CONNECT

LINKING ENERGY, SECURITY, AND PROSPERITY IN THE 21ST CENTURY

JISEA 2017 Annual Report

JISEA
Joint Institute for
Strategic Energy Analysis

CONNECTING TRANSFORMATIONAL SCIENCE TO A PROSPEROUS ENERGY FUTURE

The National Renewable Energy Laboratory (NREL) has conducted transformational science to lead American energy innovation for 40 years. In 2009, along with five university partners, we founded the Joint Institute for Strategic Energy Analysis (JISEA) to expand the possibilities of analysis in order to illuminate crucial connections between energy, society, and economics.

JISEA's work has examined these connections for one primary purpose: to provide objective, credible research and analysis that enable decisions. This year, JISEA has shown us that nuclear-renewable hybrid energy systems can provide clean energy for U.S. industry. Natural gas can fuel a transportation revolution in California. Domestic energy manufacturing can increase U.S. prosperity.

As NREL celebrates 40 years of research and innovation, I am even more excited about the next 4 decades. JISEA's research will continue to elucidate opportunities to help stimulate our economy, ensure our security, and protect our health. Together, NREL and JISEA will continue to lead energy innovation in America. I hope you'll join us.

Dr. Martin Keller

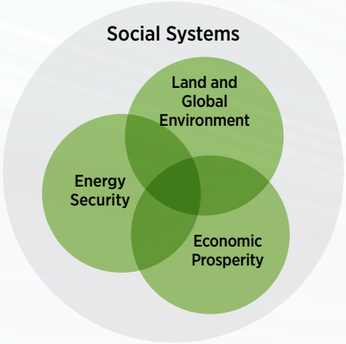
Laboratory Director
National Renewable Energy Laboratory

ADVANCING INTERCONNECTIONS THROUGH QUALITY, OBJECTIVE ANALYSIS

We are honored to serve on JISEA's Advisory Council and are pleased to provide a brief reflection on JISEA's unique contributions to our evolving energy systems.

JISEA's research and analysis connects technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy. Enhanced and emboldened by the capabilities of its founding institutions and research affiliates, JISEA provides timely, quality, objective analysis—analysis that can inform and speed the transition to a sustainable, safe, and independent energy future. In the past year:

- JISEA collaborated with Idaho National Laboratory scientists to research nuclear-renewable hybrid energy systems. The analysis shows that these connected systems can provide electricity and energy to industry in addition to improving grid operation.
- JISEA continued as a leader in natural gas research. JISEA explored the market potential of low-carbon natural gas produced from regionally abundant resources for use in transportation applications in California, finding that low-carbon natural gas may be economically competitive with fossil-based fuels by 2030. In addition, researchers from three JISEA founding partners identified opportunities to reduce product loss by identifying the biggest methane-emitting natural gas wells.
- The Clean Energy Manufacturing Analysis Center, operated by JISEA, connected energy and economics in the first edition of its flagship report by examining four clean energy technologies to quantify the economic impacts of their manufacturing sectors.



These and the other successes illustrated in this report represent a sampling of JISEA's 2016 accomplishments and its unique ability to illuminate ever-important connections between energy, security, sustainability, and prosperity.

We look forward to continuing our work with JISEA to advance important interconnections as we work together toward a prosperous energy future.

Joan MacNaughton
Chair, The Climate Group

Bill Ritter
Director, Center for the New Energy Economy, Colorado State University

