NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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REALIZING CLEAN ENERGY'S POTENTIAL

Lessons Learned in the U.S. West

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IN THE UNITED STATES AND AROUND THE WORLD, ELECTRICITY AND TRANSPORTATION SYSTEMS ARE INCREASINGLY POWERED BY CLEAN, RENEWABLE ENERGY SOURCES.

These global trends are manifest in the U.S. West, where state and regional policies have changed the energy landscape and created a learning laboratory for renewable development and deployment. NREL's analysis has been instrumental in articulating challenges, evaluating options, and offering solutions to support expansion and integration of renewables into the western grid. The results from these studies have guided decision makers in state governments, utilities, and regulatory agencies in the West (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming) by shedding light on:

- **Growth and potential for renewable energy in the western United States**
- **System-level changes as renewable energy grows beyond requirements of state renewable portfolio standards (RPS)**
- **Challenges and opportunities for new RE projects in the West.**

Potential for Renewable Energy in the West

The western United States has abundant energy resources—coal in Wyoming, natural gas in Alaska, California, and North Dakota, nuclear and hydropower in the northwest, high quality solar in the southwest, and geothermal and wind in every western state.

Led by the example of California, western states have been proactive in deploying renewable electricity over the last decade. At the end of 2012, installed renewable electricity capacity in the western states approached 80 GW, or about one-half of the nation's total installed renewable electricity capacity.

State and federal incentives, in combination with state renewable portfolio standards—policies establishing thresholds for how much electricity supply must come from renewable energy—have been key drivers for growth of renewable energy in the West. Of the 13 western states, all have an RPS or renewable goal except Alaska, Idaho, and Wyoming. Today, most western states are on track to meet their final RPS requirements, and there is room for more renewables growth. NREL estimates technical potential for renewables in the western states at 80,000 GW.

For the western states, this is good news. Steady energy demand both regionally and nationally and a push for more renewable energy could mean new jobs and economic development throughout the region. New investments in power generation and transmission infrastructure to meet increasing energy demand and support improvements in power systems reliability and operations in the West provide opportunities for economic development in the states and at the sites where the investments are constructed, as well as in those regions that manufacture equipment for the power sector.

