JISEA Joint Institute for Strategic Energy Analysis

Renewable Energy Technologies for the Energy Transition

Energy and the Economy Conference

Federal Reserve Bank of Kansas City

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National Renewable Energy Laboratory

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

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:

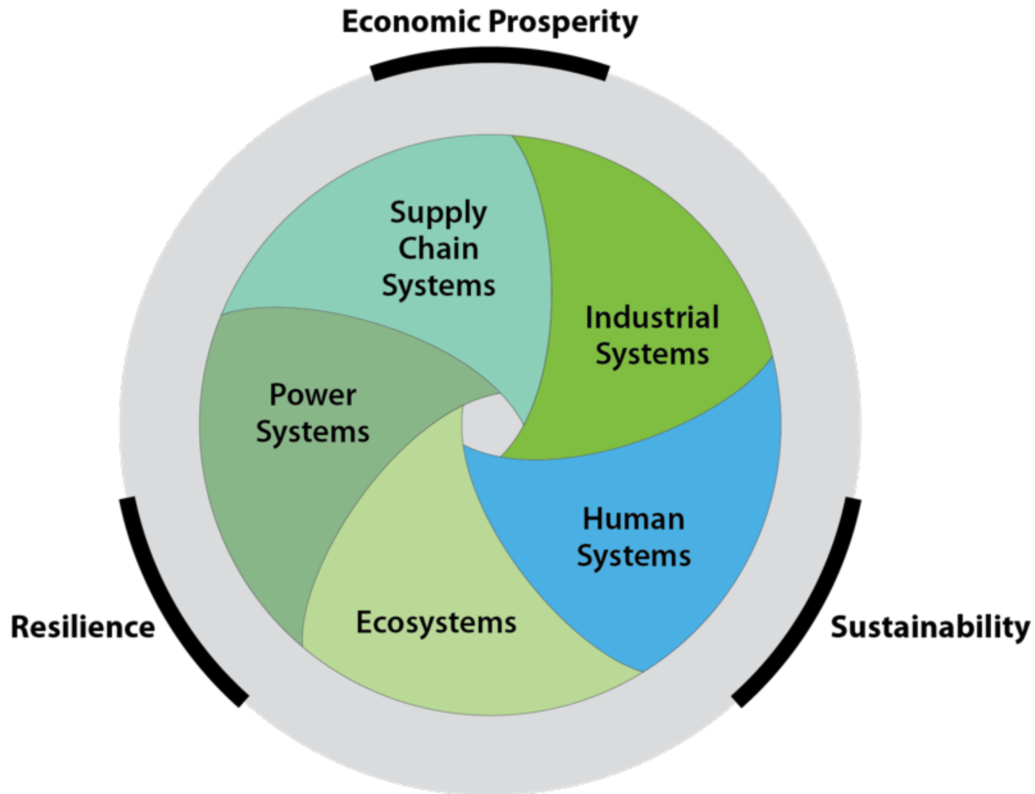
- 2050 employees, plus 400 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

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.



Founding Members

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

Outline

- Energy Technology Trends
  - Example: Wind Turbines
- Renewable Energy Intersections

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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

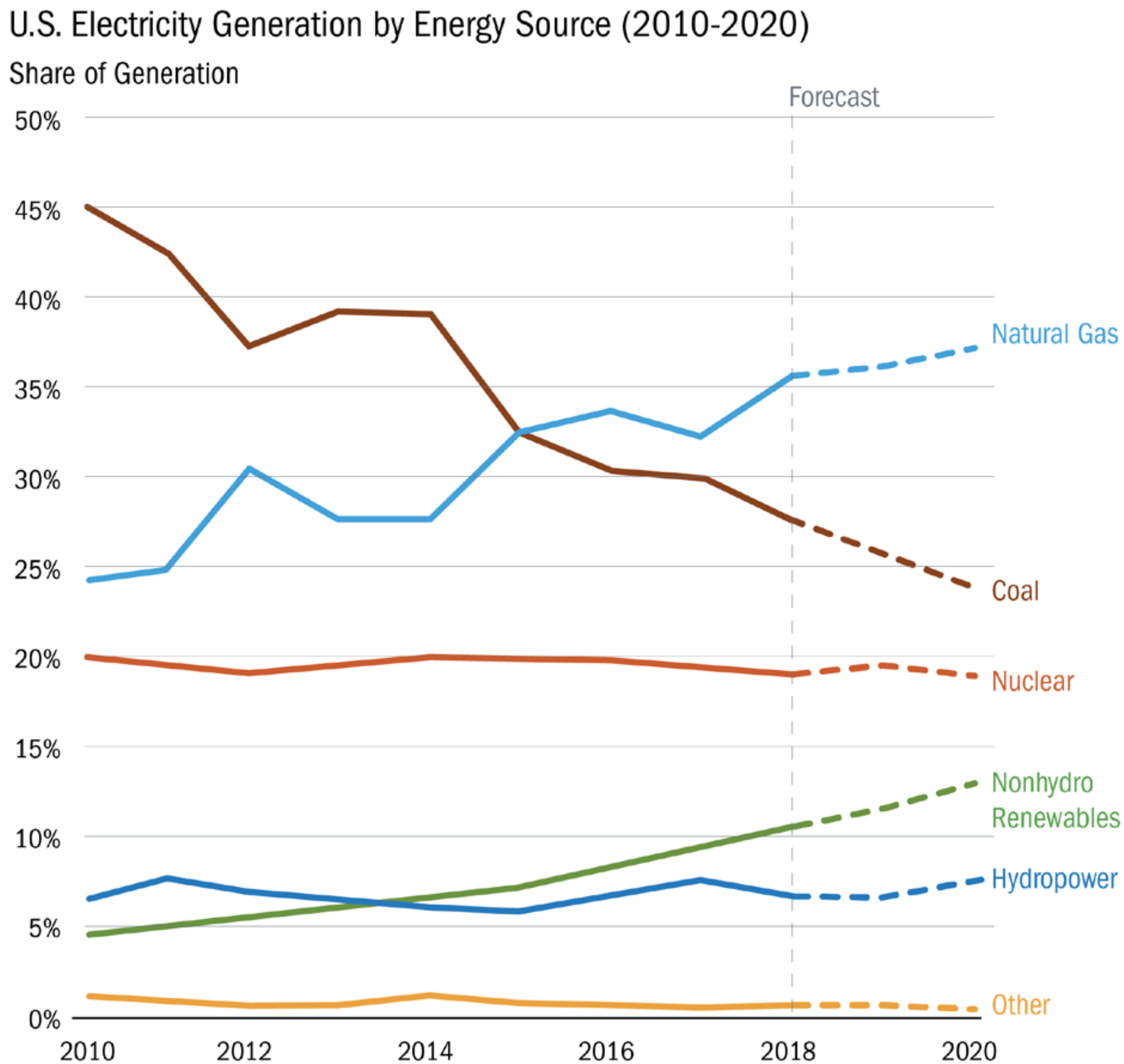
EFFICIENCY & HEAT USE

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%.

