Innovations in Renewable Energy Technologies, Systems, and Energy Analysis

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Outline

- About NREL and JISEA
- Renewable Technologies Analysis
- Energy Systems and Scenarios Analysis
- Partnering and Collaborations

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- **About NREL and JISEA**
- Renewable Technologies Analysis
- Energy Systems and Scenarios Analysis
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17 U.S. Department of Energy National Laboratories

- Office of Sciece 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"

U.S. DEPARTMENT OF ENERGY

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

Computations 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

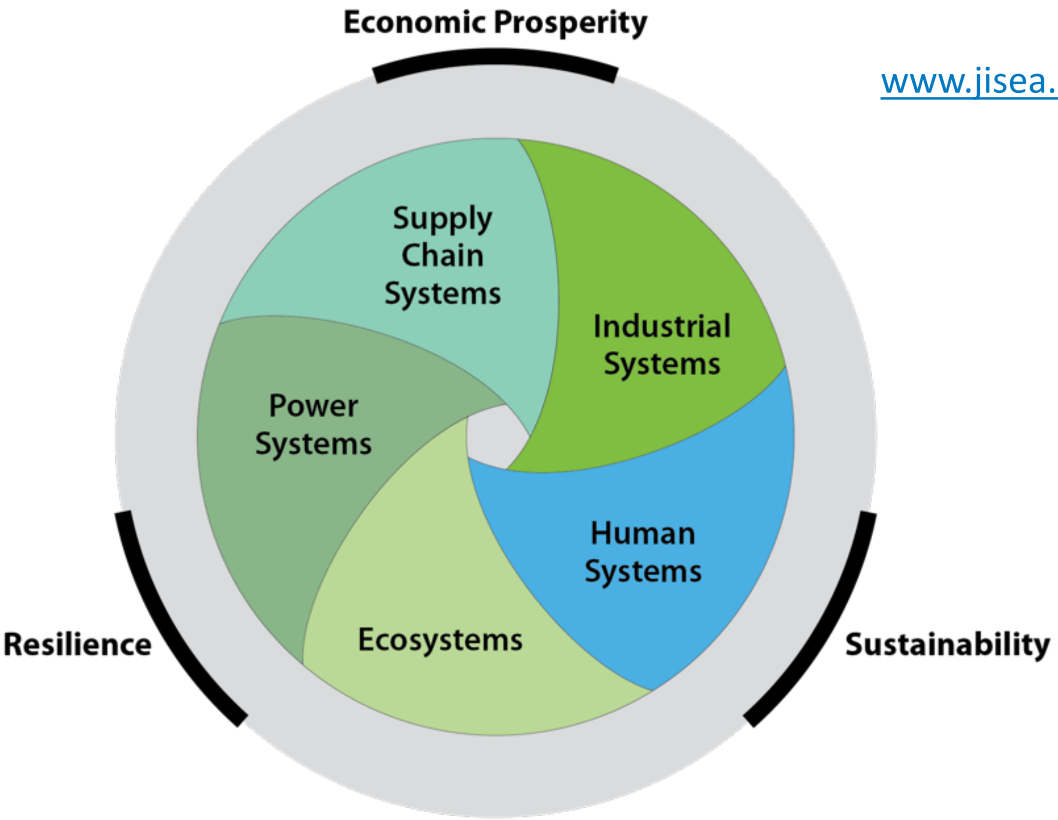
Energy system integration

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.



www.jisea.org

Founding Members

NREL National Renewable Energy Laboratory | Colorado School of Mines | Colorado State University | MIT Massachusetts Institute of Technology | Stanford University | University of Colorado Boulder

JISEA

Research Portfolio

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

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Solar Research

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.

Water Power

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

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.

Wind Research

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.

Wind Machines – Scale, Capacity Factor Increasing, Manufacturing Costs Declining

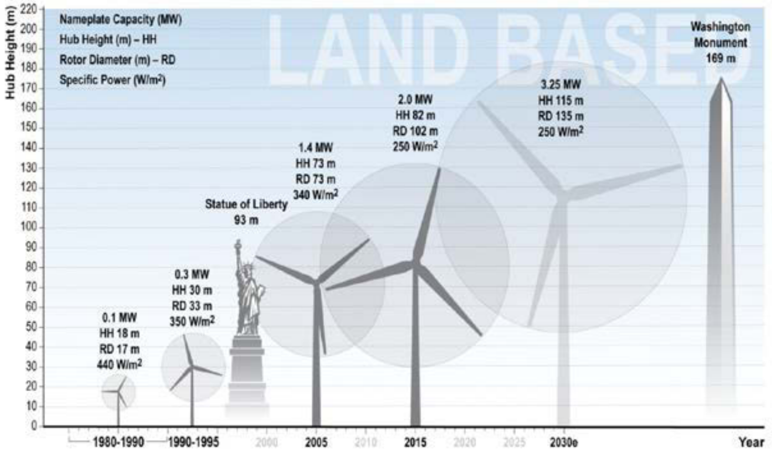
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

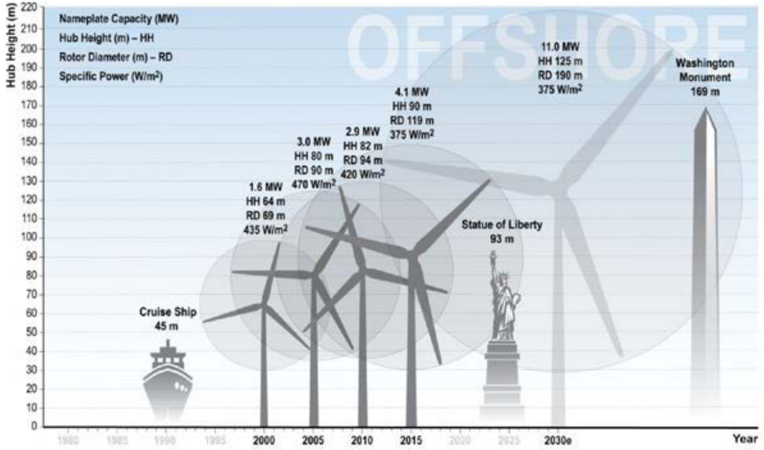
1998-2001: 24.5%

2004-2011: 32.1%

2014-2015: 42.6%

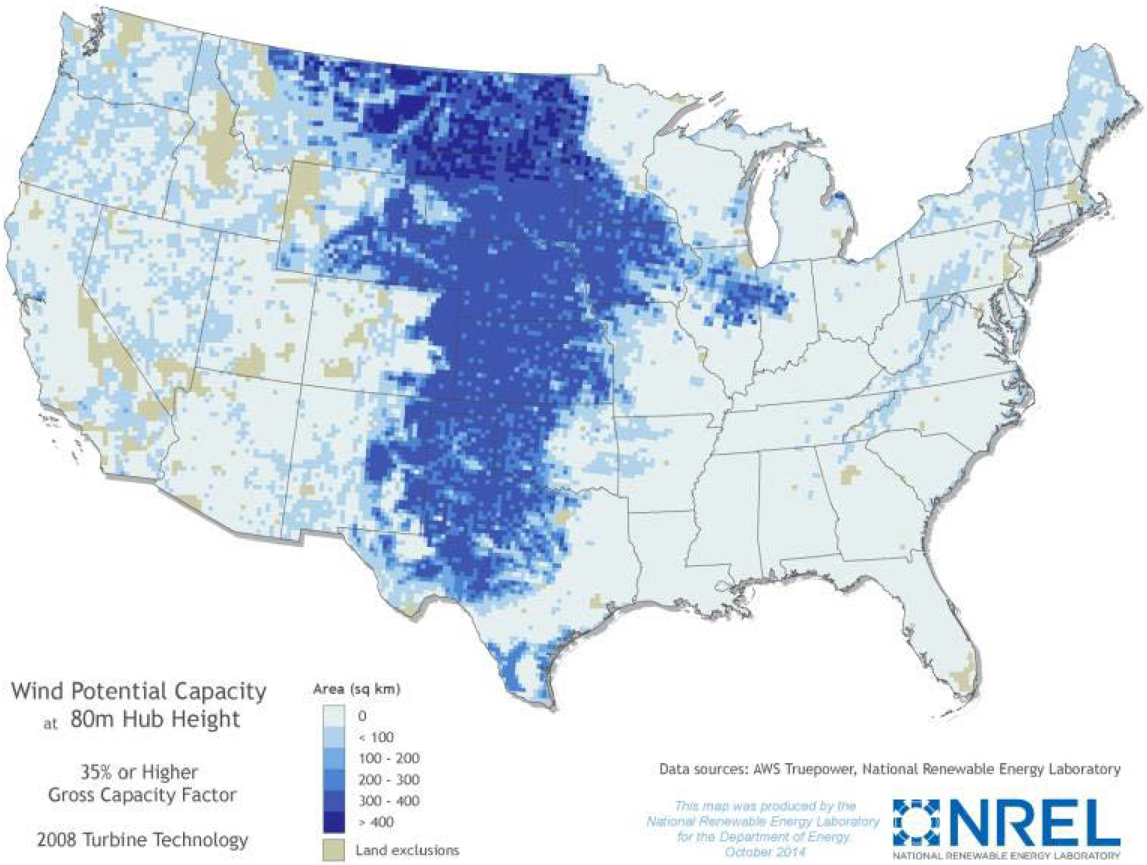
Compare: Natural Gas Plant: 56%; Coal Fired Plant: 53%; Nuclear: 92%; Solar Photovoltaic: 27%