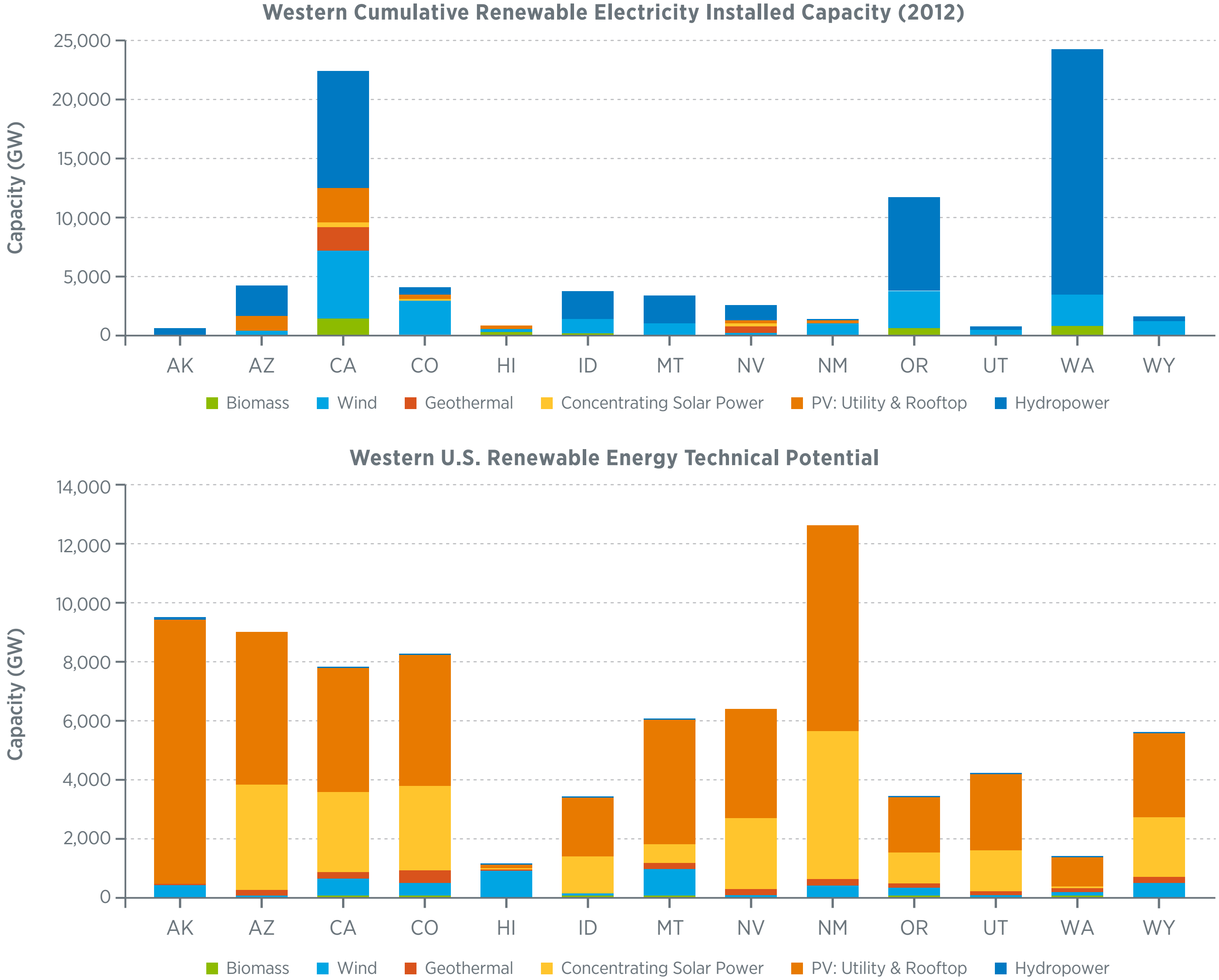

Figure 1. The technical potential for renewables in the Western United States is approximately 80,000 GW.
Source: 2012 RE Data Book; U.S. Renewable Energy Technical Potentials; A GIS-Based Analysis

ECONOMIC IMPACTS OF TRANSMISSION, NG, AND RE EXPANSION IN COLORADO AND WYOMING

NREL estimated the cumulative 20-year economic impact of new renewable and natural gas electricity generation and transmission projects in Wyoming and Colorado at $3.7 billion—an average of $790 million annually during construction ($2.4 billion total) and $70 million per year during operations. The planned projects in Wyoming and Colorado could support nearly 4,000 jobs annually over an estimated three-year construction period and nearly 400 long-term jobs in manufacturing and operations and maintenance. These estimates are consistent with impacts reported by communities that have experienced wind power development activity in Colorado, Iowa, Minnesota, Texas, and elsewhere.

System-Level Changes Can Enable Western States to Add More Renewable Generation

As western states move closer to meeting their RPS targets and as the economics of wind and solar power continue to improve, changes to grid operational practices throughout the West will be required to reliably balance supply and demand at all time scales. California Independent System Operator (CAISO) created the "duck chart" to illustrates the challenges system operators face as the state increases solar generation. Figure 2, based on CAISO's chart, shows how high levels of solar impact the net load (load minus solar generation) and highlights the potential for overgeneration and the steep ramping required to balance supply and demand through the day.