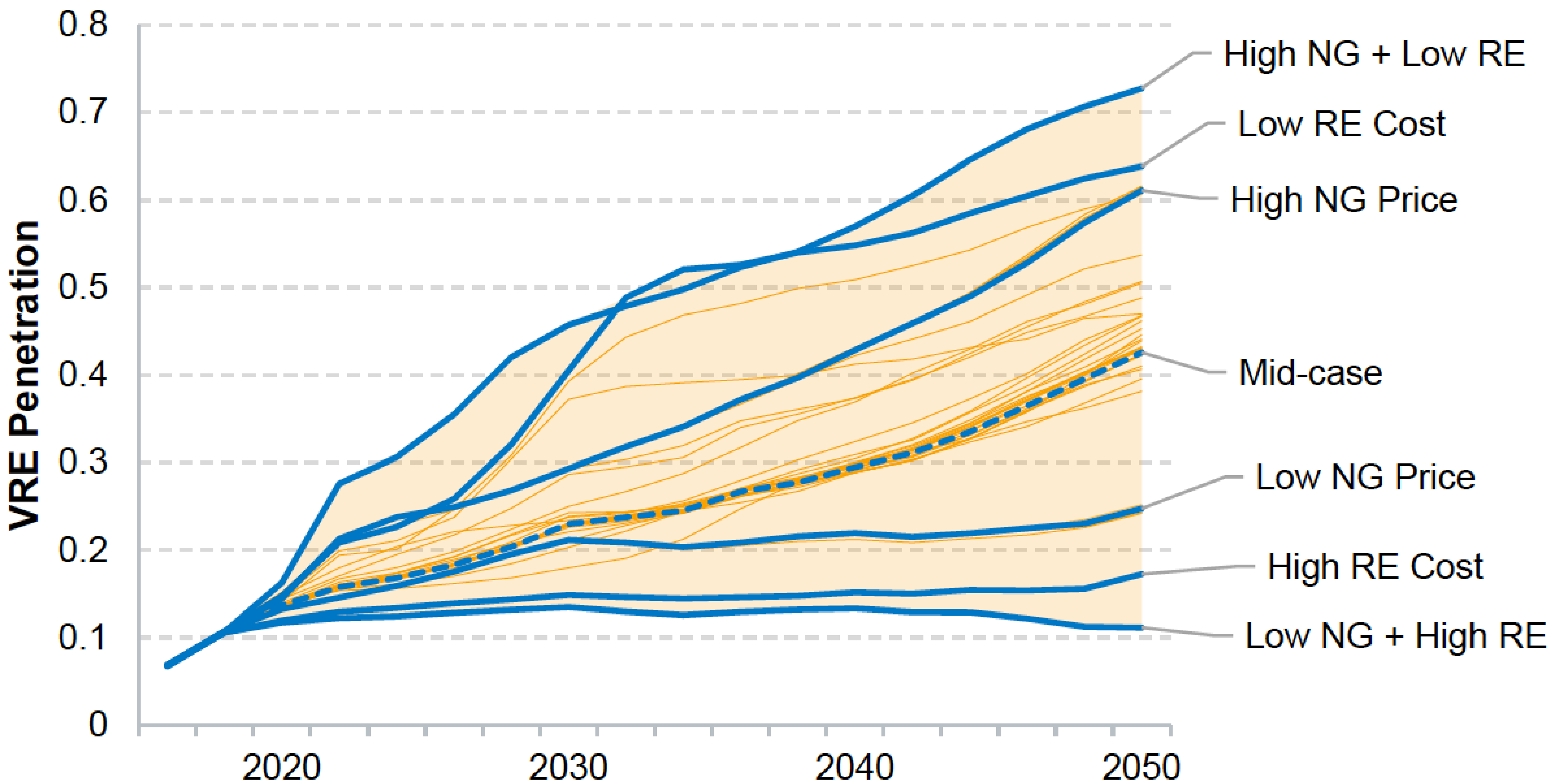
With hydropower, renewable energy is 17%.

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



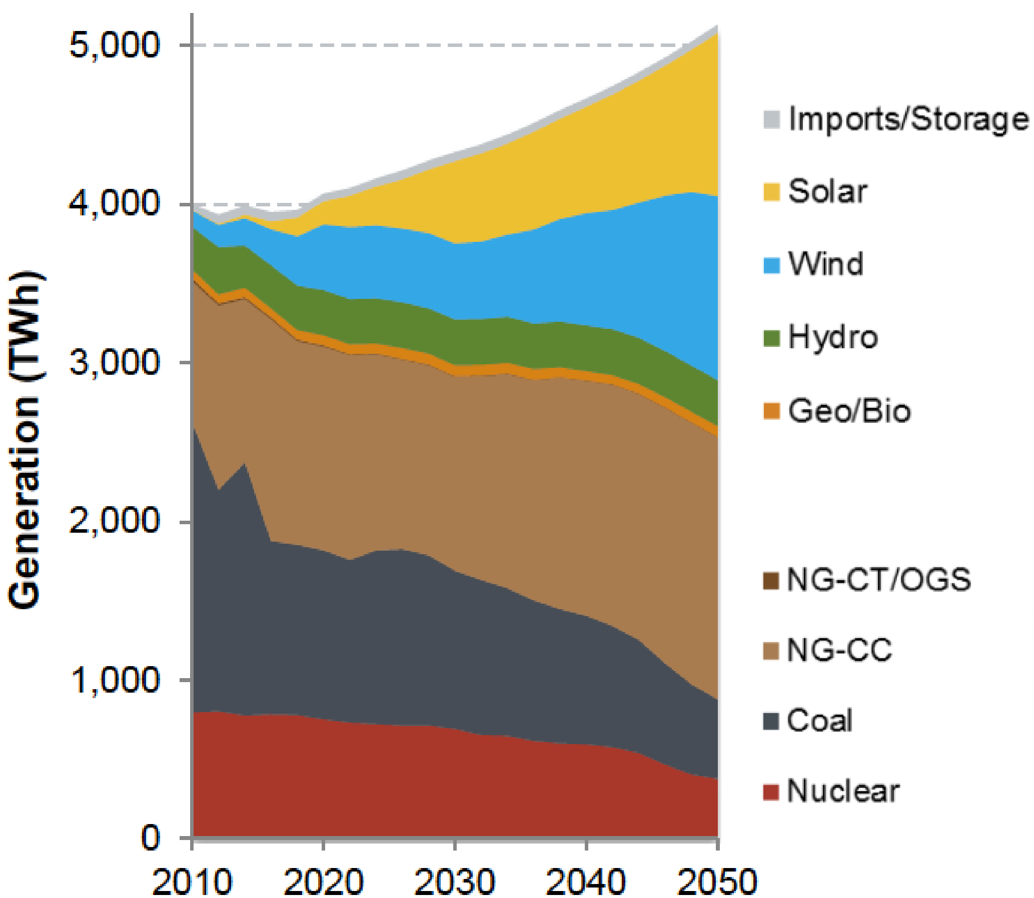
Source: United States Energy Information Agency, *Today in Energy,* 18 January 2019

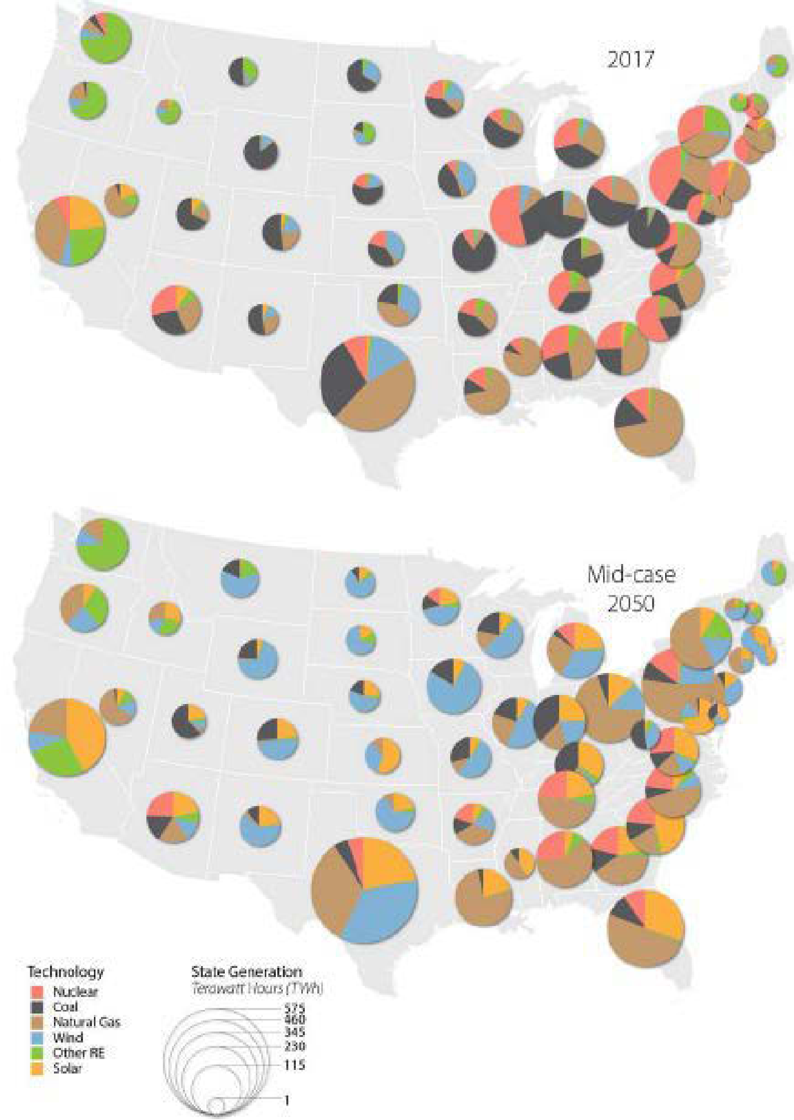
Future electricity generation will depend on technology development and markets



