VISION

ILLUMINATING THE PATHWAYS TO A CLEAN ENERGY ECONOMY

JISEA 2016 Annual Report

JISEA
Joint Institute for
Strategic Energy Analysis

LAYING A FOUNDATION FOR ENERGY SYSTEMS INNOVATION

Vision—the ability to see what is possible—has been a major driver of advances in science, technology, and human civilization throughout history. Today, we can celebrate the progress we've made at making clean energy technologies the fastest growing segment of new power sector additions around the globe. At the same time, we need vision to help us see the potential for and the pathways to a clean energy future.

When I assumed the role of director of the National Renewable Energy Laboratory, I was pleased to find this sort of visionary thinking in the Joint Institute for Strategic Energy Analysis (JISEA).

JISEA has an impressive history of bold, agenda-setting analysis that illuminates potential for a clean energy economy and articulates the innovations in technology, business models, and systems that are needed to get us there. JISEA looks at renewable technologies—and beyond renewable technologies—to reveal potential for technologies such as natural gas, nuclear power, and hydrogen. JISEA examines ways these technologies can work in conjunction so that the whole is greater than the sum of its parts. And because the problems of carbon and climate change are not confined to our national borders, JISEA engages in emerging economies around the world to realize the vision of a clean energy future.

Is that pie-in-the-sky thinking? I don't think so.

Henry David Thoreau once said, "If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them."

I am pleased with the vision that JISEA provides us, and look forward to insights yet to be revealed.

Dr. Martin Keller

Laboratory Director
National Renewable Energy Laboratory

ENVISIONING A CLEAN ENERGY ECONOMY

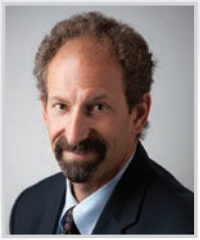
On the heels of the 21st Conference of Parties (COP21) in Paris and the resulting climate agreement, opportunities to realize the vision of a clean energy economy abound. JISEA explores the intersections of the environmental, social, financial, technological, and political elements of energy systems to envision pathways to decarbonization. Together, we can move along these pathways from transitional planning to transformational realization. In the past year:

- JISEA contributed to the U.S. Department of Energy's first Quadrennial Energy Review by illuminating methane emission abatement as one pathway to decarbonization.

- JISEA's founding institutions and affiliates, along with the China National Renewable Energy Centre and the Danish Energy Agency, began a collaboration focused on sharing experiences in the planning, deployment, and operation of high-penetration renewable electricity grid systems to pave the way for decarbonization of China's power system.

- JISEA inaugurated the Clean Energy Manufacturing Analysis Center (CEMAC), a multi-lab collaborative dedicated to global clean energy manufacturing analysis to illuminate the economic and technical elements of decarbonization pathways.

This report demonstrates JISEA's successes over the past year and previews our coming work. As we look to the coming year, JISEA will continue to navigate complex issues, present unique perspectives, and envision a clean energy economy.



Douglas J. Arent, MBA, Ph.D.

Executive Director
Joint Institute for Strategic Energy Analysis
National Renewable Energy Laboratory

CONTENTS

PATHWAYS TO DECARBONIZATION

CREATING A RESILIENT, RELIABLE, LOW-CARBON ELECTRICITY SYSTEM IN THE UNITED STATES

Many combinations of technologies and operational innovations provide pathways to a clean energy system that can power economic growth and quality of life. The shale gas revolution is reshaping the energy sector in ways that breach the boundaries of traditional energy sector analysis and touch on areas as diverse as foreign policy and industrial dynamics. JISEA's work continues to provide crucial illumination of the role of natural gas as one pathway to decarbonization.

Understanding the opportunities for developing complementary resources—like natural gas and renewable energy—in the context of a national and global energy economy transition is paramount. All resource development has benefits and impacts.

For example, using natural gas and renewable energy in unison is one potential pathway toward a low-carbon, resilient, and affordable energy system. While the two resources have historically been viewed as competitors, natural gas and renewables are increasingly recognized as complementary, not only technologically but also financially.

Concerns about natural gas development include local community impacts, air quality, water quality, induced seismicity, and greenhouse gas emissions, particularly methane. Methane emissions account for roughly 10% of U.S. greenhouse gases, and a quarter of these are attributed to the natural gas sector.

JISEA's work continues to illuminate areas of both caution and opportunity as the nation embraces the promise of natural gas and renewables as valuable energy resources. While we cannot ignore the associated concerns and risks, we also cannot ignore the potential for progress, particularly in the near to medium term, if we "get gas right."

JOIN THE CONVERSATION ▶

#GettingGasRight

NATURAL GAS AND RENEWABLE ENERGY SYNERGIES ▶

Let's 'Get Gas Right' and Exploit Synergies of Natural Gas and Renewables.
cgmf.org/blog-entry/179/Let's-'get-gas-right'-and-exploit-synergies-of-natural-gas-and-renewables.html

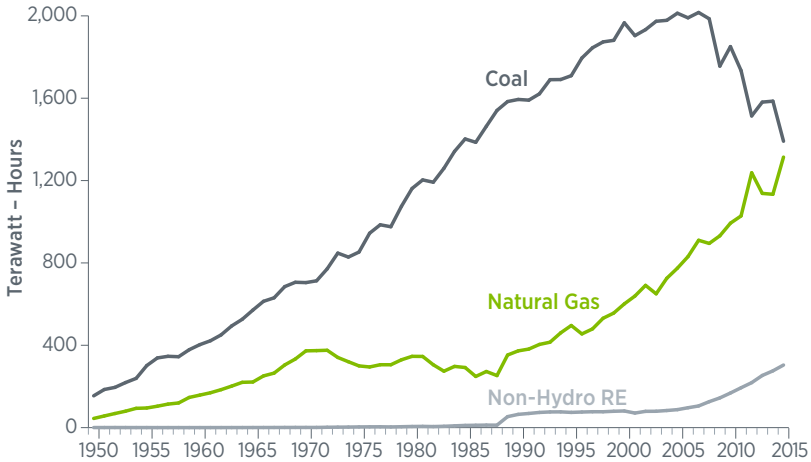
EXPLORING NATURAL GAS AND ITS ROLE IN THE EVOLVING POWER SECTOR

JISEA's monograph series, *Natural Gas and the Evolving U.S. Power Sector*, explores trends in the U.S. electricity sector; how natural gas affects policy, operational, and investment decisions; the question of natural gas as a bridge to a more sustainable electricity sector; and the flexibility attributes that natural gas can offer to electric power sectors.

