JISEA Joint Institute for Strategic Energy Analysis

Renewable Energy for Resilience & Adaptation

Workshop on Adaptive Actions Toward a Sustainable and Resilient Future

MIT, Cambridge, Massachusetts

10 January 2020

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National Renewable Energy Laboratory

NREL National Renewable Energy Laboratory · Colorado School of Mines · 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
- Renewable Energy and Adaptation/Resilience

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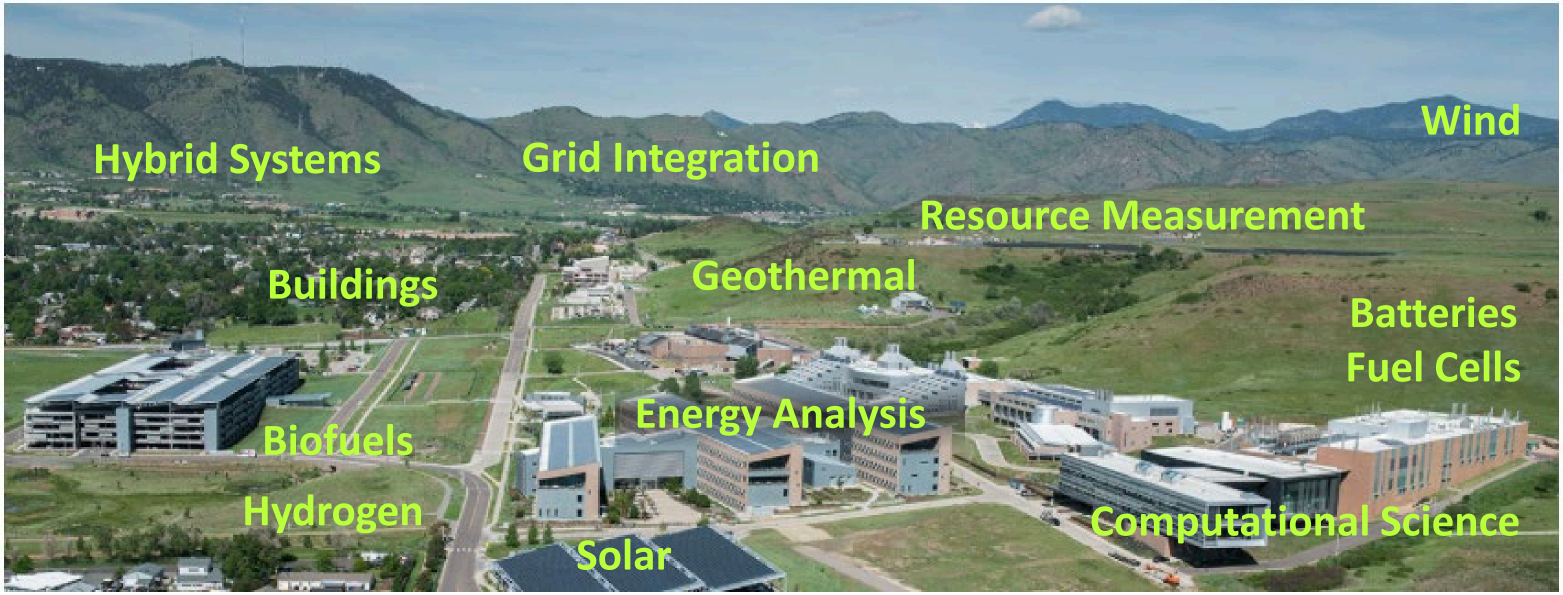
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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:



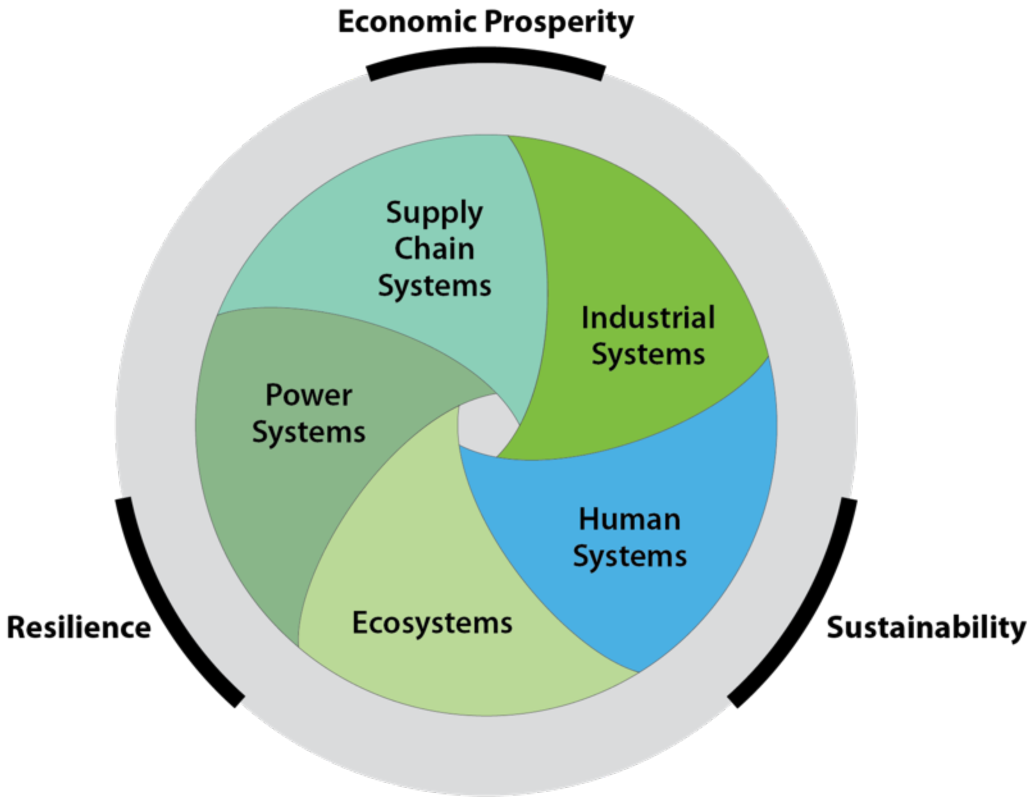
- 2300 employees, plus more than 450 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre Flatirons campus with the National Wind Technology Center near Boulder, Colorado
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

www.nrel.gov/about

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
Massachusetts Institute of Technology
Stanford University
University of Colorado Boulder

JISEA's Research Portfolio

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

JISEA Sponsors:
Ability to convene consortiums

AGA American Gas Association
American Electric Power Boundless Energy
Anadarko
anga America's Natural Gas Alliance
Baylor University
Center for the New Energy Economy Colorado State University
Children's Investment Fund Foundation
ClimateWorks
Colorado Center for Renewable Energy Economic Development
ConocoPhillips
cps Energy
Deutsche Bank

Dow
E+TWG
EDF Environmental Defense Fund Finding the ways that work
encana. natural gas
energy technologies institute
ExxonMobil
GE
gti
Hogan Lovells
Kinder Morgan
The Cynthia & George Mitchell Foundation
nationalgrid The Power of Action

Novim
Payne Institute Colorado School of Mines
rasei
Siebel
SoCalGas
Southern Company
swn Southwestern Energy
国家电网公司 State Grid Corporation of China
The William and Flora Hewlett Foundation
UBS

Research Affiliates

Houston Advanced Research Center, Rice University Baker Institute, Energy Institute at University of Texas at Austin, Masdar Institute, Carnegie Mellon, Eskom, International Institute for Applied Systems Analysis, KTH Royal Institute of Technology, Renewable and Appropriate Energy Laboratory at UC Berkeley, Masdar Institute

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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

