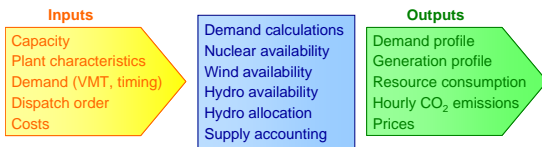


## How will advanced vehicles and alternative fuels affect California's electricity sector?

The answer is not straightforward, as a shift away from conventional internal combustion engines and petroleum-based fuels could integrate previously distinct energy systems. Emissions and economic impacts associated with such a shift in the transportation sector should be assessed with an understanding of interactions between the sectors. In this research, we develop the California Electricity Dispatch model, which allocates electricity generation on an hourly basis to meet demand. It includes a stochastic representation of generation resources to account for uncertainties in electricity supply and provides a probabilistic representation of CO<sub>2</sub> emissions associated with providing power for vehicle and other electricity demands. The present analysis investigates transportation electricity demand impacts on the current electricity grid in California. Future work will consider the evolution of electricity generation capacity and hourly demand impacts within future grid contexts.

## California Electricity Dispatch (CED) Model



CED allocates generation among available power plants to meet hourly electricity demands for a single year. The model constructs an hourly transportation electricity demand curve based on user inputs (% of VMT met by new vehicles and timing of demand) and adds prescribed non-vehicle demands. It determines the availability of three types of power plants that are represented stochastically – hydro, nuclear, and wind power – and dispatches power plants according to a fixed order that accounts for must-run conditions and variable generation costs. Hourly generation and the associated costs and CO<sub>2</sub> emissions are accounted, and several hundred runs provide probabilistic results related to variable supply availability.

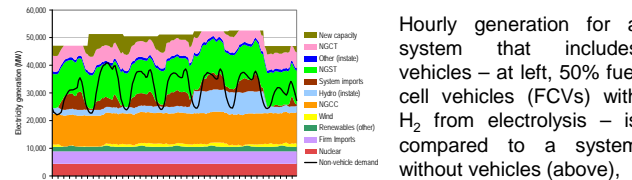
Characterization of California's current electricity sector (in dispatch order)

	Summer capacity (MW)	Annual generation (GWh)	Variable cost (¢/kWh)	CO <sub>2</sub> emissions (g/kWh)
<b>Must-run</b>				
Coal	389	--	--	1,018
Nuclear	4,390	--	--	0
Wind	2,439	--	--	0
Biomass	1,004	--	--	62
Solar	402	--	--	150
Geothermal	2,032	--	--	0
Firm imports	--	39,311	--	721
Baseload hydro	900	≥7,884	--	0
<b>Dispatchable</b>				
Peaking hydro	7,000	Varies	--	0
Other	35	--	0.3	510
NW imports	--	21,447	4.4	212
NG Combined Cycle (NGCC)	15,061	--	7.3	562
SW imports	--	21,707	8.1	579
NG Steam Turbine (NGST)	16,415	--	8.4	585
Oil	789	--	8.7	786
NG Gas Turbine (NGCT)	6,670	--	9.4	605
Additional SW Imports	6,162	--	9.4	579

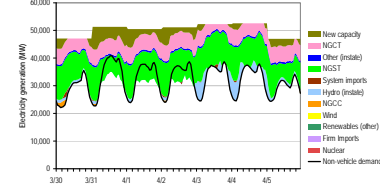
Sources: E&D 2007 database (NERC), eGRID2006 database (U.S. EPA), 2006 Annual Energy Outlook (EIA), American Wind Energy Association, California Energy Commission, Pacific Gas & Electric Company.

## Dispatch model output

By allocating generation on an hourly basis, marginal generation providing for new electricity demands from transportation is accurately identified.

