Joint Institute for Strategic Energy Analysis

Renewable Energy Technology and Systems Integration for the Oil and Gas Industry

Webinar for the Chevron Flexibility Mechanisms Evaluation Network

7 April 2020

Jill Engel-Cox, Director, Joint Institute for Strategic Energy Analysis




NATIONAL RENEWABLE ENERGY LABORATORY
COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
COLORADO STATE UNIVERSITY
Massachusetts Institute of Technology
STANFORD UNIVERSITY
University of Colorado Boulder

Outline

- About NREL and JISEA
- Energy Technology Markets and Trends
  - Example: Wind Turbines
- Hydrogen and Industrial Systems
- Renewable Energy for Oil & Gas

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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"

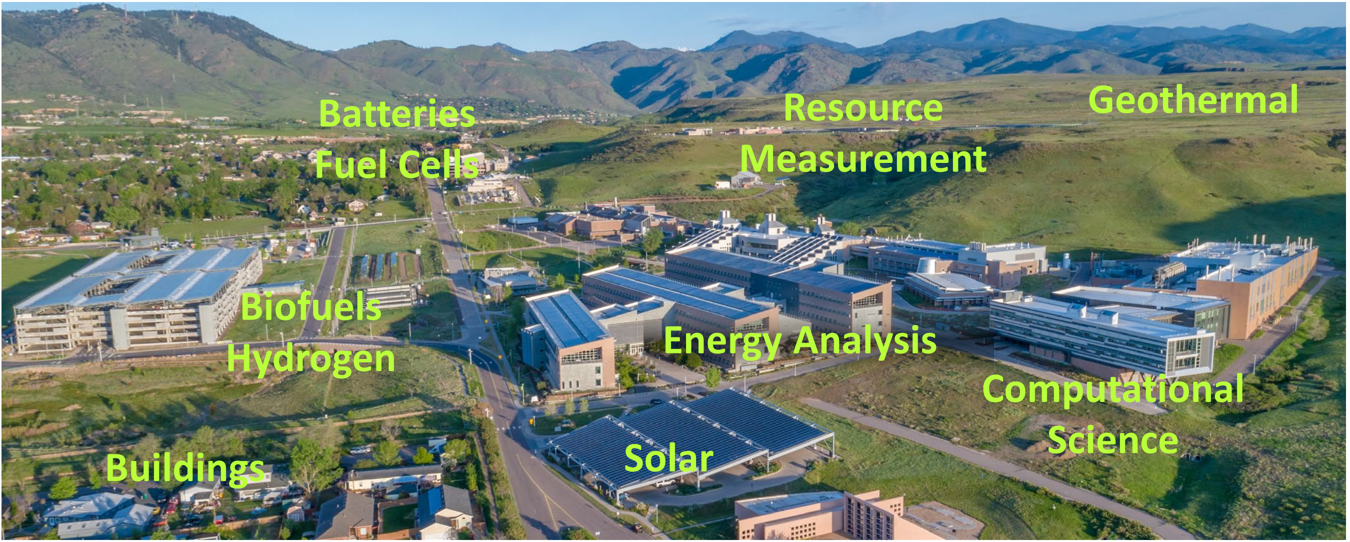
U.S. DEPARTMENT OF ENERGY

NATIONAL RENEWABLE ENERGY LABORATORY

www.nrel.gov/about

Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

Example Technology Areas:



- 2,300 employees, plus 460 postdoctoral researchers, interns, visiting professionals, and subcontractors
- 327-acre main campus in Golden & 305-acre Flatirons Campus with National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1,000 scientific and technical materials published annually

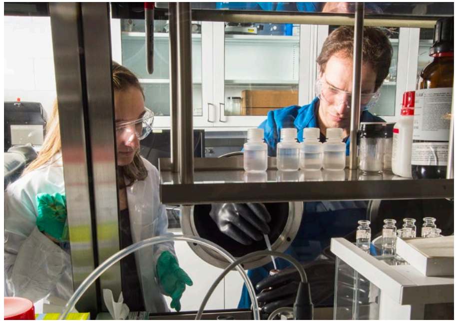
Partnering for Impact

ExxonMobil

EATON
Powering Business Worldwide

WELLS FARGO

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.

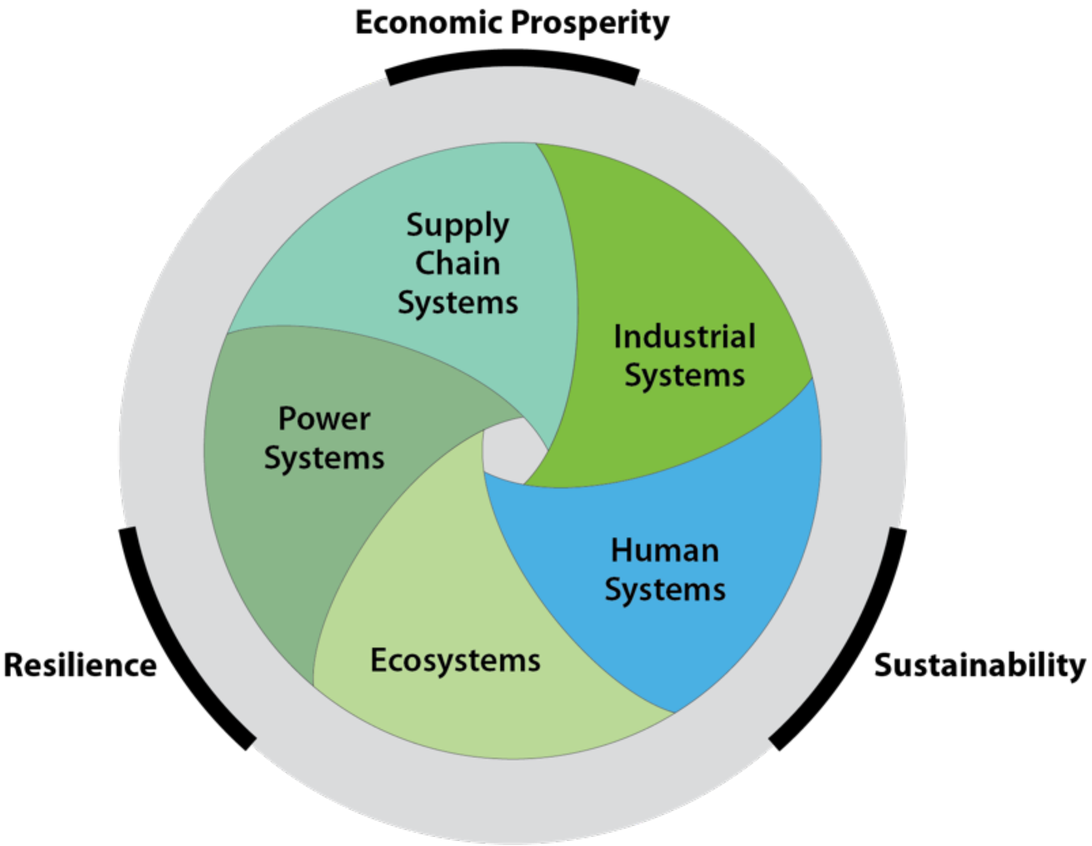
NREL and Eaton are working together in the ESIF on grid intelligence, distributed energy resource management, advanced energy storage systems, virtual modeling and analysis, high-performance computing, and other research.

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

JISEA

Joint Institute for Strategic Energy Analysis

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



Founding Partners:

NREL National Renewable Energy Laboratory · Colorado School of Mines (Earth • Energy • Environment) · Colorado State University · Massachusetts Institute of Technology · Stanford University · University of Colorado Boulder

JISEA

Joint Institute for Strategic Energy Analysis

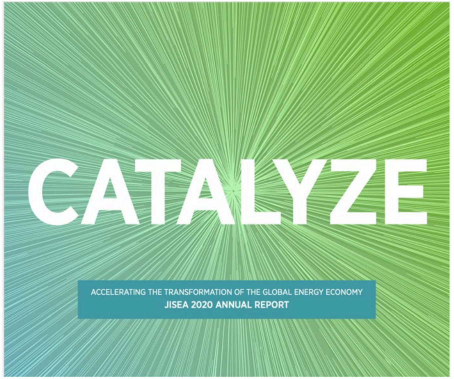
Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.

Brings together consortiums of diverse partners

JISEA Research Portfolio

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

Learn more on our website and in the 2020 Annual Report.



@JISEA1 www.jisea.org

Learn more at our JISEA Virtual Meeting

Thursday 9 April 2020: Register at link on our LinkedIn, Twitter, or at https://www.jisea.org.

AGENDA:

Welcome and Introduction to JISEA (9:00 – 9:05 MDT) – *Jill Engel-Cox*

Power Systems (9:05 – 10:30 MDT)

- Innovative Utility Offerings at the Distribution Edge
  - *Travis Lowder and Jeffrey Logan*
- Options for Resilient and Flexible Power Systems in South America
  - *Jeffrey Logan and Josh Prado*
- Power and Natural Gas Systems Interface
  - *Bri-Mathias Hodge*

Industry & Agriculture (10:30 – 12:00 MDT)

- Renewable Energy in Mining
  - *Tisi Igogo and Travis Lowder*
- LED Lighting: A Global Enterprise
  - *Samantha Reese*
- Spanning the Nexus: Integrated Energy Research on Agriculture & Water Challenges
  - *Jordan Macknick and James McCall*

