JISEA Joint Institute for Strategic Energy Analysis

Renewable Energy for Industrial Environmental Management

University of Illinois Champaign-Urbana

5 September 2019

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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.

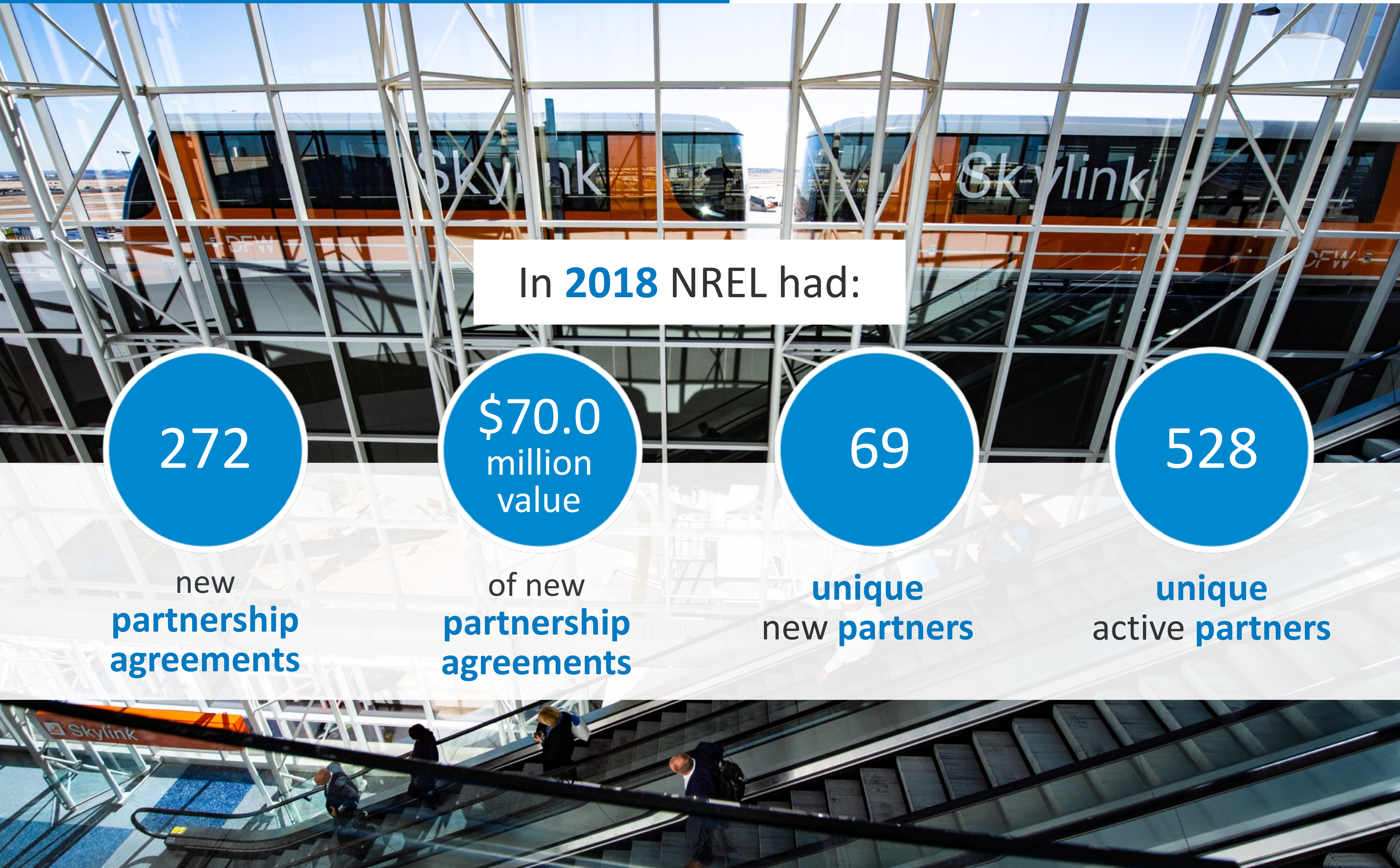
Example Technology Areas:

- 2050 employees, plus 400 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre 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

NREL Partners with Business

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

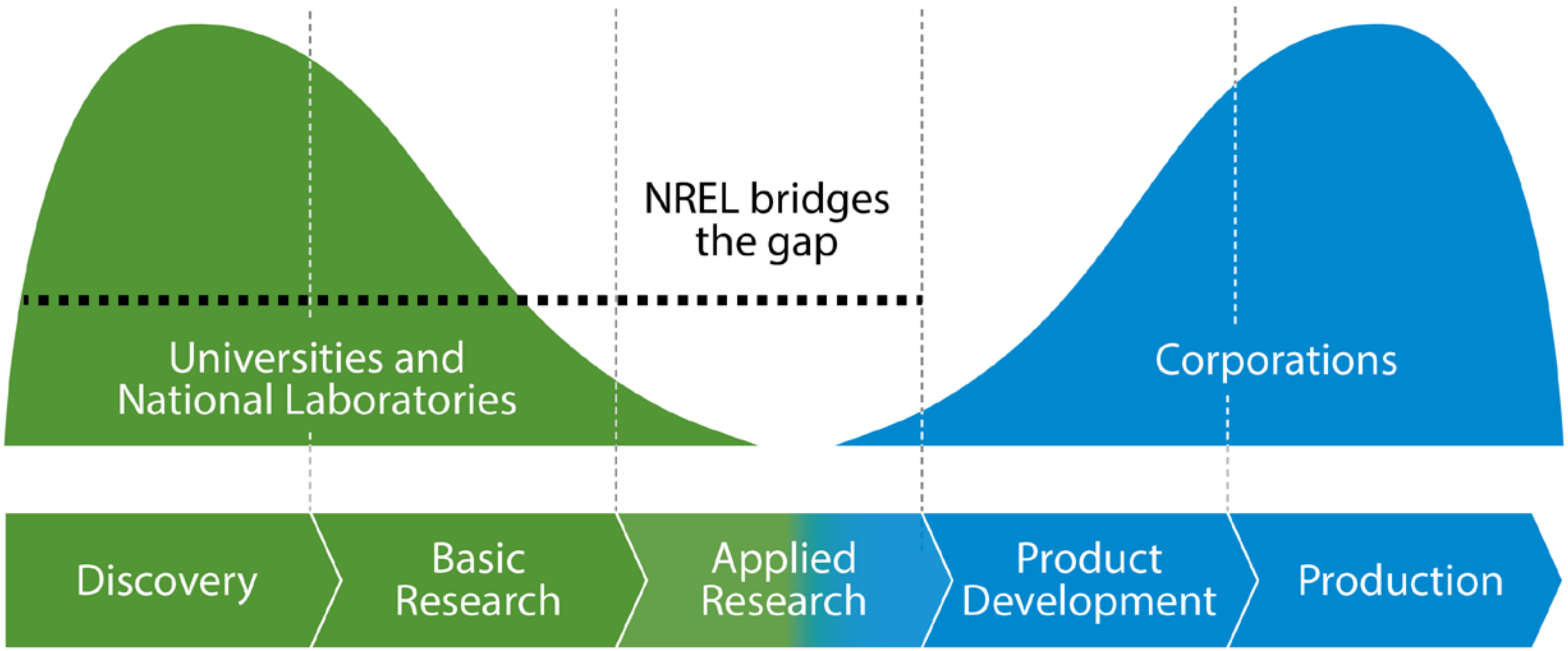


In **2018** NREL had:

- **272** new **partnership agreements**
- **$70.0 million value** of new **partnership agreements**
- **69 unique** new **partners**
- **528 unique** active **partners**

NREL aims to reduce risk in bringing innovations to market

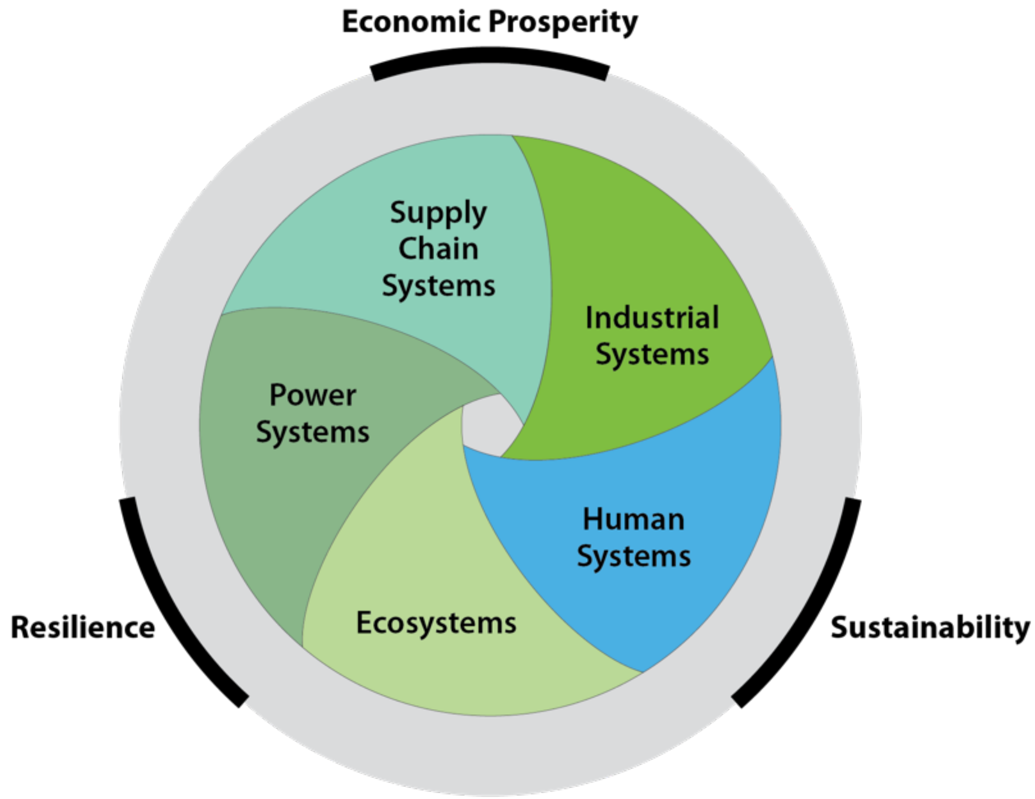
- NREL helps bridge the gap from basic science to commercial application
- Forward-thinking innovation yields disruptive and impactful results to benefit the entire U.S. economy
- Accelerated time to market delivers advantages to American businesses and consumers



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

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 The Thomas and Stacey Siebel Foundation
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

Outline

- Energy Markets and Trends
- Clean Energy Technology Manufacturing and Trade
    - Wind Turbines
- Nuclear, Renewables, and Gas

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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

