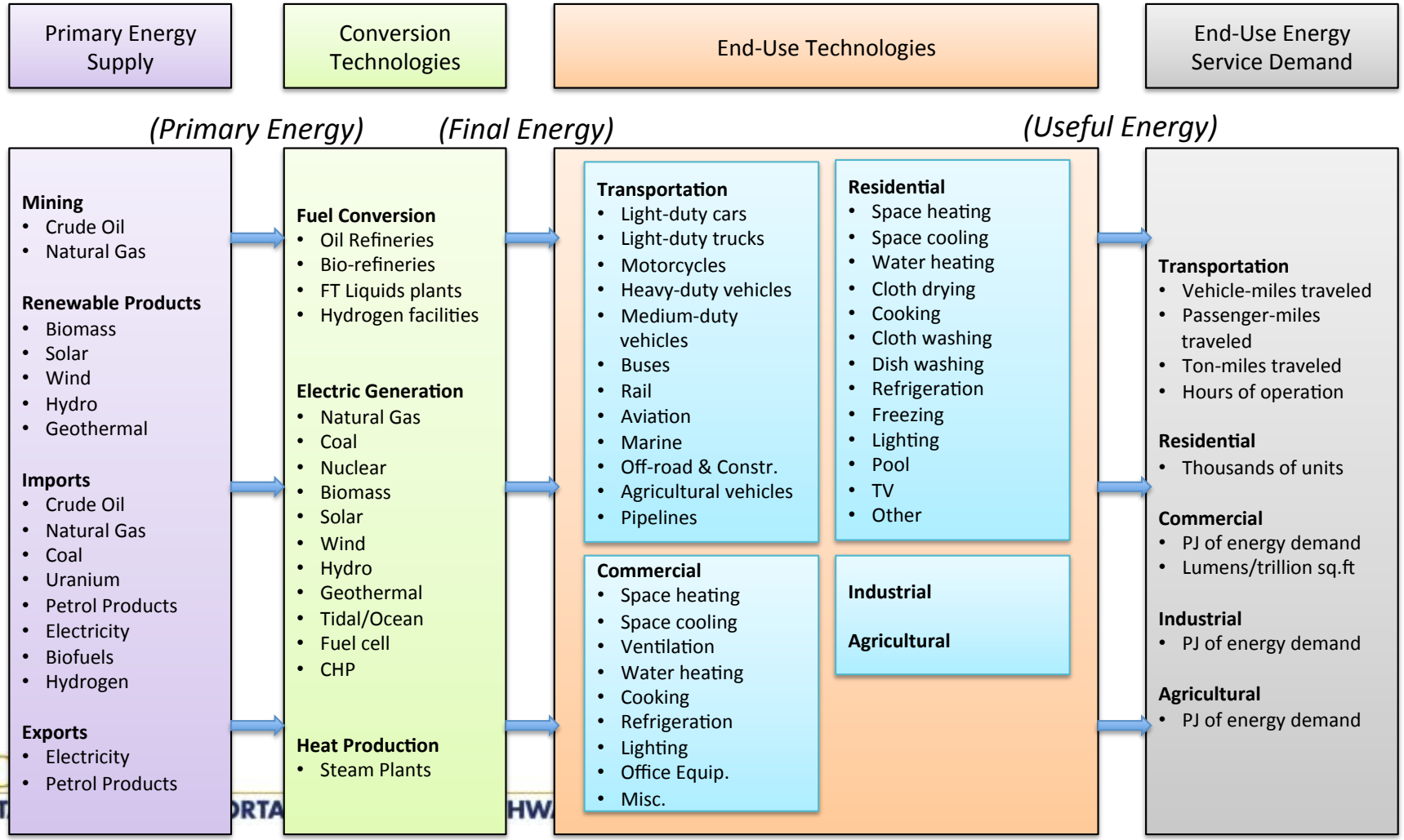
CA-TIMES is useful for answering many questions

- Current work
  - How does placing a limit (or cap) on GHG emissions influence the evolution of the energy system in terms of technology adoption and system costs?
  - What is the incremental cost (or savings) of GHG mitigation?
  - How do policies and the availability of technologies and resources influence the mitigation strategies and costs?
- Potential future work
  - How do policies interact with one another? What are the integrated effects (costs/benefits) of policies or possible tradeoffs?
  - What are the effects of technology forcing policies on mitigation costs and emissions (endogenous learning)?
  - How can policy incentives/investments affect consumer choices in alternative fuels/technologies?
  - What's the role of demand reduction? How does demand reduction interact with the other policies/mitigation options?
  - How does the presence or absence of GHG policies outside of California affect California GHG emissions and costs?

CA-TIMES v1.5 Model Scope

Representation of entire California Energy System

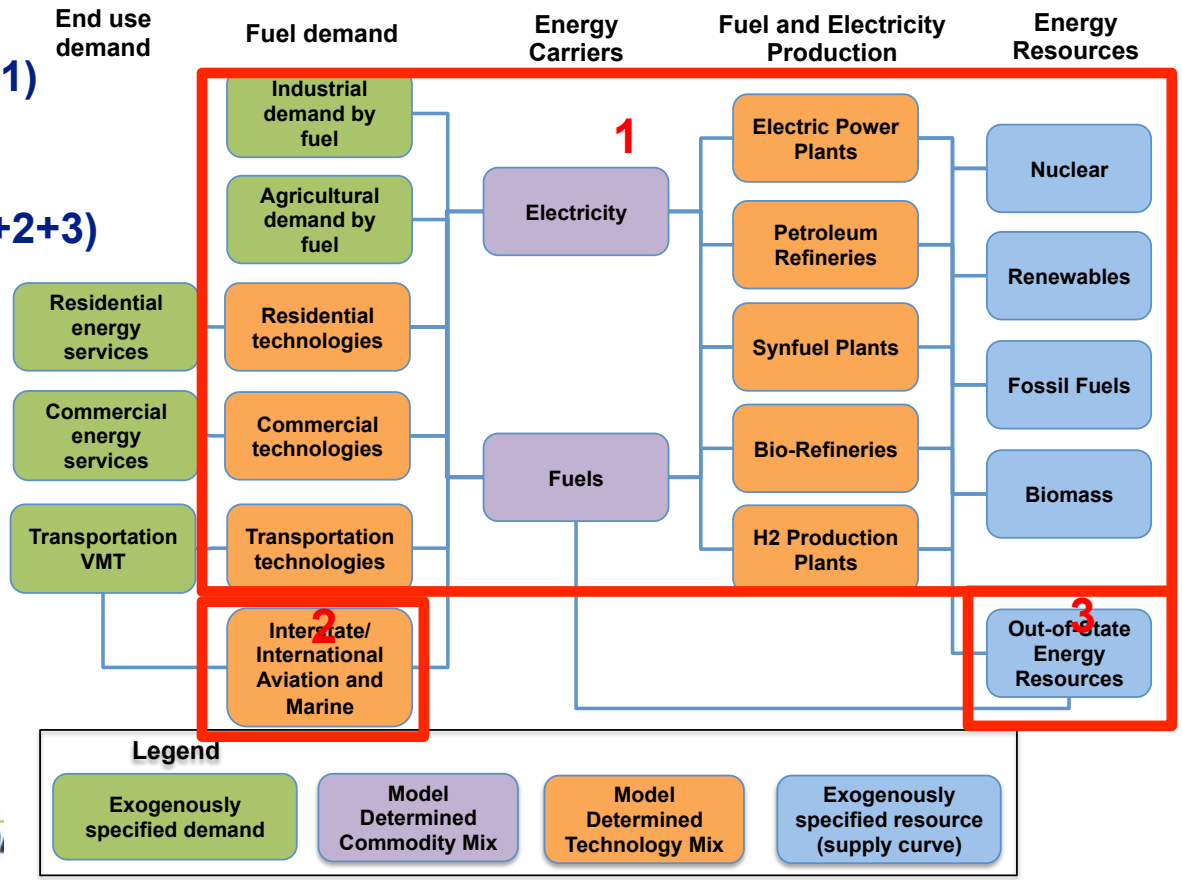
Reference Energy System (RES)



Examine Emissions Across Three System Boundaries

- We only account for ***energy-related*** GHG emissions
  - Ignore cement and other industrial processes, ag and waste emissions as well as natural sources and sinks
  - CARB's 1990: 427 MMT vs CA-TIMES 391 MMT (difference 36 MMT)

- **Capped instate emissions (1)**
- **Capped + Other instate emissions (1+2)**
- **Life-cycle CA emissions (1+2+3)**



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Two BAUs, Two GHG Caps, and Nine Sensitivity Analyses