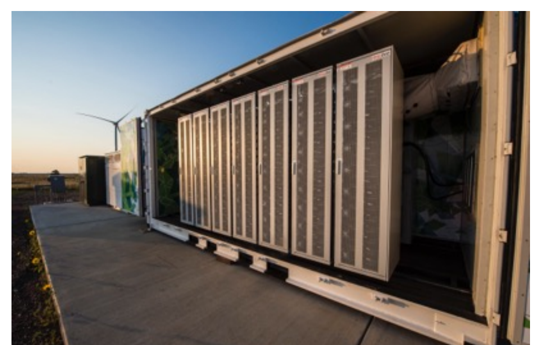
CONCENTRATING SOLAR

HYDROPOWER

Large & Small

Wave & Tidal

BATTERIES & STORAGE

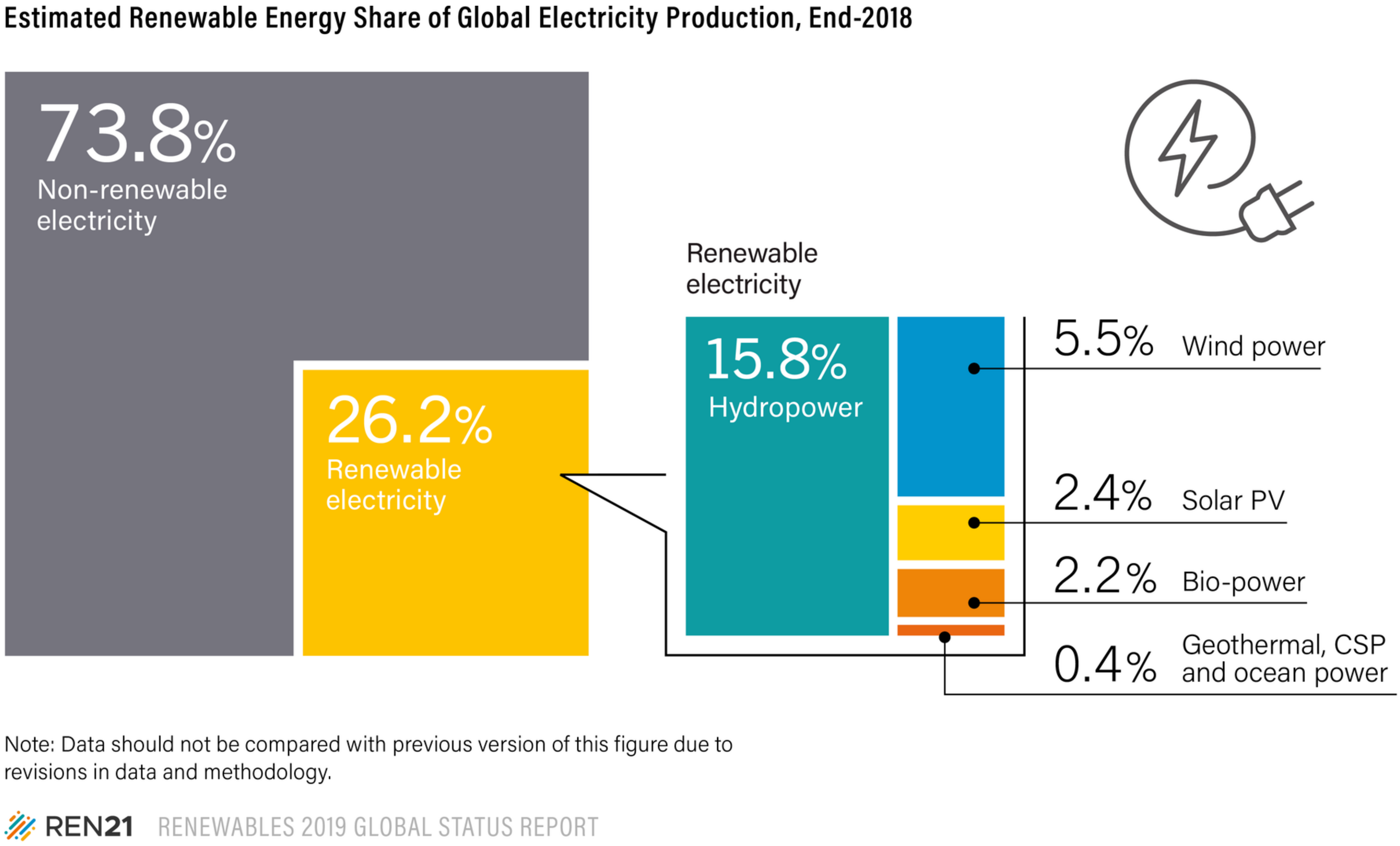


BIOMASS & WASTE

HYDROGEN & GAS

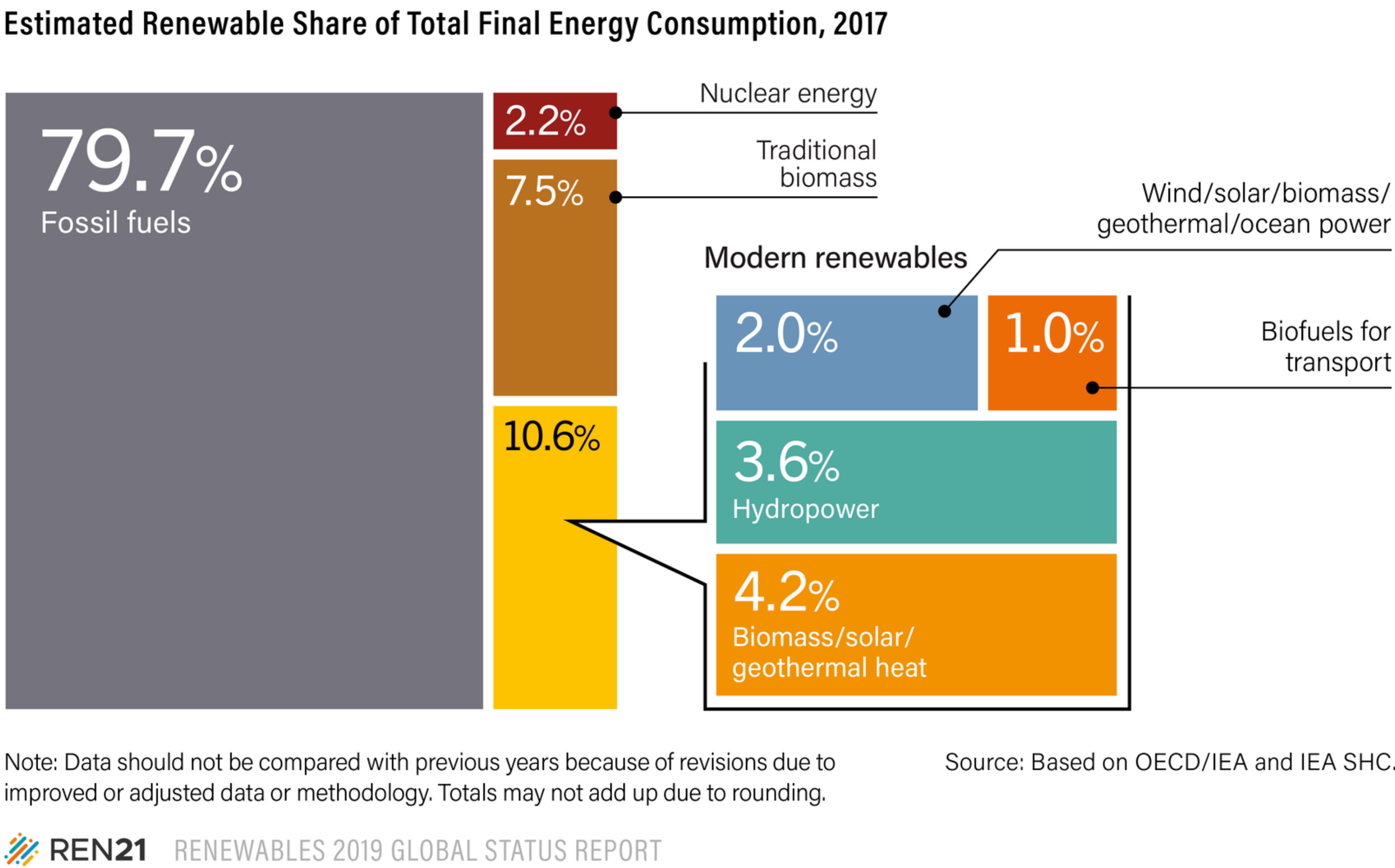
EFFICIENCY & HEAT USE

Global share of renewable electricity



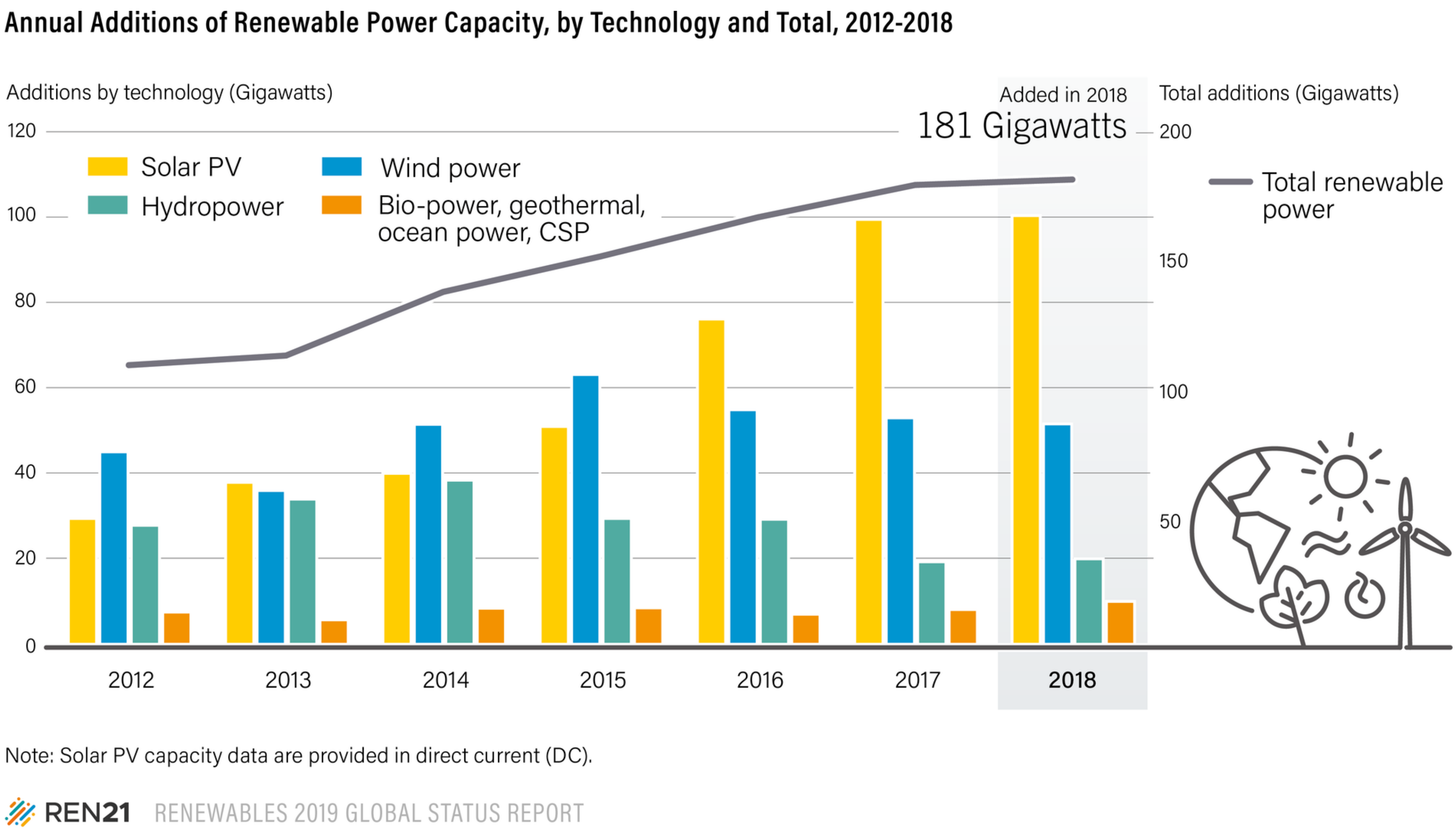
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

Global share of renewable energy



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

Global growth of renewable power



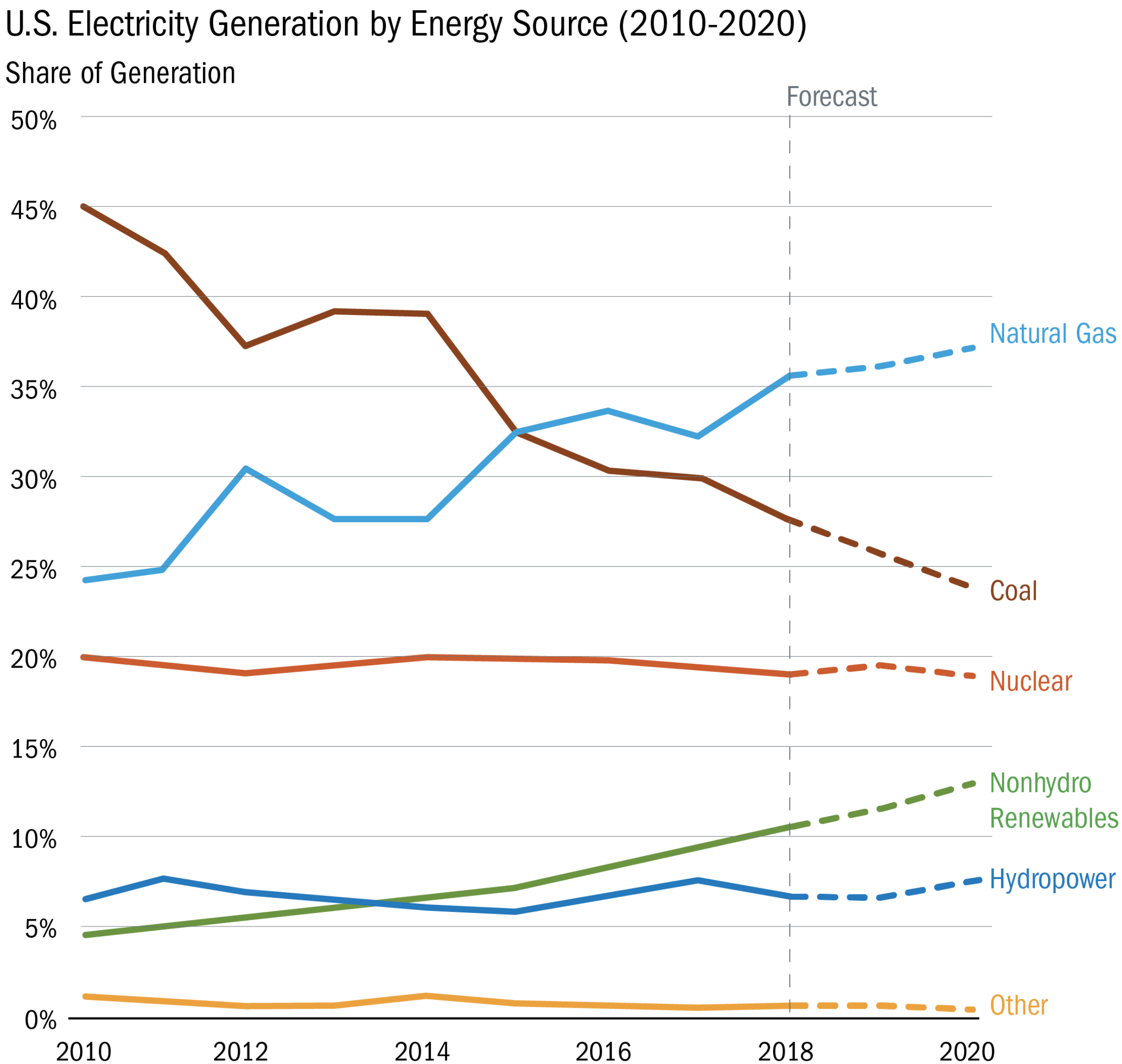
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

U.S. Electricity Trending to Gas and Renewables

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%.