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Clean energy is diverse

WIND
Onshore

Offshore

GEOTHERMAL

Images from https://images.nrel.gov/

SOLAR PV
Distributed & Micro Grids

Utility Grid Connected

CONCENTRATING SOLAR

HYDROPOWER
Large & Small

Wave & Tidal

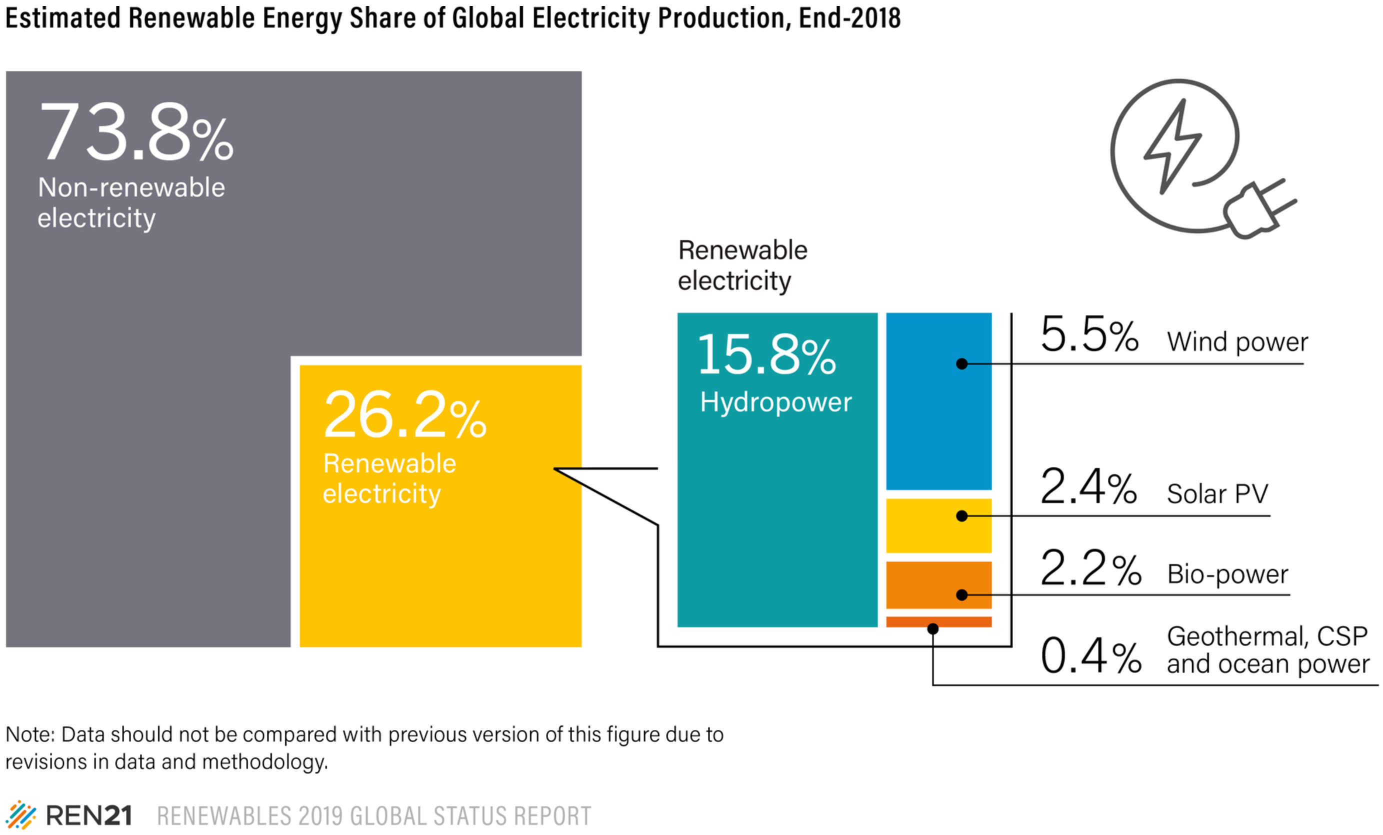
BIOMASS & WASTE

HYDROGEN & GAS

BATTERIES & STORAGE

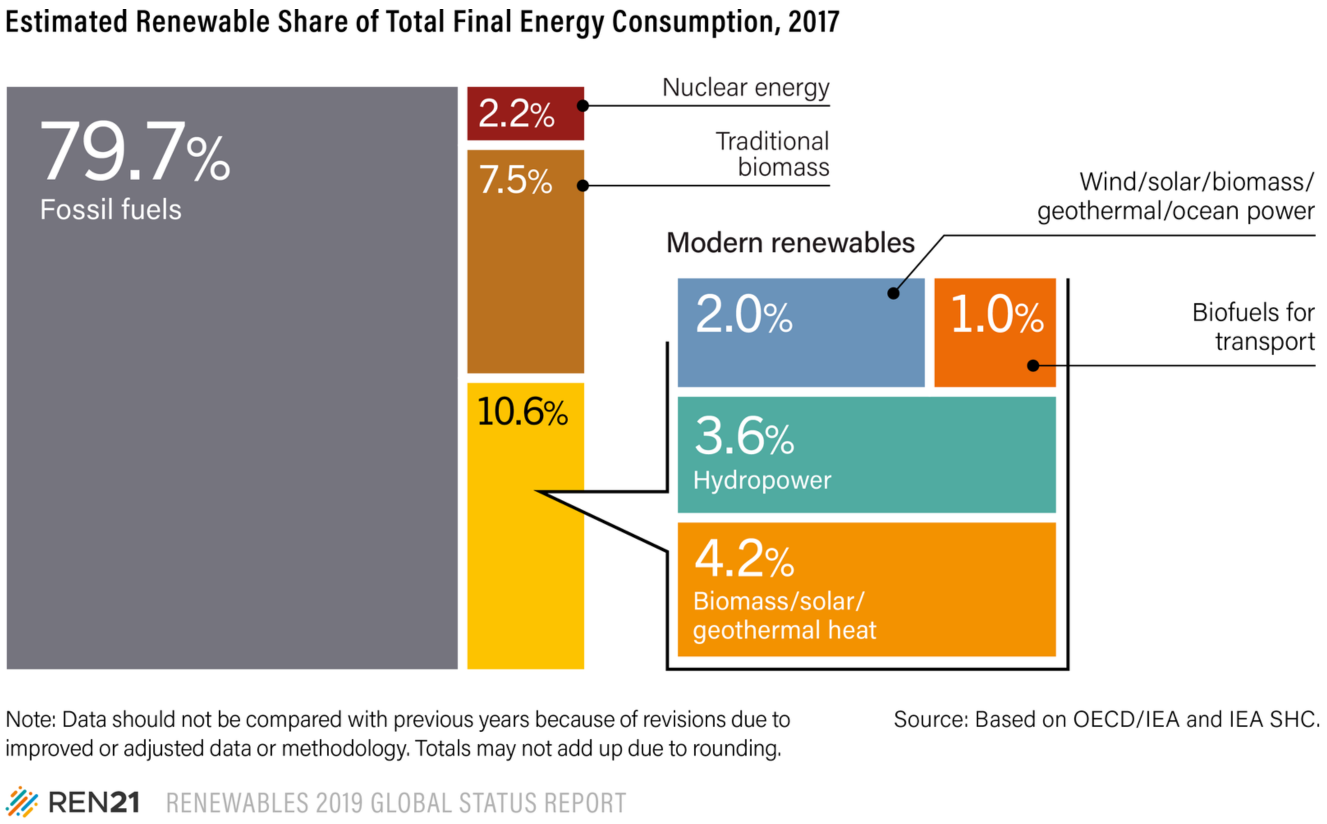
EFFICIENCY & HEAT USE

Global share of renewable electricity



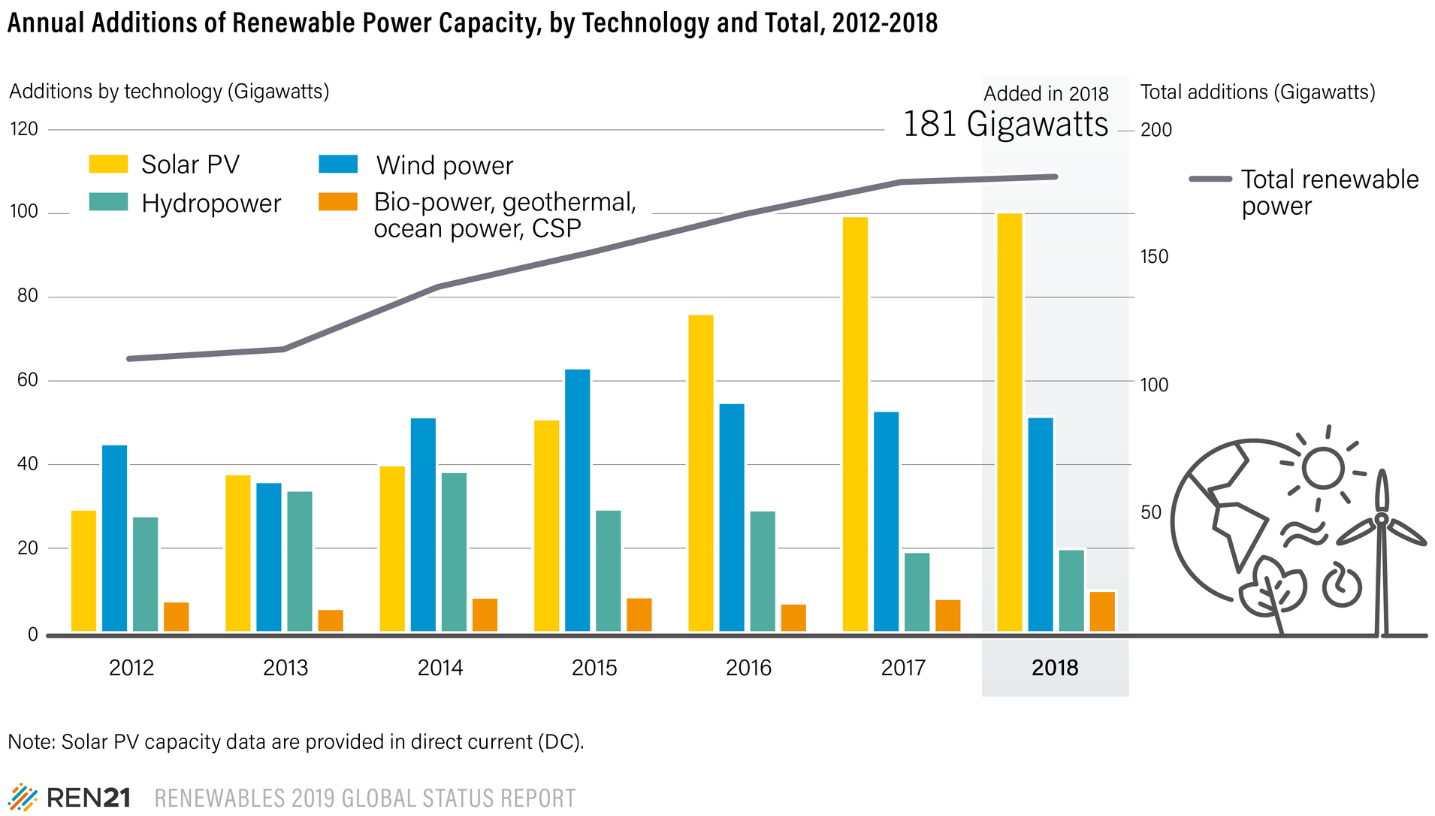
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

Global share of renewable energy



Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

Global growth of renewable power



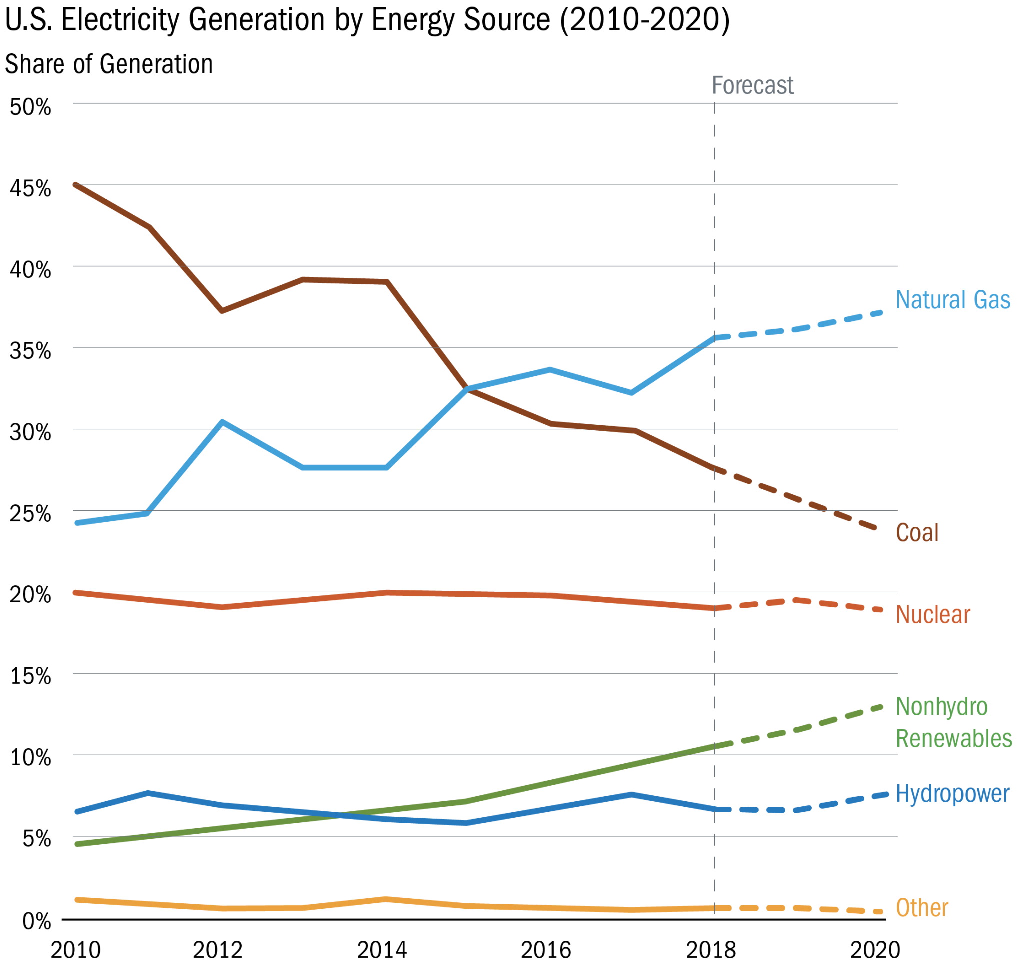
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

U.S. Energy Supply is Shifting

In 2019, renewable energy—not including hydropower—generates 11% of the total U.S. electricity (~7% wind, 2% solar, 1.5% biomass, 0.5% geothermal)

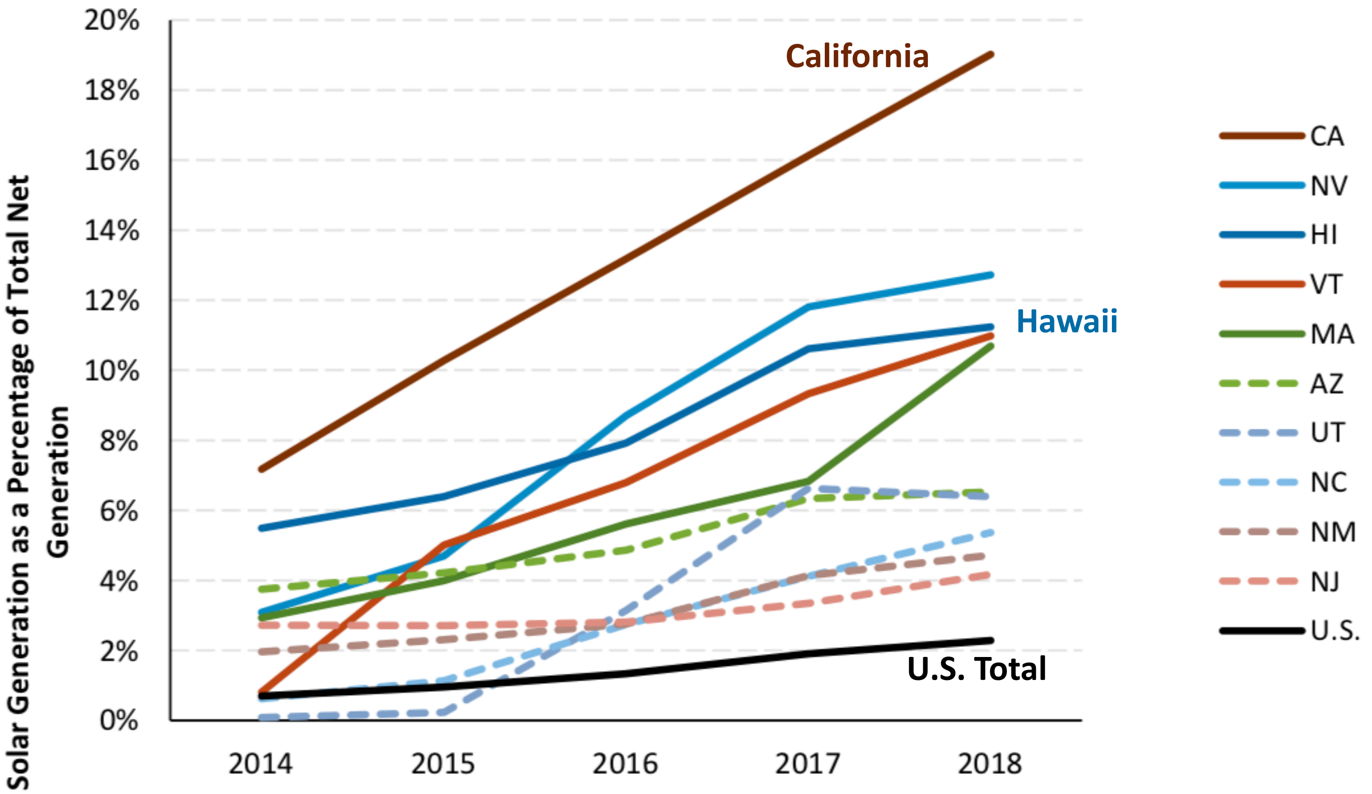
With hydropower, renewable electricity is ~18%

Natural gas power is ~38%



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

Variation by Location: Solar Generation as a % of Total Generation, 2014-2018, by U.S. State

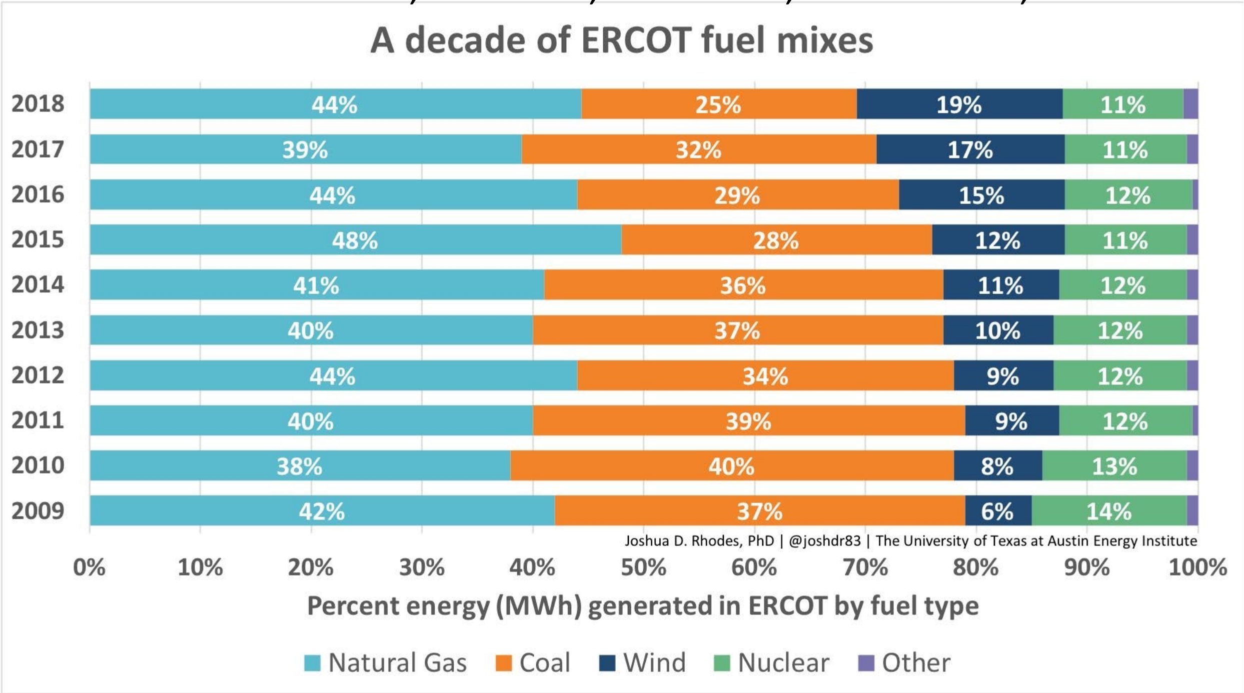


Source: NREL, Q4 2018/Q1 2019 Solar Industry Update, May 2019.

