UC DAVIS INSTITUTE OF TRANSPORTATION STUDIES

SUMMARY FOR POLICYMAKERS

Modeling Optimal Transition Pathways to a Low Carbon Economy in California

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Introduction

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 could be implemented. Major transformations of the energy system will be needed to meet the state's long-term goal of reducing GHG emissions to 80% below 1990 level by 2050, but they are poorly understood, in terms of the resources and technologies that will need to be brought to bear, the policies that will induce these major shifts and the social, environmental and economic aspects of major transformations. Energy models such as CA-TIMES are useful to understand how the future energy system could develop, from a technology, cost and emissions perspective. The CA-TIMES model is a bottom-up, technology-rich energy system optimization model for California that focuses primarily on the two key areas: gaining a better understanding of the resources and technologies that can help reduce emissions from the energy sector and the policies that are needed to bring them about. The key questions we try to answer in this Policy Brief include:

- 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 mitigating GHG in California?
- How do policies and the availability of technologies and resources influence the mitigation strategies and costs?

Our analysis includes numerous scenario variations to understand how the evolution of the energy sector could change with respect to technology adoption, fuel and energy resource utilization and emissions under different sets of input assumptions. These variations are based primarily upon different assumptions about technology or resource cost and availability.

Modeling Results for Meeting 2050 GHG Reduction Target

Overall conclusions. The primary GHG scenarios (which exclude nuclear power and carbon capture and sequestration) achieve quite significant reductions in GHG emissions (75% below 1990 levels). Meeting the 80% reduction target is possible with additional availability of low-carbon carbon energy resources / technologies such as nuclear power, carbon capture and sequestration or increased supplies of wind and solar electricity generation and biomass. Carbon capture and sequestration appears to be one of the key technologies that can enable the state to meet the emissions target at fairly low cost, in part because it enables negative emissions (essentially offsets) in the production of biofuels with carbon capture and sequestration (CCS). Elastic demand scenarios are also examined to reflect more realistic consumers' demand reduction behaviors in response to price increases from GHG mitigation. These scenarios suggest that large reductions in emissions and cost savings are possible with demand reduction. Across all of the 80% GHG reduction scenarios, total cumulative emissions reductions relative to the business-as-usual (BAU) scenarios are between 2000 to 4229 million tonnes of CO_2 and mitigation costs range from -$75 to $124/tonne CO_2e when future costs are discounted at 4%.

Transportation Sector. The transportation sector comes to rely increasingly on biofuels (as well as hydrogen and electricity) and decreases reliance on petroleum (see Figure 1). Total fuel demand drops 27% from 2010 to 2050: petroleum use drops from 95% to 41% of total fuel demand, while biofuels make up 37%, natural gas 5%, hydrogen 9% and electricity 9% in 2050. The average transportation fuel carbon intensity (CI, in gCO_2e/MJ adjusted for energy efficiency ratio for vehicles that run on electricity and hydrogen) declines by 53% for on-road transportation and 44% for all transportation in 2050.

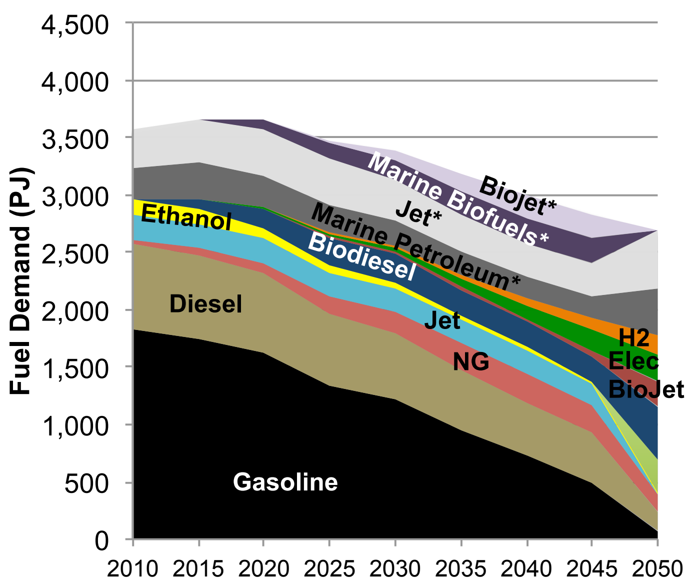
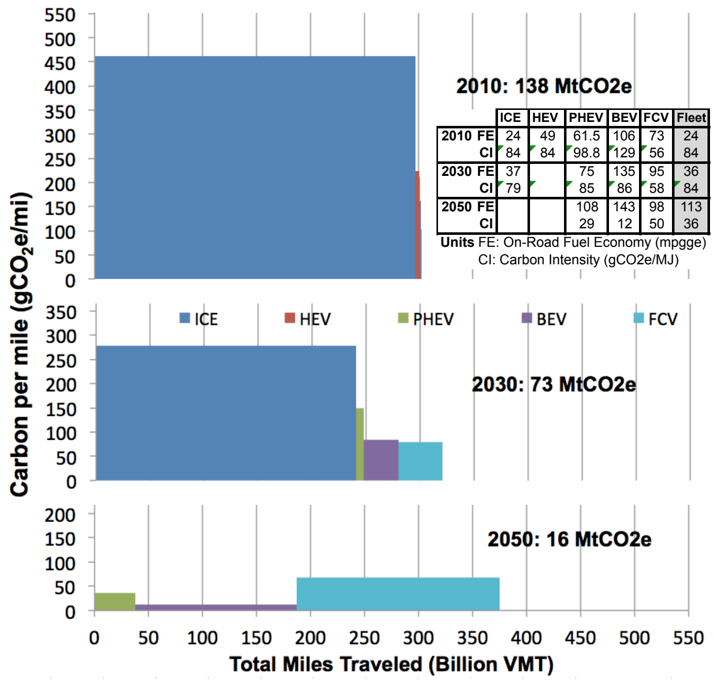


