California TIMES (CA-TIMES) Model: Modeling Optimal Transition Pathways to a Low Carbon Economy in California

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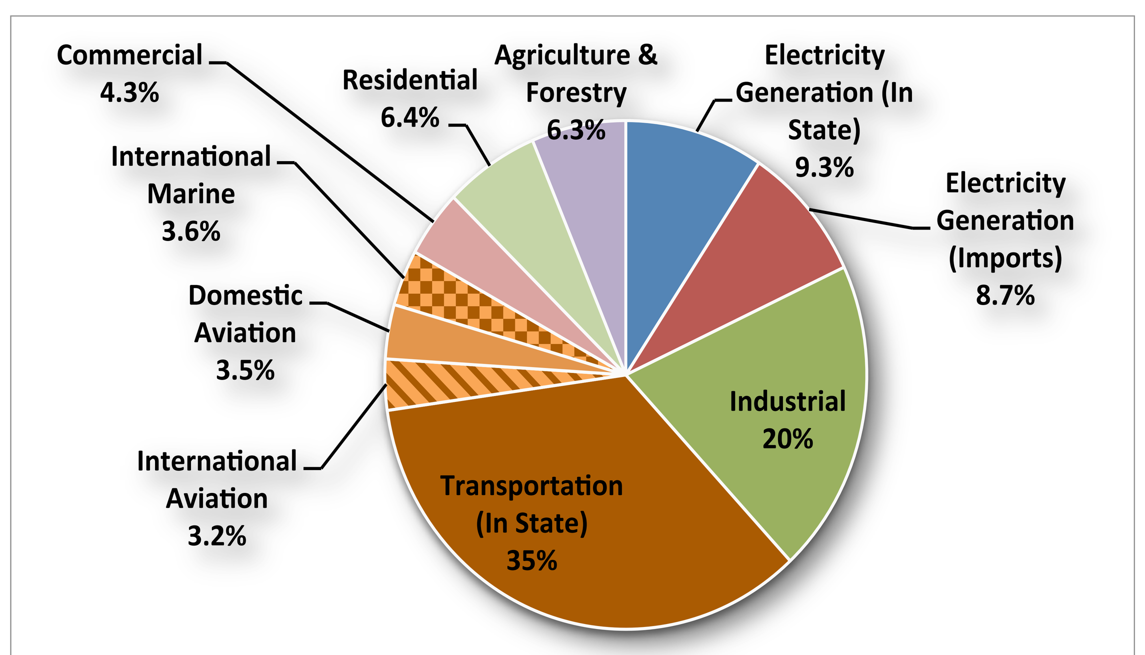
The CA-TIMES Model

- TIMES (The Integrated MARKAL-EFOM1 System) model is an Energy–Economy–Engineering–Environment (4E) model.
- 4E models are widely used for transition scenarios for multidisciplinary subjects.
- Identifies most cost-effective pattern of resource use and technology deployment over time under various technological, behavioral, resource, and policy constraints.
- Powerful tool for policy analysis for the energy system:
  - Policy scenarios
  - 'If-Then' scenarios
  - Sensitivity analysis
- Rich in "bottom-up" technological detail – describes in detail technology operation, efficiency, availability, fuel production/ demand, retrofit, and retirement in flexible time slices.
- Model covers **all sectors** of the California energy system (not Rest of World).