Katherine Sierra
Non-Resident Senior Fellow, The Brookings Institution

CONTENTS

ENERGY & SECURITY

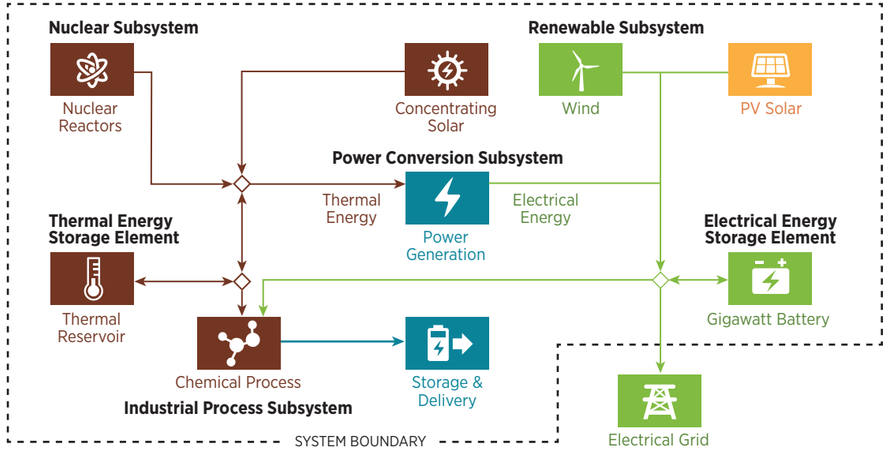
INNOVATIVE SYSTEMS SOLUTIONS FOR SECURE AND ABUNDANT ENERGY

Nuclear and renewable energy are essential components of the clean, affordable, domestic energy needed to power America's economy. When JISEA and Idaho National Laboratory combined forces to evaluate nuclear-renewable hybrid energy systems, the teams discovered that these two very different technologies, when linked together, have the potential to provide low-emission electricity and energy to industry, produce high value goods like synthetic gasoline, and improve the operation of the grid.

Nuclear-renewable hybrid energy systems are physically coupled facilities that include both nuclear and renewable energy sources that produce electricity and an additional product such as a fuel, thermal energy, hydrogen, or desalinated water. These systems potentially generate dispatchable electricity and provide energy for industrial processes. A series of reports investigates the technical and economic aspects of these hybrid systems and identifies potential industrial needs for thermal energy that these systems can meet.

- When considering the 14 U.S. industries with the most emissions, approximately 960 plants represent less than 0.5% percent of all manufacturing in the United States, but those plants emit nearly 25% of all industrial sector greenhouse gas —5% of all U.S. greenhouse gas emissions in 2014. The first report in the series identifies key greenhouse gas emission sources in the industrial sector and proposes low-emitting alternatives using targeted, process-level analysis of industrial heat requirements.[1]

- Certain hybrid configurations are profitable when driven by their industrial product. The second report introduces two hypothetical nuclear-renewable hybrid energy systems and evaluates the economic potential of these systems. The analysis shows that the hybrid systems have internal flexibility that makes them beneficial as a partial hedge against uncertain industrial product prices.[2]
- Under a variety of scenarios, the economically optimal nuclear-renewable hybrid energy system configuration includes a nuclear reactor that generates a thermal product such as steam or a heat transfer fluid—a configuration that can economically reduce greenhouse gas emissions from industry, according to the third report.[3]



A generalized nuclear-renewable hybrid energy system schematic showing the system boundary and linkage to the grid.

DISCOVER: NUCLEAR-RENEWABLE SYNERGIES ▸

[1] *Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions.* nrel.gov/docs/fy17osti/66763.pdf

[2] *The Economic Potential of Two Nuclear-Renewable Hybrid Energy Systems.* nrel.gov/docs/fy16osti/66073.pdf

[3] *The Economic Potential of Three Nuclear-Renewable Hybrid Energy Systems Providing Thermal Energy to Industry.* nrel.gov/docs/fy17osti/66745.pdf

"Changing the Game by Linking Nuclear and Renewable Energy Systems." energy.gov/eere/articles/changing-game-linking-nuclear-and-renewable-energy-systems

CATALYST

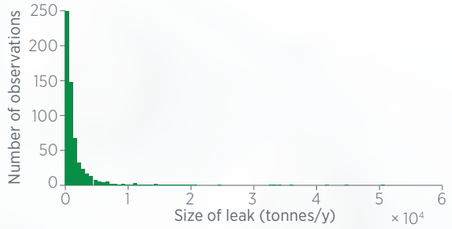
EXPLORING NATURAL GAS AS PART OF A SECURE, PROSPEROUS, CLEAN ENERGY SYSTEM

JISEA's robust natural gas research portfolio continues to examine the role of natural gas in the United States energy economy. In 2016, JISEA and its founding partners presented an opportunity to reduce methane leakage by tracing the biggest emitters, which could reduce product loss.