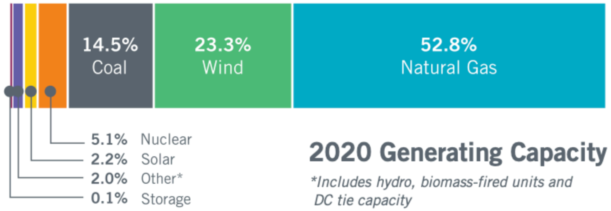
Texas electricity transition favors wind and gas

Electricity Generated:

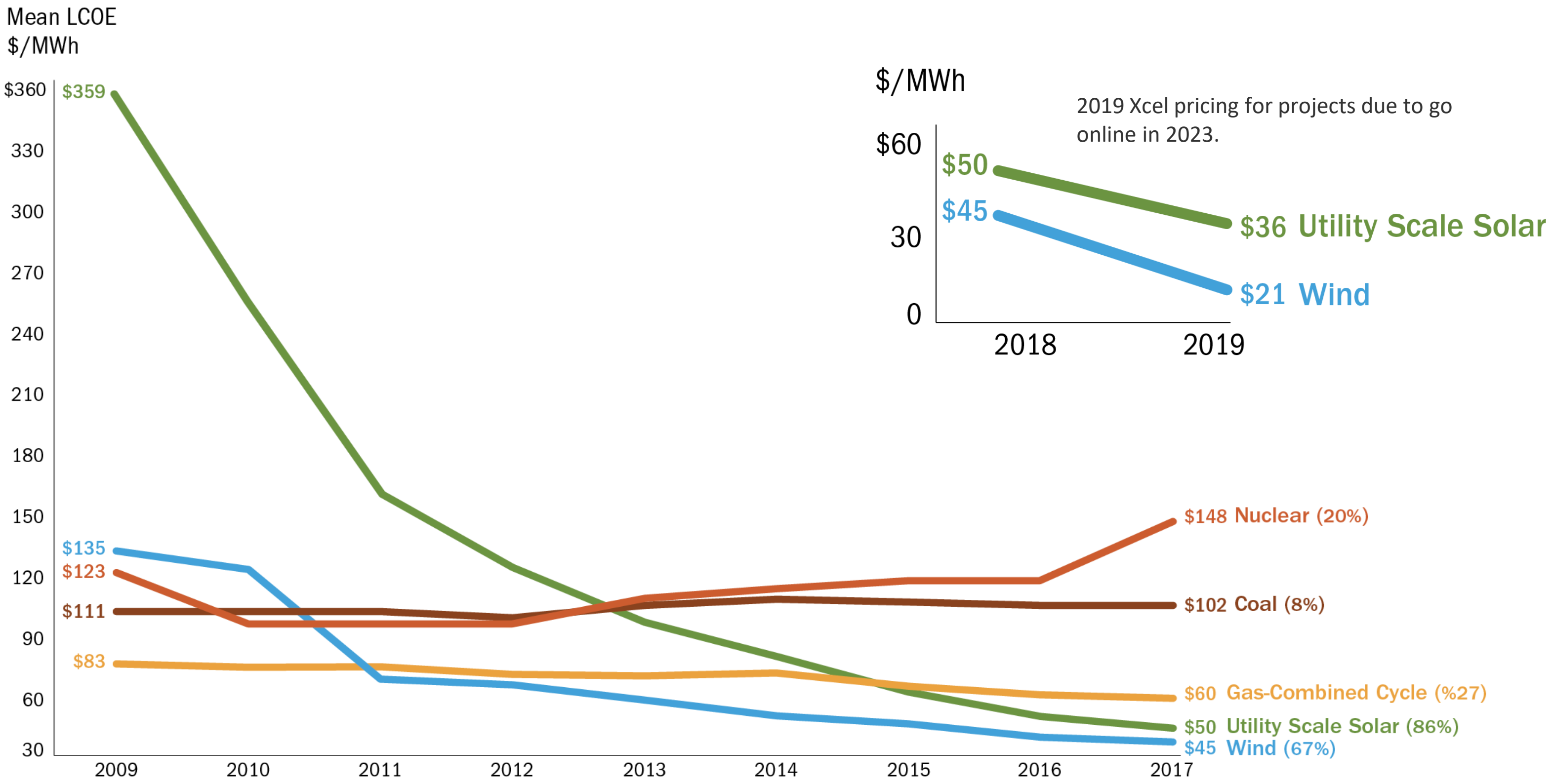
2019: 47% Natural Gas, 20% Coal, 20% Wind, 11% Nuclear, 2% Other



Electricity Capacity:

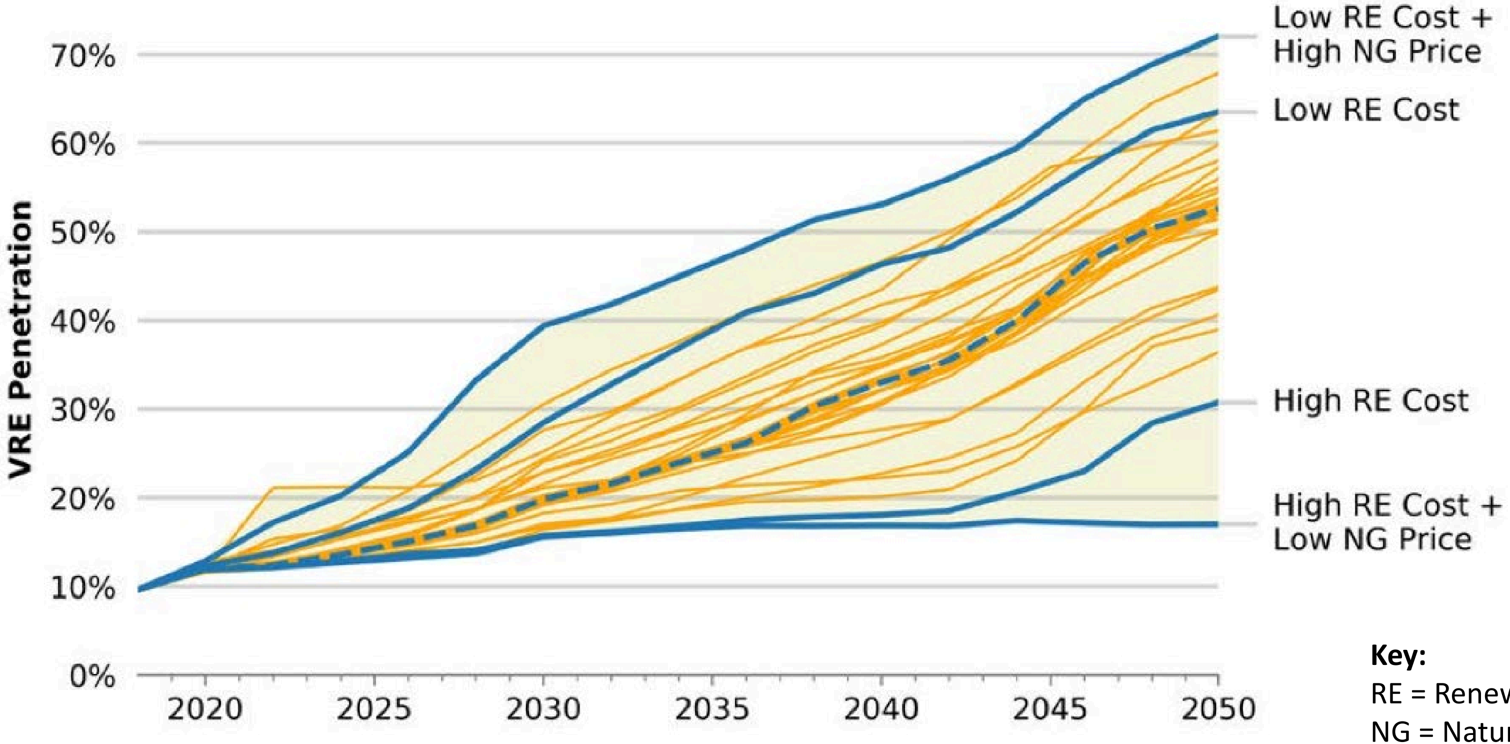


Costs for renewables are falling



Source: *Lazard's 2017 Levelized Cost of Energy Analysis,* Version 11, 2 November 2017

NREL models scenarios of future electricity generation

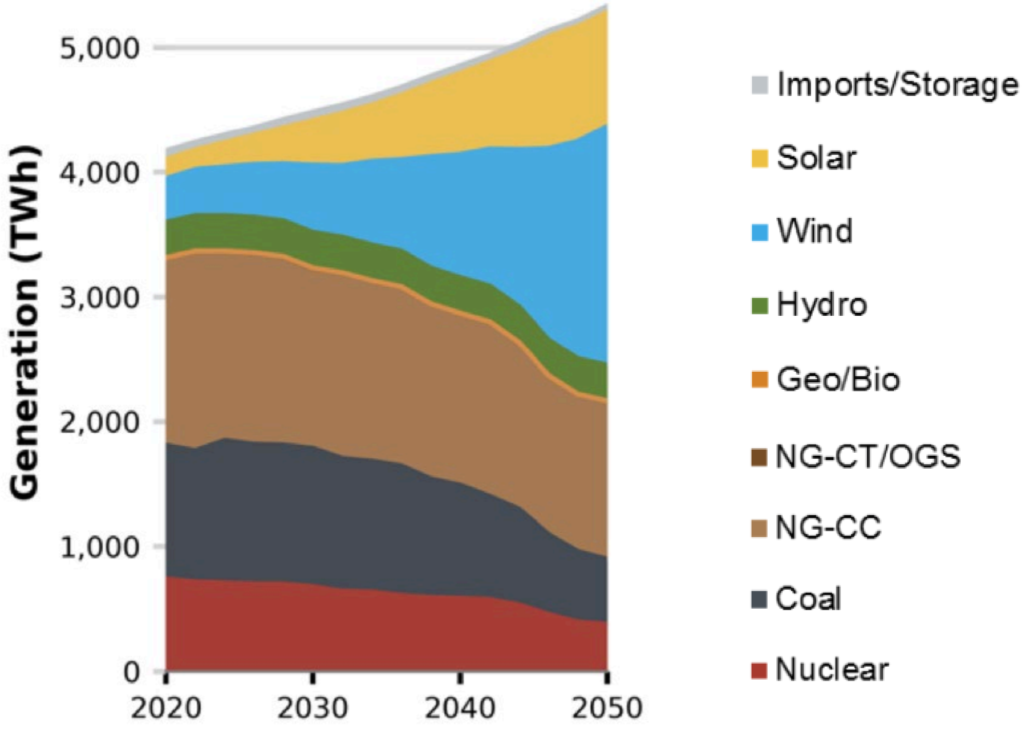


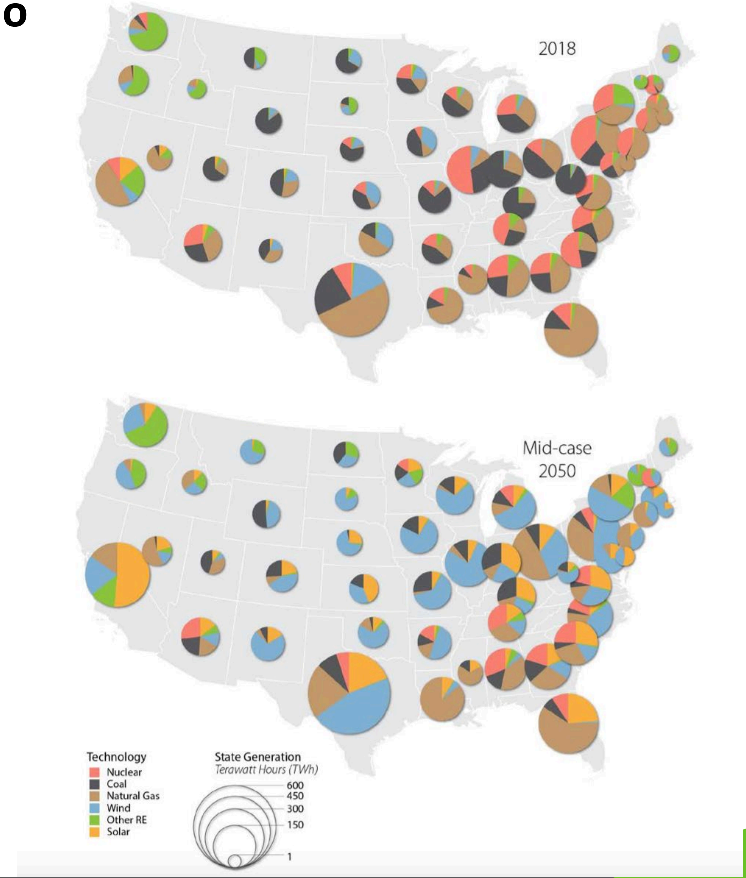
Key:
RE = Renewable Energy
NG = Natural Gas
VRE – Variable Renewable Energy

Generation projections across 36 scenarios: NREL 2019 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





Generation projections across 36 scenarios: NREL 2019 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