Figure 1. Transportation fuel consumption in 80% GHG step reduction scenario (* denotes fuel demand for cross-boundary marine and aviation, activities not included in emissions cap).

Light-Duty Vehicles. On-road fuel economy increases from approximately 27 mpgge in 2010 to over 110 mpgge by 2050. This substantial increase in fuel economy is driven in part by shifts from combustion vehicles to electric-drive battery electric vehicles, plug-in hybrid electric vehicles and and fuel cell vehicles, which make up 40%, 10% and 50% of light duty vehicles respectively in 2050 (Figure 2). Sensitivity scenarios show that combustion vehicles can make up a substantial portion of the vehicle mix if there is a much greater supply of low-carbon liquid fuels as seen in the high biomass and carbon capture and sequestration scenarios or if travel demand is further reduced.



		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

Figure 2. Comparison of the carbon per mile and miles traveled for different vehicle types and total emissions from LDVs in 2010, 2030 and 2050 in the primary GHG mitigation scenario.

Biofuels and Hydrogen. Biomass is used almost exclusively for the production of biofuels, which are critical for decarbonizing the transportation sector. Biofuel consumption in the BAU scenario (which includes the Low Carbon Fuel Standard to 2020) is 1080 PJ or 8.2 billion gallons of gasoline equivalent (billion GGE). GHG scenarios have slightly lower biofuel production than the *BAU* scenario (in 2050, the GHG scenarios have approximately ~7.3 billion GGE, or about 37% of transportation fuel demand). Ethanol makes up a tiny fraction of biofuels production in the GHG scenarios, with most production occurring through Fischer-Tropsch synthetic production of gasoline, diesel and jet fuels. Approximately 40% of biomass comes from in-state resources, with the remainder coming from the rest of the Western US. In 2050, the in-state biomass is primarily municipal solid waste (MSW), yellow grease and tallow, while out-of-state biomass comes primarily from energy crops, agricultural residues and MSW. Hydrogen is made primarily from natural gas, with some contribution from grid electrolysis. Natural gas steam reforming is the least carbon intensive means of producing hydrogen without CCS or excess biomass supplies as marginal electricity for electrolysis comes from natural gas generation and the additional efficiency loss makes it higher carbon than natural gas steam reforming.

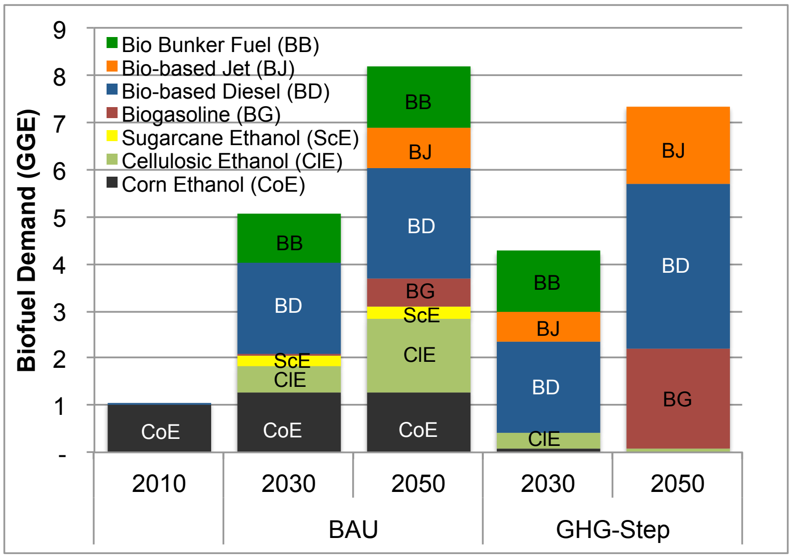


Figure 3. Biofuel production by category for the *Reference* and *GHG-Step* scenarios.