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

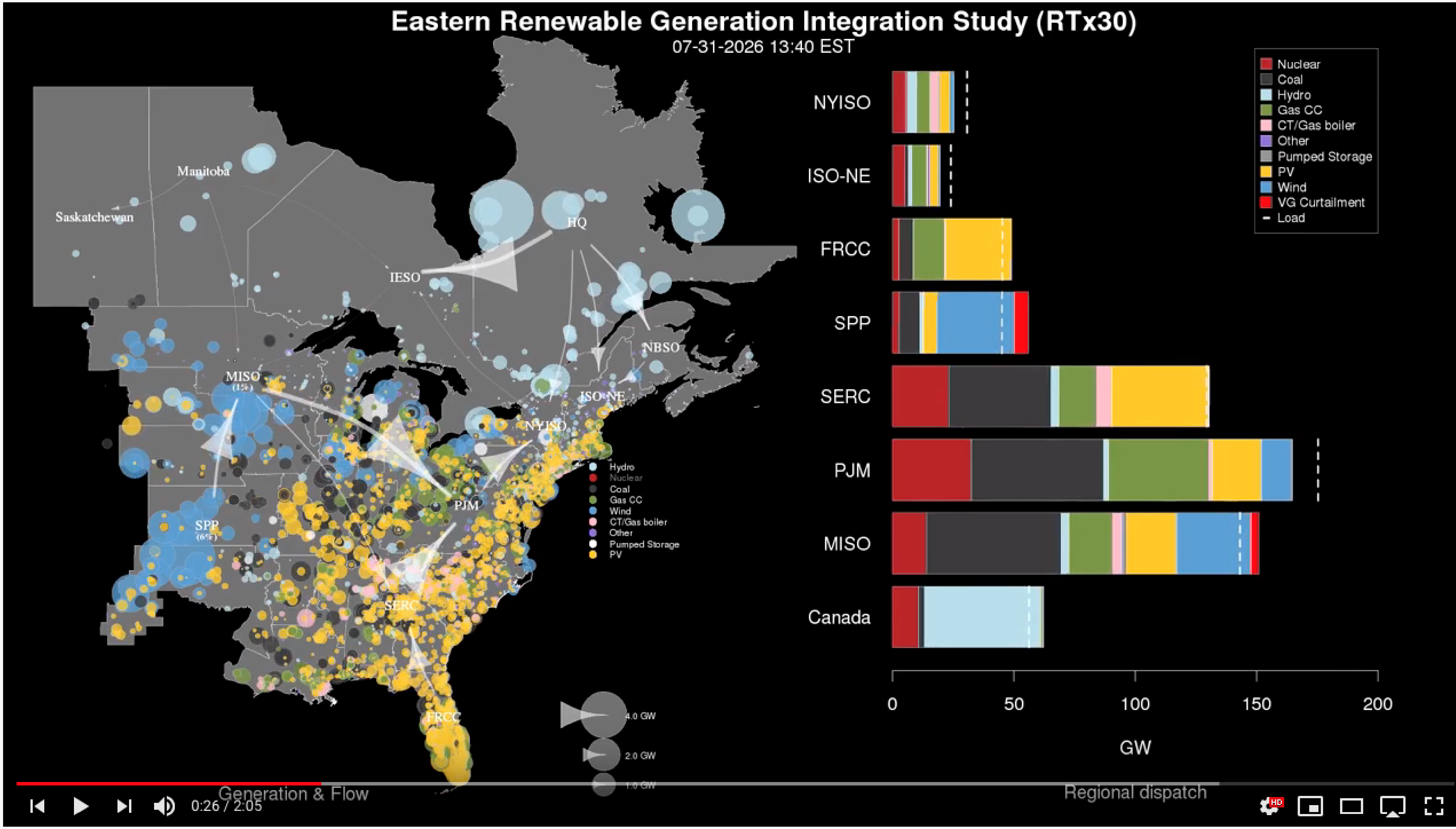
Future electricity generation will also depend on location and policy





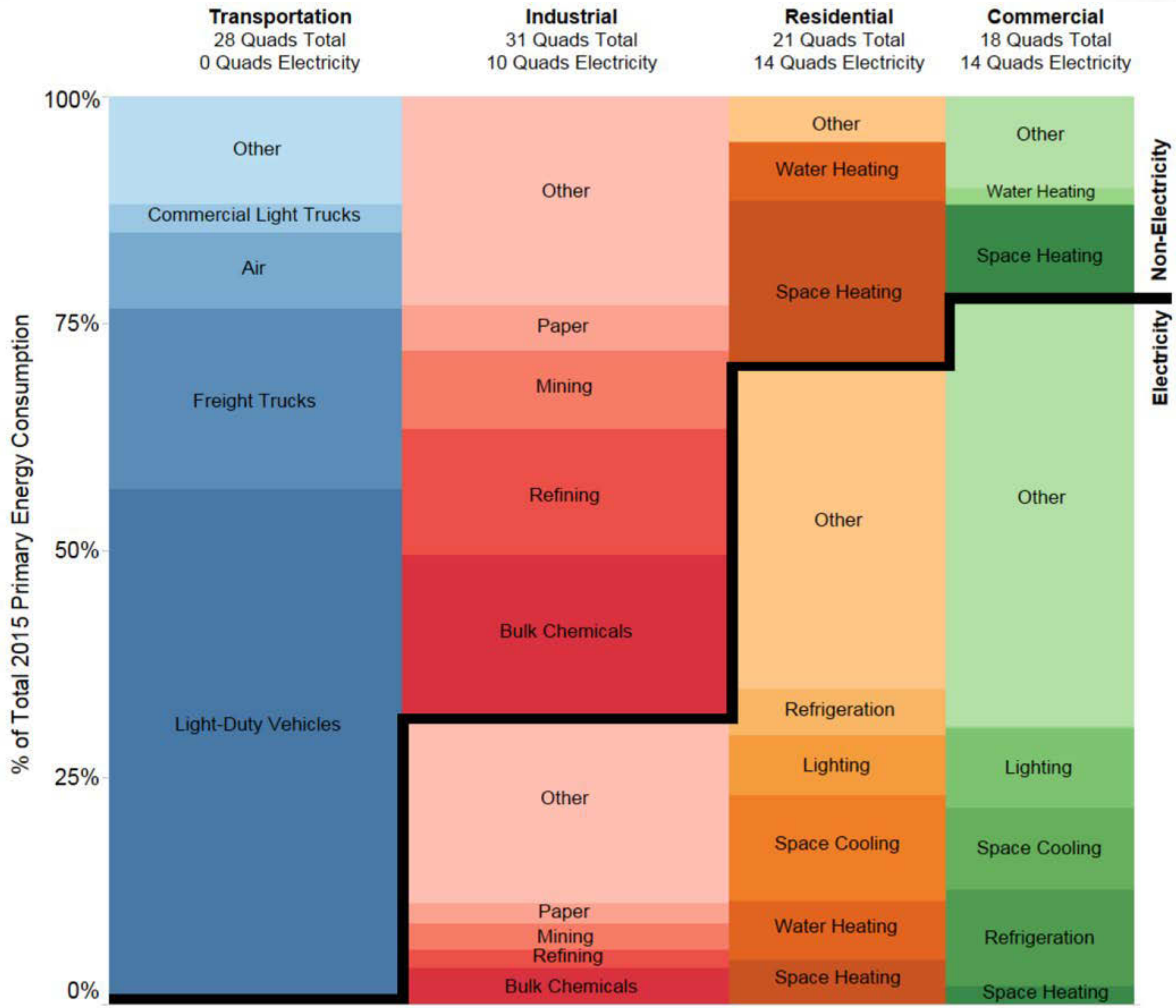
Generation by technology type in the Central Scenario, from: NREL 2018 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

Advanced grid integration studies required to understand deployment and transmission