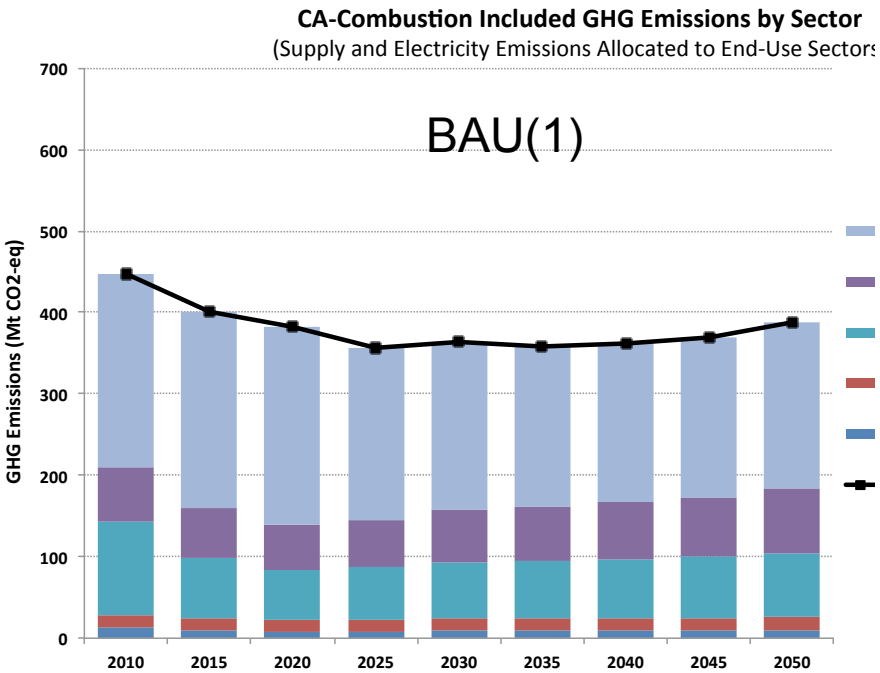
- *BAU* – Existing policies, including CAFE, LCFS, ZEV, RPS
  - Light-duty VMT grows slightly per capita (9% from 2010 to 2050)

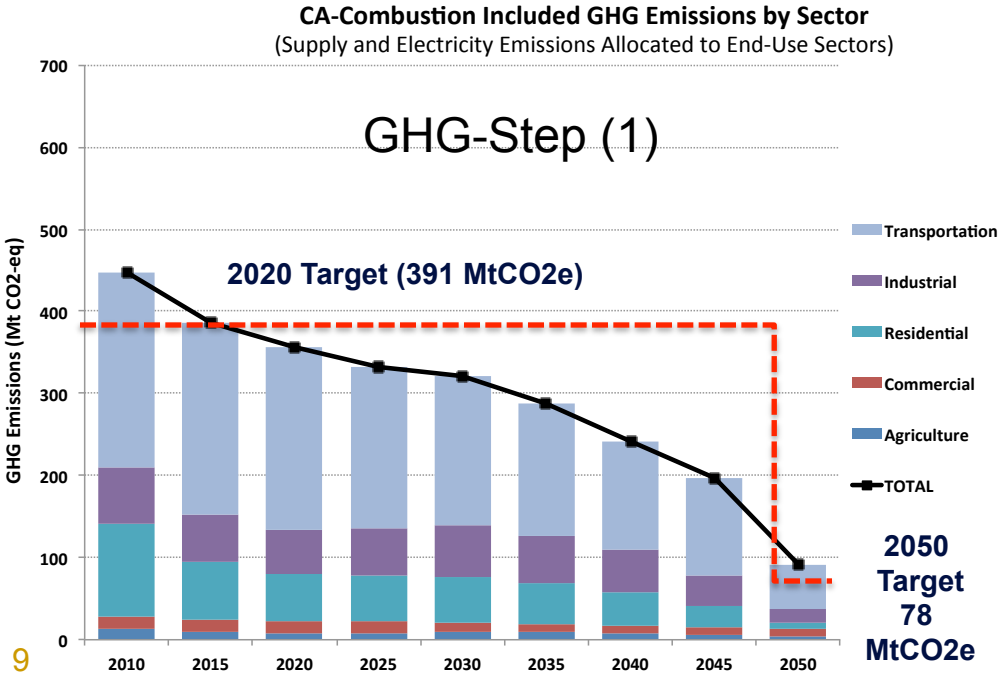
- *BAU-LoVMT* – Same as BAU but with lower VMT
  - 24% lower LDV VMT than BAU (17% reduction/capita from 2010-2050)
  - 10% lower MD and HD truck VMT than BAU
  - **Cost/benefits of VMT reductions are not quantified** (infrastructure, smart growth, health and quality of life are not included in the cost calculations)

- GHG scenarios – Includes 80% GHG emissions reduction cap in 2050 and low VMT assumptions (same as *BAU-LoVMT*)

CA-TIMES Modeling Results – GHG emissions

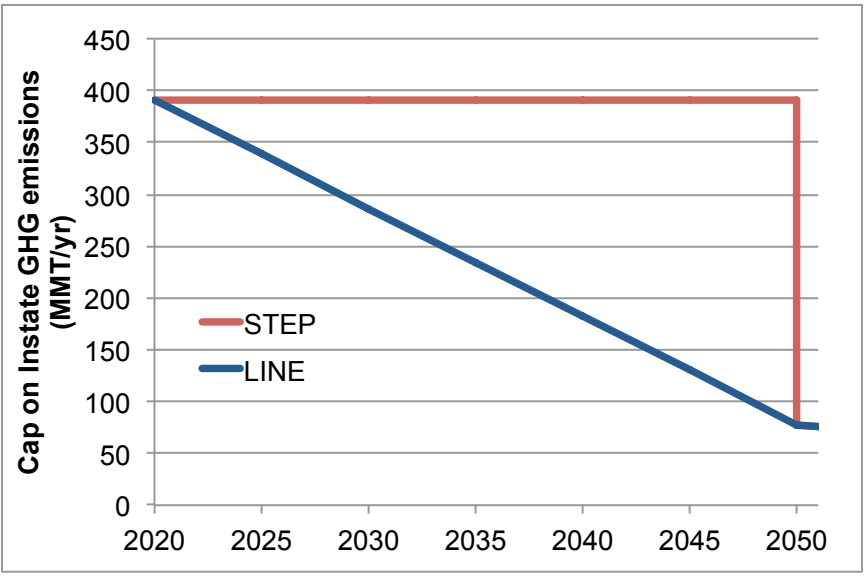
- GHG emissions in *BAU* and Primary GHG scenario (*GHG-Step*)
- *GHG-Step* scenario achieves **75%** GHG reduction
  - CCS and nuclear power are not available in this scenario
  - Ignores out-of-state aviation and marine travel and excludes offsets
  - Significant emissions reduction across all sectors (44 to 81% reduction)
  - Transportation continues to contribute majority of emissions

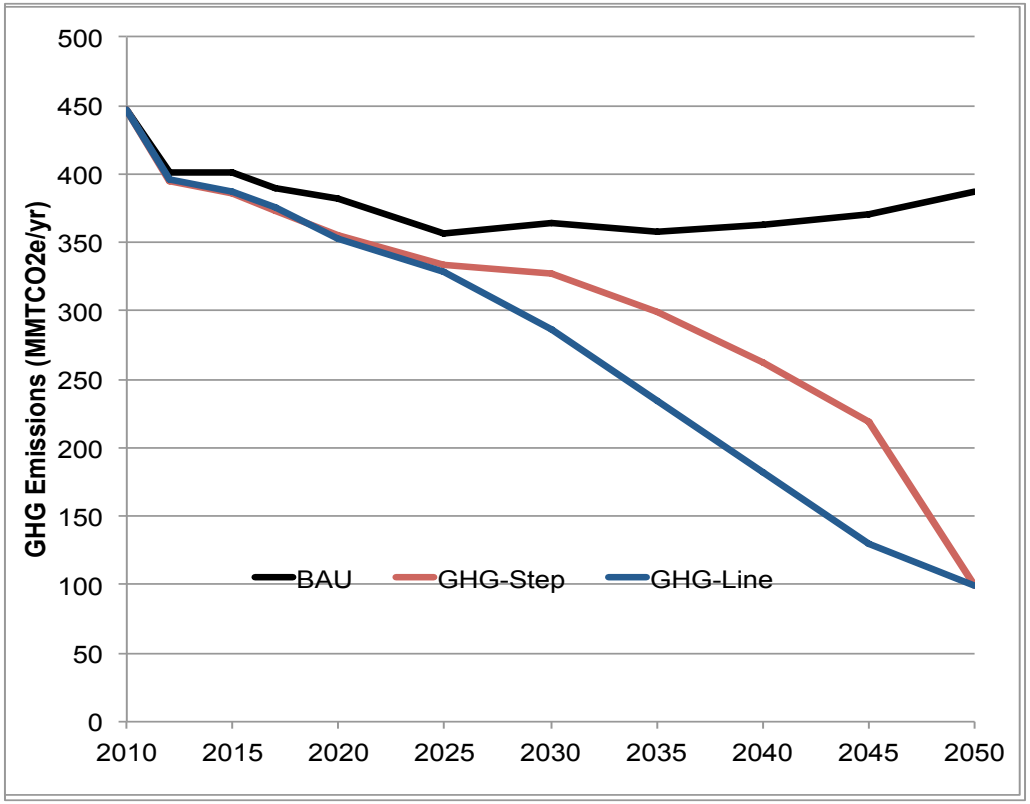




GHG Targets and Emissions Under & Outside the Caps

- A linear cap is more stringent between 2020-2050 than "Step" cap
- *GHG-Line* makes earlier investments in low-carbon technologies and resources (at higher cost)
- Same level in 2050, but different cumulative emissions (2010-2050)
- Included vs Overall emissions