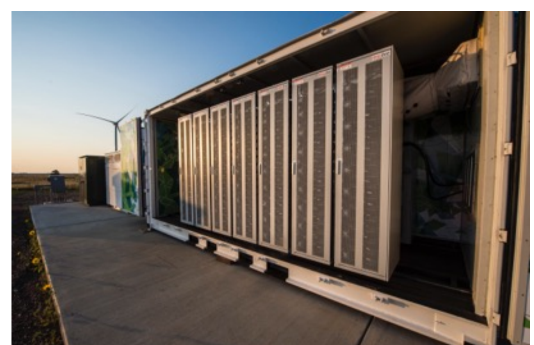
CONCENTRATING SOLAR

HYDROPOWER

Large & Small

Wave & Tidal

BATTERIES & STORAGE

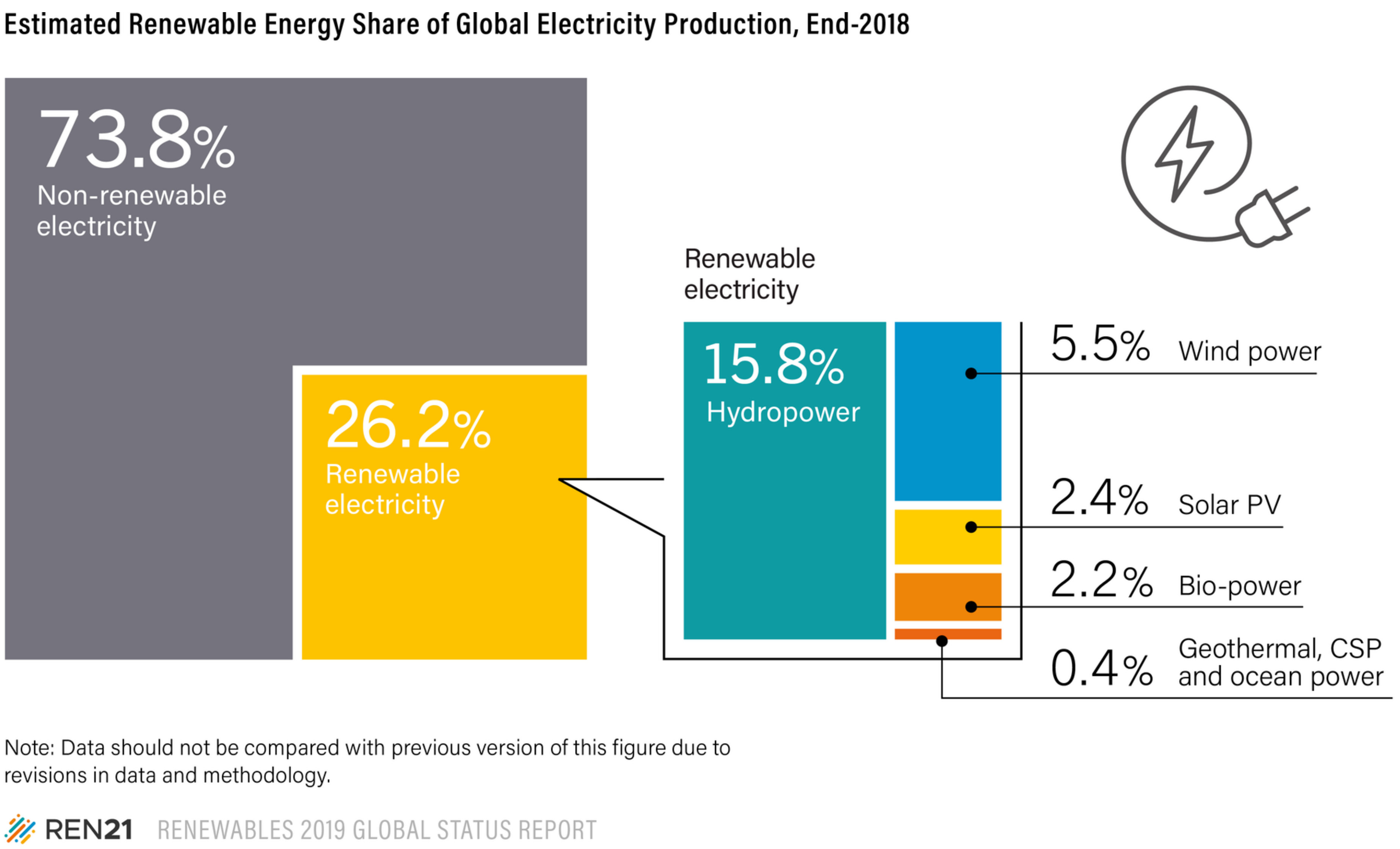


BIOMASS & WASTE

HYDROGEN & GAS

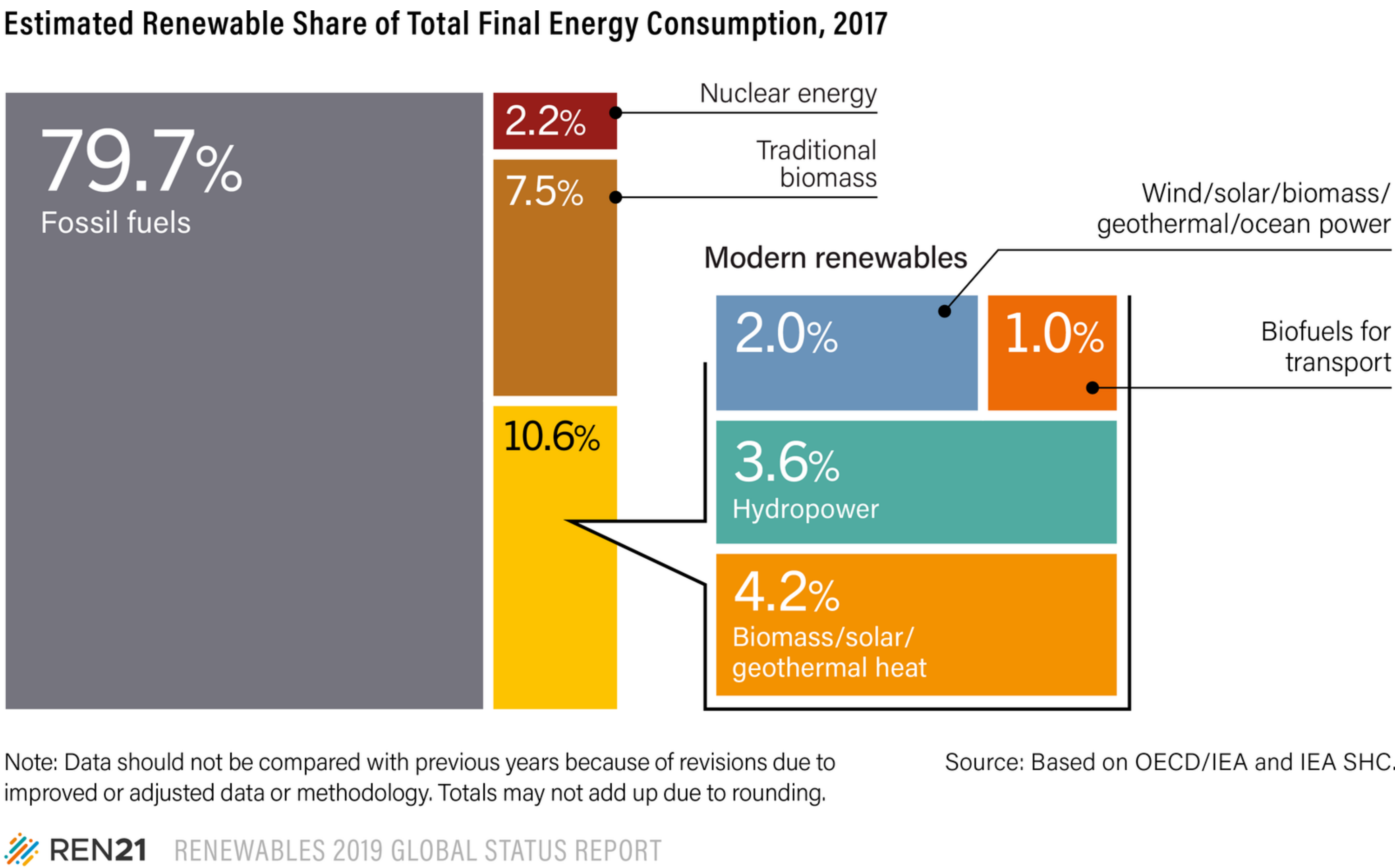
EFFICIENCY & HEAT USE

Global share of renewable energy



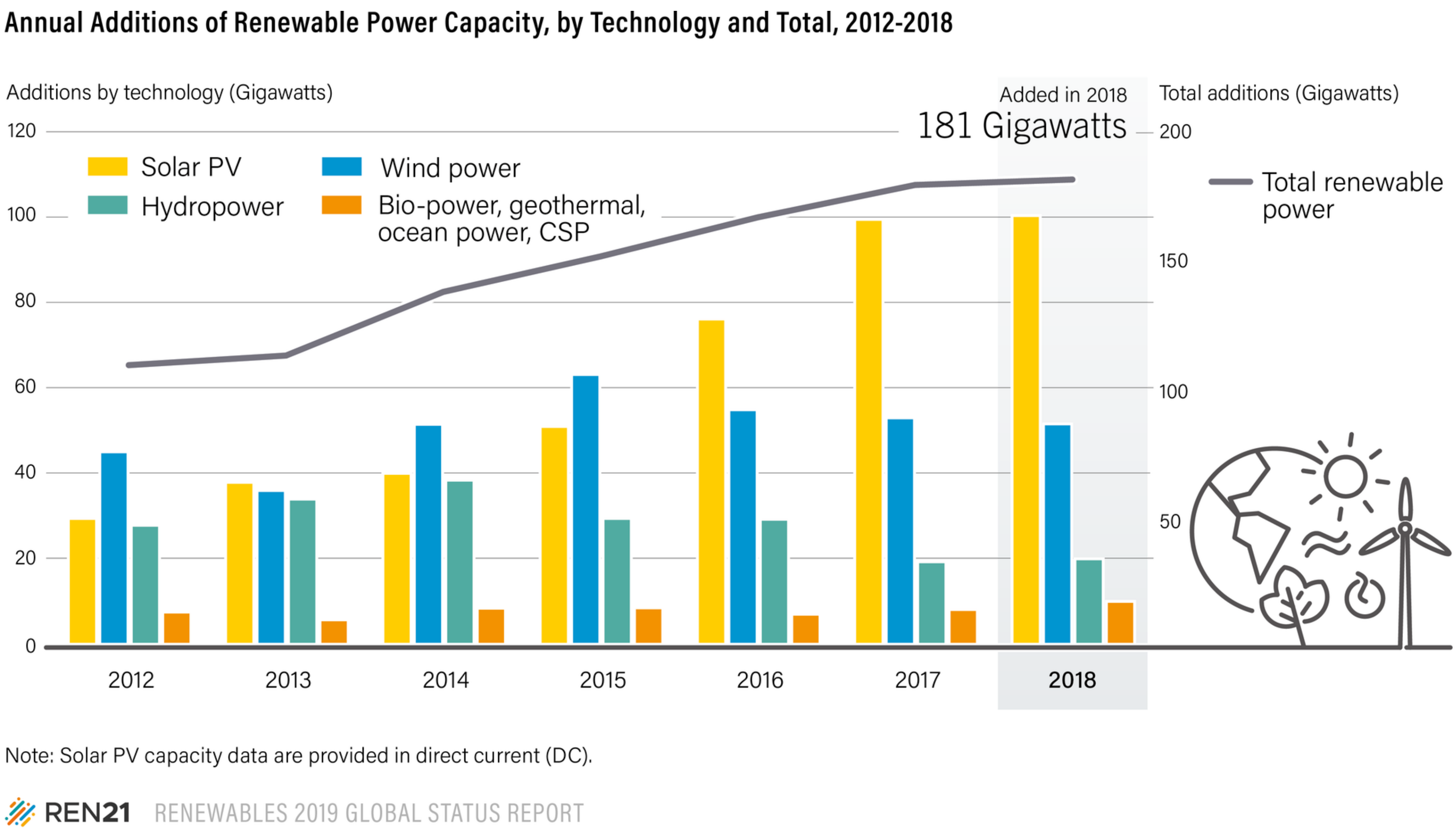
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

