JISEA Joint Institute for Strategic Energy Analysis

Renewable Energy for Industrial Environmental Management

Colorado Environmental Management Society

2019 Fall Conference, Denver, Colorado

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Jill Engel-Cox, Ph.D.
Director, Joint Institute for Strategic Energy Analysis
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
- Energy Technology Markets and Trends
  - Example: Wind Turbines
- Renewable Energy for Oil and Gas and other Industries

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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.

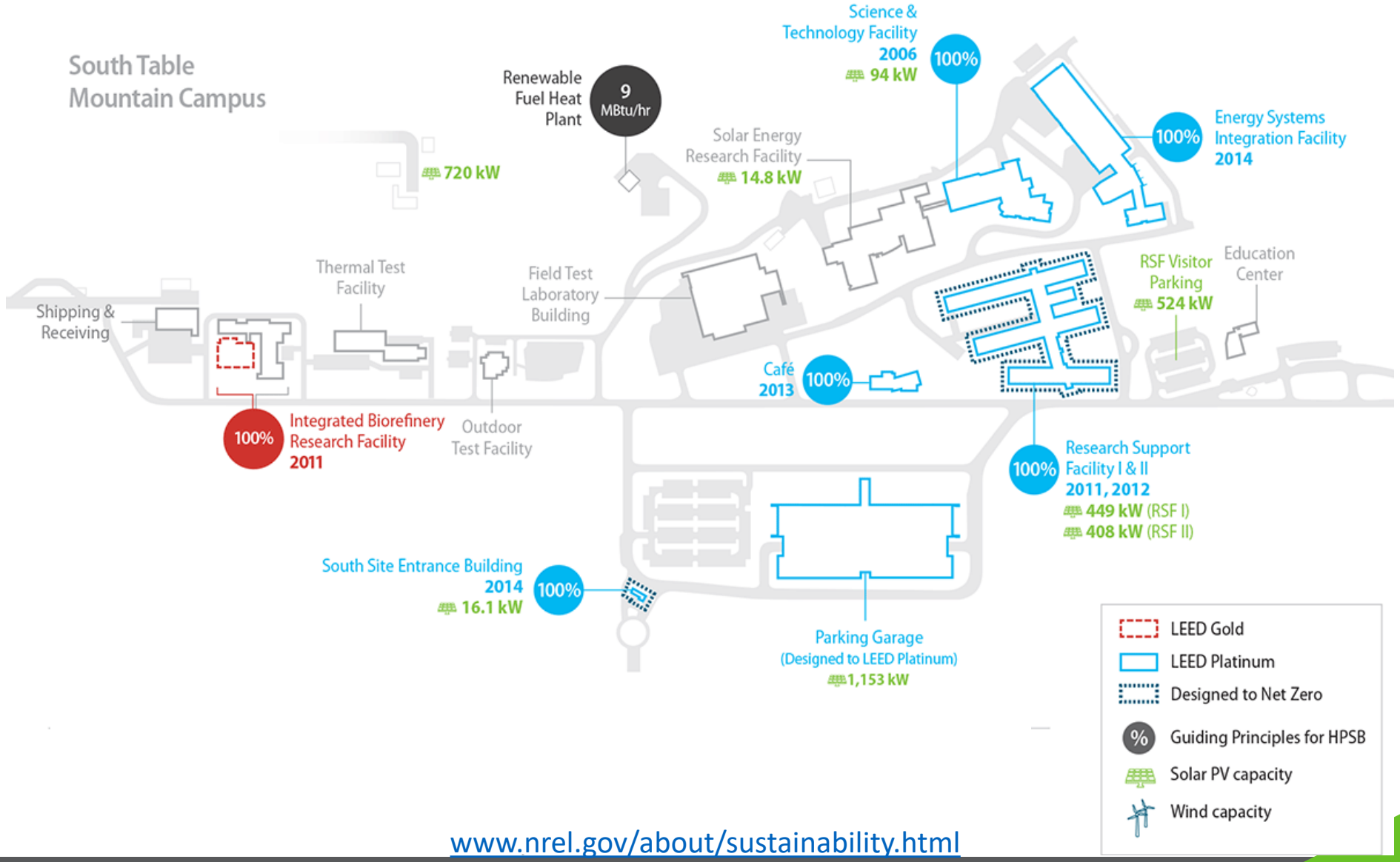
Example Technology Areas:

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

www.nrel.gov/about

NREL Sustainable Campus

NATIONAL RENEWABLE ENERGY LABORATORY



www.nrel.gov/about/sustainability.html

NREL Sustainable Data Center

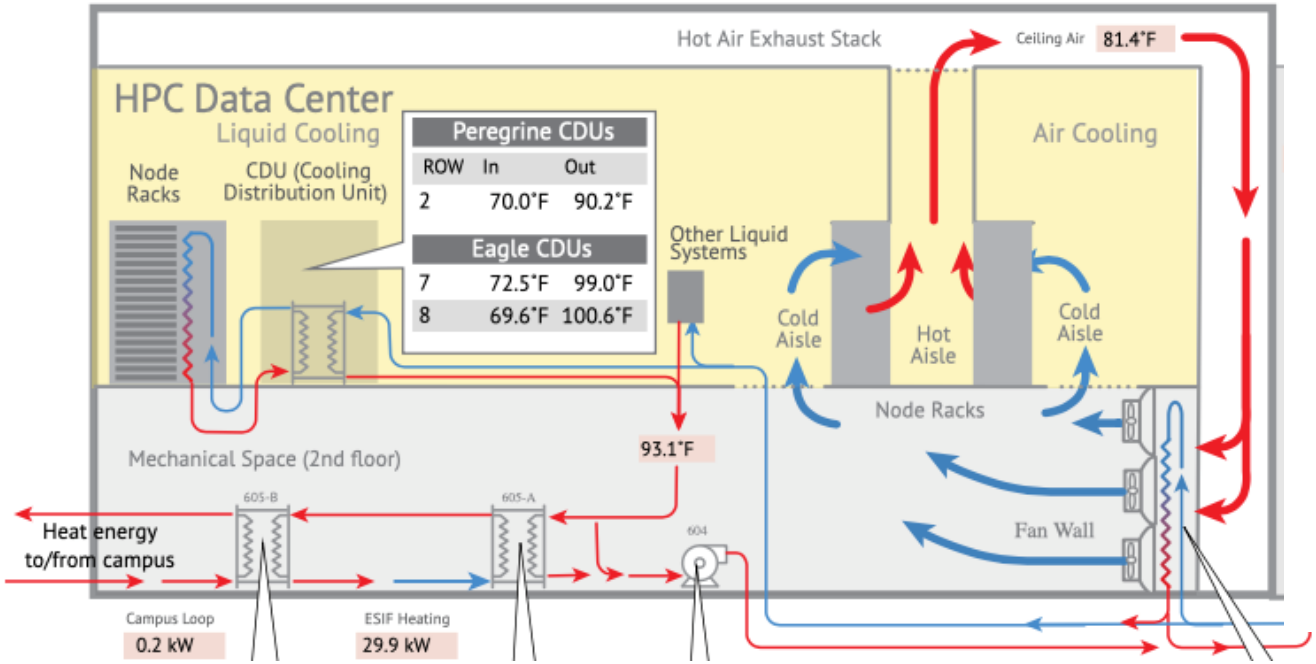
NATIONAL RENEWABLE ENERGY LABORATORY

ESIF HIGH PERFORMANCE COMPUTING DATA CENTER

As of Mon Oct 7 16:00:20 MDT 2019

		Lights & Plugs		Cooling		Pumps		HVAC		IT Equipment		Re-use		IT Equipment
PUE 1.039	= ( )	5.97	+	7.57	+	8.21	+	9.37	+	807.86			/	807.86
ERE 1.001	= ( )	5.97	+	7.57	+	8.21	+	9.37	+	807.86	-	30.10	/	807.86

Values in kW



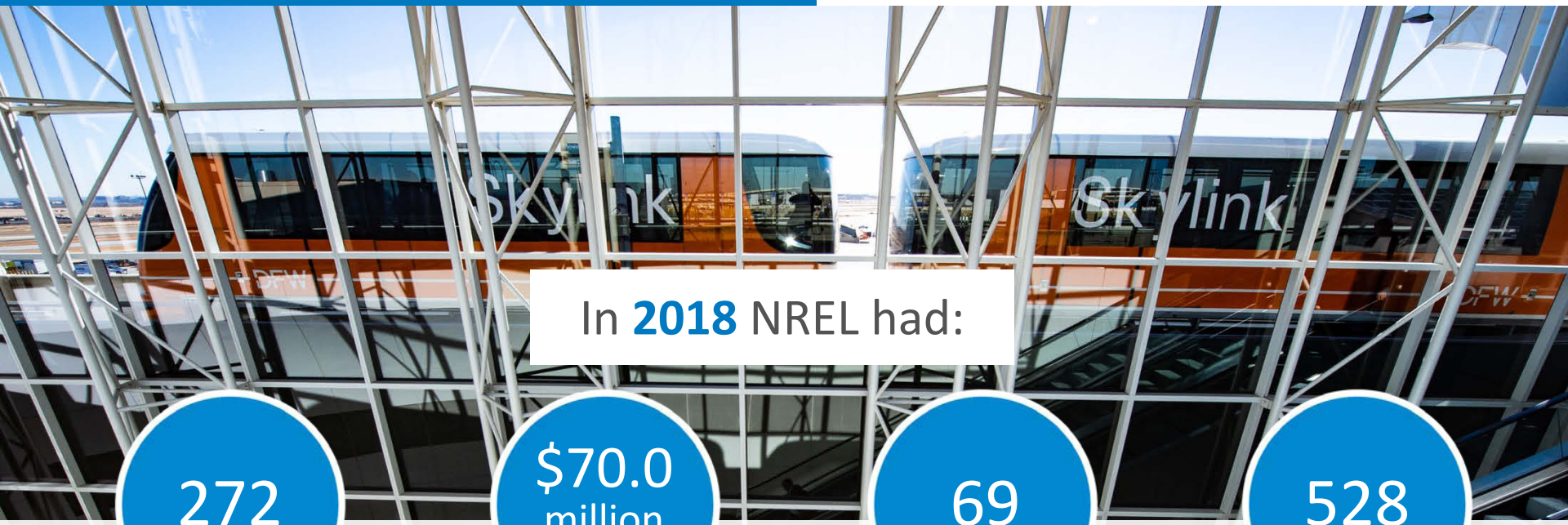
PUE = Power Usage Effectiveness (typical computing center has PUE = 1.8)

ERE = Energy Reuse Effectiveness

www.nrel.gov/computational-science/hpc-data-center.html

NREL Partners with Business

Nearly **820** active partnerships with industry, academia, and government



In **2018** NREL had:

272
new **partnership agreements**

$70.0 million value
of new **partnership agreements**

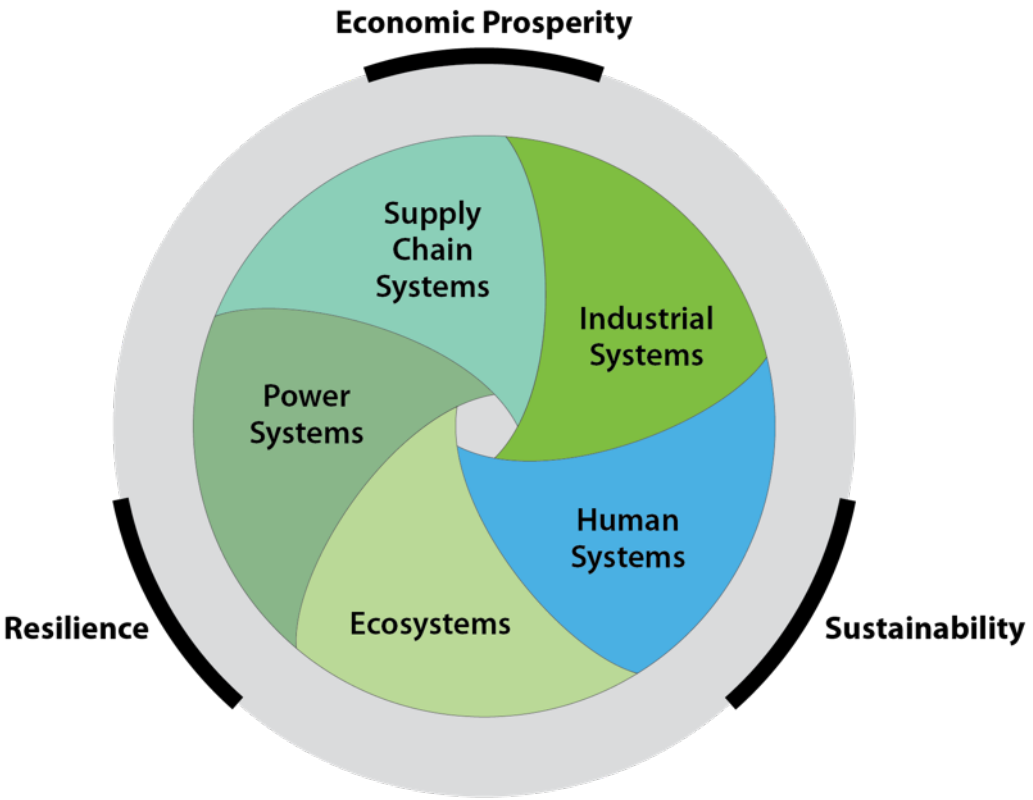
69
unique new **partners**

528
unique active **partners**

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

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  - Example: Wind Turbines
- Renewable Energy for Oil and Gas and other Industries