City 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

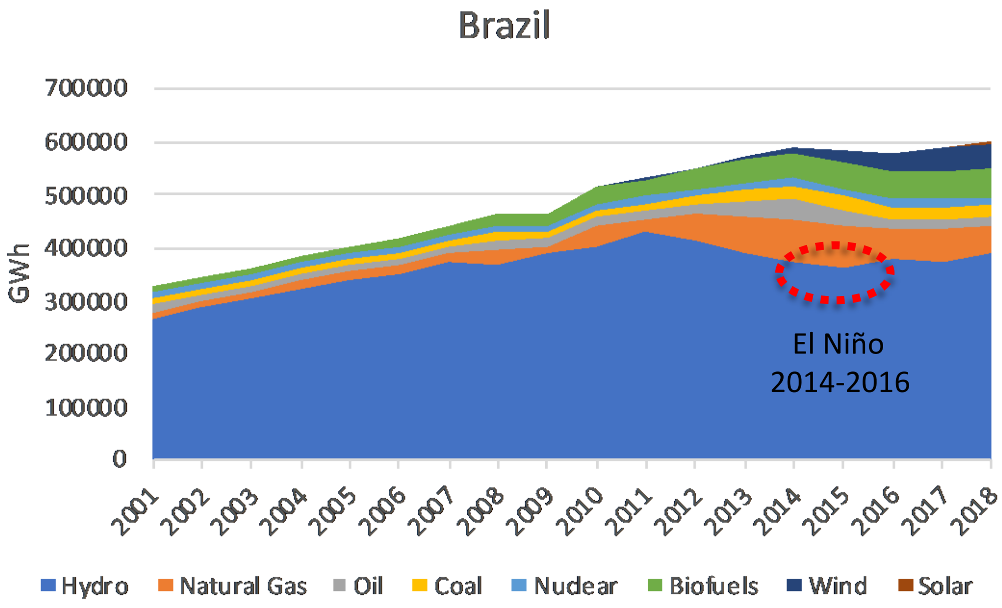
Job creation

Job migration

Economic development

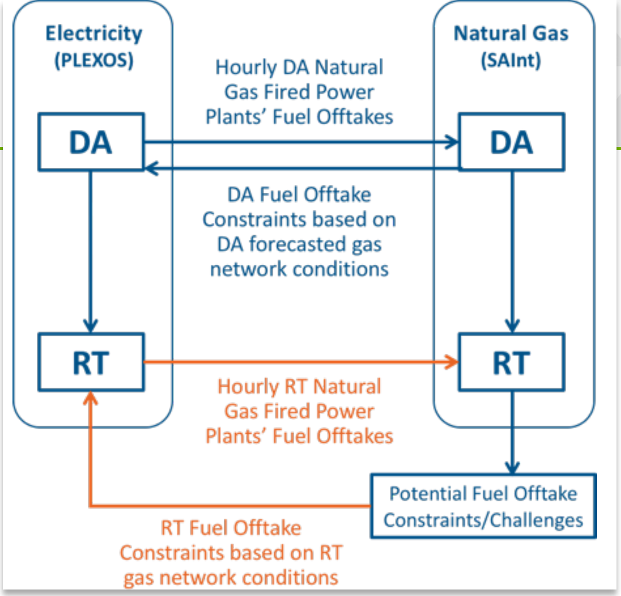
South America: Adaptation of hydropower to changing hydrological phases and increased renewables

- 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
  - Increase coordination among dam operators and other end users (e.g. agricultural sector) to better serve water needs
  - 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

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:

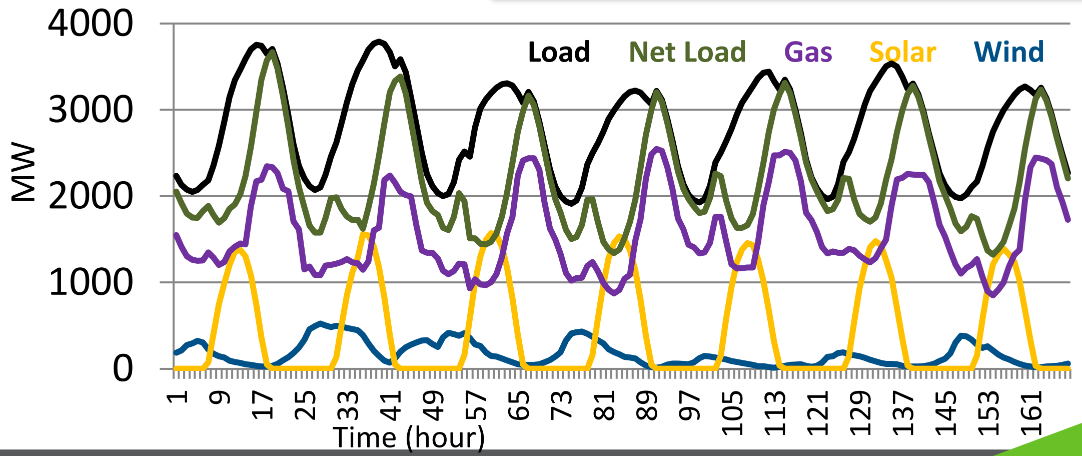
Co-simulate power and natural gas network operations.

Define an interconnected power and natural gas test system

Determine value of coordination of day-ahead operations

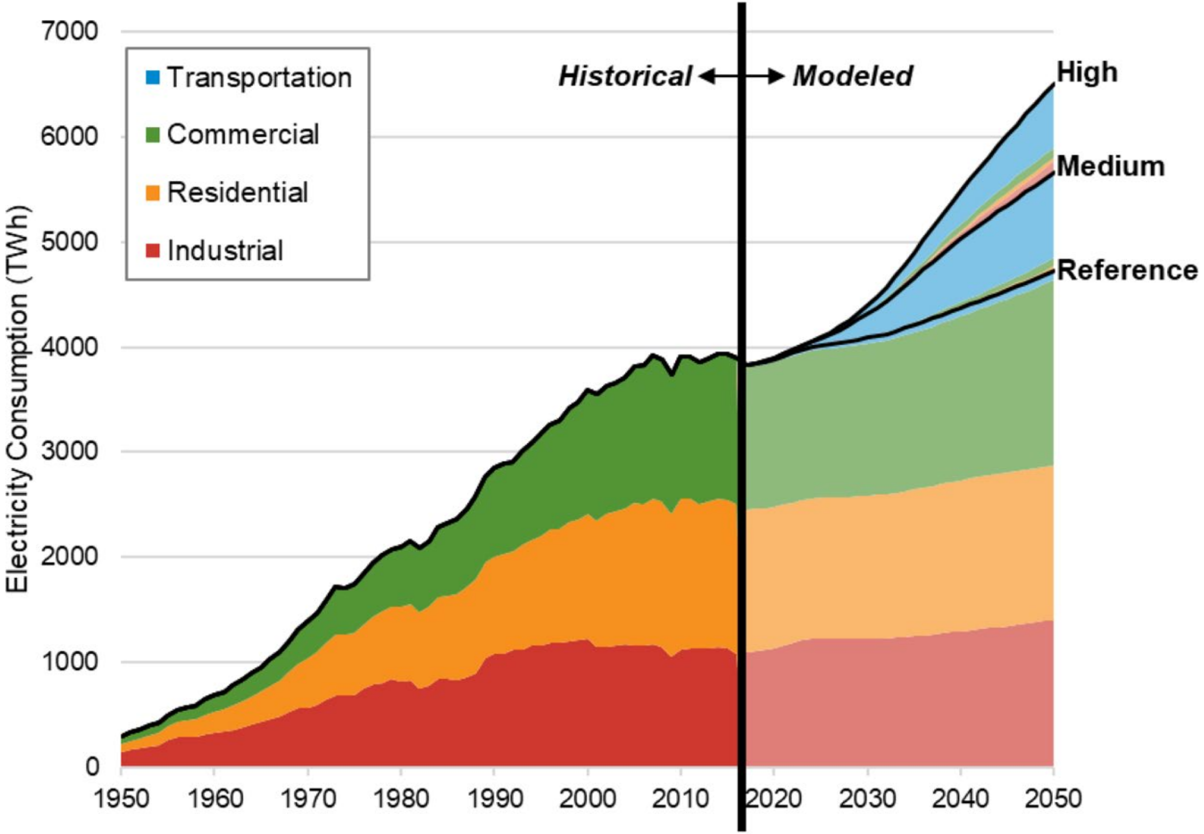
Funded through JISEA sponsorship by:

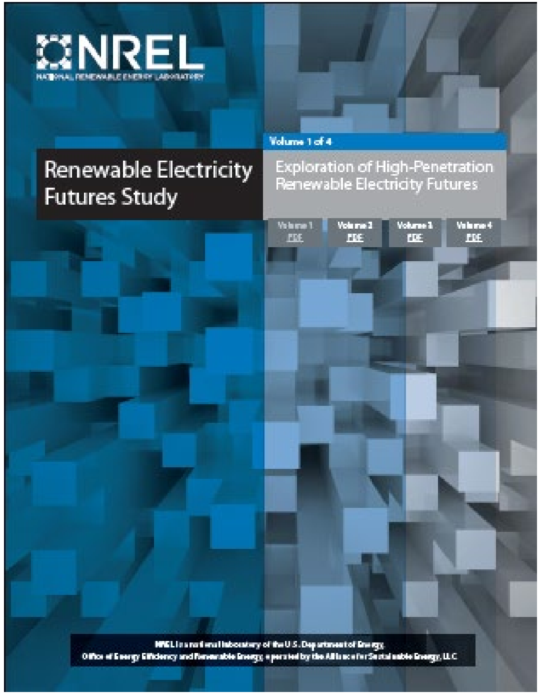
- American Electric Power
- Environmental Defense Fund
- Hewlett Foundation
- Kinder Morgan
- American Gas Association
- Midcontinent Independent System Operator



Source: JISEA project in progress.

Electrification Futures Study





All Figures from NREL's Electrification Futures Study: www.nrel.gov/efs

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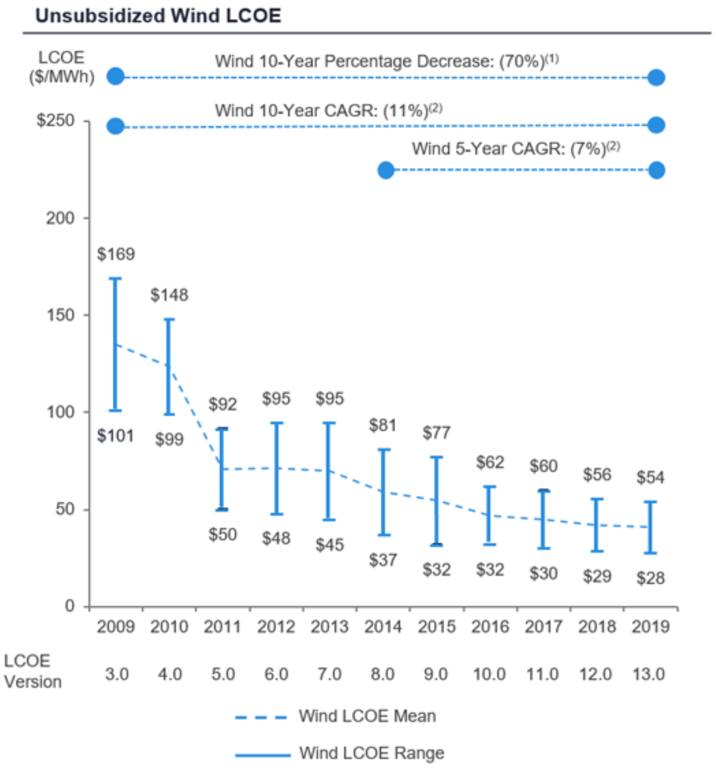
Wind Turbines – Onshore and Offshore

Peetz Table Wind Energy Center
- Peetz, Colorado
- 430 MW, 300 turbines
- Opened 2001, expanded 2007
- Capacity Factor 34.5%

Block Island Wind Farm
- New Shoreham, Rhode Island
- 30 MW, 5 turbines
- 100 m hub height, 150 m diameter
- Opened 2016
- Capacity Factor 48% (projected)

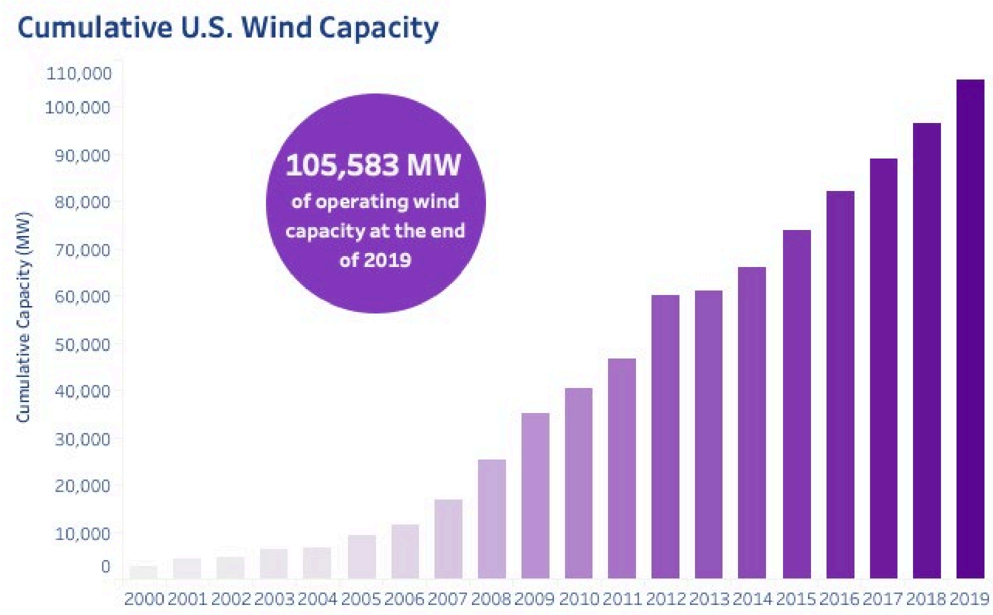
Wind market growth driven by price declines



Source: Lazard estimates.

(1) Represents the average percentage decrease of the high end and low end of the LCOE range.

(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.

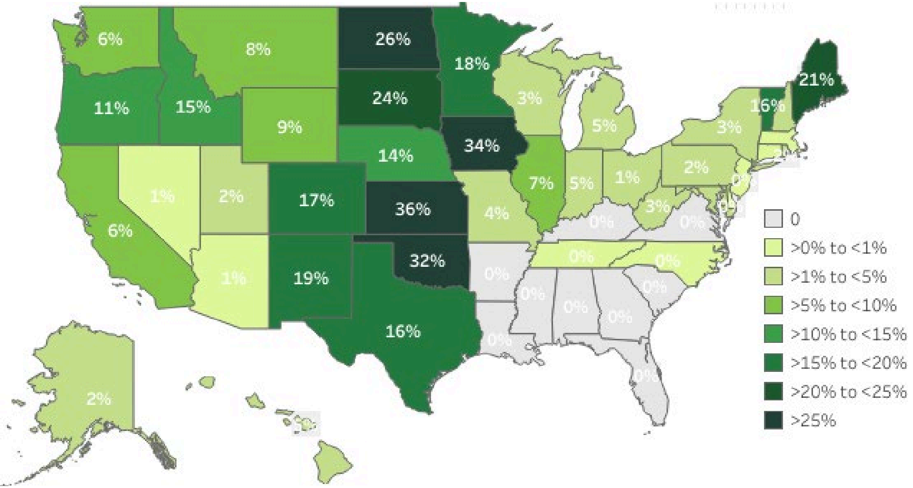


Source: Lazard, https://www.lazard.com/perspective/lcoe2019; AWEA, https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance.

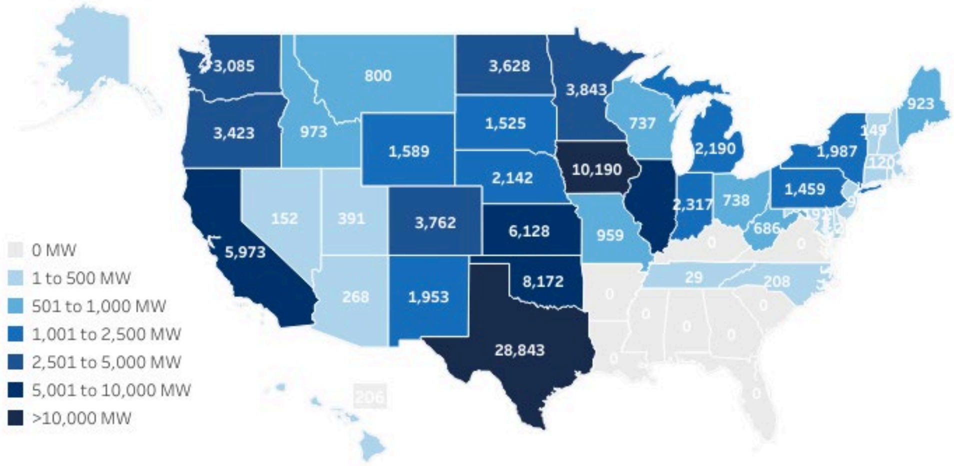
U.S. Wind Market (installed capacity, MW)

Wind capacity installed in Oklahoma, Iowa, and Kansas supplied >30% of all in-state electricity generation in 2018. 14 states were greater than 10%.