Global share of renewable energy



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

Global growth of renewable energy



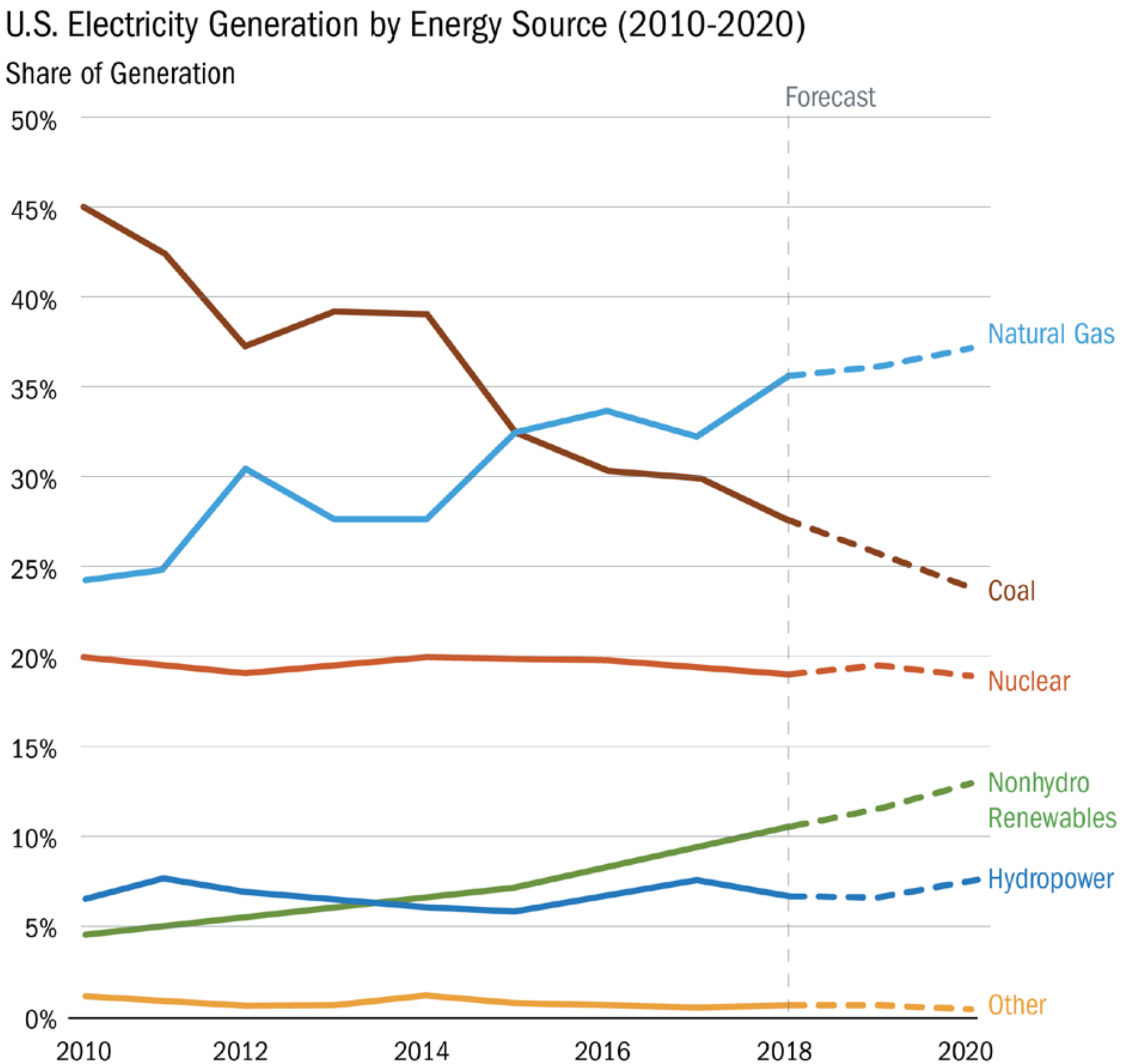
Source: REN21 Renewables 2019 Global Status Report, http://www.ren21.net/gsr-2019/

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%.

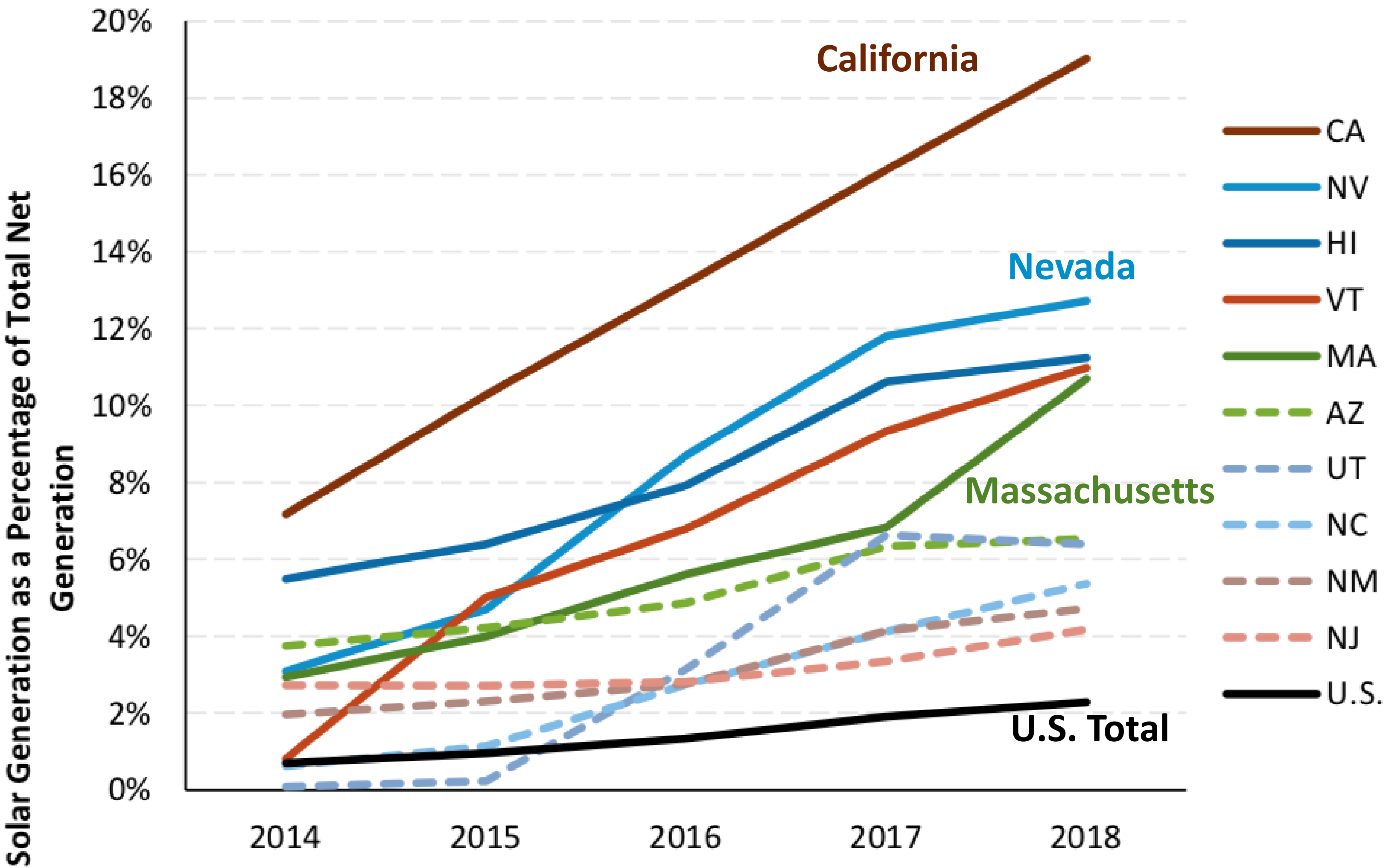
With hydropower, renewable energy is 17%.

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

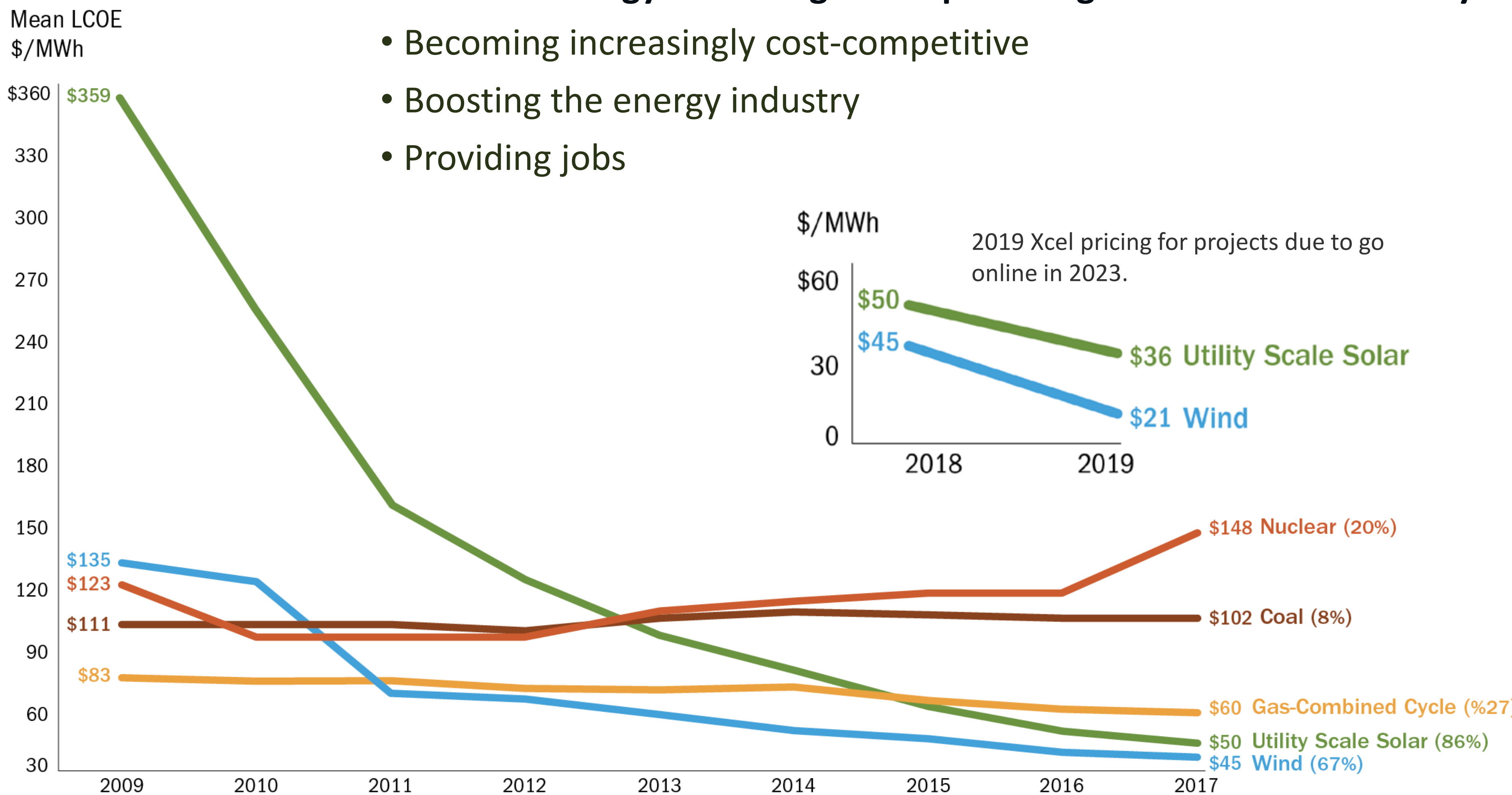


Source: NREL, Q4 2018/Q1 2019 Solar Industry Update, May 2019.

Costs for Renewables are Falling

Advanced energy technologies are providing real-world solutions by:

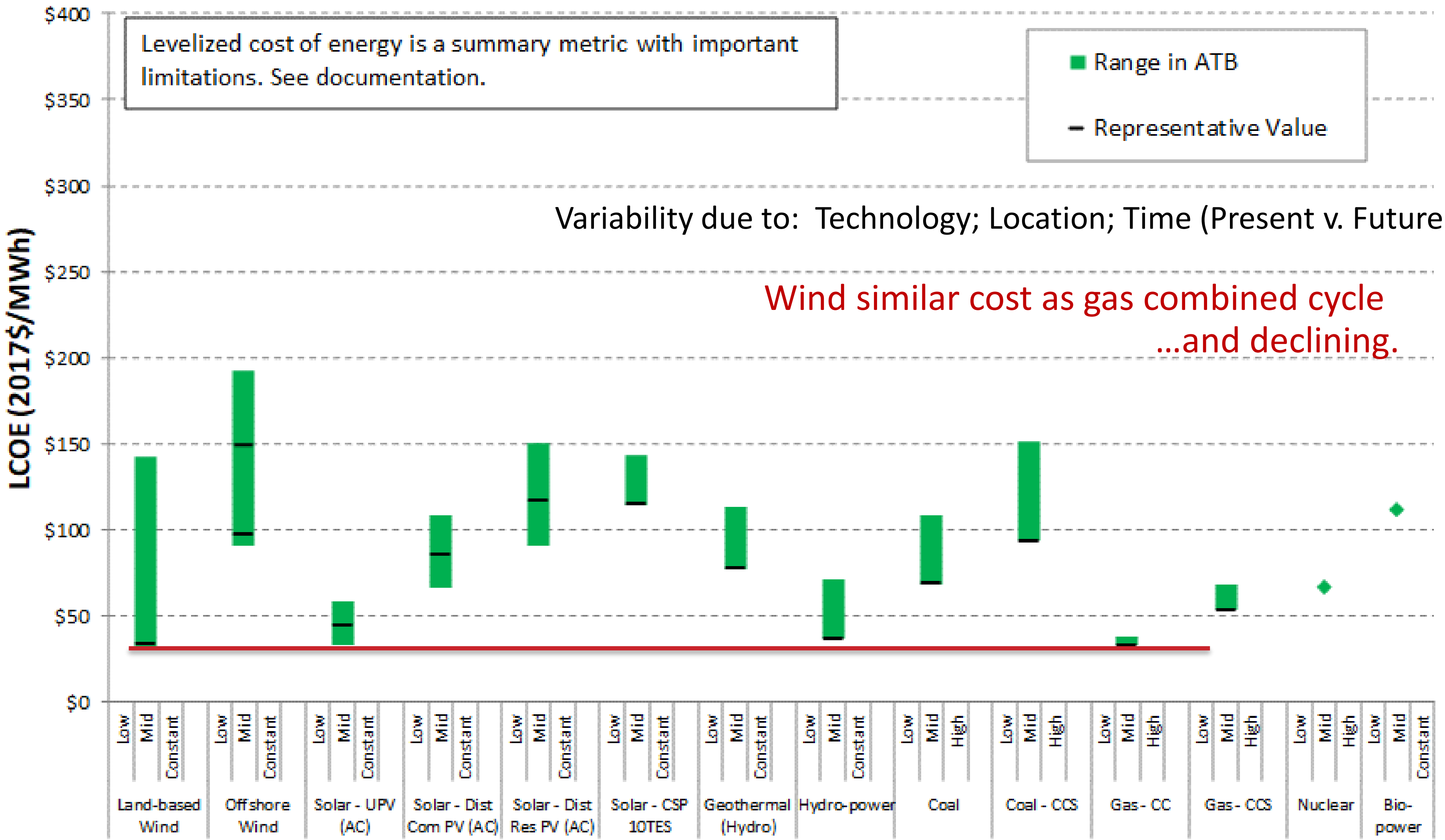
- Becoming increasingly cost-competitive
- Boosting the energy industry
- Providing jobs



