National Renewable Energy Laboratory
Analysis Capabilities

Overview

The National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency research and development (R&D). NREL's mission and strategy are focused on advancing the U.S. Department of Energy's and our nation's energy goals. The laboratory's scientists and researchers support critical market objectives to accelerate research from scientific innovations to market viable alternative energy solutions.

NREL's world-leading energy decision science and analysis capability draws on extensive knowledge of energy resources, technologies, markets, policies, and systems to conduct leading-edge analysis and to develop data, tools, and models that are broadly disseminated for energy stakeholder and public use. The insights gained from these analyses and tools inform RD&D directions, policy formulation, and technology and investment decisions. NREL's capability is increasingly underpinned by strong domain knowledge in energy informatics, which derives knowledge and insights from measured and modeled data sets. Primary supporting disciplines include engineering, environmental science, applied math, finance, economics, and social and political science.

NREL has a deep understanding of existing electricity, buildings, and fuels and transportation infrastructure and practical knowledge of the barriers to deploying existing or new clean energy technologies within these systems. NREL researchers apply computational methods to develop resource and technology screening and decision tools. Particular strengths are in techno-economic analyses of renewable and efficiency technologies, geospatial resource data and analysis, sustainability and impact analysis, and evaluation of optimal technology options for off-grid and grid-connected power systems.

NREL stewards its crosscutting analysis and decision support capability in its Strategic Energy Analysis Center (SEAC) and technology-specific modeling and analysis capabilities in the science and technology research centers. During FY12, SEAC conducted approximately $30 million of analytic research for the Department of Energy (DOE) and others. NREL extends it analytical capabilities by collaboration with stakeholders throughout the energy analysis community, from university researchers to other laboratories and to analysts working for federal, state and local governments. It hosts the Joint Institute for Strategic Energy Analysis (JISEA), whose founding partners include NREL, Massachusetts Institute of Technology, Stanford University, University of Colorado, Colorado State University and the Colorado School of Mines. Focused on the nexus of energy, finance and society, JISEA conducts studies and supports research by diverse teams involving NREL experts, industry and academic participants from the founding and affiliate research institutions from around the world. Recent analyses have explored the potential synergies between renewables and other energy pathways, with a particular focus on nuclear and natural gas.

NREL's energy analysis is conducted in support of NREL programs and initiatives, DOE's Office of Energy Efficiency and Renewable Energy (EERE), technology transfer, and the greater energy community, providing technical knowledge and tools to help inform decisions that include energy program development, investment prioritization, policy formulation, and energy project development. For example, the Department of Defense looks to NREL as a strategic technical resource as it addresses energy security issues at fixed installations and forward operating bases. Other major governmental partners include the Department of State, Environmental Protection Agency, Department of Interior,

and Department of Homeland Security (DHS). Analysis clients include companies from the oil and gas and electric utility industries. NREL analysts partner with others at other national laboratories or leading research institutions as well; for example, NREL is collaborating with Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL) and Northwestern University on tool and data development for EERE's Advanced Manufacturing Office. NREL is a primary technical resource for United States Agency for International Development (USAID) and the Department of State on clean energy and climate programs. In addition, NREL provides analytical support at the state and local government level such as the Wyoming Infrastructure Authority, NYSERDA, and the California Energy Commission, and to international entities. Through the Laboratory Consortium that NREL leads, NREL is working with Argonne National Laboratory, Brookhaven National Laboratory, LBNL, ORNL, and Pacific Northwest National Laboratory to support the USAID funded *Enhancing Capacity for Low Emission Development Strategies* (EC-LEDS) program in more than 8 developing countries.

Analysis Capabilities

Analysis at NREL aims to increase the understanding of the current and future interactions and roles of energy policies, markets, resources, technologies, environmental impacts, and infrastructure. These analyses are used to inform energy system decisions as energy-efficient and renewable energy technologies advance from concept to commercial application. Distinctive analysis capabilities include the following:

- Techno-economic modeling and analysis
- Sustainability analysis
- Clean energy manufacturing and supply chain cost and economic competitive analysis
- Integrated electric sector/grid modeling
- Project finance analysis
- Market and policy analysis
- Geospatial and resource energy analysis
- Energy informatics
- Web-based energy decision tools

Techno-economic modeling and analysis: NREL's technology systems analysis examines the performance and cost of technologies, systems, and processes or identifies and evaluates the tradeoffs among currently available electricity generation and fuels technologies given location-specific resources and demand profiles. NREL has technology-specific models that support analysis in the buildings efficiency, transportation (vehicles and renewable fuels), and electricity end-use sectors, as well and models that encompass multiple technologies to enable comparisons within and across sectors on a consistent basis.

Sustainability Analysis: NREL's sustainability analysis investigates the environmental, life-cycle, climate, and other impacts of renewable energy technologies. Our energy choices have global implications that affect greenhouse gas emissions, water resource distribution, and mineral consumption. The school of thought is that renewable energy technologies are more sustainable than many current sources of energy. However, we need to verify that this is true before we miss some important opportunities.

NREL's capabilities in this analysis area include:

- resource-use optimization
- life cycle assessment
- environmental externalities analysis, including carbon and other air emissions
- co-benefits analysis
- Water and land use requirements and distribution analysis.