Starting in mid-2008, U.S. electricity generation from coal began to decline substantially. By late 2015, coal-fired electricity output was down more than 25% compared to its peak. Natural gas generation, in contrast, has been growing since about 1990, a trend that predates the shale gas revolution.[1]

Do these trends mean that natural gas can serve as a bridge fuel, replacing the more carbon-intense coal generation in the near term and eventually phasing down in favor of zero-carbon emission resources? Our analysis indicates that the answer may depend on the price of natural gas and the level of carbon reduction targets in place.[2]

As natural gas takes on a larger role in the generation of electricity, opportunities arise to explore how natural gas and renewable energies work synergistically to provide reliable, resilient, low-carbon power in an economically efficient manner.



THE EFFECTS OF METHANE EMISSIONS ▸

[1] *Estimating U.S. Methane Emissions from the Natural Gas Supply Chain: Approaches, Uncertainties, Current Estimates, and Future Studies.* nrel.gov/docs/fy16osti/62820.pdf

[2] *Potential Cost-Effective Opportunities for Methane Emission Abatement.* nrel.gov/docs/fy16osti/62818.pdf

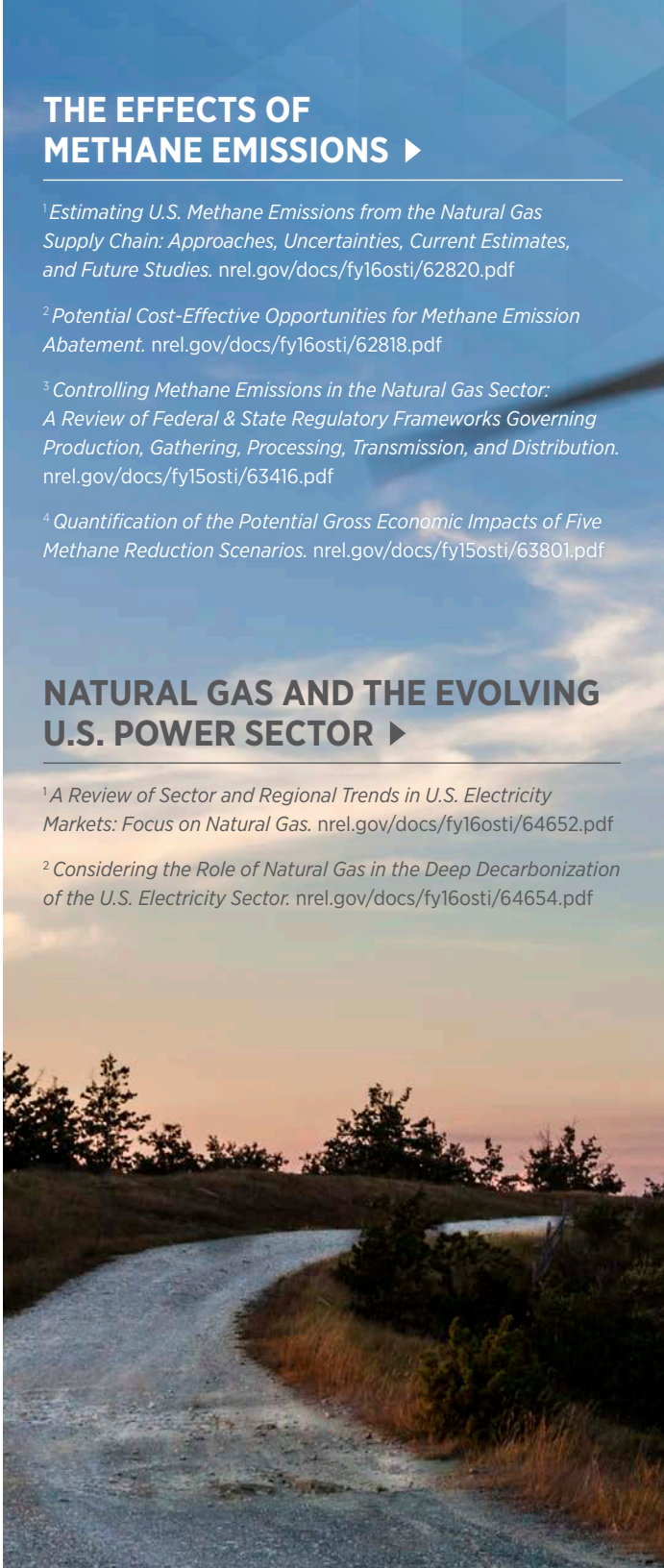
[3] *Controlling Methane Emissions in the Natural Gas Sector: A Review of Federal & State Regulatory Frameworks Governing Production, Gathering, Processing, Transmission, and Distribution.* nrel.gov/docs/fy15osti/63416.pdf

[4] *Quantification of the Potential Gross Economic Impacts of Five Methane Reduction Scenarios.* nrel.gov/docs/fy15osti/63801.pdf

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



EXAMINING NATURAL GAS FOR THE U.S. DEPARTMENT OF ENERGY'S QUADRENNIAL ENERGY REVIEW

When the White House called on the U.S. Department of Energy's Office of Energy Policy and Systems Analysis (EPSA) to conduct a Quadrennial Energy Review, EPSA turned to JISEA and its broad natural gas expertise to evaluate the environmental, economic, and technological effects of methane emissions.

JISEA's founding institutions collaborated on a series of four reports that illuminates methane emission abatement as one pathway to decarbonization.