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

Cost of Renewable & Traditional Electricity Equalizing

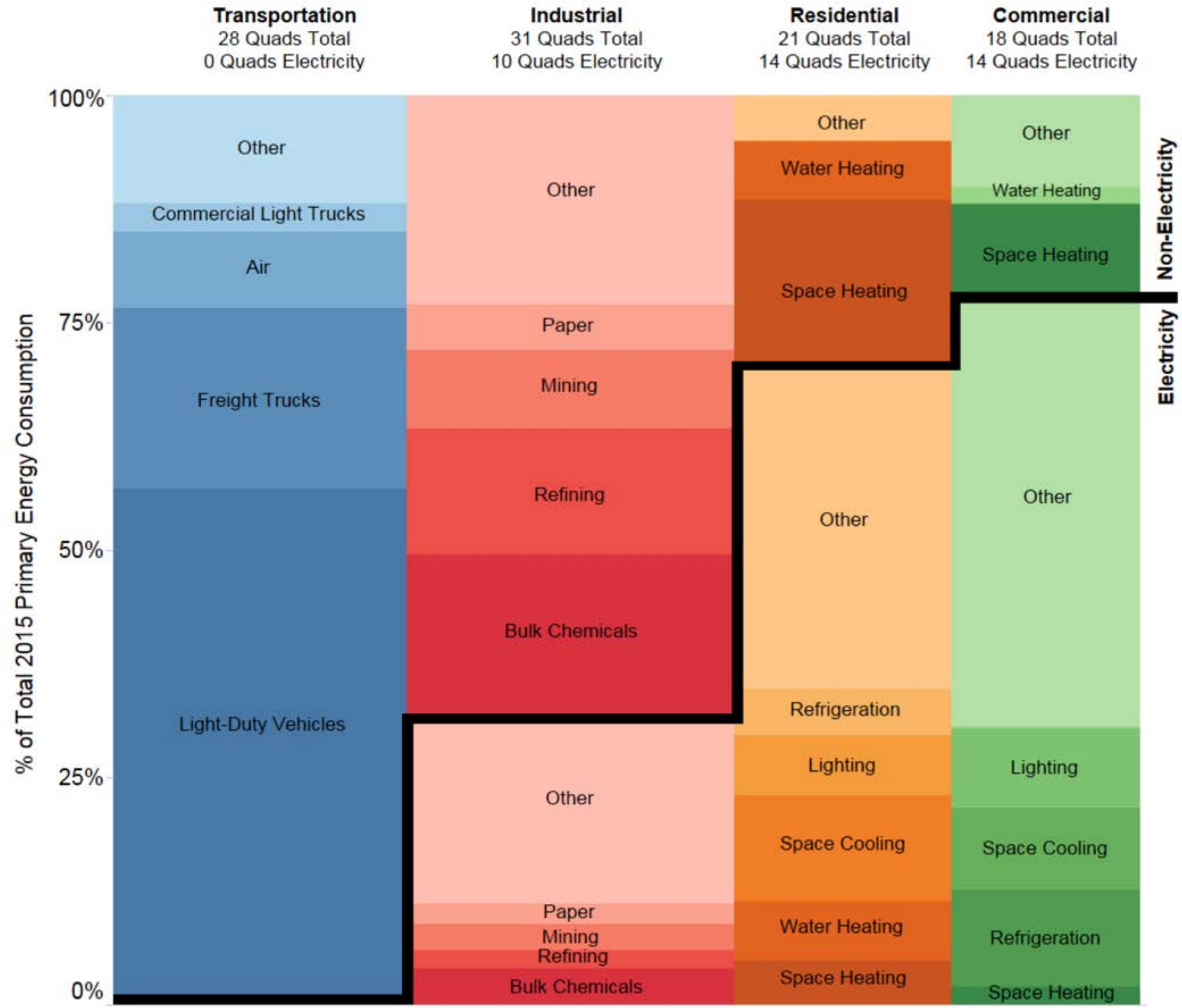
Levelized Cost of Electricity ranges by technology. Values are in 2017$.



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

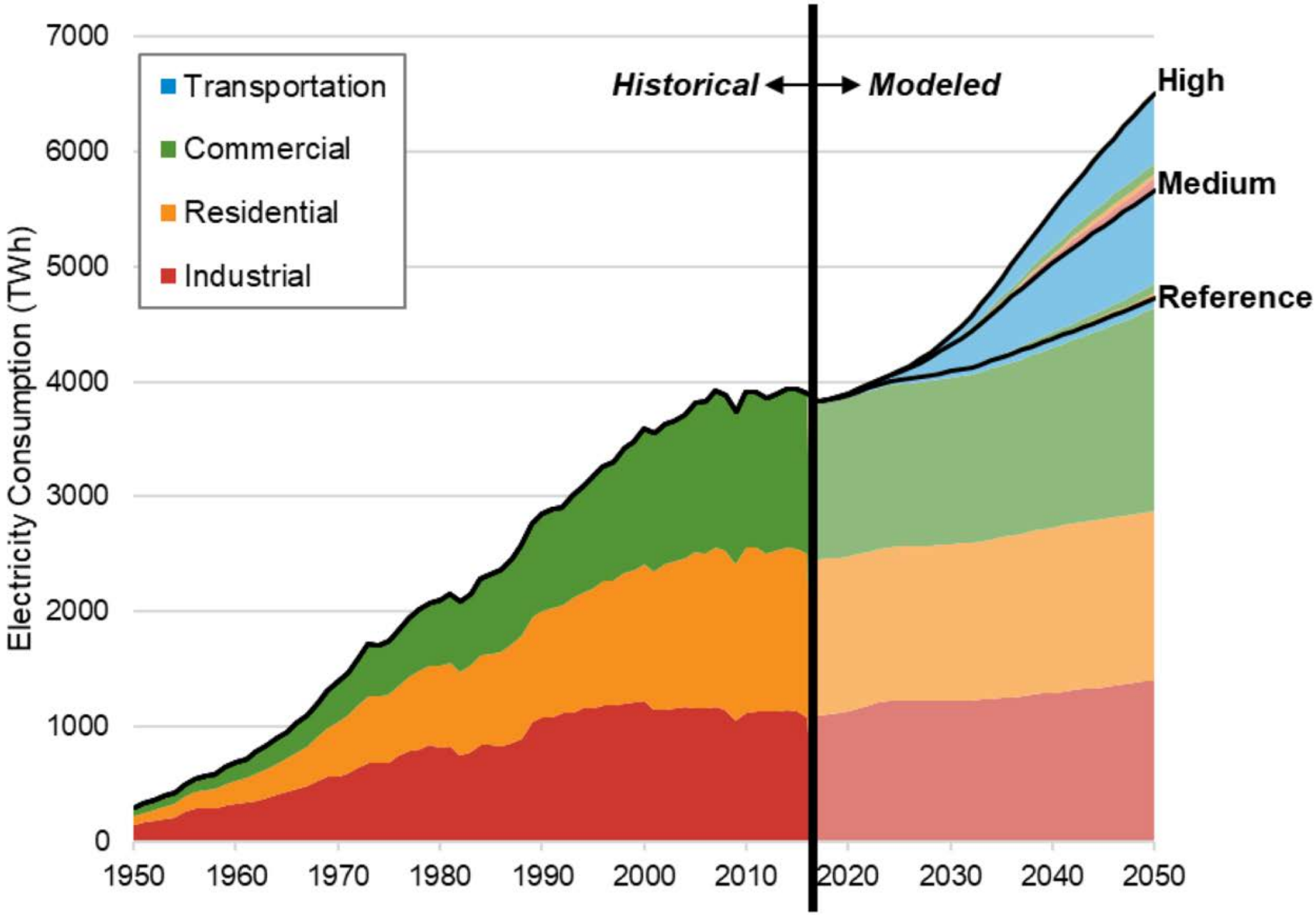
Source: National Renewable Energy Laboratory Annual Technology Baseline (2019), http://atb.nrel.gov

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
- Nuclear, Renewables, and Gas

Wind Turbines - Onshore

Twin Groves Wind Farm
- McLean County, Illinois
- 396 MW, 240 turbines
- 80 m hub height
- Opened 2008
- Capacity Factor 34%