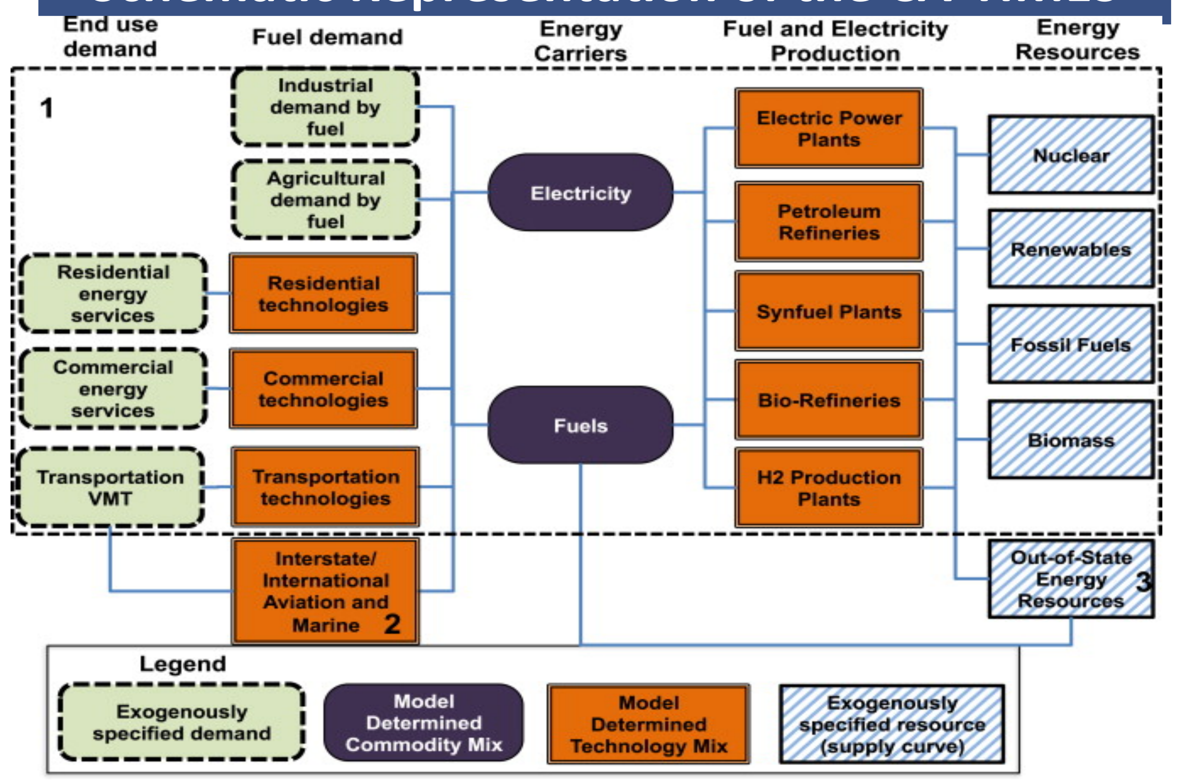
Motivation

- California has taken important first steps towards addressing the state's greenhouse gas (GHG) emissions through a variety of important and innovative policies (including AB32, cap and trade, the low carbon fuel standard, GHG regulations for cars and trucks).
- These policies represent a framework through which further reductions past the 2020 timeframe will be implemented.
- Understanding the long-term future is challenging because of the uncertainty that exists about options, resources and technologies that will be available and used to meet the deep reductions in GHG emissions needed by 2050 and beyond to address the worst impacts from climate change.
- CA studies either do not take costs into consideration or lack a systems modeling approafile://localhost/.file/ id=6571367.37774101ch
- CA-TIMES is useful to understand how the future energy system could develop, from the least cost perspective to achieve GHG emission target in 2050.
- CA-TIMES was designed to investigate the question of how California could meet an 80% reduction target for GHG

Sector-wise Emissions in CA (2010)



Schematic Representation of the CA-TIMES

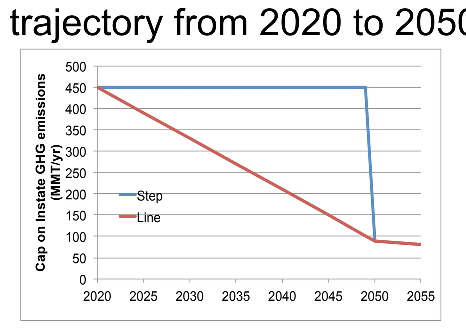


Reference Case Scenario Policies

- Current biofuel tax credits
- Current biofuel import tariffs
- Current transportation fuel taxes
- CAFE standards to 2016 and 2025
- Federal and California electric vehicle subsidies
- Low carbon fuel standard (LCFS) biofuel volume scenario to 2022
- Power plant electricity GHG standard
- Renewable portfolio standard (33% by 2020 and remains until 2050)
- Renewable electricity production tax credit, solar investment tax credit
- Zero Emission Vehicle (ZEV) mandate policy constraint to 2025