The bulk of methane emissions in the United States come from a small number of "super emitting" natural gas wells, according to researchers from Stanford, Colorado State University, and NREL. Published in the journal *Energy and Environmental Science*, the findings present a potential opportunity to target and fix the biggest emitters and significantly reduce the amount of methane leaking into the atmosphere.

For the study, Adam Brandt of Stanford University, Daniel Cooley of Colorado State University, and Garvin Heath of NREL analyzed approximately 15,000 measurements from 18 prior studies of natural gas leaks from across the United States. The team used a statistical technique called extreme value theory, which is useful for analyzing infrequent but highly consequential events.

In addition to presenting an opportunity to more easily reduce methane leakage, the study may mean that super-sensitive leak detectors are not necessary to reduce emissions. Less sensitive (and cheaper) detection technologies can still help identify the majority of problem leaks.



The largest 5% of methane leaks are responsible for more than 50% of total volume leakage, according to the study.

LEARN: METHANE LEAK DISTRIBUTIONS ▸

"Methane Leaks from Natural Gas Systems Follow Extreme Distributions"
pubs.acs.org/doi/abs/10.1021/acs.est.6b04303

news.stanford.edu/2016/10/26/super-emitters-responsible-bulk-u-s-methane-emissions

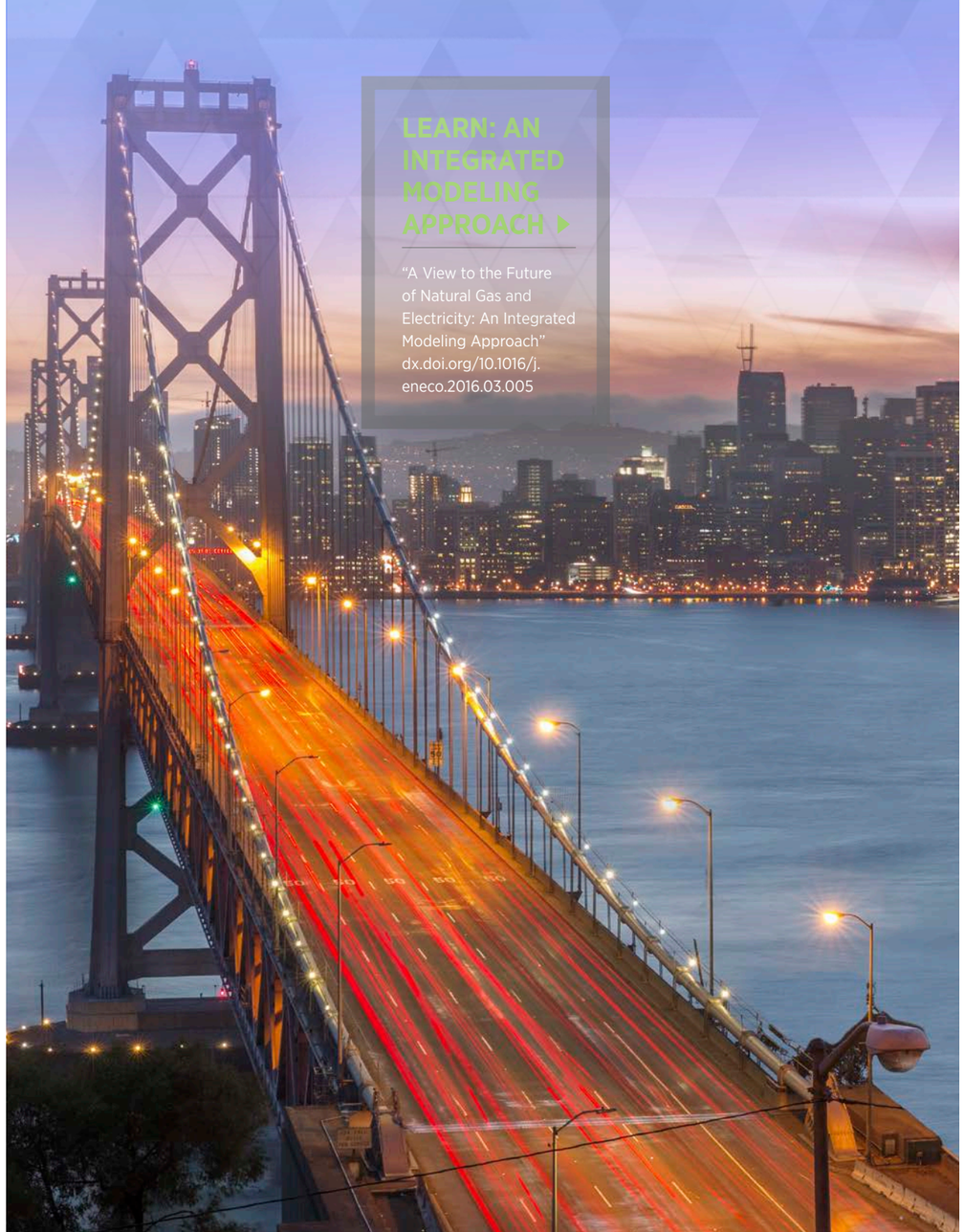
cpr.org/news/newsbeat/new-study-narrows-focus-on-location-of-methane-leaks