Clean Energy Manufacturing and Supply Chain Cost and Economic Competitiveness Analysis: NREL looks at economic competitiveness through the lens of the national energy dialogue, which is increasingly focused on American prosperity and U.S. competitiveness in the global economy. NREL conducts industry-validated analysis to quantify specific factors that drive U.S. competitiveness in clean energy sectors and examines the broader impacts of manufacturing on the economy, including assessing manufacturing costs, supply-chain constraints, innovation opportunities, and comparative advantages associated with deployment of renewable energy technologies. NREL maintains data and information on current clean energy technology performance and costs, including photovoltaic (PV*)* manufacturing costs used, to understand the opportunities for further cost reduction and to benchmark the state-of-the-art technology in the United States relative to other countries. Analysis also investigates the potential impact of growing renewable technology deployment on state and national economies, including jobs and workforce development needs.

Integrated Electric Sector/Grid Modeling: Integrating higher levels of renewable resources into the U.S. electricity system could pose challenges to the operability of the nation's grid. NREL's electric sector integration analysis work investigates, with electric utilities, energy policymakers, and other industry partners, the potential impacts of expanding renewable technology deployment on electricity, grid operations and infrastructure expansion. Analysis investigates the feasibility of higher levels of renewable electricity generation on the grid, options for increasing electric system flexibility to accommodate higher levels of variable renewable electricity, and the impacts of renewable electricity generation on the efficiency and emissions of conventional generators.

Project Finance Analysis: At the project level, NREL’s financial analysis helps potential renewable energy developers and investors gain insights into the complex world of project finance. Renewable energy project finance requires knowledge of federal tax credits, state-level incentives, renewable attribute markets, renewable technology installation and operation costs, and many other site-specific considerations. Analysis also examines the effects that policy can have on the development and financing of renewable energy projects, including how policies such as feed-in tariffs, clean renewable energy bonds, and power purchase agreements can shape the pace and structure of financing.

Market and Policy Analysis: NREL’s market and policy analysis assesses the current state of renewable energy and energy efficiency technologies in the marketplace and explores future technology, policy, and market development scenarios and their implications, providing strategic information to stakeholders interested in rapidly changing electricity and fuels markets. Market analysis focus areas include technology and program market data, and renewable energy certificate and green power markets. Policy analysis assesses the market implications of policies that can advance — or provide alternatives to — renewable energy technology deployment, at the national, state, and local level. NREL analyzes existing policies and proposed policy legislation related to clean energy.

Geospatial and Resource Energy Analysis: NREL conducts geospatial analysis of renewable resource availability, location, accessibility, quality, and other characteristics. These geospatial analysis capabilities are used broadly to screen opportunities across regions and sites, identify the technical and economic potential for clean energy development, and create supply curves that help inform energy plans.

Energy Informatics: NREL is invested in acquiring and adapting systems to access, manage, mine, and visualize data sets of various types and sources, including complex and massive streams of measured and modeled data from energy system experiments and deployed systems, to build knowledge and derive insights to inform decisions. Access to these data will represent a significant user resource to enable virtual experimentation, developing and testing advanced data mining and visualization techniques, and validating models.

Tools and Models

NREL analysts develop or support a variety of tools and models to assess, analyze, and optimize renewable energy and energy efficiency technologies. Many of these tools can be applied on a global, regional, local, or project basis. Increasingly, the tools are being delivered as complete Internet-based applications that access data repositories maintained by NREL and others, and as web services, so that other application developers can directly utilize NREL-developed algorithms and data.

Geospatial Tools: NREL has developed a variety of geographic information system (GIS) based applications that are freely available to the public. A listing and links to some examples is provided below:

- **OpenPV** – The Open PV Project is a community-driven database of PV installations. Users can visualize trends in PV costs, installations, and add their individual information to the database. http://openpv.nrel.gov/

- **PVWATTS** – NREL's PVWatts™ calculator estimates the energy production and cost savings of grid-connected PV energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations. http://www.nrel.gov/rredc/pvwatts/

- **IMBY** – The In My Backyard (IMBY) tool estimates the electricity you can produce with a solar PV array at your home or business. Homeowners, businesses, and researchers use IMBY to develop quick estimates of renewable energy production. http://www.nrel.gov/eis/imby/

- **BioPower Tool** – The BioPower Tool is an interactive geospatial application allowing users to view biomass resources, infrastructure, and other relevant information, as well as query the data and conduct initial screening analyses. http://maps.nrel.gov/biopower/launch

- **Solar Power Prospector** – This interactive mapping tool allows users to examine, distribute, and analyze solar resource data for the United States and northern Mexico. It assists in making decisions about optimal locations for CSP plants. http://maps.nrel.gov/prospector

- **Geospatial Toolkits –** NREL's Geospatial Toolkit (GsT) is a map-based software application that integrates resource data and base GIS data to allow data visualization, simple renewable energy related GIS analysis, and mapping for users in selected countries who otherwise may not have access to such information. http://www.nrel.gov/international/geospatial_toolkits.html

- **HyDRA** – HyDRA (Hydrogen Demand and Resource Analysis) is a web-based application that allows users to explore, query, download, and analyze dynamic spatial data related to the hydrogen infrastructure. HyDRA contains data from a wide range of sources including modeling results that estimate hydrogen demand, resource, infrastructure, cost, production, and distribution. http://maps.nrel.gov/hydra