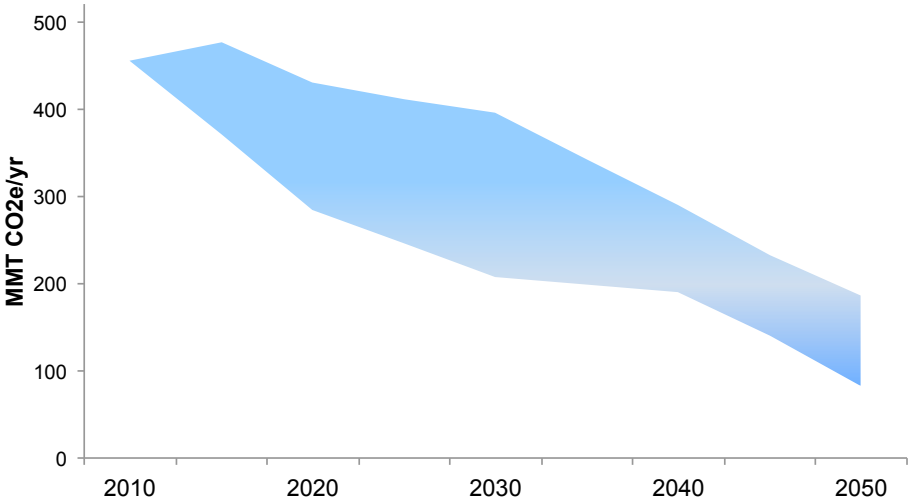




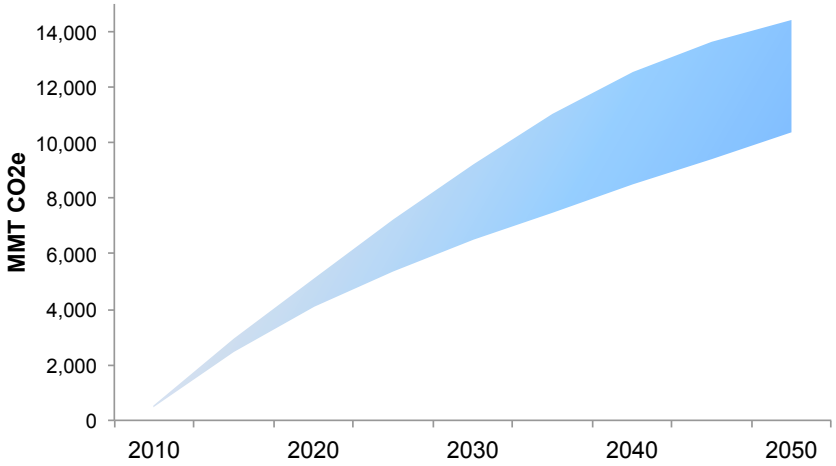
California Climate Policy Modeling (CCPM) Comparison

	ARB-VISION	BEAR	CA-TIMES	GHGIS	LEAP-SWITCH	PATHWAYS
Development						
Modeling team(s)	CARB	UC Berkeley	UC Davis	LBL/ARB	LBL, UCB	E3/LBL
Software	Excel	GAMS	GAMS	Excel	AMPL	Excel
Structure						
Sectors modeled	Transportation	All	All	All	All	All
Solution algorithm	Fleet turnover / spreadsheet	General Equilibrium	Optimization or Partial Equilibrium	Scenario-based	Spreadsheet (LEAP) + Optim. (SWITCH)	Backcasting
Forecast period	2000-2050	2005-2080	2010-2055	2010-2050	2010-2050	2008-2050

Annual Emissions



Cumulative Emissions



Scenarios that Achieve Deep GHG Emission Reductions by 2050

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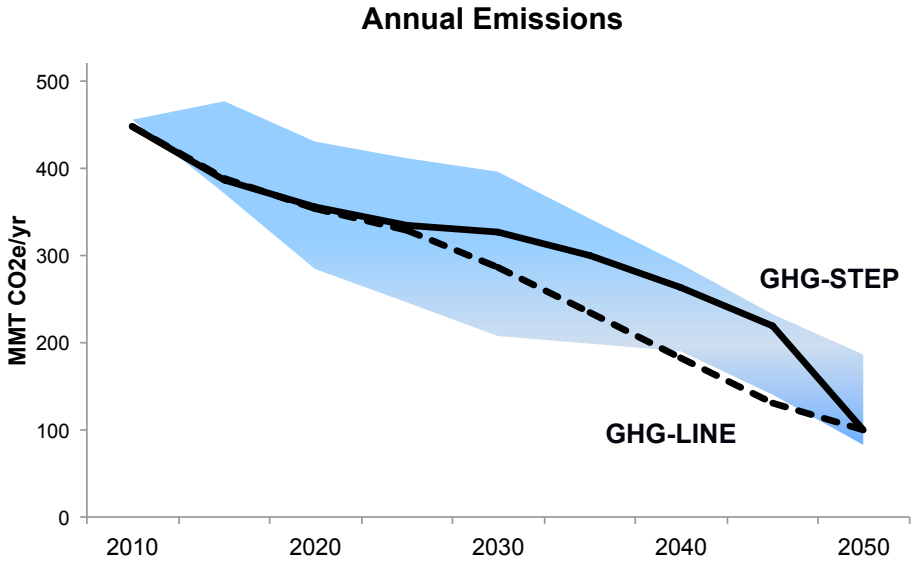
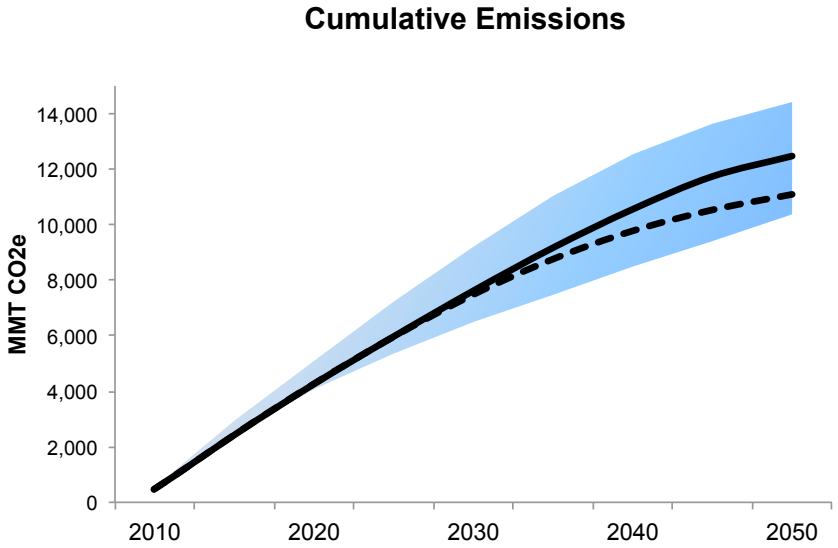
http://policyinstitute.ucdavis.edu/initiatives/ccpm/

California Climate Policy Modeling (CCPM) Comparison

- CA-TIMES is one of the few economic models that integrate across all sectors
- Optimized solution with a 2050 cap (*GHG-Step*) favors later reductions
  - 4% discount rate
  - CA-TIME v1.5 does not include learning-by-doing in which early investment can lead to more cost reductions





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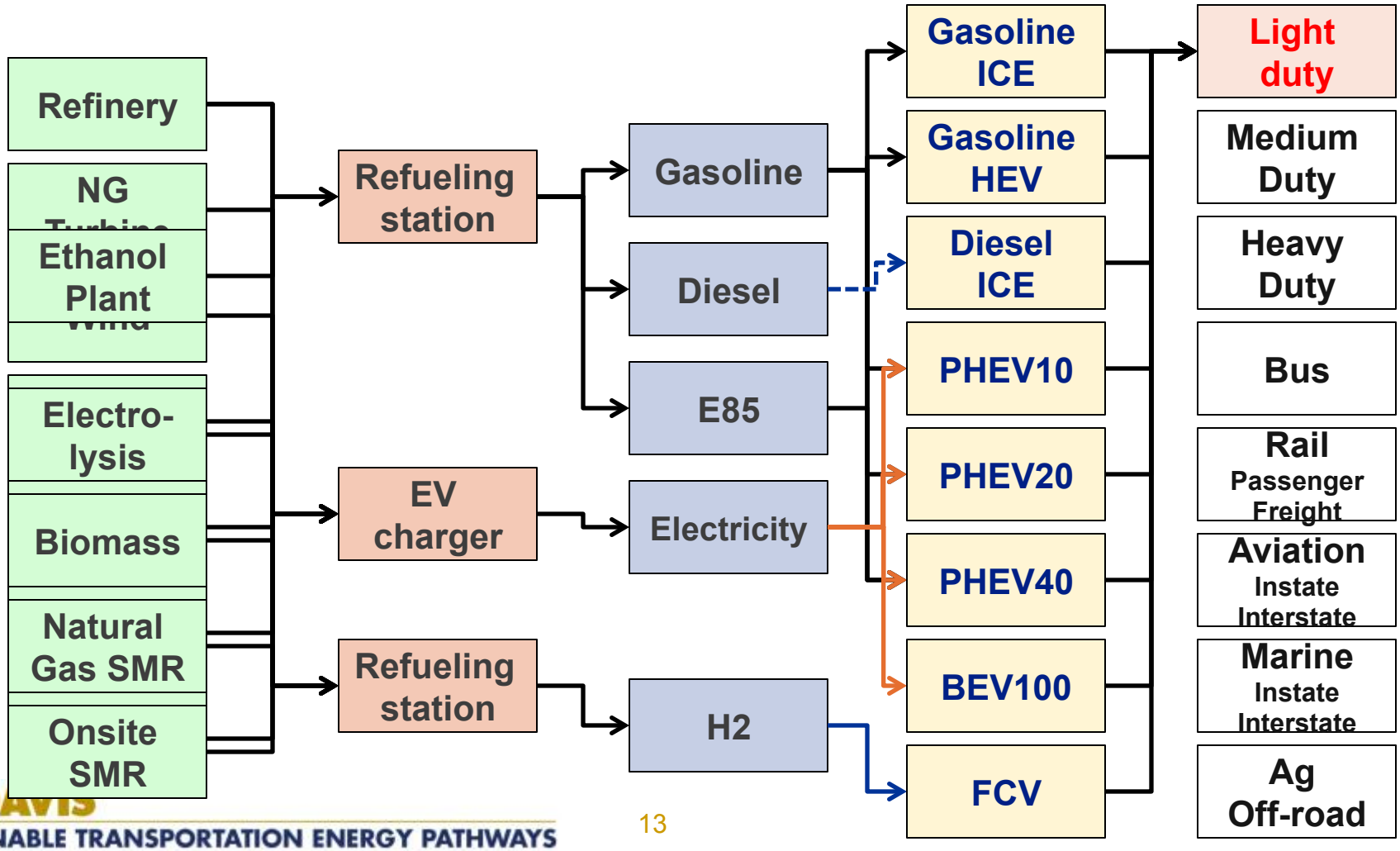
* CA-TIMES emissions do not include non-energy emissions

