NREL
NATIONAL RENEWABLE ENERGY LABORATORY

WITH GRID FLEXIBILITY, CALIFORNIA CAN SLASH EMISSIONS WHILE LIMITING CURTAILMENT

California can achieve a 50% reduction in CO_2 levels by 2030 in the electric sector under a wide variety of scenarios and assumptions, according to the *Low Carbon Grid Study (LCGS): Analysis of a 50% Emission Reduction in California*, published in January 2016 by the Department of Energy's National Renewable Energy Laboratory.

The report evaluates electric sector impacts in terms of several key operational and economic metrics, including production costs, emissions, curtailment, and impacts on the operation of gas generation and imports. A focus of the study is the impacts of electric system flexibility measures on key operational and economic metrics. Enhanced flexibility scenarios increase California's ability to export California-entitled energy (power from out-of-state generators owned by California or contracted to California utilities), shut down gas generation to make room for renewables, and use storage to reduce curtailment and peak-load energy needs. Under conventional flexibility assumptions, the grid does not have these additional flexibility measures.

Methodology and Major Assumptions

NREL used the PLEXOS model to simulate the unit commitment and dispatch of the generating fleet in the western United States for 23 different scenarios, which included a variety of assumptions regarding the generator portfolios, energy efficiency, storage, and grid flexibility.

The portfolios (Figure 1) for this study are:

- **Baseline:** Assumes prior renewable portfolio standard (RPS) legislation (33% by 2020) and energy efficiency projected by the California Energy Commission (CEC) (this scenario has 36% renewable penetration and 340 TWh annual load).
- **Target:** Achieves LCGS goal of 50% carbon reduction by 2030 using a higher level of energy efficiency and a diverse mix of renewable resources (56% renewable penetration1 and 320 TWh annual load). This Target portfolio includes 2.2 GW additional storage.
- **High Solar:** Assumes the same quantity of renewables, storage, and load as Target but with a less diverse mix of resources: more photovoltaics (PV) and less wind, concentrating solar power (CSP), biomass, and geothermal (56% renewable penetration1 and 320 TWh annual load).

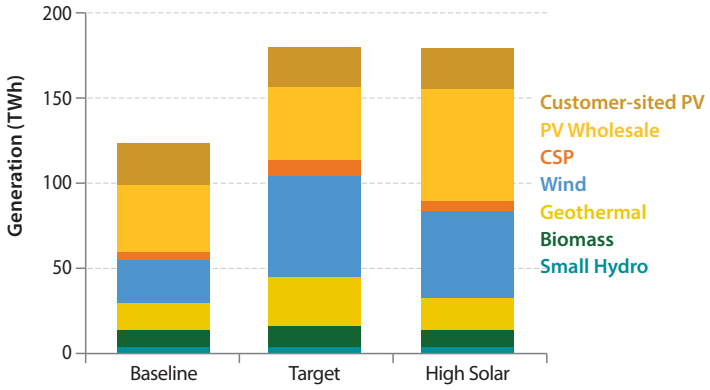

Figure 1. Renewable generation in LCGS portfolios

All portfolios include 23 TWh of rooftop or customer-sited PV penetration (7% of annual load).

In addition to the "Enhanced" and "Conventional" flexibility assumptions, NREL also modeled scenarios with higher west-wide renewable penetrations, lower gas prices, higher CO_2 prices, and different hydro resource levels for a total of 23 scenarios. Modeling assumptions are not policy recommendations but proxy representations of potential operating conditions based on recent proposals and policies.

Key Findings

- California can achieve a 50% reduction in CO_2 levels by 2030 in the electric sector under a wide variety of scenarios and assumptions.
- The energy efficiency and renewable energy additions reduce production costs by $4.85 billion in the model with enhanced flexibility (see Table 1). The conventional grid flexibility assumptions increase production costs by $65 million in the Baseline and $550 million in the Target scenario. The model shows enhanced flexibility yields much higher cost reductions in scenarios with high penetration of renewables.

Table 1. Reduction in Production Cost Compared to Baseline Enhanced

Portfolio	Conventional flexibility	Enhanced flexibility
Baseline	-$65M	0
Target	$4,300M	$4,850M

- For comparison, a companion report by JBS Energy (Marcus 2015) found that the annualized capital costs of the incremental renewable generation, transmission, and storage capacity between the Target and Baseline portfolios was $5.1 billion, for a total cost increase (including capital and production costs) of 0.6% of the annual revenue requirement

[1] *Renewable percentages include rooftop PV and are a fraction of total California load plus transmission losses, which differs from current RPS calculations.*

**NREL is a national laboratory of the U.S. Department of Energy,
Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.**

for California utilities. Depending on technology costs and economic conditions, the overall cost impact of the carbon reductions ranges from -3% to 6% of the annual revenue requirement for California utilities.