- **Mapsearch –** For most people, maps are synonymous with GIS, and they are the final delivered product for the majority of NREL's GIS projects. The GIS team has an online map repository for publicly available products. Users may browse, search and download hundreds of maps produced by NREL. http://www.nrel.gov/gis/mapsearch.html

Crosscutting Analysis Models: NREL's models and tools help analysts' provide insight into renewable energy technologies and their uses. Integrated assessments using these models and tools enable NREL analysts to analyze energy scenarios and/or the benefits and impacts of and uncertainties and risks associated with energy plans, programs, portfolios, or policy options. Some key NREL models include:

- **Biomass Scenario Model** – The Biomass Scenario Model (BSM) is a system dynamics model of the full cellulosic ethanol supply chain for the United States. The BSM represents the primary system effects and dependencies in the biomass to biofuels supply chain and provides a framework for developing scenarios and conducting biofuels-related analysis. https://bsm.nrel.gov/

- **Cost of Renewable Energy Spreadsheet Tool (CREST)** – CREST is an economic cast flow model designed to enable public utilities commissions and the renewable energy community assess projects, design cost-based incentives (e.g., feed-in tariffs), and evaluate the impact of tax incentives or other support structures, currently for solar (PV and solar thermal), wind and geothermal technologies. https://financere.nrel.gov/finance/content/crest-model

- **Jobs and Economic Development Impacts (JEDI)** – These economic input/output-based models are used to calculate gross jobs (direct, indirect and induced), earnings and economic outputs within a region or state resulting from construction and operation of RE installations. http://www.nrel.gov/analysis/jedi/

- **REFlex** – REFlex is a reduced form dispatch model that evaluates the limits of variable renewable generation as a function of system flexibility. It can also evaluate the role of enabling technologies such as demand response and energy storage. Contact: Paul.Denholm@nrel.gov

- **Regional Energy Deployment System (ReEDS)** – Regional Energy Deployment System (ReEDS) is a multiregional, multi-time period, GIS, and linear programming model of capacity expansion in the electric sector of the United States. http://www.nrel.gov/analysis/reeds/

- **Regional Planning Model (RPM)** – An integrated resource planning and dispatch tool for regional electric systems, with high spatial and temporal resolution; an hourly chronological model with a highly discretized regional structure that co-optimizes transmission, generation, and storage options. Contact: Trieu.Mai@nrel.gov

- **REopt** – An early screening tool that identifies and prioritizes renewable energy projects using site, resource, cost, incentive and financial data. http://www.nrel.gov/tech_deployment/tools_reopt.html

- **SERA (Scenario Evaluation, Regionalization and Analysis)** – The SERA model is a geospatially and temporally oriented infrastructure analysis model that determines the optimal production and delivery scenarios for hydrogen, given resource availability and technology cost. http://en.openei.org/wiki/Scenario_Evaluation,_Regionalization_%26_Analysis_%28SERA%29

- **Stochastic Energy Deployment Systems (SEDS)** – The SEDS model is a stochastic, capacity-expansion, simulation model of the U.S. energy market. Contact: emily.newes@nrel.gov

- **System Advisor Model (SAM)** – The SAM model is a performance and financial model designed to predict performance and cost of grid-connected power projects based on installation and operating costs and system design parameters. The model addresses projects on the customer side of the utility meter, buying and selling electricity at retail rates; and on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement. https://sam.nrel.gov/

Data Sets

Access to data is essential to models and tools. NREL collects and makes available a range of data sets for the broader research community. NREL maintains knowledge resources on policies at the state and national level, utility-rate data, as well as renewable energy cost, performance, and installation information (e.g., PV, renewable fueling stations). Laboratory analysts provide access to high-quality measured and modeled national and global renewable resource data at various time scales; these are also made available as data sets, maps and tools. Some examples are described below:

Energy Data for Decision Makers: NREL's digital assets platform links energy communities and decision makers such as policy makers, researchers, technology investors, venture capitalists, and market professionals – with valuable energy data, information, analyses, tools, images, maps, and other resources. The Open Energy Information (http://www.openei.org) open data platform, developed by NREL with DOE support, catalyzes the world's energy information and links data together in new ways using "linked open data". Another example, the SmartGrid data hub (http://www.smartgrid.gov/), collects data from DOE American Recovery and Reinvestment Act (ARRA)-funded SmartGrid projects throughout the United States. These digital assets provide worldwide access to NREL's valuable analytical capabilities to help inform the energy decisions that will transform our energy system.

Geographic Data: NREL's Data and Visualization team has access to a wide variety of geospatial data; some is available to the public; others are proprietary, but may be used in analyses and can then be made publicly available. The data downloads are available in ESRI's shapefile format, which will require an ESRI GIS or compatible product to view and manipulate. This data is intended for users familiar with and who have access to GIS software, and includes renewable energy resource data for the United

States as well as a limited number of international locations. For more information visit http://www.nrel.gov/gis/data.html. A sampling of key datasets is listed below:

- **Biomass resources** – County-level summaries of available biomass in the United States, representing 2005 and 2008. The data contains residue quantities for crop, manure, forest, primary mill, secondary mill, urban mill waste, landfill, wastewater and switch grass. The 2008 county dataset has been further processed to produce a second dataset showing residue distribution at a finer resolution for crop, forest, landfill, primary mill, urban and secondary mill, and wastewater. A 2010 update dataset was completed for crops, plus specifics for sugarcane and sugar beets. Additional biomass-related resource datasets include biodiesel facilities, ethanol plants and pulp mills. For biomethane specifically, datasets include anaerobic digester gas facilities, dairy farms and sewage treatment plants.