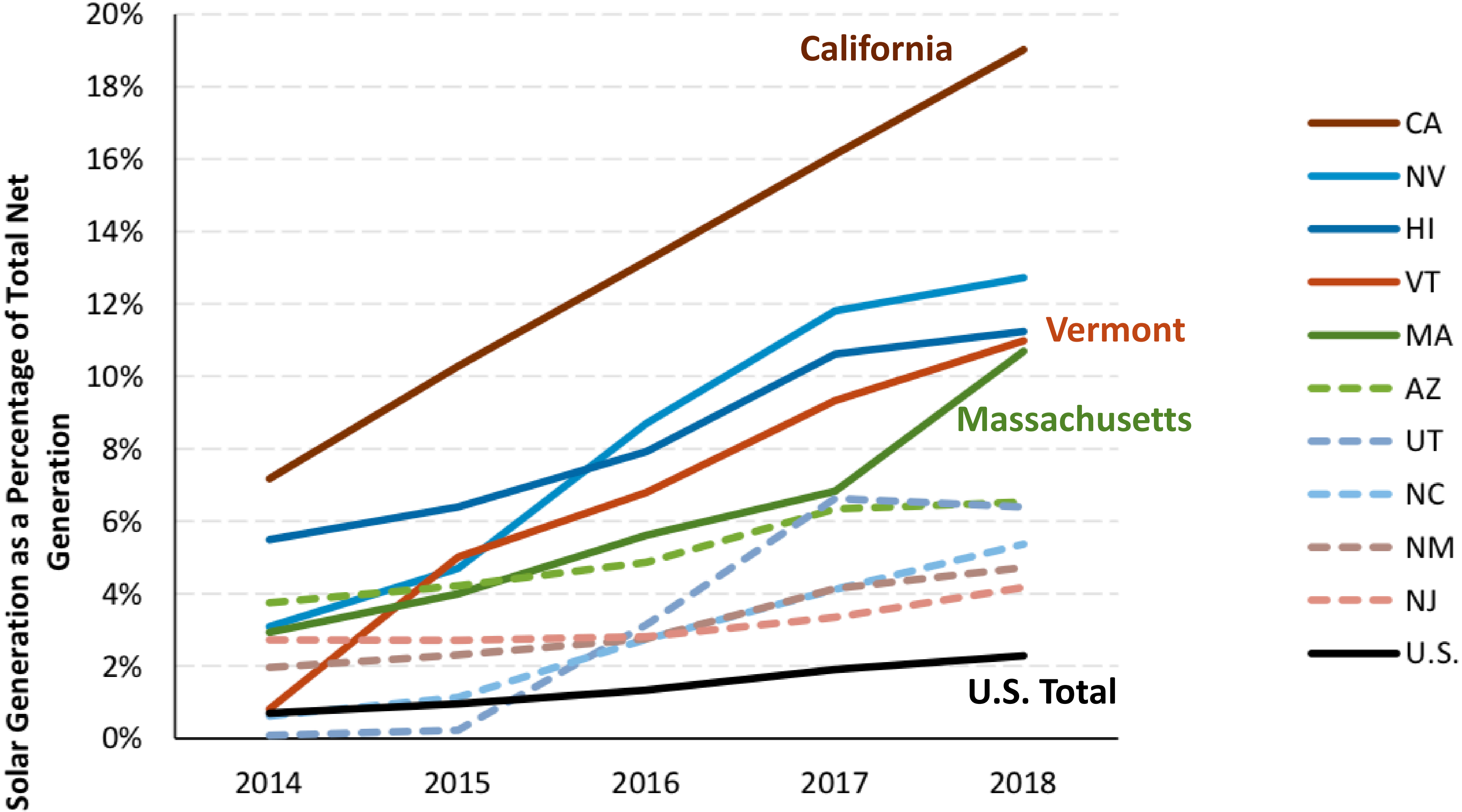
With hydropower, renewable energy is 17%.

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



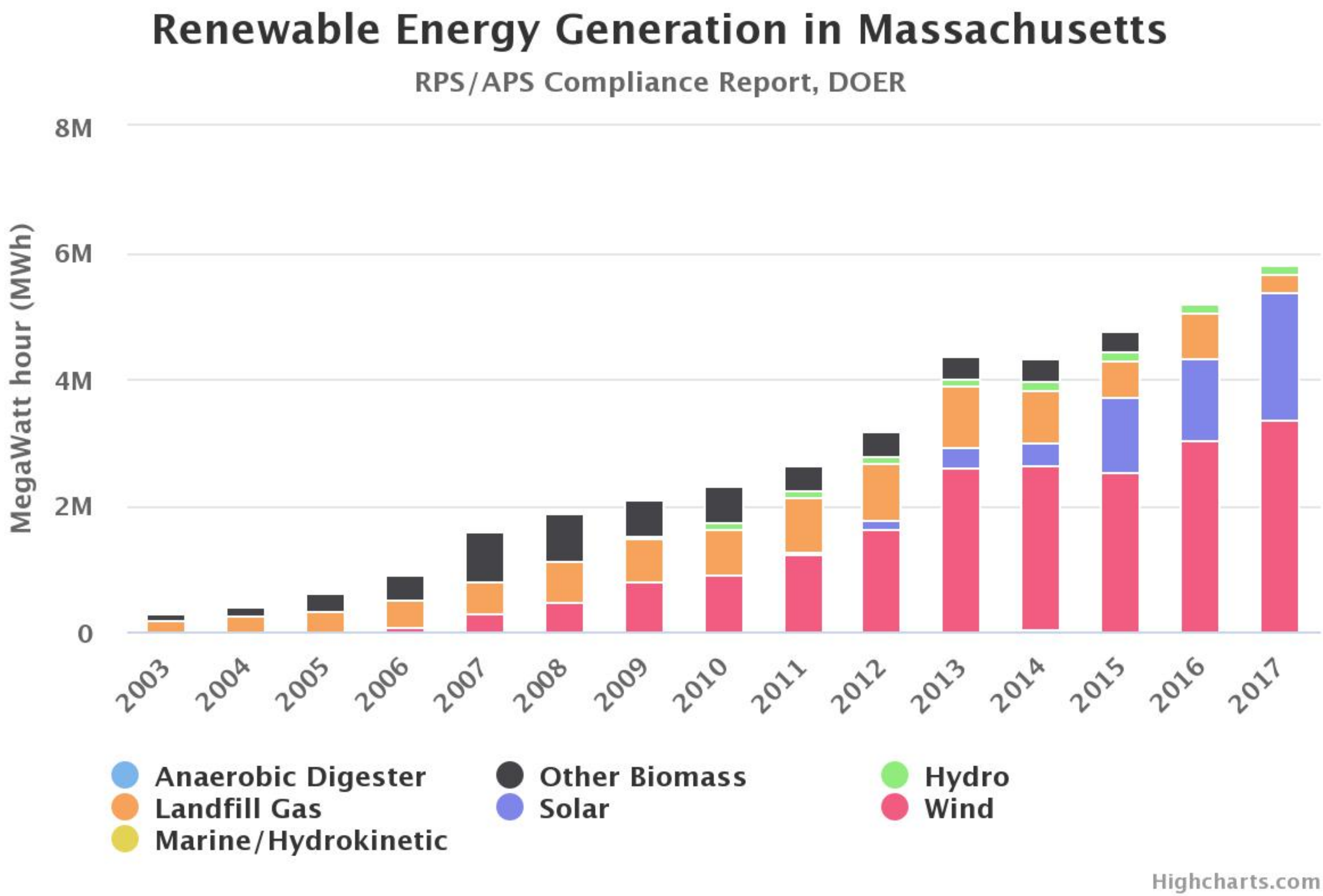
Source: United States Energy Information Agency, *Today in Energy,* 18 January 2019

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



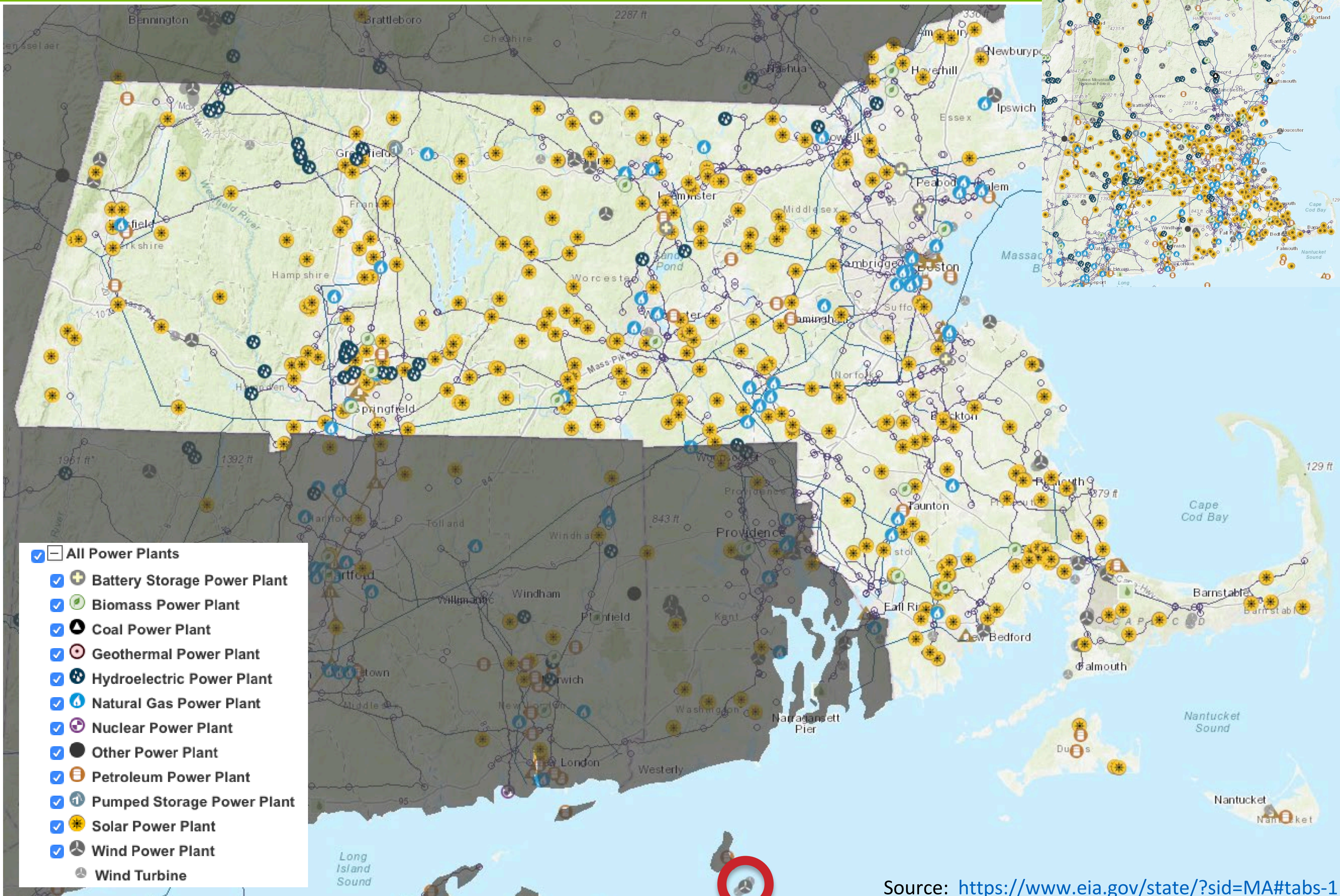
Source: NREL, Q4 2018/Q1 2019 Solar Industry Update, May 2019.

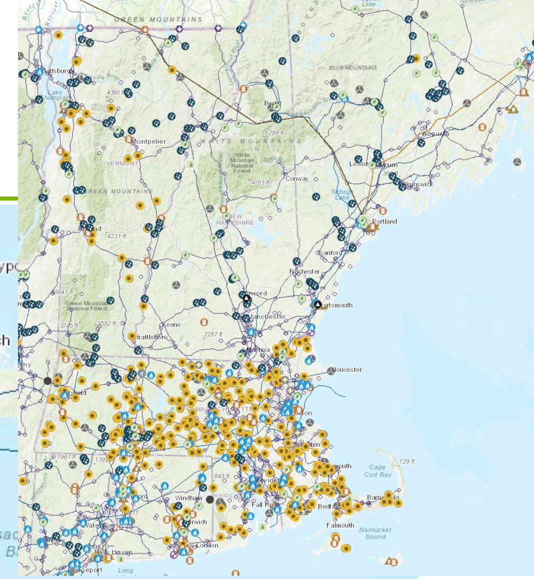
Massachusetts Renewable Energy is Growing