MODELING THE FUTURE OF NATURAL GAS AND ELECTRICITY

JISEA teamed with the Baker Institute for Public Policy at Rice University—a JISEA research affiliate—to link high-resolution models of the natural gas and electricity sectors.

Rice University's World Gas Trade Model details the U.S. natural gas sector. NREL's Regional Energy Deployment System (ReEDS) models the U.S. electricity sector. National-level sector evolution results from the combined models are similar to the results from the stand-alone models. Regional and state-level results from models, however, vary considerably. These regional differences have potentially significant implications for electric sector planners.

The paper, published in the journal *Energy Economics*, demonstrates the importance of regional detail in evaluating future renewable energy sources and natural gas interactions in the U.S. power generation sector. Rice's World Gas Trade Model transfers natural gas prices to the ReEDS model, which in turns solves the capacity expansion and dispatch problem for the electricity sector and returns the electricity sector natural gas demand to the World Gas Trade Model. Various stakeholders can now consider regionally distinct representations of natural gas and electricity markets in order to make informed decisions.



LEARN: AN INTEGRATED MODELING APPROACH ▶

"A View to the Future of Natural Gas and Electricity: An Integrated Modeling Approach" dx.doi.org/10.1016/j.eneco.2016.03.005

CAN DOMESTIC LOW-CARBON NATURAL GAS PRODUCTION FUEL TRANSPORTATION IN CALIFORNIA?

A new report in the *Natural Gas and the Evolving U.S. Power Sector* monograph series examines the possibility.

In California, a favorable policy environment and customer perception may position California as an early mover in the adoption of alternative fuel vehicles, including domestically sourced low-carbon natural gas vehicles. Low-carbon natural gas—a gas with the same basic characteristics of natural gas but with a lower carbon content—can be obtained by either replacing or supplementing fossil natural gas with hydrogen produced from renewable energy sources (e.g., electrolysis using electricity from renewable sources) or with renewable biogas (e.g., bio-methane from the anaerobic digestion of biomass waste). JISEA's latest monograph, *Low-Carbon Natural Gas for Transportation: Well-to-Wheels Emissions and Potential Market Assessment in California*, explores the market potential of low-carbon natural gas for transportation in California. The monograph analyzes economic and lifecycle greenhouse gas emissions and finds that low-carbon natural gas production potential in California could result in accelerated natural gas vehicle adoption by 2030.