Wind Share of State Electricity Generation (2018)



Wind Capacity by State



Source: American Wind Energy Association, https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance

Wind Machines – Scale, capacity factor Increasing, Manufacturing costs declining

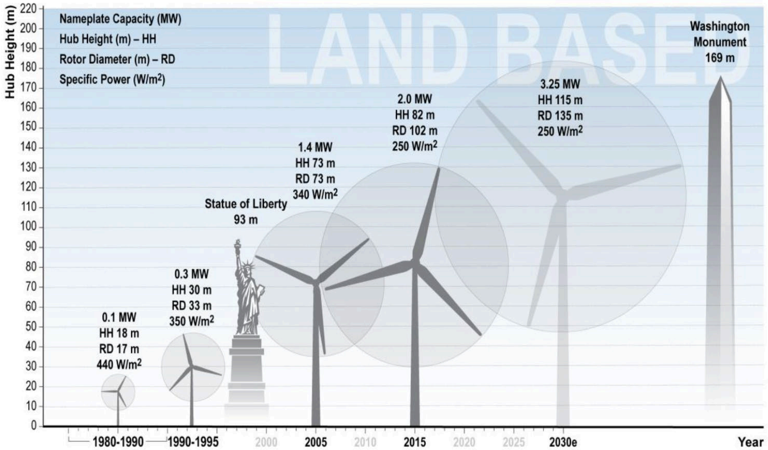
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

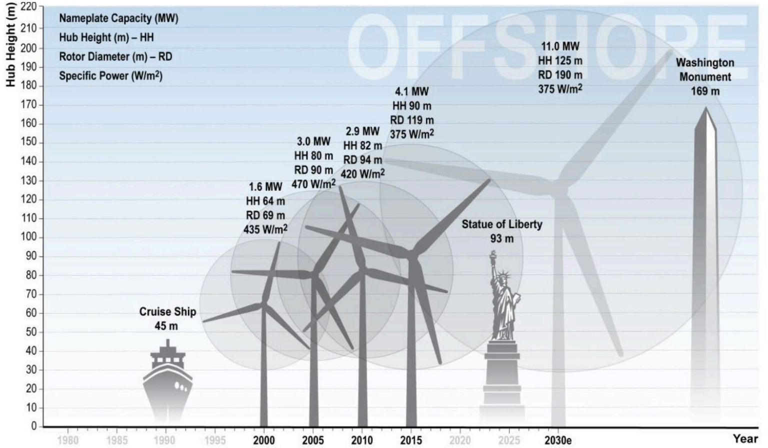
1998-2001: 24.5%

2004-2011: 32.1%

2014-2015: 42.6%

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

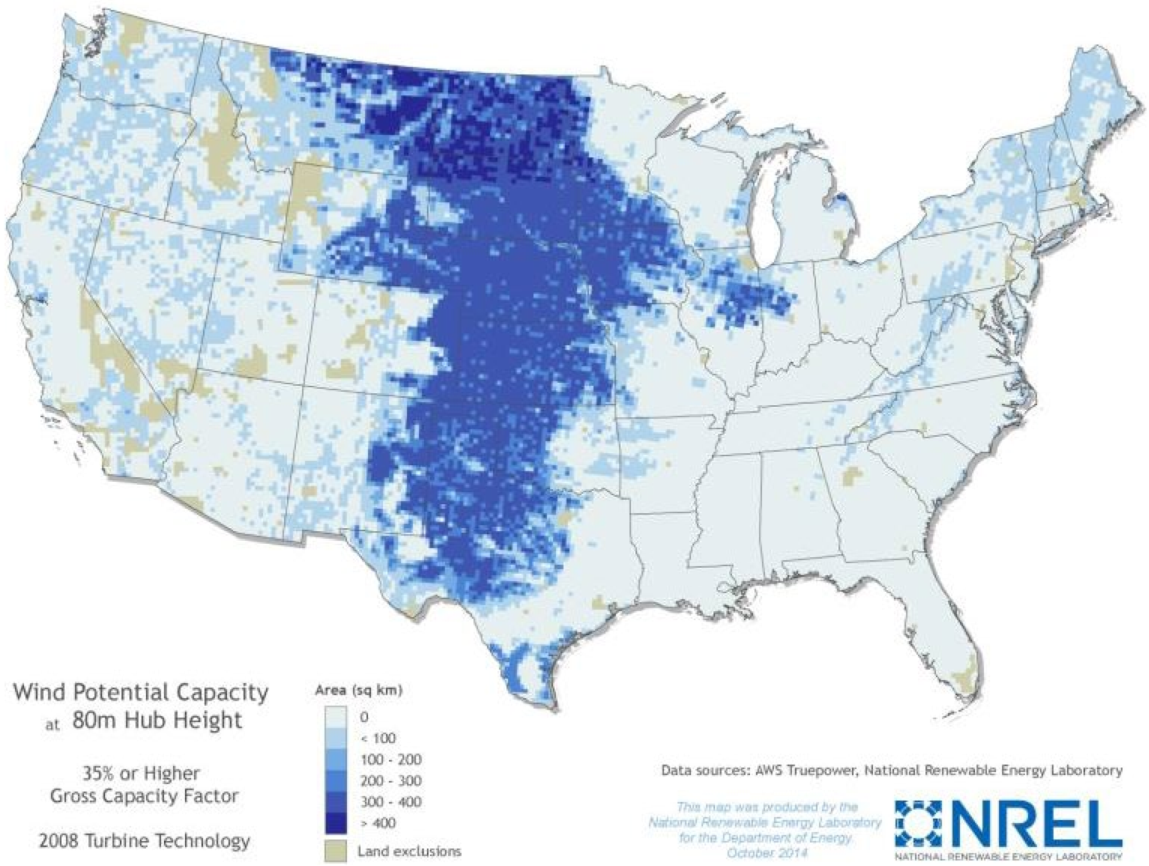




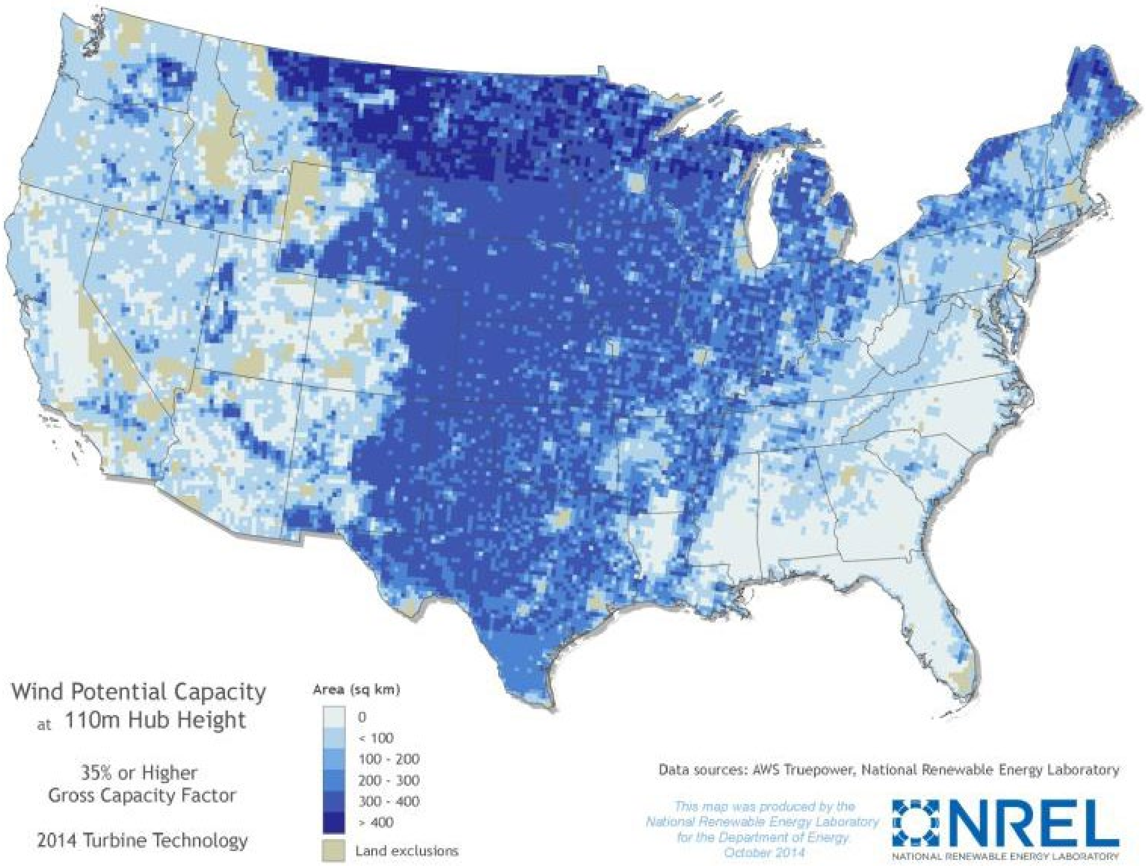
Source: LBNL, https://emp.lbl.gov/sites/all/files/scaling_turbines.pdf

Wind energy potential capacity at 80m hub height

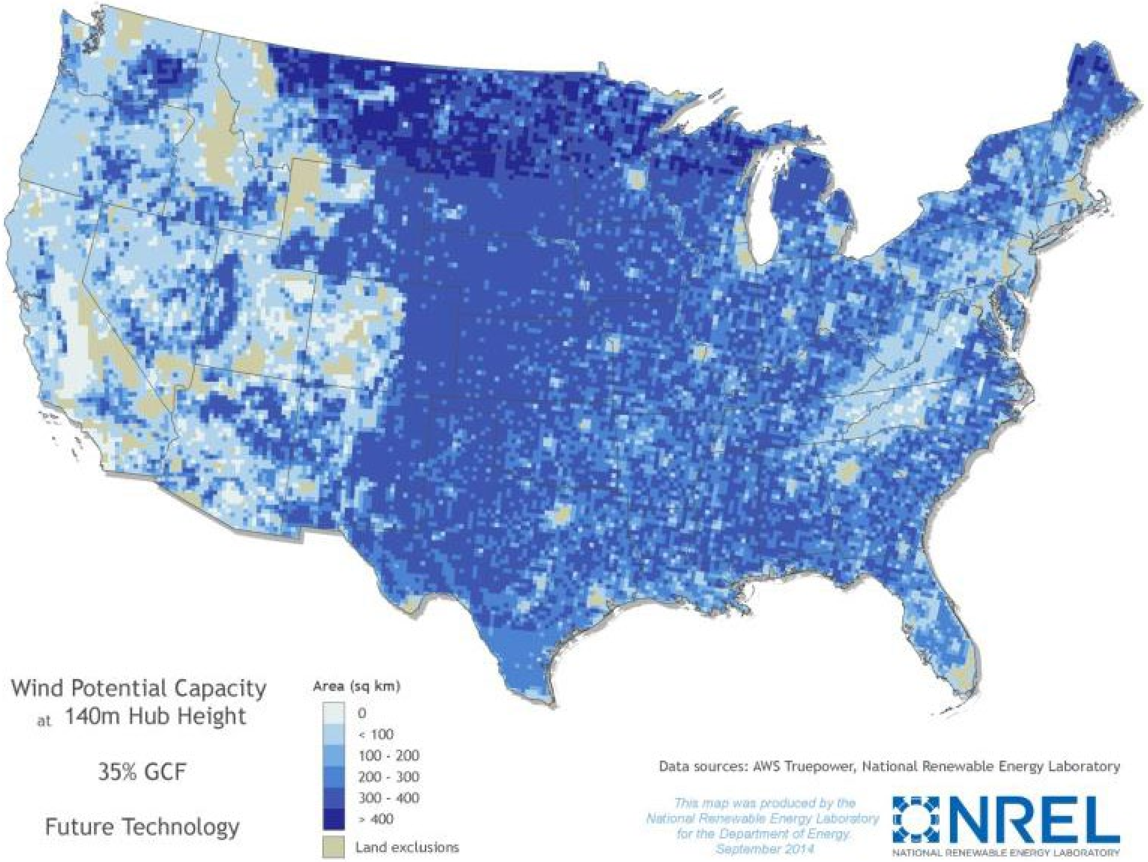
2008 turbine technology



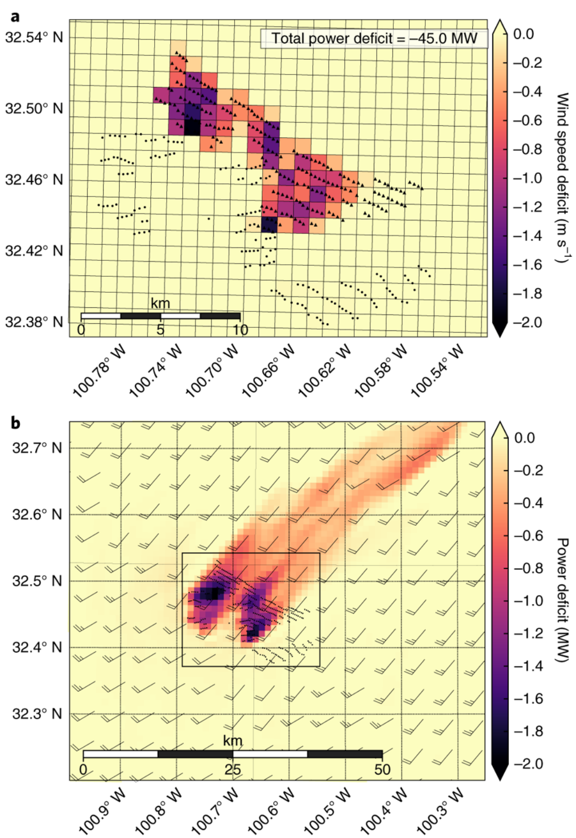
Wind energy potential capacity at 110m hub height
Current turbine technology