Transportation Sector Energy System

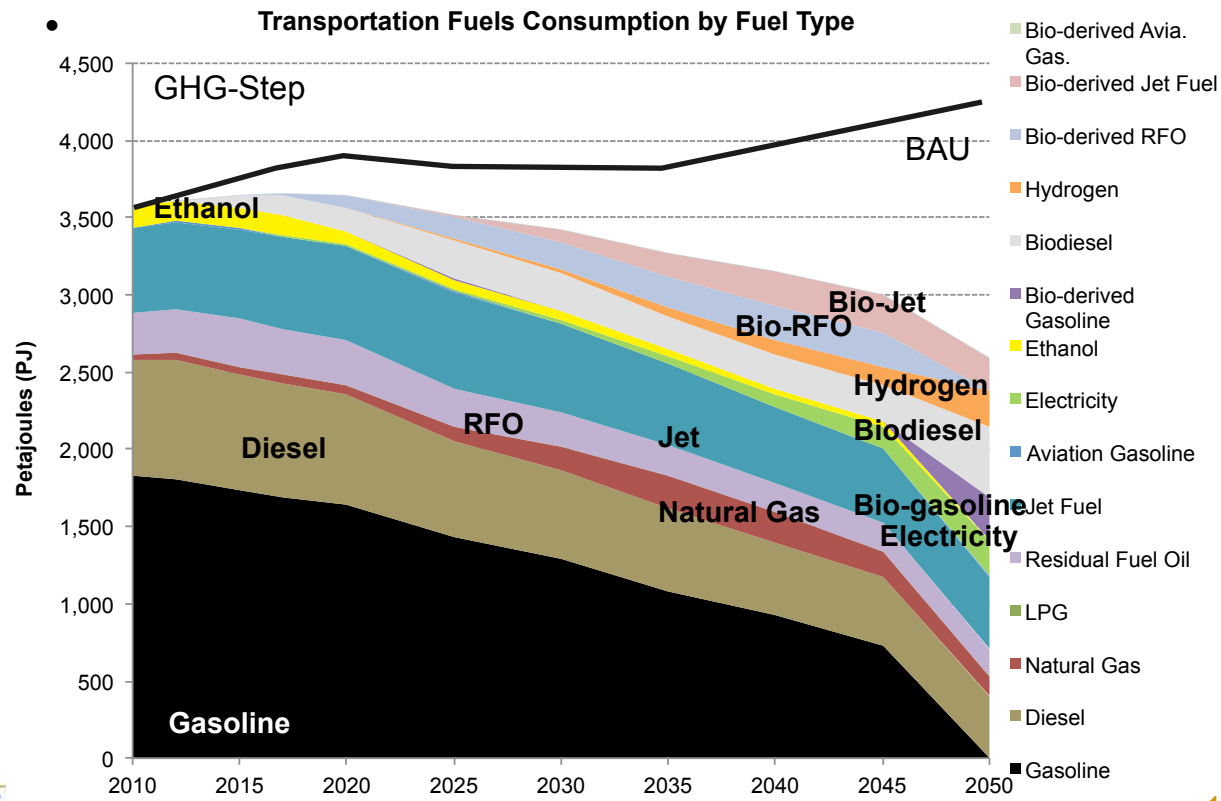
- Transportation is driven by exogenously specified demand for vehicle miles, ton-miles in different sectors



Total Transport Fuel Use – *GHG-Step* Scenario

- Decrease in petroleum and increase in biofuels, hydrogen and electricity
- Difficulty in electrifying most transport sectors
- Liquid fuels requirements and limited biofuels availability (7.3 billion GGE) makes it hard to fully decarbonize sector
- Includes fuels for interstate/international aviation and marine

Fuel	2010 share (%)	2050 share (%)
Petroleum	95%	41%
Electricity	<0.1%	9%
Hydrogen	0%	9%
Biofuels	5%	37%
Natural gas	0%	5%



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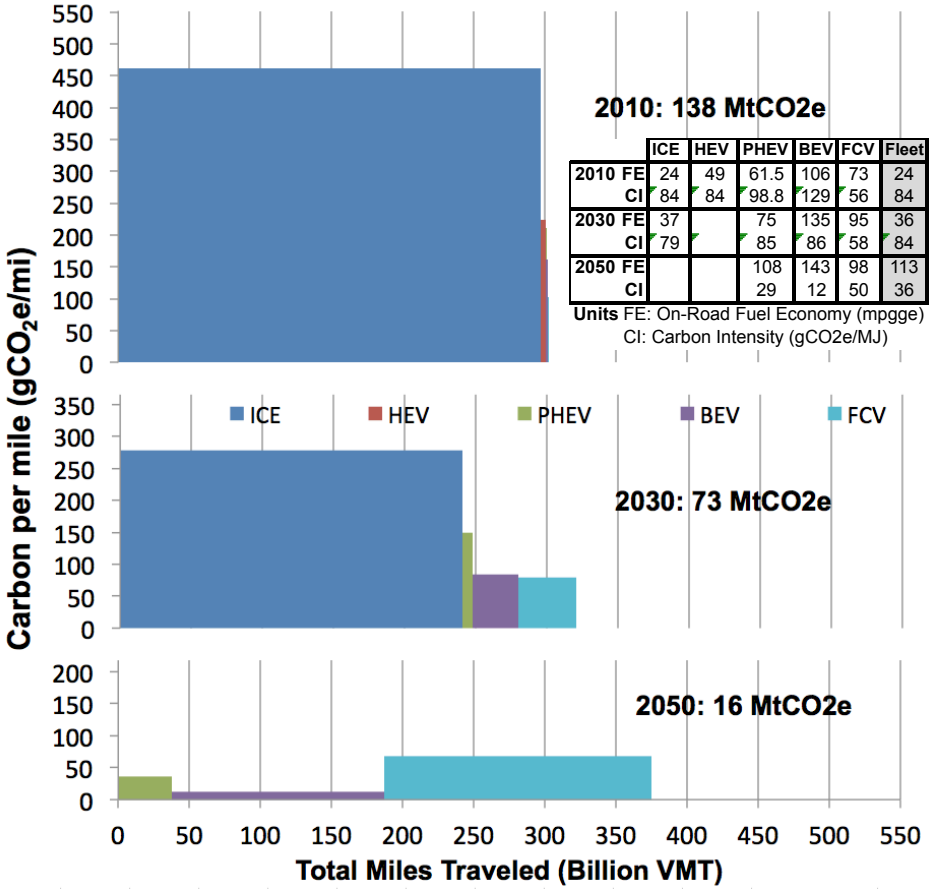
Light-Duty Vehicles – *GHG-Step* Scenario

- Light-duty vehicles exhibit significant electrification to primarily battery electric and H2 fuel cell vehicles
  - Small contribution from PHEVs in 2050
  - On-road fuel economy climbs to over 110 mpgge in 2050
  - LDV fuel demand decreases by 77% (2010 to 2050)
  - Liquid fuel demand decreases from ~15 BGGE to 0.3 BGGE
  - H_2: 1.9 BGGE
  - Elec: 1.1 BGGE