- **Geothermal resources** – Datasets include hydrothermal well sites from the USGS, and enhanced geothermal systems potential (EGS) which was derived by NREL using modeled temperature at depth data from 3.5 to 9.5 km in 1 km intervals from the Southern Methodist University geothermal lab.

- **Hydrogen** – Datasets include hydrogen generation potential from biomass, coal, gas, solar, wind and all renewable sources, estimated by NREL. There is also a hydrogen refueling facilities dataset.

- **Solar resources** – Datasets include photovoltaic solar resource and concentrating solar resource (CSP) for all 50 states. The data for Hawaii and the lower 48 states are a 10-km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998 – 2005. The data for Alaska are a 40-km dataset produced by the Climatological Solar Radiation Model (NREL, 2003.) Data for other collector types include East-West 1-axis tracker and global horizontal for the lower 48 and Hawaii, and solar vent preheat for the lower 48 and Alaska. Additional solar resource datasets include the National Solar Radiation Database (NSRDB) and Typical Meteorological Year (TMY2/3) sites. Since 1981, NREL has continuously gathered basic solar radiation information and its Colorado site, and now gathers high-resolution data (in 1-minute intervals) from the World Meteorological Organization's first-class instruments. Daily instrument maintenance and annual calibrations are performed to ensure data quality. The Solar Radiation Research Laboratory is heavily instrumented with pyranometers, pyrheliometers, pyrgeometers, photometers, and spectroradiometers to provide the solar resource information necessary for renewable energy research and development.

- **Wind resources** – 50-meter onshore wind power density and speed for most states, including land-based areas where applicable. A few states in the Southeastern United States, as well as portions of Alaska, have only low resolution (40 km) wind power resource data produced by the 1987 Wind Energy Atlas of the United States. NREL maintains 90-meter offshore wind speed for most states, extending to 50 nautical miles offshore. Additional wind resource datasets include state/regional datasets at different heights, and wind data modeled for specific years. For more information see http://www.windpoweringamerica.gov/wind_maps.asp

- **Energy Infrastructure** – Fueling stations (biodiesel, compressed natural gas, electricity, ethanol/E85, gasoline, hydrogen, liquid natural gas or liquid petroleum gas), biodiesel plants, electric control centers (facilities responsible for balancing electricity load), electric power generating plants, electric service territories, electric substations, electric transmission lines, energy

control areas (aggregation of electric retail service areas based on control area membership), Federal Energy Regulatory Commission (FERC) regions, natural gas storage, North American Electric Reliability Council (NERC) regions and subregions, nuclear research facilities, oil/gas facilities, oil/gas pipelines, oil terminals, offshore oil platforms, pipeline interconnects (includes oil/gas/petrochemical, etc.), propane retailers, Radiological Assistance Program (RAP) regions (provides Department of Energy {DOE} assistance to organizations responding to nuclear emergency), refineries, strategic petroleum reserves, oil/gas wells.

Recent Studies, Reports, Other Examples

Manufacturing, Supply Chain and Economic Competitiveness

Goodrich, A.; Hacke, P.; Wang, Q.; Sopori, B.; Margolis, R.; James, T. L.; Woodhouse, M. (2013). Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technology Improvement Opportunities for Further Reductions in Manufacturing Costs. Solar Energy Materials and Solar Cells. Vol. 114, July 2013; pp. 110-135; NREL Report No. JA-6A20-57504. http://dx.doi.org/10.1016/j.solmat.2013.01.030

Goodrich, A.; Woodhouse, M.; Hacke, P. (2012). Value Proposition for High Lifetime (p-type) and Thin Silicon Materials in Solar PV Applications. [Proceedings] 38th IEEE Photovoltaic Specialists Conference (PVSC '12), 3-8 June 2012, Austin, Texas. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) pp. 003238-003241; NREL Report No. CP-6A20-56932. http://dx.doi.org/10.1109/PVSC.2012.6318267

Goodrich, A.; James, T.; Woodhouse, M. (2012). Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities. 64 pp.; NREL Report No. TP-6A20-53347. http://www.nrel.gov/docs/fy12osti/53347.pdf

Feldman, D.; Barbose, G.; Margolis, R.; Wiser, R.; Darghouth, N.; Goodrich, A. (2012). Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. 30 pp.; NREL Report No. TP-6A20-56776; DOE/GO-102012-3839. http://www.nrel.gov/docs/fy13osti/56776.pdf

Friedman, B. (2012). PV Installation Labor Market Analysis and PV JEDI Tool Developments (Presentation). NREL (National Renewable Energy Laboratory). 28 pp.; NREL Report No. PR-6A20-55130. http://www.nrel.gov/docs/fy12osti/55130.pdf