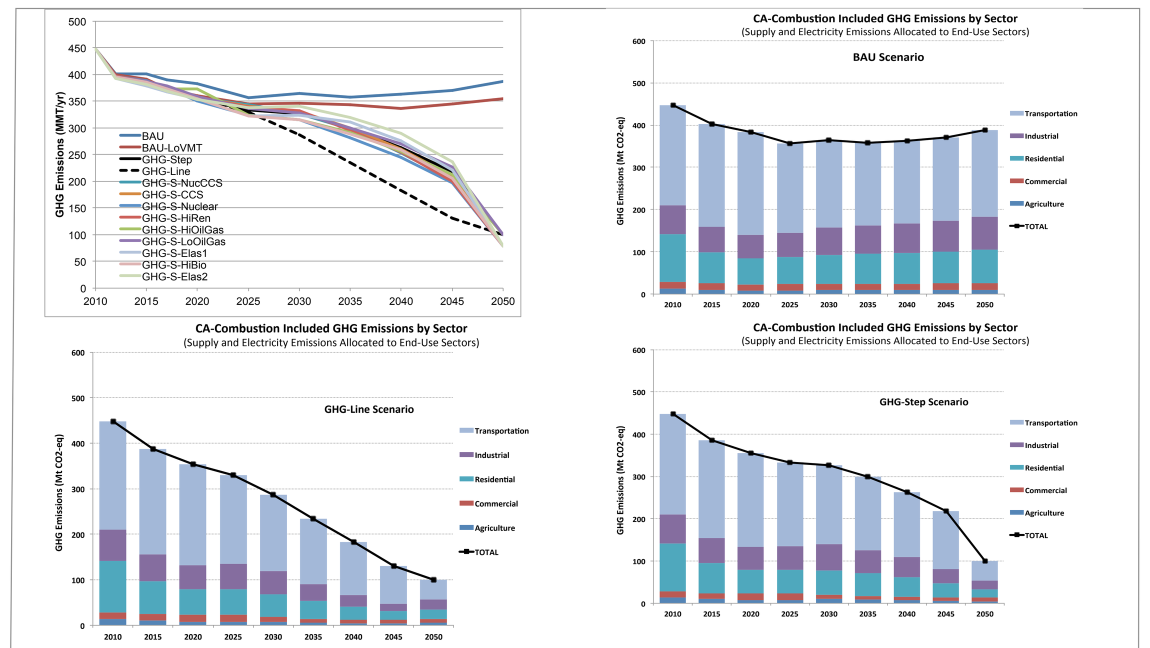
Greenhouse Gas Scenarios

- GHG scenarios include all policies that are represented in the Reference Case are, as well as additional policies that would also need to be enacted.
- There are two types of caps: "Step" cap which is held at the 2020 target (1990 levels) between 2020 and 2050 but then dropped to 80% below 1990 emissions in 2050.
- "Line" cap that is a declining carbon cap – specifically, a straight-line trajectory from 2020 to 2050 is assumed.



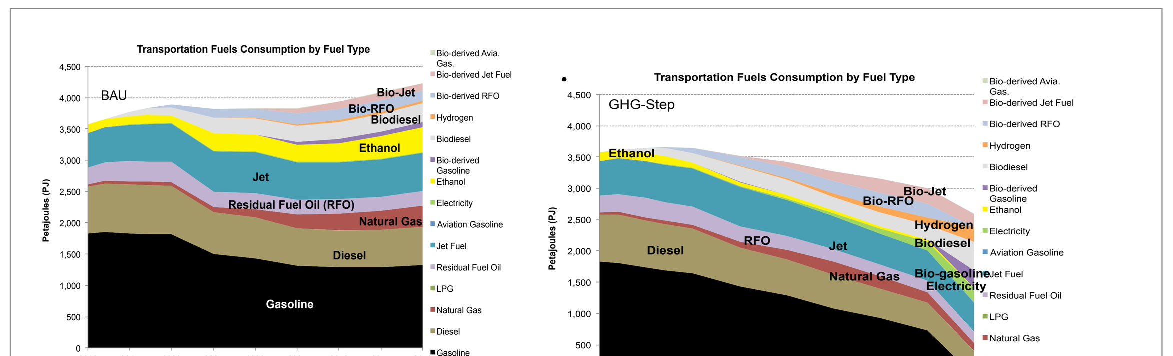
- In the GHG scenarios, VMT reductions are implemented for many transport sectors. These lead to a reduction in light-duty vehicle (LDV) VMT by 24%, and heavy-duty vehicle (HDV) and medium-duty vehicle (MDV) VMT by 10% in 2050 relative to the Reference case.
- Passenger automobile share of the light duty vehicle market is expected to climb to 75% in the GHG scenarios (the baseline share in the Reference case is 65%).
- Several scenario variations and sensitivity analysis were performed in terms of:
  - Nuclear power plant availability
  - Carbon capture and sequestration availability
  - Rapid deployment of wind and solar
  - Sensitivity on battery and fuel cell costs
  - Sensitivity on oil and natural gas prices
  - Elastic demand
  - Increased biomass production