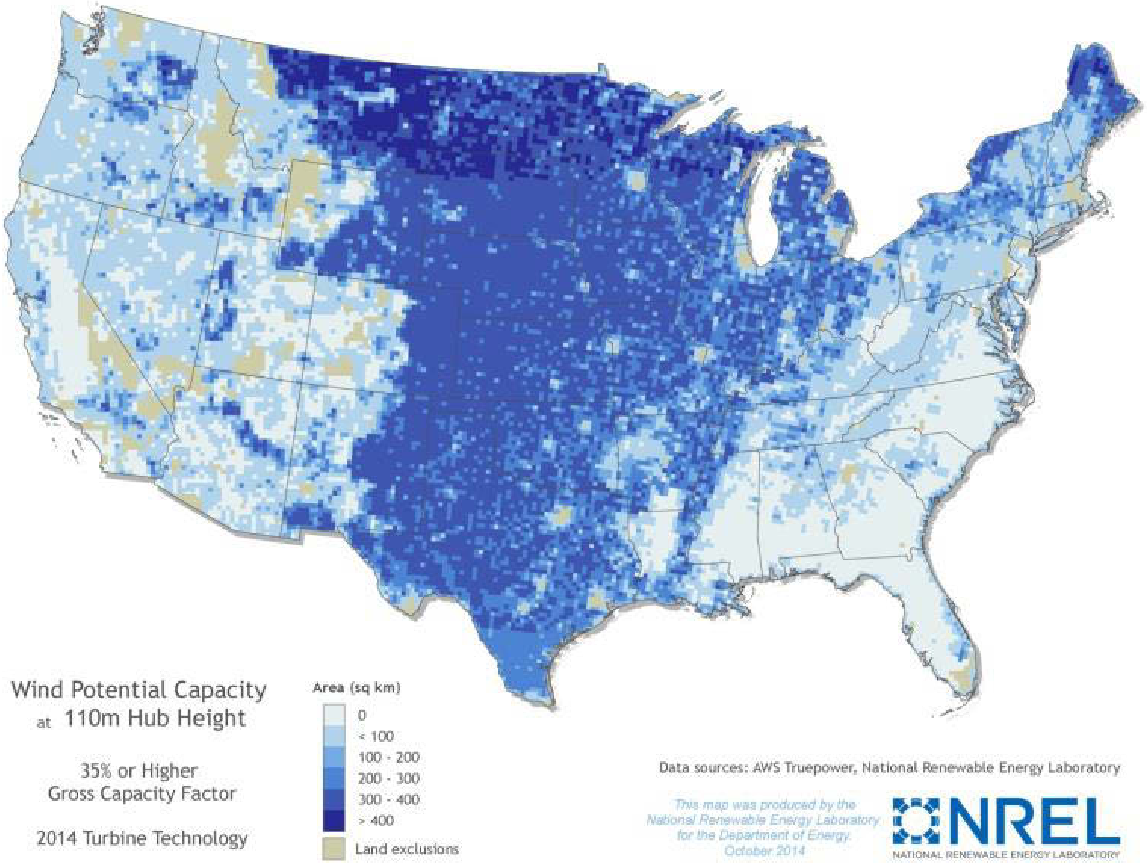


Source: LBNL, https://emp.lbl.gov/sites/all/files/scaling_turbines.pdf

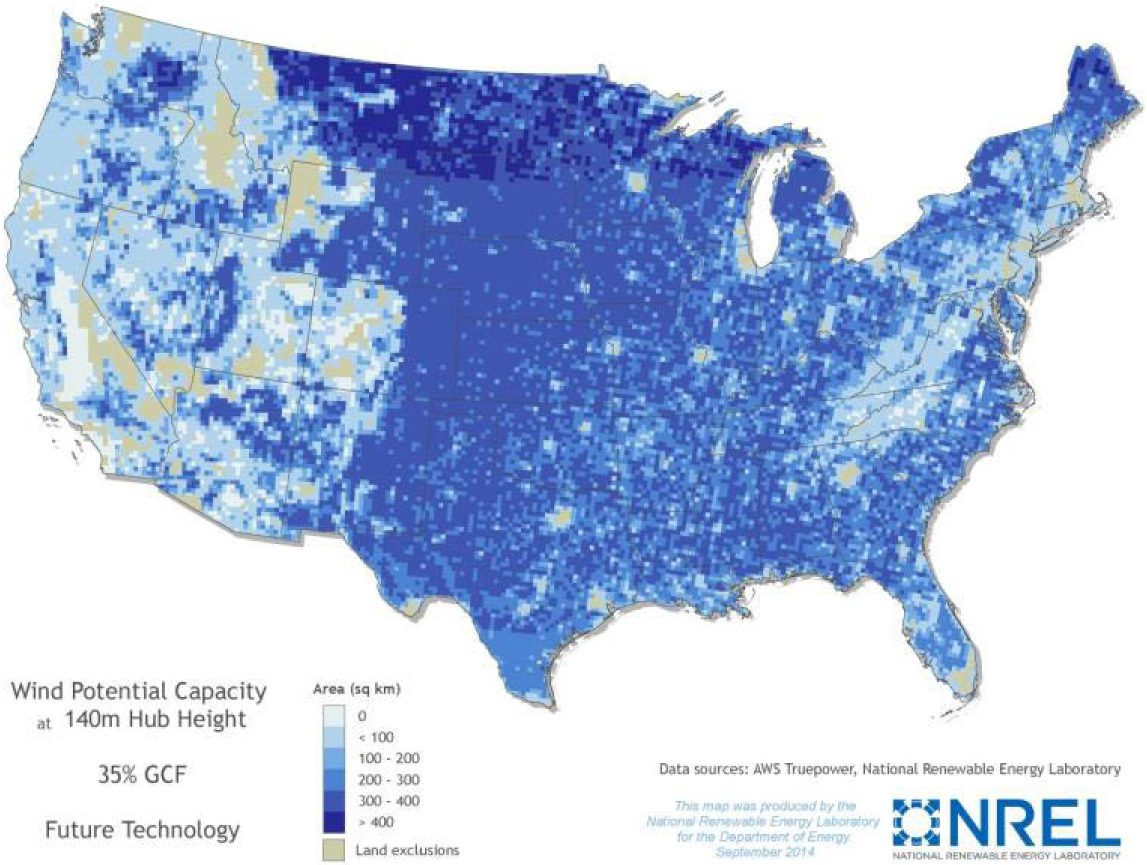
Wind energy potential capacity at 80m hub height 2008 turbine technology



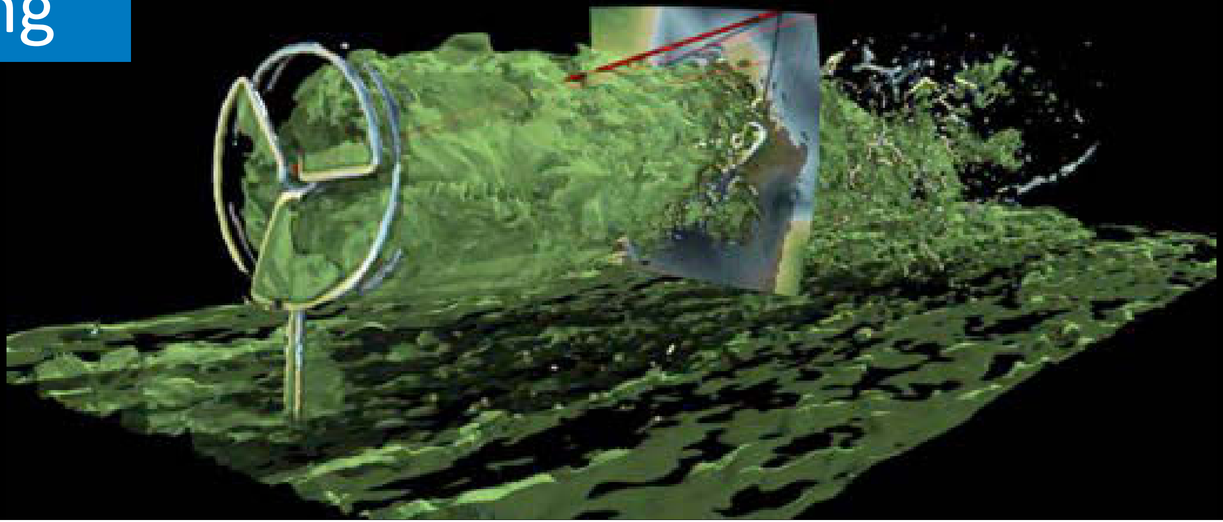
Wind energy potential capacity at 110m hub height 2014 turbine technology

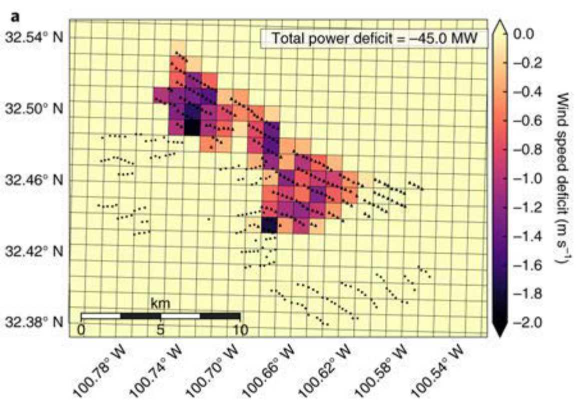


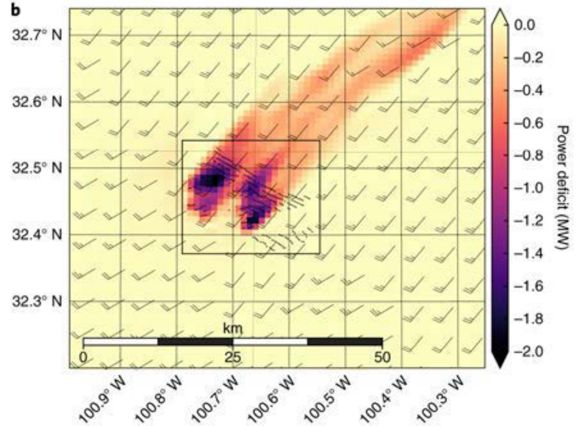
Wind energy potential capacity at 140m hub height ‘near-future’ turbine technology



Wind plant modeling





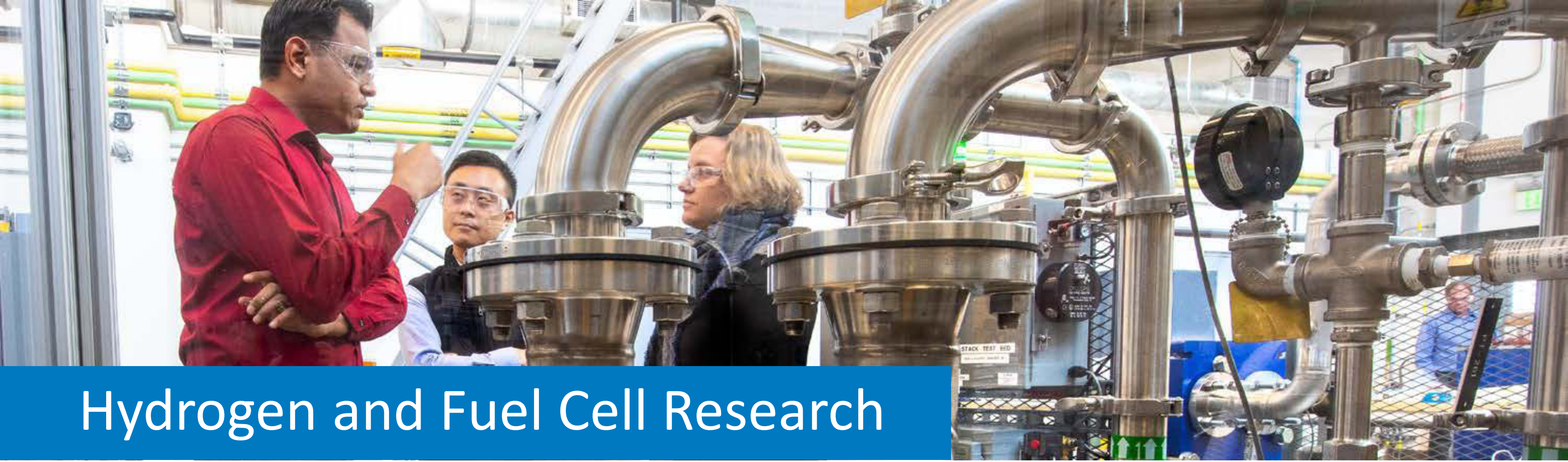


Blade-resolved simulations of whole wind plants

- 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.