Woodhouse, M.; Goodrich, A.; James, T. L.; Margolis, R.; Lokanc, M.; Eggert, R. (2012). Supply Chain Dynamics of Tellurium (Te), Indium (In), and Gallium (Ga) Within the Context of PV Module Manufacturing Costs (Presentation). NREL (National Renewable Energy Laboratory). 25 pp.; NREL Report No. PR-6A20-57138. http://www.nrel.gov/docs/fy13osti/57138.pdf

Goodrich, A.; James, T.; Woodhouse, M. (2011). Solar PV Manufacturing Cost Analysis: U.S. Competitiveness in a Global Industry (Presentation). NREL (National Renewable Energy Laboratory). 45 pp.; NREL Report No. PR-6A20-53938. http://www.nrel.gov/docs/fy12osti/53938.pdf

Finance

Mendelsohn, M.; Feldman, D. (2013). Financing U.S. Renewable Energy Projects Through Public Capital Vehicles: Qualitative and Quantitative Benefits. 38 pp.; NREL Report No. TP-6A20-58315. http://www.nrel.gov/docs/fy13osti/58315.pdf

Mendelsohn, M.; Harper, J. (2012). Section 1603 Treasury Grant Expiration: Industry Insight on Financing and Market Implications. 41 pp.; NREL Report No. TP-6A20-53720. http://www.nrel.gov/docs/fy12osti/53720.pdf

Steinberg, D.; Porro, G.; Goldberg, M. (2012). Preliminary Analysis of the Jobs and Economic Impacts of Renewable Energy Projects Supported by the ..Section..1603 Treasury Grant Program. 33 pp.; NREL Report No. TP-6A20-52739. http://www.nrel.gov/docs/fy12osti/52739.pdf

Mendelsohn, M.; Kreycik, C.; Bird, L.; Schwabe, P.; Cory, K. (2012). Impact of Financial Structure on the Cost of Solar Energy. 40 pp.; NREL Report No. TP-6A20-53086. http://www.nrel.gov/docs/fy12osti/53086.pdf

Feldman, D.; Mendelsohn, M.; Coughlin, J. (2012). Technical Qualifications for Treating Photovoltaic Assets as Real Property by Real Estate Investment Trusts (REITs). 15 pp.; NREL Report No. TP-6A20-55396. http://www.nrel.gov/docs/fy12osti/55396.pdf

Schwabe, P.; Mendelsohn, M.; Mormann, F.; Arent, D. J. (2012). Mobilizing Public Markets to Finance Renewable Energy Projects: Insights from Expert Stakeholders. 17 pp.; NREL Report No. TP-6A20-55021. http://www.nrel.gov/docs/fy12osti/55021.pdf

Market

Eurek, K.; Denholm, P.; Margolis, R.; Mowers, M. (2013). Sensitivity of Utility-Scale Solar Deployment Projections in the SunShot Vision Study to Market and Performance Assumptions. 55 pp.; NREL Report No. TP-6A20-55836. http://www.nrel.gov/docs/fy13osti/55836.pdf

Ong, S.; Clark, N.; Denholm, P.; Margolis, R. (2013). Breakeven Prices for Photovoltaics on Supermarkets in the United States. 40 pp.; NREL Report No. TP-6A20-57276. http://www.nrel.gov/docs/fy13osti/57276.pdf

Milligan, M.; Clark, K.; King, J.; Kirby, B.; Guo, T.; Liu, G. (2013). Examination of Potential Benefits of an Energy Imbalance Market in the Western Interconnection. 122 pp.; NREL Report No. TP-5500-57115. http://www.nrel.gov/docs/fy13osti/57115.pdf

Mendelsohn, M.; Lowder, T.; Canavan, B. (2012). Utility-Scale Concentrating Solar Power and Photovoltaic Projects: A Technology and Market Overview. 65 pp.; NREL Report No. TP-6A20-51137. http://www.nrel.gov/docs/fy12osti/51137.pdf

Bush, B.; Jenkin, T.; Lipowicz, D.; Arent, D. J.; Cooke, R. (2012). Variance Analysis of Wind and Natural Gas Generation under Different Market Structures: Some Observations. 50 pp.; NREL Report No. TP-6A20-52790. http://www.nrel.gov/docs/fy12osti/52790.pdf

Speer, B. (2012). Geothermal Brief: Market and Policy Impacts Update. 35 pp.; NREL Report No. TP-6A20-53288. http://www.nrel.gov/docs/fy13osti/53288.pdf

Drury, E.; Miller, M.; Macal, C. M.; Graziano, D. J.; Heimiller, D.; Ozik, J.; Perry, T. D. (2012). Transformation of Southern California's Residential Photovoltaics Market Through Third-Party Ownership. Energy Policy. Vol. 42, March 2012; pp. 681-690; NREL Report No. JA-6A20-51514. http://dx.doi.org/10.1016/j.enpol.2011.12.047

Ong, S.; Campbell, C.; Clark, N. (2012). Impacts of Regional Electricity Prices and Building Type on the Economics of Commercial Photovoltaic Systems. 41 pp.; NREL Report No. TP-6A20-56461. http://www.nrel.gov/docs/fy13osti/56461.pdf

Milligan, M. (2012). Market Implications of High Levels of Wind and Solar Generation. Proceedings of the 2012 IEEE Power and Energy Society General Meeting, 22-26 July 2012, San Diego, California. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) 1 pg.; NREL Report No. CP-5500-54737. http://dx.doi.org/10.1109/PESGM.2012.6345455