Results: Emissions by Sector



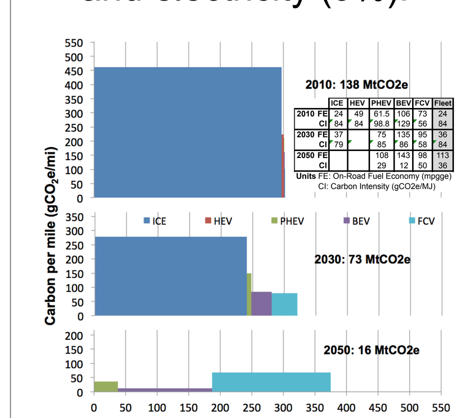
- In the Reference case, in 2050, instate GHG emissions are approximately 1% lower than 1990 levels.
- Both GHG scenarios are able to reduce *Included Instate* emissions below 1990 levels by 74.6% falling just short (5.4%) of the 80% target.
- Emissions and fuel use from cross-boundary aviation and marine trips international are not included in the GHG target, consistent with the state's treatment of emissions categories.
- The emission levels in 2030 range from 286 MMTCO2e in the GHG-Line scenario to 341 MMTCO2e in the GHG-S-Elas2 scenario.

Transportation Sector

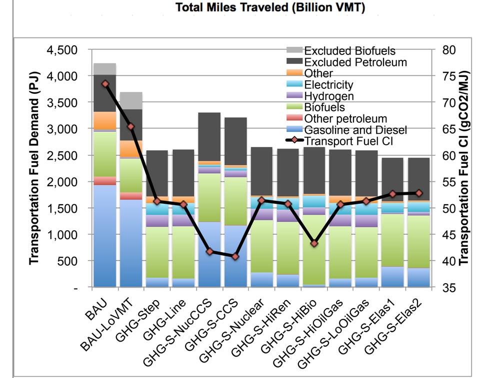


➢ In the GHG Scenario:

- Gasoline is entirely gone in as light-duty vehicles shift to electric drive vehicles.
- Diesel declines slightly but is still needed in heavy and medium duty trucks.
- Biofuels grow significantly to make up 37% of fuel use in 2050, while petroleum-based fuels account for approximately 41% of 2050 fuel use.
- The remainder comes from natural gas (5%), hydrogen (9%) and electricity (9%).

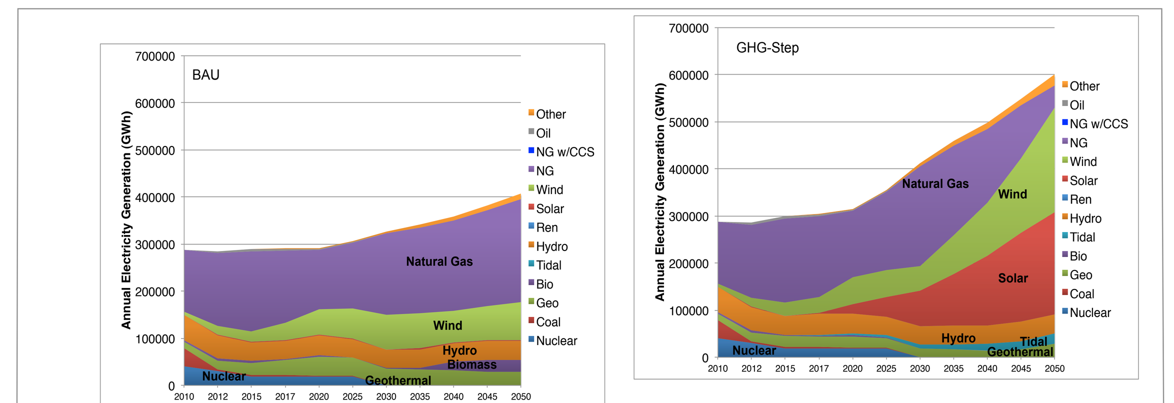


- The Light-duty sector is pretty much decarbonized in 2050 only emitting only 16 MMTCO2e (89% reduction from 2010 emissions).