Source: https://www.mass.gov/info-details/renewable-energy-snapshot

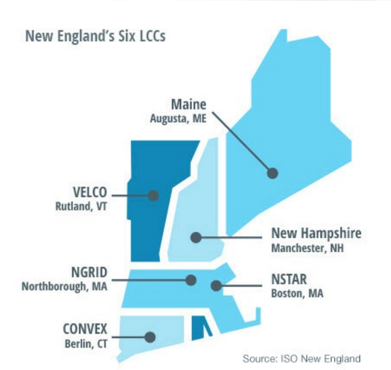
Massachusetts Energy System

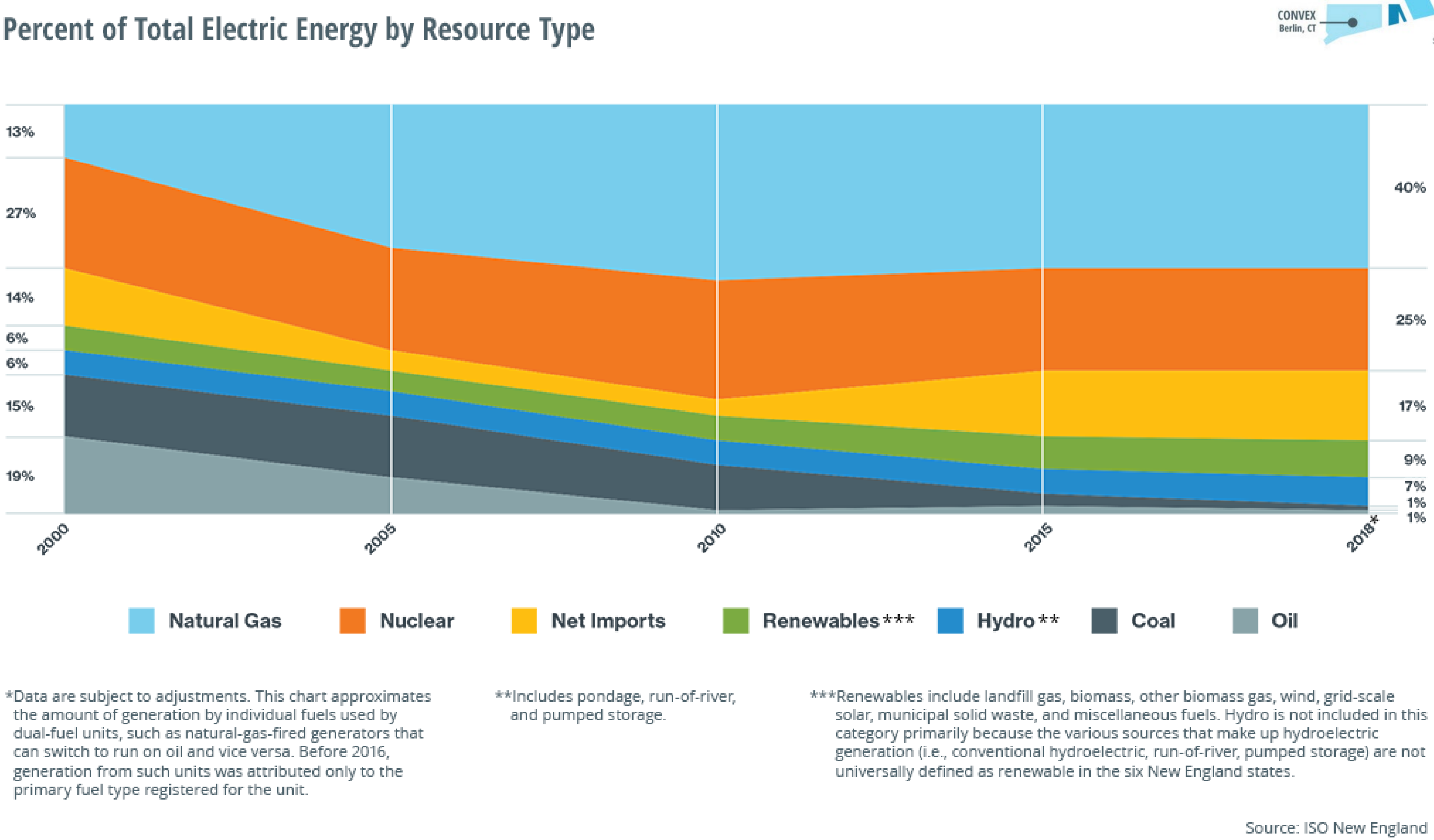




Source: https://www.eia.gov/state/?sid=MA#tabs-1

New England Electric Energy



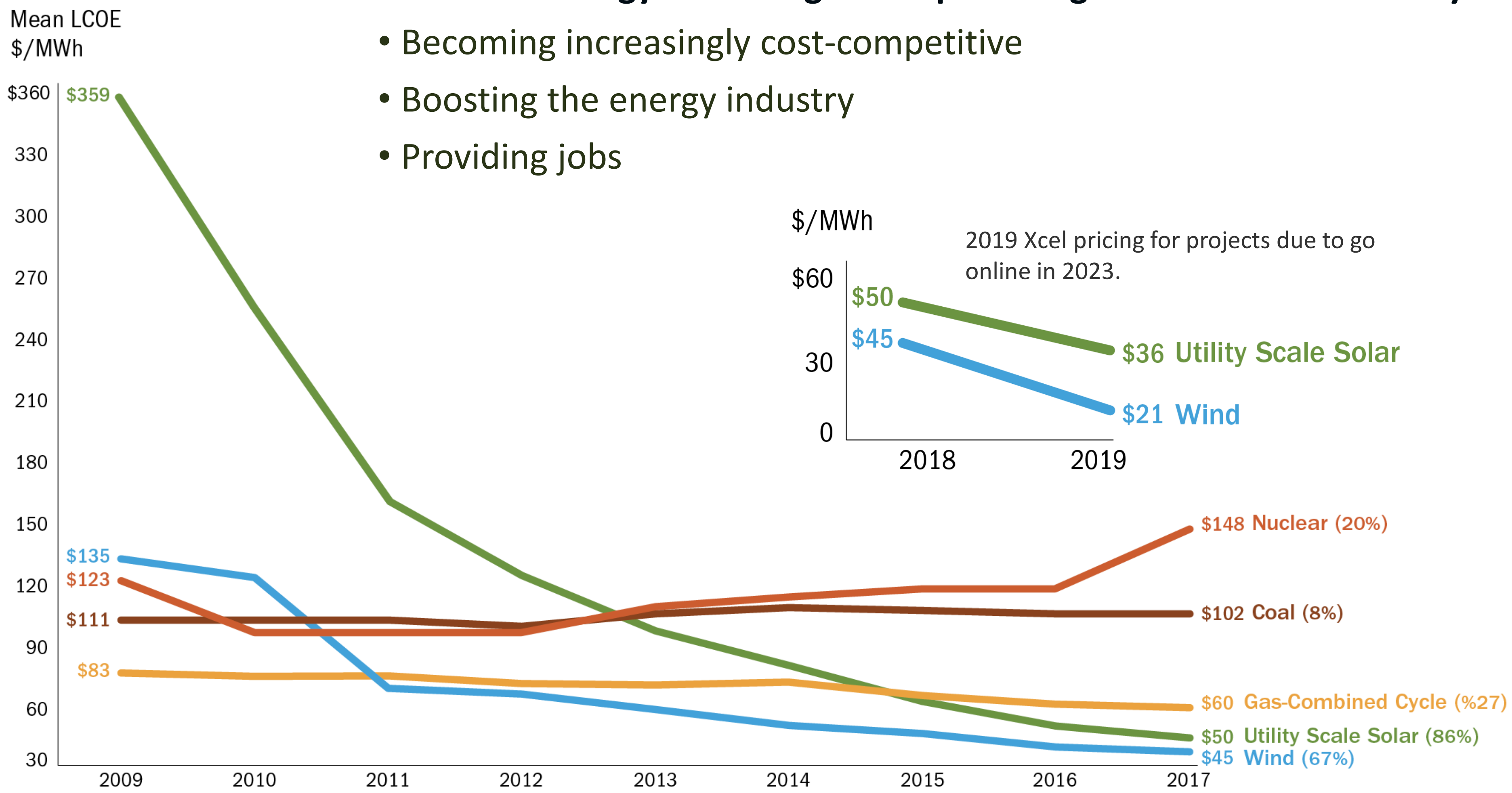


Source: Independent system Operator (ISO) New England, https://www.iso-ne.com/about/key-stats/resource-mix/

Costs for Renewables are Falling

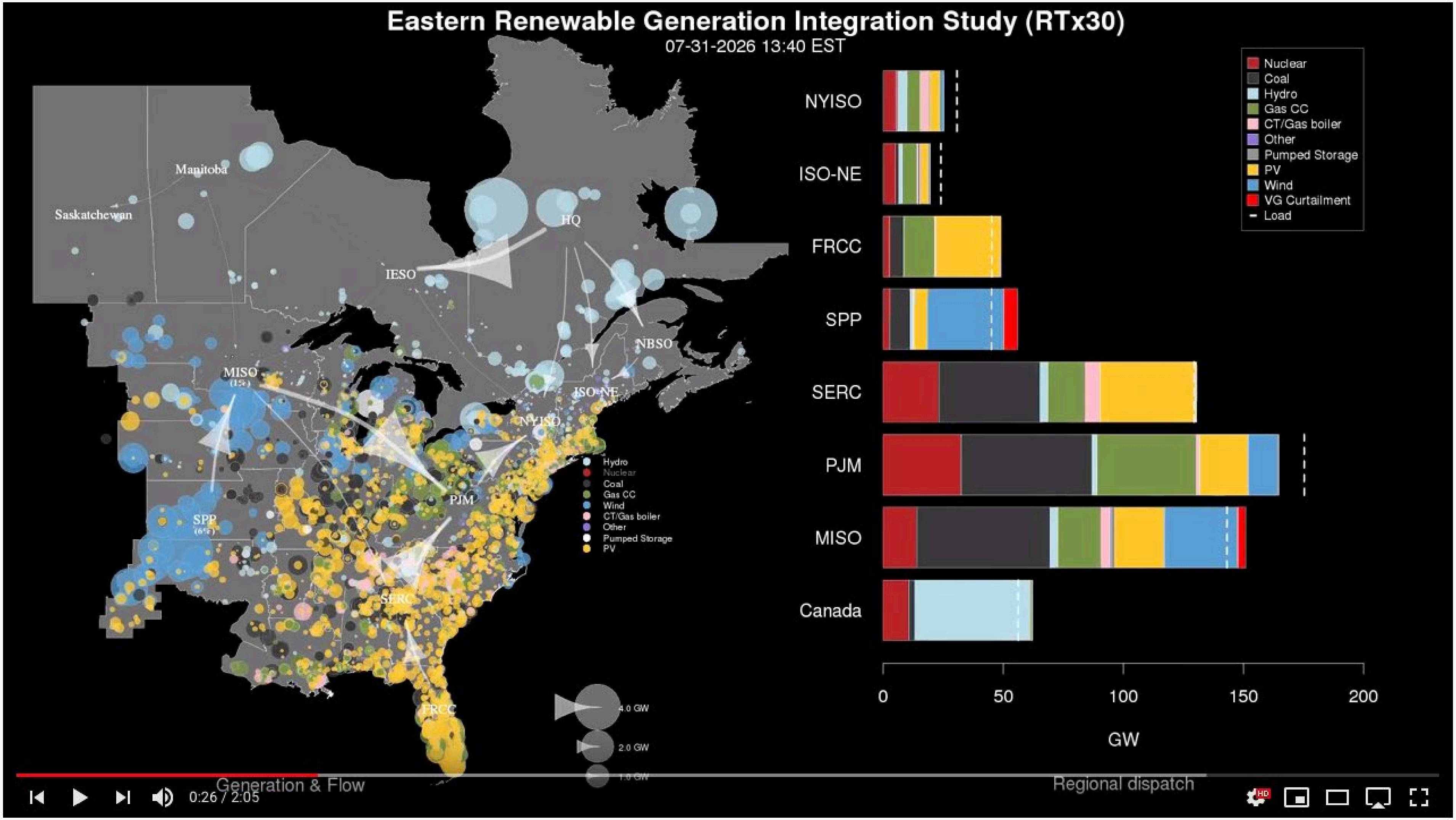
Advanced energy technologies are providing real-world solutions by:

- Becoming increasingly cost-competitive
- Boosting the energy industry
- Providing jobs



