17 U.S. Department of Energy National Laboratories

Office of Science laboratory
National Nuclear Security Administration laboratory
Office of Fossil Energy laboratory
Office of Energy Efficiency and Renewable Energy laboratory
Office of Nuclear Energy, Science and Technology laboratory
Office of Environmental Management laboratory

“Government owned, contractor operated”
NREL at a Glance

2,300
Employees, plus more than 460 early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

about 900
Partnerships with industry, academia, and government

Campus operates as a living laboratory
NREL Science Drives Innovation

Renewable Power
- Solar
- Wind
- Water
- Geothermal

Sustainable Transportation
- Bioenergy
- Vehicle Technologies
- Hydrogen

Energy Efficiency
- Buildings
- Advanced Manufacturing
- Government Energy Management

Energy Systems Integration
- Grid Integration
- Hybrid Systems
Advanced, scalable analytic insights

**Materials by design**
Develop new techniques to predict material properties of novel alloys and design materials with prescribed physical properties.

**Biomass pyrolysis**
Simulations guiding optimization of reactions and catalysts to reduce cost of fuel production.

**Perovskite-like PV materials**
Computation drive search for new perovskite-like materials, more stable, do not contain lead.

**Renewable fuels**
Simulations of enzyme-plant cellulose interactions to reduce fuel costs.

**Wind energy**
Model wake fields and inflow conditions in wind plants with realistic terrain to reduce cost of electricity.

**Electric vehicles**
Multi-scale simulations of electric drive vehicle battery systems to create cutting-edge battery simulation tools to aid safe affordable designs.

**Energy system integration**
Modeling the Eastern Interconnect at native spatial scales under different renewable penetration scenarios.
JISEA
Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.

Founding Members

www.jisea.org
JISEA
Research Portfolio

- Clean Energy for Industry and Agriculture
- Energy System Integration and Transformation
- Advanced Manufacturing Analysis
- International Collaboration and Capacity Building
Outline

About NREL and JISEA

Renewable Technologies Analysis

Energy Systems and Scenarios Analysis

Partnering and Collaborations
Understanding how to achieve affordable and dispatchable solar generation systems that operate as a typical power plant is the ultimate pinnacle for solar to achieve extremely high penetration levels in our grid system.

Research Challenges
• Develop solar interface and control technologies to enable greater grid reliability, resilience, and overall system efficiency
• Reduce solar hardware costs through innovative materials, manufacturing, and design, and de-risk technology to reduce balance of system costs
• Develop CSP-integrated or stand-alone thermal energy storage to provide flexible, long-duration storage needed to enable high penetrations of renewables on the grid
• Increase solar system lifetimes and performance through improved efficiency and lower degradation rates
• Understand how to integrate and optimize solar at scale within systems such as buildings, microgrids, distribution systems, and hybrid systems.
Driving innovation in the design and utilization of next generation marine energy and hydropower/pumped storage technologies through foundational research, tool development, and laboratory and in-water characterization.

Research Challenges
- Understand the needs of the rapidly evolving grid and how to optimize hydropower operations and planning.
- Support innovative technologies that would improve hydropower and pumped storage capabilities to meet grid needs.
- Develop disruptive innovations to drastically reduce marine energy system costs.
- Identify key opportunities and develop reliable marine energy hybrid microgrids for Blue Economy applications.
Geothermal provides both heat and power—24 hours a day, 7-days a week—increasing grid reliability and security, with the smallest footprint of any renewable. Reducing costs and enabling geothermal anywhere can increase deployment nearly 26-fold by 2050.

**Research Challenge**
- Reduce well field development costs through increased drilling efficiency and drilling rates and reduced material construction costs.
- Enable development of geothermal anywhere through new technologies such as Enhanced Geothermal Systems (EGS) or Advanced Geothermal Systems (AGS).
- Economically recover lithium and other critical minerals from geothermal brines to meet U.S. and global demands.
- Identify the feasibility of hybrid geothermal-solar systems and subsurface thermal energy storage.
Enabling low-cost and accessible wind energy by joining forces with DOE, industry, and interagency and state partners to advance scientific knowledge and technological innovation.