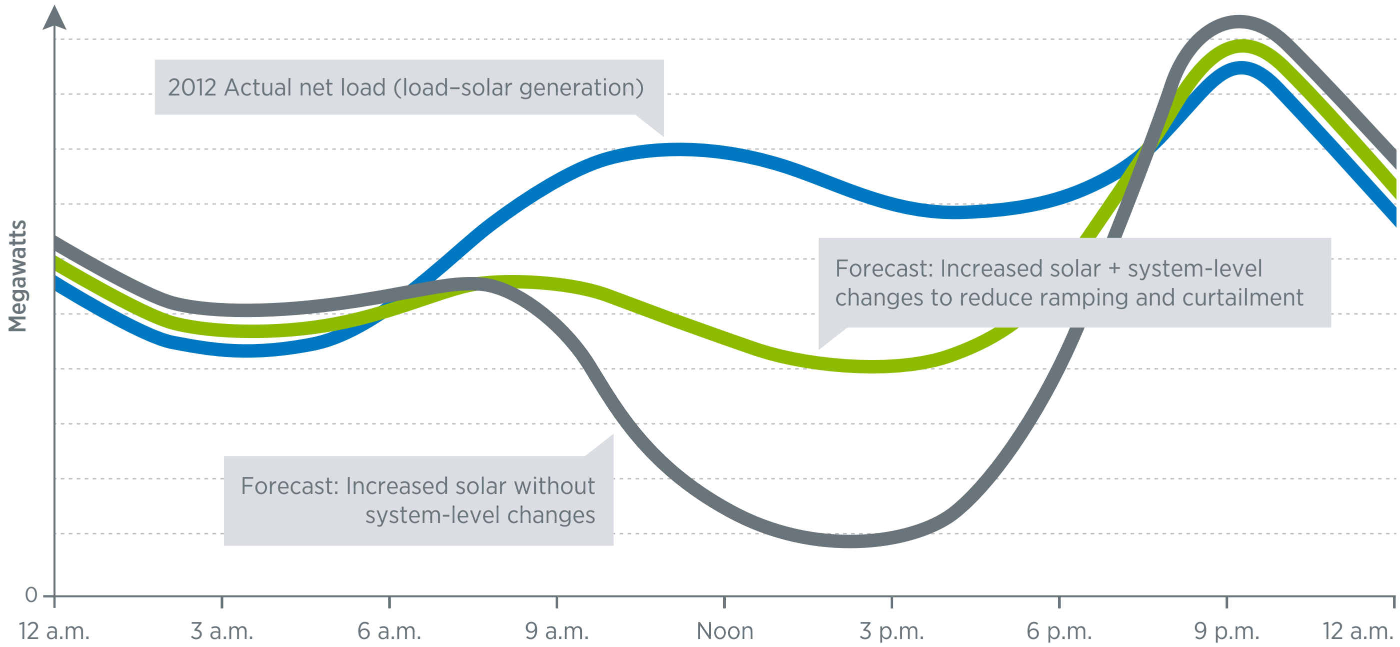

Figure 2. Without system-level changes, conventional generation must ramp more to accommodate increased solar generation.

System-level changes including increased ramping of conventional generators, curtailment of wind and solar, and larger balancing areas can help to meet this future net load curve. In addition, the use of demand response, energy storage, and other smart grid technologies can help to "flatten" the duck's belly by reducing net load during the daylight hours.

Increased Ramping of Conventional Generators Has Net Benefit

The practice of cycling power plants to accommodate fluctuations in electricity supply and demand is well established. However, when wind and solar energy displace fossil fuels, utilities must ramp down and ramp up, or cycle, conventional coal and natural gas generators more frequently to accommodate more variable wind and solar power.

NREL investigated the potential wear-and-tear costs and emissions impacts of increased cycling in the *Western Wind and Solar Integration Study Phase 2* (WWSIS-2). From a system perspective, avoided fuel costs outweigh the increased cycling costs for fossil-fueled plants. Specifically, more frequent cycling to accommodate increased wind and solar generation increases operating costs by 2% to 5% for the average fossil-fueled plant ($0.47 to $1.28 per megawatt-hour of generation). This equates to total annual cycling costs of $35 million to $157 million across the West. However, high levels of wind and solar power would reduce fossil fuel costs by approximately $7 billion per year across the West, for a net savings of more than $6 billion. WWSIS-2 also found that the increase in plant emissions from cycling is more than offset by the overall reduction in CO_2, NO_X, and SO_2. In high-penetration scenarios, net carbon emissions were reduced by approximately one-third.

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260-300 billion lbs 29-34%	Negligible Impact
NO_x	170-230 million lbs 16-22%	3-4 million lbs
SO_2	80-140 million lbs 14-24%	3-4 million lbs

Figure 3. NREL analysis found net value in high penetrations of renewable electricity. Reducing fossil fuel costs by approximately $7 billion per year across the West offsets increased cycling costs of $35 million to $157 million per year. Similarly, while plant emissions of CO_2, NO_x, and SO_2 increase slightly due to more cycling, net carbon emissions were reduced by approximately one-third.