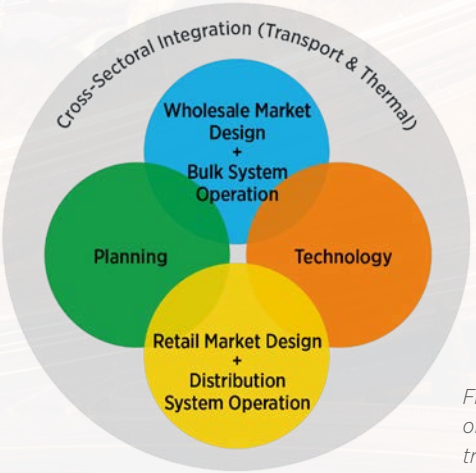
- The natural gas, coal, and oil industries produce approximately 39% of anthropogenic methane emissions in the United States. Within the natural gas industry, 43% of total methane emissions come from compressors and compressor stations, mostly from the processing and transmission and storage segments. Leaks from main and service pipelines made of cast iron and unprotected steel contribute 33% of total distribution segment emissions—despite representing the fewest miles of any piping material.[1]
- Many opportunities to abate methane emissions exist, but the potential and cost-effectiveness of each opportunity can vary. For a natural gas producer, every unit of saved gas represents additional gas that can be sold. Depending on the structure of the natural gas market, however, recovered gas may or may not represent a revenue stream for the owner of, or investor in, improved infrastructure.[2]
- The current federal regulatory framework for air pollution does not require controls for methane emissions directly, but in general, policy strategies that reduce natural gas system leakage also conserve natural gas, which can result in savings for consumers in addition to climate benefits. State and federal regulators could take several approaches to reduce methane emissions through policies to increase efficiency, enhance safety, and improve the environmental performance of natural gas systems.[3]
- The reduction of methane emissions has the potential to reduce overall greenhouse gas emissions while simultaneously improving business economics and supporting jobs and other economic activity in the United States.[4]

SHIFT

MOVING FROM TRANSITIONAL PLANNING TO TRANSFORMATIONAL IMPLEMENTATION

Pathways toward power sector transformation are beginning to take shape, necessitating robust, innovative ideas and implementation frameworks.

Power system transformation is a complex, active process that is taking place in different forms and at different degrees around the world. This transformation has multiple drivers, including technological innovations, policy goals, and social dynamics. Transformation also has multiple enablers, particularly policy, financial, and business model innovation. This complex set of forces and trends presents both challenges and opportunities, necessitating not only new conceptualizations of how power systems might function, but new approaches to spur innovation and amplify public benefits. Fostering a global dialogue about the scope and nature of power system innovation can support the development of effective policy visions and robust implementation frameworks. A report from the 21st Century Power Partnership, for which JISEA acts as operating agent, provides a collection of empirical examples of the types of innovations that are emerging around the world. This survey provides real-world examples—and possibly inspiration—to enable decision makers to take transformative action.



Five broad categories of power system transformation indicators

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

READ THE EXAMPLES OF POWER SYSTEM TRANSFORMATION ▸

Status Report on Power System Transformation
nrel.gov/docs/fy15osti/63366.pdf

COLLABORATING ACROSS THE GLOBE TO ENABLE TRANSFORMATION

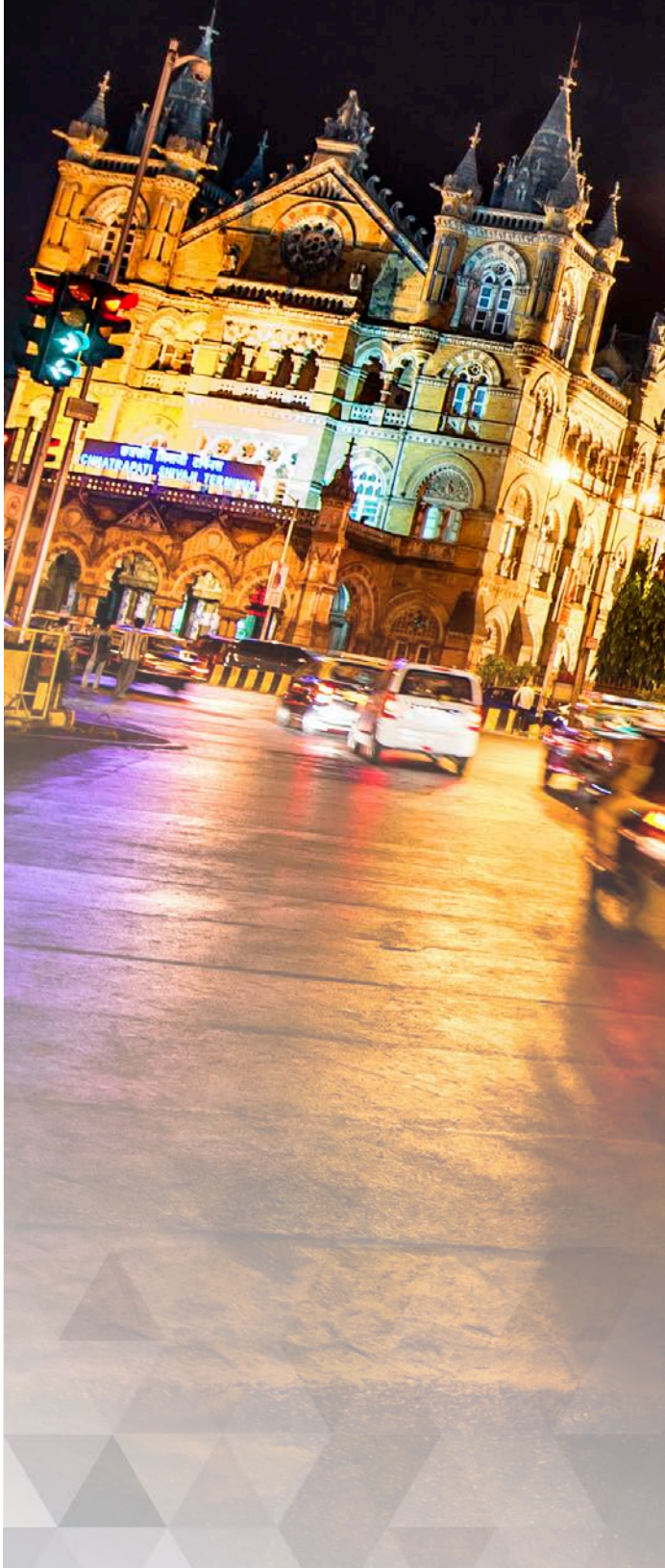
The 21st Century Power Partnership continues to provide analytic and technical support to Mexico, South Africa, and India. In cooperation with other Clean Energy Ministerial countries, development agencies, and a public-private leadership forum, this support will help enable clean power sector transformation.