Electricity Supply. To meet the 2050 GHG goal, electricity demand in 2050 increases substantially (~50%) relative to the BAU scenario, due to the significant shift towards electricity usage and away from natural gas and other fuels in buildings, industry and the transport sector. The electricity mix in California undergoes substantial decarbonization in the carbon-constrained scenario (Figure 3). Because nuclear power and carbon capture technologies are not available, the bulk of electricity generation is met by growing supplies of wind and solar power (in 2050, wind capacity is 74 GW while solar capacity is 104 GW). Overall the CI of electricity declines from 360 g/kWh to under 30 g/kWh in 2050.

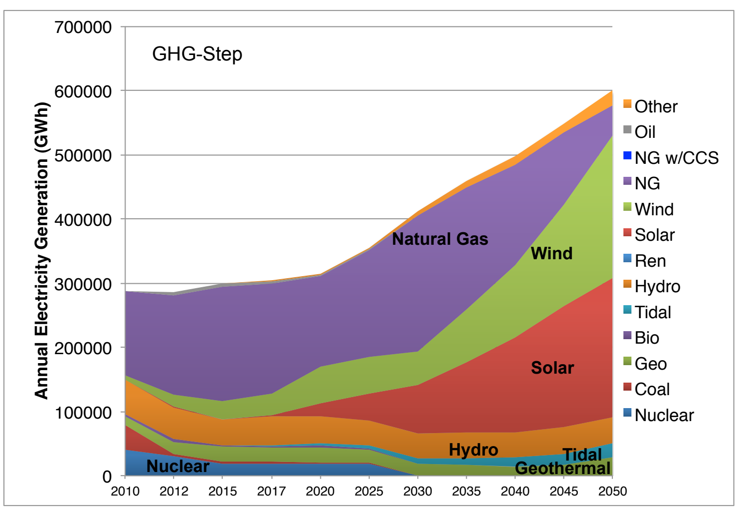


Figure 1. Electricity generation by source type in the primary GHG mitigation scenario.

Residential and Commercial Sectors. The residential and commercial sectors show substantial efficiency improvements and reductions in final energy demand. In 2010, electricity accounted for 58% of commercial energy use and 36% of residential energy use, and increased to 69% in commercial and 49% in residential sectors by 2050. The energy weighted efficiency improvements are 380% and 330% for the residential and commercial sectors, respectively from 2010 to 2050.

System Costs. Mitigation costs are calculated using the cumulative cost difference and difference in cumulative GHG emissions between the BAU and GHG scenarios. The discounted value (4%) of mitigation costs are between -\$75 to \$18/tonne CO_2e vs BAU and between \$9 to \$124/tonne CO_2e compared with a Reference scenario with lower VMT. Total mitigation costs (discounted) amount to less than 0.5% of cumulative state Gross State Product (GSP) from 2010 to 2050.

Key Conclusions

The CA-TIMES model is a useful tool for analyzing the evolution of the California energy system under different assumptions about low-carbon technologies and resources, and to understand how policy can shape that evolution. Some of the robust results from the modeling:

- Among all GHG scenarios, emission in 2035 range from 234 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 (the carbon intensity in all GHG scenarios is between 2 and 27 gCO_2e/kWh).
- Battery and fuel cell powered vehicles are important and make up between 50% and 100% of light-duty vehicles in 2050.
- Biomass is used almost exclusively for the production of biofuels, which are critical for decarbonizing the transportation sector. If CCS is available, biofuels production with CCS can provide significant negative emissions and offset petroleum usage.
- The residential and commercial sectors will increasingly rely on low carbon electricity (making up 49 to 69% of their final energy use)
- Costs of mitigation can vary significantly depending upon assumptions about resource and technology availability and costs, but overall mitigation costs are relatively small compared to expected GSP.

Important Caveats to these Modeling Results

The primary focus of CA-TIMES development (and other similar energy and emissions models) has been on creating a simplified but realistic representation of the state's energy supply system. These scenarios are not predictions of the future, but help to identify and analyze the policies, technologies and resources that can be used to meet California's ambitious GHG reduction targets. Large-scale energy system models such as CA-TIMES require thousands of input assumptions regarding the availability, costs, and efficiency of technologies, the availability and costs of resources, and economic parameters such as discount rate, consumers' elasticity to prices, all of which have a large degree of uncertainty when looking to 2050.

For more information and to download the main report visit: **http://steps.ucdavis.edu/research/projects/ca-times/**

Sustainable Transportation Energy Pathways Program (NextSTEPS) is a four-year (2011-2014) multidisciplinary research consortium, part of the Institute of Transportation Studies at the University of California, Davis. Our mission is to:

- Generate new insights and tools to understand the transitions to a sustainable transportation energy future for California, the US and the world (Research)
- Disseminate valued knowledge and tools to industry, government, the environmental NGO community, and the general public to enhance societal, investment, and policy decision making, (Outreach)
- Support the training of the next generation of transportation and energy leaders and experts. (Education)