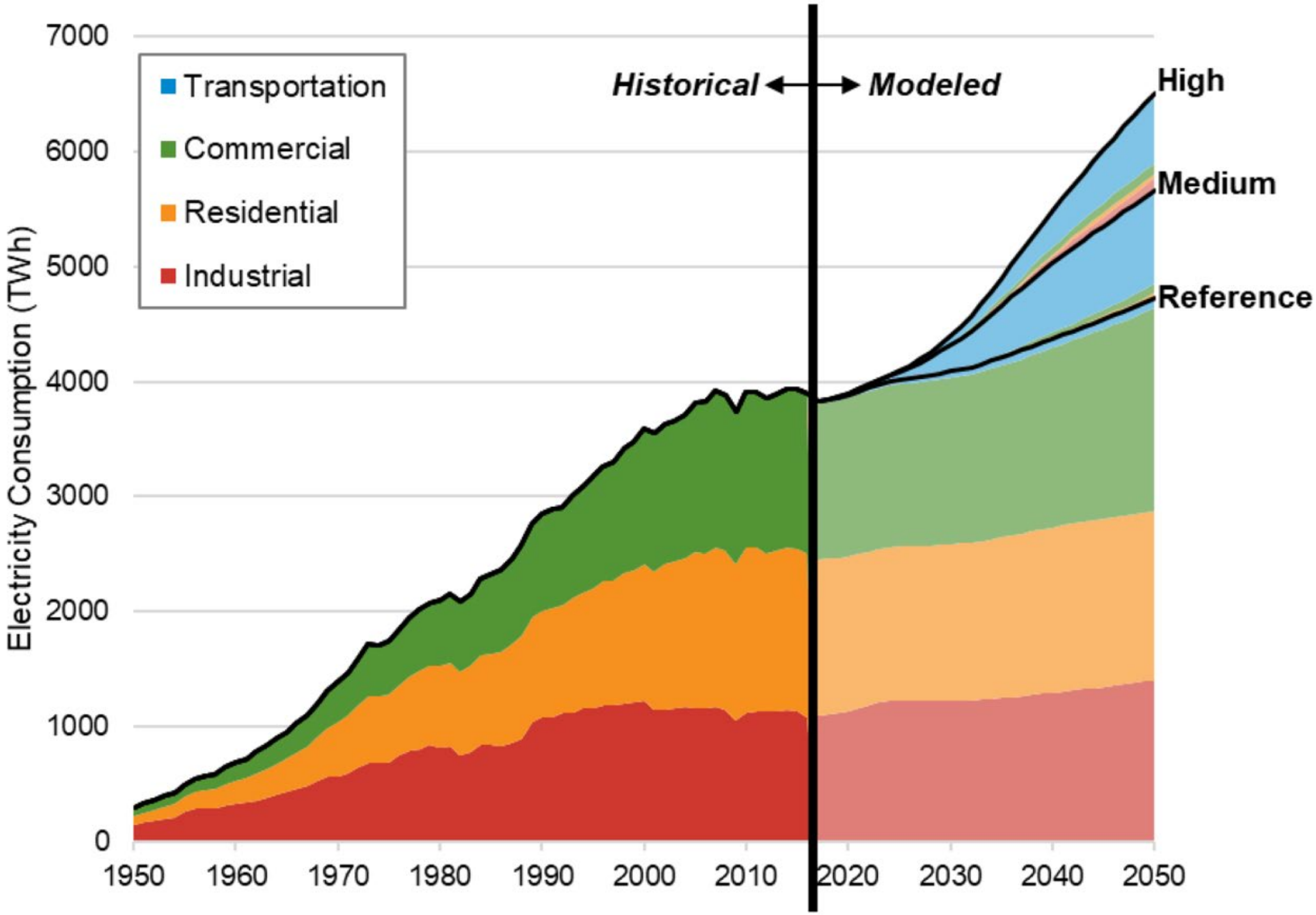
Source: *Lazard's 2017 Levelized Cost of Energy Analysis,* Version 11, 2 November 2017

Advanced grid integration studies



https://www.youtube.com/watch?v=li8jO-pKgvc&list=PLmIn8Hncs7bEl4P8z6-KCliwbYrwANv4p&index=19

Electrification Futures Study



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

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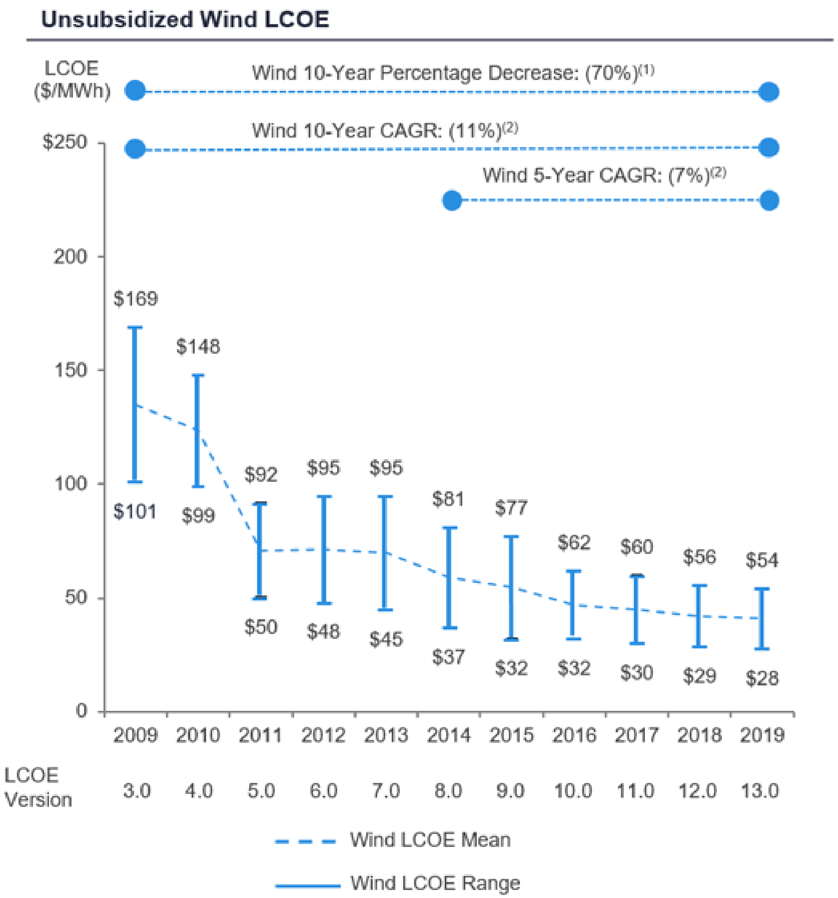
Wind Turbines – Onshore and Offshore

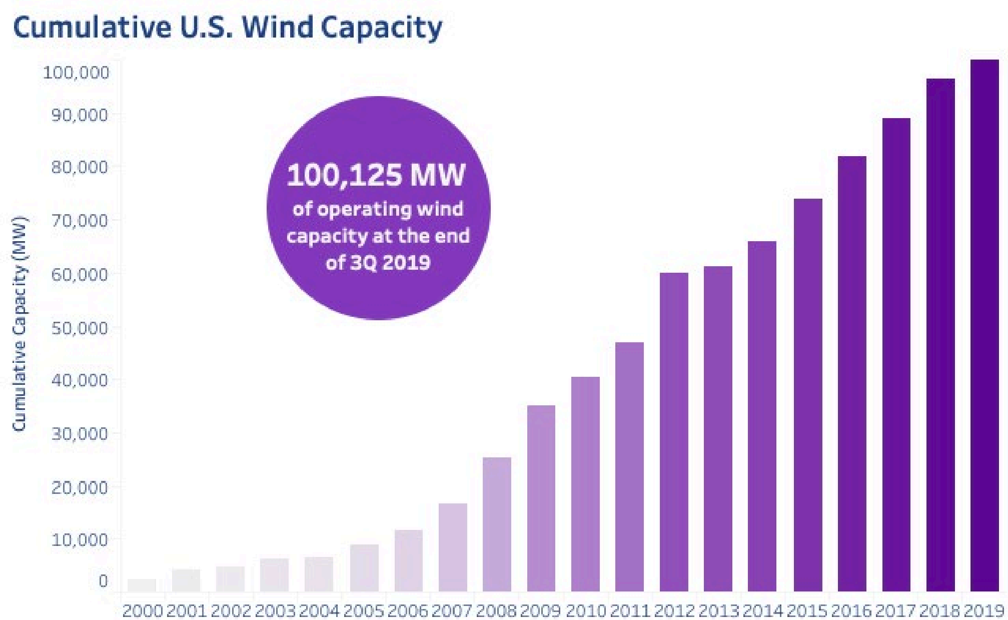
Block Island Wind Farm
- New Shoreham, Rhode Island
- 30 MW, 5 turbines
- 100 m hub height, 150 m diameter
- Opened 2016
- Capacity Factor 48% (projected)

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

Wind Market Growth Driven by Price Declines



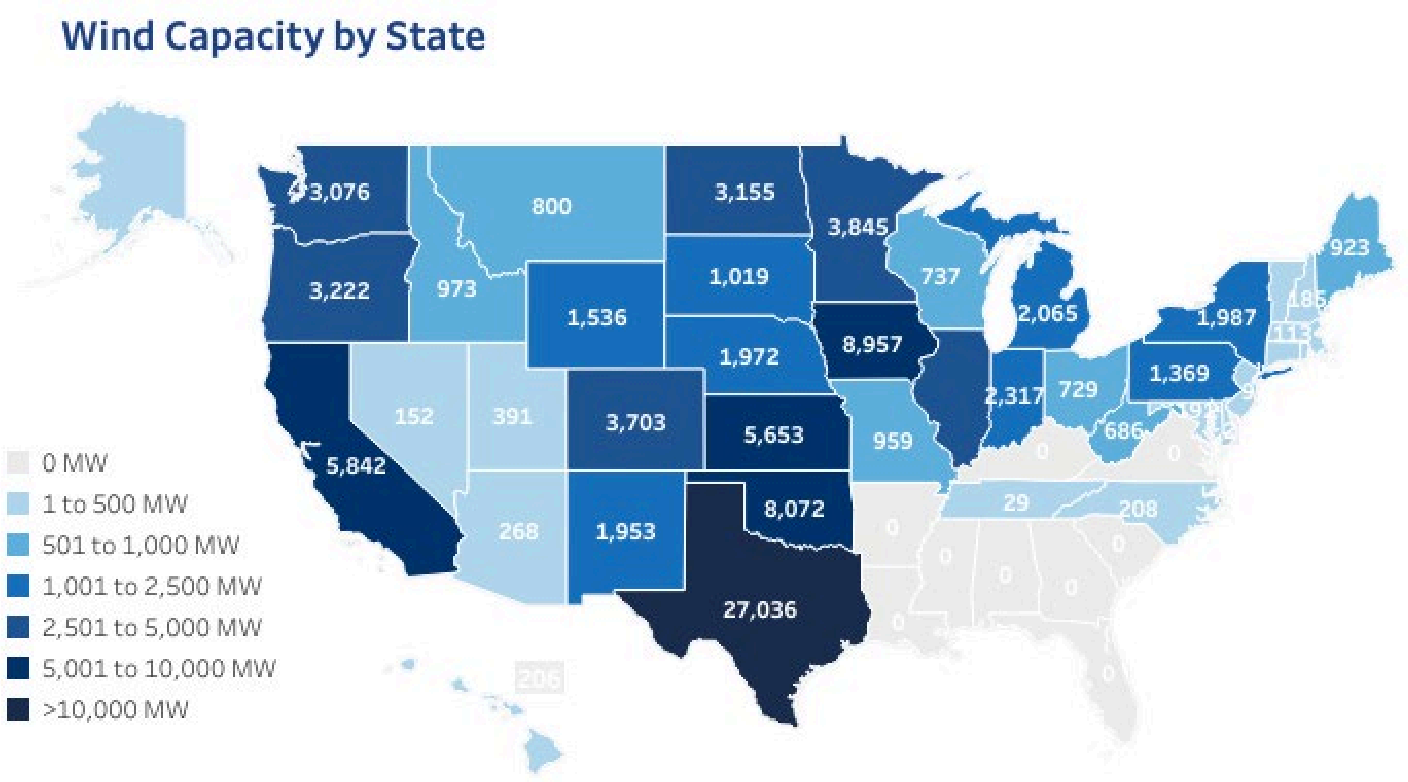
Source: Lazard estimates.
(1) Represents the average percentage decrease of the high end and low end of the LCOE range.
(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.