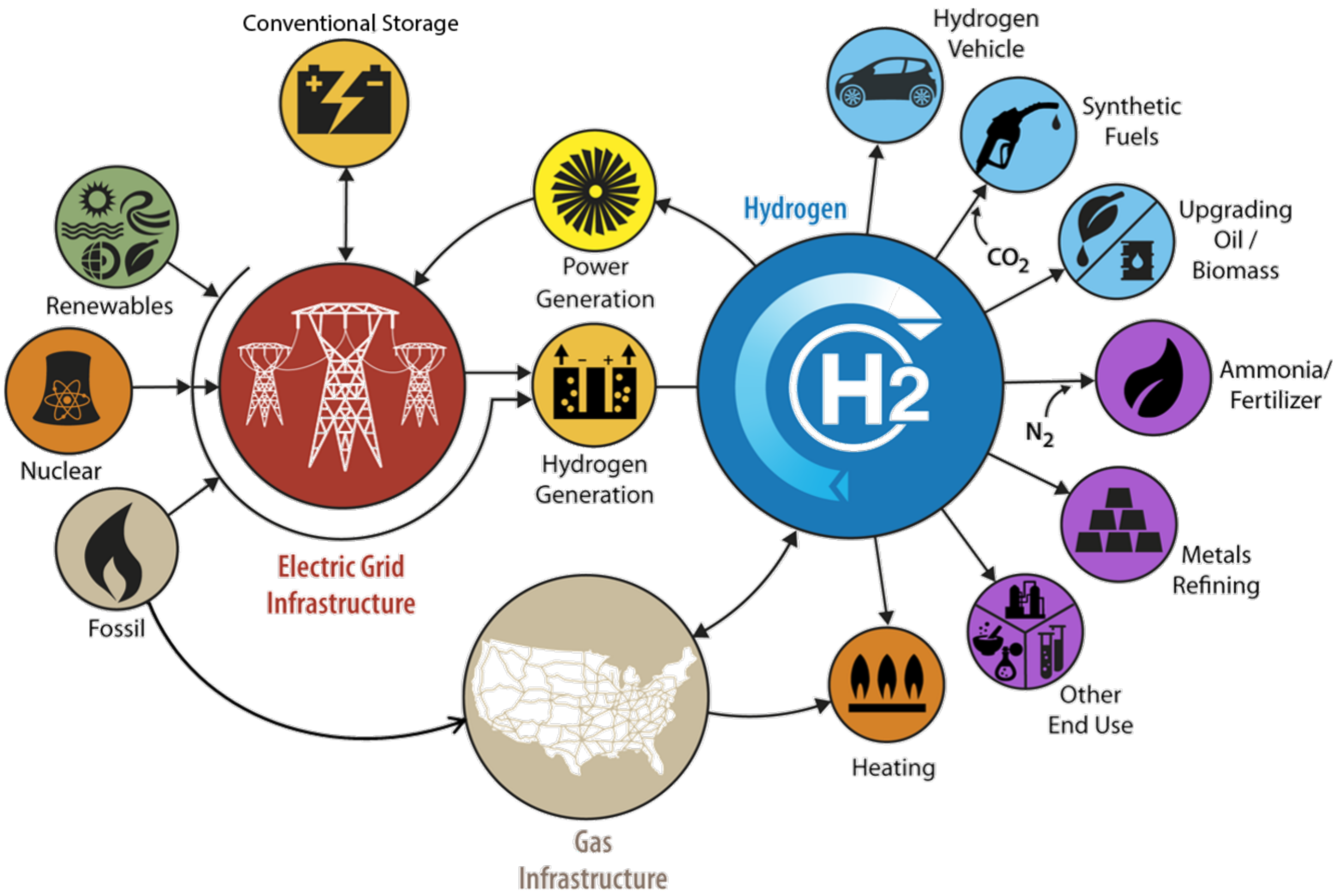
Hydrogen and Fuel Cell Research

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

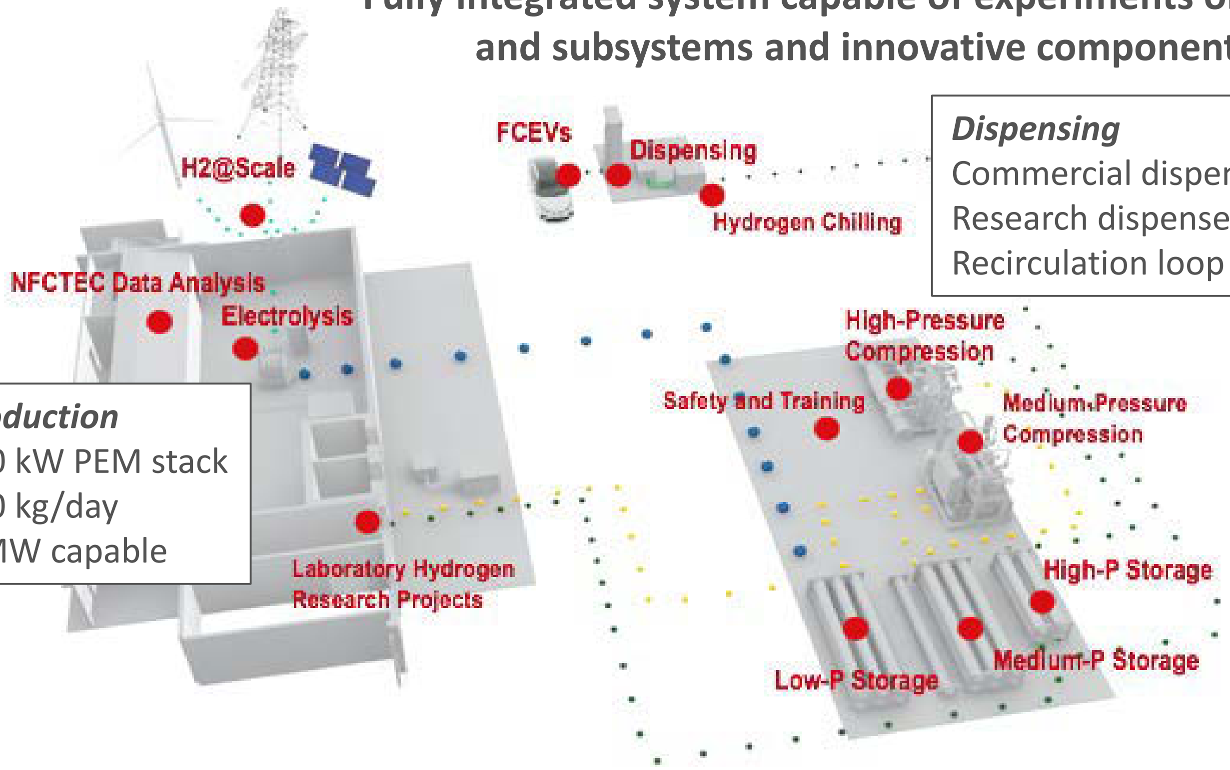
- Improve the economics of hydrogen production to enable it to shift energy across time, sectors, and location—including providing electric grid support.
- Develop materials and advanced cell concepts for polymer electrolyte fuel cells and electrolyzers, focusing on the emerging markets of intermittent 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.

Hydrogen @Scale



Hydrogen Infrastructure Testing and Research Facility

Fully integrated system capable of experiments on advanced components and subsystems and innovative component/system concepts



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)

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

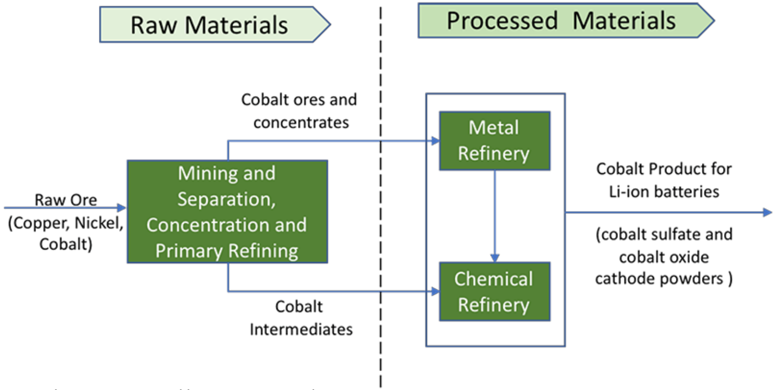
Storage
90 kg @ 900 bar
80 kg @ 415 bar
210 kg @ 200 bar

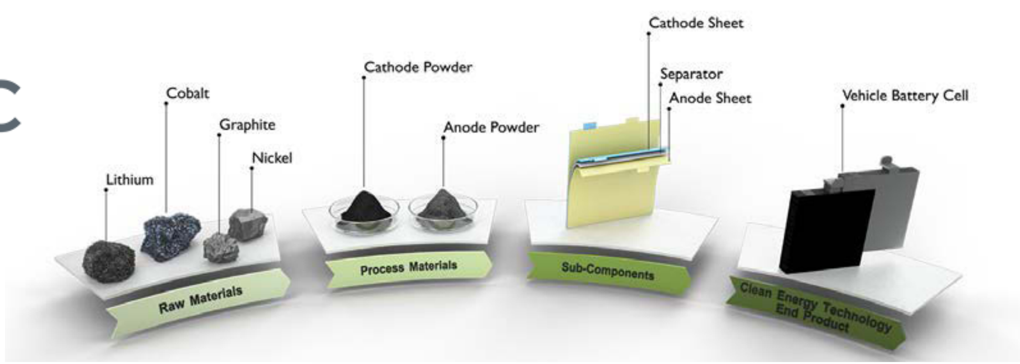
Hydrogen Infrastructure Testing and Research Facility