- Curtailment of renewable generation is much lower in the enhanced flexibility cases (<1%) than the conventional flexibility cases (up to 10%); see Figure 2. The level of grid flexibility can be as significant as the portfolio in driving curtailment.

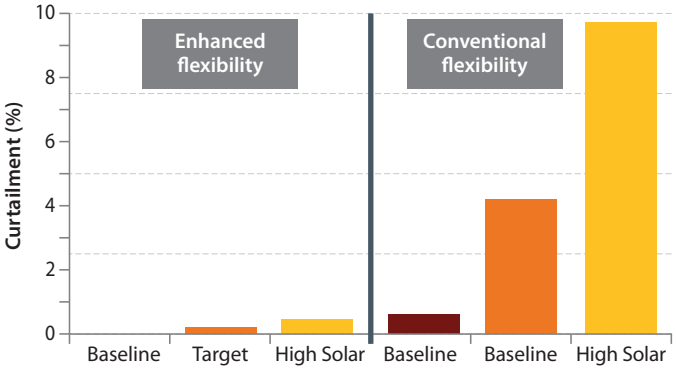

Figure 2. Curtailment in six selected LCGS scenarios

- The enhanced operational flexibility options tend to increase cycling at California gas generators; storage and demand response can help reduce emissions and curtailment while reducing cycling.
- Achieving high levels of renewable penetration in the rest of the western United States does not change the key conclusions on curtailment, emissions, and production costs in California based on the optimal west-wide dispatch modeled. Achieving enhanced levels of flexibility may be more difficult if neighboring states will not purchase California-entitled generation even when that is the lowest-cost option.
- Flexibility comes from a wide variety of sources, including physical imports, storage, the gas fleet, demand response, and hydro generation.
- GE Energy examined the dynamic grid issues associated with the LCGS scenarios (Miller 2015) and found that California should be able to procure enough frequency response from existing sources without increasing curtailment. More work needs to be done to understand transient stability in the LCGS scenarios.

Future work should examine issues related to bilateral contracts and other sources of market friction; stability impacts of a low-carbon grid; and cost-effective mitigation options for these potential issues.

Conclusion

The modeling results indicate that achieving a low-carbon grid (with emissions 50% below 2012 levels) is possible by 2030 with relatively limited curtailment (less than 1%) if institutional frameworks are flexible. Modeling results suggest that without flexible institutional frameworks and a diverse generation portfolio, curtailment could increase to as much as 10% and that the system could see higher operational costs ($800 million) and carbon emissions (up to 14%) compared to scenarios with more flexibility and diversity.

ABOUT THE LOW CARBON GRID STUDY

This study was funded by a variety of industry and foundation sources with the goal of understanding the impacts of a low-carbon grid in California. The LCGS study comprises three reports:

- **Grid modeling:** Brinkman, G., J. Jorgenson, J. Caldwell, A. Ehlen. *Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California*. National Renewable Energy Laboratory. 2016.
- **Capital cost analysis:** Marcus, B. *Low Carbon Grid Study: Comparison of 2030 Fixed Cost of Renewables and Efficiency, Integration with Production Cost Savings*, JBS Energy, 2015.
- **Dynamic reliability analysis:** Miller, N. *Low Carbon Grid Study: Discussion of Dynamic Performance limitations in WECC*, GE Energy Consulting, 2015.

A Steering Committee helped guide the study and a Technical Review Committee helped review the study. Although the members of the Steering Committee and Technical Review Committee helped prepare and review the reports, analysis may not reflect the specific views or interpretations of any member of either committee.

Organizations represented on the Steering Committee:
Abengoa, Alton Energy, California Energy Storage Alliance, Electric Power Research Institute, American Wind Energy Association, BrightSource, CalEnergy, Geothermal Energy Association, Geothermal Resources Council, California Wind Energy Association, California Biomass Energy Alliance, California Energy Efficiency Industry Council, Clean Line Energy, CleanPath, EDF Renewable Energy, EDP Renewables, Energy Foundation, Energy Innovation, EnerNOC, CPower, General Electric, Iberdrola, Invenergy, Large-scale Solar Association, LS Power, NRG, Pathfinder / Zephyr, Recurrent, Rockland Capital, Solar Energy Industries Association, SolarReserve, SunPower, Terra-Gen, Wellhead Electric.

Organizations represented on the Technical Review Committee:
California Energy Commission, California Independent System Operator, California Public Utilities Commission, NV Energy, Pacific Gas & Electric, Sacramento Municipal Utility District, San Diego Gas & Electric, Southern California Edison, Western Interstate Energy Board, Western Grid Group, Woodruff Expert Services

For more information on Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California, *download the full report at nrel.gov/docs/fy16osti/64884.pdf or contact Greg Brinkman at gregory.brinkman@nrel.gov or 303.384.7390.*

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov
NREL prints on paper that contains recycled content.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/FS-6A20-65805 • February 2016