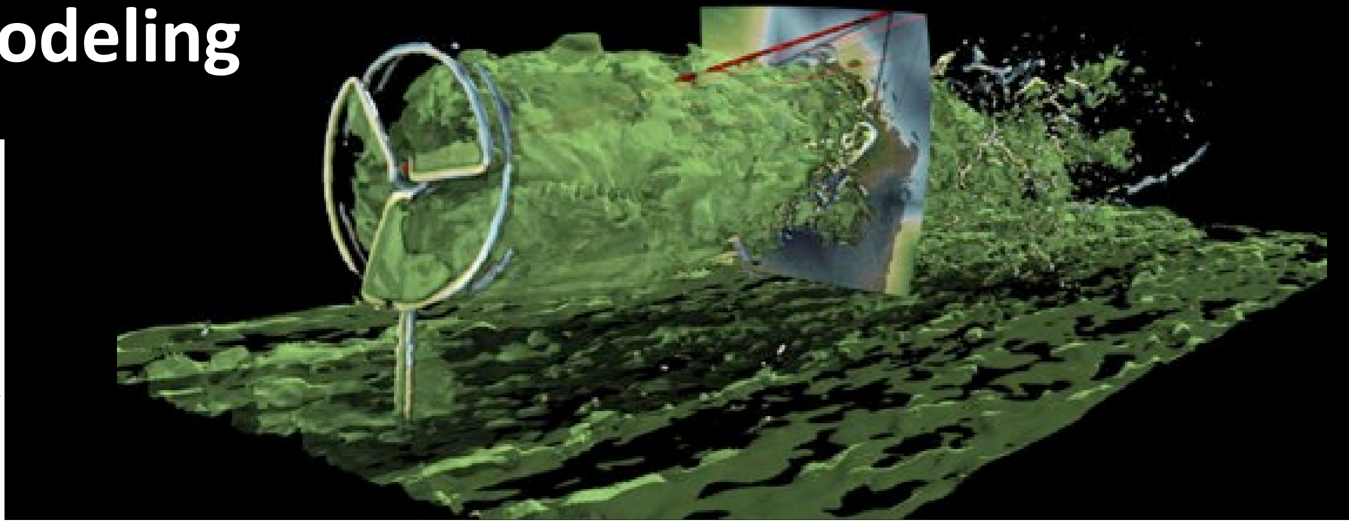


Wind energy potential capacity at 140m hub height
'Future' turbine technology



Wind plant modeling





Blade-resolved simulations of whole wind plants

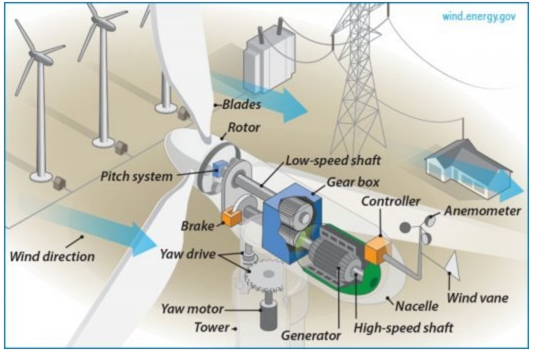
- Developing predictive capability to better understand complex fluid flow in wind plants with complex terrain, focus on turbine-turbine impacts, and address wind plant energy losses
- Growing fleet requires advanced sensors and simulation for improved reliability and energy security
- Inaccurate forecasts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

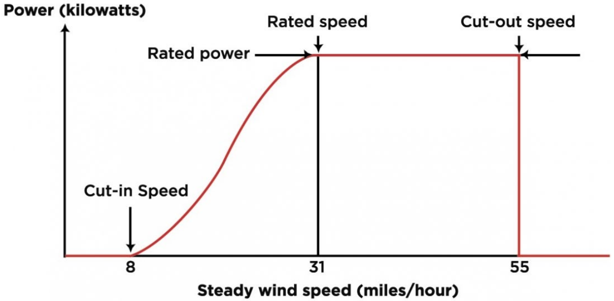
POTENTIAL IMPACT

Improve wind plant efficiency **4%** to generate **$1 billion** in annual savings.

Adaptation of wind turbines for bigger storms

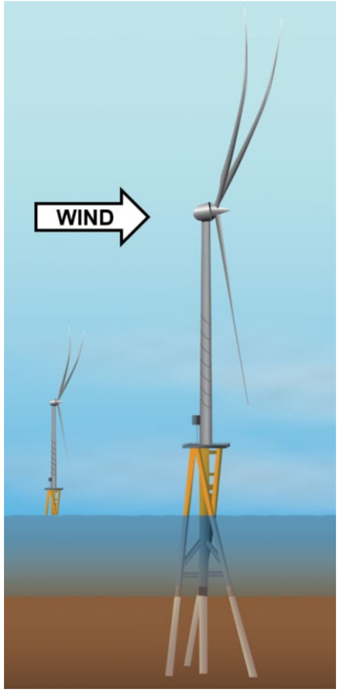
Current wind turbines face up-wind and use feathering or full shut down in high winds





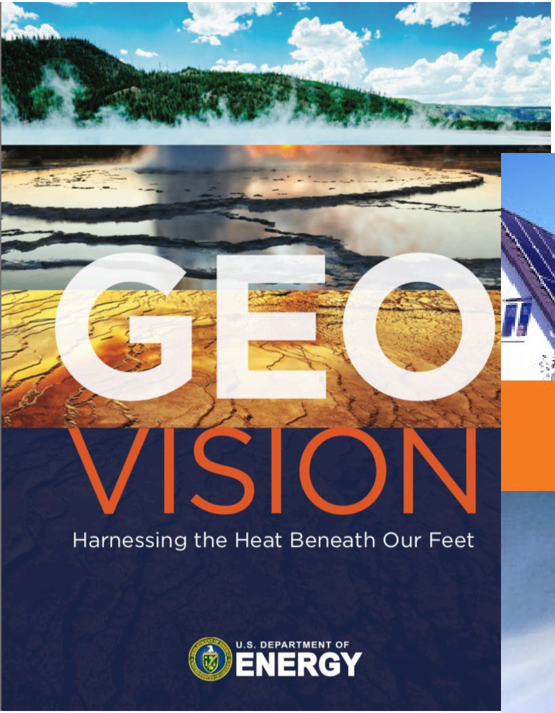
Typical wind turbine power with steady wind speed

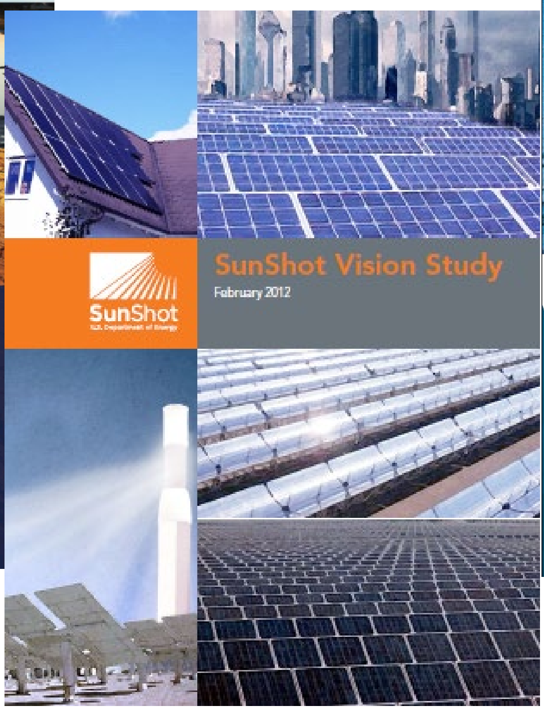
Hypothetical 50-megawatt offshore down-wind facing wind turbine for 25-meter deep waters in Gulf of Mexico

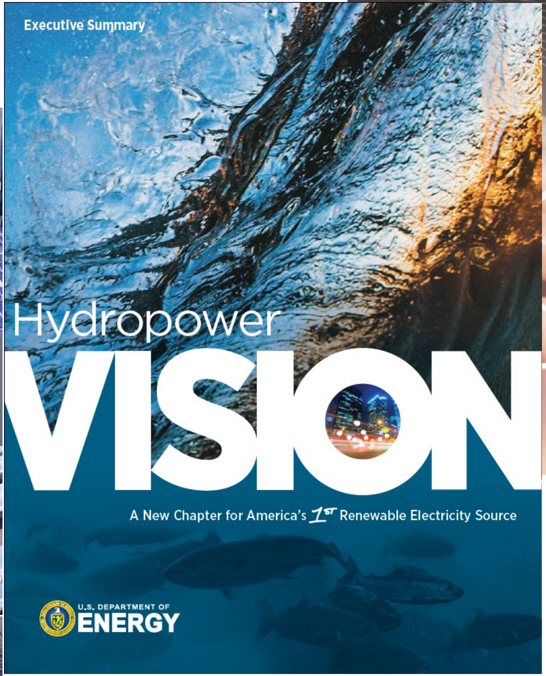


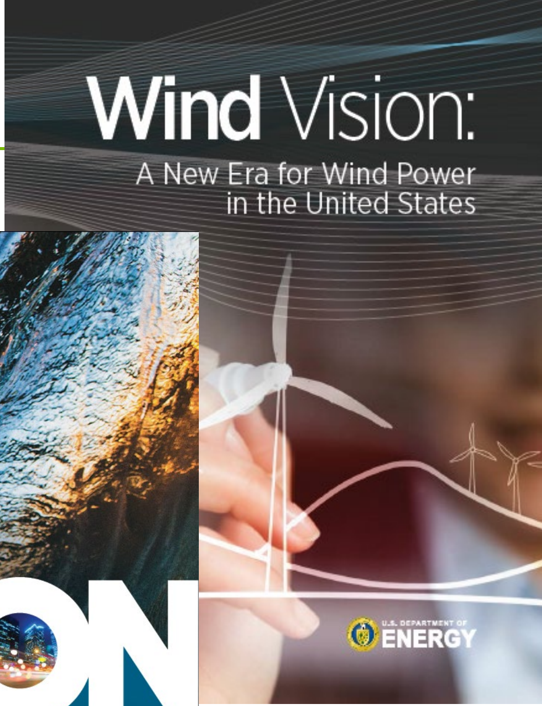
Source: https://www.energy.gov/eere/articles/wind-turbines-extreme-weather-solutions-hurricane-resiliency; https://www.colorado.edu/ecee/2016/02/17/paos-morphing-wind-turbine-inspired-nature

Technology vision studies









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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.

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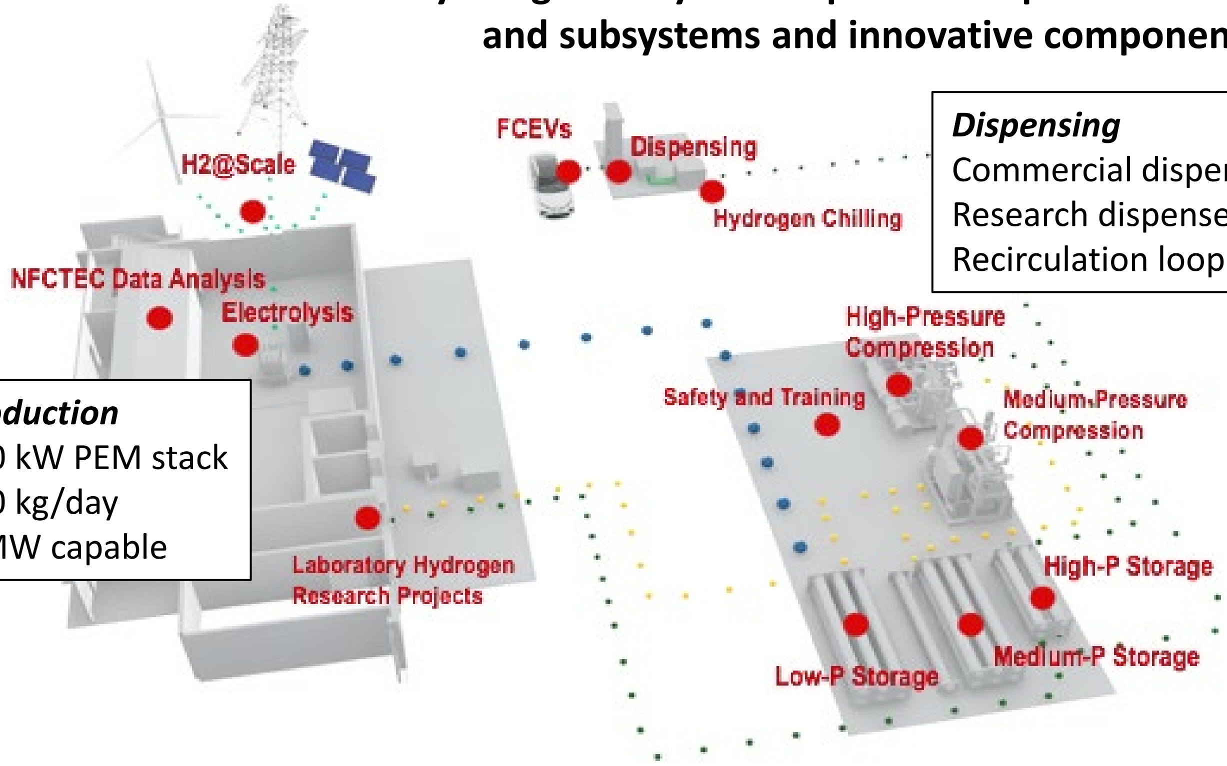
Hydrogen infrastructure testing and research facility

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)

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

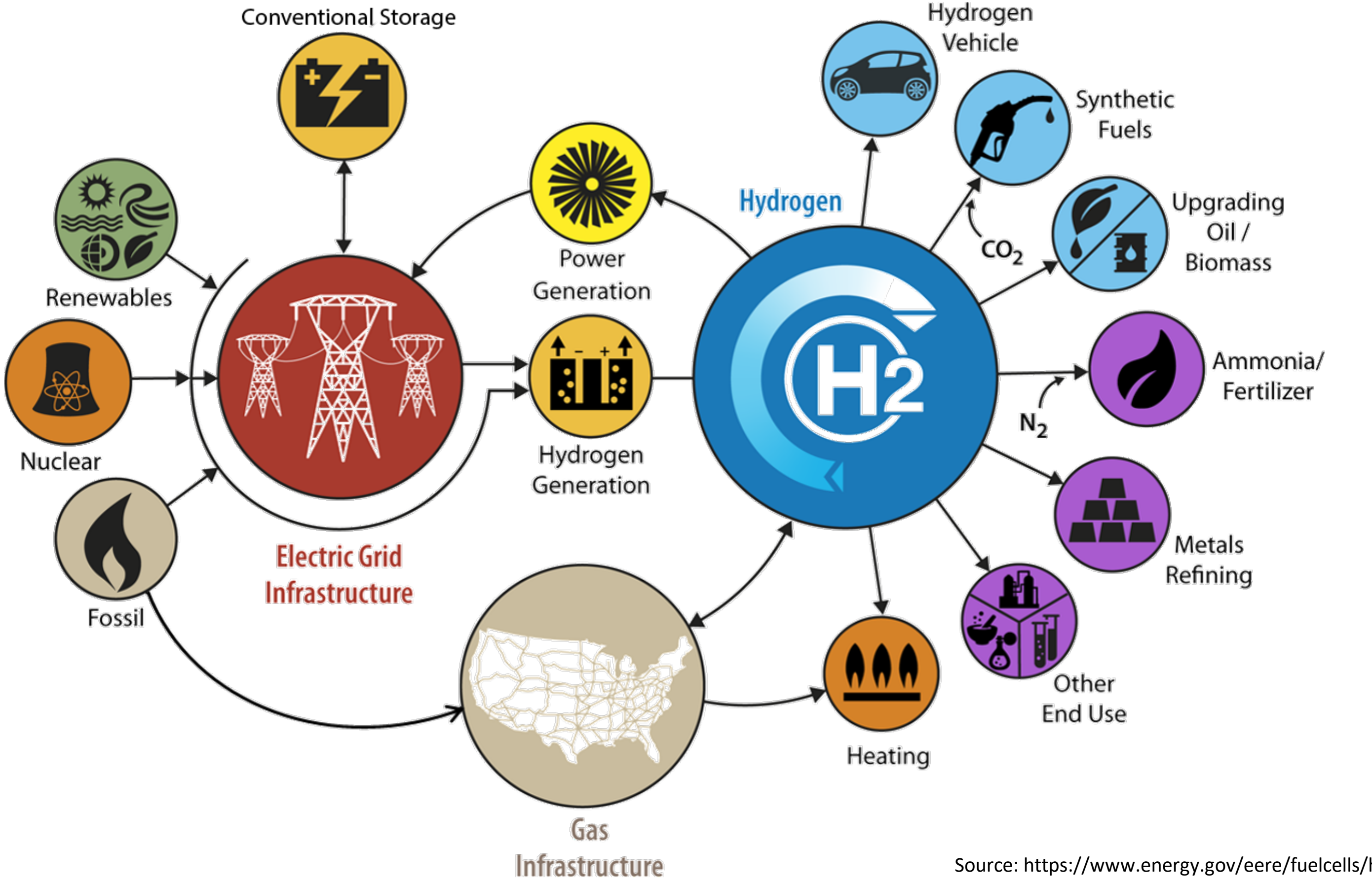
Compression
High throughput compressor up to 1 kg/min (Low-P to High-P)