**Research Challenge**

- Validate multiple wind technologies at scale to achieve an integrated energy system that can meet the complex energy challenges of the future.
- Develop taller wind turbines with larger rotors to capture greater wind resources at higher elevations and lower the levelized cost of wind energy.
- Develop innovations for offshore wind such as floating platforms, scaling solutions for larger offshore designs, advanced turbine controls, and lightweight drivetrains.
- Optimize power output across the entirety of a wind plant instead of at the individual-turbine level.
Onshore: 2-3 MW
50 m blade length

Avg. Wind Turbine Capacity Factors
(% of capacity) by Build Year
1998-2001: 24.5%
2004-2011: 32.1%
2014-2015: 42.6%

Compare: Natural Gas Plant: 56%;
Coal Fired Plant: 53%; Nuclear: 92%;
Solar Photovoltaic: 27%

Wind energy potential capacity at 80m hub height
2008 turbine technology
Wind energy potential capacity at 110m hub height
2014 turbine technology
Wind energy potential capacity at 140m hub height ‘near-future’ turbine technology

![Wind Potential Capacity at 140m Hub Height](chart)

Data sources: AWS Truepower, National Renewable Energy Laboratory

Legend:
- 0
- 100
- 1000 - 200
- 200 - 300
- 300 - 400
- 400
- Land exclusions

35% GCF

Future Technology
Wind plant modeling

Blade-resolved simulations of whole wind plants

- Developing predictive capability to better understand complex fluid flow in wind plants with complex terrain, focus on turbine-turbine impacts, and address wind plant energy losses
- Growing fleet requires advanced sensors and simulation for improved reliability and energy security
- Inaccurate forecasts cost the industry $300M+/yr
- Simulations of single blade-resolved turbine exceed current ESIF HPC capabilities

POTENTIAL IMPACT

Improve wind plant efficiency 4% to generate $1 billion in annual savings.
Enabling hydrogen to be a common means of transporting, storing, and transforming energy at the scale necessary for a clean and vibrant economy. Collaborating with key government and industry partners who will accelerate this technology development and adoption.

**Research Challenges**

- Improve the economics of hydrogen production to enable it to shift energy across time, sectors, and location—including providing electric grid support.
- Develop materials and advanced cell concepts for polymer electrolyte fuel cells and electrolyzers, focusing on the emerging markets of intermittent H2 production and heavy-duty transportation.
- Develop new infrastructure technologies to enable safe fueling for heavy-duty hydrogen trucks and reduce the cost and improve reliability of fueling FCEVs.
- Research hybrid bio-electrochemical processes and advanced cell concepts.
Fully integrated system capable of experiments on advanced components and subsystems and innovative component/system concepts

**Production**
- 250 kW PEM stack
- 120 kg/day
- 1 MW capable

**Dispensing**
- Commercial dispenser
- Research dispenser
- Recirculation loop (High-P to Low-P)

**Compression**
- High throughput compressor up to 1 kg/min (Low-P to High-P)

**Storage**
- 90 kg @ 900 bar
- 80 kg @ 415 bar
- 210 kg @ 200 bar
Raw materials and supply chains

Supply chain disruption risk

In 2017, 32 countries accounted for all global production of key NMC materials:
- 60 million tons aluminum (smelters): 54% China, 6% Russia, 5% Canada
- 16 million tons manganese: 33% South Africa, 16% China, 14% Australia
- 2.1 million tons nickel: 11% Philippines, 10% Canada, 9% Russia, 9% Australia
- 1.2 million tons natural graphite: 67% China, 13% India, 8% Brazil
- 110,000 tons cobalt: 59% Democratic Republic of Congo, 5% Russia, 5% Australia
- 43,000 tons lithium: 44% Australia, 34% Chile, 13% Argentina

Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.