Previous monographs in the *Natural Gas and the Evolving U.S. Power Sector* monograph series examined trends in the U.S. electricity sector and how natural gas affects policy, operational, and investment decisions[1] and explored the question of natural gas as a bridge to a more sustainable electricity sector.[2]

READ: LOW-CARBON NATURAL GAS & TRANSPORTATION ▶

Low-Carbon Natural Gas for Transportation: Well-to-Wheels Emissions and Potential Market Assessment in California. nrel.gov/docs/fy17osti/66538.pdf

EXPLORE: NATURAL GAS AND THE EVOLVING U.S. POWER SECTOR ▶

[1] *A Review of Sector and Regional Trends in U.S. Electricity Markets: Focus on Natural Gas* nrel.gov/docs/fy16osti/64652.pdf

[2] *Considering the Role of Natural Gas in the Deep Decarbonization of the U.S. Electricity Sector.* nrel.gov/docs/fy16osti/64654.pdf

Webinar: Natural Gas and Power Sector Decarbonization Pathways: Three Snapshots from Recent JISEA Research. jisea.org/media/webinar-20160413.wmv

PROSPERITY

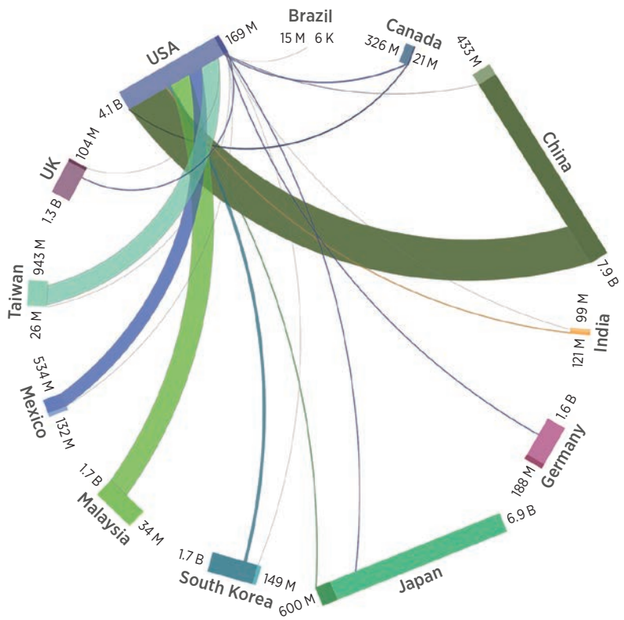
ANALYZING THE CLEAN ENERGY MANUFACTURING LANDSCAPE

Manufacturing connects the development of new energy technologies to their deployment globally. Energy technology manufacturing facilities employ millions of people along the entire supply chain, from silicon to solar modules, from steel to wind turbines, each contributing to the economies of a network of nations. The Clean Energy Manufacturing Analysis Center (CEMAC), sponsored by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy and operated by JISEA, connects energy and economics to inform decisions that can increase U.S. economic prosperity and energy independence.

In its flagship report, *Benchmarks of Global Clean Energy Manufacturing*, CEMAC presents a first-of-its-kind analysis to quantify the economic impacts of key clean energy manufacturing sectors. The analysis examined four clean energy technologies: wind turbine components, crystalline silicon solar photovoltaic (PV) modules, light duty vehicle lithium ion battery cells, and LED packages for lighting and other consumer products. CEMAC's key findings include:

- Manufacturing of clean energy technologies is a complex global enterprise, with extensive trade to support the geographical distribution of production and demand across the links in the supply chain. Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.
- Larger economies such as the United States, which has a more extensive domestic manufacturing supply chain and higher prevailing wages, tend to retain more value added from clean energy manufacturing than smaller economies.
- Production of wind turbine components and crystalline silicon modules is more concentrated than production of LED chips and light-duty vehicle lithium ion battery cells. Wind components are typically made in the same economies that have high demand, while crystalline silicon PV modules, LED chips, and light duty vehicle Li-ion battery cells are less coincident.

CEMAC Clean Energy Manufacturing Analysis Center



In 2014, the United States was a major exporter of polysilicon, one extensively traded key processed material in silicon solar photovoltaics.

DISCOVER: CLEAN ENERGY MANUFACTURING ▶

manufacturingcleanenergy.org

@CleanEnergyMfg

COOPERATION

INFORMING GLOBAL POWER MARKET TRANSFORMATION

Changes in social dynamics, technology, business models, and environmental goals put pressure on countries to improve their power systems. JISEA's multilateral collaborations work to inform energy strategies that enable clean economic growth, increase power system flexibility, and provide reliable, secure, affordable power.