In Mexico, 21st Century Power Partnership activities focus on achieving positive outcomes for all participants, especially by addressing critical questions and challenges facing policymakers, regulators, and system operators. The 21st Century Power Partnership taps into deep networks of expertise and professional connections to accelerate next-generation power system planning for 2030; provide operational support for grid integration; evaluate and expand smart grid deployment; and assist the government of Mexico with the implementation of its energy reform directives.

The 21st Century Power Partnership program in South Africa supports the country's power system transformation by accelerating the transition to a reliable, financially robust, and low-carbon power system. The 21st Century Power Partnership assists South Africa with power system expert workforce development and near-term power supply shortage mitigation.

In India, the 21st Century 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 the past year, the 21st Century Power Partnership launched a fellowship program, hosting officials from India at the National Renewable Energy Laboratory (NREL) and Lawrence Berkeley National Laboratory for training on modeling, forecasting, and grid integration management. The fellows will take this valuable information and apply it to achieve one of the 21st Century Power Partnership's main objectives: "advance integrated policy, regulatory, financial, and technical solutions for the large-scale deployment of renewable energy in combination with deep energy efficiency and smart grid solutions."



RESILIENCE

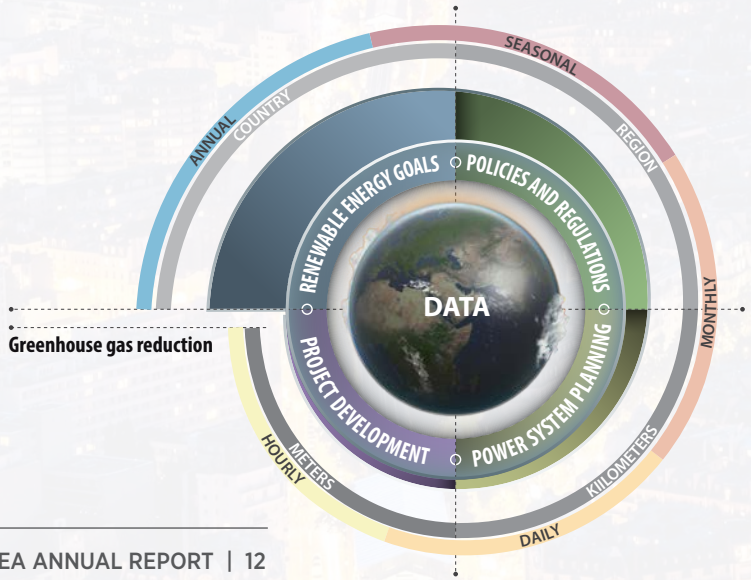
MAPPING THE ROAD FROM PARIS TO DEEP DECARBONIZATION

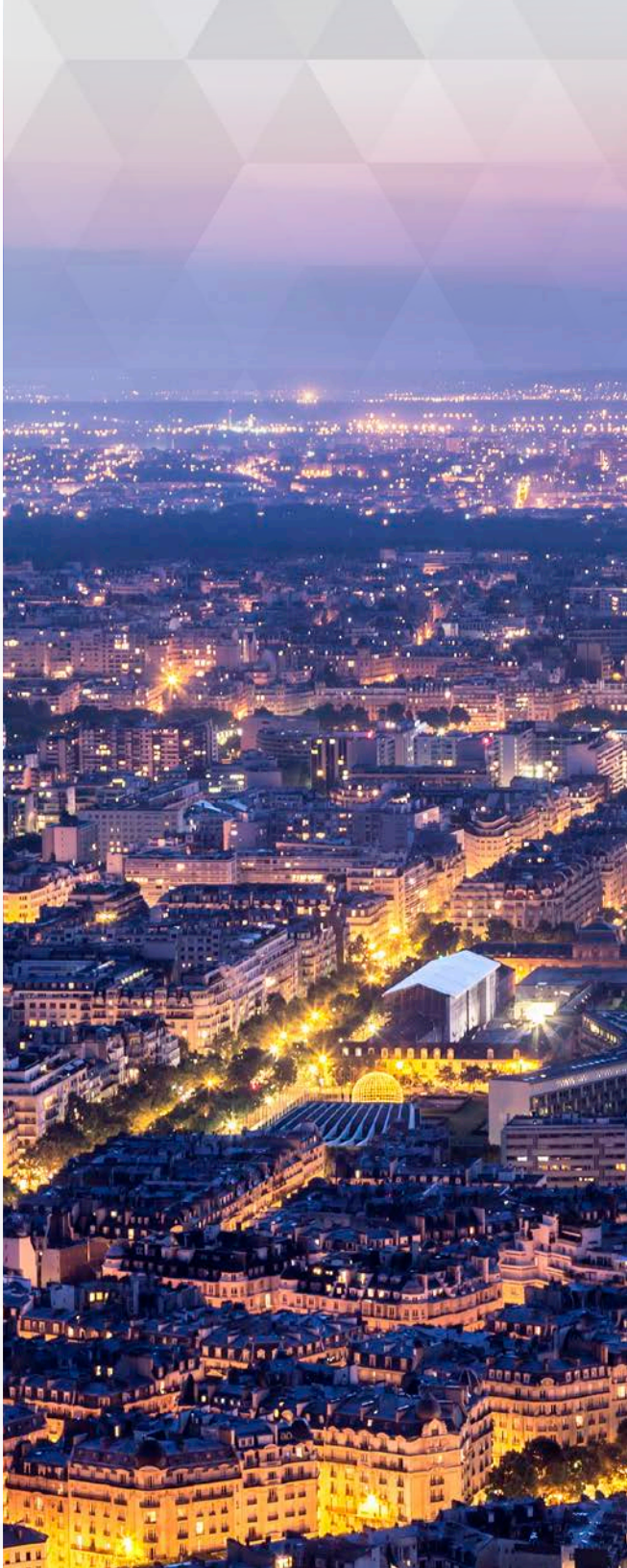
In December 2015, leaders of national governments, multinational corporations, non-governmental organizations, and subnational governments from 195 countries converged in Paris for the 21st Conference of Parties (COP21). The outcome: a bold new climate accord. The opportunity: a blueprint for moving, together, from aspiration to realization of a decarbonized energy economy.

