PNNL-EPE-176141

For DOE Internal Use

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PNNL - Summary of Economic, Market, Financial & Policy Analysis Capabilities

June 2017

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Executive Summary

PNNL specializes in analyzing and understanding the impacts of the interface between science and society. As a consequence of working closely with physicists, chemists, and engineers on the front lines of the nation's energy challenges, our research economists, social and behavioral scientists and policy analysts bring a valuable cross-disciplinary approach to the social, institutional, and policy dimensions of research, analysis, and impact assessment.

With over 130 economists, statisticians, policy, social, and behavioral scientists, PNNL has strong capabilities in economics, statistics, financial and market analyses in support of Energy Efficiency, Renewable Energy, Transportation, Environment, and National Security projects.

PNNL market and policy analyses have provided key insights and guidance to decision makers in developing significant state and national investments in smart grid and electricity infrastructure technology. PNNL regulatory analysis and energy efficiency rule development in support of the DOE's Appliance and Commercial Equipment Standards Programs have resulted in projected national cost savings of $1.1 Trillion and over 200 Quads of energy (equivalent of 2 years energy consumption in the U.S.) saved by 2035. Similarly, a recent PNNL analysis showed that a 75 percent market penetration of Electric Vehicles was feasible with the nation's existing power infrastructure.

In addition to our experienced staff, we have developed a toolbox of economic, financial, and policy simulation, analysis, and modeling capabilities that are especially focused on answering the kind of policy questions to which national and regional decision-makers need answers. Our toolbox is focused on the following areas:

- Market\Policy Simulation, Analysis & Modeling
- Market Rate Analysis
- Cost-Benefit Analysis
- Economic Analyses & Modeling
- Microeconomic, Natural Resource, Environmental, Regional & Socio Economic Modeling

We have developed and utilize specialized tools that include:

- SEDS – Stochastic Energy Deployment System Model
- IMSET – Impact of Sector Energy Technologies Model
- SEADS – Sector Energy/Employment Analysis and Data System Model
- GridLab-D – Energy Grid Simulator
- PRIMA – Platform for Regional Integrated Modeling and Analysis
- RIM – Renewables Integration Model
- ESIOS – Electric System Intrahour Operations Simulator
- PROMOD – Production Cost Modeling
- PHOENIX - Global Computable General Equilibrium Model for International Policy Analysis
- GCAM – Global Change Assessment Model

Also included herein are references to a few representative examples of the kinds of market, financial, and policy analyses, assessments and studies that we have performed over the past few years to help the DOE to better inform stronger and more impactful policy development decisions.

PNNL Example Tools & Assessments in Support of Addressing DOE's Strategies to Address National Energy Challenges

	Energy Supply	Supply/Demand	Energy Demand
Stationary	**Deploy Clean Electricity** • RIM - Renewables Integration Model • ESIOS-Electric System Intra-hour Operations Simulator • GCAM – Global Change Assessment Model • JERO – Joint Energy Efficiency & Renewable Energy Optimizer	**Modernize the Grid** • GRIDLAB-D - Energy Grid Simulator • PROMOD & PLEXOS– Production Cost Modeling & Power System Simulation • Annual SmartGrid Systems Report to Congress	**Increase Building & Industrial Efficiency** • PRIMA – Platform for Regional Integrated Modeling and Analysis • ITEMS – Industrial Technology Energy Modeling System • SEADS – Sector Energy-Employment Analysis & Data System • NEMS-PNNL: National Energy Modeling System (PNNL variant) • IMSET – Impact of Sector Energy Technologies
Transport	**Deploy Alternative Hydrocarbon Fuels** • SEDS – Stochastic Energy Deployment System • Carbon Capture & Sequestration Modeling • Biomass Availability & Market Impact Assessments	**Electrify the Vehicle Fleet** • EV Infrastructure Feasibility Studies	**Increase Vehicle Efficiency**

1.0 Overview and Approach

In addition to basic and applied research in support of DOE, PNNL has leveraged long-standing relationships with industry, academia, regulators and a wide variety of state and federal agencies, to develop unique analytic tools, metrics and methodologies necessary to infuse the energy policy development process with enhanced empirical rigor. PNNL has long recognized that establishing a robust, data-driven analytic foundation—tethered to the real-world, market-based dynamics that shape the trajectory of energy infrastructure investment and technology deployment—is key to fostering consensus across the diverse set of stakeholders necessary to make meaningful and durable progress toward accepted national energy objectives.