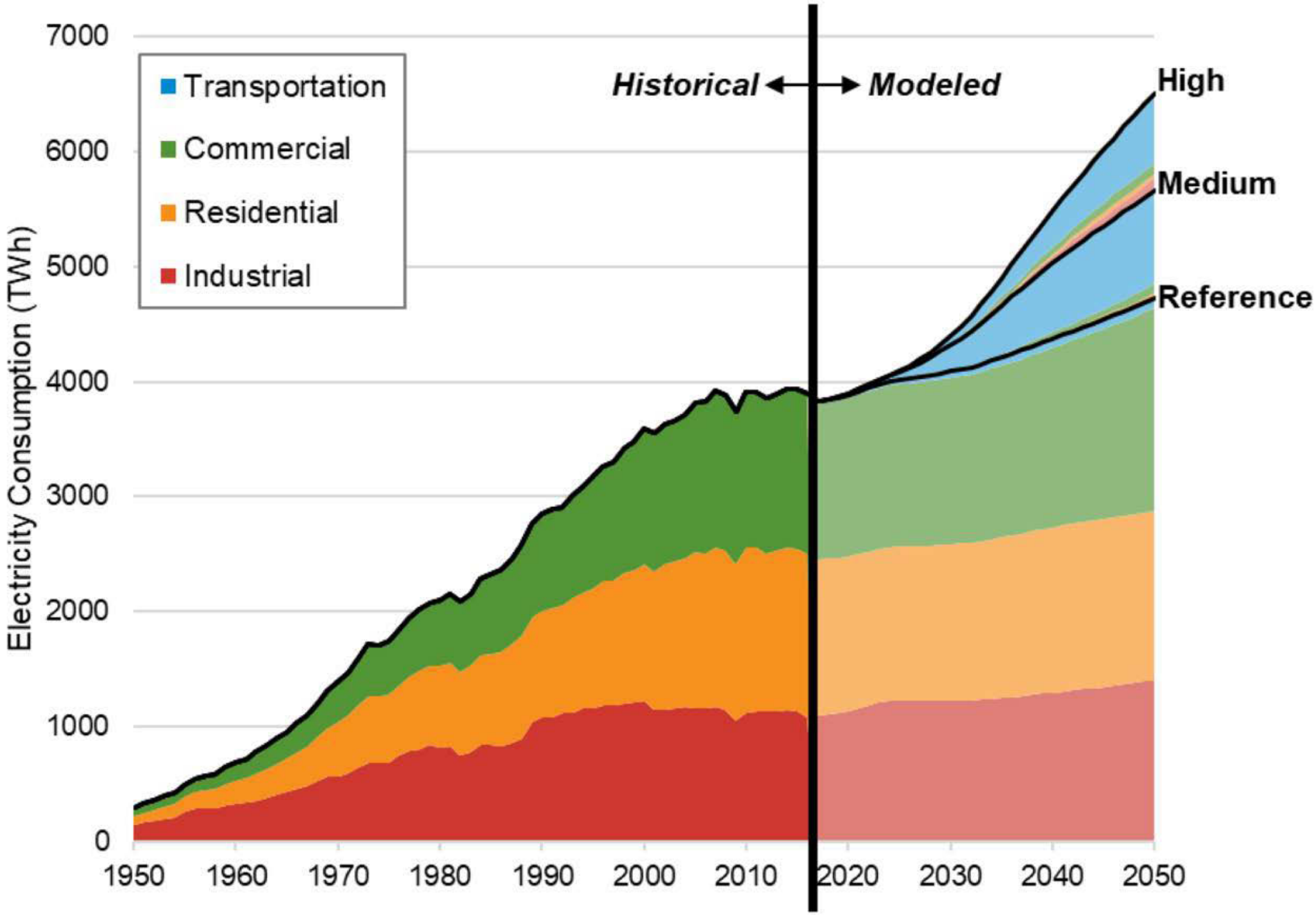
https://www.youtube.com/watch?v=li8jO-pKgvc&list=PLmIn8Hncs7bEl4P8z6-KCliwbYrwANv4p&index=19

Electrification Futures Study



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

Electrification Futures Study



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

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  - Example: Wind Turbines
- Renewable Energy Intersections

Wind Turbines

Onshore

Peetz Table Wind Energy Center

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

Offshore

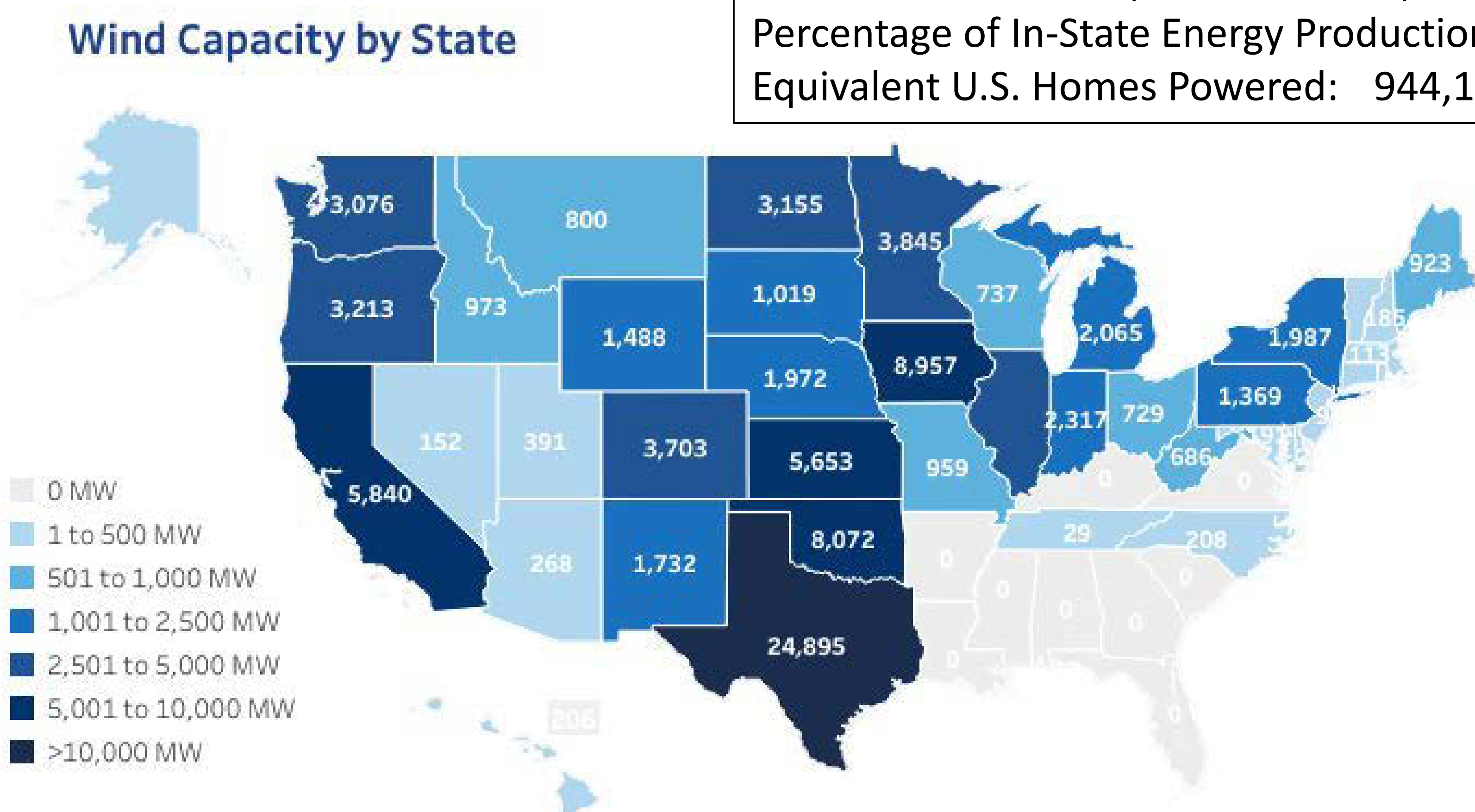
Block Island Wind Farm

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

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

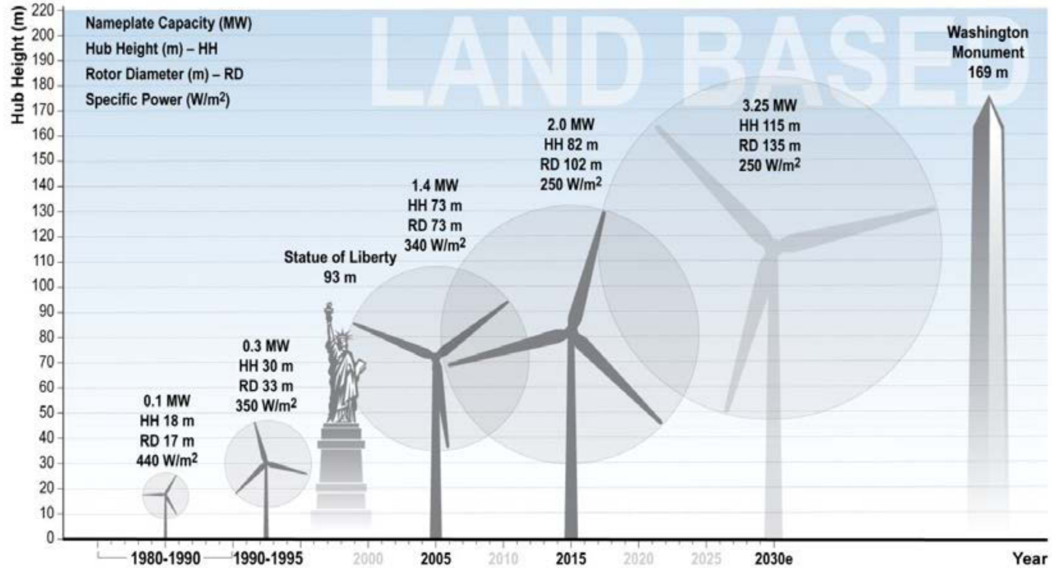
Wind capacity installed in Oklahoma, Iowa, and Kansas supplied 31%–36% of all in-state electricity generation in 2018. 14 states were greater than 10%.