Cedar Creek Wind Farm
- Grover, Colorado
- 550 MW

Wind Turbines – Offshore

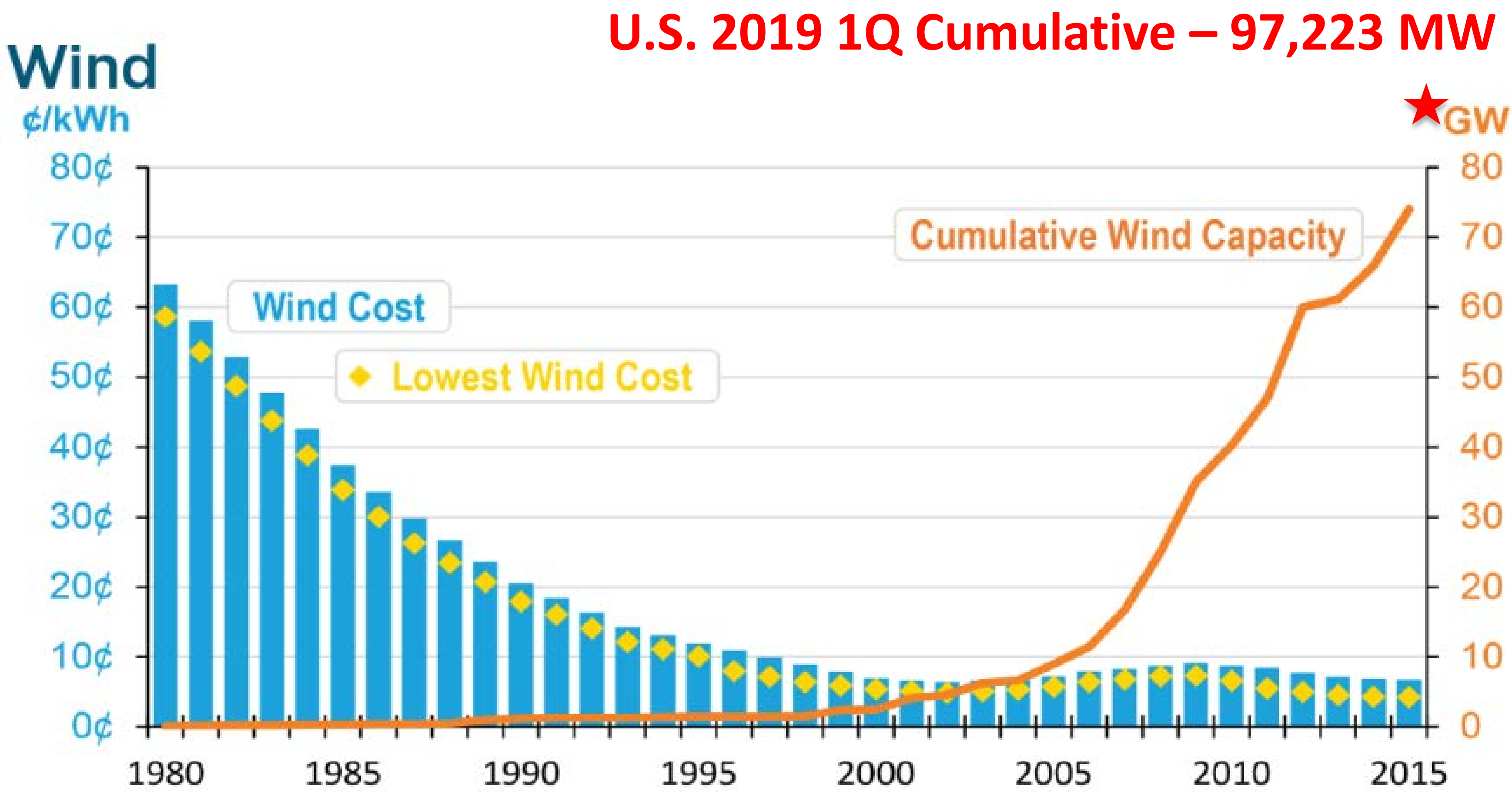
Block Island Wind Farm

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

Westermeerwind Wind Farm

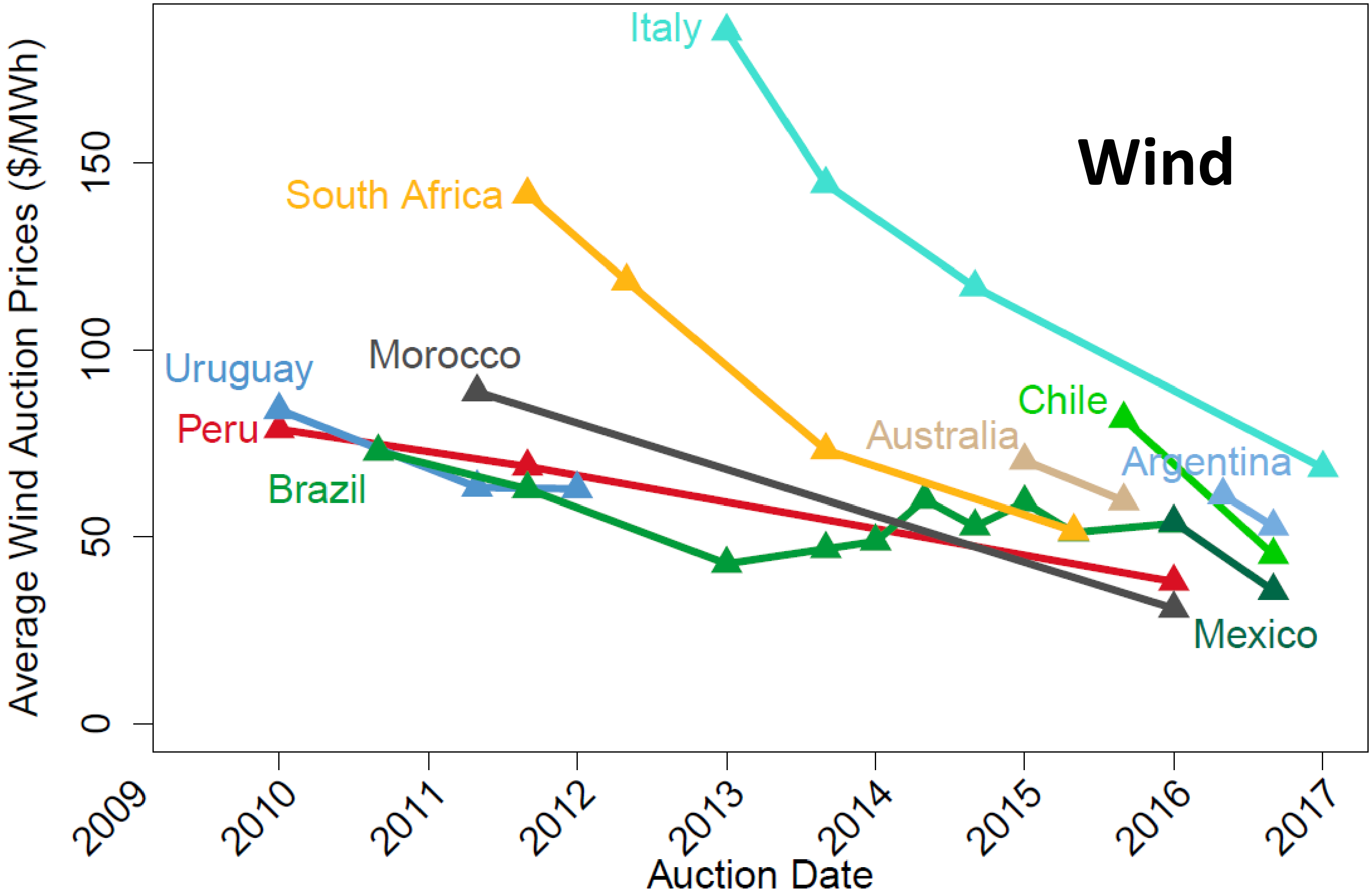
- Noordoostpolder, Netherlands
- 144 MW

Wind Market Growth Driven by Price Declines



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

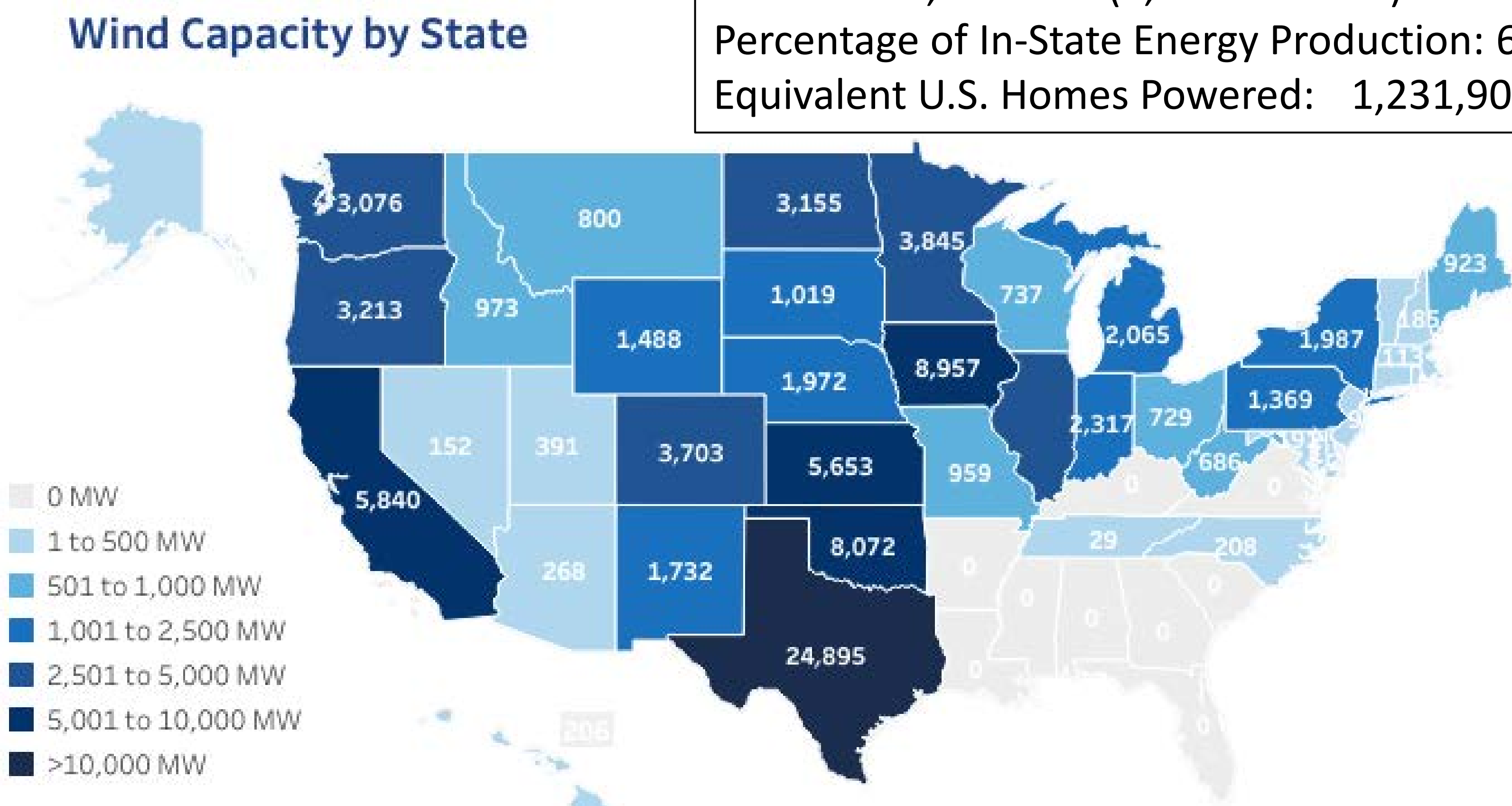


Source: IRENA Renewable Energy Auctions: Analysing 2016 (2017)

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

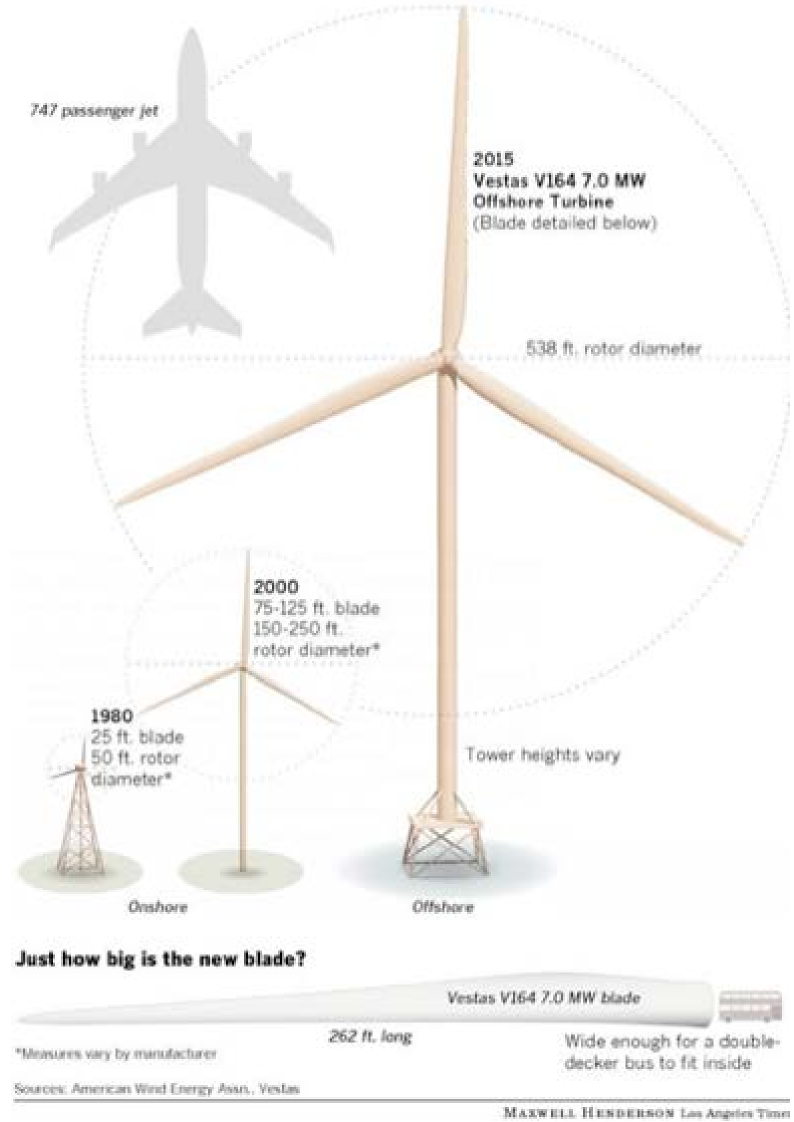
Wind capacity installed in Oklahoma, Iowa, and Kansas supplied 31%–36% of all in-state electricity generation in 2018. 14 states were greater than 10%.