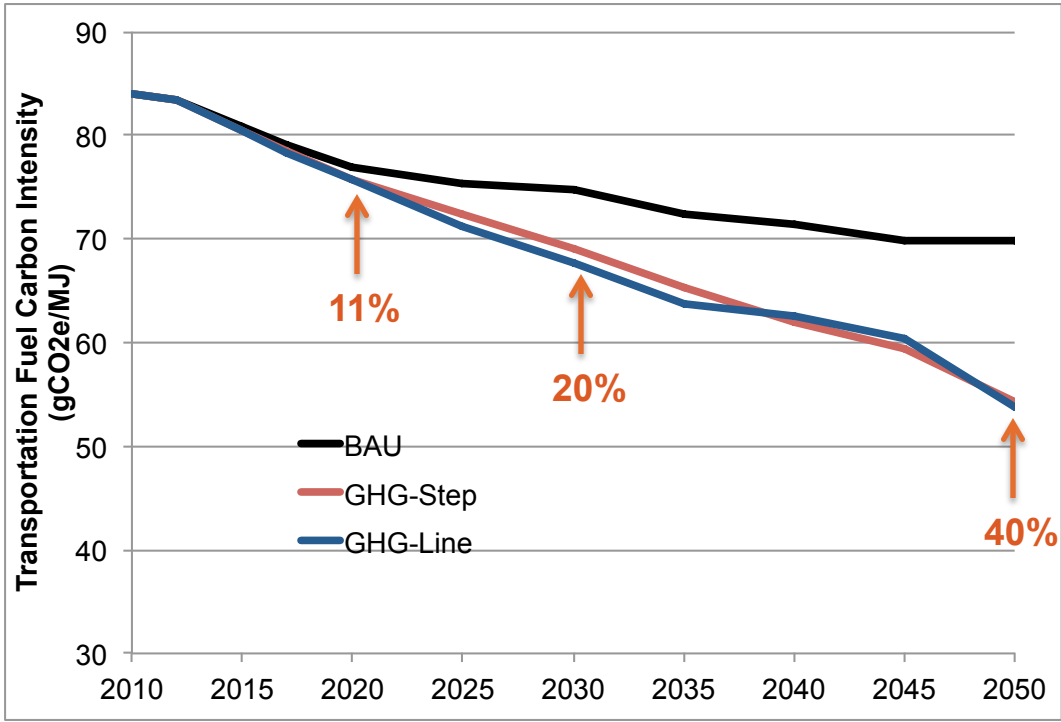


	ICE	HEV	PHEV	BEV	FCV	Fleet
2010 FE	24	49	61.5	106	73	24
CI	84	84	98.8	129	56	84
2030 FE	37		75	135	95	36
CI	79		85	86	58	84
2050 FE			108	143	98	113
CI			29	12	50	36

Units FE: On-Road Fuel Economy (mpgge)
CI: Carbon Intensity (gCO2e/MJ)

Transportation Carbon Intensity (CI) Declines 40% by 2050

- Average transportation fuel CI (gCO2e/MJ (**HHV**)) declines 40% by 2050 (~60% reduction for instate fuels)
  - Electricity: 12 g/MJ*
  - Hydrogen: 50 g/MJ*
  - Biofuel: 9 g/MJ
  - Shift high-carbon fuels (petroleum) to uncapped emissions



* (FT process for drop in fuels has char sequestration (not CCS) which lowers CI (20-30% of carbon in final fuel is sequestered)

** CI values WTW but not fully lifecycled; do not include the efficiency multipliers (EER) of the LCFS for electricity and hydrogen (CIs and EERs are fully endogenized based on scenarios)

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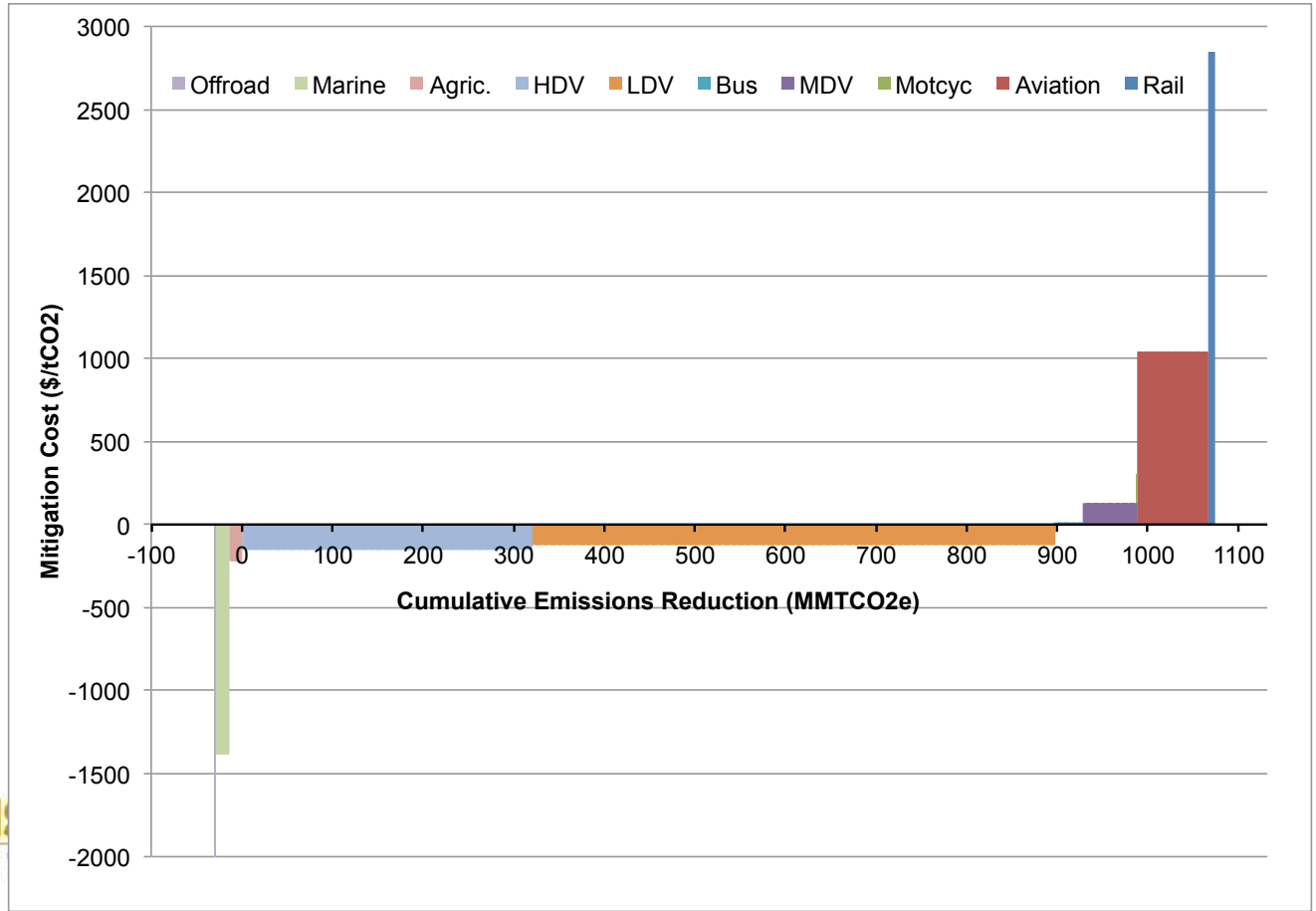
Transportation Mitigation Cost Curves

- Cumulative mitigation cost ($ spent on emissions reduction per unit of emissions reduced relative to *BAU-LoVMT* scenario)
  - Relative to optimized baseline which already includes significant transportation efficiency improvements