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

Images: NREL

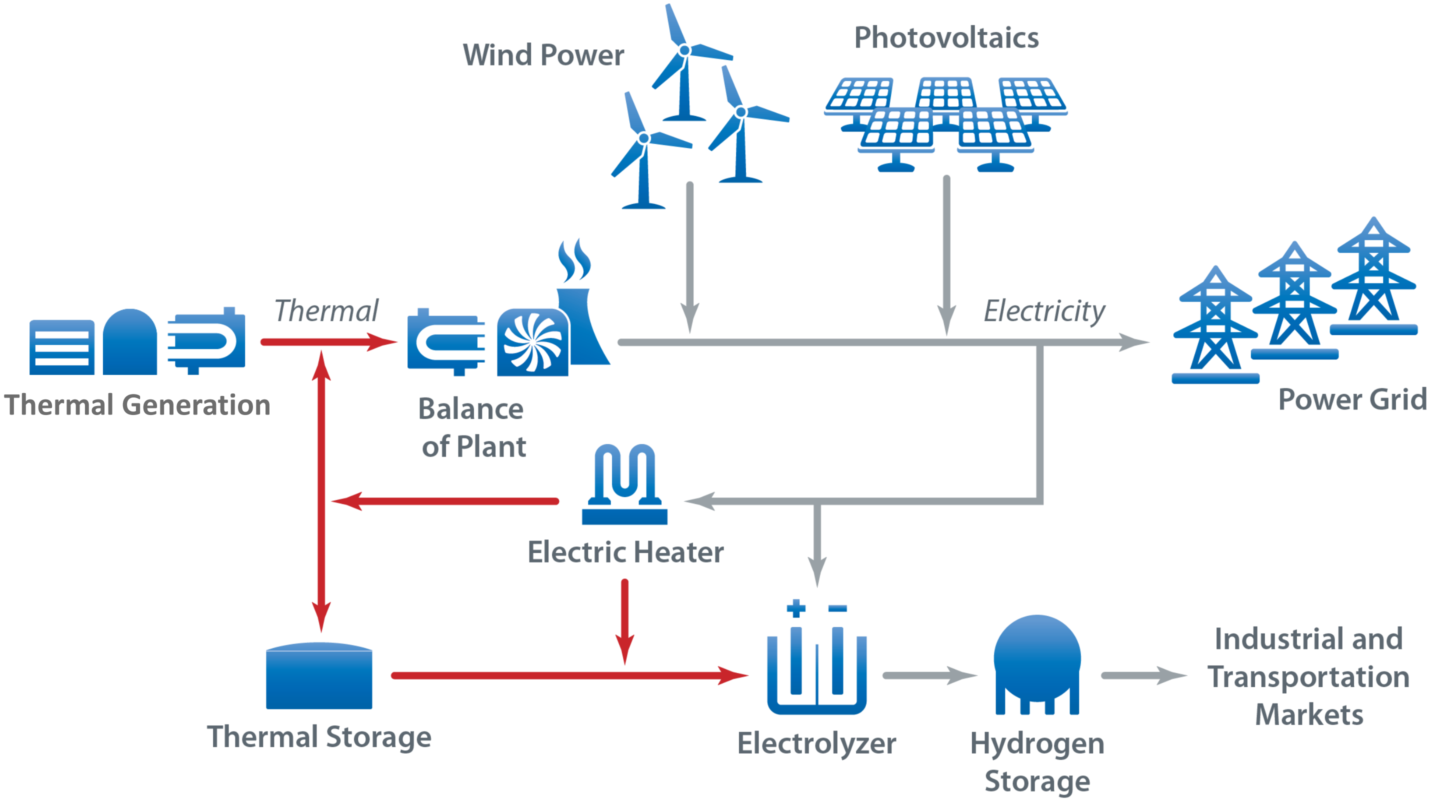
[Hydrogen Infrastructure Testing and Research Facility]

Hydrogen @Scale



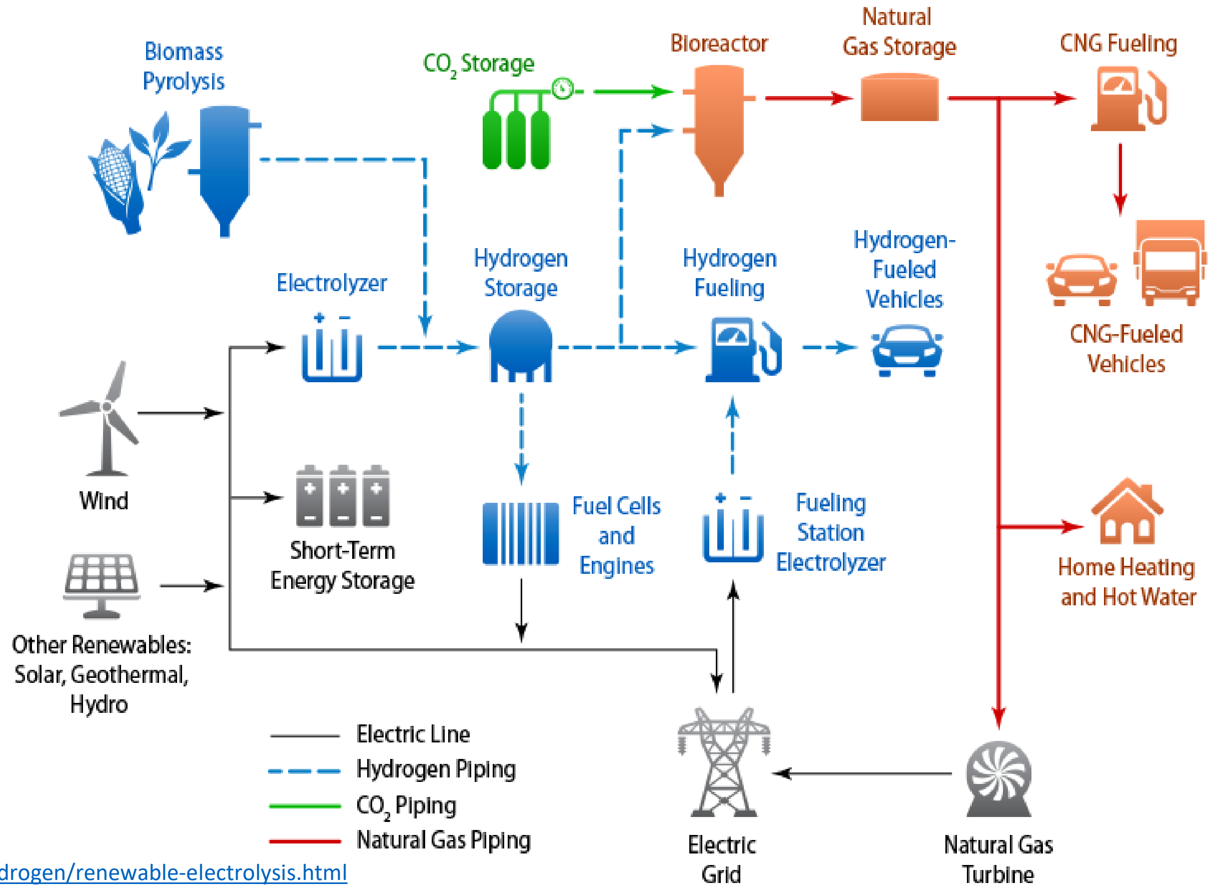
Source: https://www.energy.gov/eere/fuelcells/h2scale

Renewable hybrid energy solutions



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

Integration of renewable & carbon capture systems



Source: https://www.nrel.gov/hydrogen/renewable-electrolysis.html

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Building on our methane emissions work, started with a workshop

Workshop: Nexus of Oil & Gas and Renewables in the Energy Future, NREL, Sept 2017

Co-Sponsored with IEA Gas & Oil Technology Programme

IEA GAS & OIL TECHNOLOGY COLLABORATION PROGRAMME

Keynote: Colorado Governor John Hickenlooper

Purpose: Explore how the renewable energy industry and oil & gas industry can work together for a clean energy future

Key Topics:

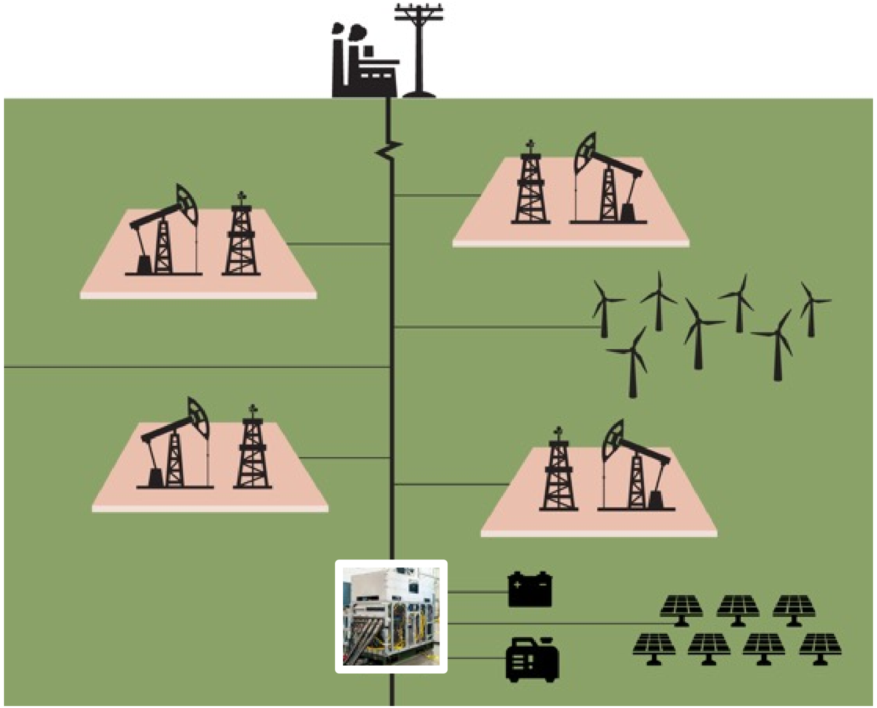
1. Renewable energy for oil and gas operations
2. Efficient use of process heat and water
3. Gas and renewable energy for utilities
4. Industry investment in renewable energy

Followup workshops in Brussels and Houston

Example Onshore Power Solution: Electrification of the Wellpad and Platform via Microgrids

- 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



Example Offshore Power Solution:
Offshore Wind for Platform Power & Water Injection

- Electricity from wind turbine is used to power pumps, treatment, and injection
- Integrated with microgrid and energy storage
- Feasibility study by DNV-GL shows the system has higher operational costs but lower capital expenditure that over a 20-year life-cycle is competitive with alternatives
- Opportunity for conversion of decommissioned platforms

Source: https://www.dnvgl.com/energy/feature-articles/win-win-wind-powered-water-injection.html

Example Thermal Solution: Enhanced Oil Recovery using Concentrating Solar Power (CSP)

Chevron/BrightSource Solar-to-Steam Demonstration

Location: Coalinga, CA
Facility Size: 100 acres
Steam Production: 29 MWt (megawatts thermal)
Electrical Output Equivalent: Approx. 13 MWe (megawatts electric)
Tower Height: 327 feet
Number of Heliostats / Mirrors: 3,822 heliostats; 7,644 mirrors
Years of Operation: 2011-2014

http://www.brightsourceenergy.com/coalinga#.V-QUkjsSfPE

Miraah CSP system in Oman

Produce 6,000 tons of solar steam each day for thermal EOR
Energy production: 1021 MWt on 741 acres
Save 5.6 trillion Btus of natural gas each year
Reduce CO_2 emissions by more than 300,000 tons each year

http://www.glasspoint.com/markets/projects/

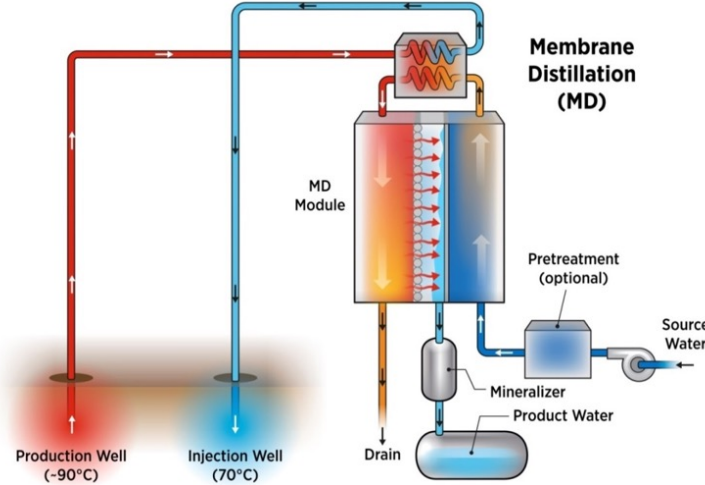
Example Thermal Solution: Geothermal-powered Desalination Technologies

NREL is working to develop desalination technologies with geothermal

- Partnership with Colorado School of Mines
- Pilot plant development in the U.S. Southwest
- Development of a geothermal desalination decision support tool

Key research benefits include:

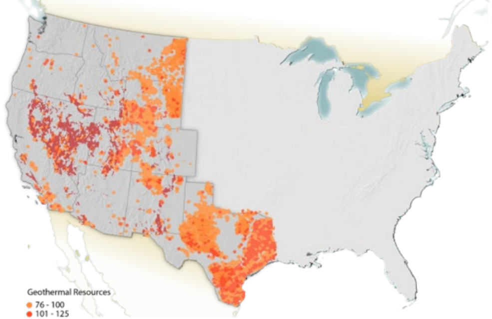
- ✓ Access to and development of data on cutting-edge RD&D in brackish water desalination technology
- ✓ Demonstration pilot
- ✓ Decision support tool to identify promising new locations



Membrane Distillation has advantages for renewable energy integration:

Uses low-temp (< 90ºC) thermal energy
Suitable for high-salinity, poor-quality source water
Compatible with sensible heat transfer
Amenable to small-scale units
Potentially low-cost membranes

Low-Temp Geothermal Resources



Turchi, C., Akar, S., Cath, T., Vanneste, J., and M. Geza (2015). "Use of Low-Temperature Geothermal Energy for Desalination in the Western United States." NREL/TP-5500-65277

Clean Power Technologies for Oil & Gas Industry Operations

Value Proposition: Demonstrate highly reliable, affordable, clean power for oil & gas operations.