### Balance of Trade

<table>
<thead>
<tr>
<th>Region</th>
<th>Polysilicon</th>
<th>PV Cell</th>
<th>PV Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>$0</td>
<td>-$256</td>
<td>-$256</td>
</tr>
<tr>
<td>Canada</td>
<td>$1</td>
<td>-$76</td>
<td>$28</td>
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<tr>
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<td>-$2187</td>
<td>$3809</td>
<td>$7177</td>
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<td>Germany</td>
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<td>$319</td>
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<td>-$40</td>
<td>-$456</td>
<td>-$376</td>
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<tr>
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<tr>
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<td>$302</td>
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<td>UK</td>
<td>$7</td>
<td>-$537</td>
<td>-$498</td>
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<tr>
<td>US</td>
<td>$1577</td>
<td>-$8095</td>
<td>-$8037</td>
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</table>

Technology vision studies
Outline

About NREL and JISEA
Renewable Technologies Analysis
Energy Systems and Scenarios Analysis
Partnering and Collaborations
U.S. Energy Supply is Shifting

Renewable energy—not including hydropower—currently produces 10% of the total U.S. electricity generation. Within the next two years, this is expected to grow to 13%.

With hydropower, renewable energy is 17%.

With nuclear (19%), U.S. low-carbon electricity is 36%.

South America: Adaptation of hydropower to changing hydrological phases and increased renewables

- Countries that traditionally rely heavily on large (dammed) hydropower face increasing risk and reliability concerns during El Niño and La Niña hydrological phases
- Rainfall and snowmelt patterns are changing making hydropower resources more unpredictable, variable
- Aging infrastructure susceptible to a variety of hazards
- Adaptation:
  - Expand emphasis of system design on flexibility and resiliency at different time scales (daily to seasonal to interannual)
  - Increase coordination among dam operators and other end users (e.g. agricultural sector) to better serve all water needs while reducing sedimentation and resource volatility
  - Increase use of medium and long-range forecasting to enable better watershed planning and dispatch
  - Diversification of energy sources, including other renewable energy and natural gas

Source: JISEA, [https://www.nrel.gov/docs/fy20osti/75467.pdf](https://www.nrel.gov/docs/fy20osti/75467.pdf)
Electricity modeling at multiple scales

**Temporal resolution**
- Annual
- Seasonal/Diurnal
- Hourly
- Sub-hourly

**Geographic scale**
- Global
- U.S.
- Regional/Balancing Area
- Generator

**IAMs, CGEs**
Global energy-economic-climate

**SolarDS**
Rooftop PV adoption

**ReEDS**
National policy, market, technology analysis

**ABM**
Agent Based Models of Customer Behavior

**RPM**
Regional integrated resource planning

**PLEXOS**
Security-constrained unit commitment & economic dispatch

**FESTIV**
Automatic generation control (AGC) & dispatch

**SAM**
Hourly plant output

**Data**
- wind, solar, demand, generator, transmission

**System Models**
- Production Cost
- Grid Simulation Models
NREL models scenarios of future electricity generation

Key:
RE = Renewable Energy
NG = Natural Gas
VRE – Variable Renewable Energy

NREL models scenarios of future electricity generation

Example: Mid Case Scenario

Example:
LA100: The Los Angeles 100% Renewable Energy Study

LADWP
$6 billion annual budget
9,400 employees
4 million residents

Advisory Group
Diverse energy backgrounds
Quarterly meetings
Policy oriented

Integrated Electricity Modeling
Full range power system modeling
Integrated transmission and distribution analysis

Environmental Analysis
Air quality
Environmental Impact

Economic Analysis
Job creation
Job migration
Economic development

Example:
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The Los Angeles 100% Renewable Energy Study

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Environmental Analysis
Air quality
Environmental Impact

Economic Analysis
Job creation
Job migration
Economic development
A Clean Energy Ministerial (CEM) initiative focused on helping countries achieve efficient, clean, affordable and reliable power system transformation. Key areas of activity include:

**Faster Learning**
Developing and sharing knowledge on key topics related to power system transformation.

**Better Tools**
Strengthening and disseminating technical tools to accelerate policy and regulatory analysis.

**Capacity Building**
Bolstering the capacity of experts to advance the policies, programs, and practices.

**Meaningful Partnerships**
Establishing applied multilateral partnership engagements to leverage knowledge, tools, and capacity.