The 21st Century Power Partnership, an initiative of the Clean Energy Ministerial operated by JISEA, helps build capacity and conducts credible, objective analysis to inform policy and regulatory decisions that guide power market transformation in South Africa, India, China, and Mexico.

- In South Africa, the Power Partnership supports power-system expert workforce development and near-term mitigation of power shortages. In 2016, JISEA and NREL hosted two fellows from Eskom, South Africa's public utility. The fellows explored techniques to reduce power sector model run times, identified and assessed power system flexibility metrics, and incorporated transmission considerations into the long term planning model.
- In India, the Power Partnership seeks to enable a smarter, cleaner, more resilient power system through three focus areas: contributing to the development of the national Renewable Energy Roadmap, sharing experiences and lessons learned, and providing power system modeling support and training.
- In China, the Power Partnership works with the China National Renewable Energy Center to support China's realization of its 20% non-fossil-fuel energy target.
- In Mexico, the Power Partnership supports Mexico in implementing recently enacted energy reform legislation that has provided a completely new energy framework for Mexico. The reform promotes clean power generation and energy efficiency, while introducing competition and inviting private investment in areas formerly wholly owned by the state. The Power Partnership program provides targeted and sustained technical assistance to develop the necessary knowledge, capabilities, data, and strategic roadmaps to inform Mexican decision makers. The program focuses on building capacity in next generation power system planning, smart grid integration, and distributed generation deployment. In addition, the NREL-led Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program is working with Mexico's re-envisioned National Electric and Clean Energy Institute (INEEL by its Spanish acronym). NREL led a review of the current status of INEEL and of international best practices that may position INEEL to thrive as a world-class research institute and support Mexico's long-term energy vision. NREL's relationship with INEEL will continue—Peter Green, NREL's newly appointed Deputy Laboratory Director for Science and Technology, serves on the INEEL Board of Directors.

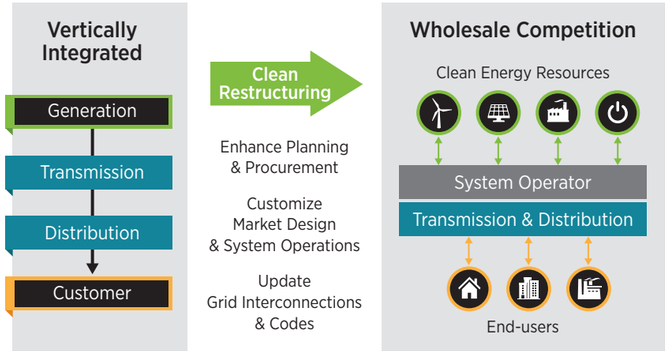
DESIGNING WHOLESALE MARKETS TO SUPPORT NATIONAL AND REGIONAL GOALS

The 21st Century Power Partnership illuminates power sector design elements to help countries embrace change and accelerate restructuring of electricity systems. Clean restructuring describes the movement from a vertically integrated power sector toward an electricity system that is reliable, affordable, resilient, and cleaner.

Decision makers can consider three main areas when embarking on a clean restructuring process.

- **Promote cleaner power systems with next-generation planning and procurement practices.** Restructuring a vertically integrated sector may result in a more dispersed and diverse set of clean and variable energy resources, changing the nature of traditional planning exercises. Advanced techniques for analyzing system level solutions with natural gas, flexible thermal generation, and variable renewable resources can help determine if generation capacity and other resources—such as demand response—can reliably serve demand.
- **Enable flexibility with market design and system operations.** The design of wholesale market rules and system operations has implications for the ability to design and operate cleaner, more modern power systems. Rules for how generation and other resources are committed and ultimately dispatched can be designed to better absorb and manage variable renewable generation and reward all sources of flexibility appropriately. Integrating advanced forecasting capabilities into market operations can improve continuous system balancing and reduce costs.
- **Create a level playing field for clean energy with grid infrastructure, interconnection, and grid codes.** As transmission assets are unbundled from generation, open and transparent processes for network expansion and investment become important in a restructured environment. Streamlining interconnection processes for new resources applying to connect to the network can alleviate barriers to entry, especially in terms of the time and cost of the application process. Grid codes can also be updated to reflect technologies with different operating characteristics and allow all resources to contribute to system reliability.