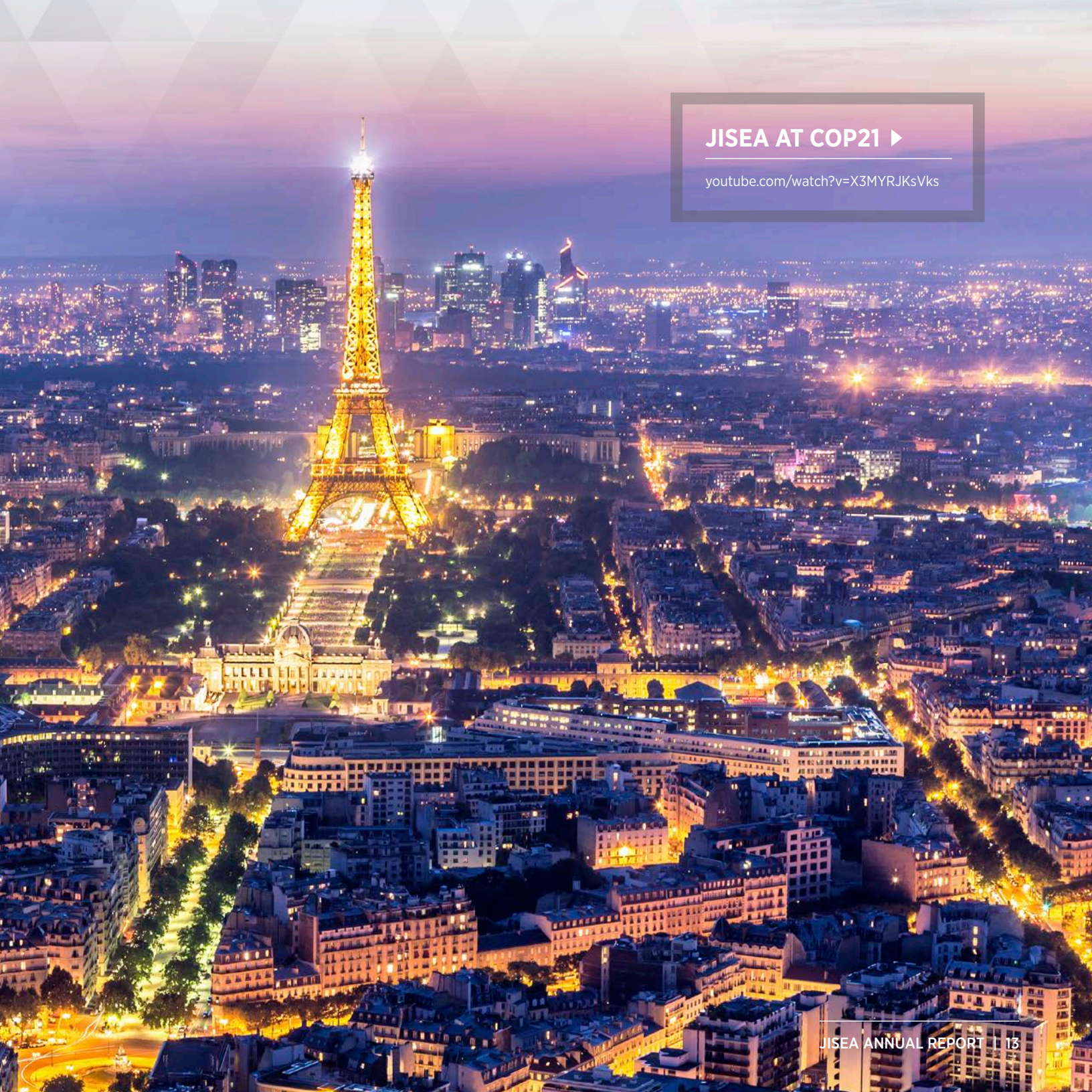
If countries' nationally determined contributions are fully realized, renewable energy technologies will produce almost 50% of global electricity by 2040, according to an analysis from the International Energy Agency.

JISEA's Doug Arent participated in the COP21 events, chairing a panel discussion on the importance of good data to setting, monitoring, and fully realizing climate and energy goals.

JISEA works with governments at all levels to establish data-driven methodologies to support countries' and municipalities' clean energy visions.







JISEA AT COP21 ▶

youtube.com/watch?v=X3MYRJKsVks

SHARING HIGH-PENETRATION RENEWABLE ELECTRICITY GRID SYSTEM EXPERIENCES ON THE PATH TO CHINA'S LOW-CARBON FUTURE

China now installs more renewable electricity each year than any other country in the world. The collaboration between JISEA and a select team of global affiliates, including the China National Renewable Energy Centre and the Danish Energy Agency, focuses on sharing experiences in the planning, deployment, and operation of high-penetration renewable electricity grid systems.

The China Grids Program for a Low-Carbon Future, funded by the Children's Investment Fund Foundation, seeks to maximize the likelihood of development of a renewable energy-friendly grid that sets the pathway for decarbonization of China's power system.

THE PATH TO CHINA'S LOW-CARBON FUTURE ▶

[1] *Electricity Capacity Expansion Modeling, Analysis, and Visualization*
nrel.gov/docs/fy16osti/64831.pdf

[2] *'Renewables-Friendly' Grid Development Strategies*
nrel.gov/docs/fy16osti/64940.pdf

[3] *Advancing System Flexibility for High Penetration Renewable Integration*
nrel.gov/docs/fy16osti/64864.pdf

[4] *Historical and Current U.S. Strategies for Boosting Distributed Generation*
nrel.gov/docs/fy16osti/64843.pdf

The first year of the collaborative program focused on expert engagements in China to share technical knowledge and experience on four topics, each with an accompanying technical report:

- **Comprehensive energy scenario design and modeling**
  Modeling the electric grid is of particular importance to China. China has dramatically increased its deployment of renewable energy and is likely to continue further accelerating such deployment over the coming decades. Careful planning and assessment of the technical, economic, social, and political aspects of integrating a large amount of renewables into the grid is needed to illuminate the pathways to China's low-carbon future.[1]

- **Renewable energy-friendly grid development**
  Wholesale power markets in the United States are diverse and evolving. The ability to manage higher grid penetrations of variable renewable resources has been part of that evolution. Regardless of how China's power market reforms unfold, one key lesson from U.S. experience is the need for adaptability. Market design should allow for future redesign and modifications to address problems that might not be apparent or foreseeable today.[2]