Clean Energy Is Diverse

WIND

Onshore

Offshore

SOLAR PV

Distributed & Micro Grids

Utility Grid Connected

HYDROPOWER

Large & Small

Wave & Tidal

BIOMASS & WASTE

HYDROGEN & GAS

GEOTHERMAL

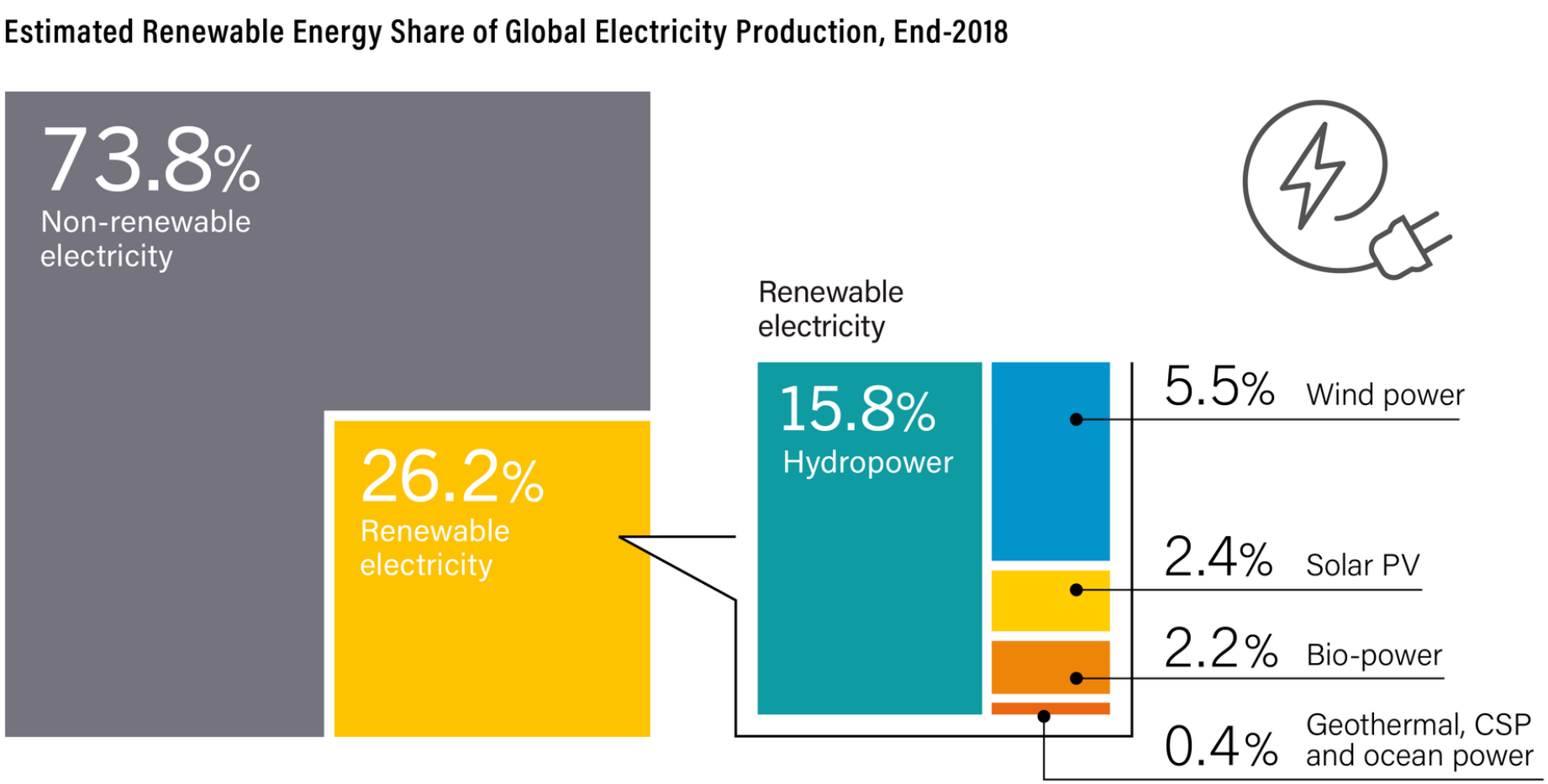
CONCENTRATING SOLAR

BATTERIES & STORAGE

EFFICIENCY & HEAT USE

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

Global share of renewable electricity

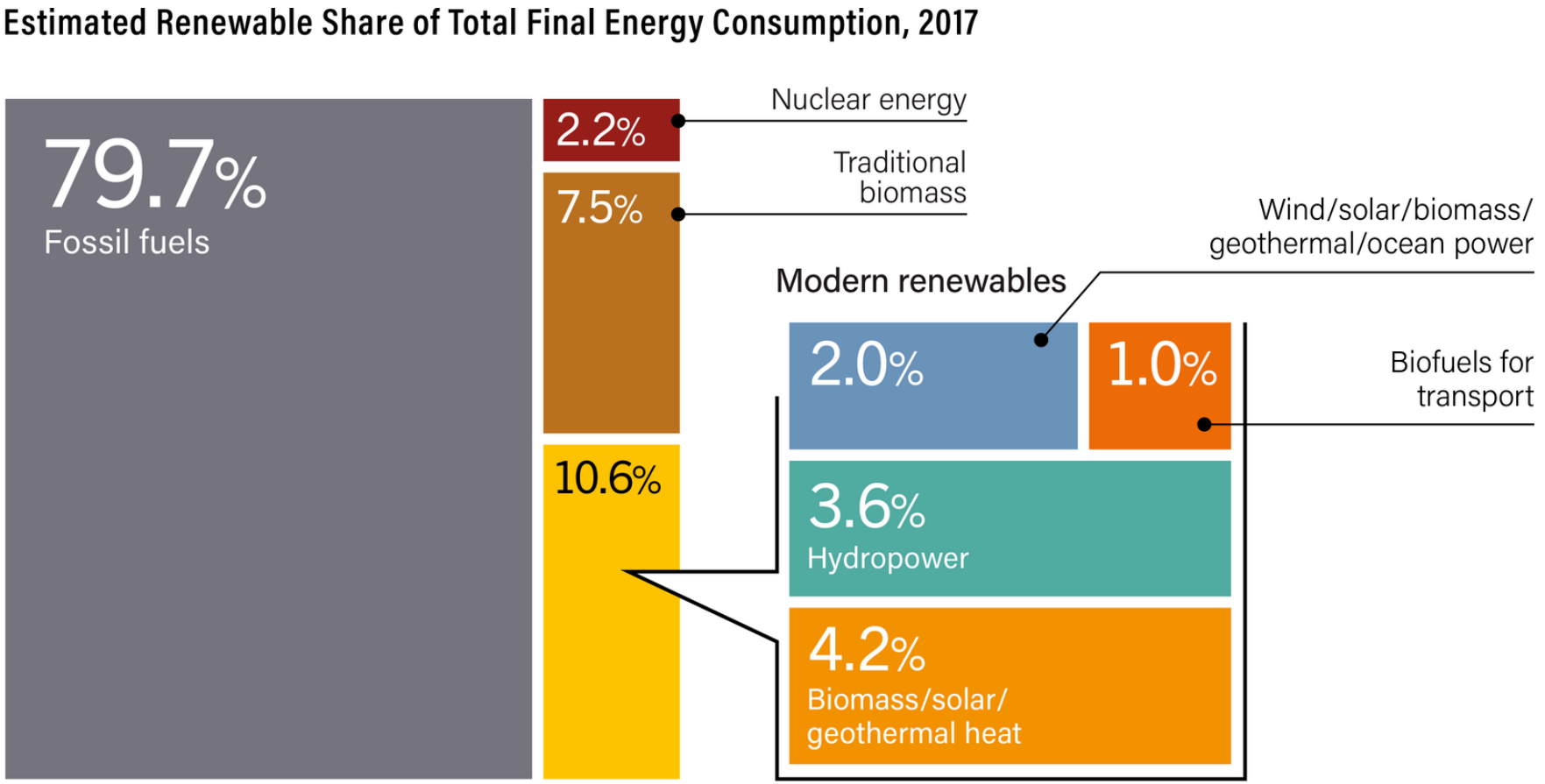


Note: Data should not be compared with previous version of this figure due to revisions in data and methodology.

REN21 RENEWABLES 2019 GLOBAL STATUS REPORT

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

Global share of renewable energy



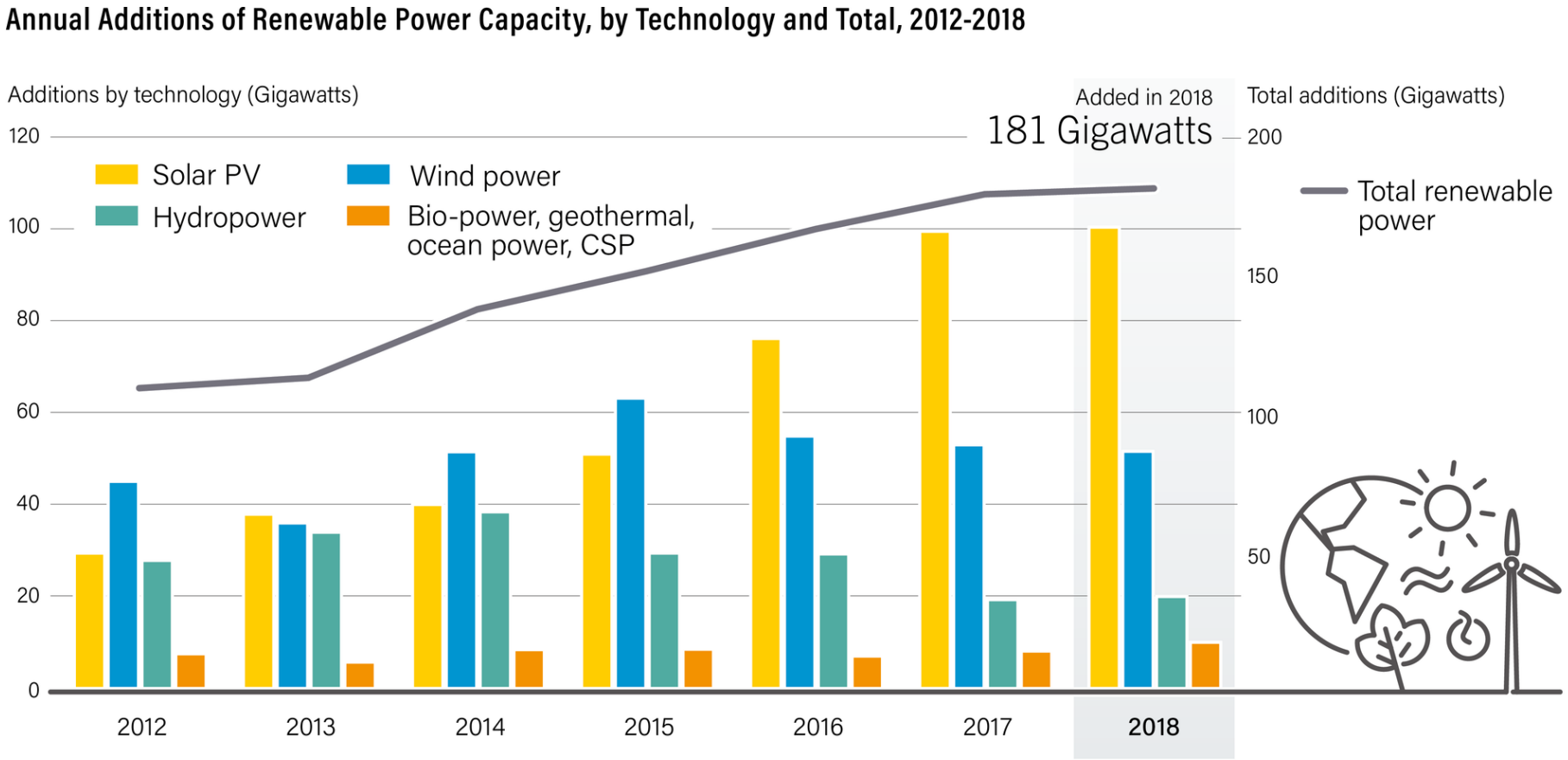
Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

Source: Based on OECD/IEA and IEA SHC.

REN21 RENEWABLES 2019 GLOBAL STATUS REPORT

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

Global growth of renewable power



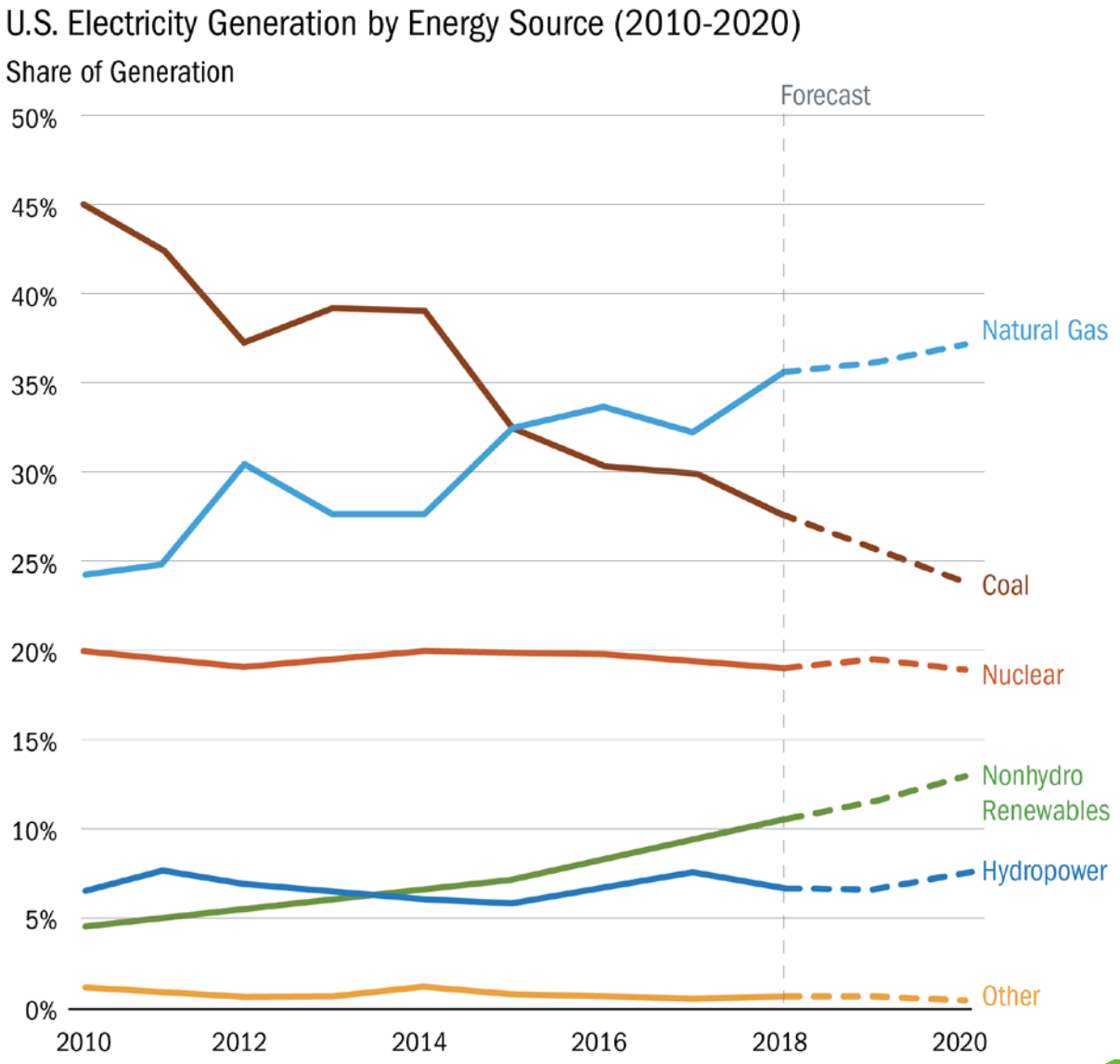
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

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%.

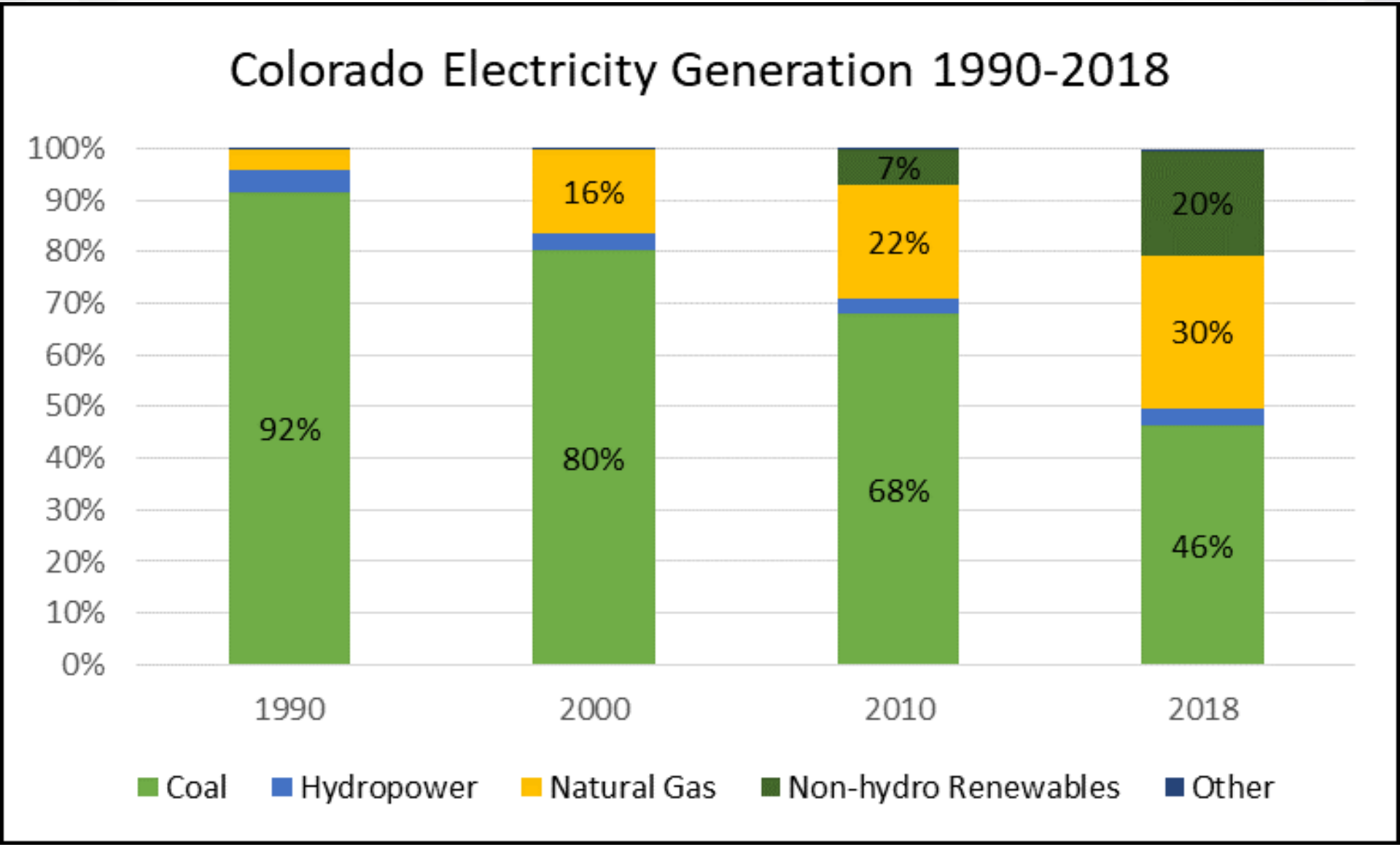
With hydropower, renewable energy is 17%.