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

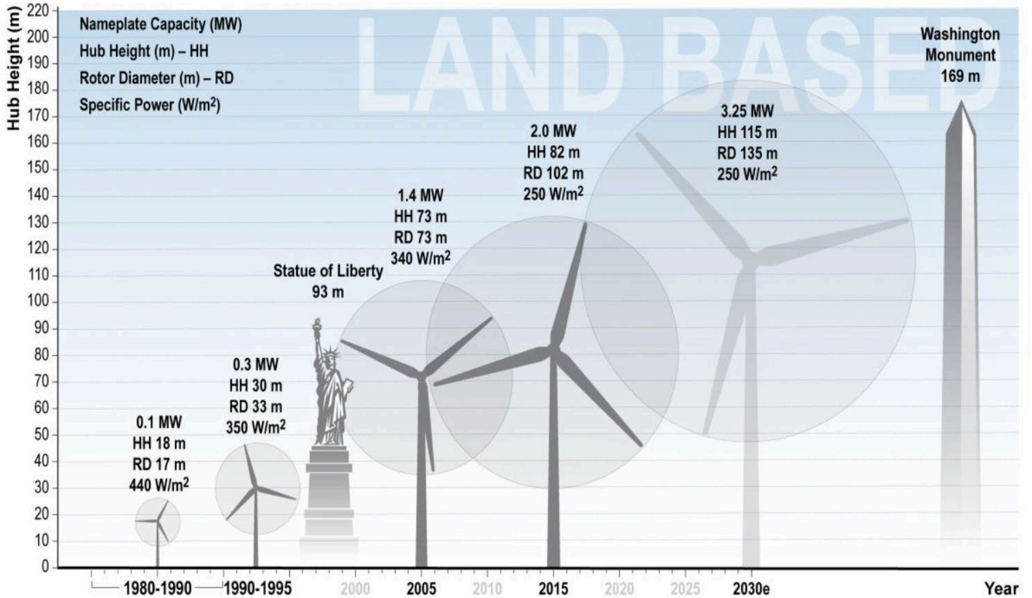
U.S. Wind Market (installed capacity, MW)

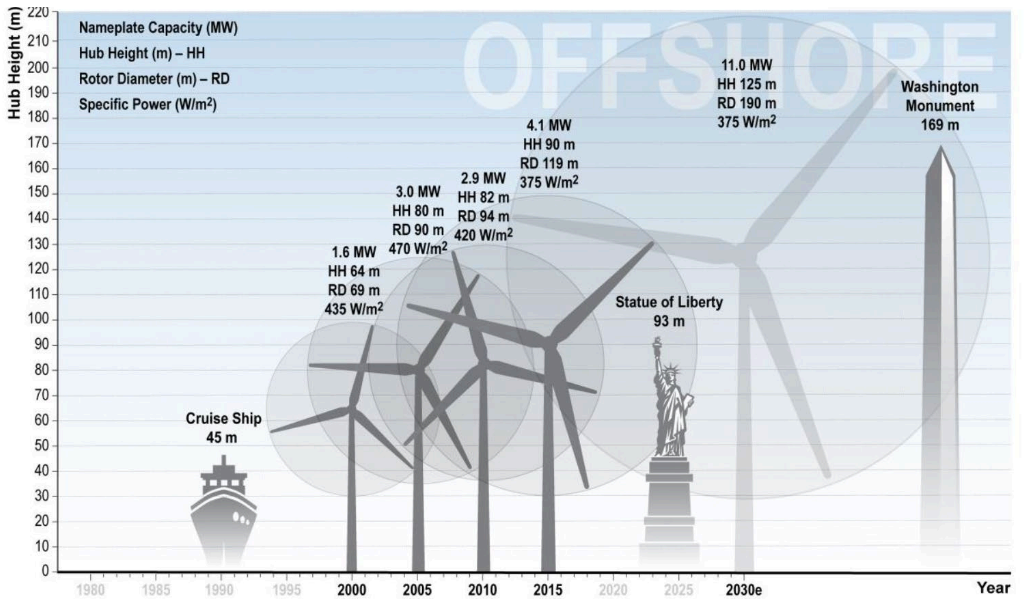
Wind capacity installed in Oklahoma, Iowa, and Kansas supplied 32%–36% of all in-state electricity generation in 2018. 14 states were greater than 10%.



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





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

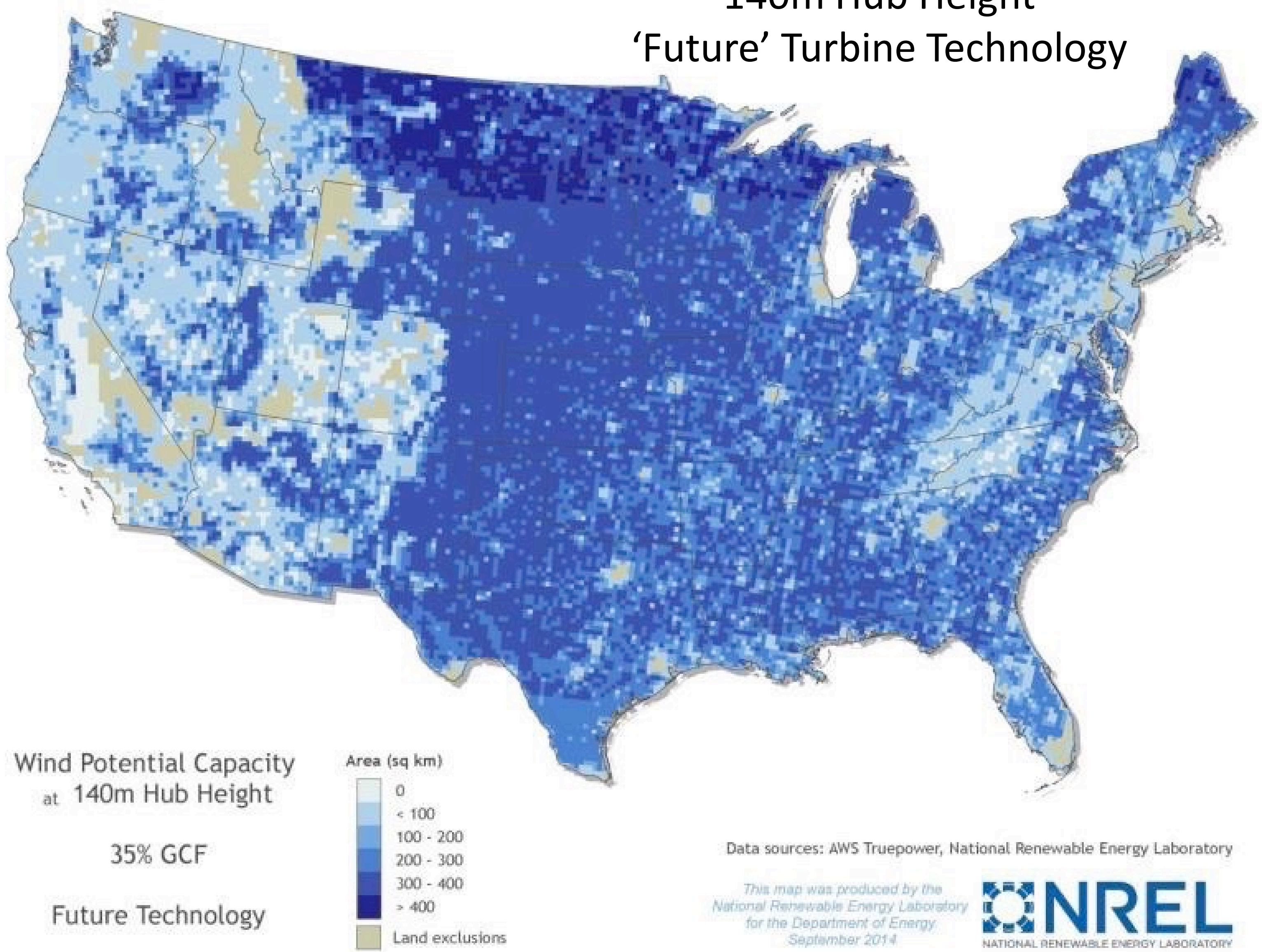
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

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 Increasing to More Places

140m Hub Height
'Future' Turbine Technology



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Energy Resilience Definition and Measures

The ability to anticipate, prepare for, and adapt to changing conditions

and

withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions

Adaptation measures used for energy resilience depend on the vulnerabilities and threats, but may include:

- Undergrounding critical lines
- Demand-side energy efficiency
- Diversifying generation
- Deploying distributed generation: PV, small wind, energy storage
- Deploying smart grids and micro-grids

Resilience Assessment



Potential Impacts

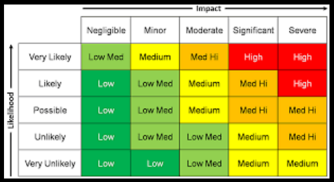
+



Probability of Occurrence

Risk Assessment Matrix:

Impact x Probability



Impact →

Likelihood	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Ranking of Threats and Vulnerabilities

High, Medium, Low

Evaluation criterion	Score Description: Good	Fair
Effectiveness	The action would completely or nearly completely reduce the vulnerability's risk.	[illegible]
Feasibility	The action could be implemented technically and	[illegible]

Resilience Options Evaluation:

Cost, effectiveness, feasibility

Resilience and Adaptation Strategies

https://www.nrel.gov/resilience-planning-roadmap/

Adaptation for PV Energy Systems

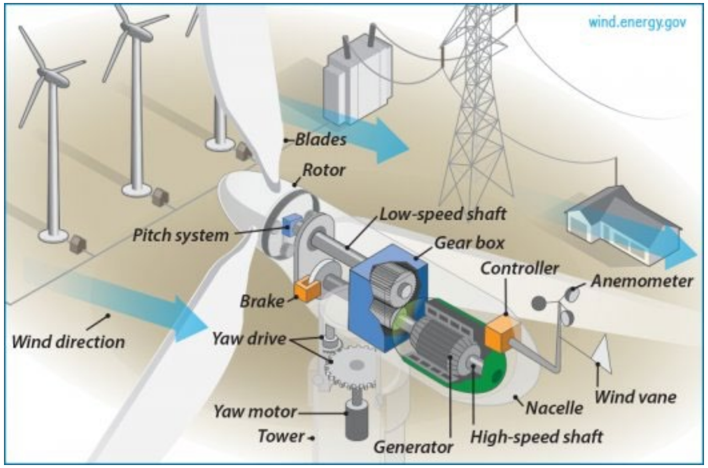
- Systems should be designed to be more resilient to hazards
  - Should include site-specific or hazard-based design, energy storage and islanding controls, site-specific storm preparation plans to further minimize damage
  - Codes and standards for technology design and deployment, such as hail, wind, temperature
- Sites should be evaluated for readiness for major storms
  - Ensure siting outside of known hazard zones where possible
  - Ensure ground mount arrays have appropriate civil engineering including soils analysis and drainage
  - Where possible, perimeter fences may be used to reduce wind loading on arrays
- Systems should be designed to withstand local hazards
  - Ensure that panel mounting equipment is rated for expected wind loads
  - Use through-bolting where possible rather than clamp-style mounting
  - Use fixed-tilt arrays (rather than tracking) to minimize failure due to torsional forces on rotating torque tubes
- Systems and grid integration should enable independent operations
  - Modeling to meet challenges with grid integration of variable resources
  - Legal framework and safety for islanding of systems for localized microgrid-based power
  - Workforce training to manage microgrids

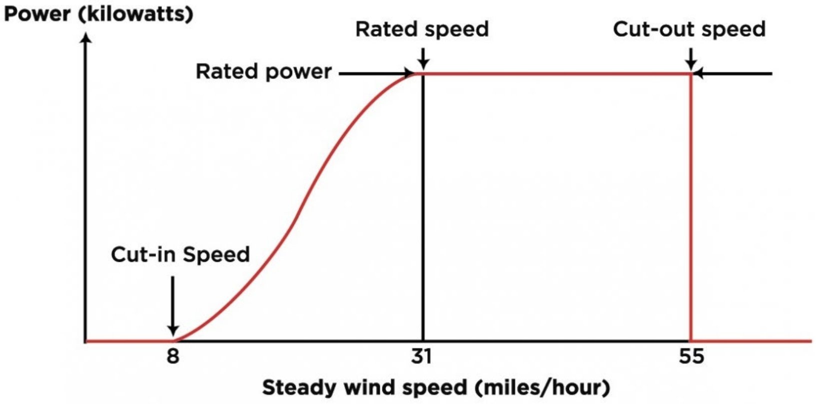
Two PV systems in Puerto Rico post-hurricane Maria that survived (top) and were damaged (bottom)

Source: https://www.nrel.gov/state-local-tribal/blog/posts/how-is-solar-pv-performing-in-hurricane-struck-locations.html