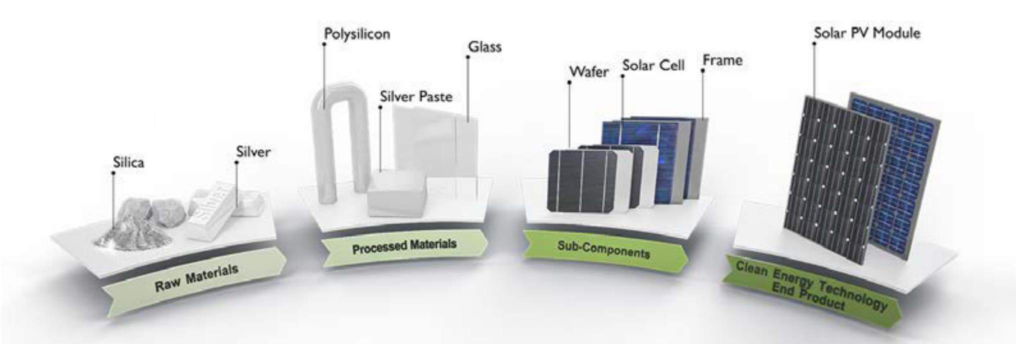
Images: NREL

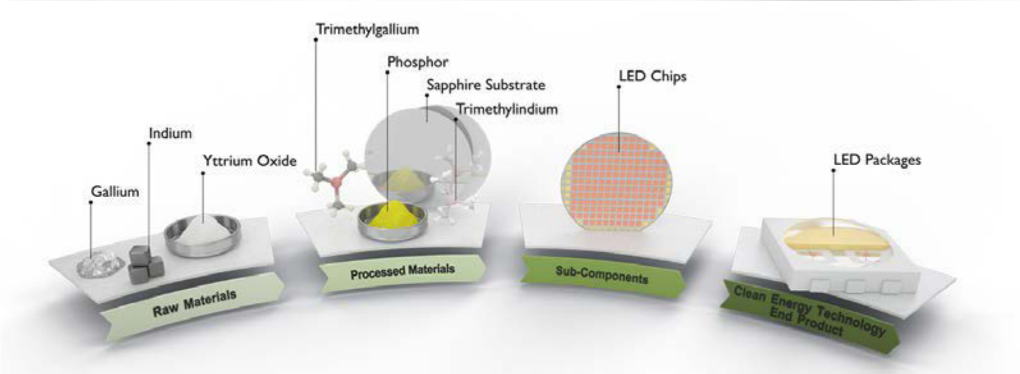
Raw materials and supply chains

CEMAC



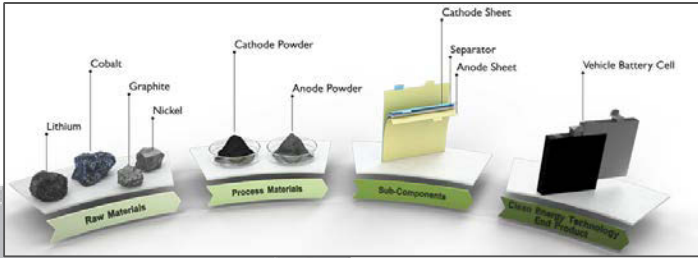


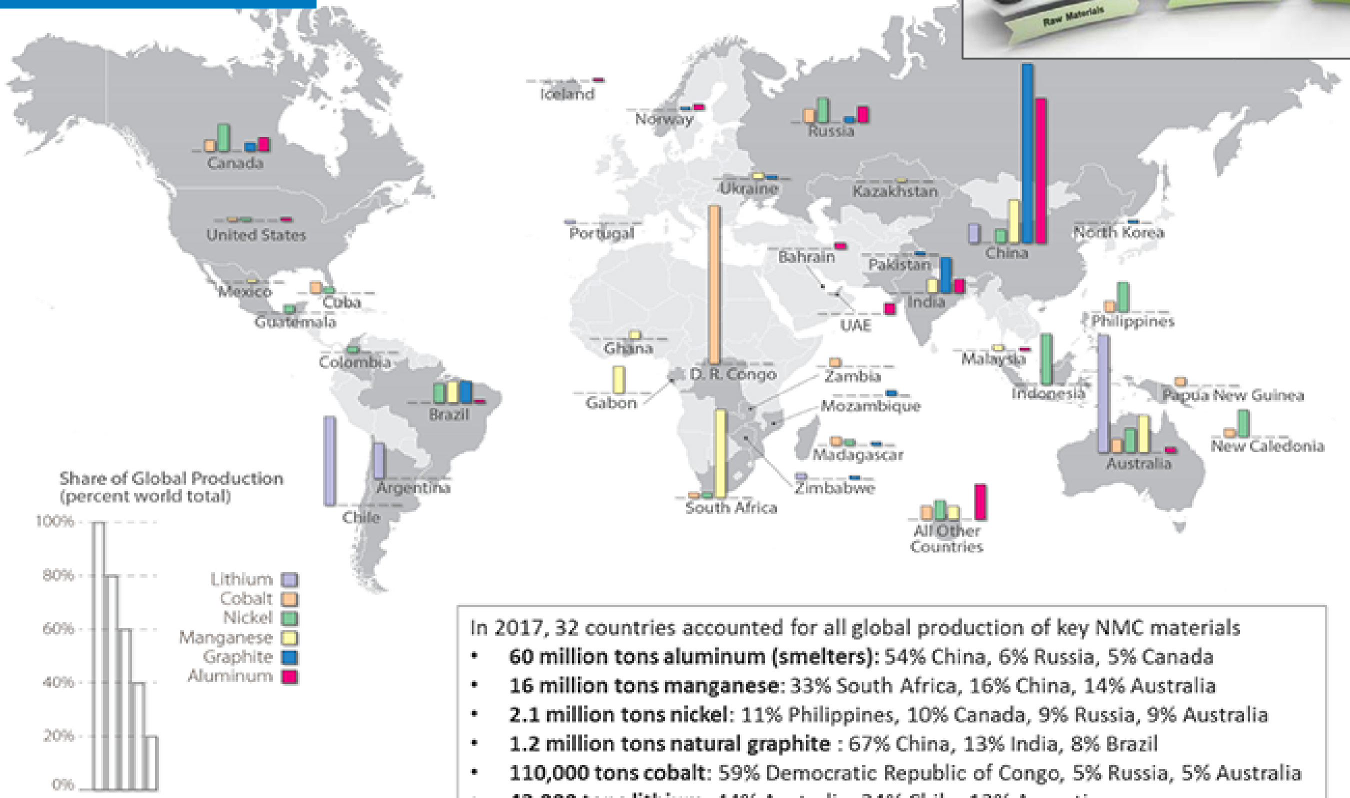




Source: JISEA/CEMAC, https://www.jisea.org/20190919.html

Supply chain disruption risk





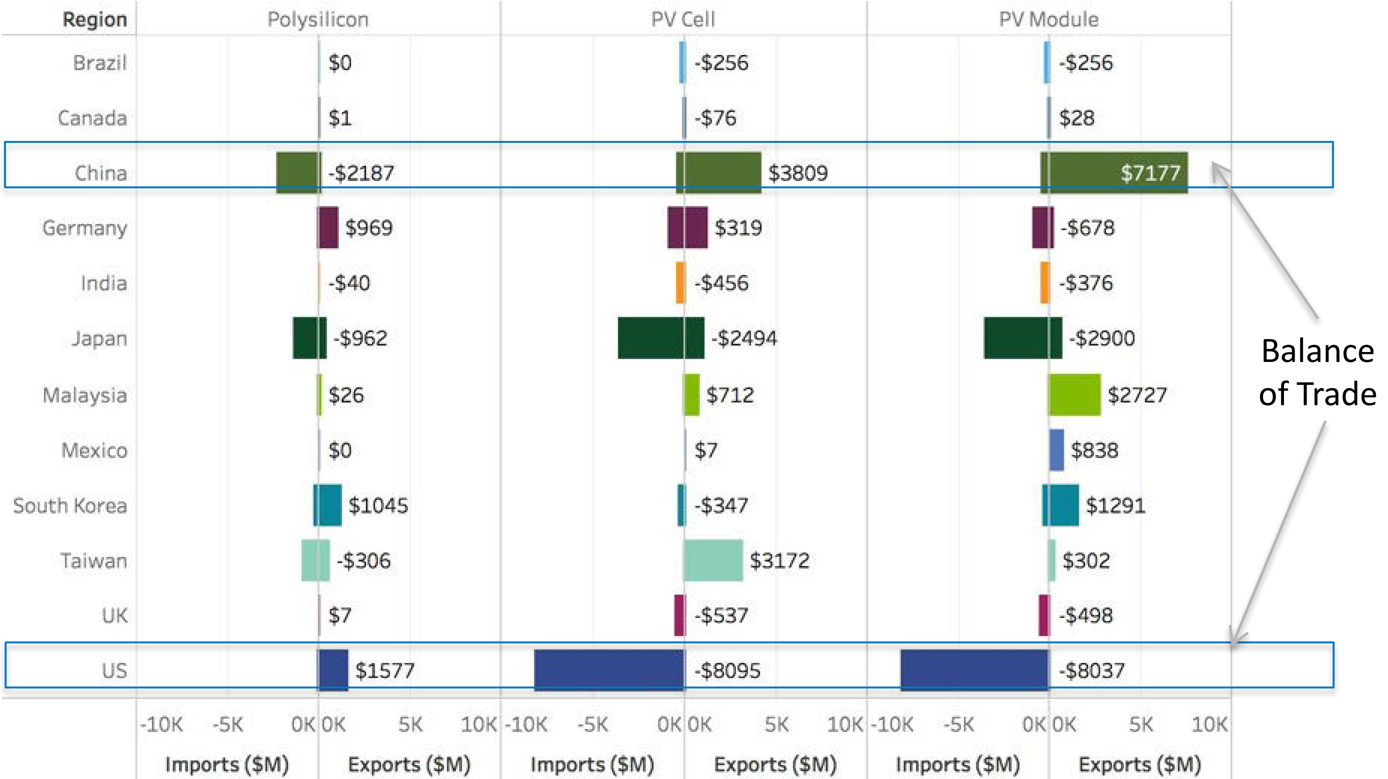
In 2017, 32 countries accounted for all global production of key NMC materials

- **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

Source: CEMAC, 2018, https://www.manufacturingcleanenergy.org/blog-20180815.html.

Policy risk: Balance of trade varies across supply chain (2016 data)

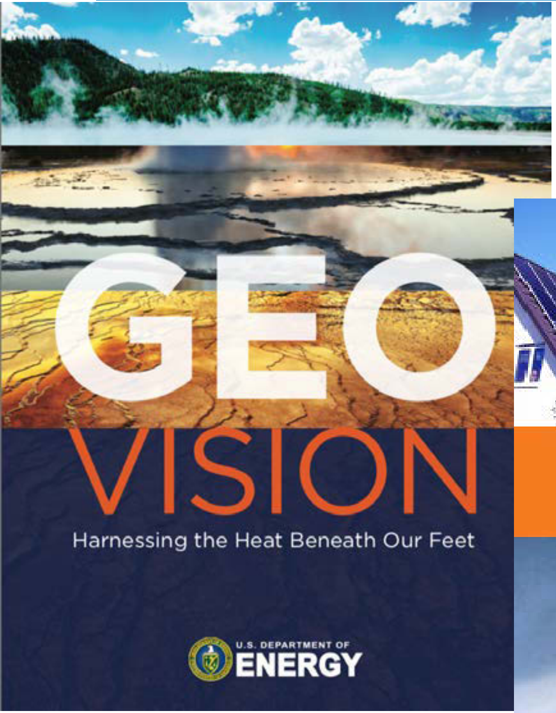
Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.

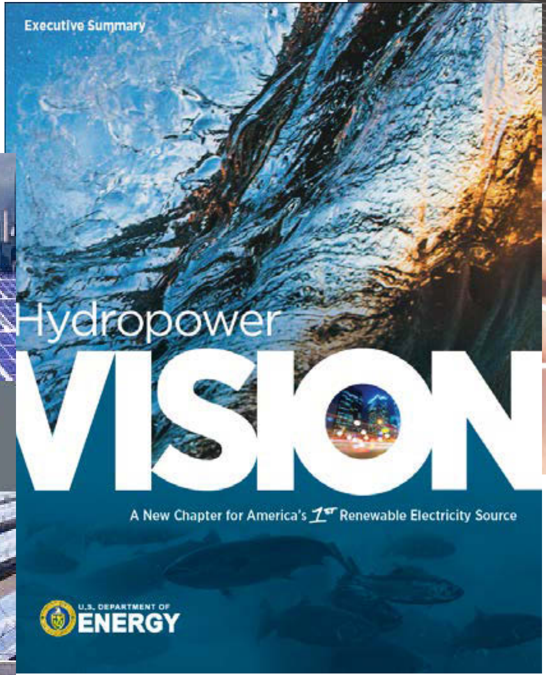


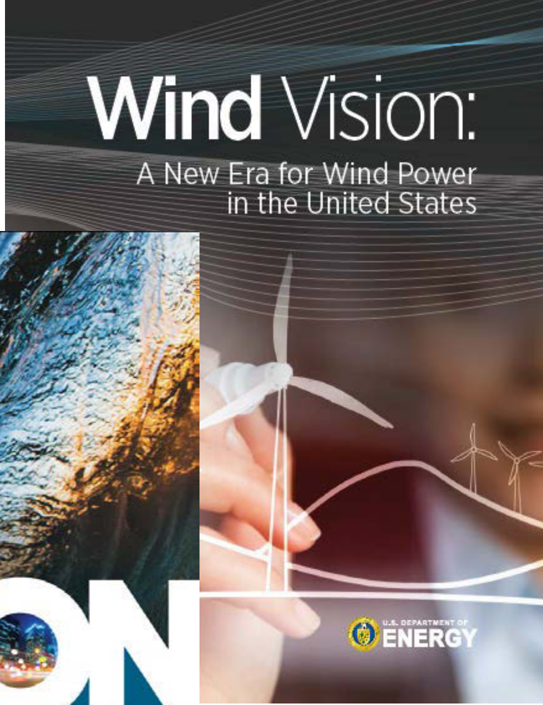
Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2018, http://www.manufacturingcleanenergy.org/blog-20180326.html.