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems



READ: DESIGN ELEMENTS OF CLEAN RESTRUCTURING ▸

Clean Restructuring: Design Elements for Low-Carbon Wholesale Markets and Beyond

Full report: nrel.gov/docs/fy16osti/66105.pdf

Overview brochure: nrel.gov/docs/fy16osti/66479.pdf

TEAM

(L-R)
Pat Statwick,
Debbie Meixner,
Doug Arent,
Maggie Mann,
and
Jill Engel-Cox.

JISEA TEAM

Douglas J. Arent, MBA, Ph.D.
Executive Director

Doug Arent is Executive Director of JISEA at NREL. In addition to his NREL responsibilities, Arent is Senior Visiting Fellow at the Center for Strategic and International Studies, serves on the American Academy of Arts and Sciences Steering Committee on Social Science and the Alternative Energy Future, is a member of the National Research Council Committee to Advise to U.S. Global Change Research Program (USGCRP), and is a Member of the Keystone Energy Board. Arent is the Editor in Chief for *Renewable Energy Focus* and is Associate Editor for the journal *Renewable and Sustainable Energy Reviews*. Arent serves on the World Economic Forum Future of Electricity Working Group and is a member of the International Advisory Board for the journal *Energy Policy* and for Energy Academy Europe.

Jill Engel-Cox, Ph.D.
Deputy Director
Program Director, Clean Energy Manufacturing Analysis Center

Jill Engel-Cox is deputy director of JISEA and program director of CEMAC. Over her 25-year career, Engel-Cox has been an engineer, researcher, program manager, and strategic planner for a diverse suite of renewable energy, clean technology, and environmental programs in the United States, Asia, and the Middle East. She also teaches industrial processes and environmental communications courses at Johns Hopkins University Engineering for Professionals Program.

Patricia Statwick, MBA, MAS
Program Administrator

Pat Statwick develops, implements, and manages JISEA programs and projects. She provides project management for projects ranging from topical scoping studies to international program operations managed by JISEA. Statwick's experience extends to technology transfer and commercialization; business development; and small business consulting.

Margaret Mann
Technical Director, Clean Energy Manufacturing Analysis Center

Margaret Mann is technical director of CEMAC. She is a senior chemical process engineer and technical lead at NREL. She has over 22 years of experience in process design and simulation, economic cost analysis, environmental life cycle assessment (LCA), and technical project management. Maggie manages the manufacturing cost analysis team in the Strategic Energy Analysis Center at NREL, including competitiveness analysis work for the U.S. Department of Energy's Clean Energy Manufacturing Initiative.

Debbie Meixner
Business Support

Debbie Meixner is the assistant to the Executive Director of JISEA. She manages the day-to-day activities of the JISEA office and coordinates special meetings and events. Debbie serves as liaison to the JISEA Advisory Council, JISEA Program Committee, and the CEMAC Advisory Committee. Debbie's background includes experience in non-profit organizations, city government, and another national laboratory.

JISEA is operated by the Alliance for Sustainable Energy, LLC, on behalf of its founding partners.

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JISEA PROGRAM COMMITTEE

JISEA's Program Committee provides guidance on program direction to the executive director and JISEA staff. The Program Committee reviews and approves JISEA's research agenda, priorities, and annual research program plan.

William Boyd
Associate Professor of Law, University of Colorado

Robin Newmark
Associate Laboratory Director, Energy Analysis and Decision Support, NREL

John Reilly
Co-Director, MIT Joint Program on the Science and Policy of Global Change; Senior Lecturer, MIT Sloan School of Management

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Research Professor, Office of Research, and Department of Geology and Geological Engineering, Colorado School of Mines (retired)

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Joan MacNaughton, Chair, The Climate Group

Bill Ritter, Director, Center for the New Energy Economy, Colorado State University

Katherine Sierra, Non-Resident Senior Fellow, The Brookings Institution

CEMAC ADVISORY COMMITTEE

The Advisory Committee provides programmatic guidance to the Clean Energy Manufacturing Analysis Center. The CEMAC Advisory Committee is composed of experts from industry, trade associations, academia, and government as well as CEMAC management.