Western Power System Operators are Reducing Curtailment of Wind and Solar

> **Curtailment (kər-tāl´-ment)** *Reduction in the output of a generator relative to what it could otherwise produce given available resources*

Even as the amount of wind on the system increases, system operators in the West are effectively reducing curtailments using a variety of solutions: transmission expansion and interconnection upgrades; operational changes such as forecasting and increased automation; and better management of reserves and generation. *Wind and Solar Energy Curtailment: Experience and Practices in the United States*, which is based on a series of interviews conducted with utilities, system operators, wind energy developers, and non-governmental organizations, documents the efforts to reduce curtailment. The study found:

- **Curtailment levels have generally been 4% or less of renewable energy generation in regions where curtailment has occurred.**
- **Many utilities in the western states report negligible levels of curtailment.**

Table 1. Utilities are Implementing Strategies to Mitigate Wind and Solar Energy Curtailment

Reserves and Generation Management	Utilities or ISOs That Implement
Automation (i.e., AGC)	ERCOT, PSCO
Use curtailed generators for positive reserves	PSCO
Reduction of minimum loads	HECO (Maui)
Increase scheduling frequency	WAPA (adopting)
Market Integration and Negative Bidding	
Economic dispatch	ERCOT, MISO, SPP (adopting)
Negative pricing	CAISO, ERCOT, MISO, PJM
Energy imbalance market	CAISO, PacifiCorp
Other Strategies	
Wind power ramp management system	AESO
Increase transmission capacity	ISO-NE, ERCOT, MISO, PJM, SPP
Improve forecasting	ISO-NE, PSCO, NV Energy, SMUD

- **Increasingly there are negotiated curtailment hours and there is greater sharing of risk among generators and off-takers.**
- **Market solutions that base dispatch levels on economics offer the advantages of creating transparency and efficiency in curtailment procedures, which apply equally to all generators.**

Larger Balancing Areas Reduce Impacts of Wind and Solar Variability

Over the last decade, NREL's foundational grid integration studies have consistently shown that two overarching operational strategies support efficient integration of variable generation into grid operations and help to mitigate associated ramping and curtailment:

- **System coordination over larger geographical areas**
- **Faster system response.**

NREL's report *Matching Western U.S. Electricity Consumption with Wind and Solar Resources* confirms the benefits of aggregating variable renewable supply over wider geographic areas. The study found that by taking advantage of geographic distribution of wind and solar resources, wind and PV can meet up to 50% of loads in the western United States without storage or curtailment.

In addition, Phase 1 of the *Western Wind and Solar Integration Study* showed it is operationally possible to accommodate 30% wind and 5% solar energy if utilities substantially increase their coordination of operations over wider geographic areas and schedule their generation and interchanges on a sub-hourly basis.

One approach to expanding wide-area coordinated operations of the bulk electric power system is through a voluntary energy imbalance market (EIM), a regional tool for addressing the difference in the real-time electricity supply and demand relative to planned dispatch schedules. *Examination of Potential Benefits of an Energy Imbalance Market* (EIM) *in the Western Interconnection* estimated the total benefit of an EIM in the Western Interconnection to be as high as $1.46 billion. The annual West-wide operating benefit of the EIM was estimated at between $146 million and $294 million (see Figure 4). Moving from an hourly dispatch interval to a 10-minute dispatch interval results in an additional benefit of approximately $1.3 billion.