Like many national laboratories, PNNL is engaged in the development and application of a wide variety of analytic methods, advanced modeling and simulation tools applicable to energy and transportation systems, from production cost modeling and life cycle cost analysis, to market and policy modeling, economic feasibility and impact analyses. But in addition, it is worth noting a handful of differentiated capabilities, which have evolved in part from more than two decades of partnerships with both a wide cross-section of industry and a variety of federal agencies. These partnerships have provided PNNL researchers uniquely rich data sets relevant to operation of the power system at both the transmission and distribution levels, the techno-economic implications of integrating new classes of assets (including variable generation, energy storage and demand response) as well as real-world performance of buildings and systems/appliances within buildings—across the civilian/commercial and residential, and federal (including defense) sectors.

In tandem with the development of unique tools described more fully below, these public/private partnerships and associated access to data have helped build a preliminary foundation for market and policy-related analytics that provide the additional degrees of granularity necessary to reflect the complex, systems-related concerns of today's industry.

The sections below detail a handful of PNNL-developed tools and methodologies that illustrate the lab's capabilities in the context of conducting economic, market, finance- and policy-related analytics. Also below is a brief accounting of PNNL's organizational structure in support of market, finance and policy analysis, and a brief treatment of key industry and policy-related partners.

2.0. Markets, Finance & Policy: Key PNNL Tools

GridLab-D – Energy Grid Simulator: Grid-Lab D is a power distribution system simulation and analysis tool that allows users to create detailed models of how new end-use technologies, distributed energy resources (DER), distribution automation, and retail markets interact and evolve over time. Its unique value is derived from its integration of power system, load and market models—further combined with communications networks, which are increasingly critical to distribution system operations. GridLab-D provides the ability to create and validate rate structures, examine consumer reaction, and verify the interaction and dependence of programs with other technologies and wholesale markets. GridLab-D is currently being used to estimate the value of the ARRA Smart-Grid demonstration projects.

PRIMA – Platform for Regional Integrated Modeling and Analysis: PRIMA provides the ability to simulate the complex interactions among climate, energy, water, and land at decision-relevant spatial scales. By bringing together models of climate, socioeconomics, hydrology, agriculture,

buildings, electricity, and other sectors, PRIMA helps regional stakeholders develop and evaluate policy strategies for responding to complex socioeconomic and environmental, energy technology and infrastructure changes. Examples are:

- Economic trade-off analyses of bio-fuels for transportation versus electrification of transportation under climate change constraints
- Regional assessments of adaptation and mitigation trade-offs between energy demand and supply sectors and land-use and water management strategies.
- Evaluate extreme weather conditions on reliability of electric grids

RIM – Renewables Integration Model: RIM is an economic dispatch model for electricity generators with ambient air and cooling water constraints. This model allows researchers to quantify the impacts of drought and heat-wave conditions on the electricity supply sector. It provides the ability to evaluate existing and future generation mix, and identify the flexibility/controllability attributes required including cycling, re-dispatch, ramping, and reserve.

ESIOS-Electric System Intra-hour Operations Simulator: ESIOS allows researchers to quantitatively analyze the impacts of new wind capacity on power system planning and operation. This tool provides the ability to evaluate existing and future generation mix, and identify the flexibility/controllability attributes required for future grid operations--including cycling, re-dispatch, ramping, and reserve. Relative to many other renewables integration models, a key differentiator is ESIOS' ability to capture intra-hour system dynamics, which is critical to understanding the techno-economic implications of balancing variable energy generation with other grid-connected assets.