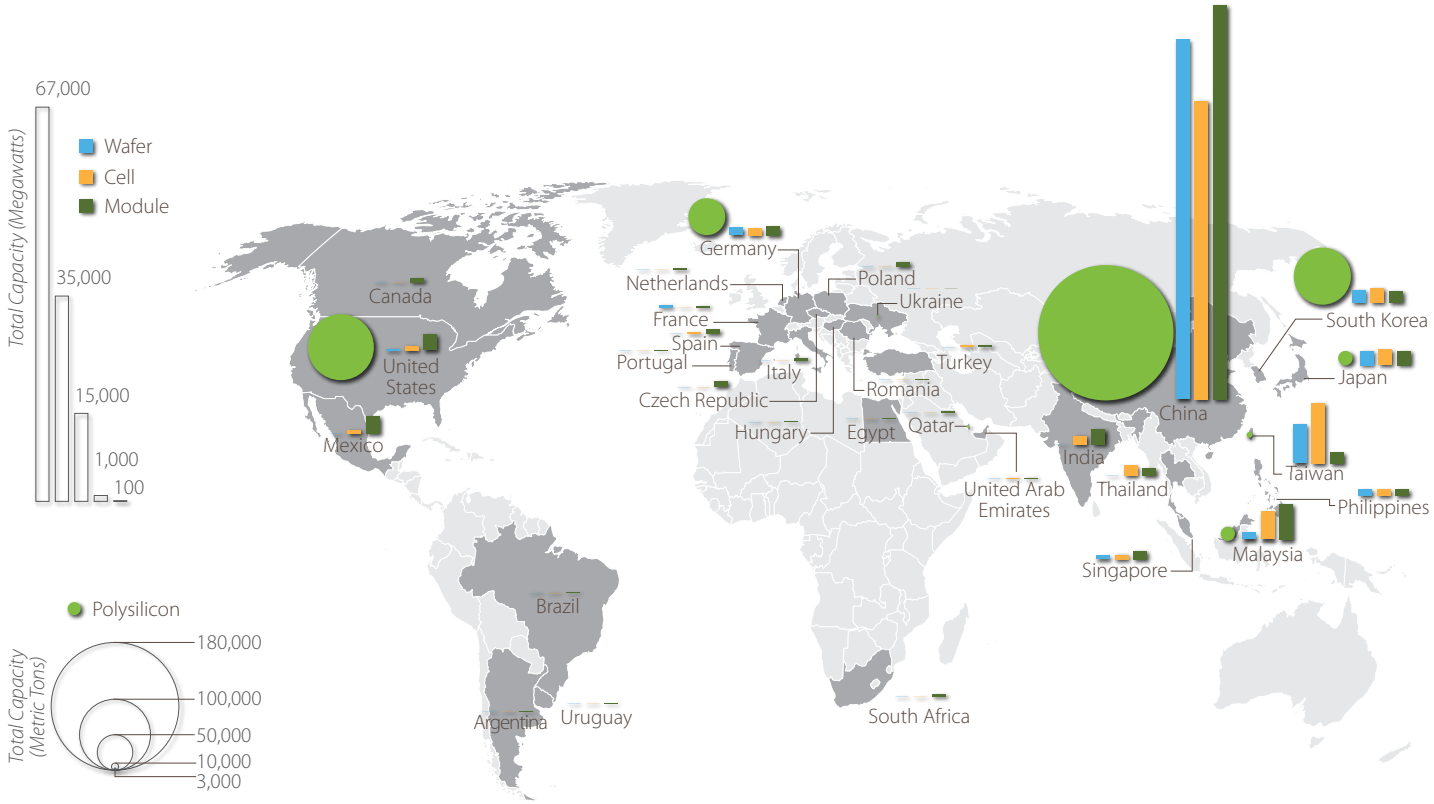
- **Power system flexibility**
  Market solutions for economic dispatch and for the acquisition of ancillary services have been shown to be effective in many parts of the world. The path forward for China may include the development of energy and ancillary service markets, but the path may instead comprise other means of providing system flexibility to deliver reliable, affordable power that accommodates the renewable energy goals of the country.[3]

- **Boosting distributed generation of renewable energy**
  Challenges in financing and interconnection management have restrained the growth potential of distributed solar photovoltaics (PV) in China. In the United States, distributed PV has achieved unprecedented levels of penetration. Many policies and strategies have, in combination, promoted this growth and comprise a body of lessons learned and best practices that can be selectively applied in other countries to stimulate their own distributed solar markets.[4]

MANUFACTURING

FINDING OPPORTUNITY FOR ECONOMIC GROWTH IN THE TRANSITION TO A CLEAN ENERGY ECONOMY

The Clean Energy Manufacturing Analysis Center (CEMAC), a multi-institution collaborative operated by JISEA, helps to illuminate the economic and technical elements of decarbonization pathways through credible, recurring global clean energy manufacturing analysis.



PV modules are becoming a commodity product, and the industry and supply chains are global. Today, China is home to the majority of PV manufacturing capacity and dominates in each stage of the crystalline silicon (c-Si) PV module value chain: polysilicon, wafers, cells, and modules.[1]

CEMAC Clean Energy Manufacturing Analysis Center

Since its formal launch in September 2015, CEMAC has initiated a series of analyses on the manufacturing of a diverse suite of clean energy technologies, from windows to geothermal binary power plants. The projects are already yielding insights:

- The market for automotive lithium-ion batteries is fairly immature, characterized today by low utilizations, relatively low yields, and a diversity of participants with varying levels of experience. Yet, the industry is moderately concentrated in terms of market share, with 93% of share divided among 11 competitors. Manufacturing costs are dropping rapidly and, as demand increases through 2020 and beyond, competitors will likely consolidate capacity, improve yields, and incrementally advance currently commercialized technologies to improve costs going forward.[2]

- The capital cost for hydrogen refueling stations is still high and varies significantly by capacity and location. For example, the cost of a 700–1,000 kilogram per day hydrogen refueling station in Japan is about twice the cost of a similar station in Europe and the United States, in part due to higher equipment costs. Future technology advancements and economies of scale will impact hydrogen refueling stations cost and hydrogen prices.[3]

CLEAN ENERGY MANUFACTURING ANALYSIS CENTER ▶

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[1] "Economic Measurements of Polysilicon for the Photovoltaic Industry: Market Competition and Manufacturing Competitiveness." *IEEE Journal of Photovoltaics*. dx.doi.org/10.1109/JPHOTOV.2014.2388076.