Adaptation of Wind Turbines for Bigger Storms

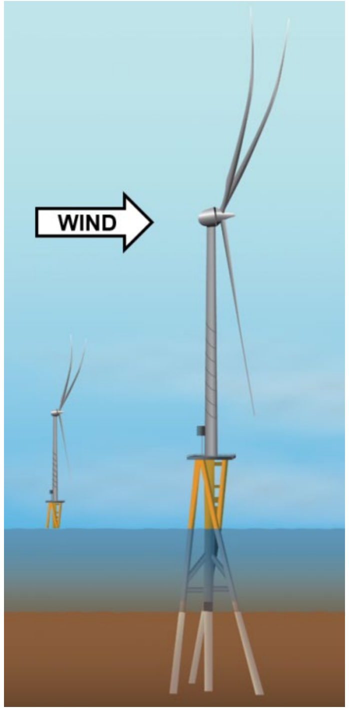
Current wind turbines face up-wind and use feathering or full shut down in high winds





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

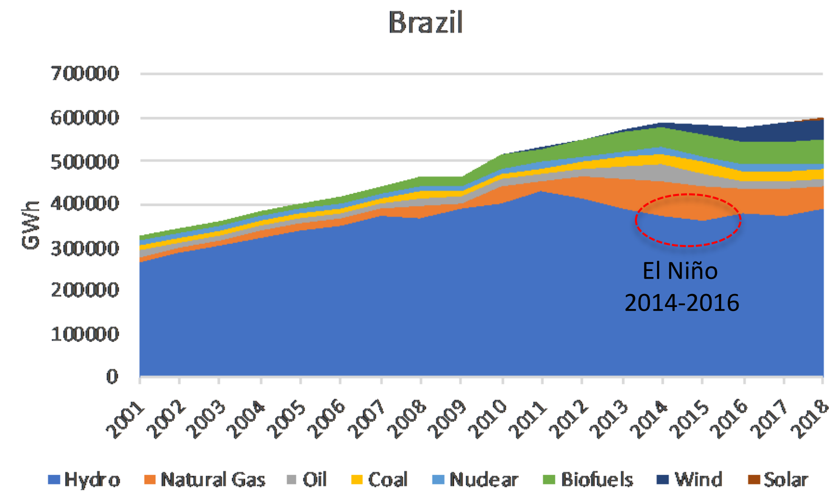


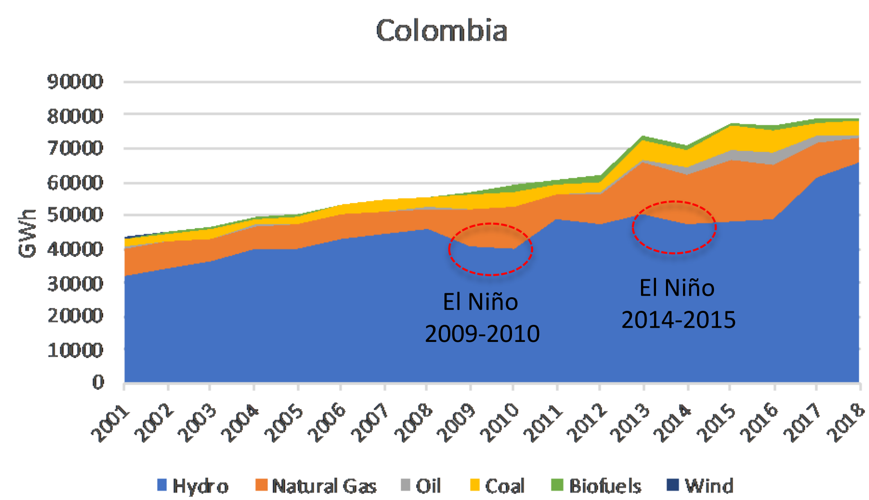
Source: https://www.energy.gov/eere/articles/wind-turbines-extreme-weather-solutions-hurricane-resiliency; https://www.colorado.edu/ecee/2016/02/17/paos-morphing-wind-turbine-inspired-nature

Adaptation of hydropower to changing hydrological phases

- 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

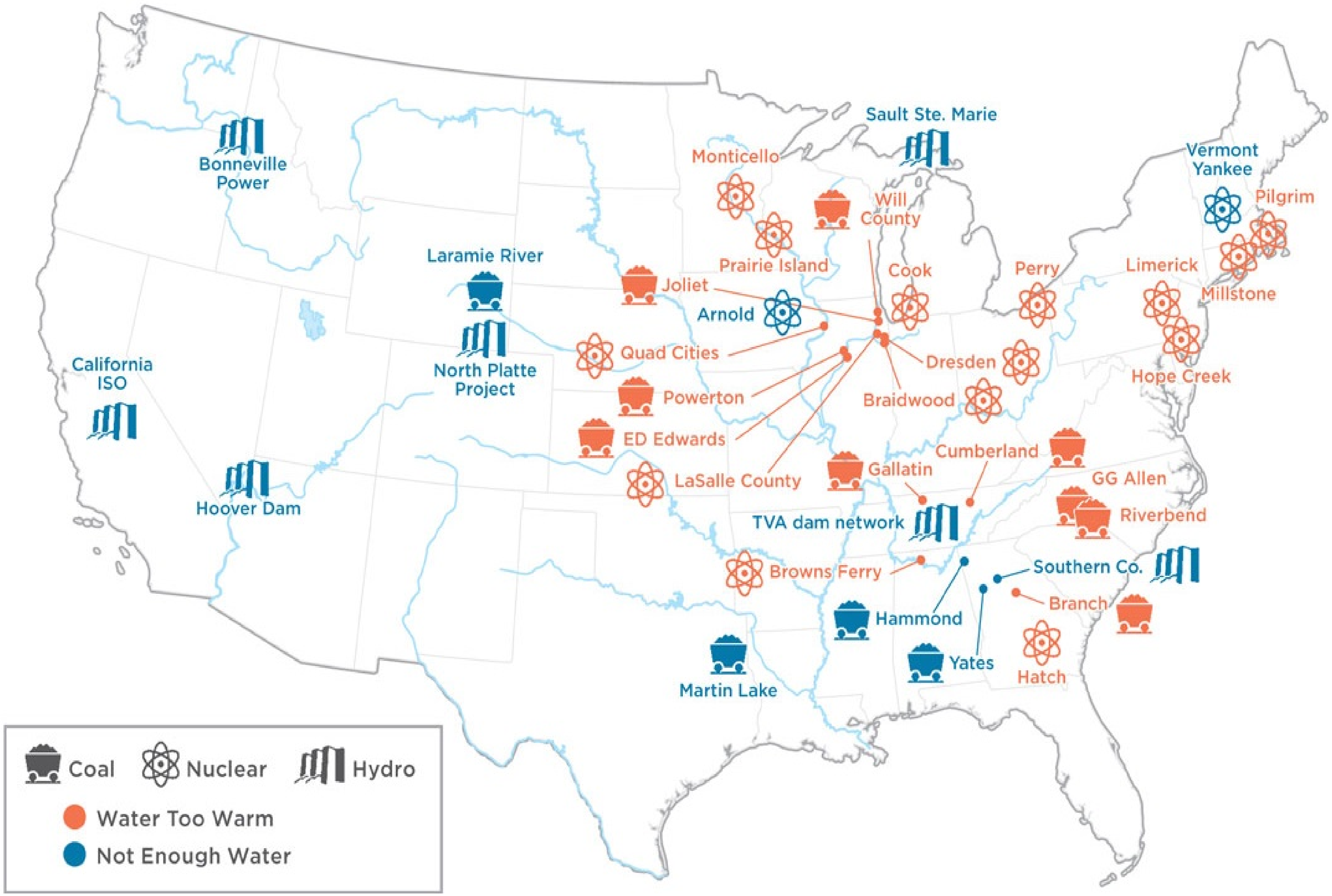
Evolving generation mixes in Brazil and Colombia





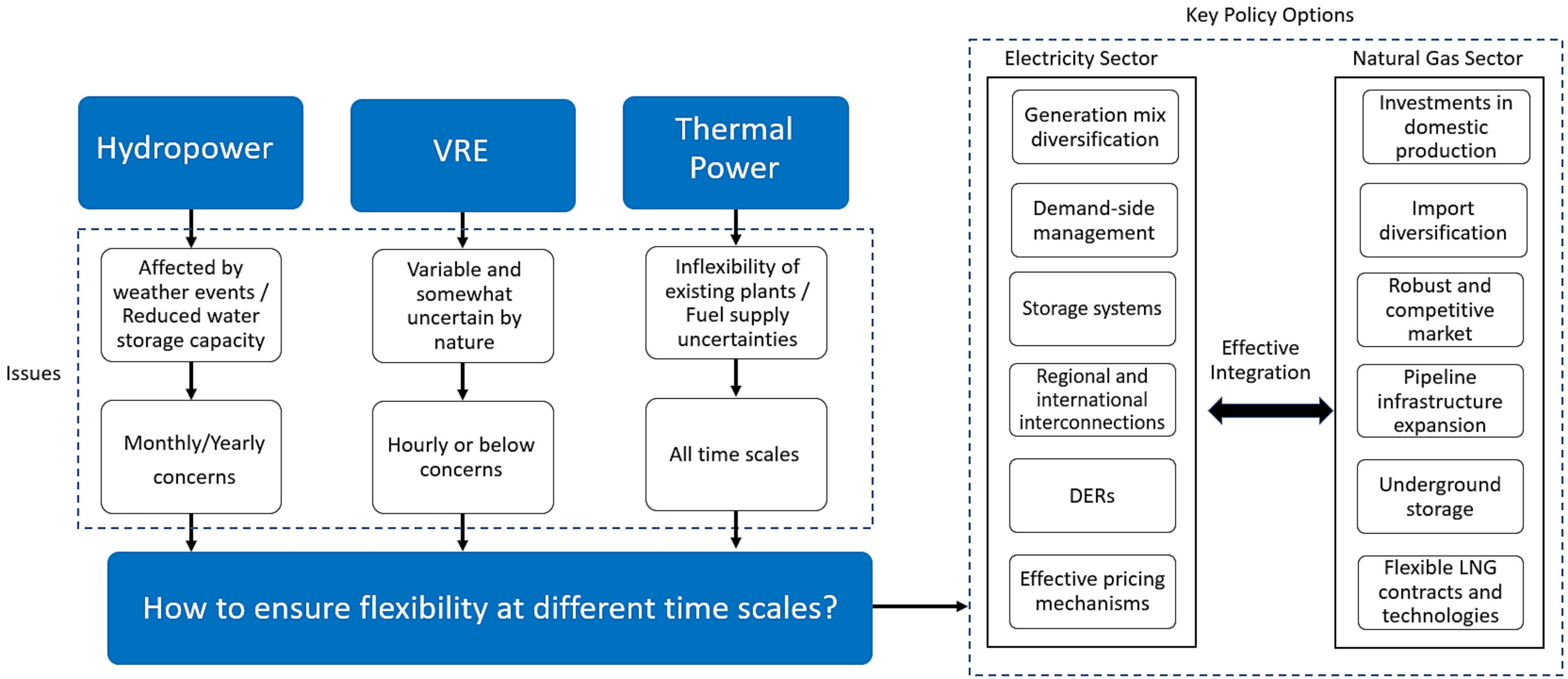
Source: JISEA, https://www.nrel.gov/docs/fy20osti/75467.pdf

Power Plants Shut Down or Curtailed Generation due to Water Temperature or Availability (2006-2013)



Source: Union of Concerned Scientists, 2014

Adaptation and Resiliency Options of Electricity Production



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

Electricity-Natural Gas Interface

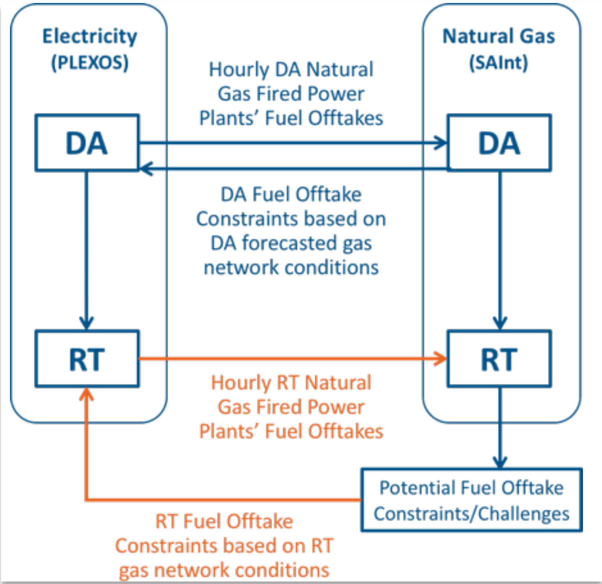
Electricity & **Gas** networks are **interconnected** energy infrastructures whose operation and reliability depend on one another. As the percent of gas and variable renewable power plants increase, the connection between these networks becomes increasingly important.