https://www.21stcenturypower.org

JISEA is the Operating Agent for the CEM Initiative 21CPP
Example: India Project

Renewable Energy Grid Integration Studies with India

- Work with stakeholders (e.g., USAID, World Bank, 21CPP and other technical partners) to Green the Grid.
- As India develops 100 GW of solar and 60 GW of wind energy, how would the system operate in 2022?
- What can policy makers do to lower the cost of operating this system and better integrate RE?
- Expanding models to provide insight on cross-border electricity trade
- Long-term Power System Planning: Deciding What to Build, Where to Build it, When
India’s power system with 160 GW wind and solar—Achieving system balance every 15 minutes

http://www.nrel.gov/india-grid-integration

Video: https://www.youtube.com/watch?v=mY1mknCwFM
Electrification Futures Study

All Figures from NREL’s Electrification Futures Study: [www.nrel.gov/efs](http://www.nrel.gov/efs)
Co-location of Wind/PV and Agriculture

- Growing food crops under partial shade of solar energy infrastructure
- Can increase crop yields and reduce water needs in hot, dry conditions
- Can also co-locate with grazing areas and collect rainwater for irrigation and cleaning
- Cooler microclimate increases PV efficiency
- Provides resilience buffer against extreme heat and addresses competing land use demands
Electricity & Gas networks are interconnected energy infrastructures whose operation and reliability depend on one another. As the percent of gas and variable renewable power plants increase, the connection between these networks becomes increasingly important.

Goal of project is to:
- Co-simulate power and natural gas network operations.
- Define an interconnected power and natural gas test system
- Determine value of coordination of day-ahead operations

Funded through JISEA sponsorship by:
- American Electric Power
- Environmental Defense Fund
- Hewlett Foundation
- Kinder Morgan
- American Gas Association
- Midcontinent Independent System Operator

Source: JISEA project in progress.
Clean Power Technologies for Oil & Gas Industry Operations

- Electrification of all equipment at wellpad connected via microgrid
- Power could consist of:
  - Field/Flare Gas fired generator
  - Solar PV/wind systems
  - Fuel cells
  - Energy Storage
    - Hydrogen
    - Batteries
  - Grid power (or offgrid)
- Benefits:
  - Resiliency during outages
  - Optimize for least cost
  - Reduce emissions
- Leverage work on
  - Remote bases & communities
  - Islands

Opportunities for Collaboration: Design of complete system, technology evaluation & selection, “utility in a cube” technology
JISEA led analysis on nuclear-renewable hybrids with NREL and Idaho National Lab

- System configurations
- Operations
- Product options
- Value Stream
- Economics & investment insights

The NICE Future initiative is part of a global partnership of countries and organizations exploring the potential for nuclear power uses, innovations, and greater systems integration, to accelerate progress toward clean energy goals.
Outline

About NREL and JISEA
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Partnering and Collaborations
We Reduce Risk in Bringing Innovations to Market

- NREL helps bridge the gap from basic science to commercial application.
- Forward-thinking innovation yields disruptive and impactful results to benefit the entire U.S. economy.
- Accelerated time to market delivers advantages to American businesses and consumers.
Partnering with Business for Competitive Advantage

Nearly 900 active partnerships with industry, academia, and government

In 2019 NREL had:

- 299 new partnership agreements
- $74.0M value of new partnership agreements
- 255 unique new partners
- 587 active partners
This is a 10-year $100 million partnership that is intended to fill gaps in traditional energy approaches. Our scientists and engineers are collaborating to conceive and create solutions for today’s energy challenges.

Shell Gamechanger Powered by NREL is our five-year multi-million-dollar partnership program with Shell. We have branded the program GCxN, and it focuses on battery longevity and advanced smart grid controls.

NREL and Eaton are working together in the ESIF on grid intelligence, distributed energy resource management, advanced energy storage systems, virtual modeling and analysis, high-performance computing, and other research.

Our Innovation Incubator (IN²) is expanding this scalable model to other partners and technologies and growing to a multiyear, $30 million program.
Questions?
Thank you

NREL/PR-6A50-76085