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



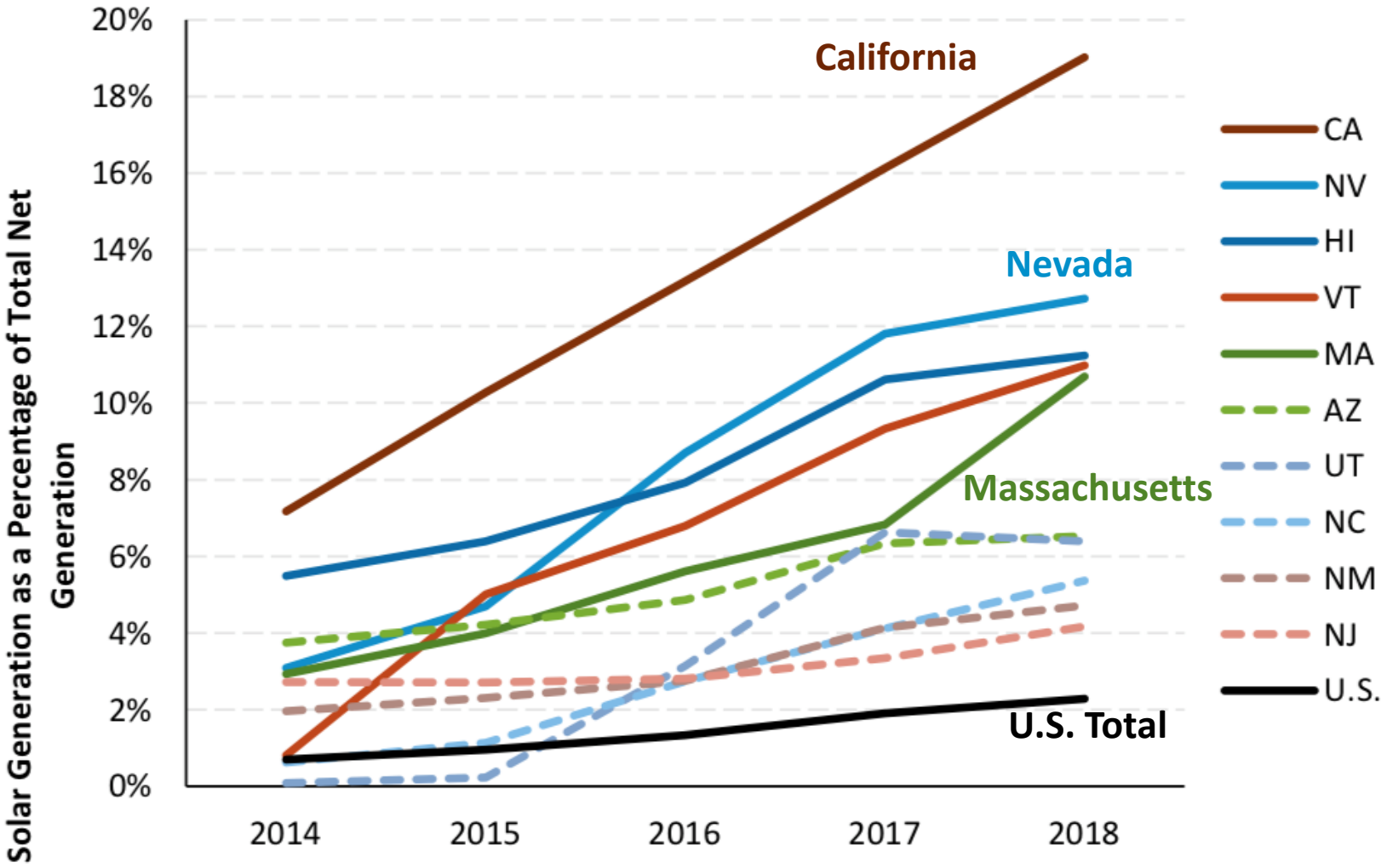
Source: United States Energy Information Agency, *Today in Energy,* 18 January 2019

Electricity Trending to Gas and Renewables



Source: Your Energy Colorado, http://yourenergy.extension.colostate.edu/fuels-electric-grid/

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

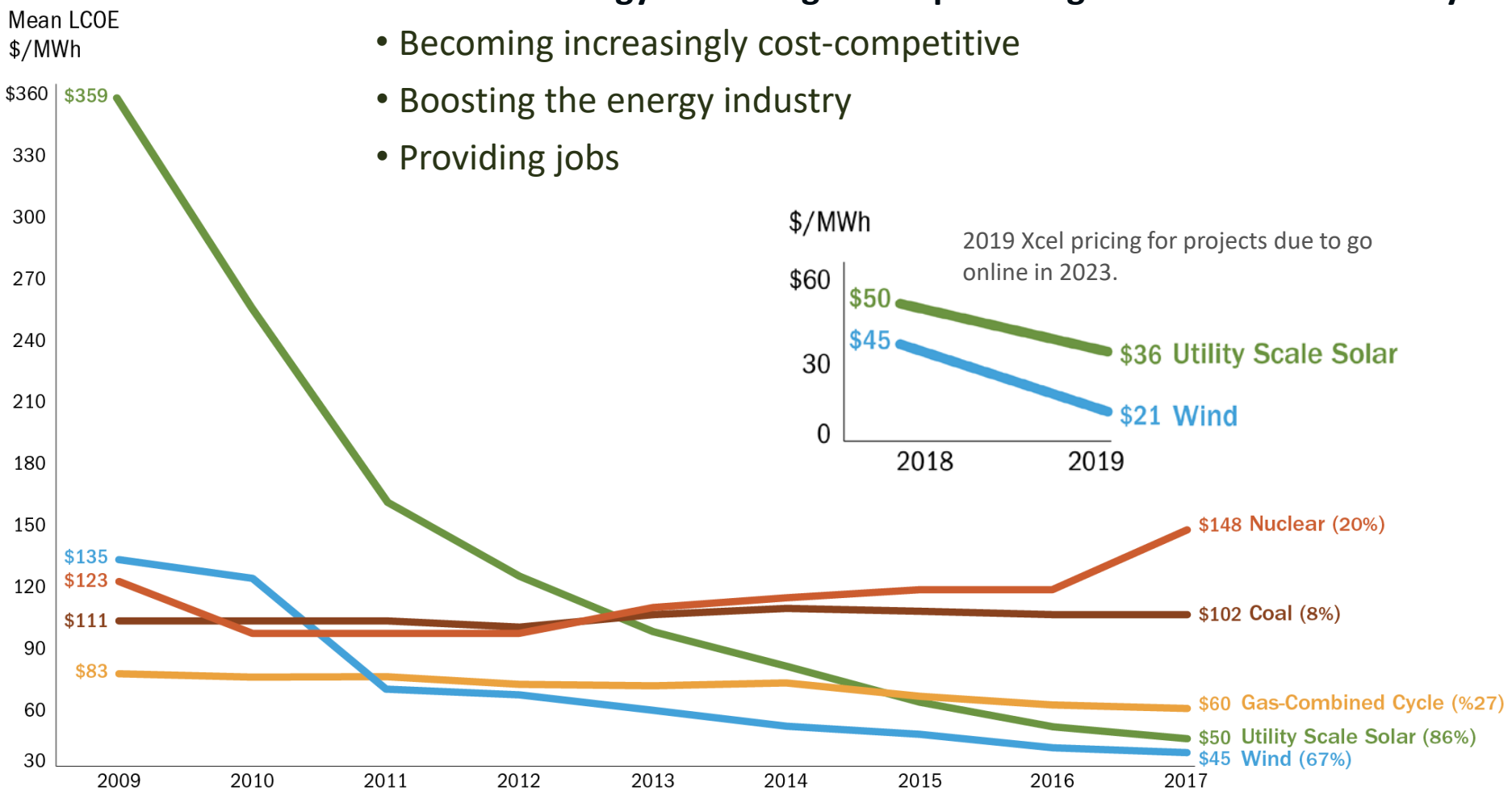


Source: NREL, Q4 2018/Q1 2019 Solar Industry Update, May 2019.

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

Cost of Renewable Electricity at Auctions Driving Decrease

Xcel Energy 2017 auction for Colorado: 430 bids (350 for renewable energy)

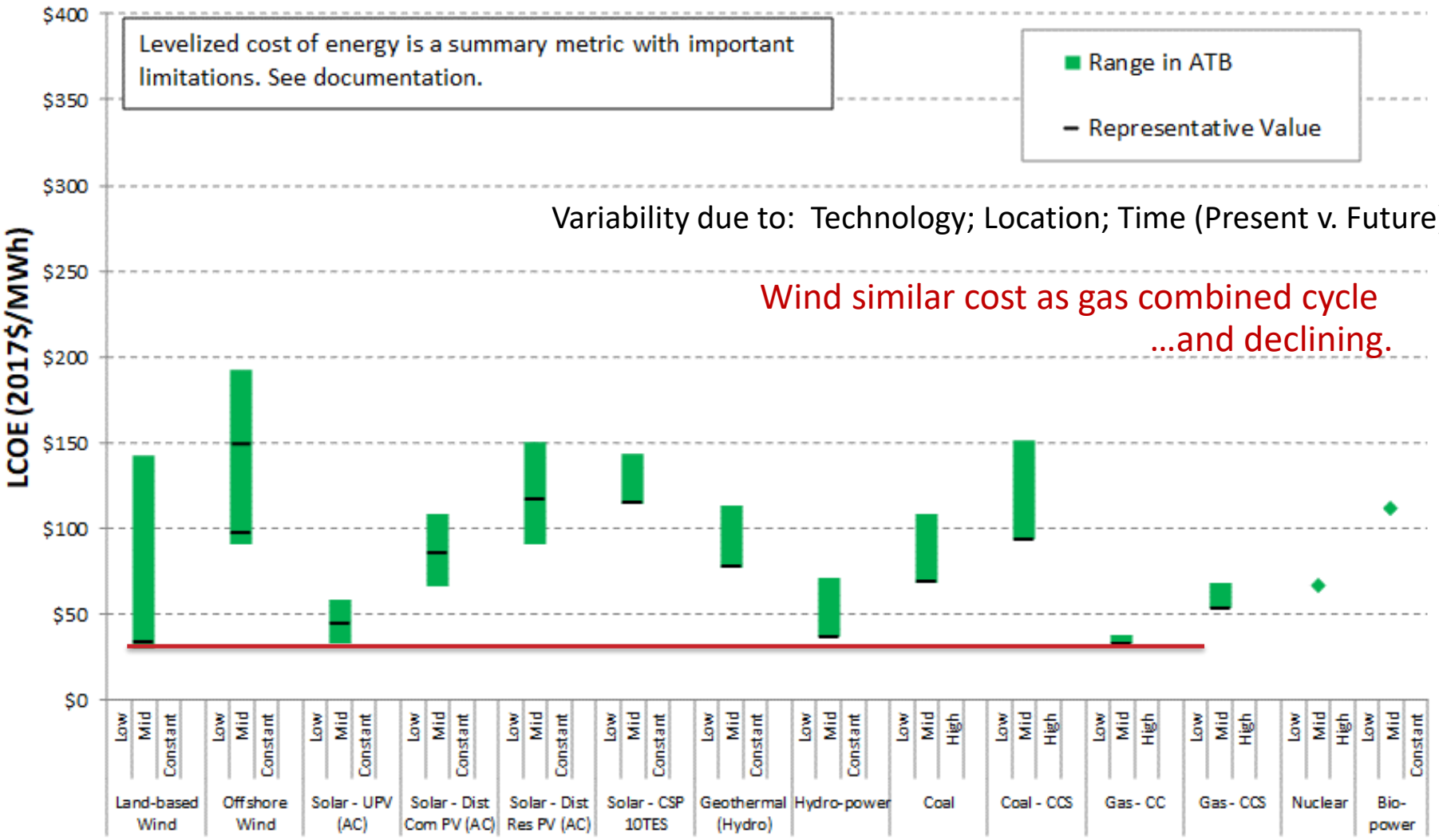
RFP Responses by Technology

Generation Technology	# of Bids	Bid MW	# of Projects	Project MW	Median Bid Price or Equivalent	Pricing Units
Combustion Turbine/IC Engines	30	7,141	13	2,466	$ 4.80	$/kW-mo
Combustion Turbine with Battery Storage	7	804	3	476	6.20	$/kW-mo
Gas-Fired Combined Cycles	2	451	2	451		$/kW-mo
Stand-alone Battery Storage	28	2,143	21	1,614	11.30	$/kW-mo
Compressed Air Energy Storage	1	317	1	317		$/kW-mo
Wind	96	42,278	42	17,380	$ 18.10	$/MWh
Wind and Solar	5	2,612	4	2,162	19.90	$/MWh
Wind with Battery Storage	11	5,700	8	5,097	21.00	$/MWh
Solar (PV)	152	29,710	75	13,435	29.50	$/MWh
Wind and Solar and Battery Storage	7	4,048	7	4,048	30.60	$/MWh
Solar (PV) with Battery Storage	87	16,725	59	10,813	36.00	$/MWh
IC Engine with Solar	1	5	1	5		$/MWh
Waste Heat	2	21	1	11		$/MWh
Biomass	1	9	1	9		$/MWh
Total	430	111,963	238	58,283		

Source: Xcel, https://www.documentcloud.org/documents/4340162-Xcel-Solicitation-Report.html

Cost of Renewable & Traditional Electricity Equalizing

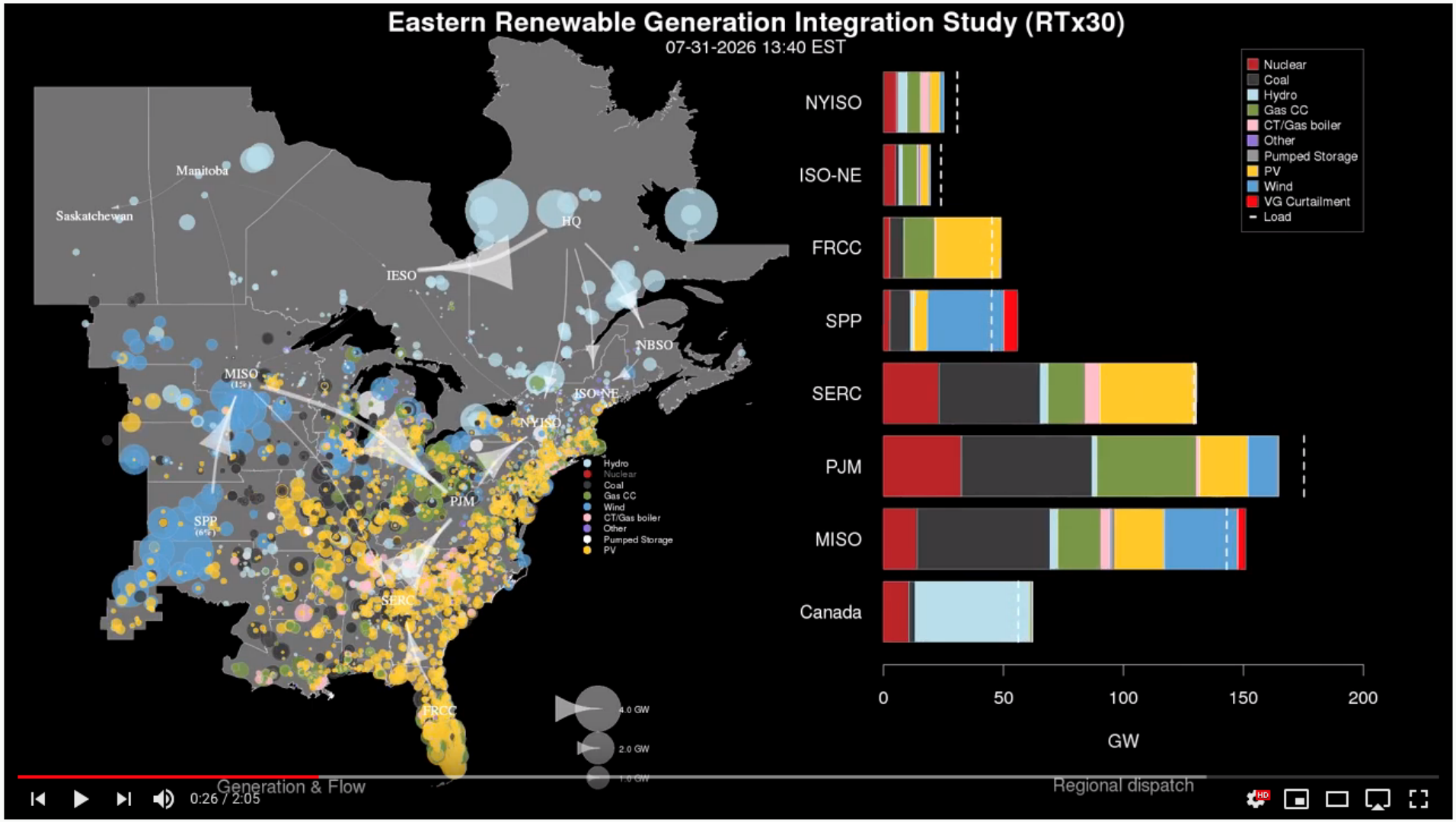
Levelized Cost of Electricity ranges by technology. Values are in 2017$.