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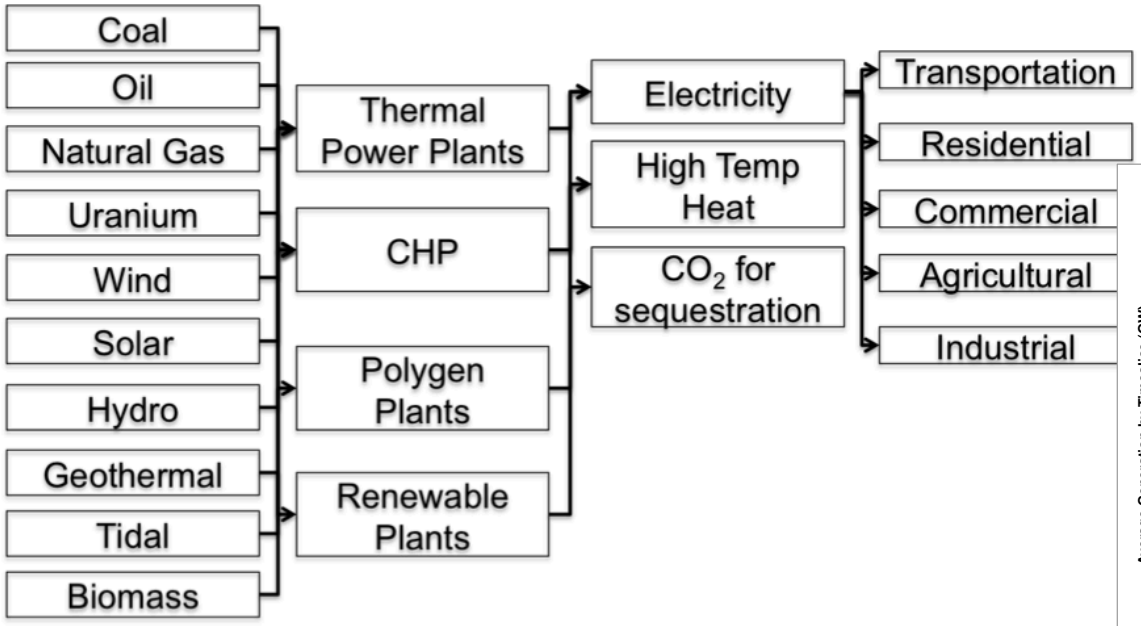
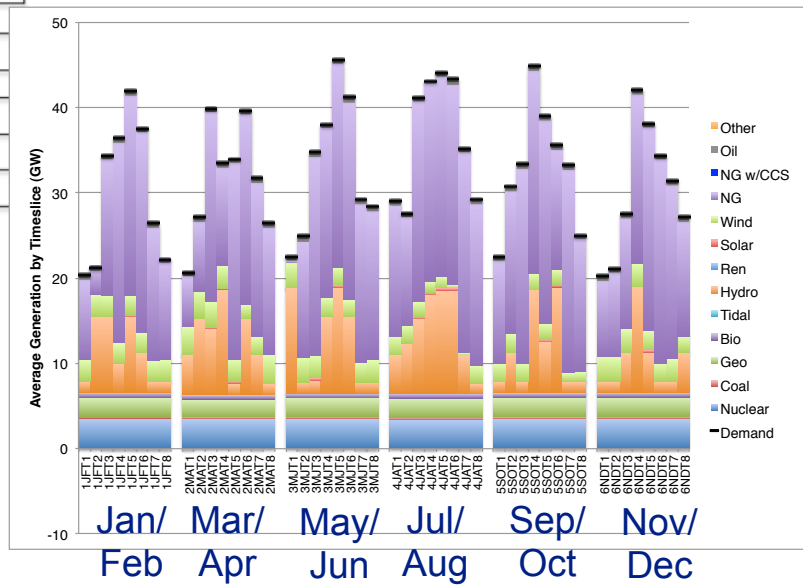
Electricity Generation and Supply

- Simplified electricity sector
  - Electricity demand is treated like one node
  - Imports are phased out after 2025, all generation is built for CA demand
  - Electricity demand is endogenously determined within model
- Regional solar and wind resources ensures generation diversity
  - CREZ groups with transmission costs



48 timeslices represented

2012 Generation



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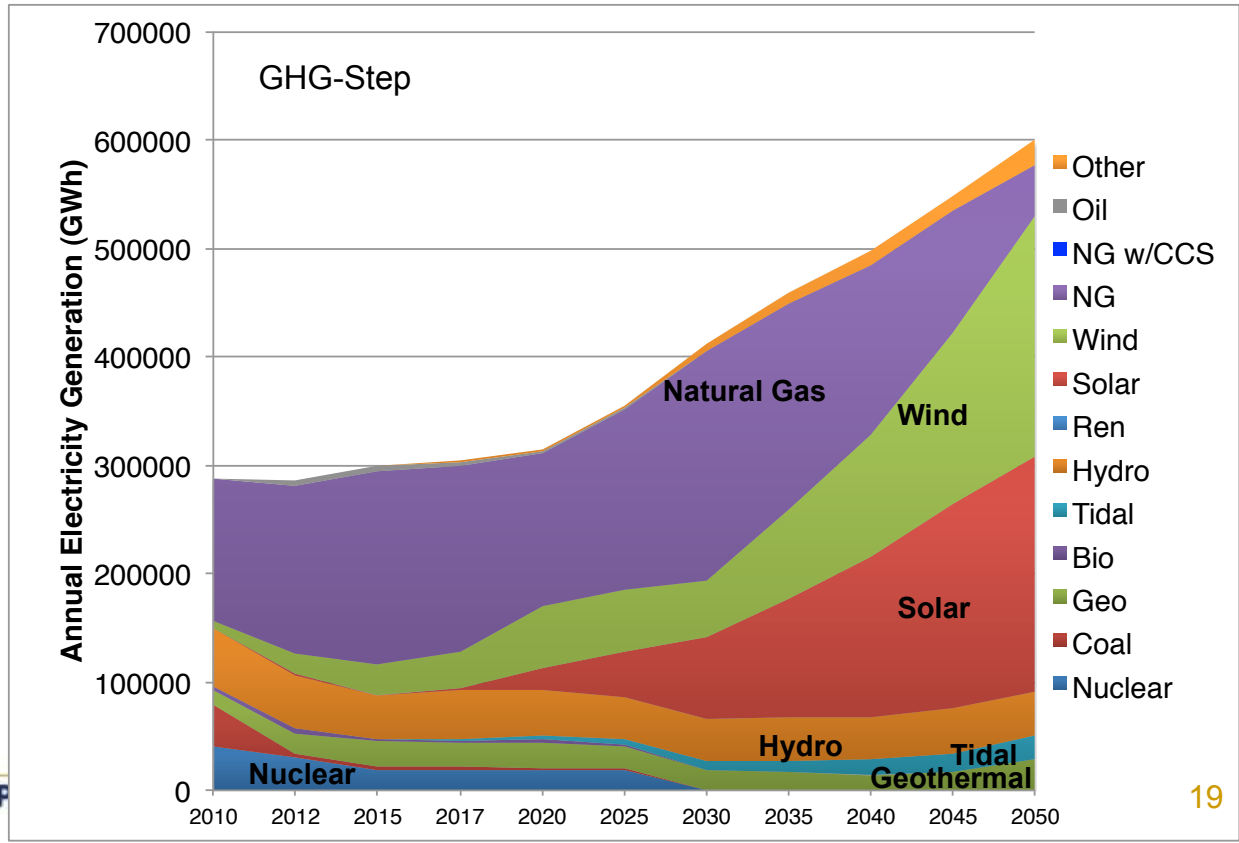
Electricity Supply More Than Doubles in the GHG Scenarios

- Electricity demand increases significantly due to electrification of end-use demands (residential, commercial, industrial, transport)
  - 2010 demand: 290 TWh, 2050 demand (BAU: 407, GHG-Step: 600 TWh)
- *Without nuclear or CCS* in primary scenario, renewable electricity sources are needed to decarbonize electricity generation
  - Wind: 221 TWh
  - Solar: 217 TWh
  - Geothermal: 28 TWh
  - Tidal: 22 TWh
  - No biomass gen
- Natural gas: 48 TWh
  8% of gen
  - NG is marginal generator
- RPS renewables
  ~80% in 2050