[2] *Automotive Lithium-Ion Battery Supply Chain and U.S. Competitiveness Considerations.* nrel.gov/docs/fy15osti/63354.pdf

[3] *Insights from Hydrogen Refueling Station Manufacturing Competitiveness Analysis.* nrel.gov/docs/fy16osti/65418.pdf

CHOICE

UNDERSTANDING ENERGY THROUGH THE LENS OF SERVICES AND PERSONAL VALUES

Personal needs—comfort, mobility, shelter, security—can involve significant energy use. But reducing energy consumption does not have to mean living, literally, in the dark.

JISEA's Doug Arent is leading an NREL team exploring energy use in terms of the services it provides. By turning the perspective from generation sources and utilities to individuals and life tasks, this area of study offers the promise of increasing quality of life and options for individuals while also informing more efficient and more effective energy system design.

- In NREL's 250-square-foot office simulator, the Comfort Suite, desk chairs warm or cool in seconds, creating a micro-climate that matches the individual preferences of the occupant. Infrared cameras show when someone's fingers are starting to chill. Sensors track the concentration of carbon dioxide as 20 ventilation registers alternately blast hot and cold air at volunteers acting as office workers. And the results are being closely monitored and evaluated by engineers and ergonomics specialists. "We'll be able to reduce operating costs for buildings but actually keep people more comfortable than we do today," NREL's Dane Christensen, a lead on the project, says. "The work that we're doing should make the world better for occupants of the buildings, as well as for the owners and the operators."[1]

- Does the carbon footprint of your grocery store purchases matter to you? NREL researcher Steven Isley developed and tested an augmented reality app for those who answer "yes." The app overlays digital information about carbon footprints to physical objects, such as cereal boxes, to provide information to help consumers make decisions based on their expressed preferences and values. Initial results, which are being submitted for publication in 2016, indicate potential for broad reductions in carbon intensity of consumer goods when consumers have access to carbon footprint data that can inform their purchase decisions.

LEARN MORE ▸

[1] "Your Office Is Too Cold. Or Too Hot. But Science Wants to Help". wired.com/2015/12/your-office-is-too-cold-or-too-hot-but-science-wants-to-help


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TEAMWORK

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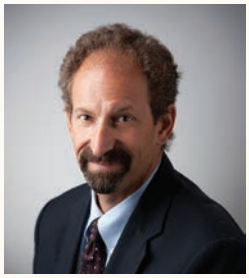
JISEA'S GLOBAL TEAM



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

Doug Arent is executive director of JISEA at the National Renewable Energy Laboratory. In addition to his JISEA leadership 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), is a member of the Keystone Energy Board, and is associate editor for the journal *Renewable and Sustainable Energy Reviews*. Arent also 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*.

Jill Engel-Cox, Ph.D.
Deputy Director

Jill Engel-Cox is deputy director of JISEA and program director of the Clean Energy Manufacturing Analysis Center (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 university graduate courses on industrial processes and environmental communications.

Patricia Statwick, MBA, MAS
Program Administrator

Pat Statwick works to develop, implement, and manage JISEA programs and projects. She provides project management assistance 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.

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.

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University of Colorado

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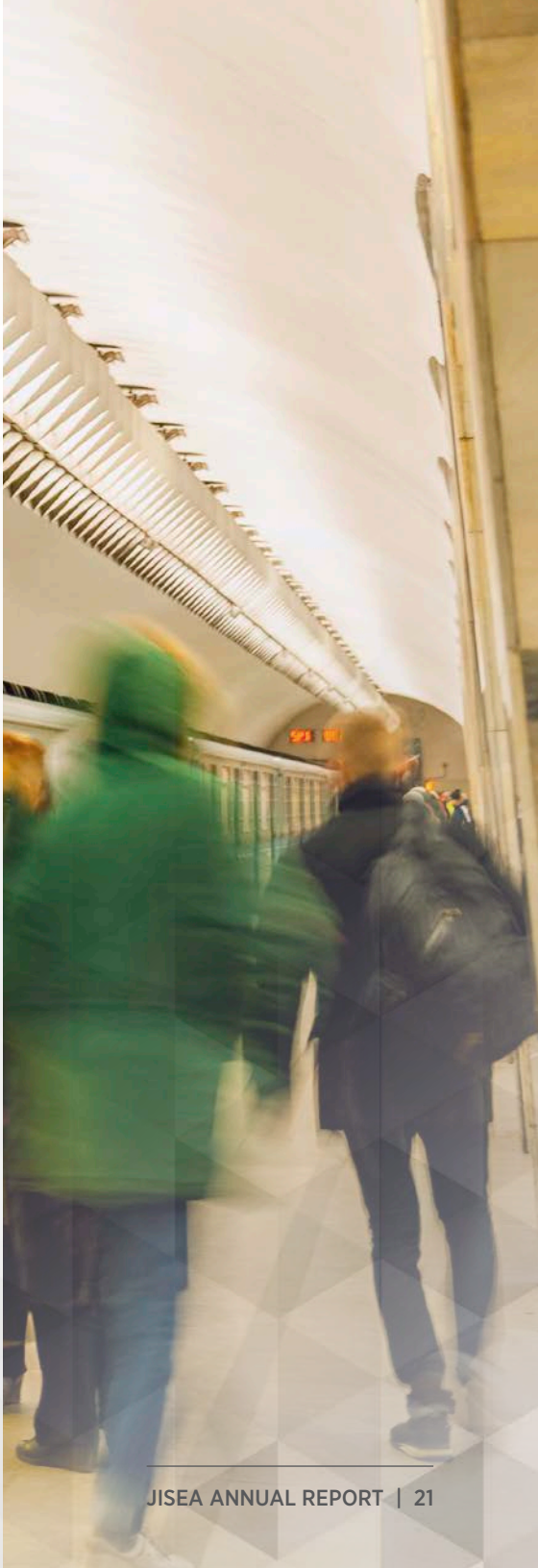

RESEARCH AFFILIATES

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

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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