2019 ATB LCOE range by technology for 2017 based on R&D financial assumptions

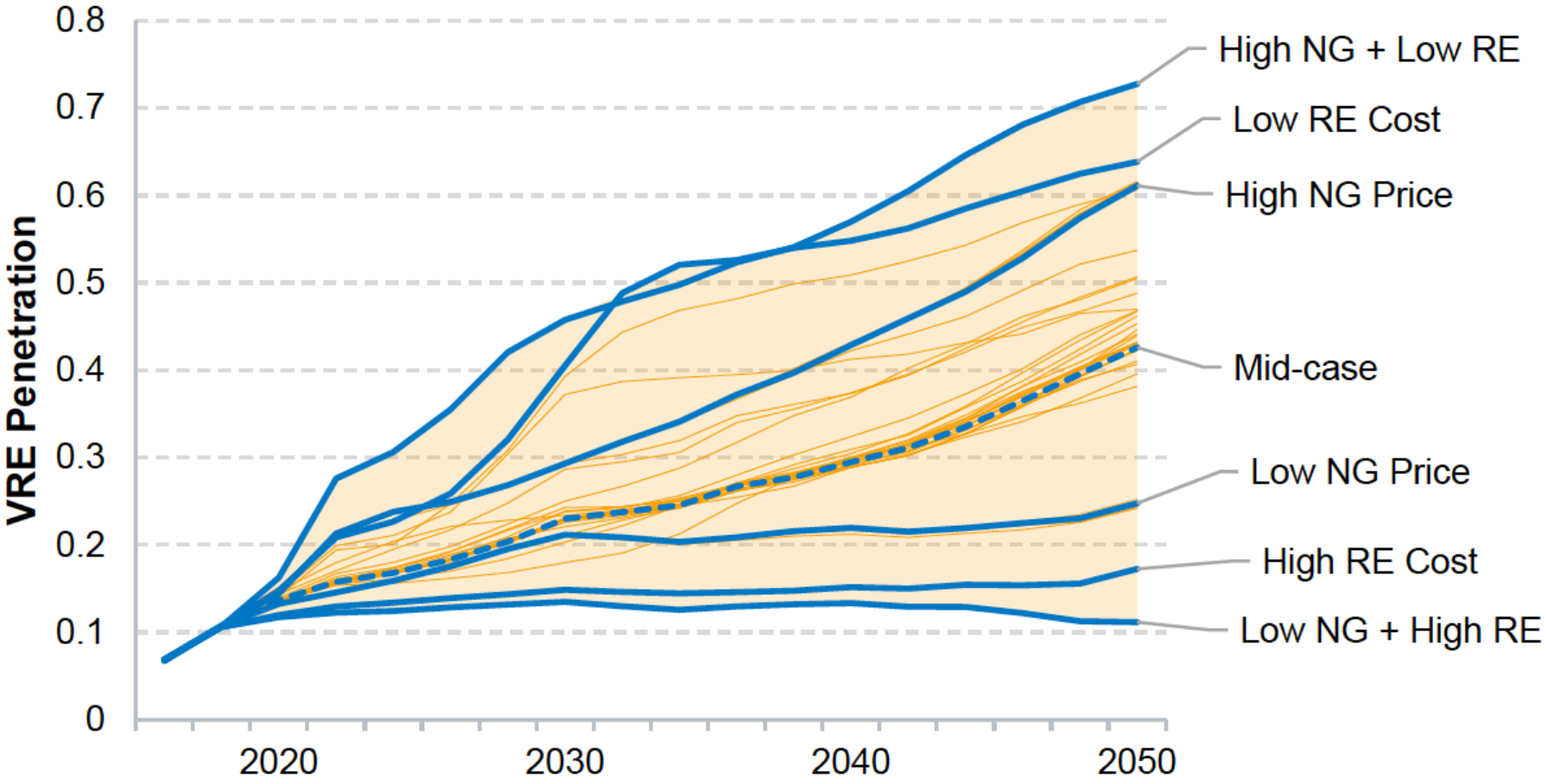
Source: National Renewable Energy Laboratory Annual Technology Baseline (2019), http://atb.nrel.gov

Advanced grid integration studies



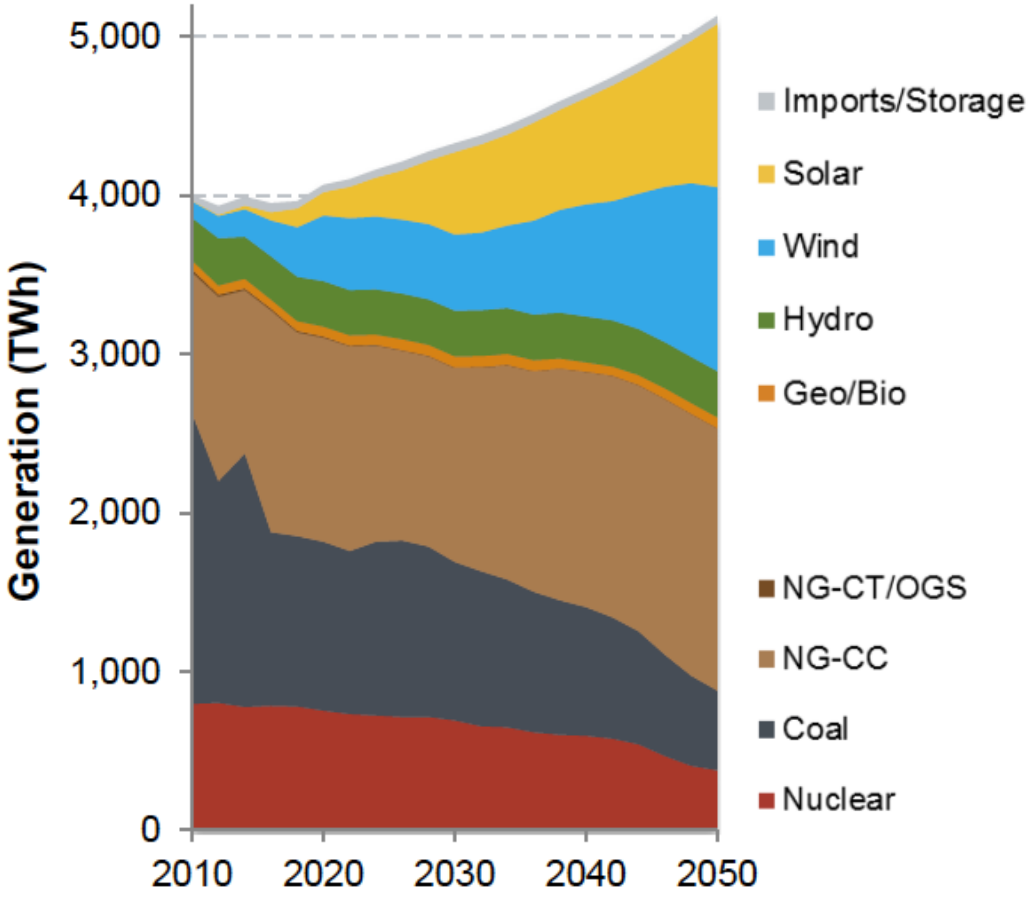
https://www.youtube.com/watch?v=li8jO-pKgvc&list=PLmIn8Hncs7bEl4P8z6-KCliwbYrwANv4p&index=19

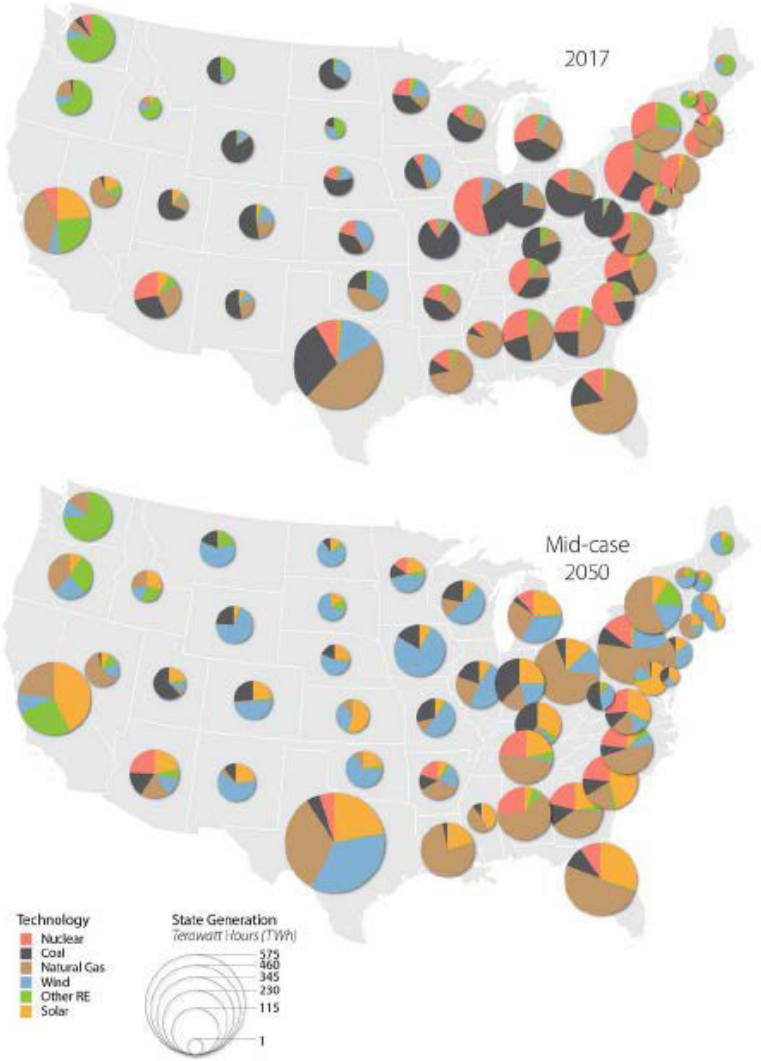
Future: NREL electricity generation scenarios



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

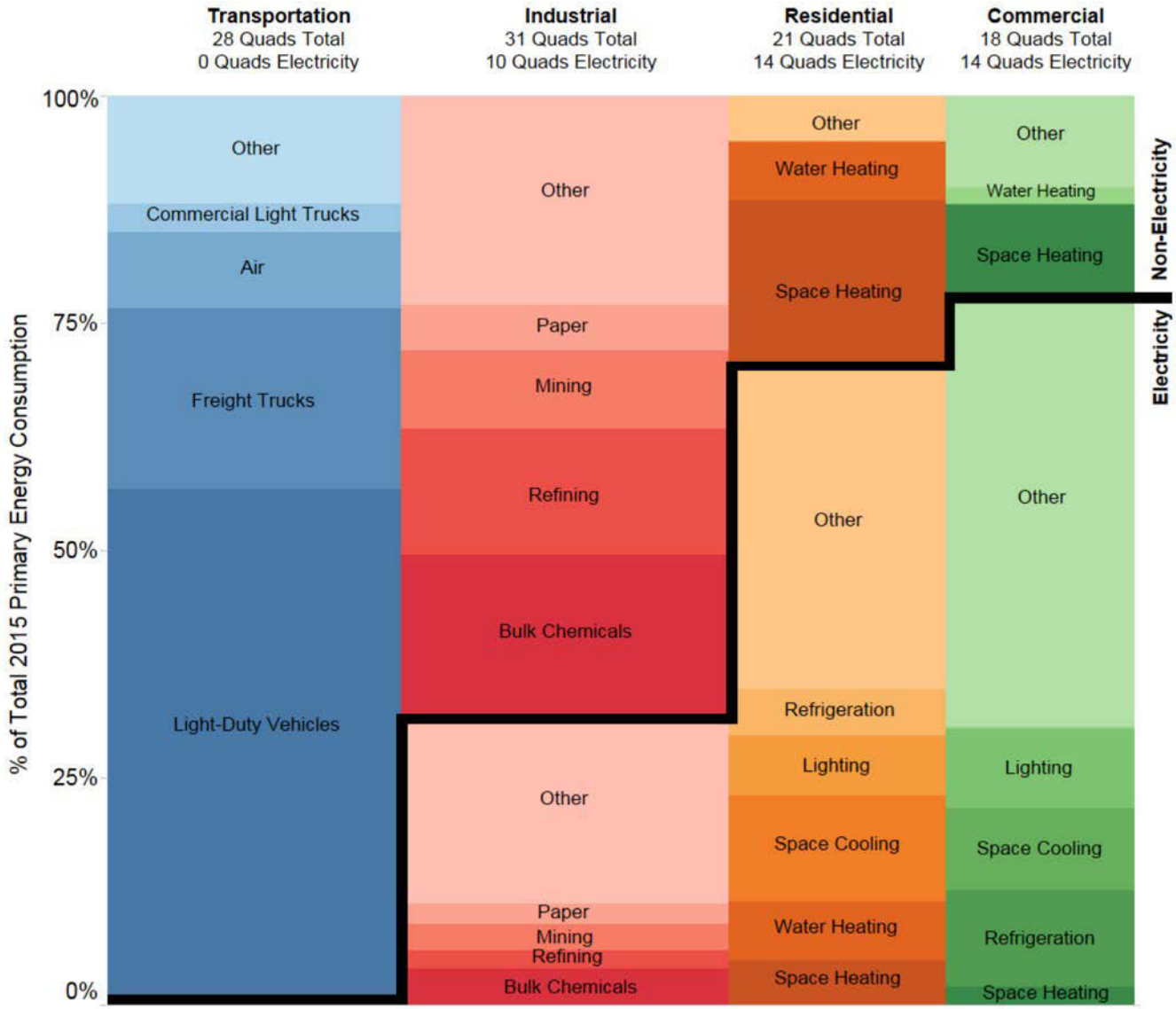
NREL electricity scenario mid-case generation mix





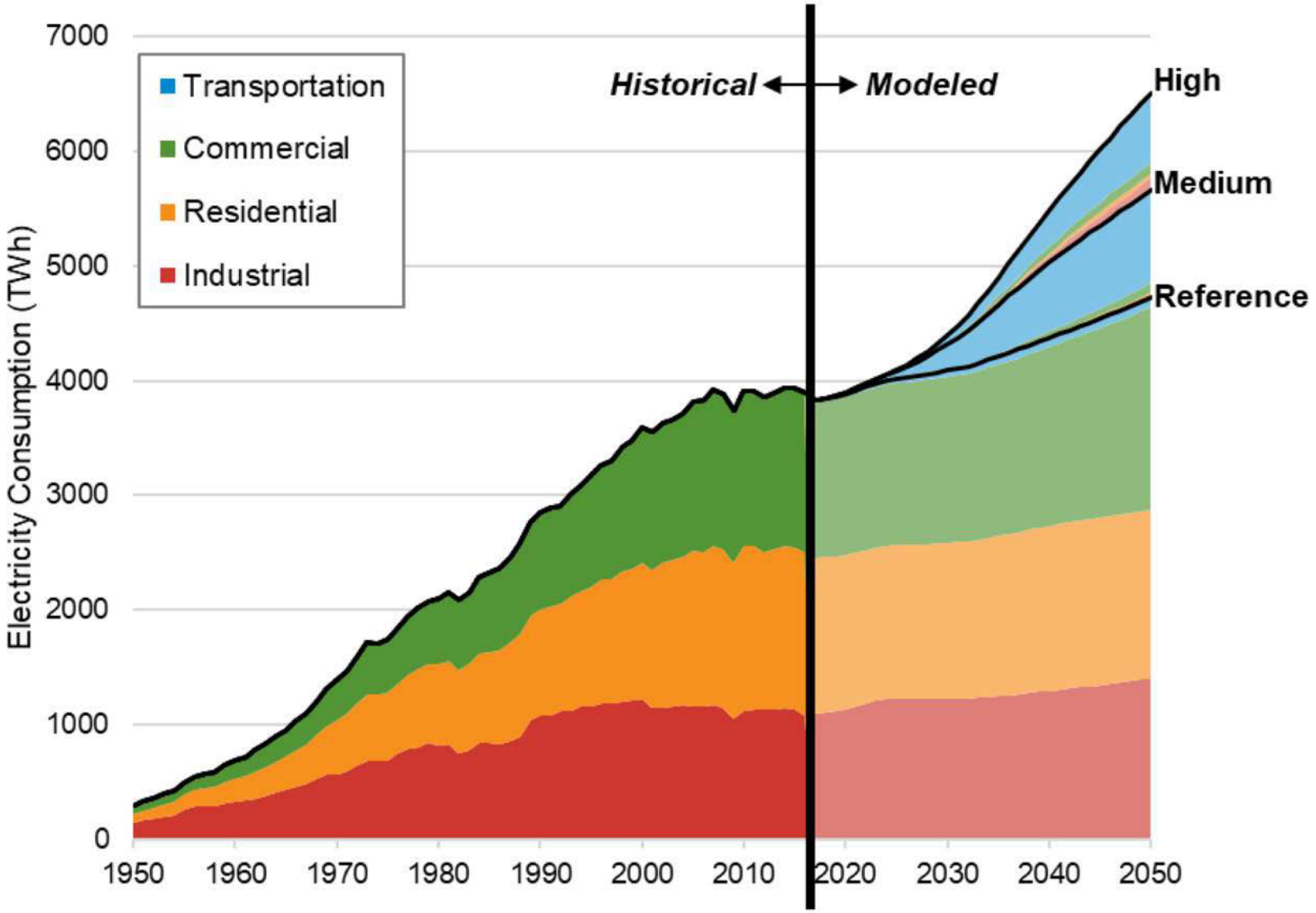
Generation by technology type in the Central Scenario, from: NREL 2018 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