WECC-Data-Enhanced PROMOD & PLEXOS– Production Cost Modeling & Power System Simulation: PROMOD and PLEXOS are utility-grade tools used widely among grid operators for electric market and power system simulation. These models incorporate extensive detail in generating unit operating characteristics, transmission grid topology and constraints, and market system operations to support economic transmission planning. This includes Financial Transmission Right (FTR), Congestion Revenue Right (CRR) and Transmission Congestion Contract (TCC) Valuation for quantifying market prices, identifying binding constraints, and evaluating the economic impacts of constraints significant to market participants. But in addition, PNNL has a calibrated WECC load models that allow for additional levels of resolution in the calculation of costs/benefits associated with new operating paradigms and the integration of new assets into the WECC system.

ITEMS – Industrial Technology Energy Modeling System: **ITEMS** provides a comprehensive economic-engineering model of U.S. manufacturing industries and can evaluate individual technology alternatives in individual industries.

SEDS – Stochastic Energy Deployment System: This model fully characterizes the energy economy, including various demand sectors and the electricity, liquid fuels, natural gas, coal and renewable energy sectors. The SEDS model is designed to account for the stochastic nature of both energy R&D and the market penetration of new technologies. SEDS structure allows for both deterministic and stochastic modeling, providing complete information regarding the likelihood of analyzed scenarios that take into account uncertainty of R&D outcomes and their impacts on the industrial sector.

SEADS – Sector Energy/Employment Analysis and Data System: SEADS provides a quick and easy tool to assess preliminary impacts of policy alternatives, for quick-turn *ad hoc* analysis requests. This tool uses an input-output model to assess the impacts of changes in final demands

on first industry output, then employment and energy use. The employment and energy impacts are derived by multiplying the industry outputs (derived from the changed final demands) by industry-specific energy and employment coefficients. The tool also allows for the specification of regional or state employment impacts.

NEMS-PNNL: National Energy Modeling System (PNNL variant): PNNL maintains the current version of EIA's NEMS model with modifications for addressing DOE/EERE question related to Commercial Appliance and Equipment Standards Program and DOE/OE questions regarding electrification of transportation. It is also worth noting that PNNL staff have made significant contributions to the NEMS to renewables model (within its electricity market model), as well NEMS' treatment of the oil and gas supply system.

IMSET – Impact of Sector Energy Technologies: IMSET enables assessment of the macroeconomic impact on the U.S. economy of DOE energy efficiency programs (jobs, personal income, gross product, investment). IMSET takes program energy savings as input and estimates economic impacts, including altered manufacturing market structure induced by development of new technologies.

GCAM – Global Change Assessment Model: GCAM is an "integrated assessment model" (IAM) that has been used extensively by the U.S. government for exploration of the markets for new energy technologies and the economic and energy system implications of policy concepts--particularly those relating to climate change mitigation. It combines representations of the global and domestic energy systems, economic systems, agriculture and land use systems, emissions of greenhouse gases, and climate change into a single platform, allowing for exploration of interactions between all of these systems simultaneously. It can be used for research and analysis at both domestic and international scales.

Phoenix – A Global Computable General Equilibrium model for International Policy Analysis: Phoenix is a global energy and economic model that focuses on the implications of national and international policies for international trade and economic growth, using a computable general equilibrium framework. It is particularly valuable for understanding the linkage between U.S. and international energy policy actions.

JERO – Joint Energy Efficiency & Renewable Energy Optimizer: JERO enables life-cycle cost analysis that simultaneously optimizes mix of renewable and energy efficiency measures for large-scale deployment.

3.0 Market, Finance & Policy: Staff Capabilities

PNNL has technical groups organized to support answering the challenging market, financial, and policy questions facing the nation in the areas of energy, environment, and national security. These technical groups are:

Energy & Environment Directorate

- Energy Policy & Economics Group – (15 economists, 10 public policy analysts)
  Group is focused on performing economic, financial and market analyses in support of Energy Efficiency, Renewable Energy and Integrated Energy Systems projects (Cost-benefit, Impacts, Predictive analytics, techno-socio economic assessments)

- Process Engineering, Modeling, & Economics Team – (4 engineering analysts)
  Team is focused on performing techno-economic and life-cycle cost assessments of thermal, catalysis, and other hydrocarbon based processes

- Risk & Decision Sciences Group – (8 policy/risk analysts)
  Group is focused on providing analysis and policy support for risk-informed decisions in uncertain and complex natural or engineered systems such as environmental cleanup, nuclear safety and licensing, preventing acts of terrorism and the proliferation of weapons of mass destruction.