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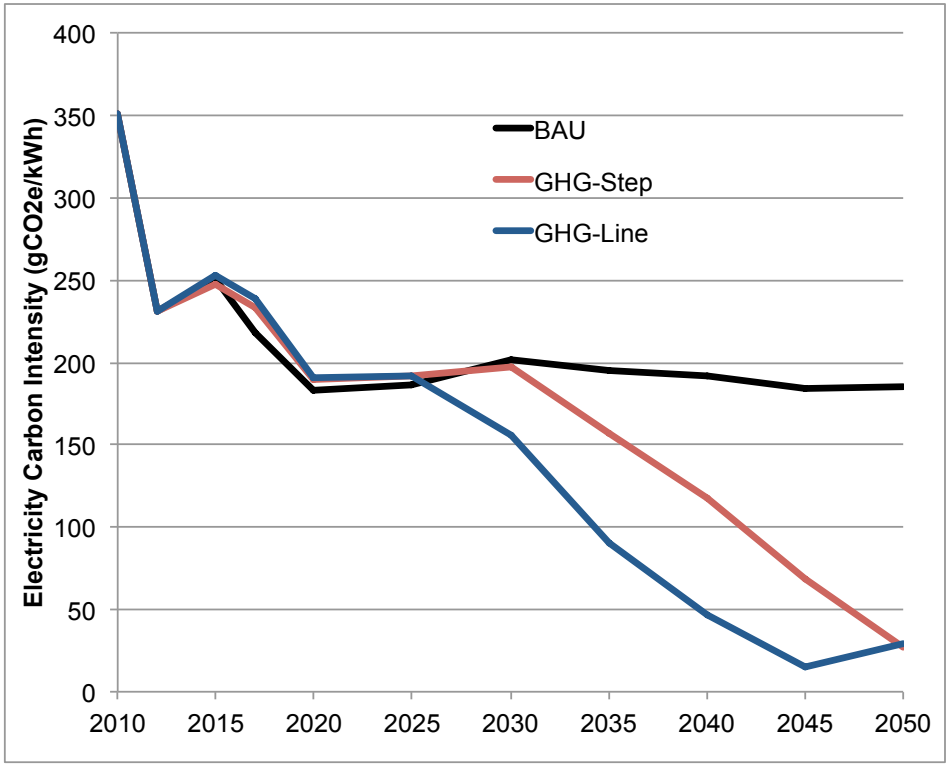
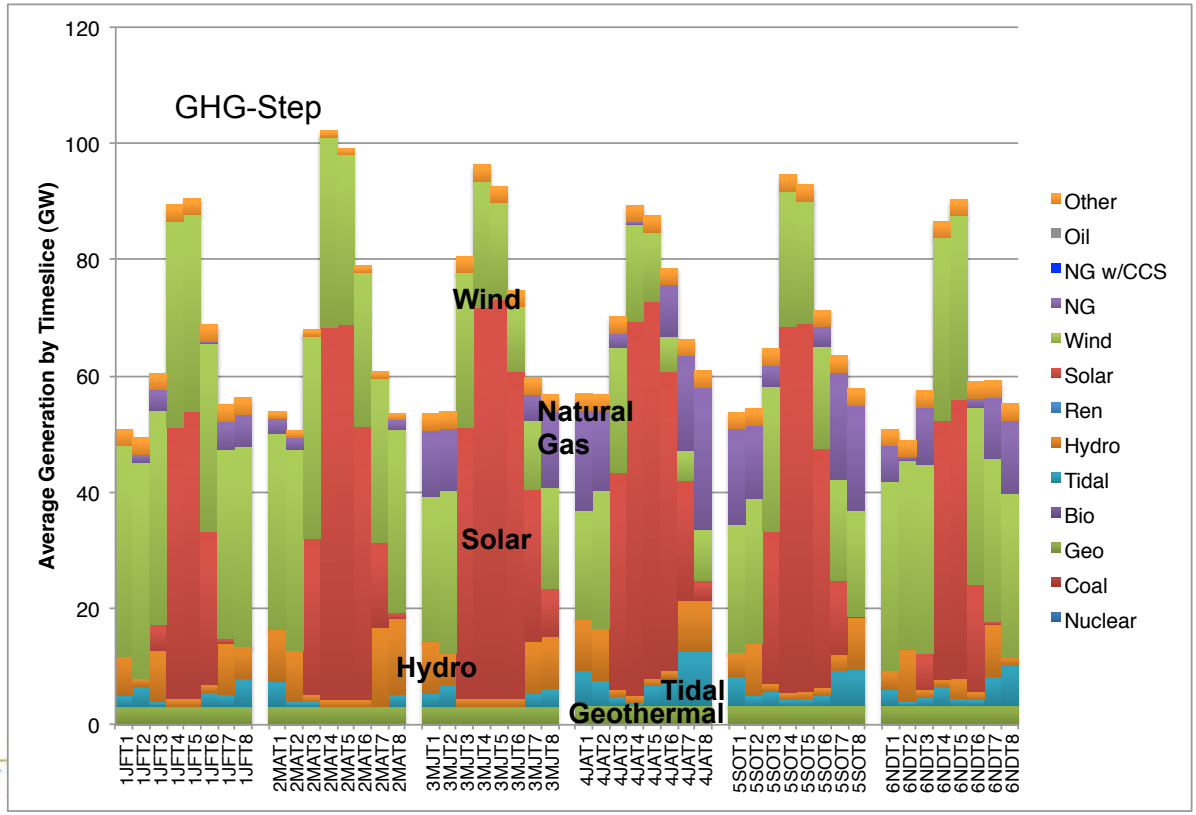
Electricity Carbon Intensity Reduced by More than 90%

- CI declines to under 30 g/kWh in 2050
  - GHG-Line earlier investment in efficiency and renewables reduces CI
  - Same level of demand and generation in 2050
- Slight increase in electricity CI in GHG scenarios relative to BAU scenario 2017 to 2025.
  - Related to the increase in total electricity demand. Same quantity of low carbon generation, so greater demand means more natural gas.



Balancing Electricity Supply and Demand

- As intermittent renewables grow to greater proportion of the generation mix, balancing demands is critical for system operation
- Natural gas and hydro are flexible, dispatchable generators
- Generation can exceed demand during some model timeslices (annual excess generation ~3-5%)



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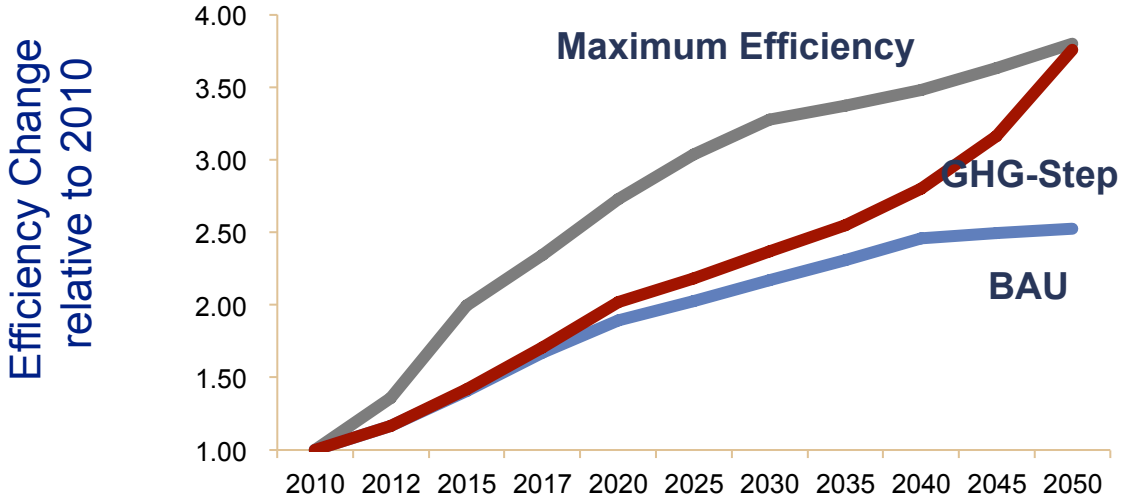
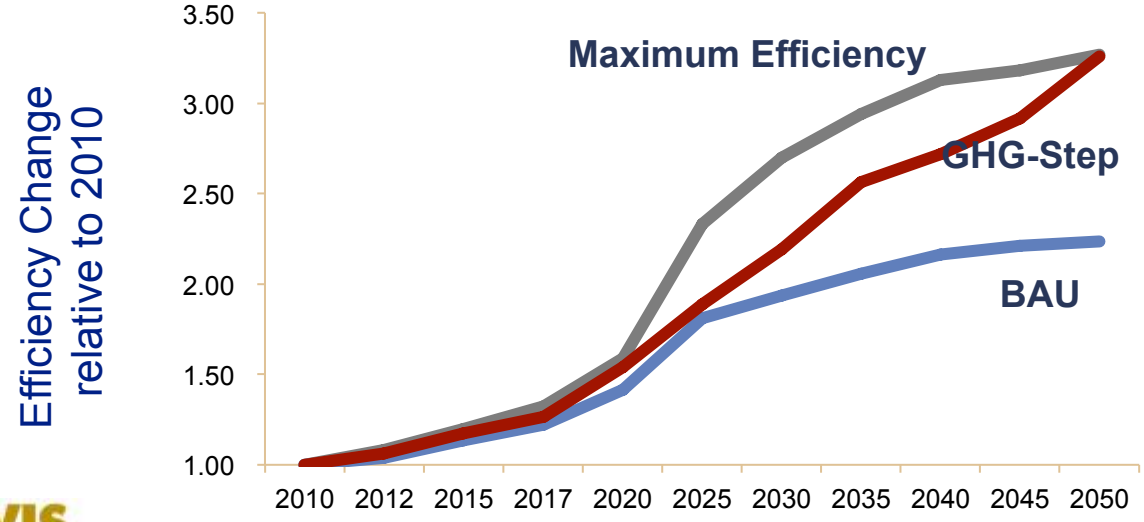
Efficiency Improvements in End Use Sectors