CEMAC

Technology vision studies







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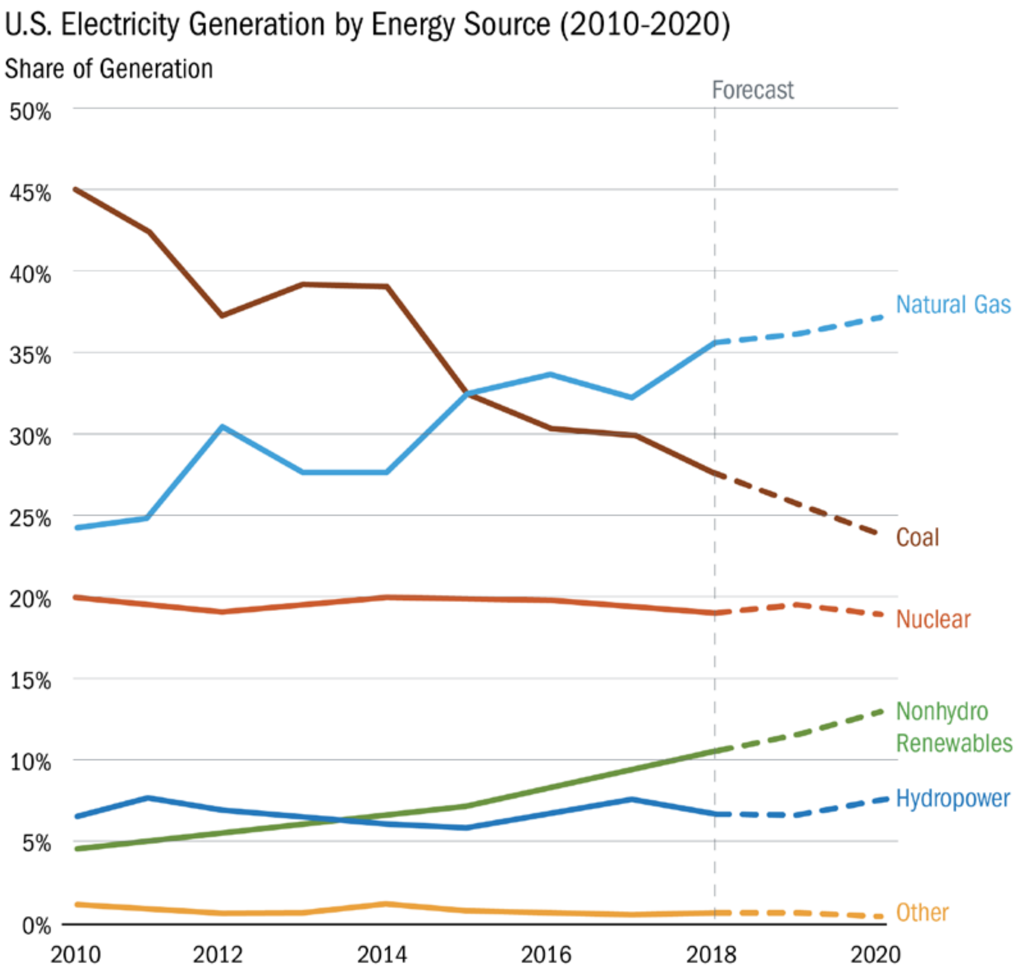
U.S. Energy Supply is Shifting

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%.

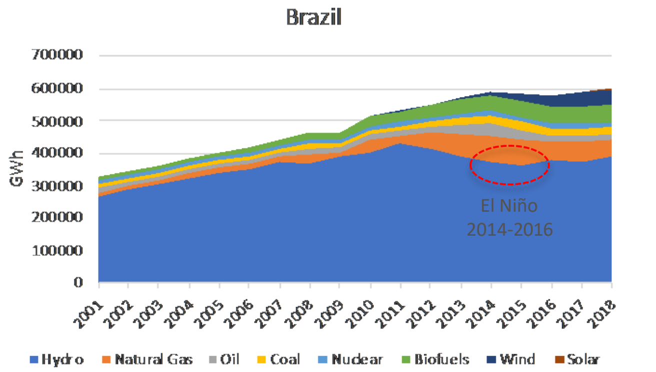


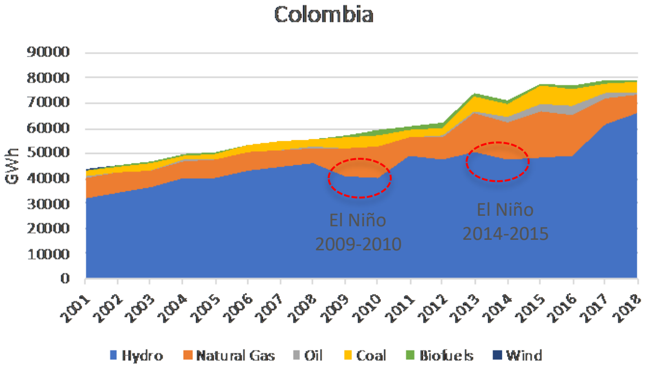
Source: United States Energy Information Agency, *Today in Energy*, 18 January 2019

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

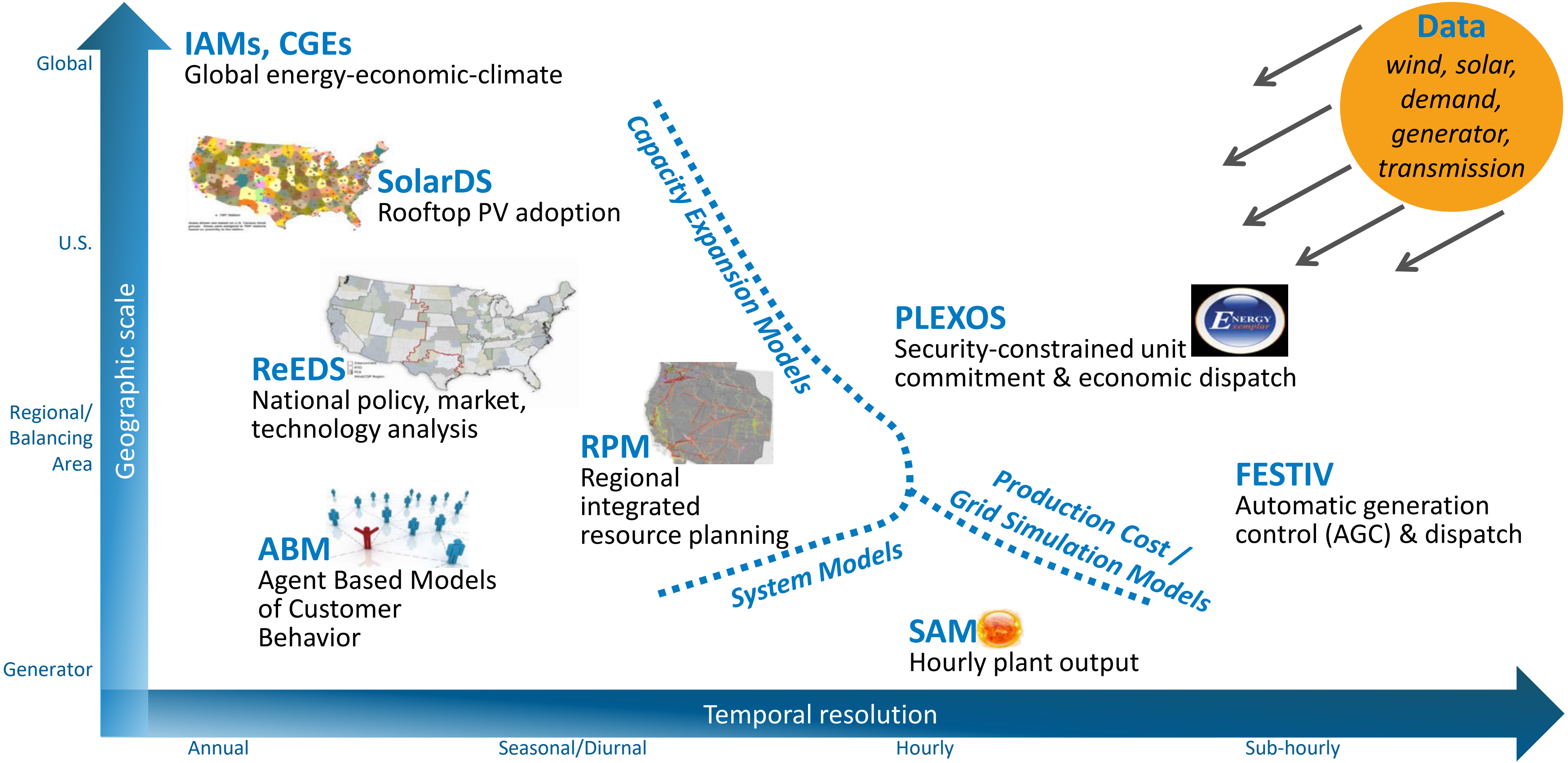
Evolving generation mixes in Brazil and Colombia