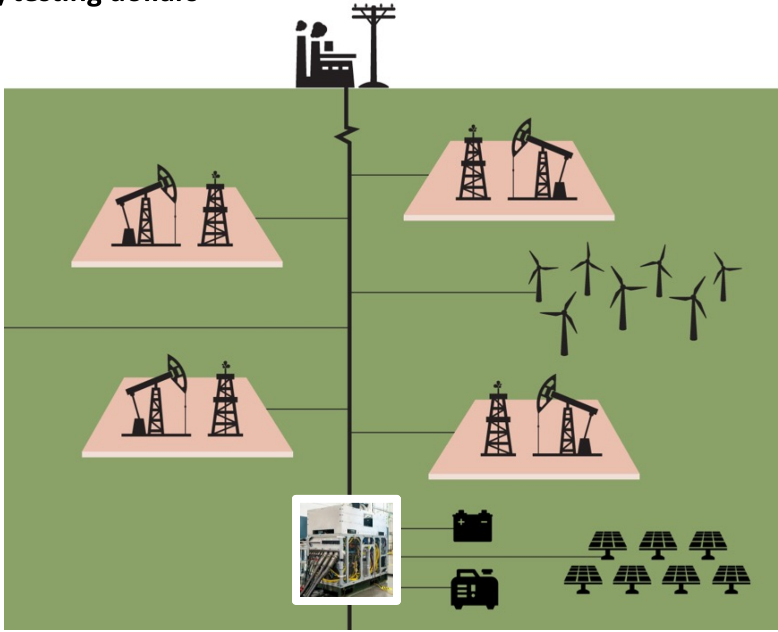
Reduce risk to operations
Collaboratively identify 'best practices' to reduce cost
Access to unique, world class capabilities
Leverage research/testing dollars

Program Results:

Operational, financial, and environmental improvements within oil & gas operations

Governance:

Consortium of industry partners to leverage resources for benefit of those involved, supported/managed by JISEA



Program Targets:

- Support the identification, development, and adaptation of **highly reliable, cost-effective clean energy solutions** for oil and gas operations
- Perform **techno-economic analysis and site-specific optimization** of combinations of renewable and conventional generation, storage, and energy conservation
- With industry partners, **demonstrate the most promising technologies** for validation of performance in a variety of field environments, while analyzing optimization scenarios.

Program approach

Phase 1:

Identify potentially highly reliable, cost-effective clean energy solutions for priority energy needs of oil and gas operations

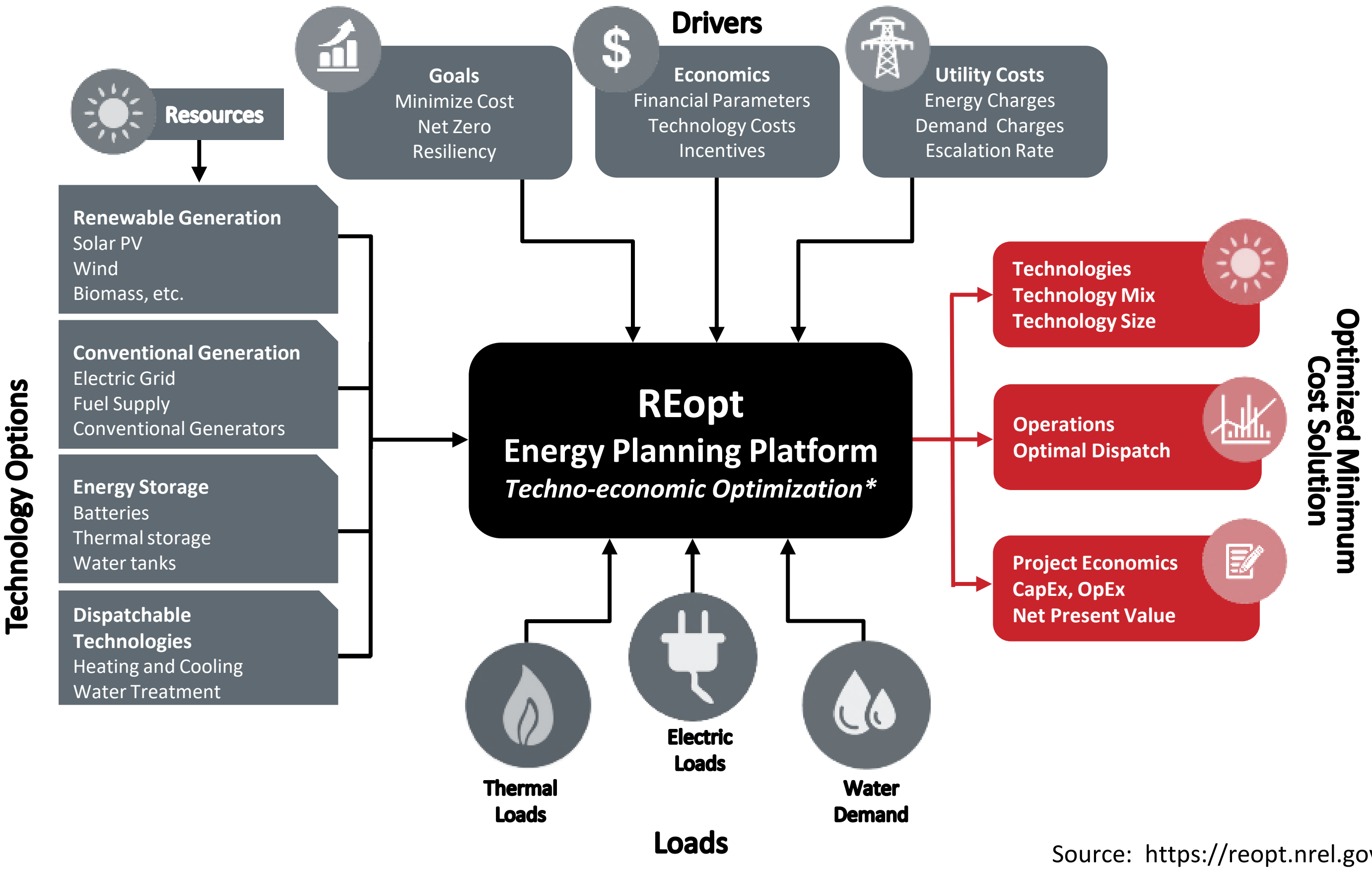
Analyze and model site- and technology-specific solutions considering:
Innovation, Performance, Costs/Savings, Deployment Potential, Project Value, Technical Risk, Business Viability

Phase 2:

Objectively evaluate real-world performance in a variety of field environments to determine return on investment and impact on environmental and social license.

Prepare analysis results to inform decisions on technologies with broad deployment potential

REopt Platform inputs and output



Source: https://reopt.nrel.gov

Analysis Overview

- Two case studies being done using publicly available data and assumptions:
  - Hypothetical refinery in Louisiana (and California)
  - Well site in Pennsylvania's Marcellus Shale (on grid and off grid)
- Preliminary analysis evaluates the opportunity for solar photovoltaics, wind turbines, and/or a battery energy storage system (BESS)
- Additional analysis considering the opportunity for thermal energy technologies, such as solar steam, biogas, electrification of thermal processes, energy efficiency measures, and/or carbon capture and sequestration (CCS)
- Supported by a consortium of industry sponsors to obtain load and generation data and evaluate these clean energy technologies at actual oil and gas sites.

  Current members:
  - Baker Hughes
  - Conoco Phillips
  - Extraction Oil and Gas
  - Kinder Morgan
  - INGAA Foundation

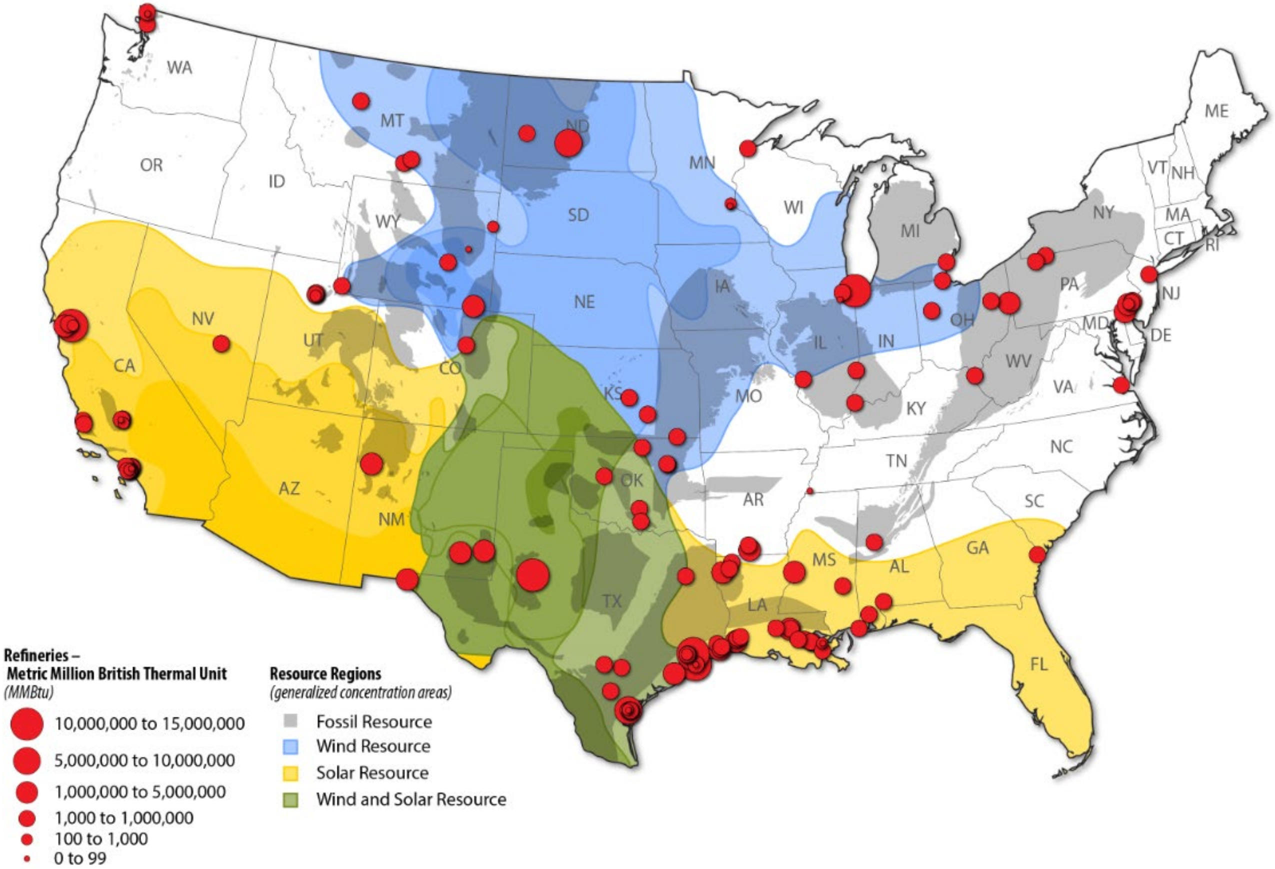
Consortium planning site analysis at:

Offgrid upstream Western U.S. site

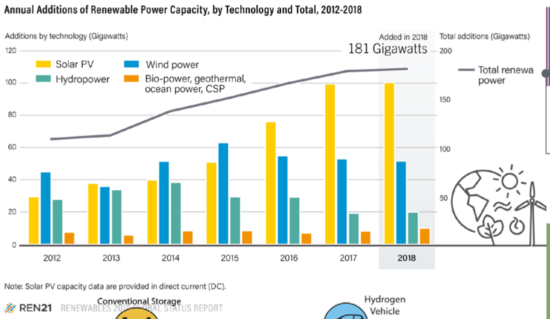
Mid-stream pipeline/compressor station

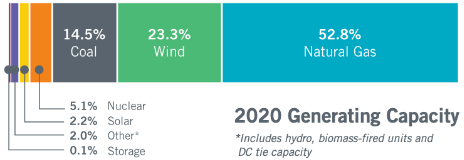
Consortium still accepting sponsors

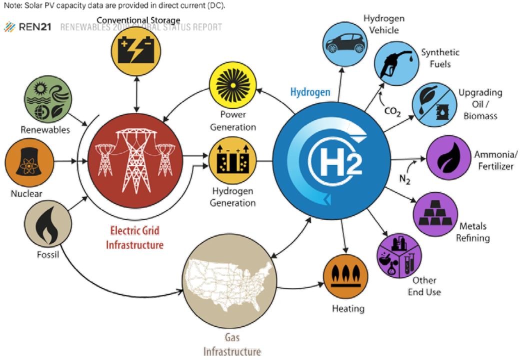
Many oil & gas regions have great wind AND solar resources

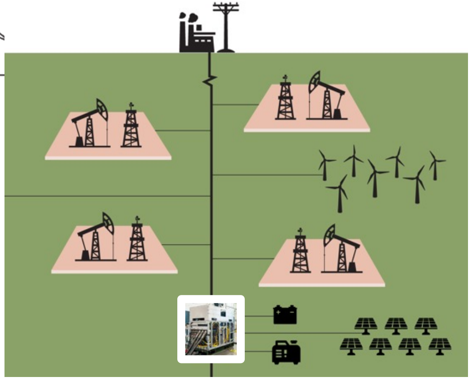


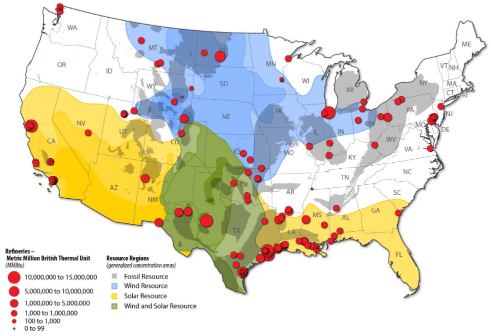
Conclusions and Discussion











- Trend toward cleaner and lower cost energy (renewables and gas) that is more distributed
- Potential for increased electrification resulting in higher demand for power
- Renewable energy can help power, industrial, and agricultural systems to reduce emissions, and operate more resiliently, but needs research and demonstration
- Need improved standards, models, policies, and technologies to enable systems to adapt

Thank you! Questions?

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JISEA Joint Institute for Strategic Energy Analysis

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