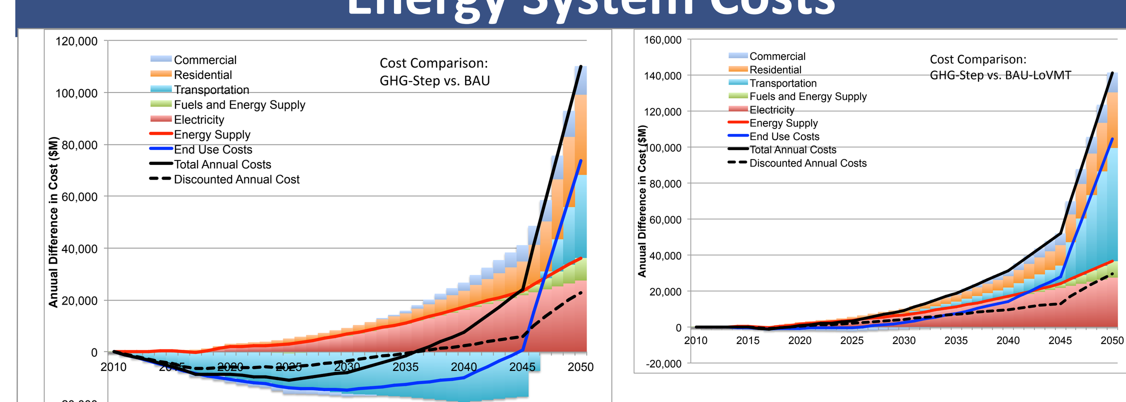
- Instate travel, petroleum usage declines to almost zero, accounting for just 180 PJ (1.4 billion GGE) in the GHG-Step and GHG-Line scenarios, compared with 2100 PJ (16 billion GGE) in the BAU scenario. Including interstate/ international aviation and marine fuels GHG-Step petroleum usage increases to 1050 PJ (8 billion GGE) vs 2800 PJ (21 billion GGE) in BAU.
- The scenarios with CCS (GHG-S-CCS and GHG-S-NucCCS) use negative emissions from bioCCS to offset emissions from continued use of petroleum for Instate travel.
- The average carbon intensity (CI) of transportation fuels declines below 55 g/MJ in all of the GHG scenarios in 2050.

Electricity Sector

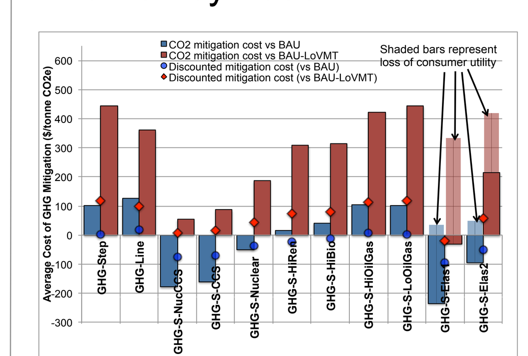


- Electricity generation in GHG scenarios is approximately 600 TWh in 2050, approximately 50% more than the Reference case.
- Geothermal and tidal generation expand as much as the economically feasible resource allows in 2050 to 28 TWh and 22 TWh respectively .
- Solar and wind power make up the bulk of the generation in 2050, with utility scale solar thermal, solar PV and wind contributing 107 TWh, 110 TWh and 221 TWh, respectively.
- The carbon intensity of the Reference scenario declines to around 200 gCO_2e/kWh in 2020 and stays constant to 2050 (184 g/kWh), while in GHG scenarios eventually decline to below 30 gCO_2e/kWh.

Energy System Costs



- the lower VMT in the GHG-Step scenario relative to the BAU scenario leads to reduced investments in vehicle purchases and negative costs associated with the transportation sector.
- Annual cost differences are relatively low (initially negative but within a range of +/- $20 billion/year, undiscounted) until 2045 when costs rise, reaching over $100 billion (undiscounted) in 2050 to try and meet the 2050 emissions target.
- Discounted to present value, the annual costs are relatively modest, becoming positive after 2035 and reach around $20 billion by 2050.



Discounting the costs at 4% discount rate lead to relatively low present value of mitigation costs ($3 to $18/$tCO_2e$ vs the BAU scenario and from $99 to $117/$tCO_2e$ vs the BAU-LoVMT scenario) because the incremental costs are typically higher in later years.

Key Conclusions

- Nuclear power and CCS are not available in the primary scenarios, and without these options, it is more difficult to meet the 80% GHG reduction target.
- Among all GHG scenarios, emission in 2035 range from 235 to 320 MMTCO2e.
- Wind and solar produce 54% to 80% of generation in most GHG scenarios, which requires very large investments and a fast ramp up of capacity.
- Electricity must be decarbonized if GHG goals are to be met.
- Battery and fuel cell powered vehicles are important and make up between 50% and 90% of light-duty vehicles in 2050.
- If CCS is available, biofuels production with CCS can provide significant negative emissions and offset petroleum usage.

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Full paper: Yang, Christopher, et al. "Achieving California's 80% greenhouse gas reduction target in 2050: Technology, policy and scenario analysis using CA-TIMES energy economic systems model." *Energy Policy* 77 (2015): 118-130.

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