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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Wind Turbines - Onshore

Peetz Table Wind Energy Center

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

Cedar Creek Wind Farm

- Grover, Colorado
- 550 MW, 397 turbines

Wind Turbines – Offshore

Block Island Wind Farm

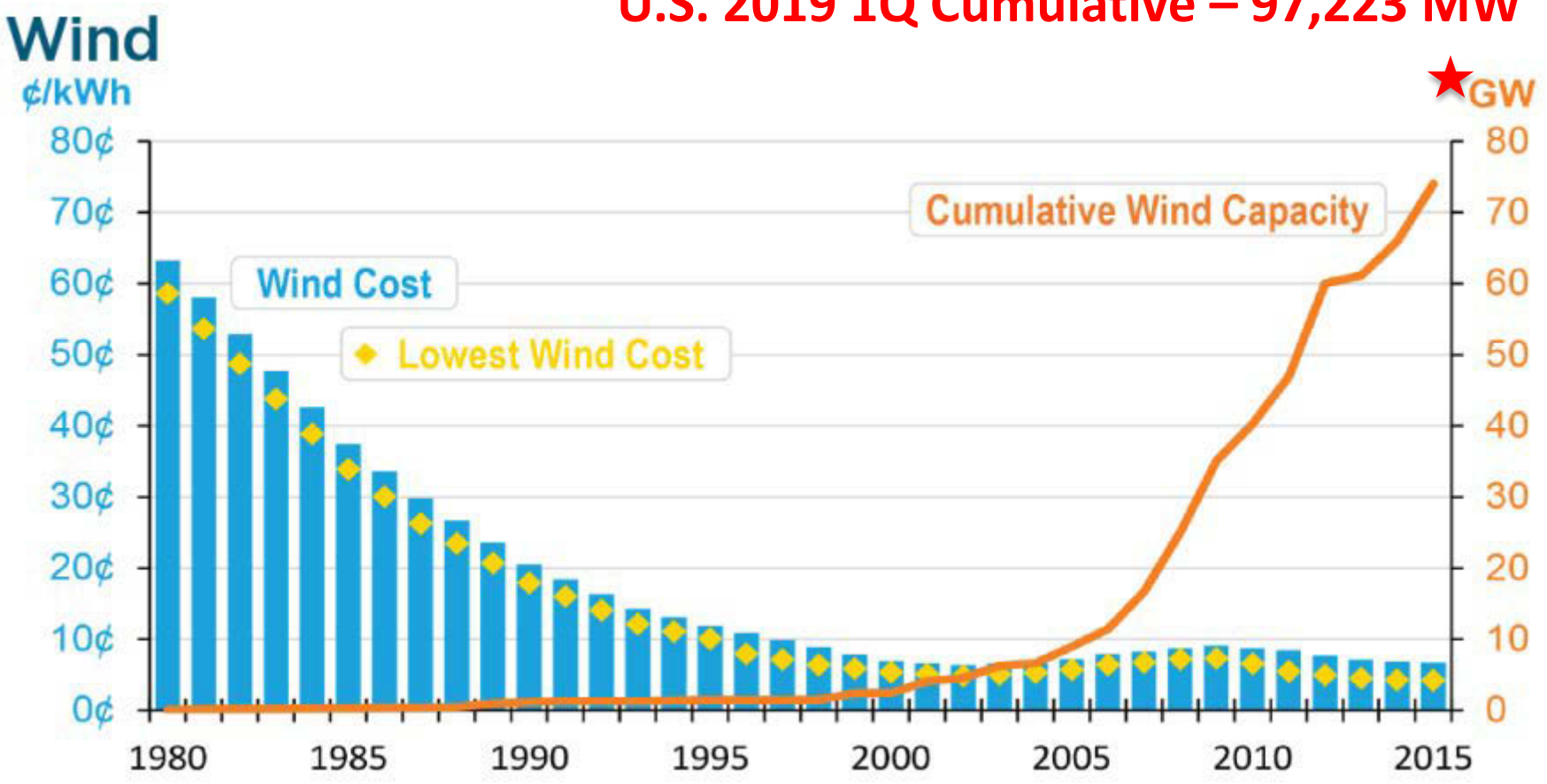
- New Shoreham, Rhode Island
- 30 MW, 5 turbines
- 100 m hub height, 150 m diameter
- Opened 2016
- Capacity Factor 48% (projected)

Westermeerwind Wind Farm

- Noordoostpolder, Netherlands
- 144 MW

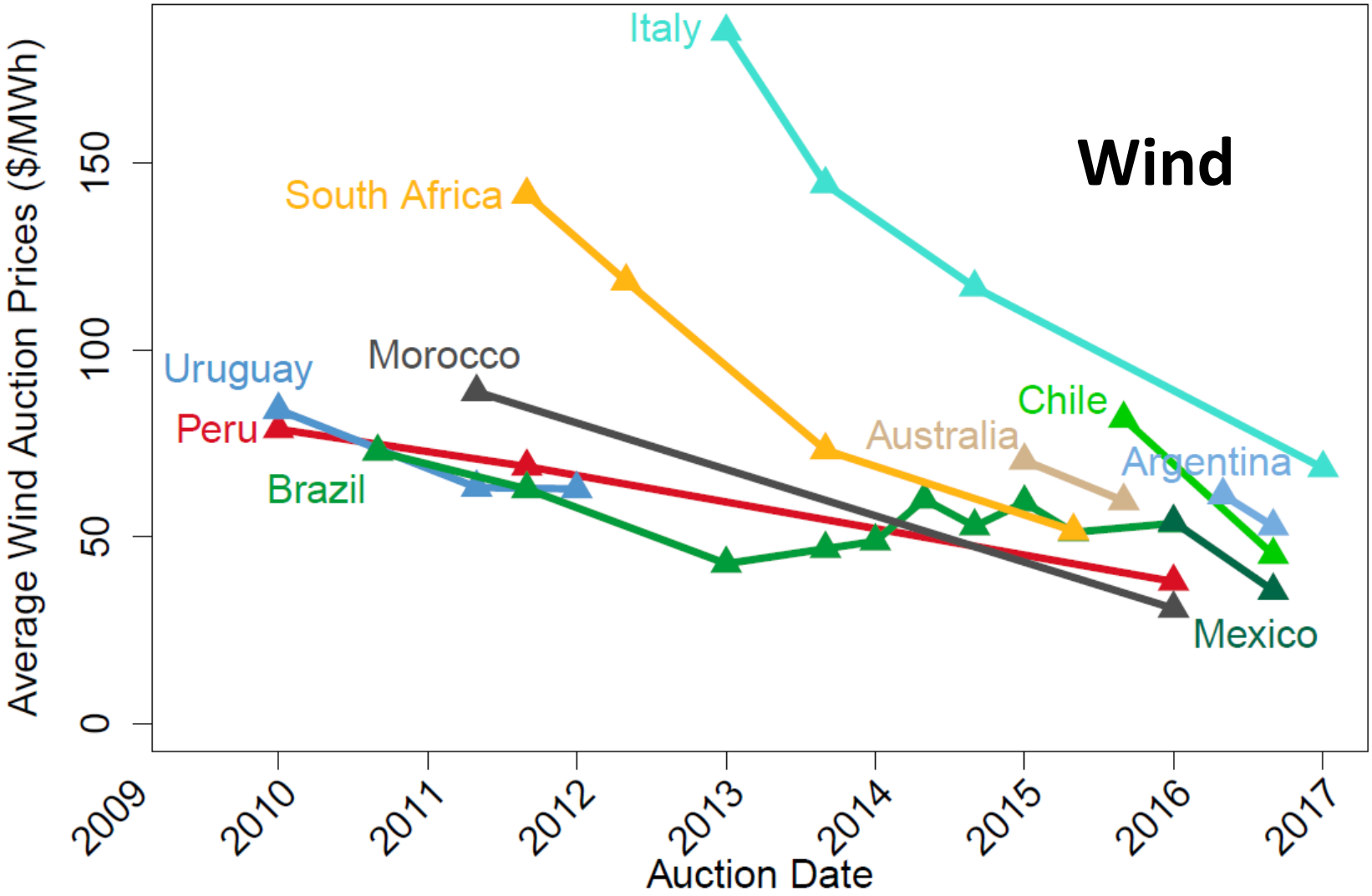
Wind Market Growth Driven by Price Declines

U.S. 2019 1Q Cumulative – 97,223 MW



Source: DOE 2016: Revolution…now, the future arrives for five clean energy technologies; AWEA, https://www.awea.org.

Cost of Renewable Electricity at Auctions Driving Decrease

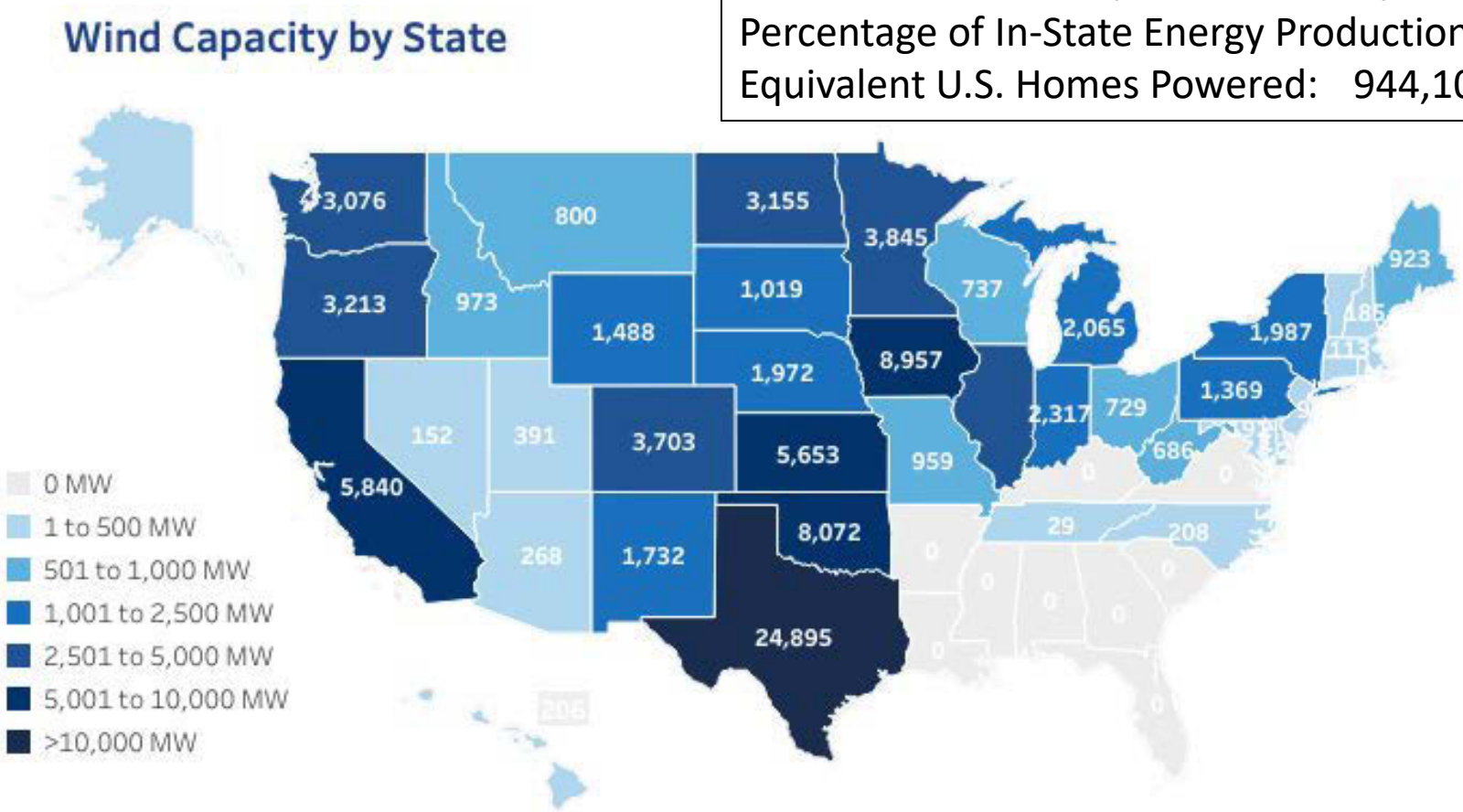


Source: IRENA Renewable Energy Auctions: Analysing 2016 (2017)

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



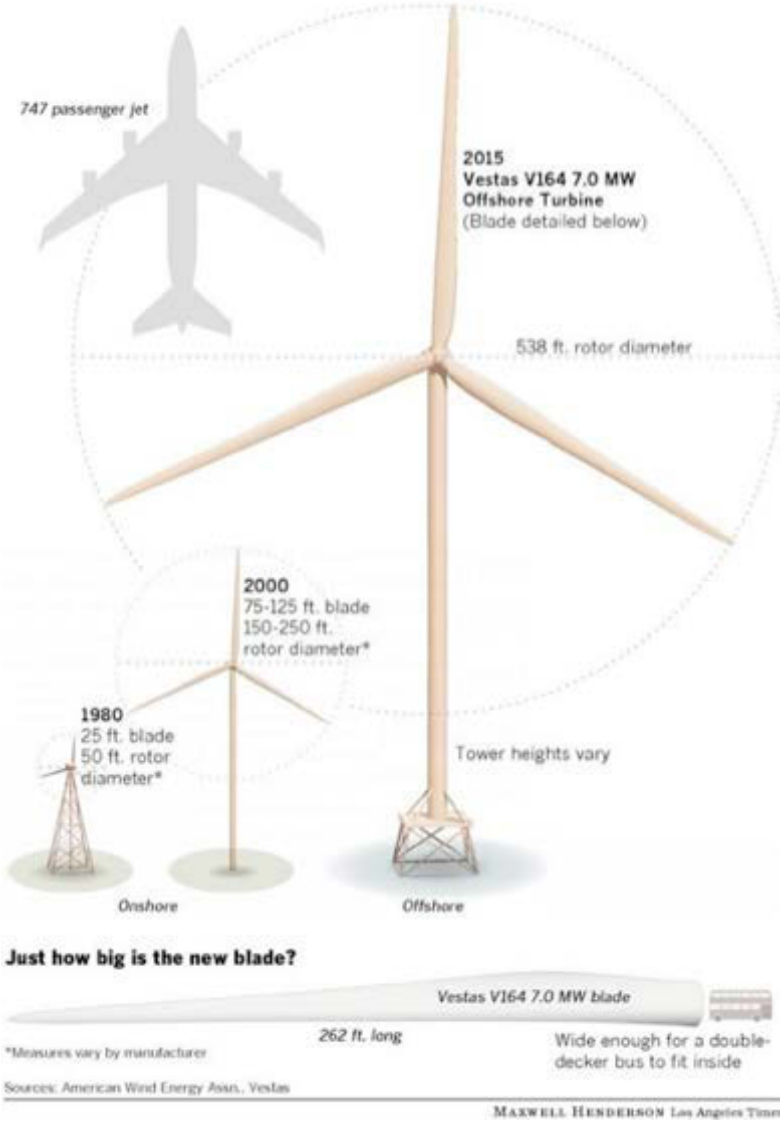
Source: American Wind Energy Association, https://www.awea.org/wind-energy-facts-at-a-glance/, https://www.awea.org/Awea/media/Resources/StateFactSheets/Colorado.pdf