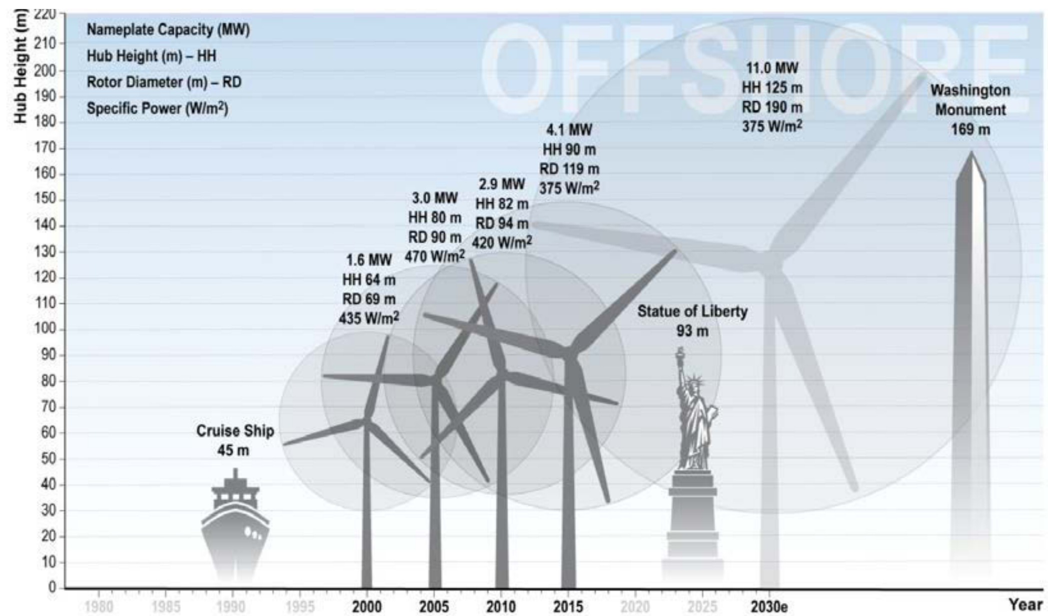
Colorado Rank – 8th for capacity
Installed: 3703 MW (2,248 turbines)
Percentage of In-State Energy Production: 17.3%
Equivalent U.S. Homes Powered: 944,100



Source: American Wind Energy Association, https://www.awea.org/wind-energy-facts-at-a-glance/, https://www.awea.org/Awea/media/Resources/StateFactSheets/Colorado.pdf

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





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

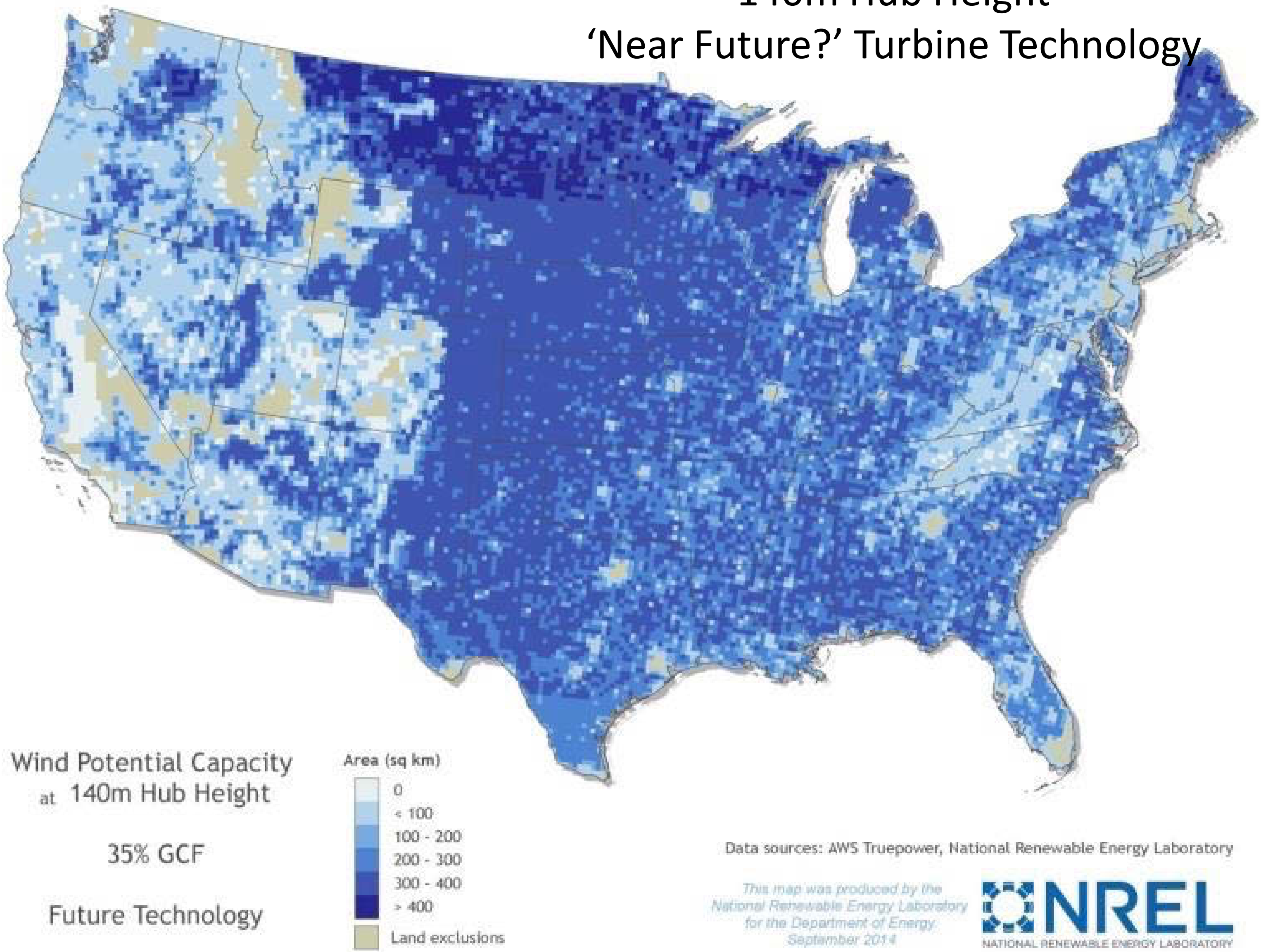
1998-2001: 24.5%
2004-2011: 32.1%
2014-2015: 42.6%

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 Increasing to More Places based on technology development

140m Hub Height
'Near Future?' Turbine Technology



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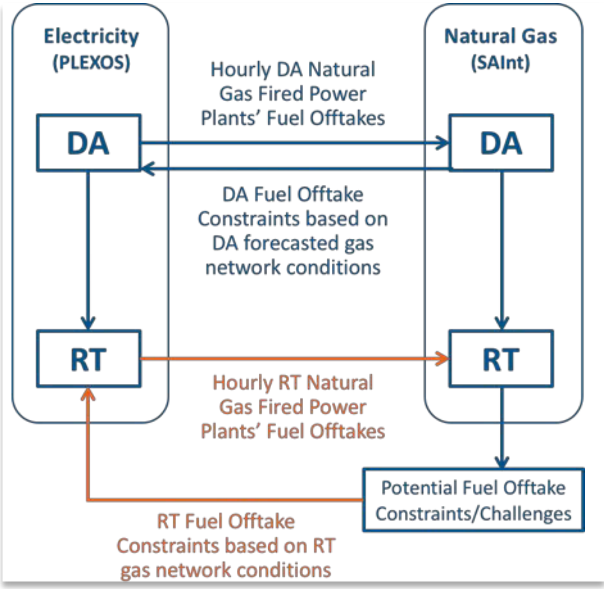
Electricity Generation: Electric-Natural Gas Interface Study

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.