National Security Directorate

- Global Security Technology & Policy – (14 public policy/regulatory analysts)
  Team is focused on legislative and regulatory development, international nuclear cooperation and engagement, integrated technical and policy analysis, global nuclear fuel cycle policy analysis, industry engagement and self-regulation, arms control and nonproliferation policy

- Applied Statistics & Computational Modeling Group – (26 statisticians/analyst)
  Group is focused on large scale systems analysis and economics, programmatic life-cycle studies that model and quantify system performance, life-cycle costs, risks, and trade-offs. Statistical data and process analysis in energy and power grid, climate, and related domain areas

Earth & Biological Sciences Directorate

- Joint Global Change Research Institute – (50 economists, engineers, scientists, analysts)
  This group performs integrated modeling and research on the implications of energy and climate policies and new energy and agricultural technologies, with a focus on economic impacts, markets for new technologies, implications of and for natural resources, greenhouse gas emissions, climate change mitigation, and climate change impacts.

4.0 Market Analysis Examples

PNNL Fuel Market Analysis
PNNL performed an assessment of the nuclear fuel fabrication market that was used as input to UxC consulting for their Nuclear Fuel Fabrication Market Outlook

U.S. Energy Sector Analyses - Buildings Sector Analysis
PNNL performed a buildings sector market analysis to support the Department of Energy's Weatherization & Intergovernmental Program planning and management decisions.

Analysis for Converting Cellulosic Feedstocks to Hydrocarbons via Biochemical Pathways Production: Technical and Market Analysis
PNNL performed techno-economic analysis of promising biochemical pathways in support of the DOE Bioenergy Technologies Office (BETO) programmatic goal to reduce the estimated mature technology processing costs for converting cellulosic feedstocks to hydrocarbons. The preliminary economics of a co-products scheme were assessed along with a market size and value determination for potential organic acids. The analysis also considered the costs associated with hydrocarbon fuel production from oleaginous yeast. A metabolic model of the yeast coupled with experimental work was developed to further inform the process and economics models.

Assessment of Energy Efficiency Project Financing Alternatives for Brookhaven National Laboratory
PNNL assessed the site's potential for various alternative financing options as a means to implement energy efficiency improvements. The assessment looked for life-cycle cost-effective energy-efficiency improvement opportunities, and through a series of staff interviews, evaluated the various methods by which these opportunities may be financed, while considering availability of funds, staff, and available financing options.

U.S. Economic Impact of Nuclear Technology Export Controls
PNNL performed an analysis of the economic impact of a proposed policy change related to nuclear technology exports. Their customer was DOE National Nuclear Security Administration, which is responsible for reviewing U.S. nuclear technology exports for potential proliferation concerns. Export trade for these kinds of items represents $2-$3 billion in business revenue annually for U.S. industry.

Analysis of the Russian Market for Building Energy Efficiency
PNNL performed an analysis of the Russian energy efficiency market for the building sector from the perspective of U.S. businesses interested in exporting relevant technologies, products and experience to Russia. The analysis focused on helping U.S. energy efficiency and environmental technologies businesses to better understand the Russian building market to plan their market strategy.

Analysis of the Implications of Increased Domestic and International Unconventional Natural Gas Supplies
PNNL is performing research exploring the implications of inexpensive and abundant unconventional natural gas supplies both domestically and internationally using the Global Change Assessment Model (GCAM). The study is focused on the changes in individual energy sectors such as buildings, industry, and electricity generation, the implications for international fossil fuel trade for and the emergence of a liquefied natural gas infrastructure, and the implications for greenhouse gas emissions and climate mitigation more generally.