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

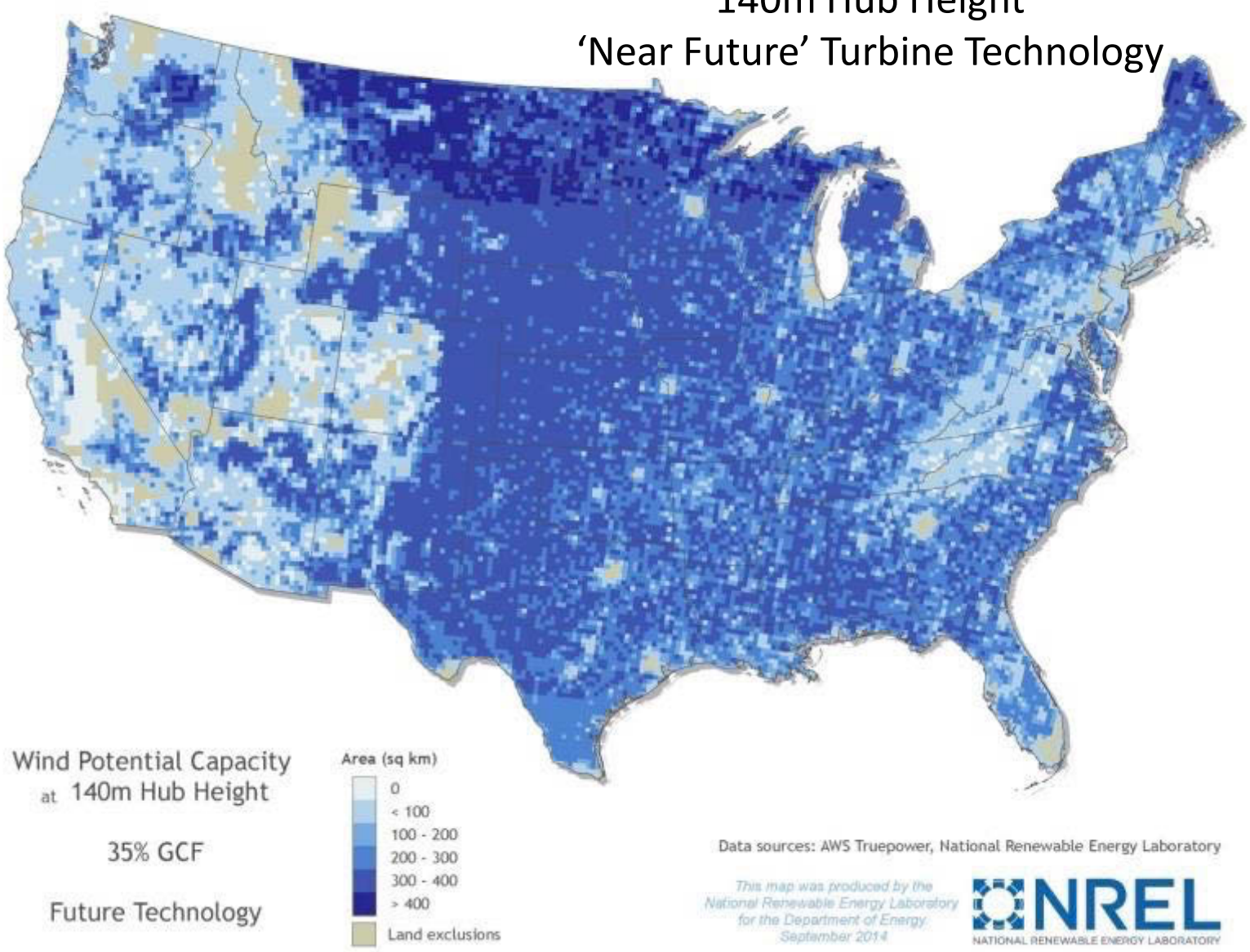
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

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

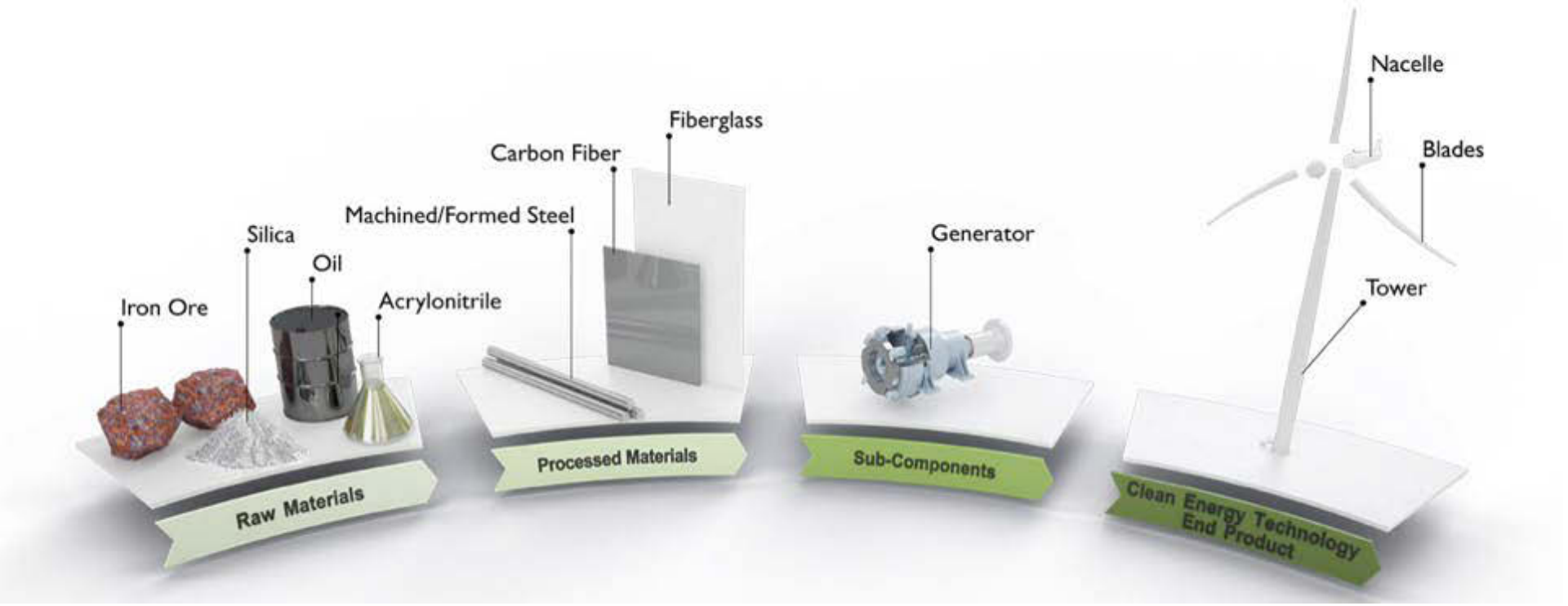
Compare: Natural Gas Plant: 56%; Coal Fired Plant: 53%; Nuclear: 92%; Solar Photovoltaic: 27%



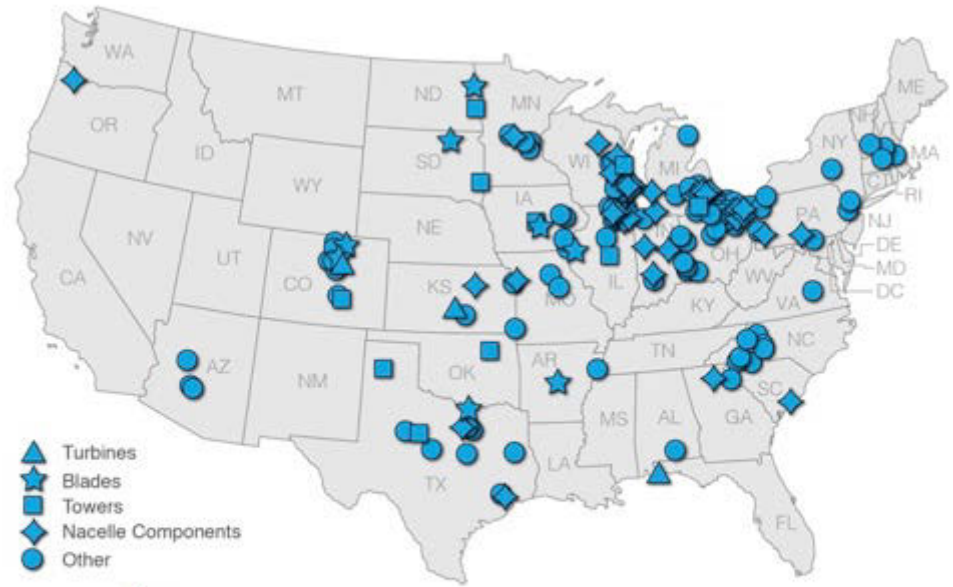
Wind Energy Potential Increasing to More Places



Supply chain of wind turbines



Wind Power Manufacturing



CEMAC
Clean Energy Manufacturing Analysis Center

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

More than 145 major wind turbine manufacturing and assembly facilities operate in the U.S. with more than 500 manufacturing facilities total contributing.

U.S. leading wind turbine manufacturing

- One of the top three countries for wind turbine manufacturing
- U.S.-made turbines installed domestically & exported to Canada, Brazil, and Mexico
- $3.76 billion value added to U.S. economy in 2014
- Domestic content is 80%–85% for towers, 50%–70% for blades/hubs, & >85% for nacelles

Leadership came from public & private support

- Technology validated and improved through NREL research and industry partnerships
- Early government policies encouraged deployment
- Market growth enabled establishment of supply chains and manufacturing at scale
- Resulting price declines enabled more growth
- Trade agreements enabled $560 million in exports in 2014
- New innovations still being developed at NREL

Sources: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017; Wind Turbines Made in the USA, CEMAC Blog, 2017.

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Electricity Generation: Electric-Natural Gas Interface Study

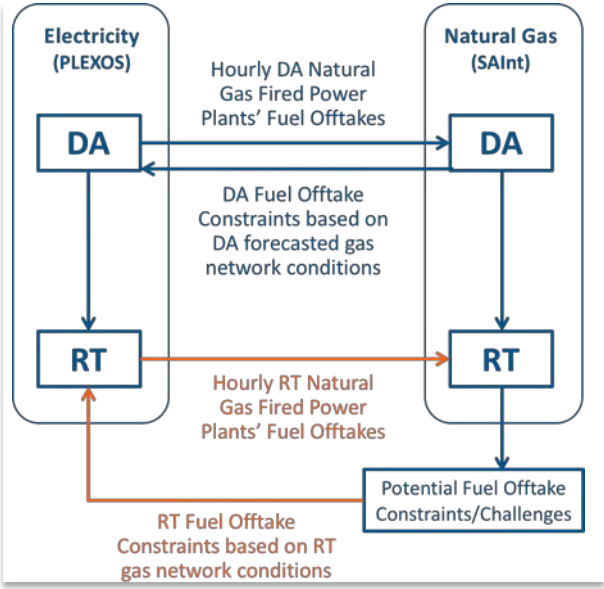
Electricity & **Gas** networks are **interconnected** energy infrastructures whose operation and reliability depend on one another. As the percent of gas and variable renewable power plants increase, the connection between these networks becomes increasingly important.

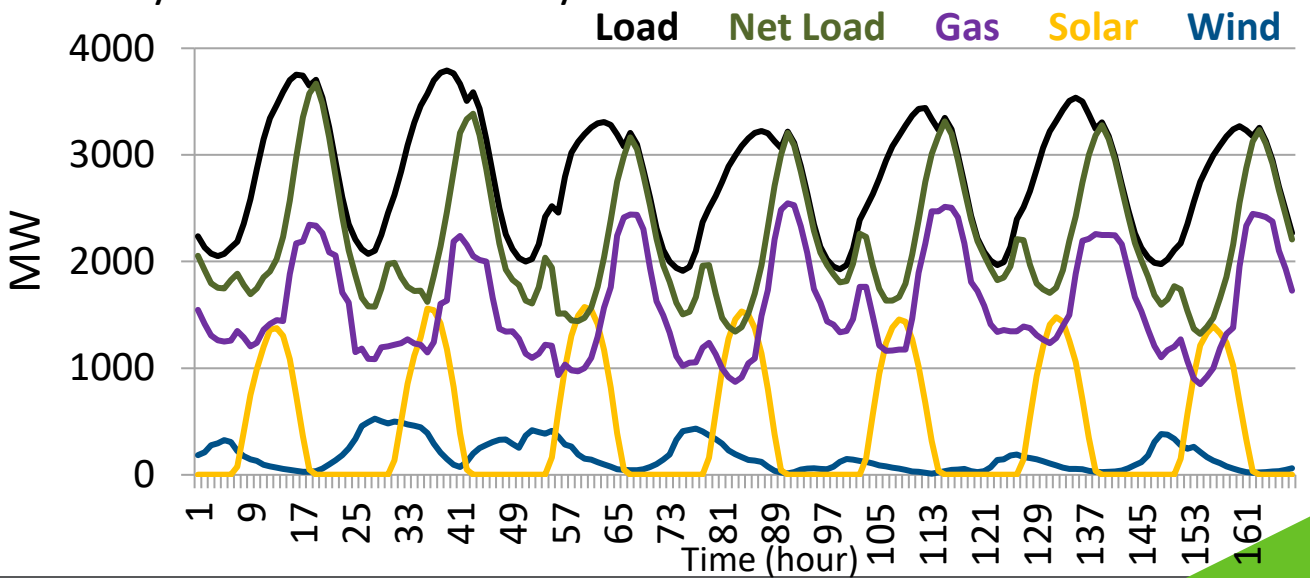
Goal of project is to:

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.