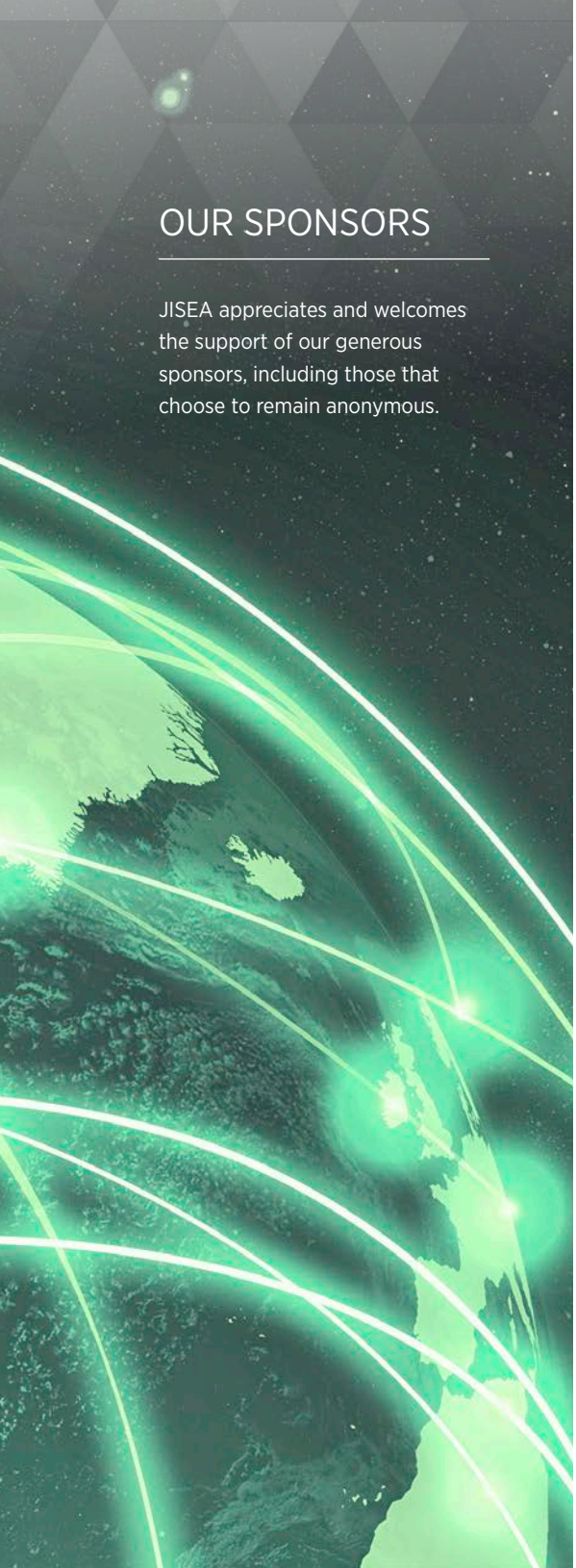
MASDAR.AC.AE

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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UBS

INNOVATE

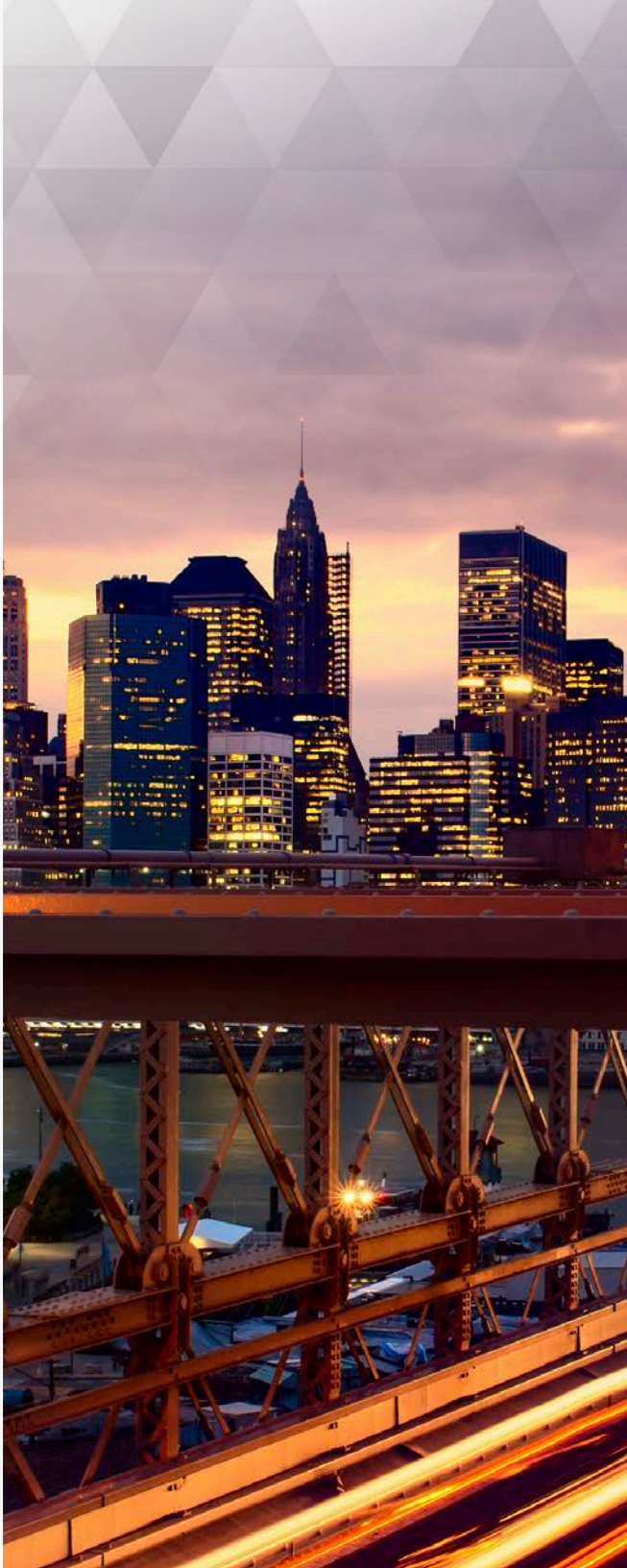
DRIVING 21st CENTURY INNOVATION TO REALIZE THE VISION

Innovation is crucial for success in 21st century business. Innovation can improve performance and disrupt entire markets. Innovation allows companies to create and capture value.

Under the narrow definition of innovation as simply a technological breakthrough, creative forms of innovation are overlooked—the forms that can accelerate the momentum of the tremendous change in today's business landscape.

In the 21st century, successful strategies consider innovation at speed and scale.

The five forces of 21st century innovation strategy



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