Because an EIM is designed to allow a broader geographic range of generation resources to contribute to the economic balancing of generation and load in real time, it can take advantage of

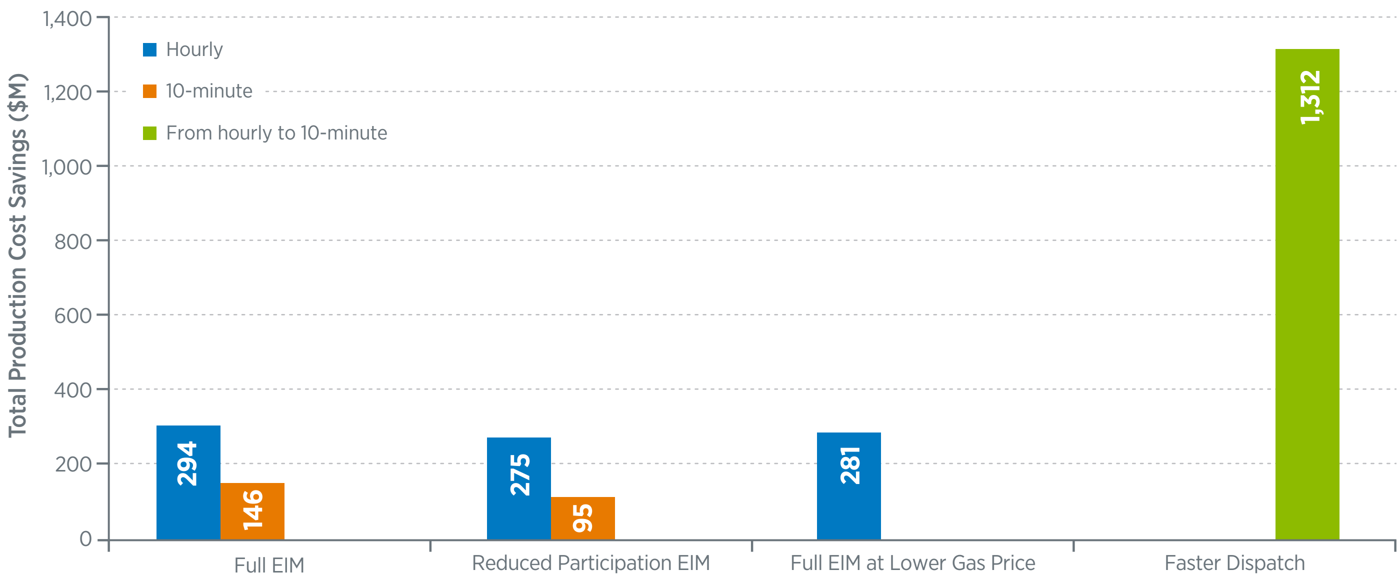

Figure 4. The total benefit of a faster dispatch interval and shared flexibility reserves could be as high as $1.46 billion—approximately $1.3 billion from moving from hourly to 10-minute dispatch intervals, and $146 million–$294 million in operating benefits from a regional EIM.

the reduction in wind and solar generation variability that is achieved by sharing generation across a wide area.

Demand Response Smooths Power System Operation

Demand response—for example, changing air conditioner set points, turning off lights, and managing the charging cycles of electric vehicles—is another approach for mitigating the impacts of variable generation.

In Hawaii, where increasing the geographical area to maintain system balance is not an option, demand response has the potential to smooth overall power system operation, with production cost savings arising from both improved thermal power plant operations and increased wind production. These are the findings of a study funded by the Joint Institute for Strategic Energy Analysis (JISEA), which investigated the potential of demand response to offset the impacts of variable wind and solar power generation on Oahu's grid operations in 2030, when Hawaii's RPS requires 40% of the state's electricity to be supplied by renewable sources.

For the 2030 system analyzed, the existence, and not necessarily the use, of the demand response program accounts for 96% of the estimated costs saved in the operation of the grid. The ability to quickly call on demand resources to meet unanticipated changes in wind generation also improves operators' ability to manage thermal generators. Benefits accrued from avoiding the dispatch of peaking generation for short periods of time, allowing for less spinning reserve thermal generation to be online at any given time, and enabling running generators to operate closer to optimal load levels. Demand response programs can provide flexibility that enables the electric power system to more easily integrate wind and solar—and may represent a lower-cost, nearer-term solution for balancing variable supplies than alternatives like energy storage and spinning reserves of fossil generation.

In California, Concentrating Solar Power with Thermal Energy Storage Increases Dispatchability of Renewables

Energy storage offers another approach to help manage the integration of variable renewable electricity into the grid. For example, concentrating solar power (CSP) systems with thermal energy storage (TES) is a dispatchable source of renewable electricity that can generate power during high-value periods when electricity demand is high and be turned off during lower-value periods.