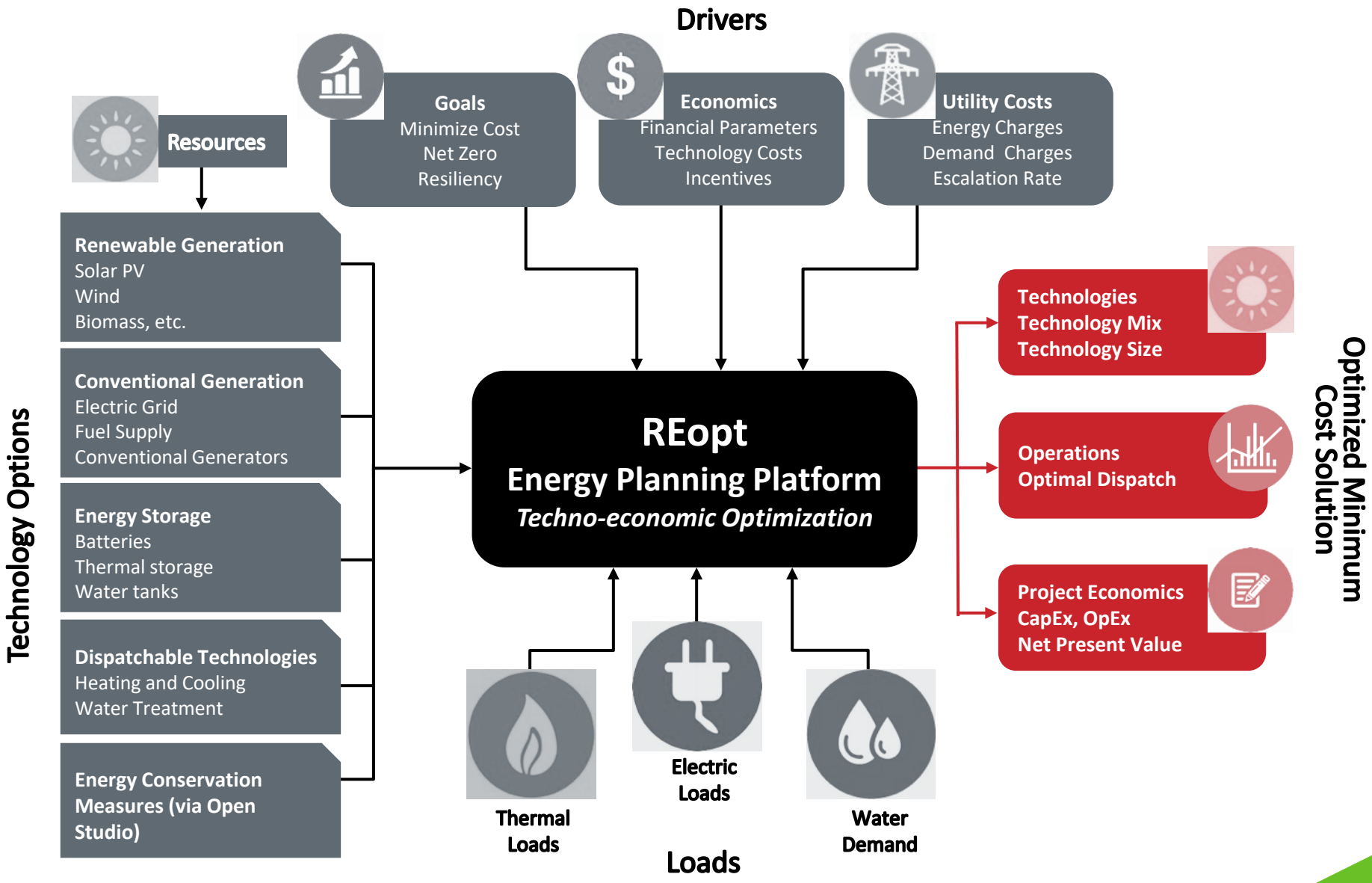
Project Objective

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**

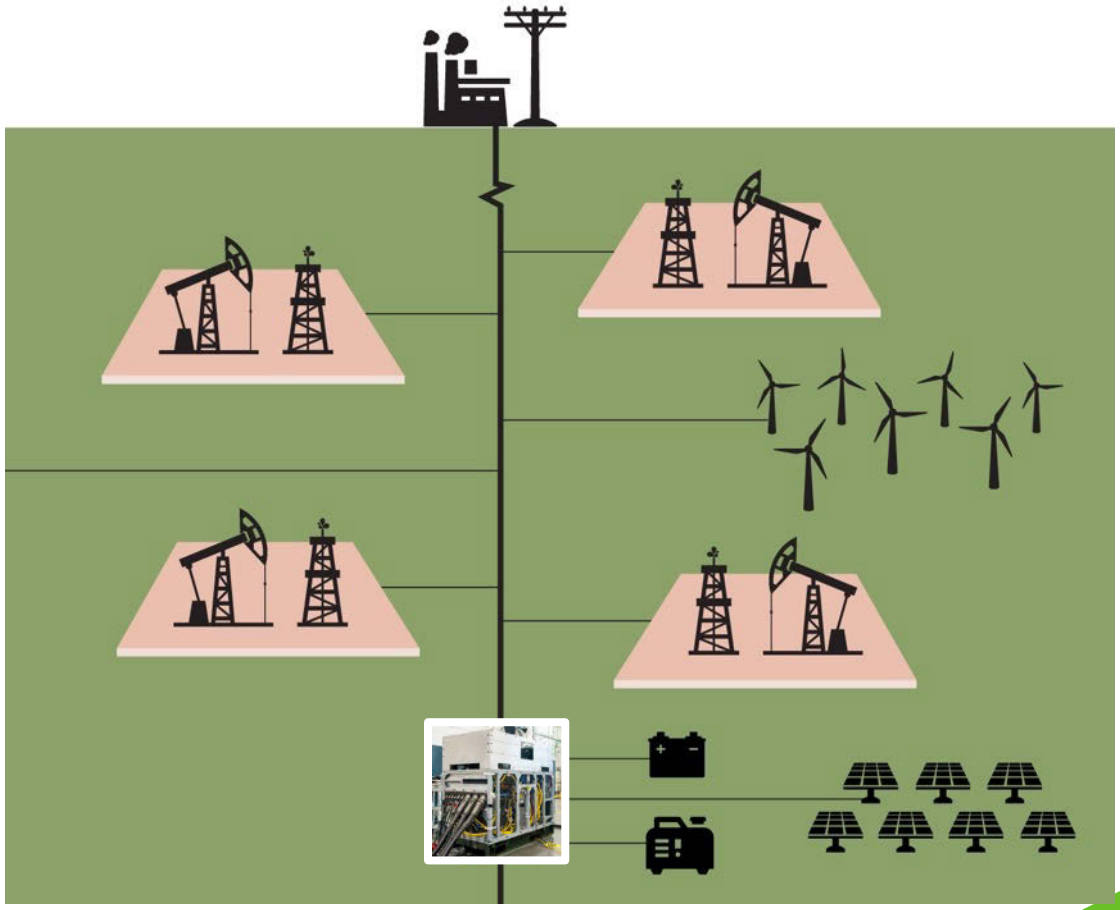
Starting similar project for mining.

REopt: Optimizing energy at site scale



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



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

Miraah

Customer: **Petroleum Development Oman**
Location: **Amal, Oman**
Status: **Under construction**
Energy Production: **1,021 MW thermal (1 GW)**

Opportunities for Collaboration: Modeling of operations, technology design optimization, and technoeconomic site analysis

Miraah CSP system designed to:

- Produce 6,000 tons of solar steam each day for thermal EOR operations.
- Save 5.6 trillion Btus of natural gas each year.
- Reduce CO2 emissions by more than 300,000 tons each year.

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

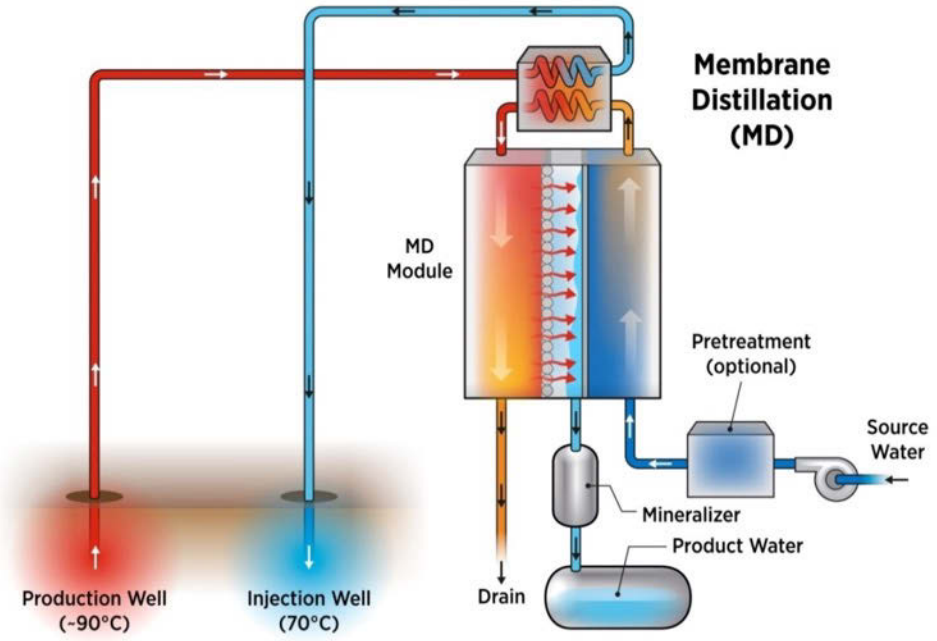
Example Thermal Solution: Geothermal-powered Desalination Technologies

NREL is working to develop desalination technologies with geothermal

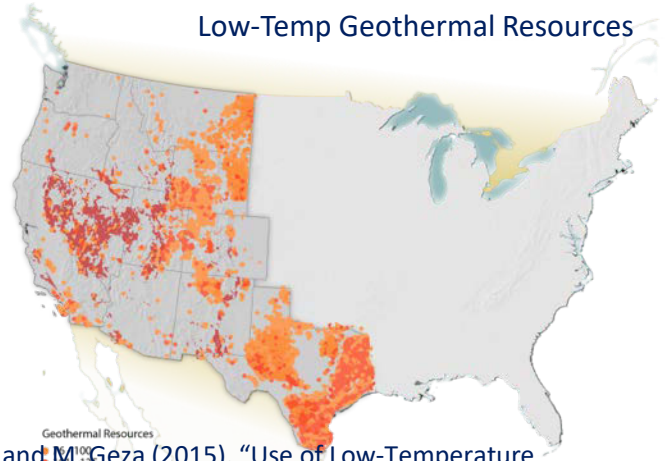
- Partnership with Colorado School of Mines
- Pilot plant development in the U.S. Southwest
- Development of a geothermal desalination decision support tool

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



Low-Temp Geothermal Resources

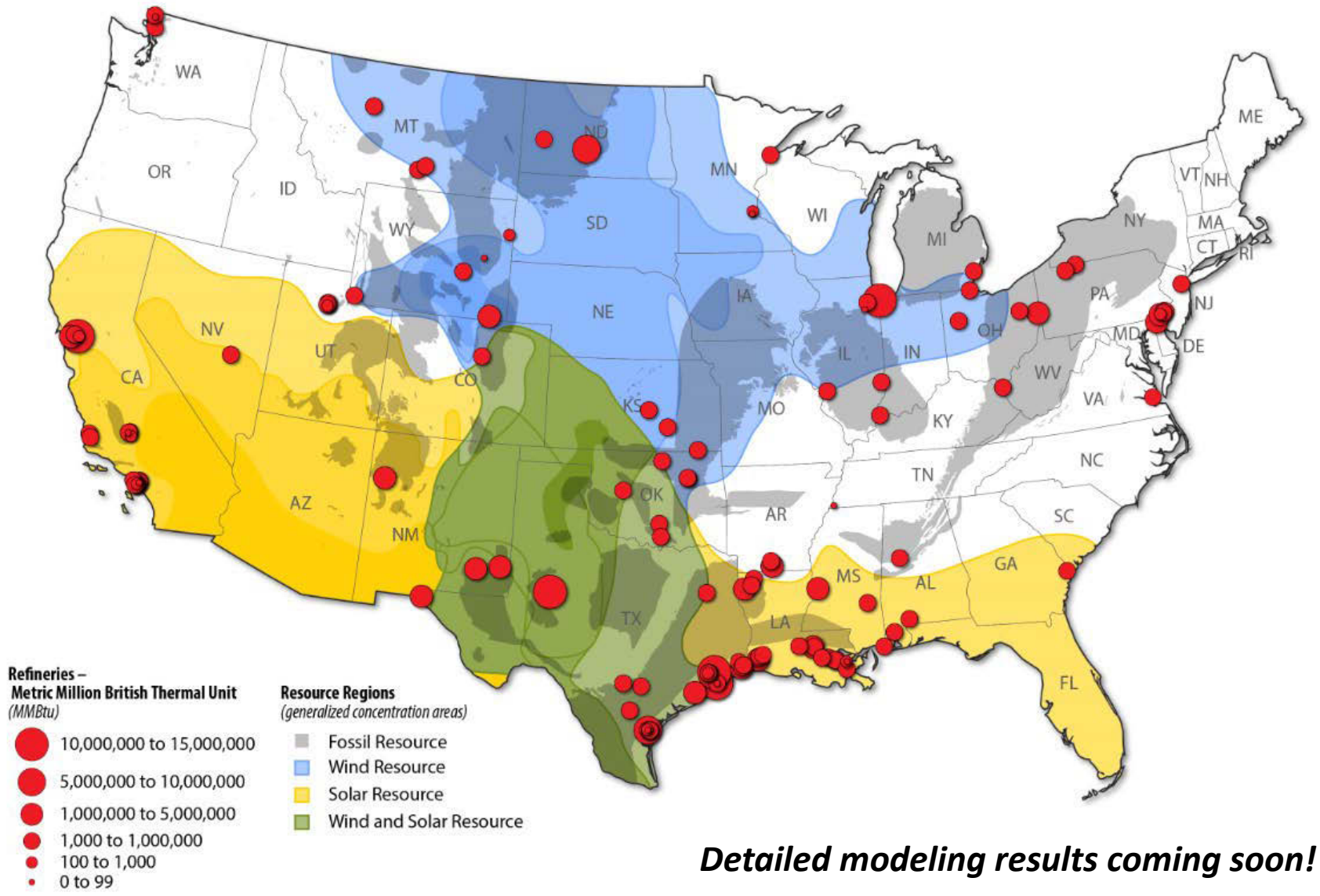


Membrane Distillation has advantages for renewable energy integration:

- 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

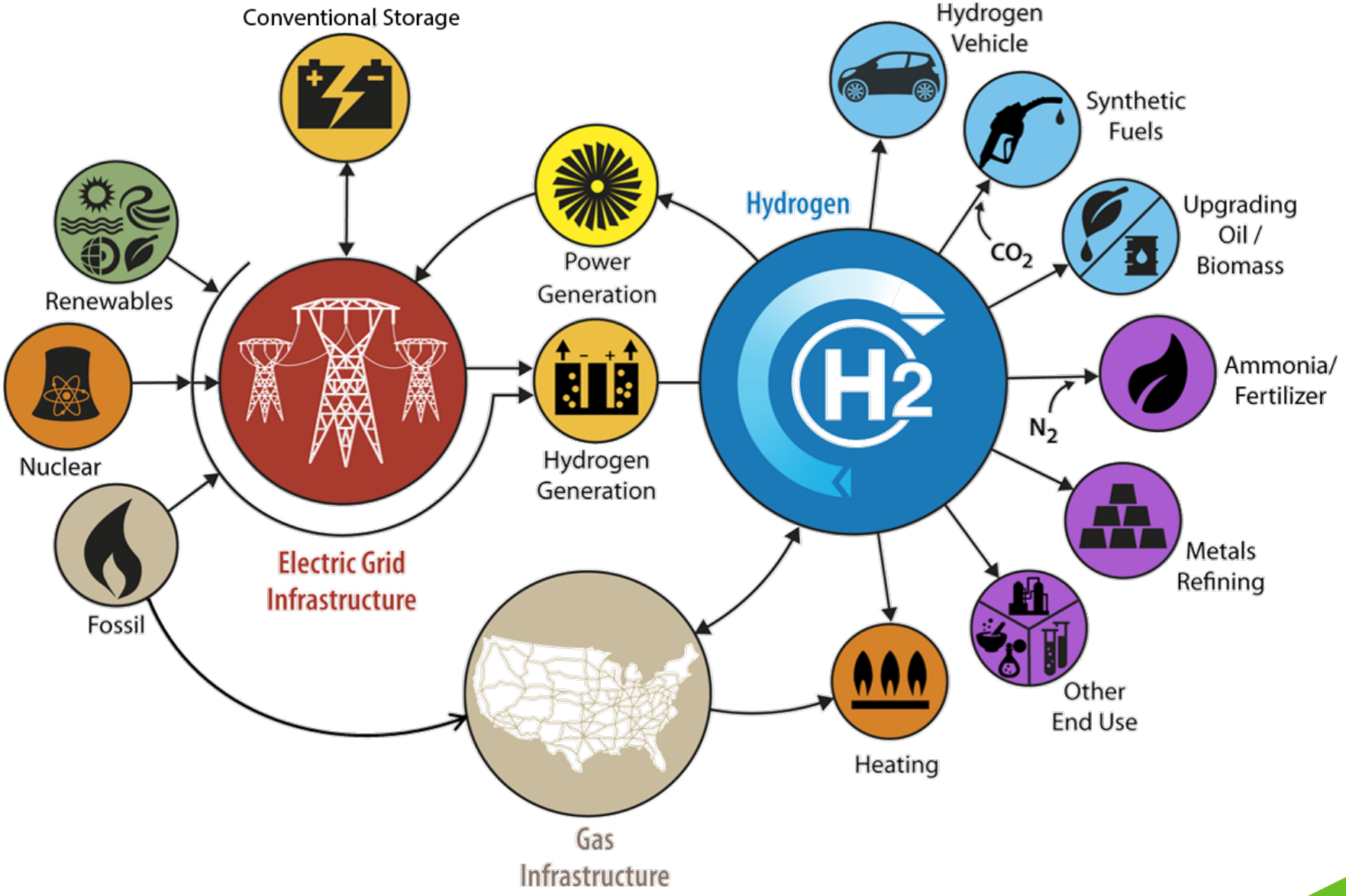
Turchi, C., Akar, S., Cath, T., Vanneste, J., and M. Geza (2015). "Use of Low-Temperature Geothermal Energy for Desalination in the Western United States." NREL/TP-5500-65277

Many refineries may have great wind AND solar resources

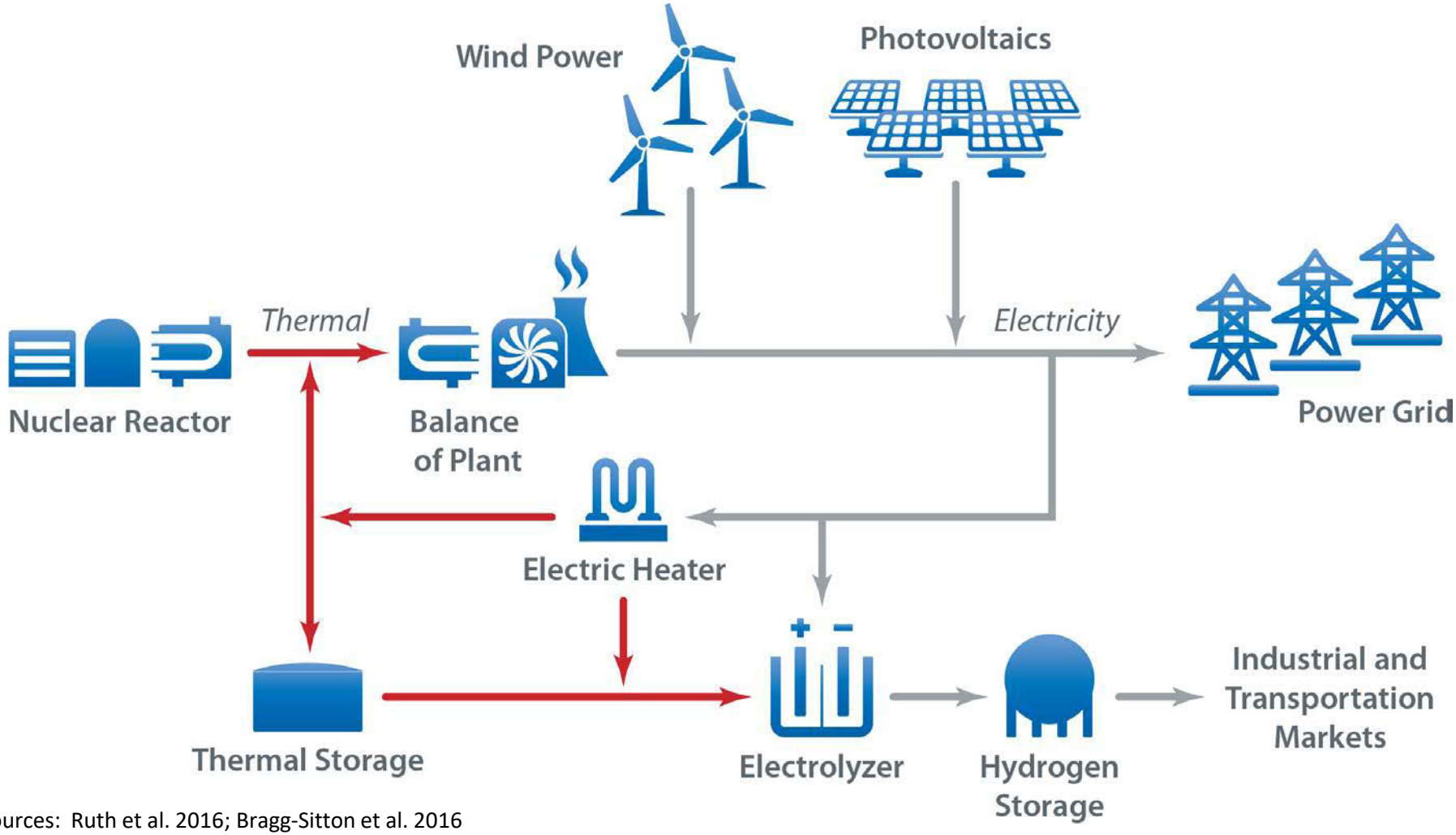


Detailed modeling results coming soon!