Long-Term Implications of Electric Vehicle Market Penetration
PNNL has conducted integrated assessment modeling, using the Global Change Assessment Model (GCAM), to explore the implications of the emergence of electric vehicles for the international energy system and the domestic energy system. The emergence of electric cars will alter the consumption of competing fossil and biofuels, increase electric power demands, and potentially alter greenhouse gas emissions. These implications will be heavily influenced by the associated policy environment, including policies to reduce greenhouse gas emissions or specifically encourage the use of electric cars.

5.0 Financial Analysis Examples

Implementation of "Payments for Specified Renewable Energy Property in Lieu of Tax Credits (Section 1603)
PNNL supported the Departments of Treasury and Energy in the development of the Application Forms, Terms and Conditions, and Guidance Documents necessary to implement Section 1603 of the Recovery Act. The purpose of the Section 1603 payment is to reimburse eligible applicants for a portion of the cost of installing specified energy property used in a trade or business or for the production of income.

Sustainability Assessment of Coal-Fired Power Plants with Carbon Capture and Storage
PNNL performed a study to identify the potential environmental, social, or risk-related issues that could impede the large-scale deployment of Carbon Capture & Storage. Performing a Life Cycle Analysis on energy generation technologies provided focus areas in which to identify technically feasible, economically viable, and environmentally conscious energy generation technologies for maximum impact.

State Highway Cost Allocation Studies: Tax Policy Options Analysis
PNNL has performed several studies examining the equity of a state's highway user tax structure. The studies are designed to determine the fair share of costs that each road user class should pay for the construction, operation, maintenance, and related costs of highways, roads, and bridges in a state. The reports examine the impact of several tax policy options from an equity standpoint.

Economic Assessment of PHEV on utilities' cost structure.
PNNL estimated the impacts of high penetration of PHEV on the cost-recovery of generation, transmission, and distribution for one vertically integrated utility company and one utility company in an organized competitive wholesale market

DOE SSL Consortium Retrofit Financial Analysis Tool Development
PNNL developed a tool in collaboration with the Clinton Climate Initiative. Users input data on the relevant variables for their particular application – such as the incumbent technology, quantities, phase-in period, prevailing electricity and labor rates, sales tax, installation cost, loan interest rate, and rebates – to get a detailed analysis that includes annualized energy-cost savings, maintenance savings, greenhouse gas reductions, and simple payback. This information is useful not only for planning and budgeting purposes, but also in applying for financing. In a market where the cost of LED street lighting has dropped more than 25 percent in the past year alone, it can help cities accurately evaluate costs in today's dollars.

6.0 Policy Analysis Examples

The Role of Policy and Regulation in the Deployment of Energy Storage in the United States
PNNL performed an analysis of the existing policy, regulatory, and market design landscapes, including current national and state legislative initiatives relevant for economic viability of stationary energy storage and offered a framework for short and long-term incentives and oversight that would be necessary to induce and manage the growth and potential for this industry

Next Steps in Grid Modernization: Early Returns on U.S. Investment, and New Innovations in Electric Infrastructure Policy & Technology
PNNL analyzed the history and current conditions of the U.S. power grid, factored in the past two decades' emergence of advanced digital and communications technologies and how this has begun to change the way the U.S. electric industry does business. The analysis summarized the recent investments in the development of tools, technologies and grid management concepts that represent the essential building blocks of a strategy to further transform the U.S. electric industry and infrastructure.

Energy Policy Act of 2005: Implications for the Residential Lighting Industry
PNNL performed analysis identifying impacts of the Energy Policy Act of 2005. The act provided tax incentives for new homes 50 percent above the 2003 IECC building code, and for commercial buildings 25 percent above ASHRAE 90.1 lighting requirements. EPACT also gave incentives for efficient appliances, central AC, heat pumps, furnaces, water, heaters, envelope improvements, stationary fuel cells, microturbines, and hybrid vehicles. It set standards for ceiling fans and torchieres. For the first time, the legislation authorized Energy Star. EPACT also directed DOE to conduct research on white LEDs

Assessing the interactions among U.S. climate policy, biomass energy, and agricultural trade
PNNL studied the multiple dimensions of bioenergy's role in U.S. climate policy and implications for ameliorating the trade and land use consequences of bioenergy. The study indicated that that widespread use of biomass in the U.S. could lead to bioenergy imports, and these import amounts would interact heavily with climate mitigation and other policies. Next, it demonstrated that while limiting biomass imports would prevent any reliance on other countries for this energy supply, it would most likely alter the balance of trade in other agricultural products against which biomass competes; for example, it might turn the U.S. from a corn exporter to a corn importer.