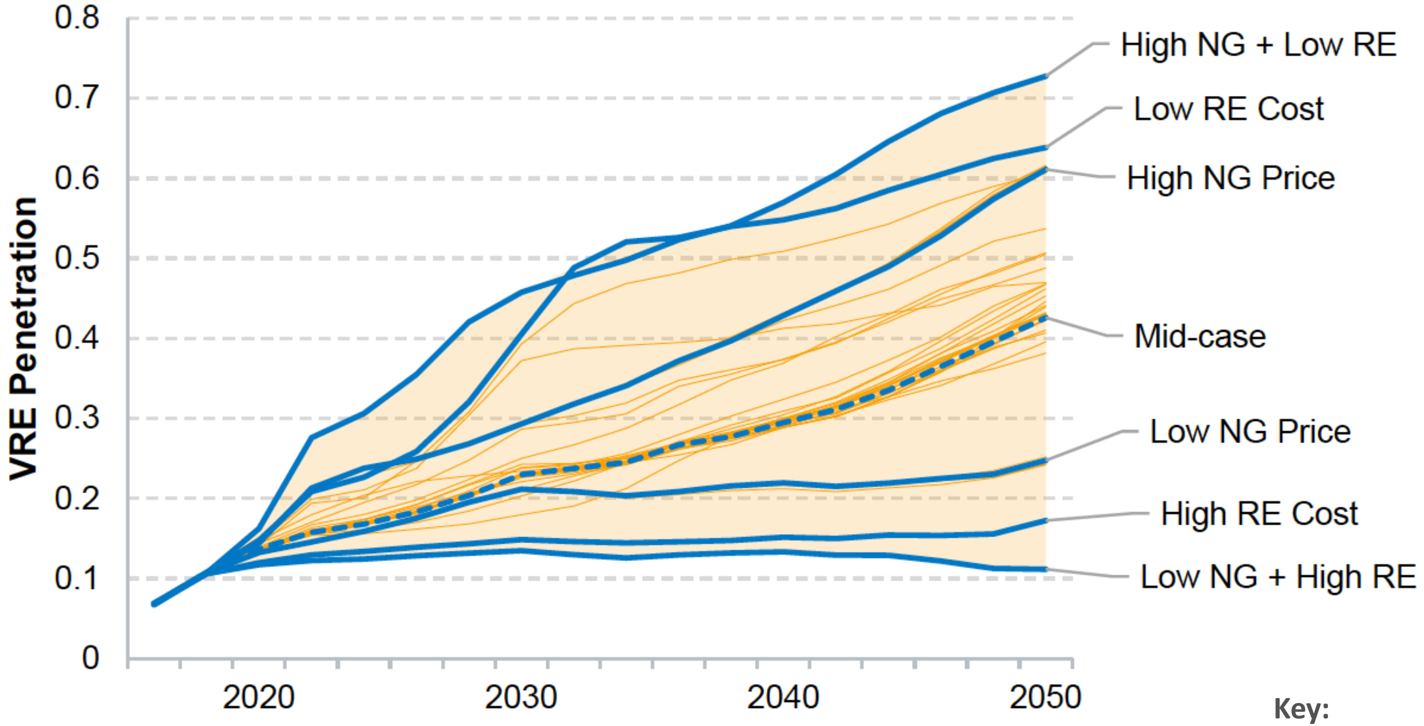


Source: JISEA, https://www.nrel.gov/docs/fy20osti/75467.pdf

Electricity modeling at multiple scales



NREL models scenarios of future electricity generation

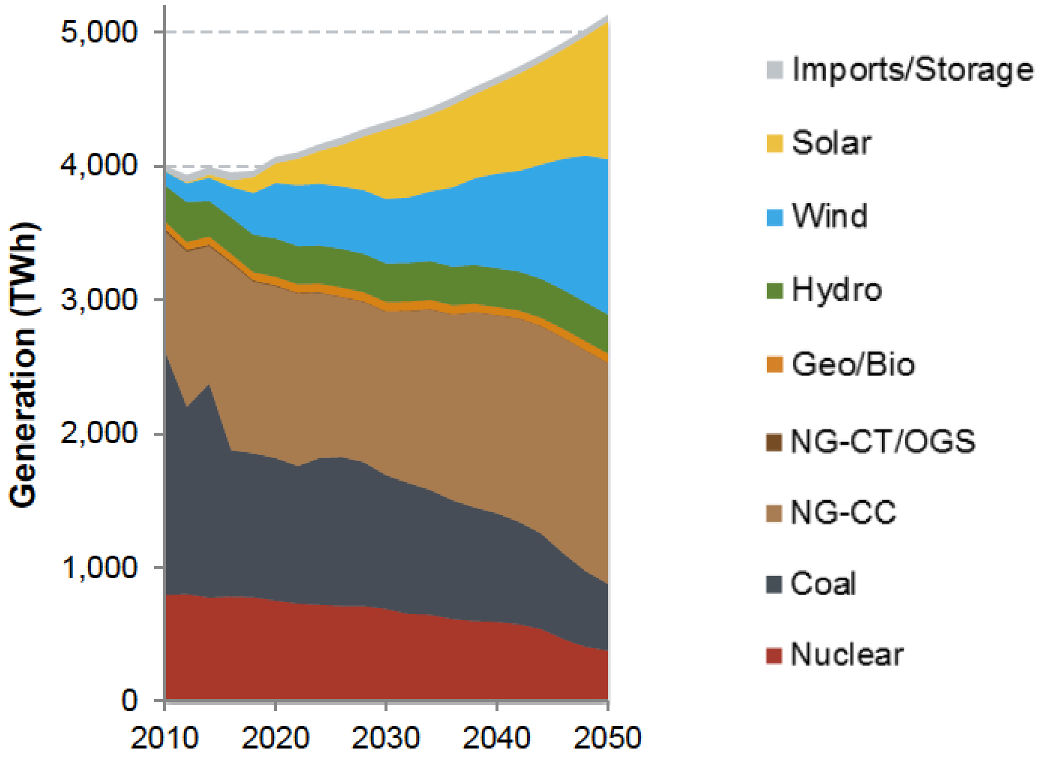


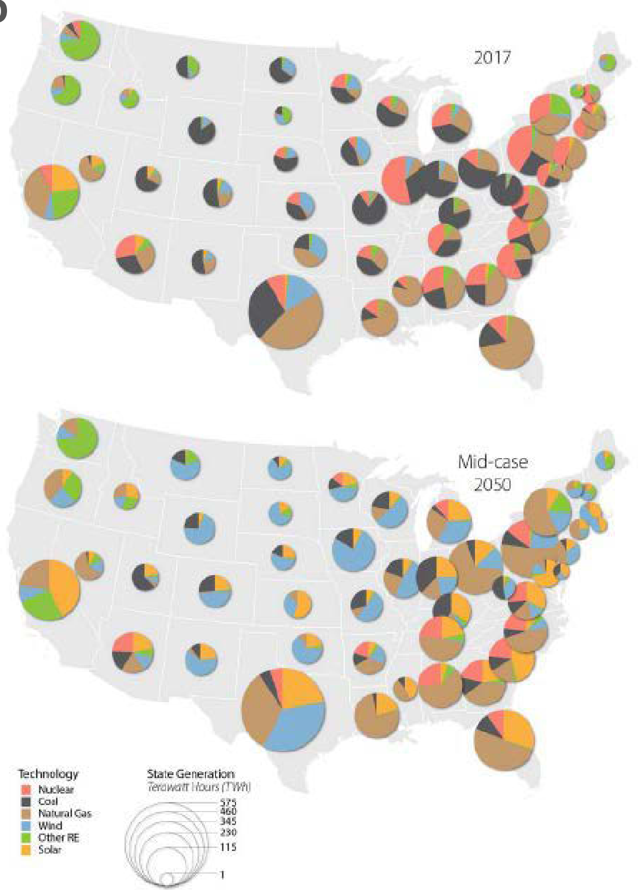
Key:
RE = Renewable Energy
NG = Natural Gas
VRE – Variable Renewable Energy

Generation projections across 42 scenarios: NREL 2018 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

NREL models scenarios of future electricity generation

Example: Mid Case Scenario





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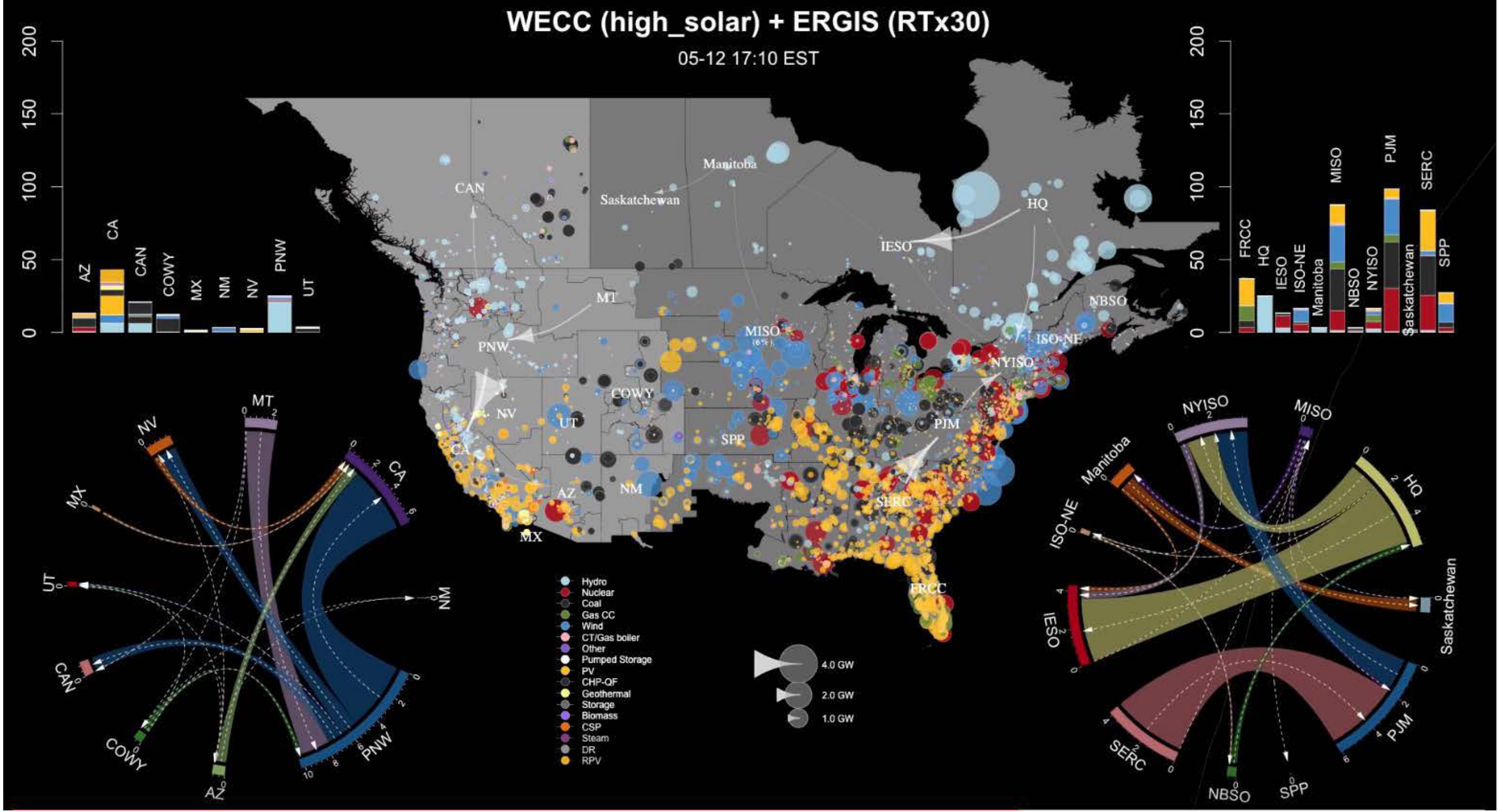


Video: https://www.youtube.com/watch?v=YcgvGe2sN8Y

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

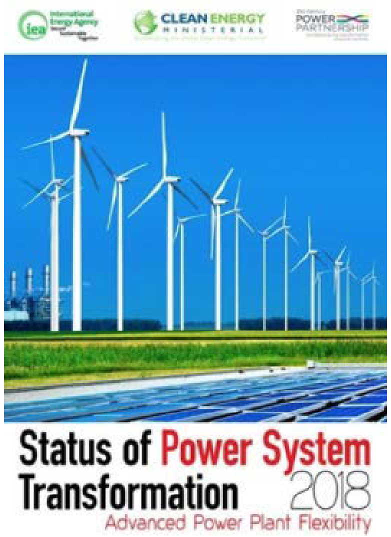
21st Century Power Partnership

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.