Sioshansi, R.; Denholm, P.; Jenkin, T. (2012). Market and Policy Barriers to Deployment of Energy Storage. Economics of Energy and Environmental Policy. Vol. 1(2), March 2012; pp. 47-63; NREL Report No. JA-6A20-53820. http://dx.doi.org/10.5547/2160-5890.1.2.4

Policy

Lee, A.; Zinaman, O.; Logan, J. (2012). Opportunities for Synergy Between Natural Gas and Renewable Energy in the Electric Power and Transportation Sectors. 59 pp.; NREL Report No. TP-6A50-56324. http://www.nrel.gov/docs/fy13osti/56324.pdf

Heeter, J.; Bird, L. (2012). Including Alternative Resources in State Renewable Portfolio Standards: Current Design and Implementation Experience. 35 pp.; NREL Report No. TP-6A20-55979. http://www.nrel.gov/docs/fy13osti/55979.pdf

Heeter, J.; Armstrong, P.; Bird, L. (2012). Market Brief: Status of the Voluntary Renewable Energy Certificate Market (2011 Data). 36 pp.; NREL Report No. TP-6A20-56128. http://www.nrel.gov/docs/fy12osti/56128.pdf

Holt, E.; Sumner, J.; Bird, L. (2011). Role of Renewable Energy Certificates in Developing New Renewable Energy Projects. 59 pp.; NREL Report No. TP-6A20-51904. http://www.nrel.gov/docs/fy11osti/51904.pdf

Palmer, K.; Paul, A.; Woerman, M.; Steinberg, D. C. (2011). Federal Policies for Renewable Electricity: Impacts and Interactions. Energy Policy. Vol. 39(7), July 2011; pp. 3975-3591; NREL Report No. JA-6A20-52457. http://dx.doi.org/10.1016/j.enpol.2011.01.035

Bird, L.; Chapman, C.; Logan, J.; Sumner, J.; Short, W. (2011). Evaluating Renewable Portfolio Standards and Carbon Cap Scenarios in the U.S. Electric Sector. Energy Policy. Vol. 39(5), May 2011; pp. 2573-2585; NREL Report No. JA-6A20-50749. http://dx.doi.org/10.1016/j.enpol.2011.02.025

Bird, L.; Reger, A.; Heeter, J. (2012). Distributed Solar Incentive Programs: Recent Experience and Best Practices for Design and Implementation. 62 pp.; NREL Report No. TP-6A20-56308. http://www.nrel.gov/docs/fy13osti/56308.pdf

Sullivan, P.; Logan, J.; Bird, L.; Short, W. (2009). Comparative Analysis of Three Proposed Federal Renewable Electricity Standards. 30 pp.; NREL Report No. TP-6A2-45877. http://www.nrel.gov/docs/fy09osti/45877.pdf

Logan, J.; Sullivan, P.; Short, W.; Bird, L.; James, T. L.; Shah, M. R. (2009). Evaluating a Proposed 20% National Renewable Portfolio Standard. 35 pp.; NREL Report No. TP-6A2-45161. http://www.nrel.gov/docs/fy09osti/45161.pdf

Logan, J.; James, T. L. (2009). Comparative Review of a Dozen National Energy Plans: Focus on Renewable and Efficient Energy. 49 pp.; NREL Report No. TP-6A2-45046. http://www.nrel.gov/docs/fy09osti/45046.pdf

Integrated Electric Sector/Grid Modeling

Drury, E.; Denholm, P.; Margolis, R. (2013). Sensitivity of Rooftop PV Projections in the SunShot Vision Study to Market Assumptions. 37 pp.; NREL Report No. TP-6A20-54620. http://www.nrel.gov/docs/fy13osti/54620.pdf

Denholm, P.; Kuss, M.; Margolis, R. M. (2013). Co-Benefits of Large Scale Plug-In Hybrid Electric Vehicle and Solar PV Deployment. Journal of Power Sources. Vol. 236, 15 August 2013; pp. 350-356; NREL Report No. JA-6A20-54247. http://dx.doi.org/10.1016/j.jpowsour.2012.10.007

Denholm, P.; Hummon, M. (2013). Summary of: Simulating the Value of Concentrating Solar Power with Thermal Energy Storage in a Production Cost Model (Presentation). NREL (National Renewable Energy Laboratory). 38 pp.; NREL Report No. PR-6A20-57376. http://www.nrel.gov/docs/fy13osti/57376.pdf

Lew, D.; Brinkman, G.; Kumar, N.; Besuner, P.; Agan, D.; Lefton, S. (2012). Impacts of Wind and Solar on Emissions and Wear and Tear of Fossil-Fueled Generators. Proceedings of the 2012 IEEE Power and Energy Society General Meeting, 22-26 July 2012, San Diego, California. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) 8 pp.; NREL Report No. CP-5500-57686. http://dx.doi.org/10.1109/PESGM.2012.6343967

Hurlbut, D. J.; Haase, S.; Brinkman, G.; Funk, K.; Gelman, R.; Lantz, E.; Larney, C.; Peterson, D.; Worley, C.; Liebsch, E. (2012). Navajo Generating Station and Air Visibility Regulations: Alternatives and Impacts (Revised). Energy Analysis, NREL (National Renewable Energy Laboratory). 126 pp.; NREL Report No. TP-6A20-53024. http://www.nrel.gov/docs/fy12osti/53024.pdf