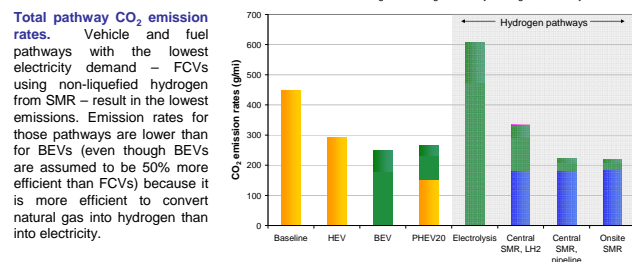
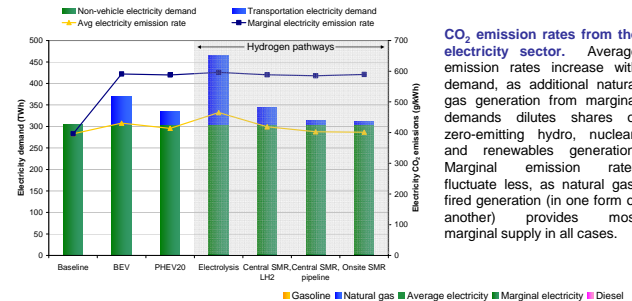


to identify power plants supplying demand on the margin (right). In California, most of those plants are fired by natural gas, and the timing of hydro generation shifts.



## Dispatch model results (50% vehicle penetration)

We compare marginal generation for several vehicle and hydrogen pathways. Electricity CO<sub>2</sub> emission rates increase with electricity demand; FCVs using hydrogen from grid-powered electrolysis result in the highest demand and emission rate, followed by battery electric vehicles (BEVs) and FCVs using hydrogen transported as a liquid. On a per-mile basis, pathways with the lowest electricity demand have the lowest total emission rates.



## Stochastic representation of generation resources

Three types of power plants are represented stochastically to account for uncertain conditions:

### Hydro

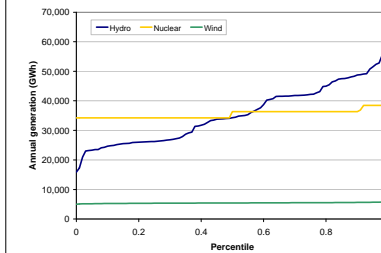
- Annual generation randomly selected, based on a historical distribution of annual hydro generation in California
- Annual hydro generation is fixed for a given run of each scenario, but its hourly distribution varies based on the demand curve

### Nuclear

- CA has 2 nuclear plants that need maintenance every 18 months
- In CED, each plant has a 2/3 chance of going down in a year
- Outages last for 40 days, occur in the spring, and do not overlap

### Wind

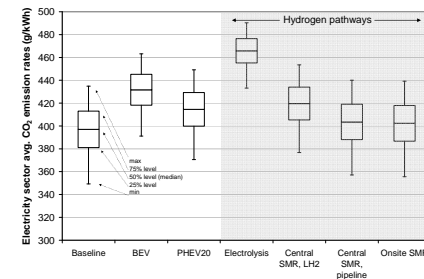
- Wind speed is modeled as a Markov process to develop probabilistic hourly wind speeds in each of 4 wind regions in CA
- A wind turbine model is applied to determine available generation



## Stochastic average electricity sector CO<sub>2</sub> emission rates

Including uncertainty in the analysis leads to a noticeable variation in emission rates (see figure below). The results illustrate that emission rates may vary significantly from year to year, largely dependent on rainfall and the availability of hydro generation.

Electricity sector average CO<sub>2</sub> emission rates, including stochastic power plant availability. Emission rates vary up to 20% in the baseline case and up to 10% between the 25<sup>th</sup> and 75<sup>th</sup> percentiles. Variance in emission rates decreases with demand, as increased natural gas generation dilutes shares of power plants that are represented stochastically.



## Future work

Future work will include a similar analysis for different grid compositions, reflecting conditions in different states or potential futures in California. We will also investigate power plant capacity retirements and additions, given significant penetrations of new vehicles and fuels, using an energy optimization model (TIMES). We expect to submit a journal article from this work within three months, and others to follow.

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