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems



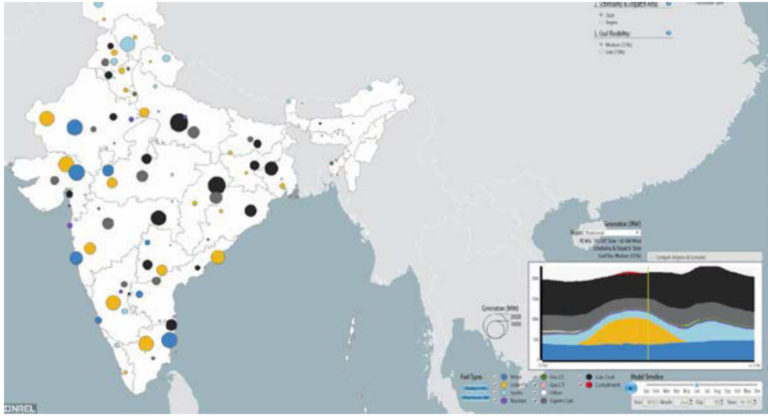
https://www.21stcenturypower.org

JISEA is the **Operating Agent** for the CEM Initiative 21CPP

Example: India Project

Renewable Energy Grid Integration Studies with India

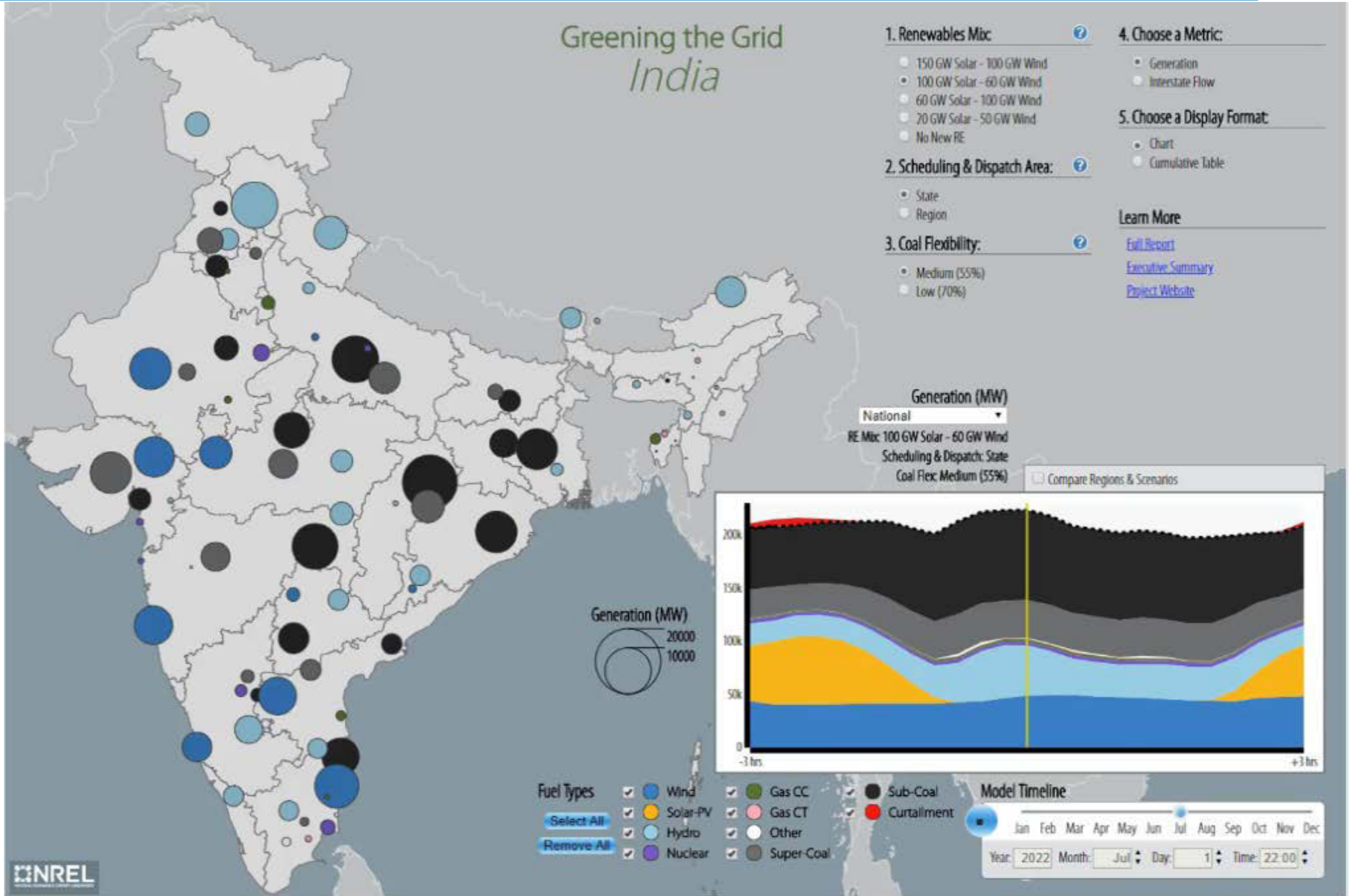
- Work with stakeholders (e.g., USAID, World Bank, 21CPP and other technical partners) to Green the Grid.
- As India develops <u>100</u> GW of solar and <u>60</u> GW of wind energy, how would the system operate in 2022?
- What can policy makers do to lower the cost of <u>operating</u> this system and 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

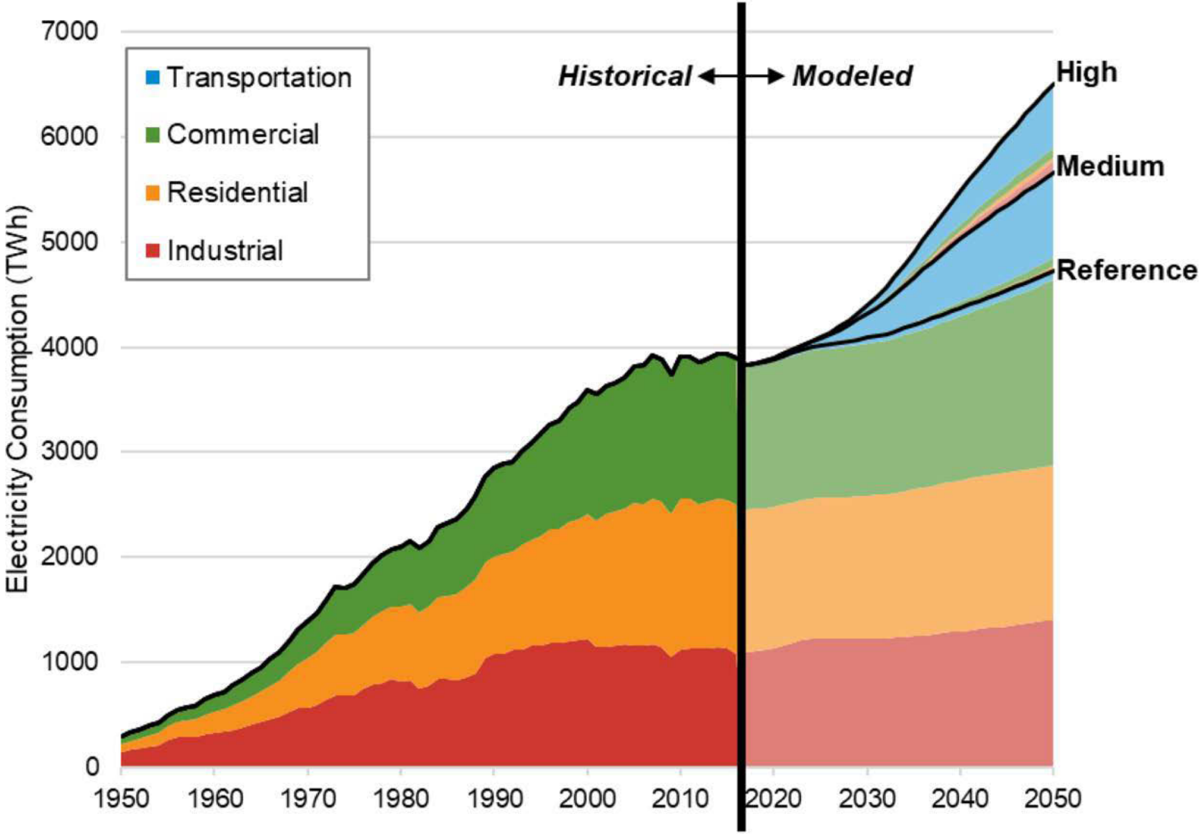
http://www.nrel.gov/india-grid-integration

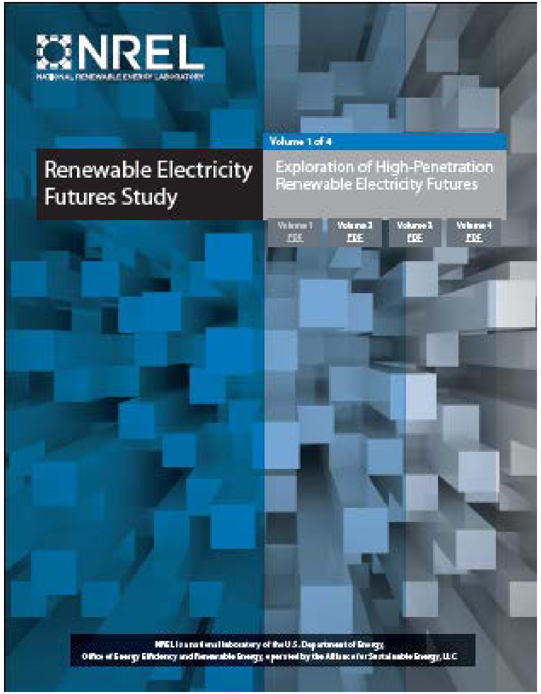
Video: https://www.youtube.com/watch?v=mY1nmknCwFM



21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Electrification Futures Study





All Figures from NREL's Electrification Futures Study: 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**

Electric-Natural Gas Interface Study

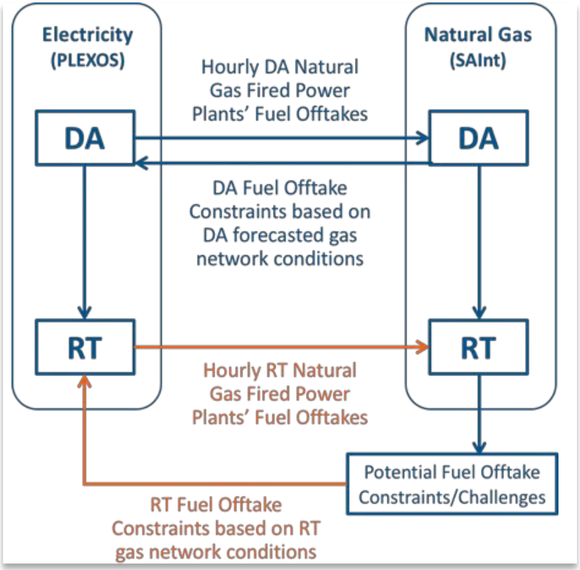
Electricity & **Gas** networks are **interconnected** energy infrastructures whose operation and reliability depend on one another. As the percent of gas and variable renewable power plants increase, the connection between these networks becomes increasingly important.

Goal of project is to:

Co-simulate power and natural gas network operations.

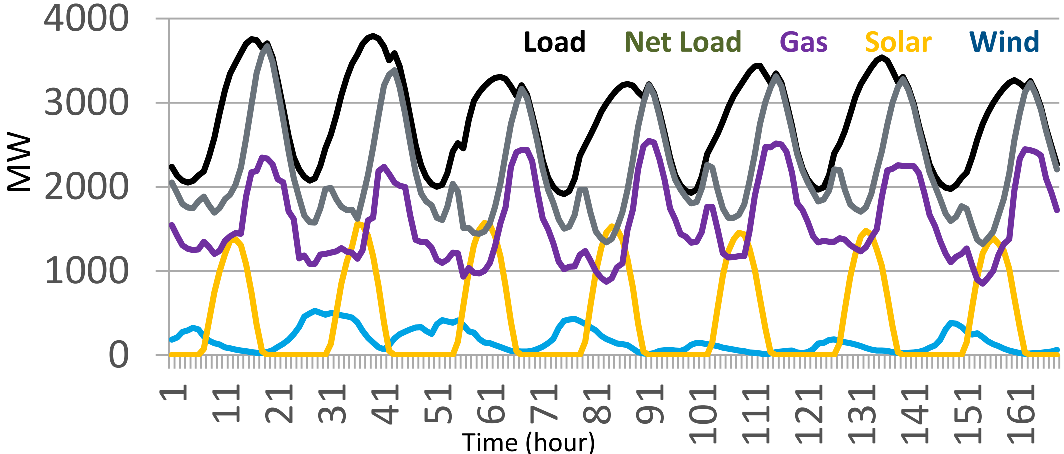
Define an interconnected power and natural gas test system

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

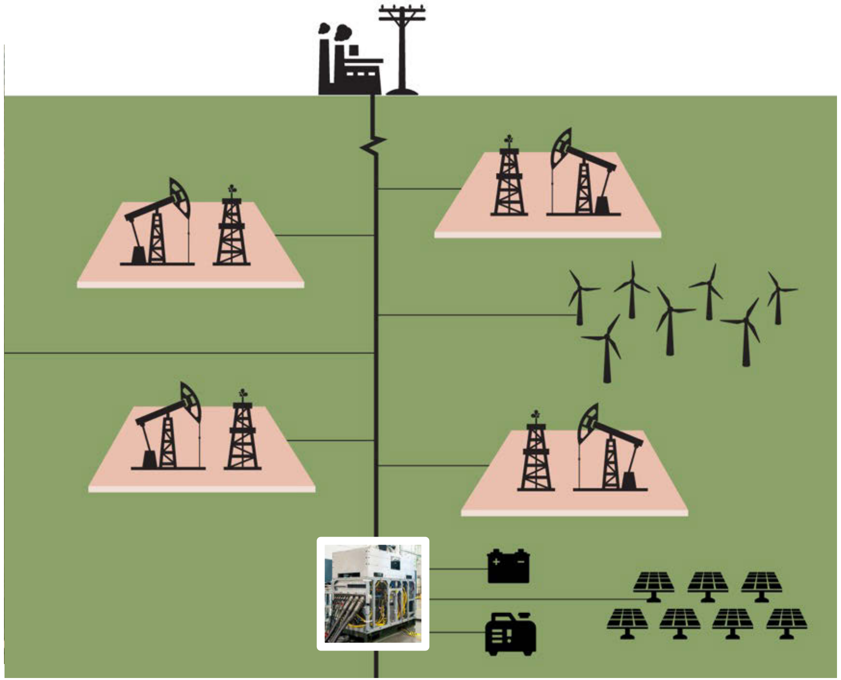


Source: JISEA project in progress.