Cochran, J.; Bird, L.; Heeter, J.; Arent, D. A. (2012). Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience, Summary for Policymakers. 20 pp.; NREL Report No. TP-6A20-53730. http://www.nrel.gov/docs/fy12osti/53730.pdf

Bird, L.; Lew, D. (2012). Integrating Wind and Solar Energy in the U.S. Bulk Power System: Lessons from Regional Integration Studies. 9 pp.; NREL Report No. CP-6A50-55830. http://www.nrel.gov/docs/fy12osti/55830.pdf

MAJOR STUDIES

Renewable Electricity Futures Study

Mai, T.; Sandor, D.; Wiser, R.; Schneider, T. (2012). Renewable Electricity Futures Study. Executive Summary. Golden, CO: National Renewable Energy Laboratory 55 pp.; NREL Report No. TP-6A20-52409-ES. http://www.nrel.gov/docs/fy13osti/52409-ES.pdf

Mai, T.; Wiser, R.; Sandor, D.; Brinkman, G.; Heath, G.; Denholm, P.; Hostick, D.J.; Darghouth, N.; Schlosser, A.; Strzepek, K. (2012). Renewable Electricity Futures Study. Volume 1: Exploration of High-Penetration Renewable Electricity Futures. (Volume 1 of 4). Golden, CO: National Renewable Energy Laboratory 280 pp.; NREL Report No. TP-6A20-52409-1. http://www.nrel.gov/docs/fy13osti/52409-1.pdf

Augustine, C.; Bain, R.; Chapman, J.; Denholm, P.; Drury, E.; Hall, D.G.; Lantz, E.; Margolis, R.; Thresher, R.; Sandor, D.; Bishop, N.A.; Brown, S.R.; Cada, G.F.; Felker, F. (2012). Renewable Electricity Futures Study. Volume 2: Renewable Electricity Generation and Storage Technologies. (Volume 2 of 4). Golden, CO: National Renewable Energy Laboratory 370 pp.; NREL Report No. TP-6A20-52409-2. http://www.nrel.gov/docs/fy13osti/52409-2.pdf

Hostick, D.; Belzer, D.B.; Hadley, S.W.; Markel, T.; Marnay, C.; Kintner-Meyer, M. (2012). Renewable Electricity Futures Study. Volume 3: End-Use Electricity Demand. (Volume 3 of 4). Golden, CO: National Renewable Energy Laboratory 132 pp.; NREL Report No. TP-6A20-52409-3. http://www.nrel.gov/docs/fy13osti/52409-3.pdf

Milligan, M.; Ela, E.; Hein, J.; Schneider, T.; Brinkman, G.; Denholm, P. (2012). Renewable Electricity Futures Study. Volume 4: Bulk Electric Power Systems: Operations and Transmission Planning. (Volume 4 of 4). Golden, CO: National Renewable Energy Laboratory 72 pp.; NREL Report No. TP-6A20-52409-4. http://www.nrel.gov/docs/fy13osti/52409-4.pdf

Transportation Energy Futures Project

Transportation Energy Futures: Project Overview and Findings (Presentation). NREL (National Renewable Energy Laboratory). (2013). 21 pp.; NREL Report No. PR-6A20-56270; DOE/GO-102013-3921. http://www.nrel.gov/docs/fy13osti/56270.pdf

Plotkin, S.; Stephens, T.; McManus, W. (2013). Transportation Energy Futures Series: Vehicle Technology Deployment Pathways: An Examination of Timing and Investment Constraints. 70 pp.; NREL Report No. TP-6A20-55638; DOE/GO-102013-3708. http://www.nrel.gov/docs/fy13osti/55638.pdf

Stephens, T. (2013). Transportation Energy Futures Series: Non-Cost Barriers to Consumer Adoption of New Light-Duty Vehicle Technologies. 60 pp.; NREL Report No. TP-6A20-55639; DOE/GO-102013-3709. http://www.nrel.gov/docs/fy13osti/55639.pdf

Melaina, M. W.; Heath, G.; Sandor, D.; Steward, D.; Vimmerstedt, L.; Warner, E.; Webster, K. W. (2013). Transportation Energy Futures Series: Alternative Fuel Infrastructure Expansion: Costs, Resources, Production Capacity, and Retail Availability for Low-Carbon Scenarios. 118 pp.; NREL Report No. TP-6A20-55640; DOE/GO-102013-3710. http://www.nrel.gov/docs/fy13osti/55640.pdf

Grenzeback, L. R.; Brown, A.; Fischer, M. J.; Hutson, N.; Lamm, C. R.; Pei, Y. L.; Vimmerstedt, L.; Vyas, A. D.; Winebrake, J. J. (2013). Transportation Energy Futures Series: Freight Transportation Demand: Energy-Efficient Scenarios for a Low-Carbon Future. 96 pp.; NREL Report No. TP-6A20-55641; DOE/GO-102013-3711. http://www.nrel.gov/docs/fy13osti/55641.pdf