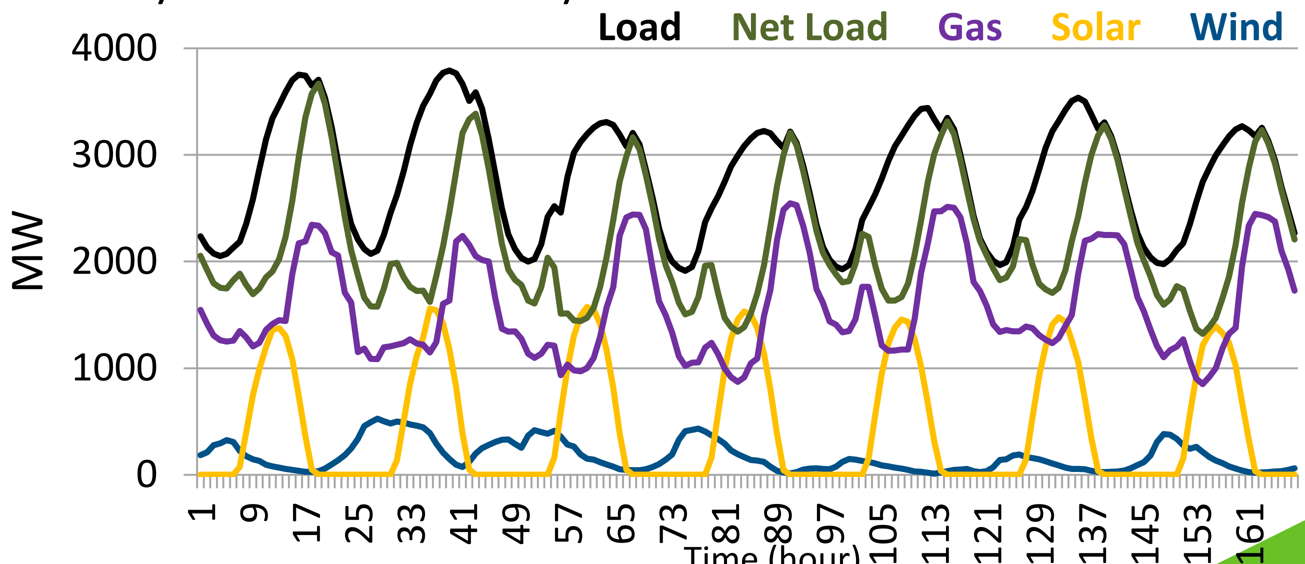
Model the Colorado interconnected power and natural gas networks and a test system with different renewable penetrations.

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 Energy for Oil & Gas Consortium

JISEA has established a collaborative program for the identification, development, modeling & analysis, and demonstration of clean power for oil and gas operations. The program will:

- 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.

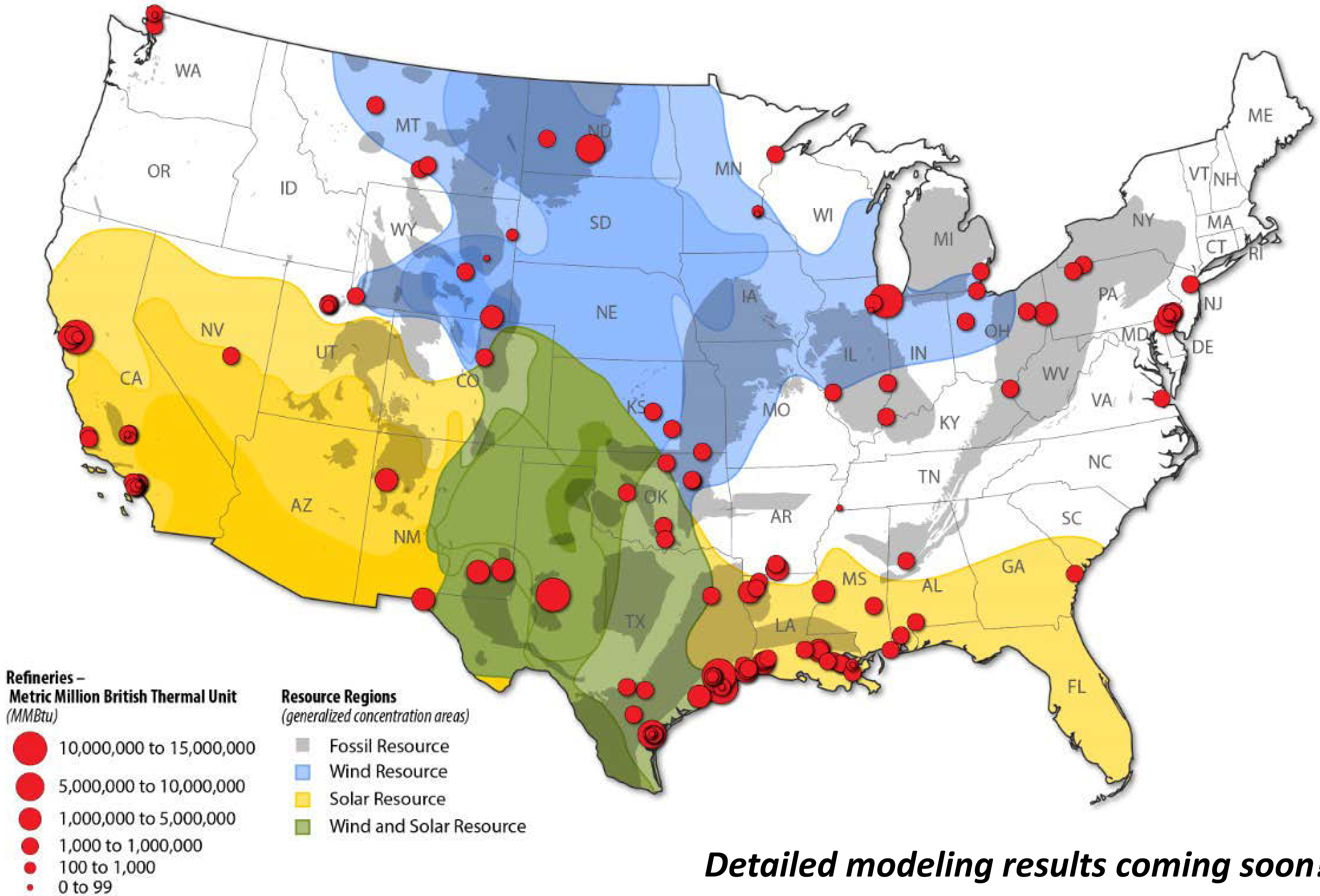
Project Objective

Demonstrate 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**

Starting similar program for mining.