Estimating the Value of Utility-Scale Solar Technologies in California Under a 40% Renewable Portfolio Standard investigated how CSP with TES could contribute to meeting California's current 33% RPS in addition to a more aggressive 40% scenario. This analysis quantified the value of CSP in reducing the need for conventional power generation from fossil fuels, and compared this value to other sources of generation, including photovoltaics. Considering both operational and capacity benefits, the total value of CSP-TES and PV were estimated to range from \$95–\$109/MWh and \$32–\$58/MWh, respectively. The value of CSP appears to be largely derived from its ability to provide firm system capacity.

Lessons Learned from Hawaii: System-Wide Operational, Technical, and Equipment Changes

The Hawaiian Islands provide unique insights into the multiple system-level changes required to integrate renewables into power grids that are geographically constrained. In addition to the potential for demand response described above, the key changes to operational practices that support 20% variable wind and solar PV penetration in Hawaii include:

- **Modifying existing units to reduce their minimum power levels by about half, thereby significantly reducing wind and solar power curtailment and creating more operational flexibility for handling challenges to the grid**
- **Relaxing the operating schedule for certain baseload units and providing reserves from alternate resources, such as demand response or a battery energy storage system**
- **Upgrading the utility's combined-cycle units to enable them to switch between single- and dual-train operation as needed to reduce renewable energy curtailment**
- **Relaxing operating schedules for oil-fired units and changing the commitment process to increase the priority of operating reserves**
- **Using a battery energy storage system to provide an additional operating reserves or to "time-shift" energy—storing the wind and solar power that would otherwise be curtailed and delivering it to the grid at the first opportunity.**

Permitting and Financing Can Make or Break Renewable Energy Projects

The Regulatory and Permitting Information Desktop (RAPID) Toolkit extends the popular Geothermal Regulatory Roadmap to cover additional renewable technologies and transmission, and provides a new suite of resources about permitting and regulations affecting energy and bulk transmission project development. NREL intends for the RAPID Toolkit to facilitate communication between project developers and agency personnel, among agencies at all jurisdictional levels, and among all project stakeholders, including the public.

Stakeholders involved in the Hawaii Clean Energy Initiative also identified permitting as a major barrier to renewable energy development in Hawaii. NREL summarized insights on the permitting process and prioritized suggestions for improvement from county agencies, project developers, and industry professionals, and an online Renewable Energy Permitting Wizard provides guidance for navigating Hawaii's permitting process.

Innovative financing structures, including a combination of government-sponsored and private funding, are helping project developers in the West overcome an important hurdle to project development and fully realize available tax benefits. In *Financing Opportunities for Renewable Energy Development in Alaska*, NREL examined four primary sources of project funding— government financed or supported (the most commonly used structure in Alaska today), developer equity capital, commercial debt, and third-party tax-equity investment—and found:

- **Tax credits and accelerated depreciation are the most powerful government-sponsored drivers of renewable energy project development in the United States, as they attract the private capital necessary to ensure a project's economic viability.**
- **Both taxable and tax-exempt entities have opportunities to participate in renewable energy project development in Alaska.**
- **Private funding is not widely used in Alaska, but is theoretically possible based on successful execution in similar locations.**

Why the West Matters

By illuminating some of the key issues facing energy decision makers in the western United States, NREL is helping to outline opportunities for new renewable electricity generation for state and regional planners, articulating the system-level operational and economic challenges of integrating renewables into the existing electric grid for utilities, and supporting streamlined permitting processes and assessment of effective financing options for project developers.

The findings are of importance to specific regional, state, and local entities including the Western Electricity Coordinating Council, the Western Governors' Association, and Wyoming Infrastructure Authority among others. Collectively, this body of work is of importance beyond the western United States as well. NREL's multidisciplinary insights at the subnational level establish a platform for wider analysis of the U.S. grid and contribute to the global energy dialogue around renewable electricity generation and integration.

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Renewable Energy Permit Wizard
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