Brogan, J. J.; Aeppli, A. E.; Beagan, D. F.; Brown, A.; Fischer, M. J.; Grenzeback, L. R.; McKenzie, E.; Vimmerstedt, L.; Vyas, A. D.; Witzke, E. (2013). Transportation Energy Futures Series: Freight Transportation Modal Shares: Scenarios for a Low-Carbon Future. 94 pp.; NREL Report No. TP-6A20-55636; DOE/GO-102013-3705. http://www.nrel.gov/docs/fy13osti/55636.pdf

Porter, C. D.; Brown, A.; DeFlorio, J.; McKenzie, E.; Tao, W.; Vimmerstedt, L. (2013). Transportation Energy Futures Series: Effects of Travel Reduction and Efficient Driving on Transportation: Energy Use and Greenhouse Gas Emissions. 113 pp.; NREL Report No. TP-6A20-55635; DOE/GO-102013-3704. http://www.nrel.gov/docs/fy13osti/55635.pdf

Porter, C. D.; Brown, A.; Dunphy, R. T.; Vimmerstedt, L. (2013). Transportation Energy Futures Series: Effects of the Built Environment on Transportation: Energy Use, Greenhouse Gas Emissions, and Other Factors. 106 pp.; NREL Report No. TP-6A20-55634; DOE/GO-102013-3703. http://www.nrel.gov/docs/fy13osti/55634.pdf

Vyas, A. D.; Patel, D. M.; Bertram, K. M. (2013). Transportation Energy Futures Series: Potential for Energy Efficiency Improvement Beyond the Light-Duty-Vehicle Sector. 98 pp.; NREL Report No. TP-6A20-55637; DOE/GO-102013-3706. http://www.nrel.gov/docs/fy13osti/55637.pdf

Western Wind and Solar Integration Study

Lew, D.; Brinkman, G.; Ibanez, E.; Kumar, N.; Lefton, S.; Jordan, G.; Venkataraman, S.; King, J. (2013). Western Wind and Solar Integration Study Phase 2 (Presentation). NREL (National Renewable Energy Laboratory). 27 pp.; NREL Report No. PR-5500-57922. http://www.nrel.gov/docs/fy13osti/57922.pdf

Lew, D.; Brinkman, G.; Ibanez, E.; Hodge, B.-M.; King, J. (2012). Western Wind and Solar Integration Study Phase 2: Preprint. 9 pp.; NREL Report No. CP-5500-56217. http://www.nrel.gov/docs/fy12osti/56217.pdf

Lew, D.; Piwko, R.; Jordan, G.; Miller, N.; Clark, K.; Freeman, L.; Milligan, M. (2011). Western Wind and Solar Integration Study. Langen, Germany: Energynautics GmbH 7 pp.; NREL Report No. CP-5500-52400. http://goo.gl/uEAda

GE Energy (2010). Western Wind and Solar Integration Study. 536 pp.; NREL Report No. SR-550-47434. http://www.nrel.gov/docs/fy10osti/47434.pdf

Eastern Wind Integration and Transmission Study

Pennock, K. (2012). Updated Eastern Interconnect Wind Power Output and Forecasts for ERGIS: July 2012. 21 pp.; NREL Report No. SR-5500-56616. http://www.nrel.gov/docs/fy13osti/56616.pdf

Eastern Wind Integration and Transmission Study (EWITS) (Revised). (2011). 242 pp.; NREL Report No. SR-5500-47078. http://www.nrel.gov/docs/fy11osti/47078.pdf

Eastern Wind Integration and Transmission Study: Executive Summary and Project Overview (Revised). (2011). 48 pp.; NREL Report No. SR-5500-47086. http://www.nrel.gov/docs/fy11osti/47086.pdf

Brower, M. (2009). Development of Eastern Regional Wind Resource and Wind Plant Output Datasets: March 3, 2008 -- March 31, 2010. 66 pp.; NREL Report No. SR-550-46764. http://www.nrel.gov/docs/fy10osti/46764.pdf

Corbus, D.; Milligan, M.; Ela, E.; Schuerger, M.; Zavadil, B. (2009). Eastern Wind Integration and Transmission Study - Preliminary Findings. Langen, Germany: Energynautics GmbH pp. 244-249; NREL Report No. CP-5500-54683. http://goo.gl/haU1x

Joint Institute for Strategic Energy Analysis (JISEA) Examples

Logan, J.; Heath, G.; Macknick, J.; Paranhos, E.; Boyd, W.; Carlson, K. (2012). Natural Gas and the Transformation of the U.S. Energy Sector: Electricity. 255 pp.; NREL Report No. TP-6A50-55538. http://www.nrel.gov/docs/fy13osti/55538.pdf

Lee, A.; Zinaman, O.; Logan, J.; Bazilian, M.; Arent, D.; Newmark, R. L. (2012). Interactions, Complementarities and Tensions at the Nexus of Natural Gas and Renewable Energy. Electricity Journal. Vol. 25(10), December 2012; pp. 38-48; NREL Report No. JA-6A50-56674. http://dx.doi.org/10.1016/j.tej.2012.10.021

Denholm, P.; King, J.; Kutscher, C.; Wilson, P. (2012). Decarbonizing the Electric Sector: Combining Renewable and Nuclear Energy using Thermal Storage. Energy Policy. Vol. 44, May 2012; pp. 301-311; NREL Report No. JA-6A20-53118. http://dx.doi.org/10.1016/j.enpol.2012.01.055