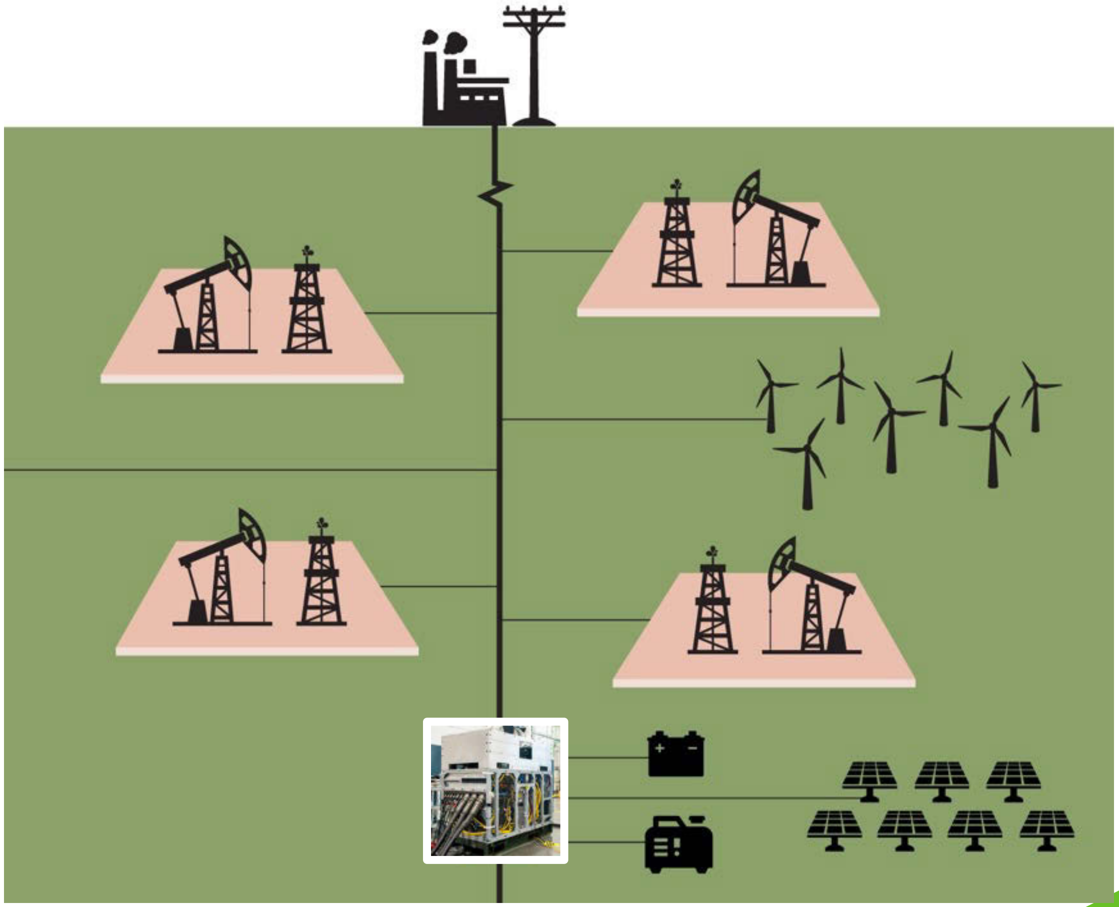
Many refineries may have great wind AND solar resources



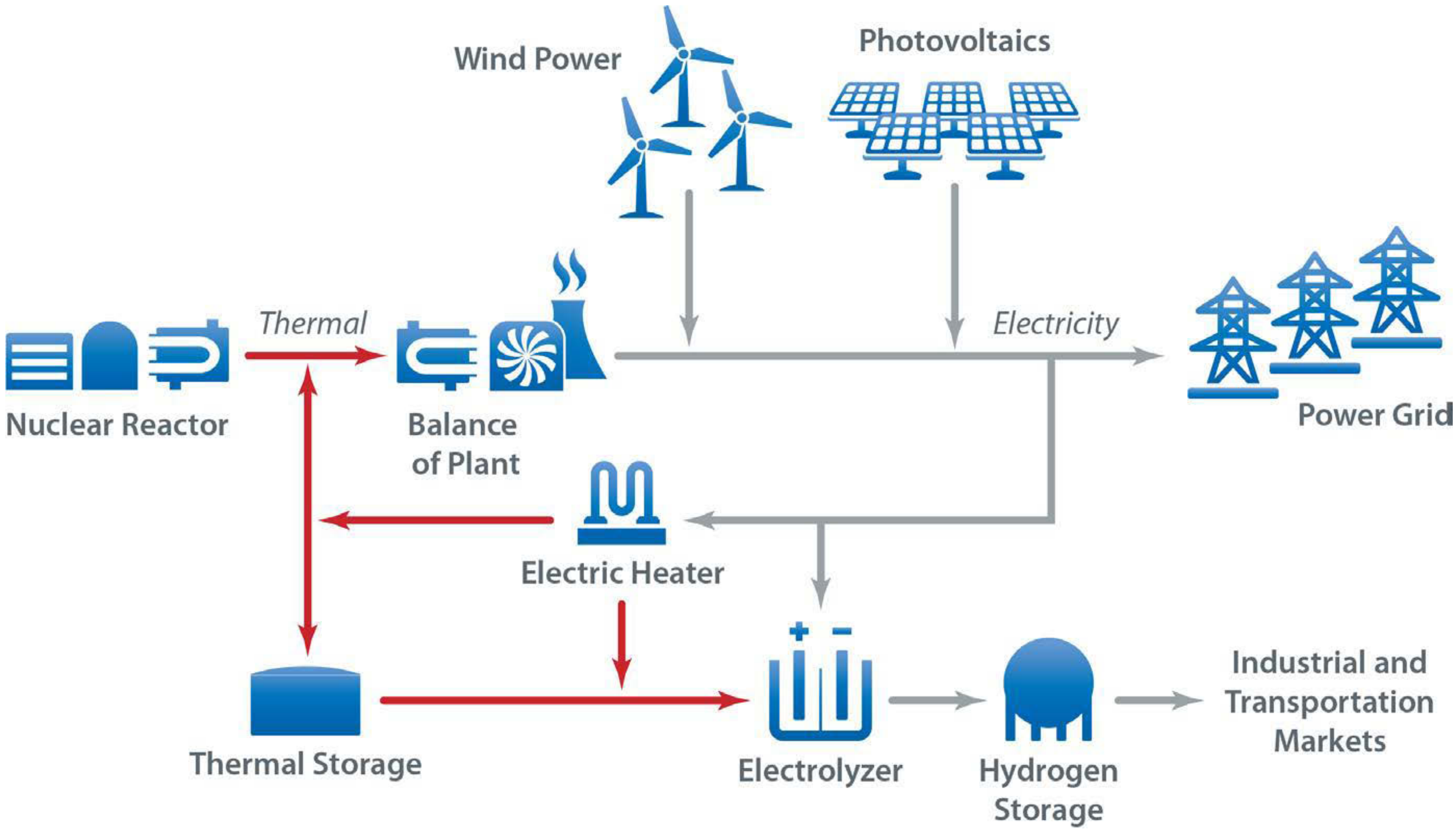
Detailed modeling results coming soon!

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



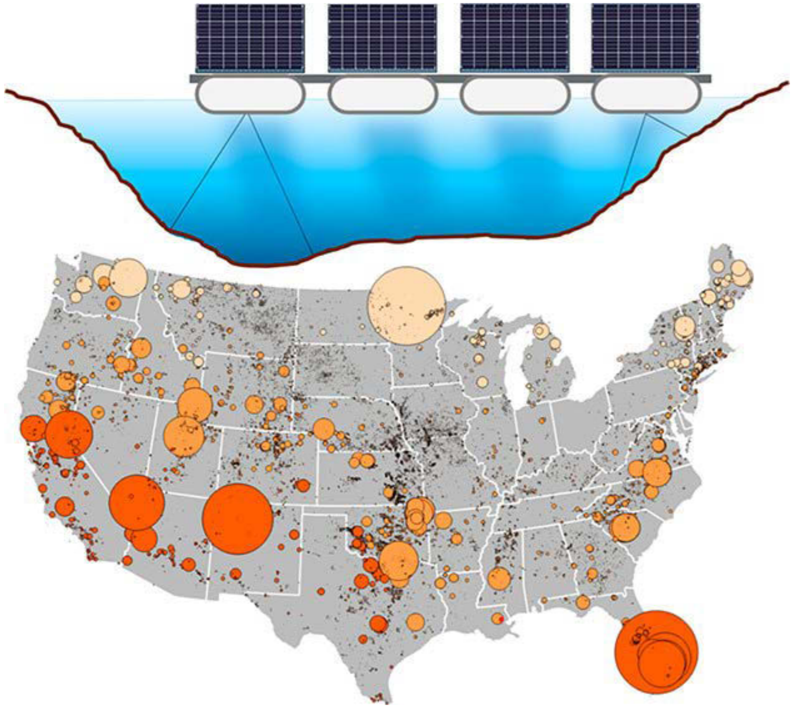
Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

Co-location of Wind/PV and Agriculture

Also looking at energy in entire food system.

Floating Solar PV (FPV)

- Analysis of cost, siting, and O&M tradeoffs
- GIS-based technical/market potential analysis for the U.S.
- Installing floating solar photovoltaics on the more than 24,000 man-made U.S. reservoirs could generate about 10 percent of the nation's annual electricity production
- Reduces evaporation and algae growth



Top image from https://images.nrel.gov/
Source: Spencer et al. 2018, Environmental Science & Technology, https://www.nrel.gov/news/press/2018/nrel-details-great-potential-for-floating-pv-systems.html.