Addressing Key Policy Issues Before the Next Catastrophe: What Decision Makers Need to Consider
PNNL identified and analyzed the wide range of questions that decision-makers at all levels of government are faced with and that must be quickly addressed and resolved in order to return the sense of community to a devastated region. The study identified the policy related issues that need to be addressed to provide clarity and information to federal officials, state and local jurisdictions, tribes, the private sector, and Non-Governmental Organizations, in order to assist in catastrophic planning and recovery efforts.

Impact Assessment of Plug-in Hybrid Vehicles on the U.S. Power Grid
PNNL performed an assessment of a 2030 scenario with 37 million plug-in hybrid electric vehicles (PHEVs) on US roads, the potential electrical grid impacts of the PHEV fleet relative to the production cost of electricity and electric sector emissions..

Modeling the Impacts of Climate Policy on the Deployment of Carbon Dioxide Capture and Geologic Storage across Electric Power Regions in the United States
PNNL performed a holistic, integrated economic analysis of the potential of carbon dioxide (CO2) capture and storage (CCS) technologies across the United States (US) electric power sector, over the time frame 2006-2045, in response to two hypothetical emissions control policies and across two potential energy supply futures that include updated and substantially higher projected prices for natural gas. A key feature of the analysis was an explicit attempt to model the inherent heterogeneity of the nation's current and future electricity production infrastructure and the inherent heterogeneity of the nation's candidate deep geologic CO2 storage formations.

Market-Driven Nonproliferation: Leveraging Competitive Advantage to Support U.S. Policy
PNNL analyzed the respective goals of industry and government on nonproliferation, and put forward potential policy options that could incentivize industry to take steps to go beyond compliance.

Bioenergy and the Importance of Land Use Policy in a Carbon-Constrained World
PNNL studied several different land use policies using the Joint Global Change Research Institute's Global Change Assessment Model (GCAM). The study included the analysis of policies that focuses on just the above-ground or vegetative terrestrial carbon rather than the total carbon, policies that focus exclusively on incentivizing and protecting forestland, and policies that apply an economic penalty on the use of biomass as a proxy to limit indirect land use change emissions. For each policy, we examined its impact on land use, land-use change emissions, atmospheric CO2 concentrations, agricultural supply, and food prices.

Techno-economic Performance Evaluation of Compressed Air Energy Storage in the Pacific Northwest
PNNL performed a techno-economic evaluation to provide a preliminary, region-specific analysis of costs, seasonality, capacity, and duration of strategic options for subsurface energy storage.

Distributed Wind Policy Comparison Tool
PNNL led the development of a web-based Distributed Wind Policy Comparison Tool (www.windpolicytool.org), a DOE-funded project that examines which policy options have the most impact on improving the bottom line of wind turbines up to 100 kW providing power for on-site use.

Implications of U.S. and International Climate Policy Approaches
A series of PNNL studies have used the Global Change Assessment Model (GCAM) to explore the implications of different climate reduction goals and of means of achieving those goals, including, for example, clean energy standards, renewable portfolio standards, CAFE standards, renewable fuel standards, and building energy standards. Important considerations are the macroeconomic impacts and the implications for new energy technology markets and deployments

7.0 Representative Partnerships

PNNL has conducted direct research for utilities across North America including EPRI, NRECA, AEP, PJM, TVA, NEISO, BPA, PG&E, SCE, Nevada Power, ERCPT, Southern Company, Duke Energy, PacifiCorp, PGE, Avista, and Seattle City Light.

In addition, PNNL has supported diverse state and regional government entities on projects requiring market or policy analysis, including the Northwest Power and Conservation Council, California Energy Commission, the California Institute for Energy and Environment (CIEE), the Northwest Power Pool, Western Governors Association, and NYSERDA.