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

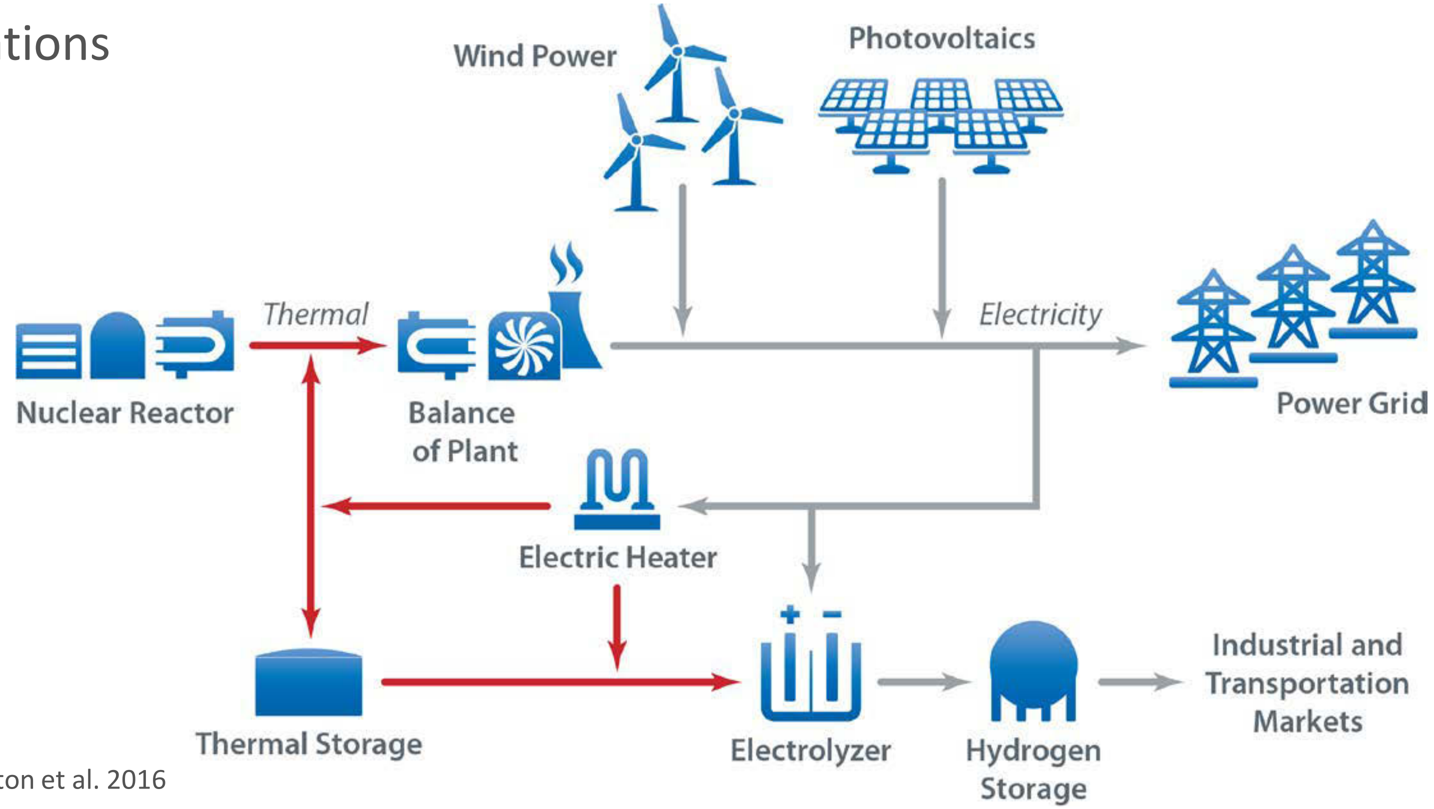
Opportunities for Collaboration: Design of complete system, technology evaluation & selection, "utility in a cube" technology



Renewable and Sustainable Nuclear Energy Systems

JISEA led analysis on nuclear-renewable hybrids with NREL and Idaho National Lab

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



Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

Nuclear Innovation: Clean Energy Future (NICE Future)

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.

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

Lead Countries


Canada


Japan


USA

Participant Countries


Argentina


Poland


Romania


Kenya


Russia


UAE


UK

NICE Future
Nuclear Innovation: Clean Energy Future

External Partners

International Energy Agency
OECD Nuclear Energy Agency
International Atomic Energy Agency
International Framework for Nuclear Energy Cooperation
Generation IV International Forum
ClearPath
Third Way
Energy for Humanity
Energy Options Network
Women in Nuclear Global
International Youth Nuclear Congress
Nuclear Industry Council
Nuclear Energy Institute
World Nuclear Association
American Nuclear Society

JISEA is the **Operating Agent** for the CEM Initiative NICE Future

Outline

About NREL and JISEA

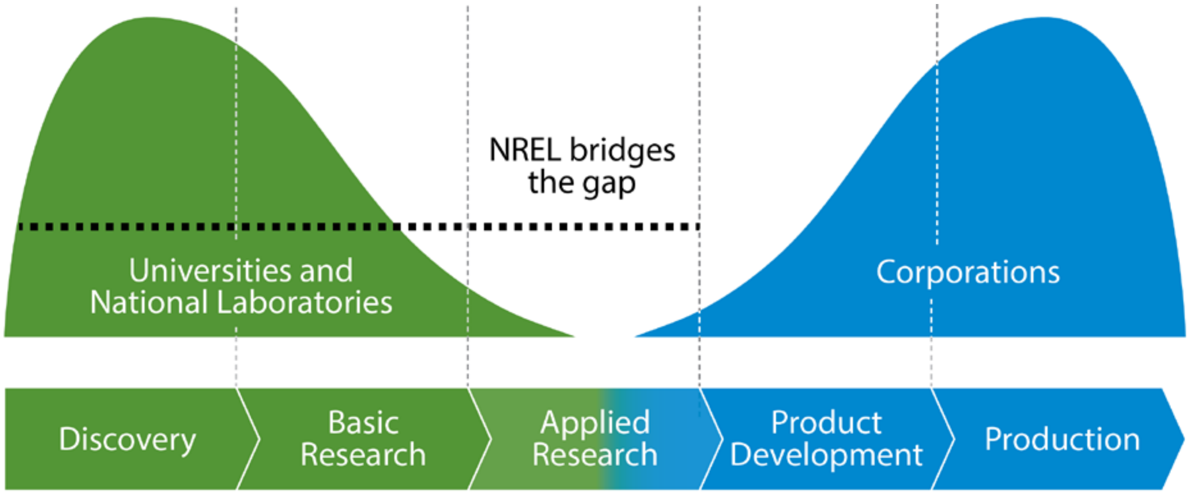
Renewable Technologies Analysis

Energy Systems and Scenarios Analysis

Partnering and Collaborations

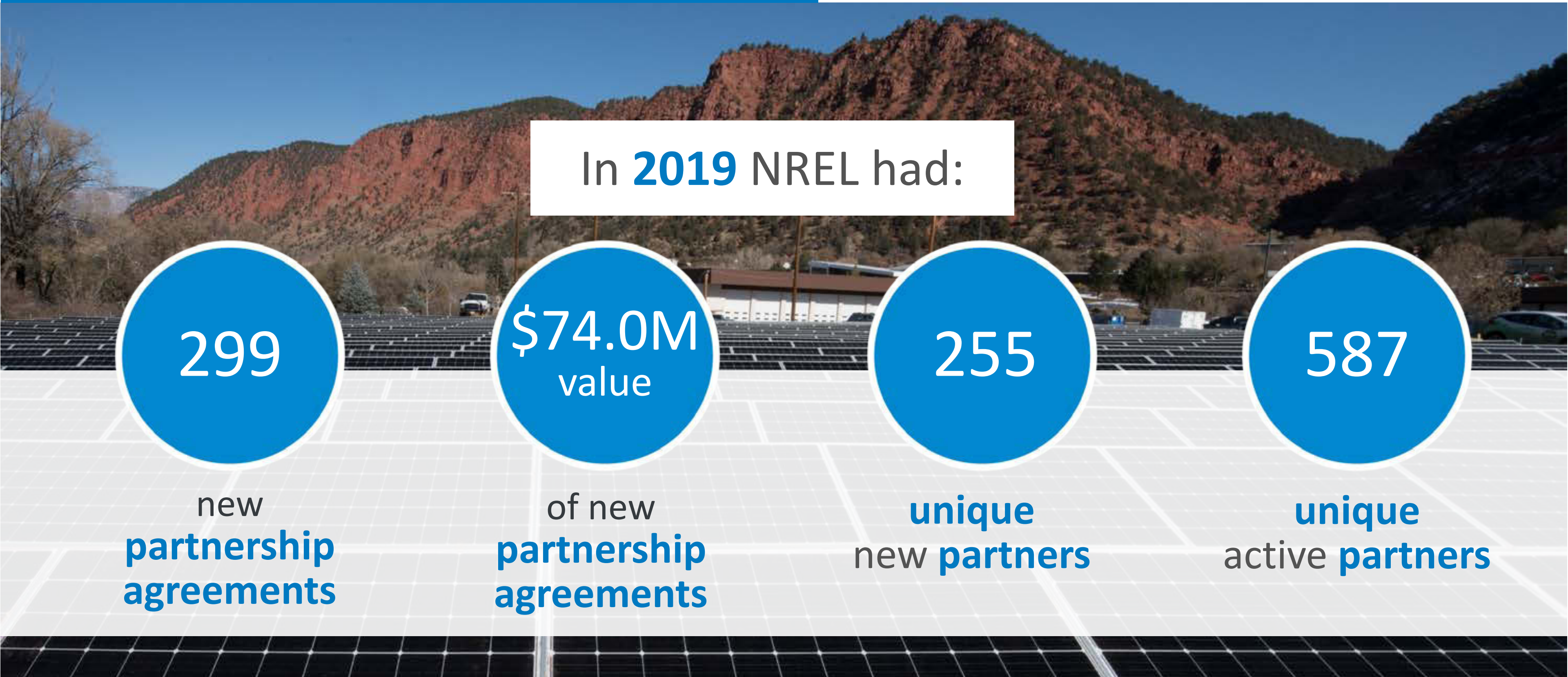
We Reduce Risk in Bringing Innovations to Market

- 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**

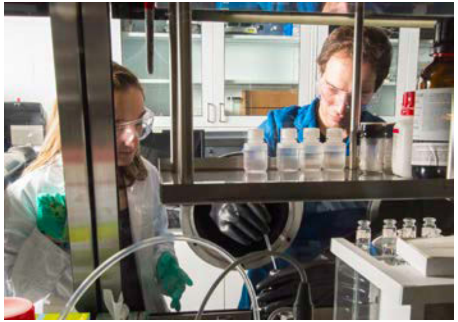
255 unique new **partners**

587 unique active **partners**

Partnering for Impact

ExxonMobil

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.

EATON
Powering Business Worldwide

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.

WELLS FARGO

Our Innovation Incubator (IN^2) is expanding this scalable model to other partners and technologies and growing to a multiyear, $30 million program.

Questions?

Thank you

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JISEA Joint Institute for Strategic Energy Analysis

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