Illinois Rank – 6th for capacity
Installed: 4,887 MW (2,778 turbines)
Percentage of In-State Energy Production: 6.8%
Equivalent U.S. Homes Powered: 1,231,900



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



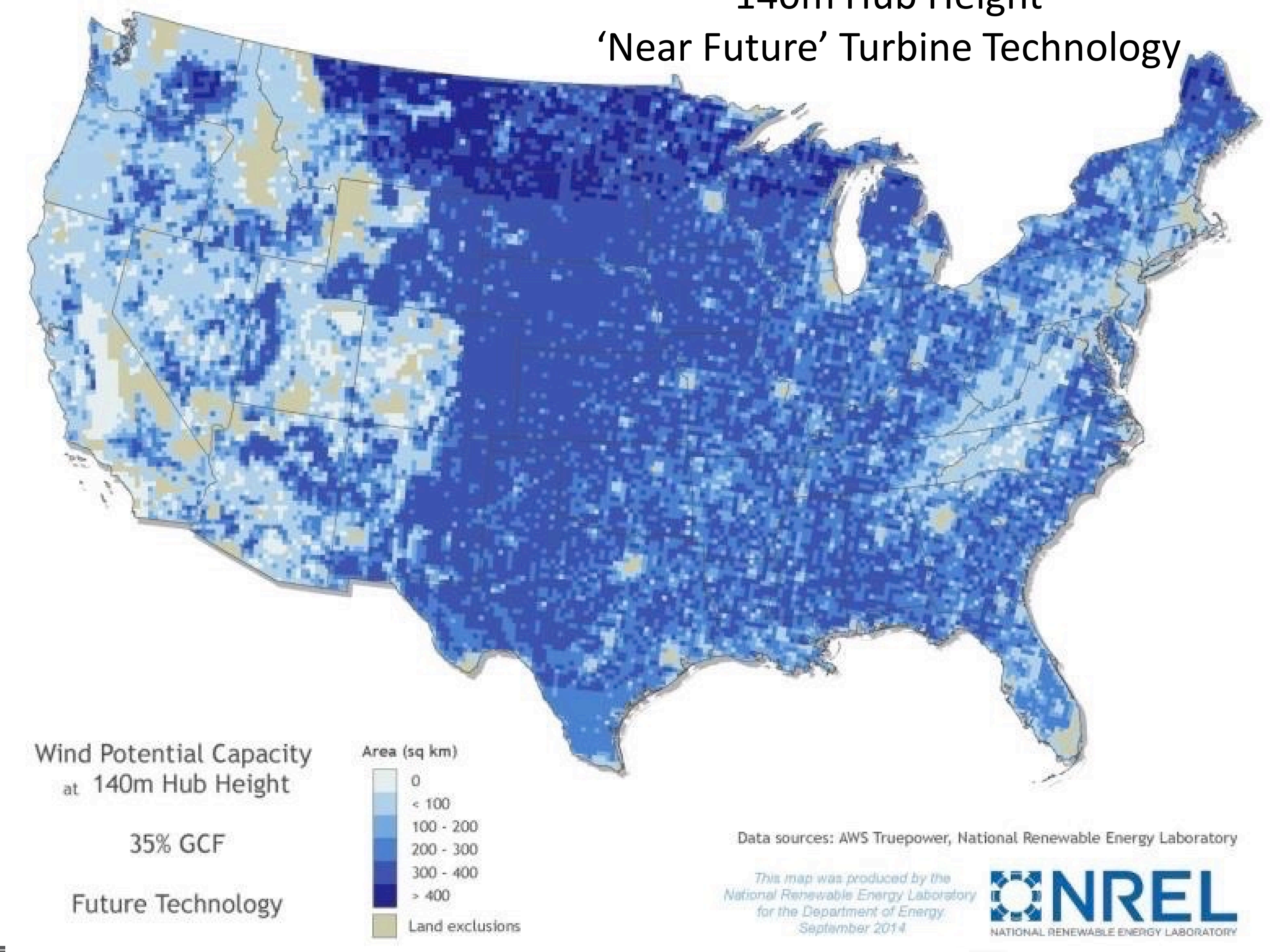
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

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

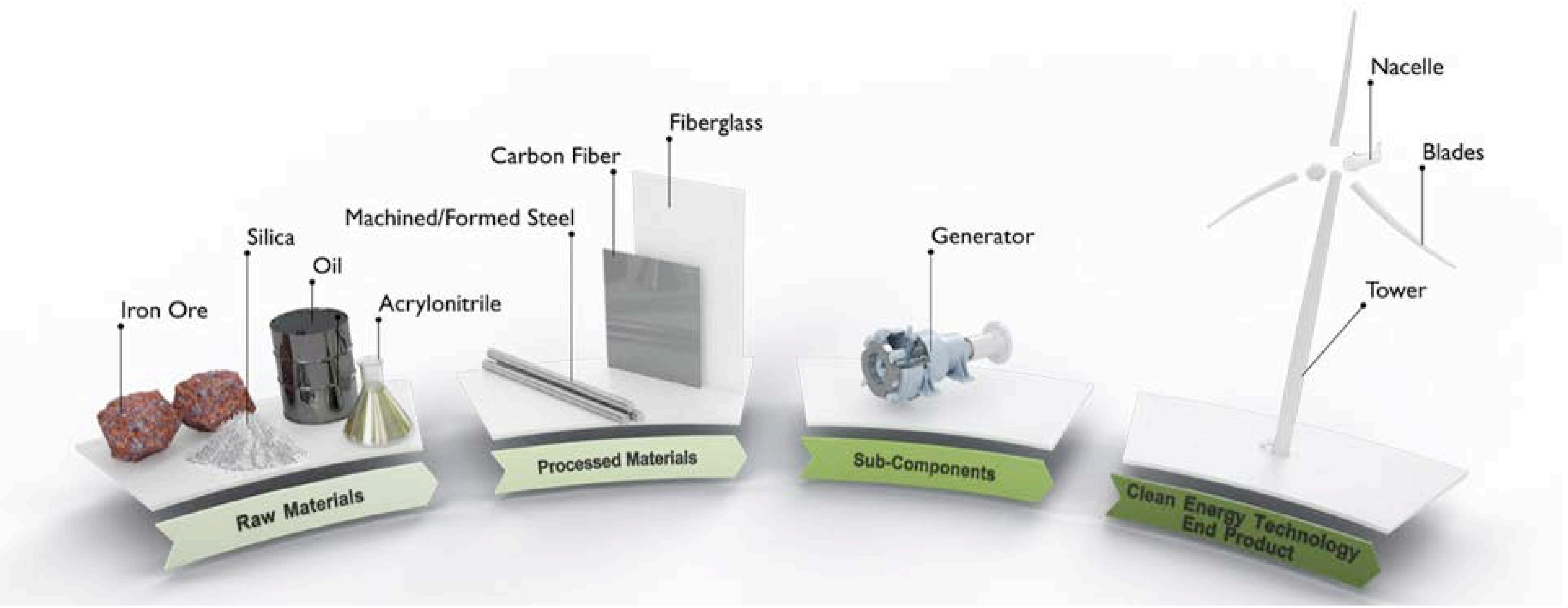
Compare: Natural Gas Plant: 56%; Coal Fired Plant: 53%; Nuclear: 92%; Solar Photovoltaic: 27%

Wind Energy Potential Increasing to More Places

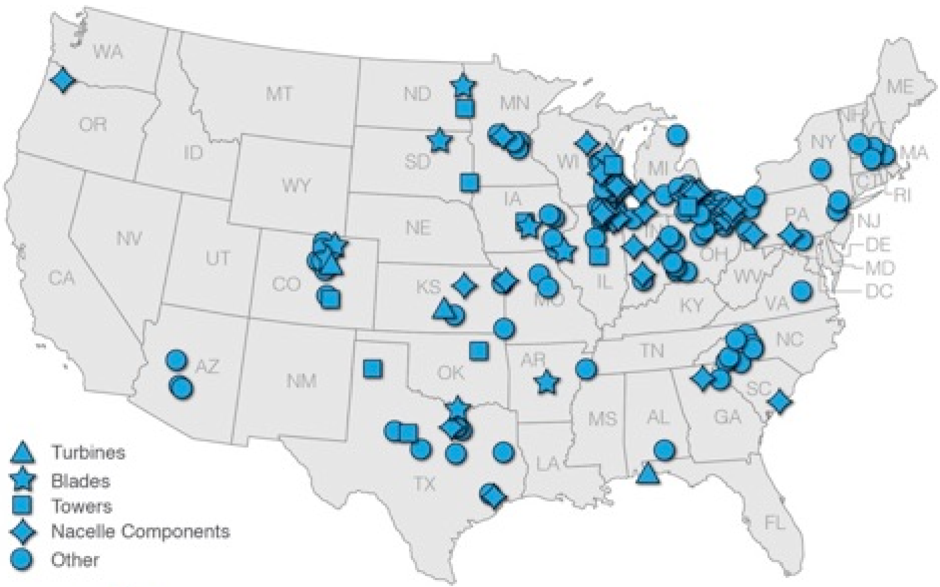
140m Hub Height
'Near Future' Turbine Technology



Supply chain of wind turbines



Wind Power Manufacturing



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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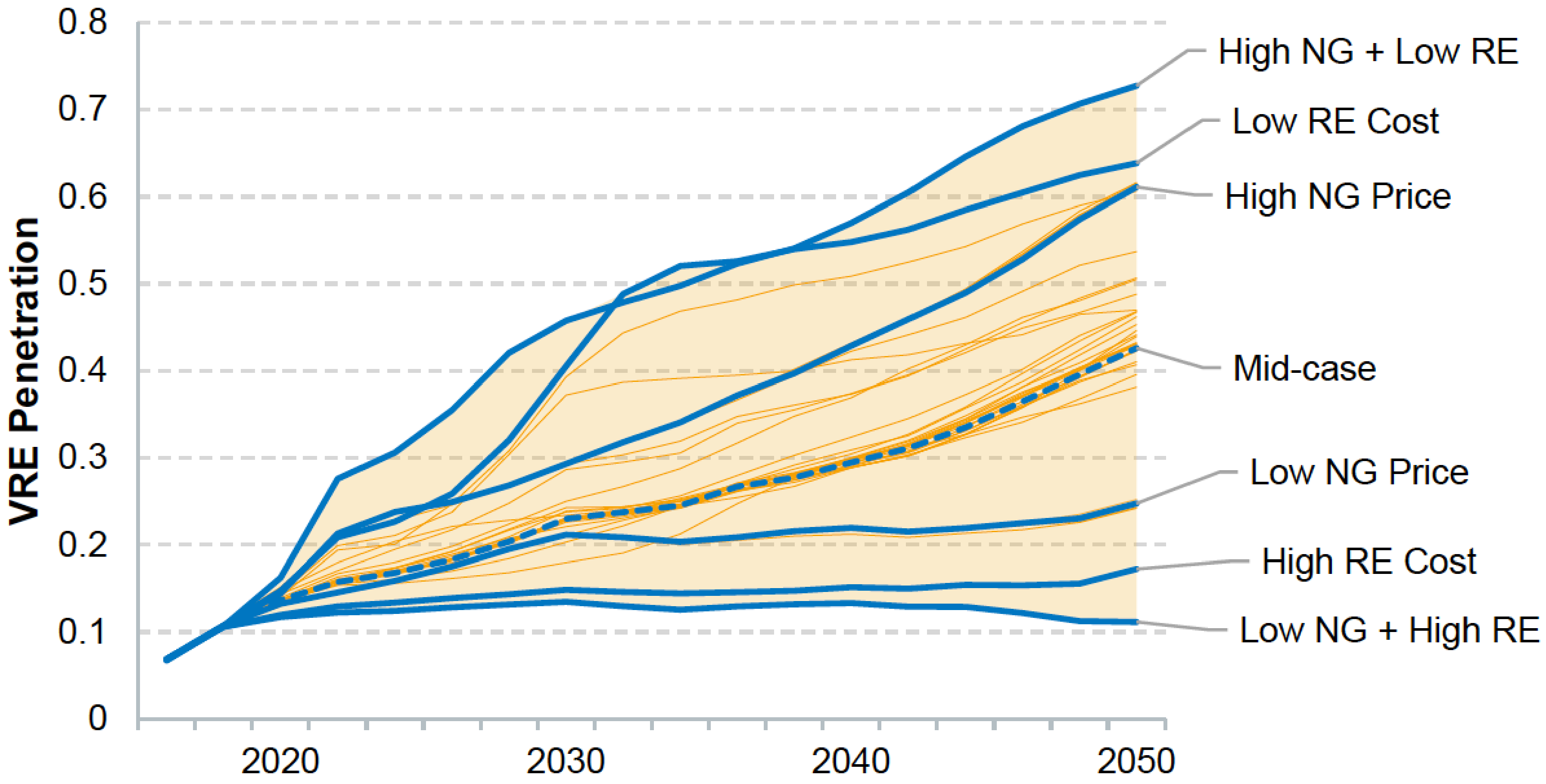
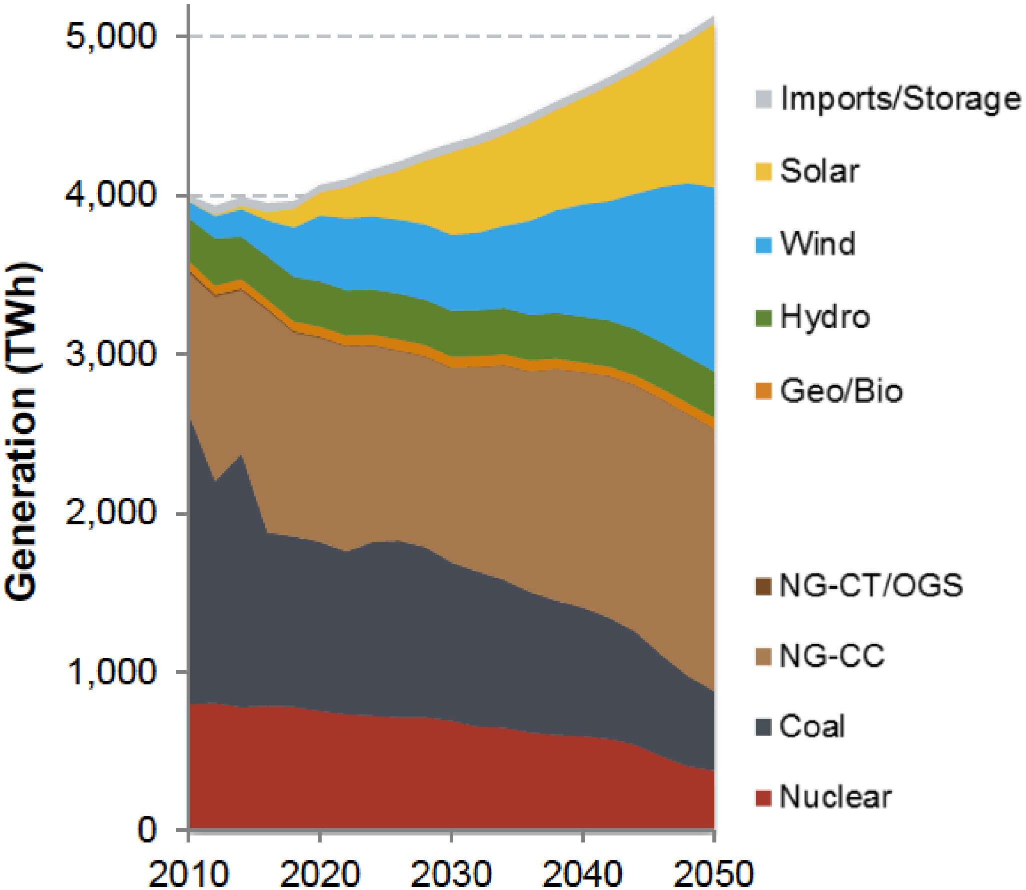
- Nuclear, Renewables, and Gas… and intersections