Tom Catania, *Chair,* University of Michigan

Paul Camuti, Ingersoll-Rand

Dylan Cooper, The Dow Chemical Company

David Eaglesham, Pellion Technologies

Steven Freilich, *Vice-Chair,* DuPont (emeritus)

Paul Kaleta, First Solar, Inc.

Wayne Mays, Iberdrola Renewables

Adam O'Malley, U.S. Department of Commerce

Ken Ostrowski, McKinsey & Company

Ryan Preclaw, Barclays

Swami Venkataraman, Moody's Investors Service

Charles W. Wessner, Georgetown University

Matt Zaluzec, Ford Motor Company

RESEARCH AFFILIATES

JISEA augments the capabilities of its founding institutions with those of leading analysis centers across the globe.

Rice University's Baker Institute Center for Energy Studies

BAKERINSTITUTE.ORG/CENTER-FOR-ENERGY-STUDIES

CES provides new insights on the role of economics, policy, and regulation in the performance and evolution of energy markets.

Carnegie Mellon University Department of Engineering and Public Policy

CMU.EDU/EPP

The Department of Engineering and Public Policy, a unique department within the College of Engineering at Carnegie Mellon University, focuses on addressing technology-based policy problems.

Energy Institute at The University of Texas at Austin

ENERGY.UTEXAS.EDU

The Energy Institute is dedicated to broadening the educational experience of students by creating a community of scholars around energy issues of importance to Texas, the nation, and the world.

Eskom

ESKOM.CO.ZA

Eskom generates, transmits, and distributes electricity to industrial, mining, commercial, agricultural, and residential customers and redistributors in South Africa and throughout the continent.

Houston Advanced Research Center

HARC.EDU

HARC provides independent analysis on energy, air, and water issues to people seeking scientific answers. HARC focuses on building a sustainable future that helps people thrive and nature flourish.

International Institute for Applied Systems Analysis

IIASA.AC.AT

IIASA conducts policy-oriented research into the most pressing areas of global change—energy and climate change, food and water, poverty and equity—and their main drivers.

KTH Royal Institute of Technology

KTH.SE/EN

KTH, the largest and oldest technical university in Sweden, offers education and research ranging from natural sciences to engineering, architecture, industrial management, and urban planning.

Masdar Institute of Science and Technology

MASDAR.AC.AE

The Masdar Institute is the world's first graduate-level university dedicated to providing real-world solutions to issues of sustainability.

Renewable and Appropriate Energy Laboratory

RAEL.BERKELEY.EDU

Based at the University of California – Berkeley, RAEL focuses on designing, testing, and deploying renewable and appropriate energy systems.

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ACCELERATE

CONNECTING FINANCE AND TECHNOLOGY TO ADVANCE ENERGY AND SUSTAINABILITY SOLUTIONS

JISEA and its founding partners and affiliates support the energy innovation pipeline by accelerating the transfer of renewable energy and energy efficiency technologies into the marketplace.

The Wells Fargo Innovation Incubator (IN^2) program brings together leading technology deployment accelerators and industry labs, research institutes, and universities to accelerate the commercialization of advanced energy and sustainability solutions. The IN^2 platform is funded by the Wells Fargo Foundation and co-administered by NREL. The incubator combines strategic financing, technology and technical assistance, strategic customer site validation, and ongoing financial support.

Following a competitive review process, early-stage companies are invited into the IN^2 program, where they receive grant funding or non-dilutive capital. In partnership with NREL's Innovation and Entrepreneurship Center, JISEA works to connect emerging clean energy businesses with the financial community, NREL technical expertise and facilities, and the broader clean energy ecosystem.

With new commercialization acceleration models, the clean energy future looks bright.

EXPLORE: MORE INNOVATIVE COMMERCIALIZATION MODELS ▸

nrel.gov/docs/fy16osti/65374.pdf

WATCH: IN^2 OVERVIEW ▸

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