Goal of project is to:

Co-simulate power and natural gas network operations.

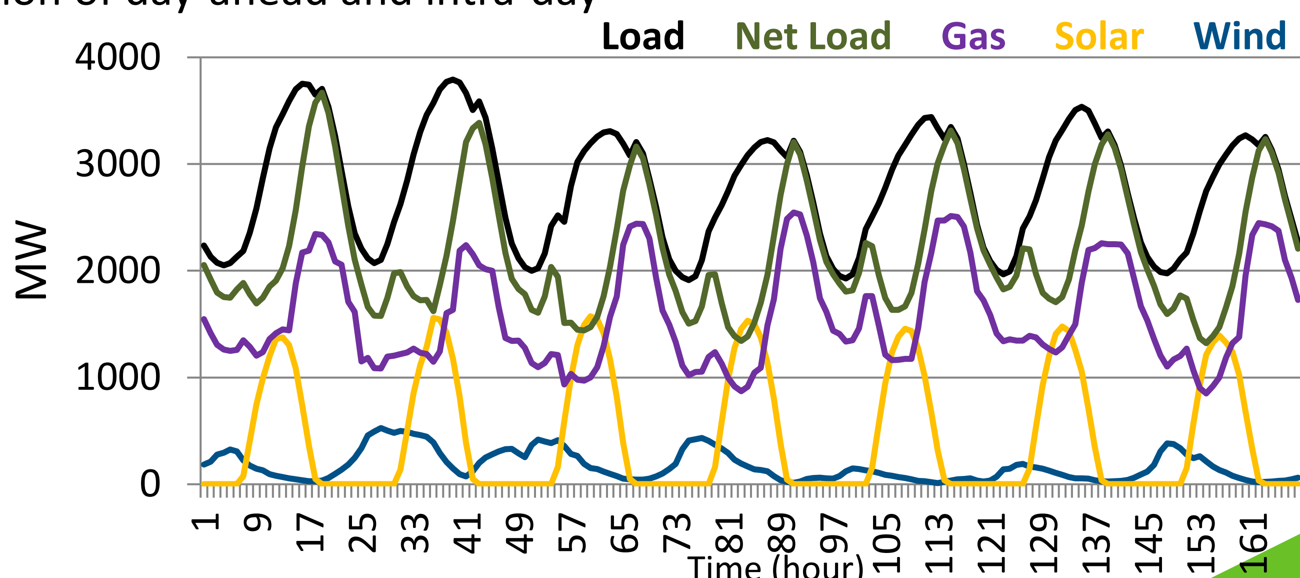
Model the Colorado interconnected power and natural gas networks and a test system with different renewable penetrations.

Determine value of coordination of day-ahead and intra-day operations.



Funded through JISEA sponsorship by:

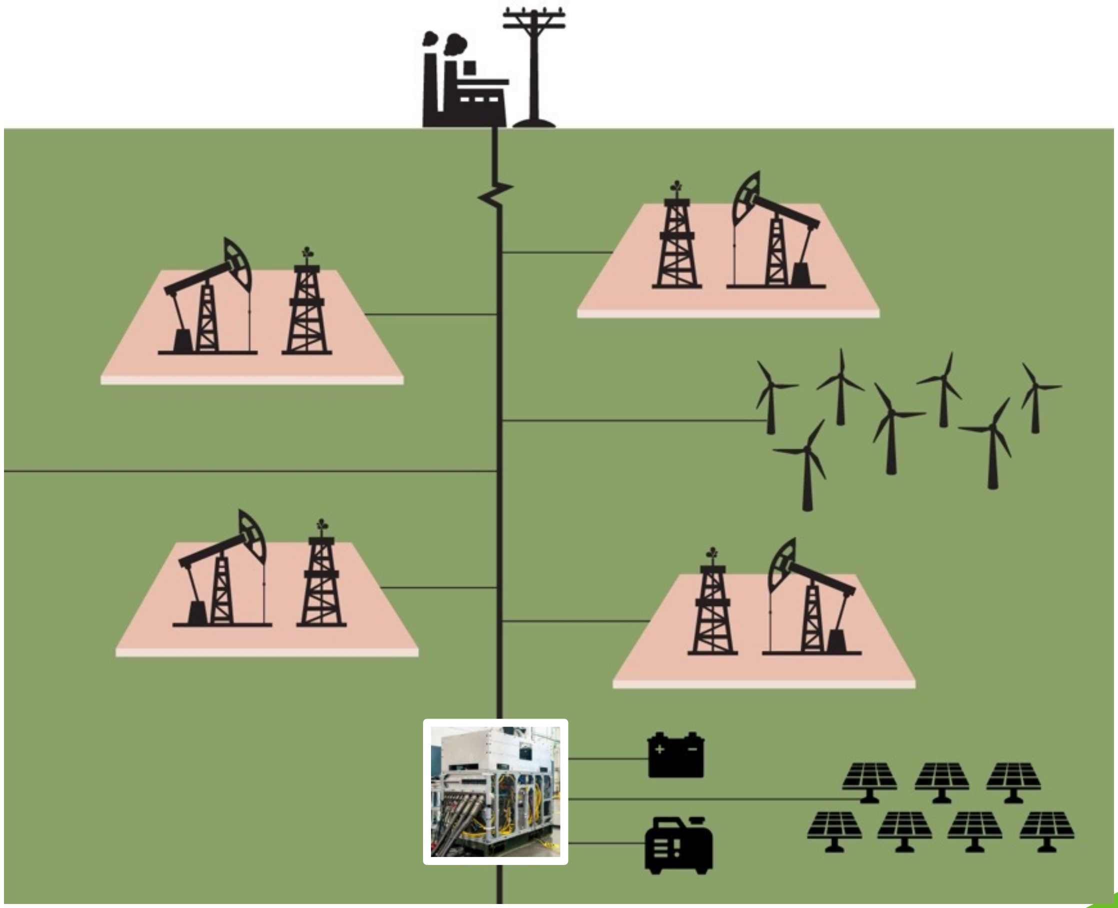
- American Electric Power
- Environmental Defense Fund
- Hewlett Foundation
- Kinder Morgan
- American Gas Association
- Midcontinent Independent System Operator



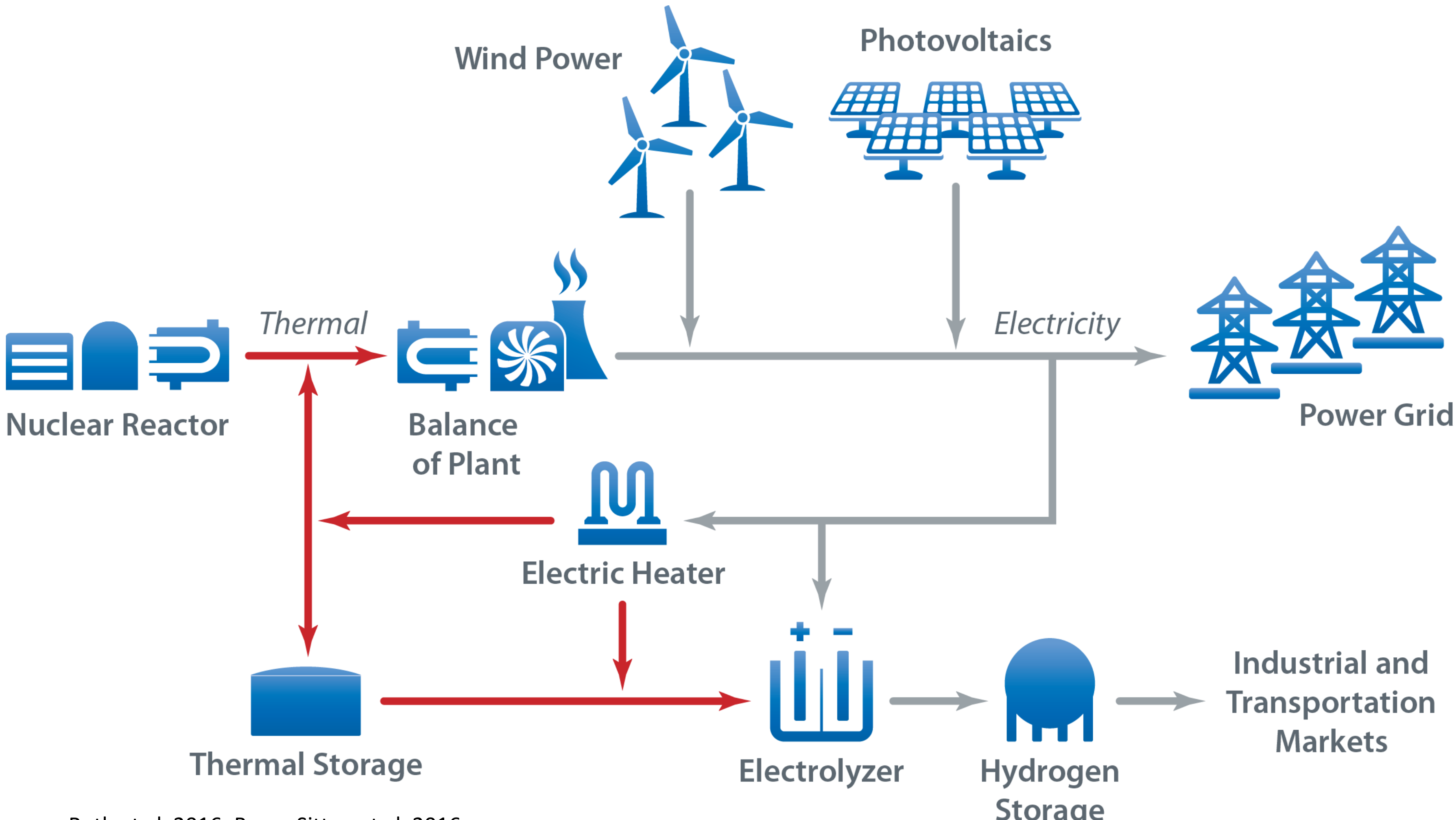
Source: JISEA project in progress.

Clean Power Technologies for Oil & Gas Industry Operations: Electrification of 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



Renewable Hybrid Energy Solutions

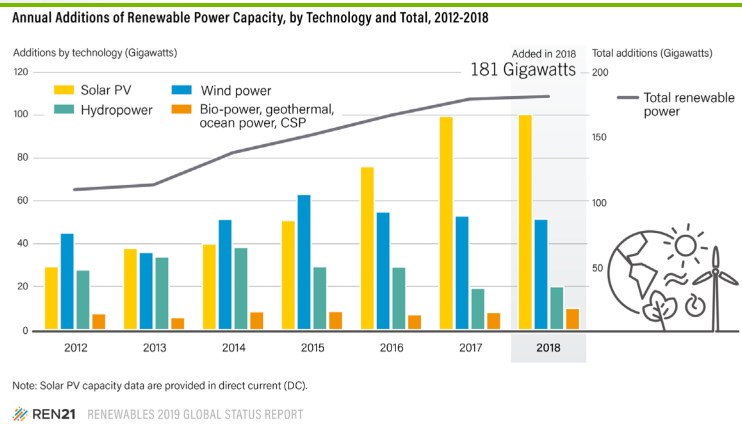


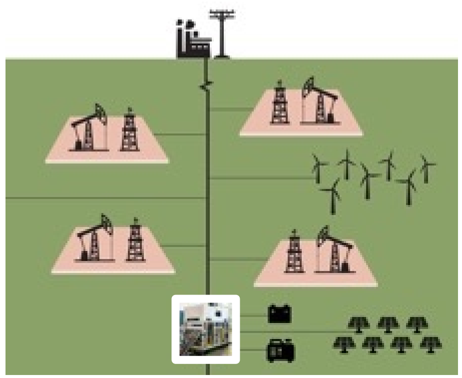
Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

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 a resilience buffer against extreme heat and addresses competing land use demands**

Conclusions and Discussion





- Trend toward cleaner and lower cost energy that is more highly distributed
- Potentially increased electrification resulting in higher demand for power
- Renewable energy can help power, industrial, and agricultural systems reduce emissions, and operate more resiliently, but needs research
- Renewable energy technologies need to adapt to larger storms, changing temperatures, and greater variability of conditions
- Need improved standards, models, policies, and technologies to enable systems to adapt




Questions and Discussion

Thank you!

NREL/PR-6A50-75738

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