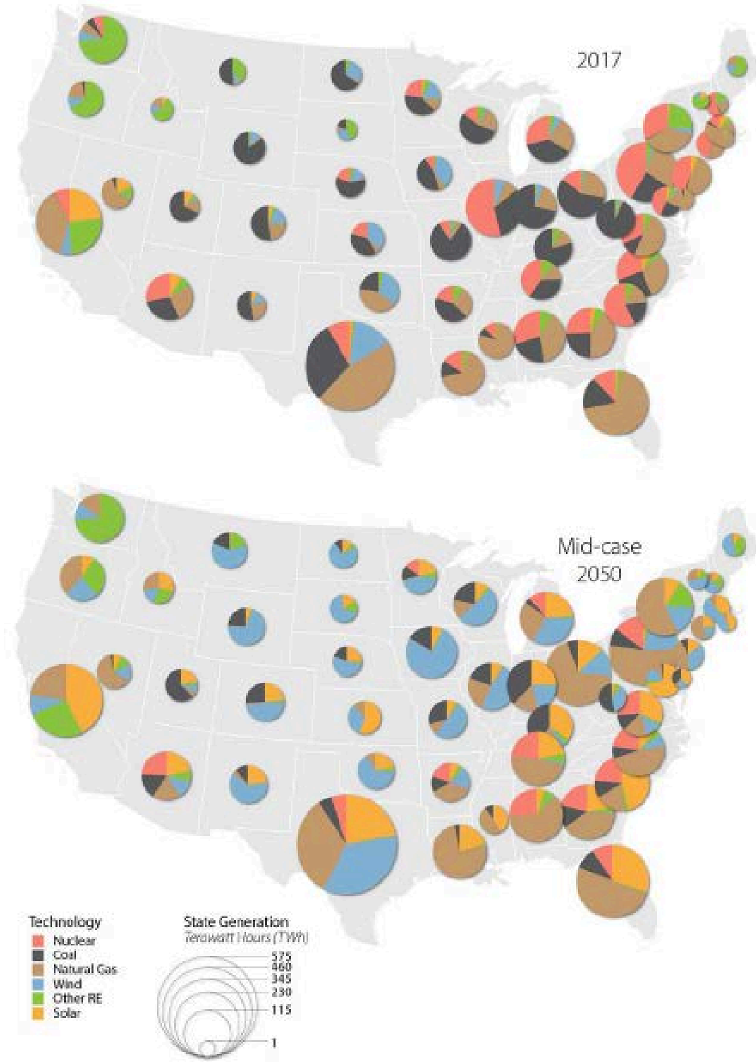
Future: NREL electricity generation scenarios



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

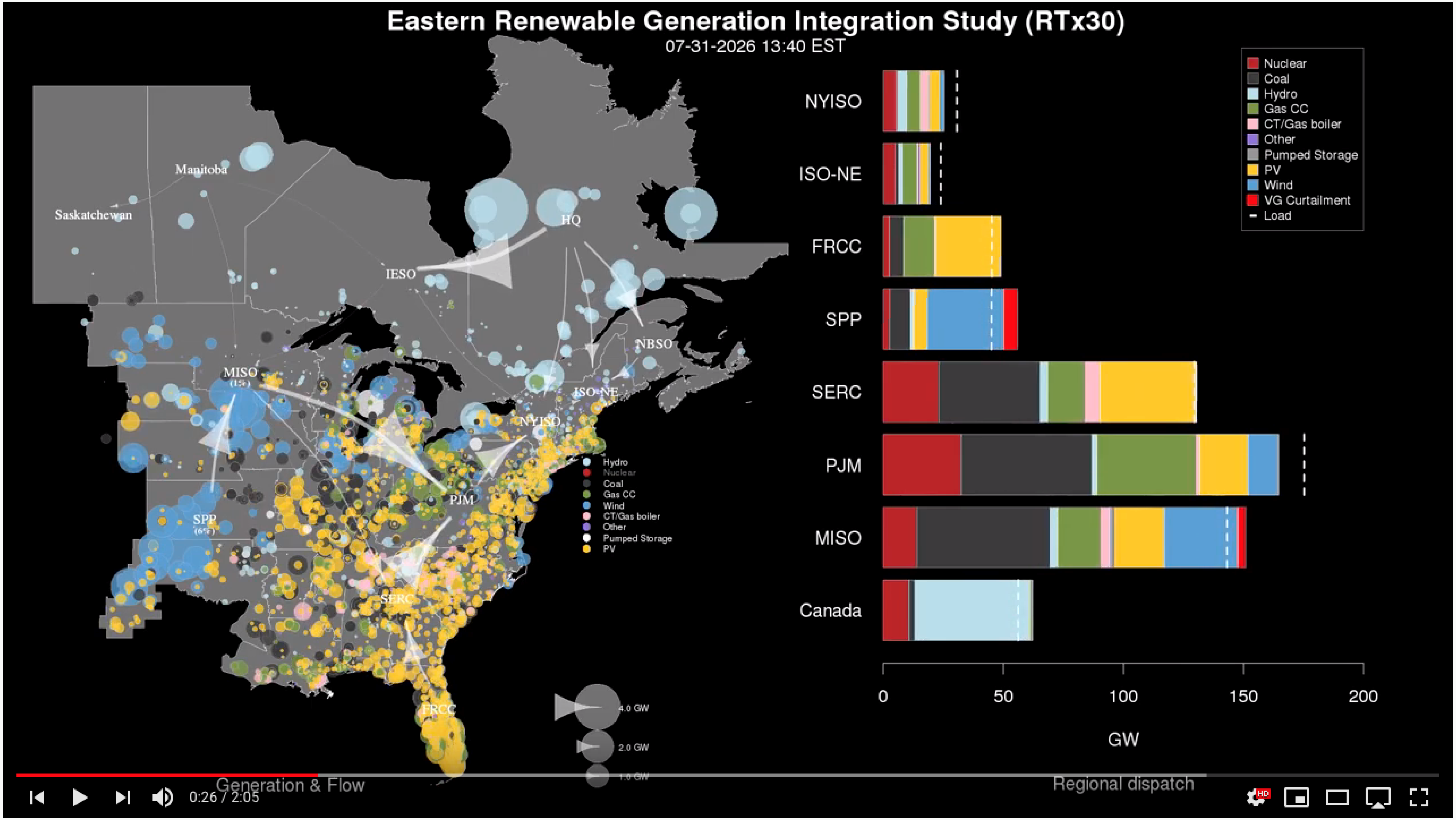
NREL electricity scenario mid-case generation mix





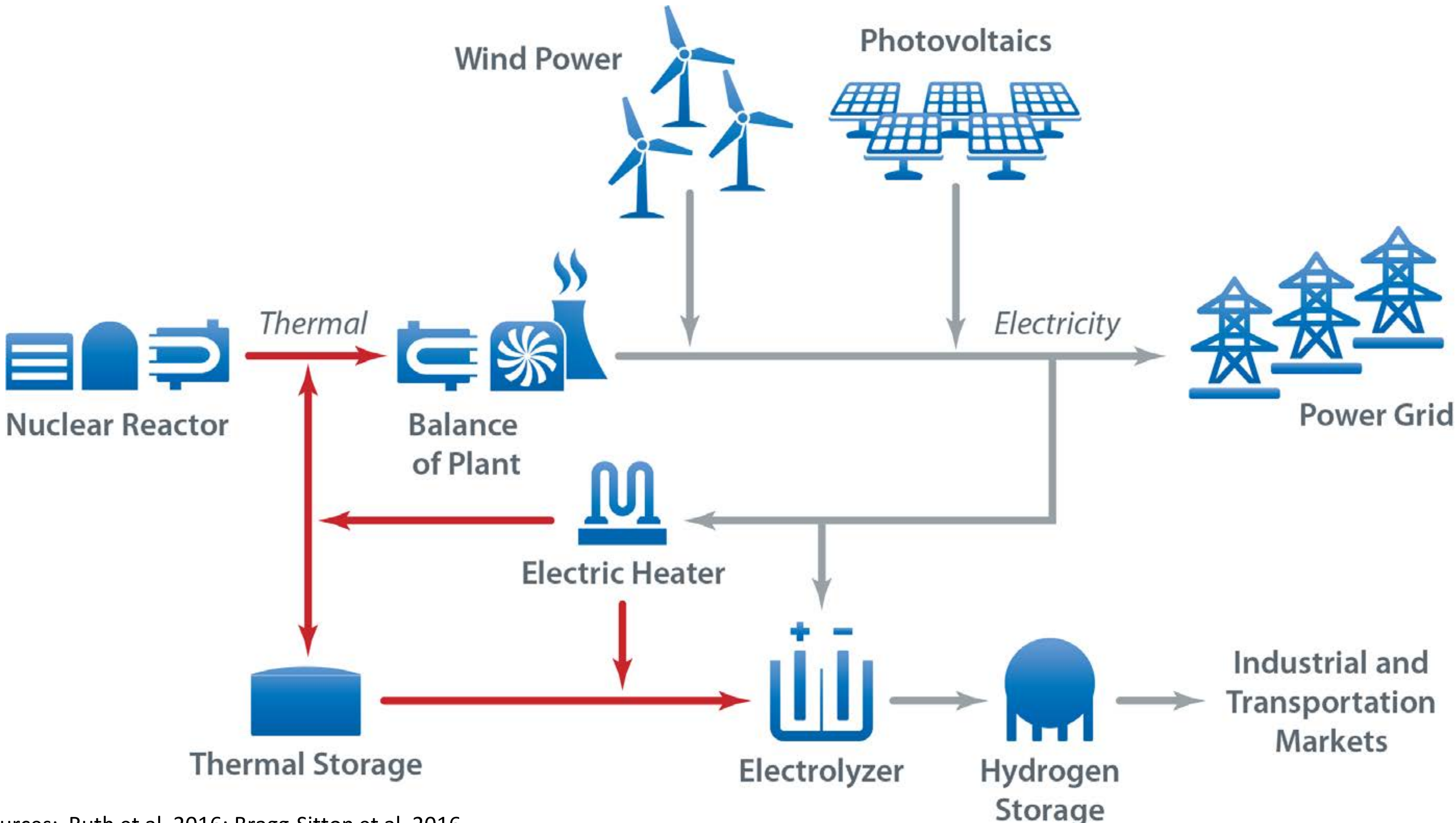
Generation by technology type in the Central Scenario, from: NREL 2018 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