Hydrogen @ Scale



Renewable Hybrid Energy Solutions



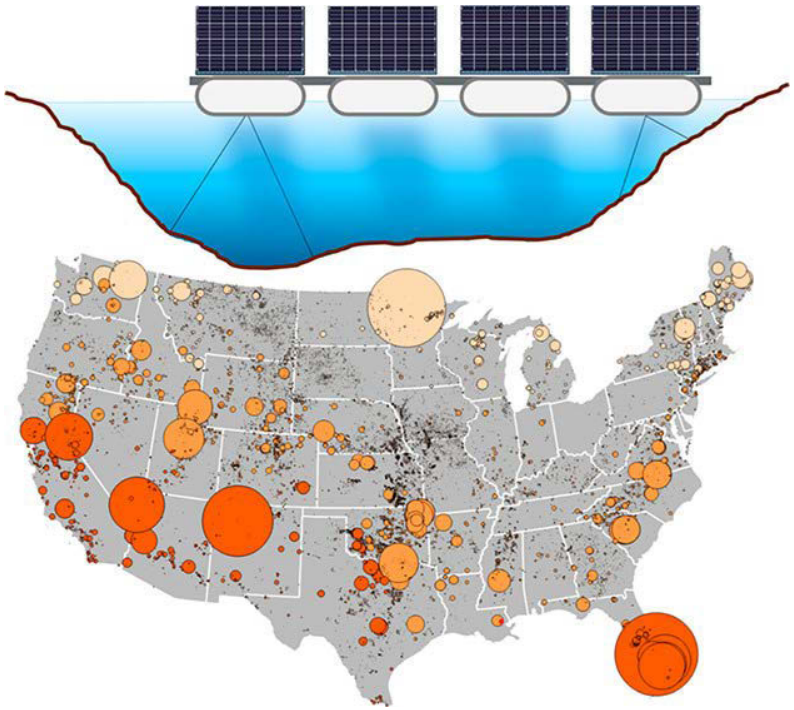
Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

Co-location of Wind/PV and Agriculture

Also looking at energy in entire food system.

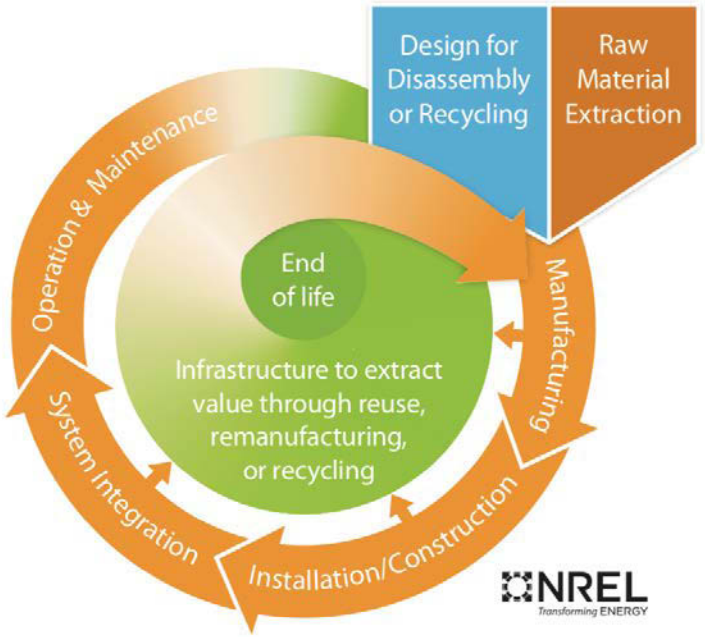
Floating Solar PV (FPV)

- 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.

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

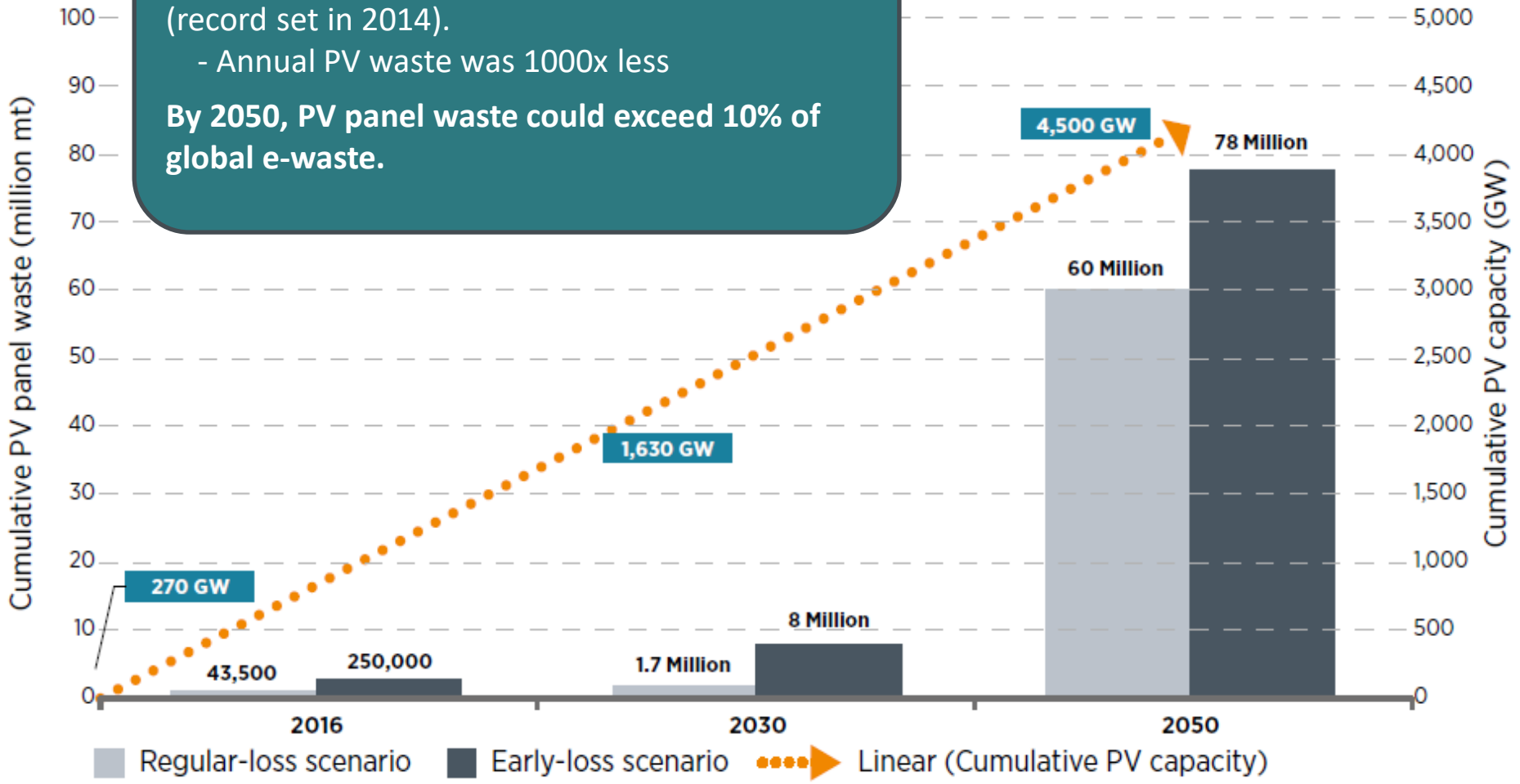
Reduce: thrifting, materials/element substitution

Reliability: validate performance, lifetime, predictability

Circular Economy: Growing PV Waste Will Need Technology, Engineering, and Policy Solutions

Global e-waste = 41.8 million metric tonnes (record set in 2014).
- Annual PV waste was 1000x less

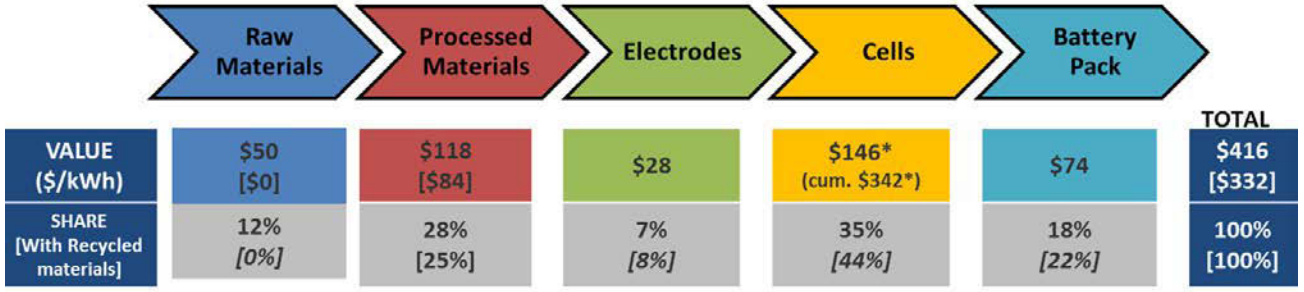
By 2050, PV panel waste could exceed 10% of global e-waste.



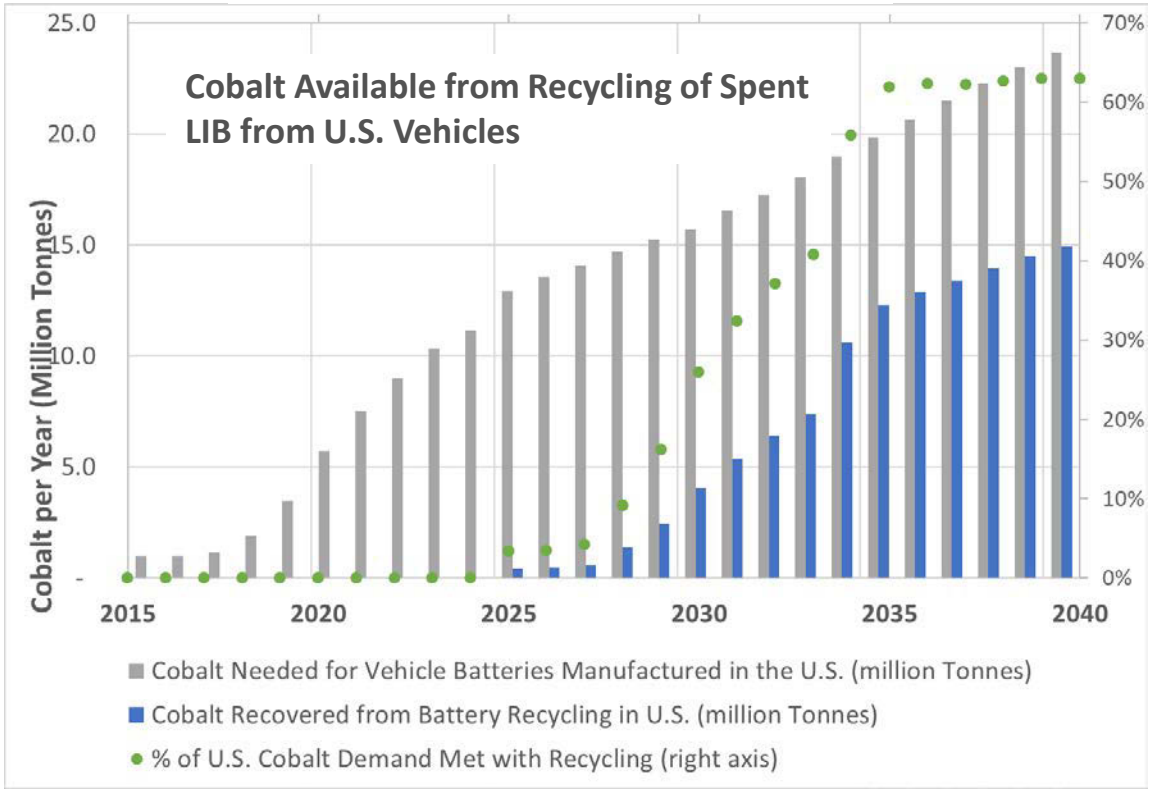
Source: IEA/IRENA 2016

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

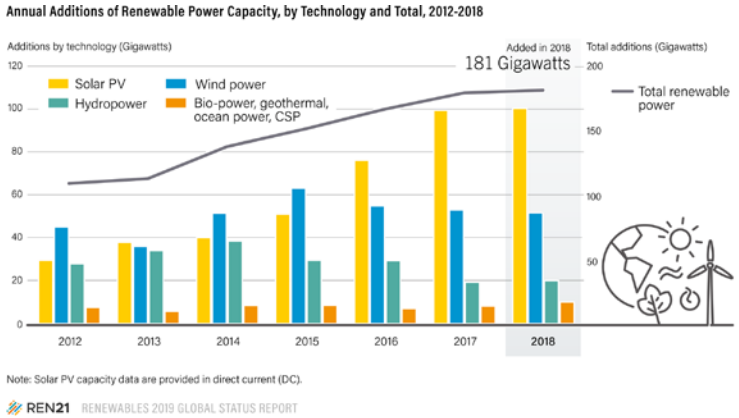
- Total global automotive Li-ion battery capacity is expected to exceed 90 GWh and require more than 500 thousand tons of battery materials (Li, Co, Mn, Ni, and Gr) by 2020
- Today, LIB recycling capacity is concentrated in EU and China
- U.S. is poised for expansion of LIB recycling capacity; by 2040, 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.

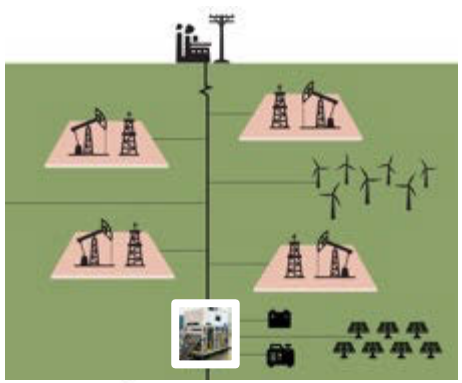


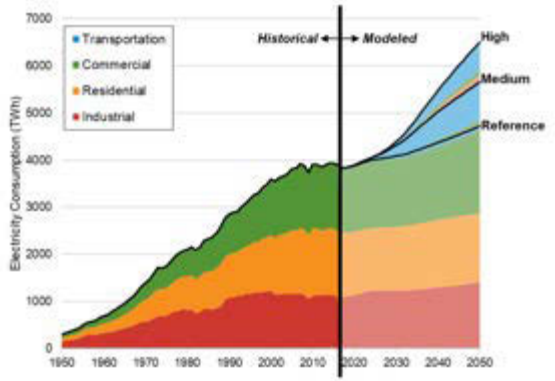
LIB Pack Value Chain in 2016 ($US/kWh)



Conclusion and Discussion







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




Questions and Discussion

Thank you!

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