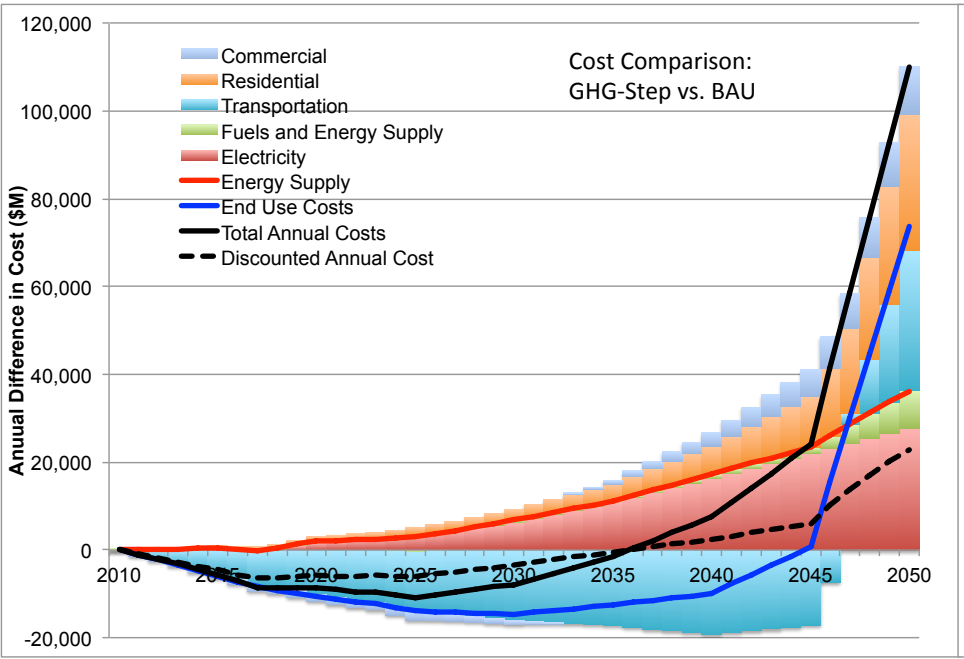
Residential

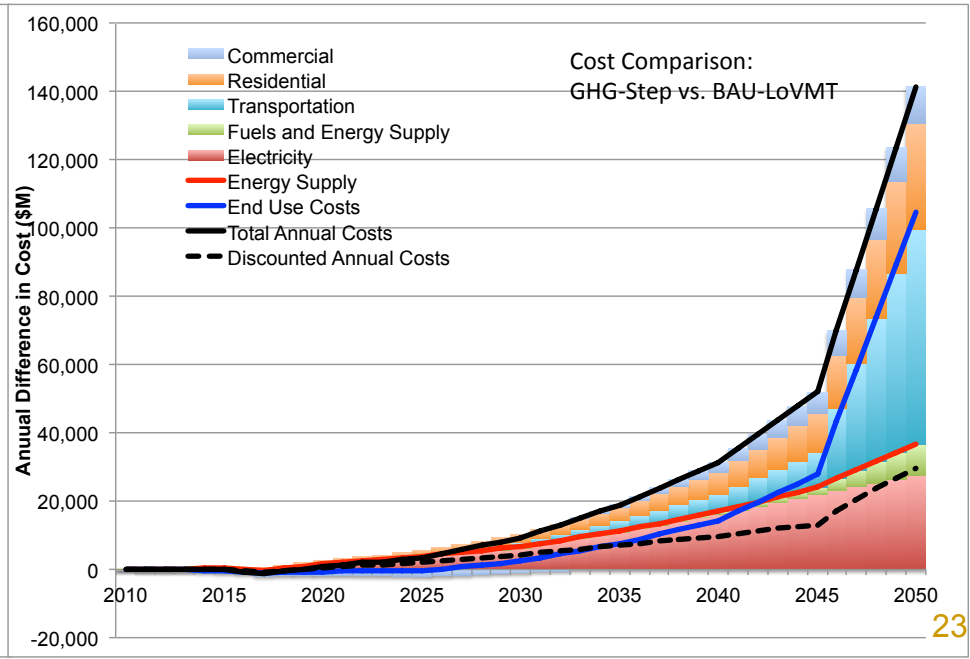


Commercial

GHG Scenario Costs (relative to *BAU* and *BAU-LoVMT*)

- The incremental cost of the GHG scenario is calculated as the difference in annual cost between the *GHG-Step* scenario and *BAU* scenarios
  - Two different BAU scenarios (*BAU* and BAU-*LoVMT*)
    - GHG-Step has same VMT demand as BAU-LoVMT and lower than BAU
    - Transport costs are mostly negative compared to BAU because lower VMT means fewer vehicle and fuel purchases (even if they are more expensive)
  - Cost differences rise over time as more expensive, efficient, low-carbon technologies are adopted
  - Costs of industrial/ag sectors mitigation not modeled





Key Results from Scenario Variations

- Availability of CCS technology has the largest impact on the results
  - Used in electric sector and for negative emission biofuels (bioCCS)
  - Can use more natural gas and biomass provides offsets
- Other low carbon electricity scenarios (Nuclear and High Ren.)
  - Further lower electricity CI and increase quantity
- Higher biomass supply increases supply of biofuels
  - Enables greater reductions from transport sector
- Elasticity scenarios reduce emissions via demand reduction
  - Reduction in electricity (~10-14%) and fuels (5%) demand
  - Reductions mean that limited renewables and biofuels can make up greater proportion of electricity/fuel mix lowering average CI

Mitigation Costs by Scenario

- Cost of emissions reduction
  - Depends on which BAU comparison is made (BAU or BAU-LoVMT)
  - Is cost of elastic demand reductions (loss of consumer utility) included?
- Average cost of cumulative emissions reduction ($/tonneCO2e)

Mitigation Cost vs BAU-LoVMT

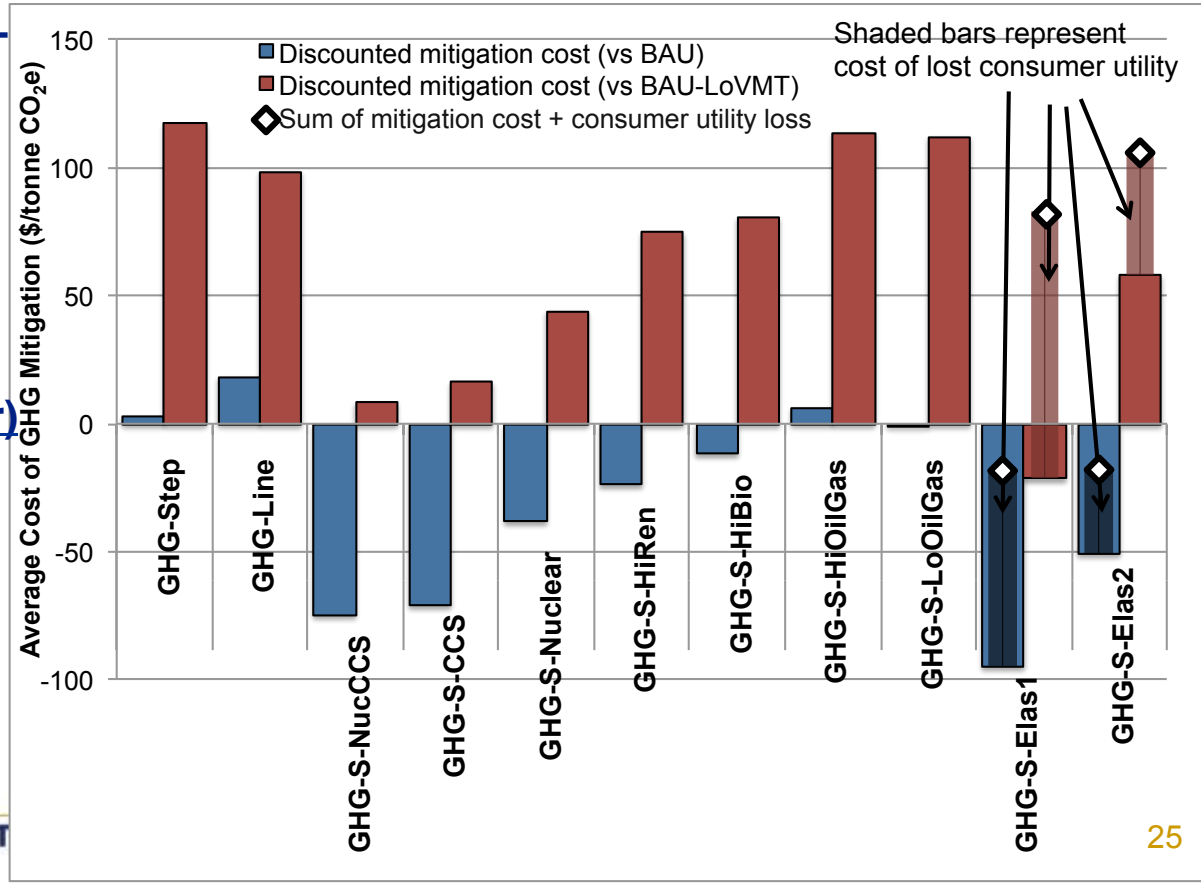
$20 to 332 billion (4% disc.)

per resident per yr

$9 to $177/person/yr (4% disc.)

% of 2010-2050 GSP (@3.3%/yr)

0.03% to 0.49% (4% disc.)



Other CA-TIMES Models

- These models are too complex to be fully integrated with core model at this point:
  - Consumer Choice for Light Duty Vehicles (COCHIN)
    - Kalai Ramea, David Bunch
    - Introducing non-monetary factors and consumer heterogeneity into the optimization decision-making framework of TIMES, based upon consumer choice modeling work from Z. Lin and D. Greene at Oak Ridge Lab
  - Air Quality Modeling of Future Energy Systems in California
    - Christina Zapata, Mike Kleeman
    - Using detailed, spatial air quality models to assess the criteria pollutant and health impacts of future, low-carbon scenarios
  - Hydrogen Infrastructure Deployment
    - Christopher Yang, Joan Ogden
    - Tracks evolution of California hydrogen infrastructure with disaggregated demands by region under different scenarios
  - Water Use in Future Energy Systems
    - Jacob Teter, Kate Tiedeman, Gouri Shankar Mishra, Sonia Yeh
    - Assessment of the water use impacts of future, low-carbon energy systems in 2030

Key Conclusions

- Carbon intensity of electricity reduced by 90% by 2050
  - Renewables produce 60 to 85% of total generation in GHG scenarios, requiring large investments and fast ramp up
  - 70 to 100 GW capacity of wind and solar each must be installed by 2050
- Carbon intensity of transportation fuels decreased by 40% by 2050; on-road LD fuel economy climbs to over 110 mpgge in 2050
  - Low-carbon biofuels are critical for decarbonizing non-LDV modes of transportation given limitations on electrifying transport
- Electricity demands grow by 80-140% under GHG scenarios from greater electrification of all end use sectors
- Carbon reduction costs range -$75 to $124/tonne CO_2 (4% discount).
  - Availability of CCS, nuclear, and renewables, and demand reduction all serve to lower the mitigation costs.

Thank you!

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