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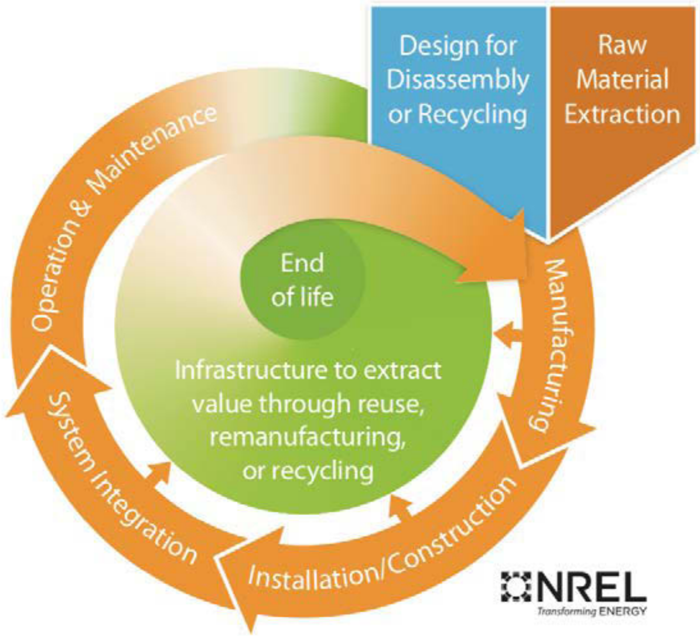
Transitioning from a Linear to a Circular Economy



D R^n R Needs

Design: Disassembly, recycle/reuse, materials/components/systems

Recycle/Reuse: complex heterogeneous waste; collection, pre-treatment, separations
Repurpose/Remanufacture: components, materials
Reduce: thrifting, materials/element substitution

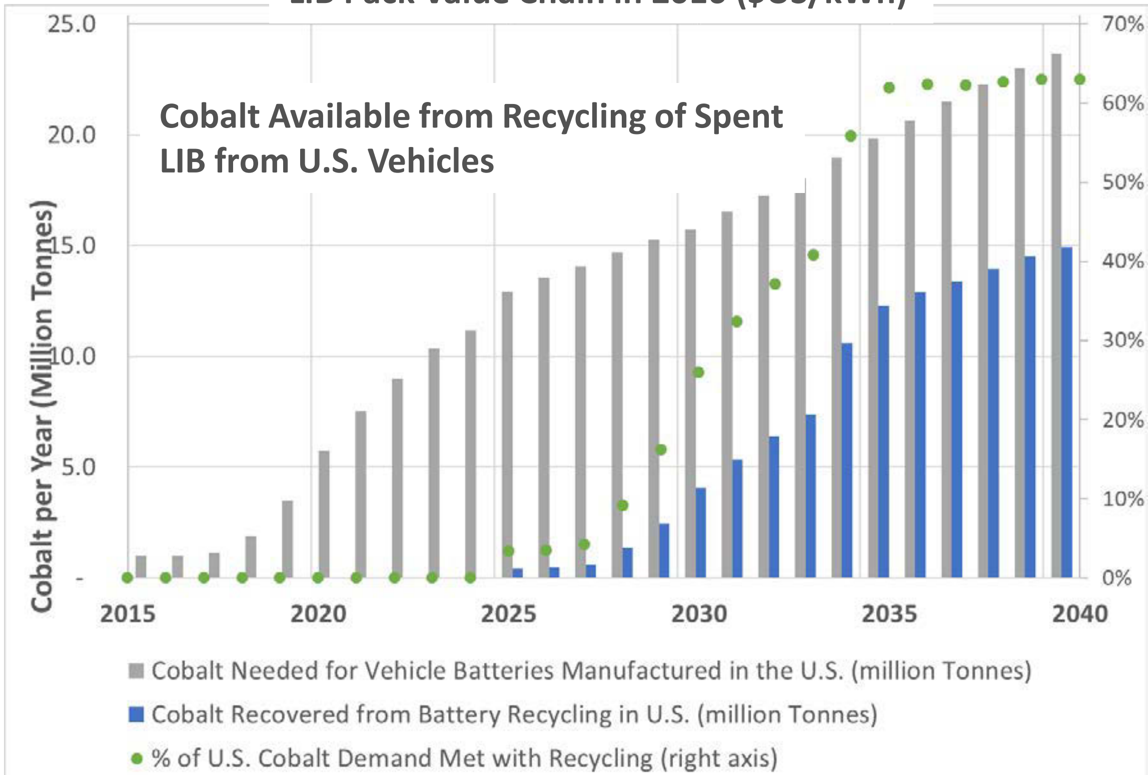
Reliability: validate performance, lifetime, predictability

Recycling of Li-ion batteries could supply 65% of U.S. cobalt demand by 2040

- Total global automotive Li-ion battery capacity is expected to exceed 90 GWh and require more than 500 thousand tons of battery materials (Li, Co, Mn, Ni, and Gr) by 2020
- Today, LIB recycling capacity is concentrated in EU and China
- U.S. is poised for expansion of LIB recycling capacity; by 2040, spent batteries from vehicles sold in the U.S. could supply 65% of US cobalt for US vehicle manufacturing
- Recovered cathode materials could save ~ 20% of the total LIB pack cost, with more savings achieved by recovering other materials and parts from spent batteries.

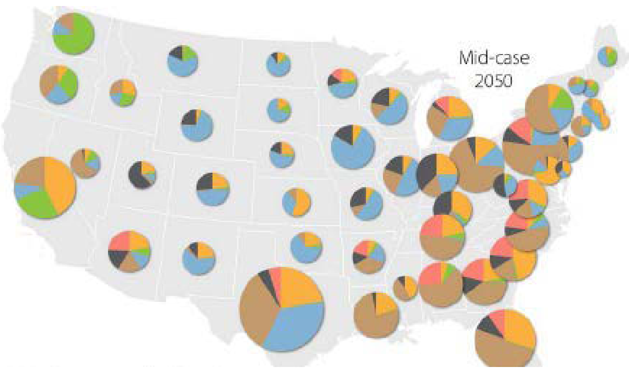
	Raw Materials	Processed Materials	Electrodes	Cells	Battery Pack	TOTAL
VALUE ($/kWh)	$50 [$0]	$118 [$84]	$28	$146* (cum. $342*)	$74	$416 [$332]
SHARE [With Recycled materials]	12% *[0%]*	28% [25%]	7% *[8%]*	35% *[44%]*	18% *[22%]*	100% [100%]

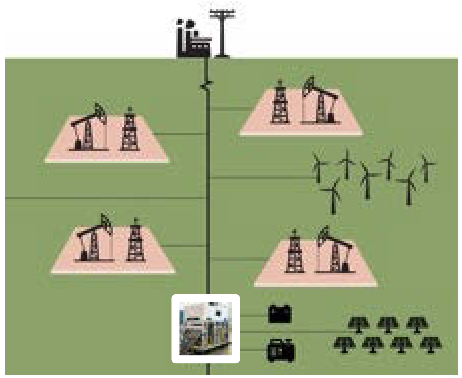
LIB Pack Value Chain in 2016 ($US/kWh)

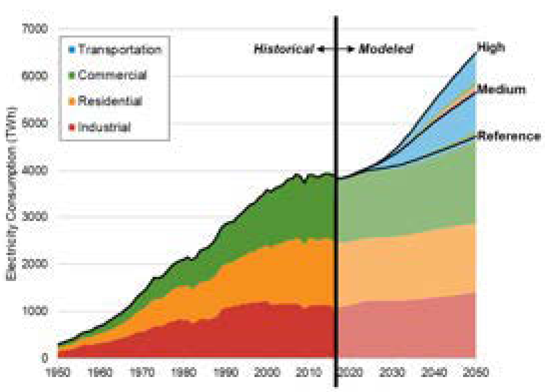


Source: Mayyas et al. 2019, https://www.sciencedirect.com/science/article/pii/S2214993718302926

Conclusion







Trends and Potential Future Scenarios:

- Moving toward cleaner and lower cost energy (renewables and gas) with potential for growth in manufacturing, extraction, deployment
- Increasing intersection of renewable energy with other sectors of local economy:
  - Oil & gas industry
  - Agriculture
  - Manufacturing
- Potentially increased electrification resulting in higher demand for power and higher-value use of hydrocarbon resources
- Systems thinking needed for circular economy and power to materials

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Questions and Discussion

Thank you!

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