Advanced grid integration studies



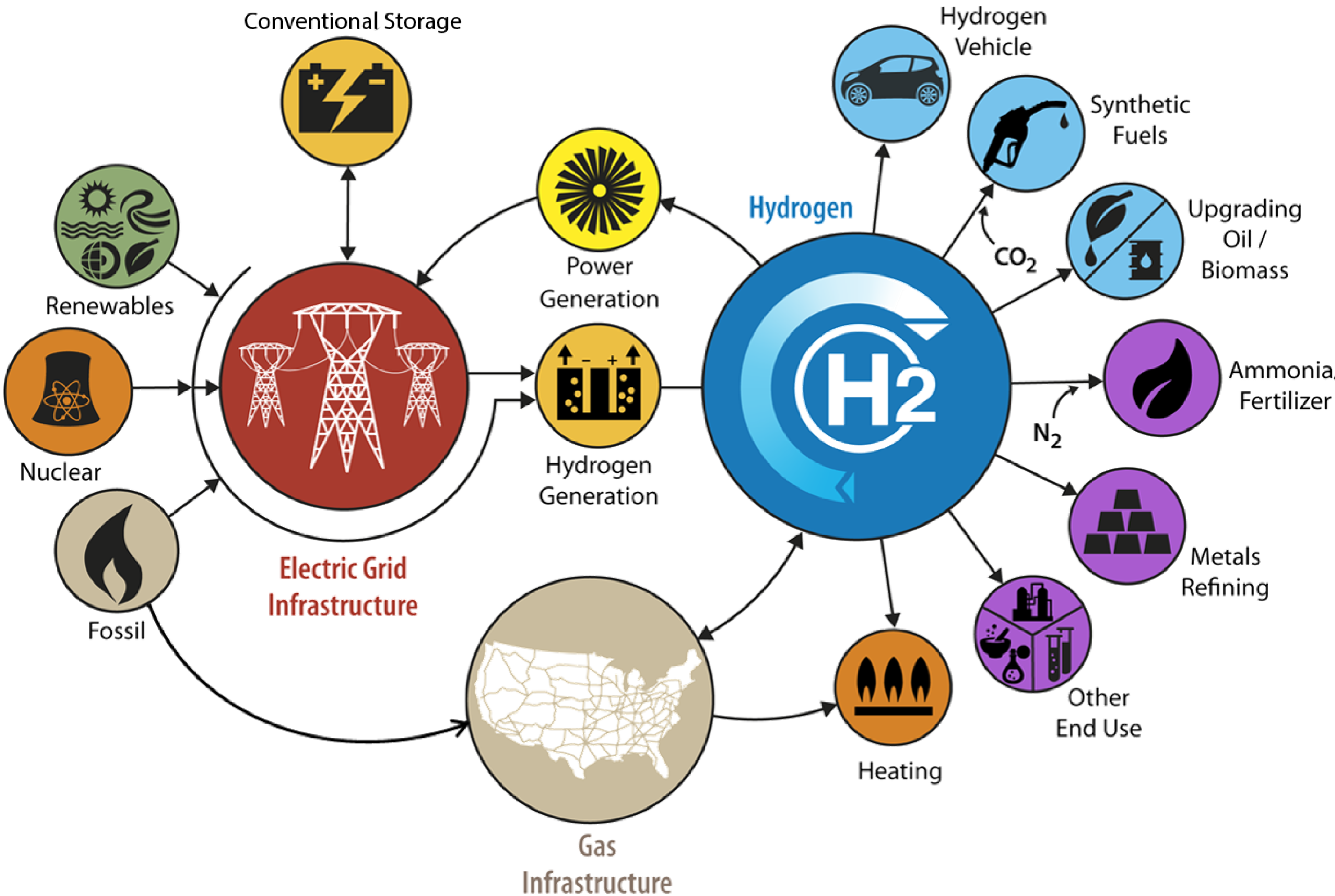
https://www.youtube.com/watch?v=li8jO-pKgvc&list=PLmIn8Hncs7bEl4P8z6-KCliwbYrwANv4p&index=19

Renewables and Nuclear Hybrid Energy Solutions



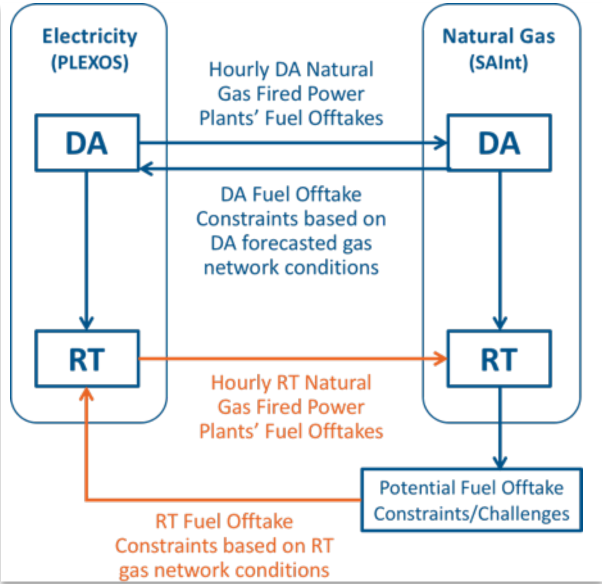
Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

Hydrogen @ Scale



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:

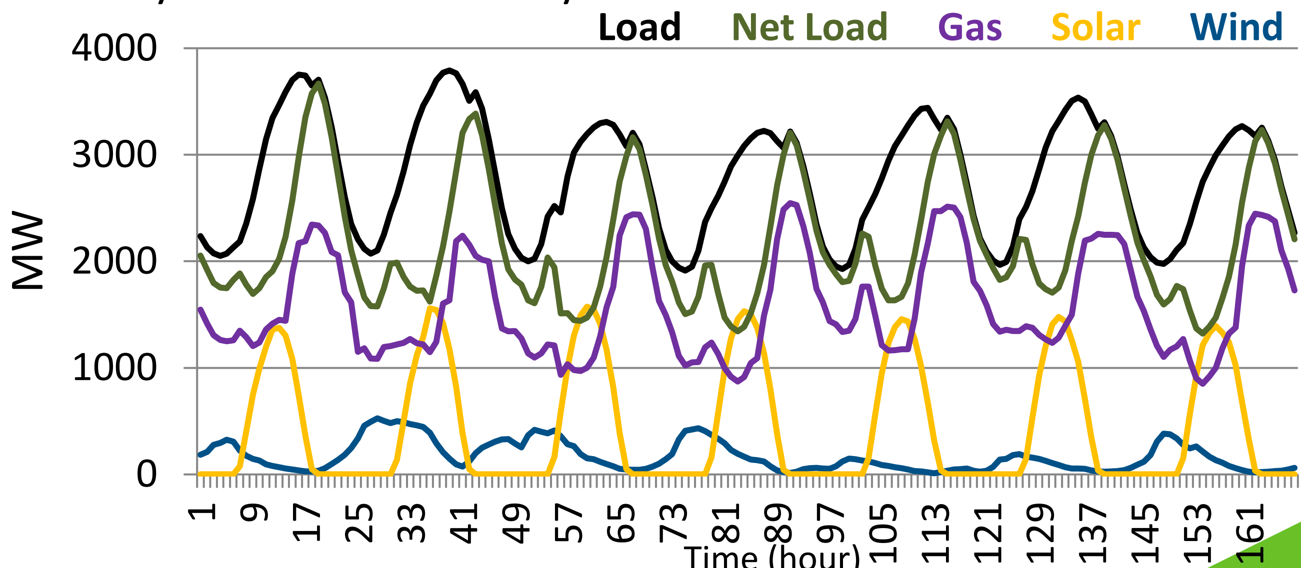
Co-simulate power and natural gas network operations.

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:

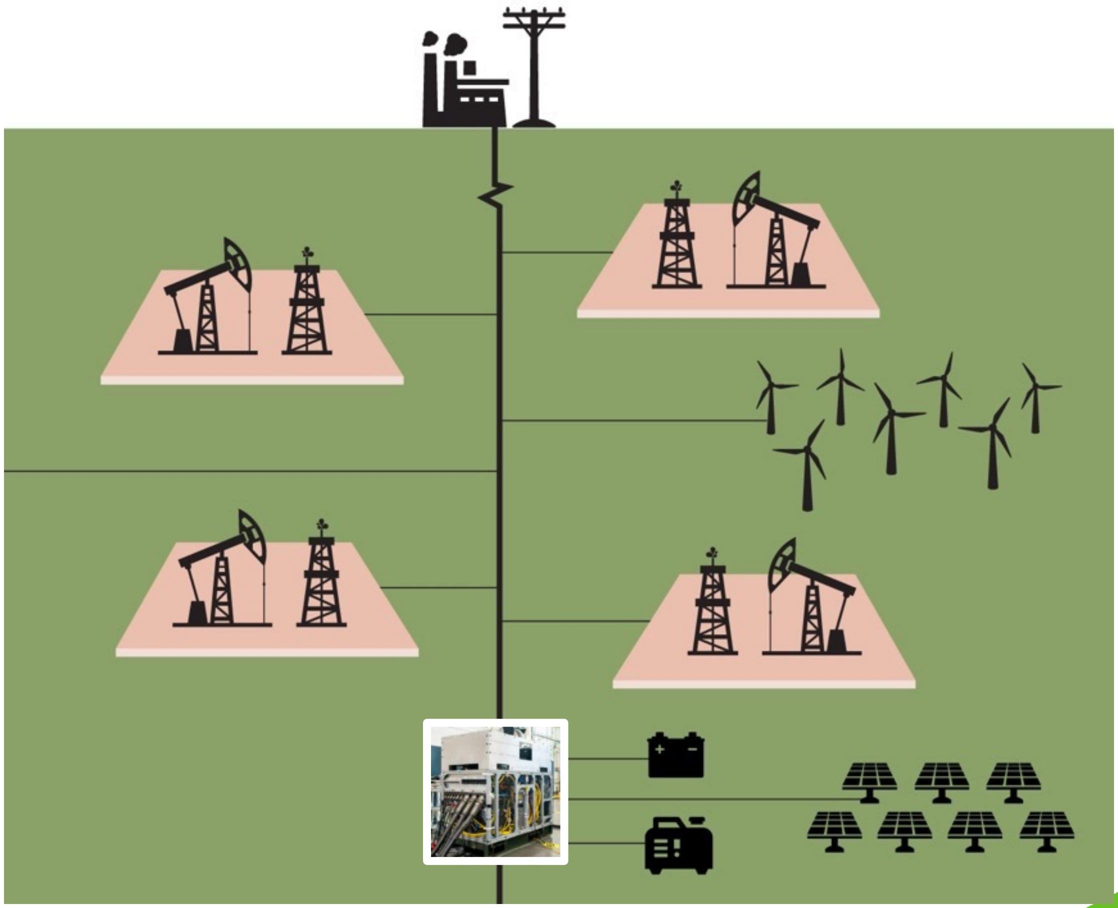
- American Electric Power
- Environmental Defense Fund
- Hewlett Foundation
- Kinder Morgan
- American Gas Association
- Midcontinent Independent System Operator



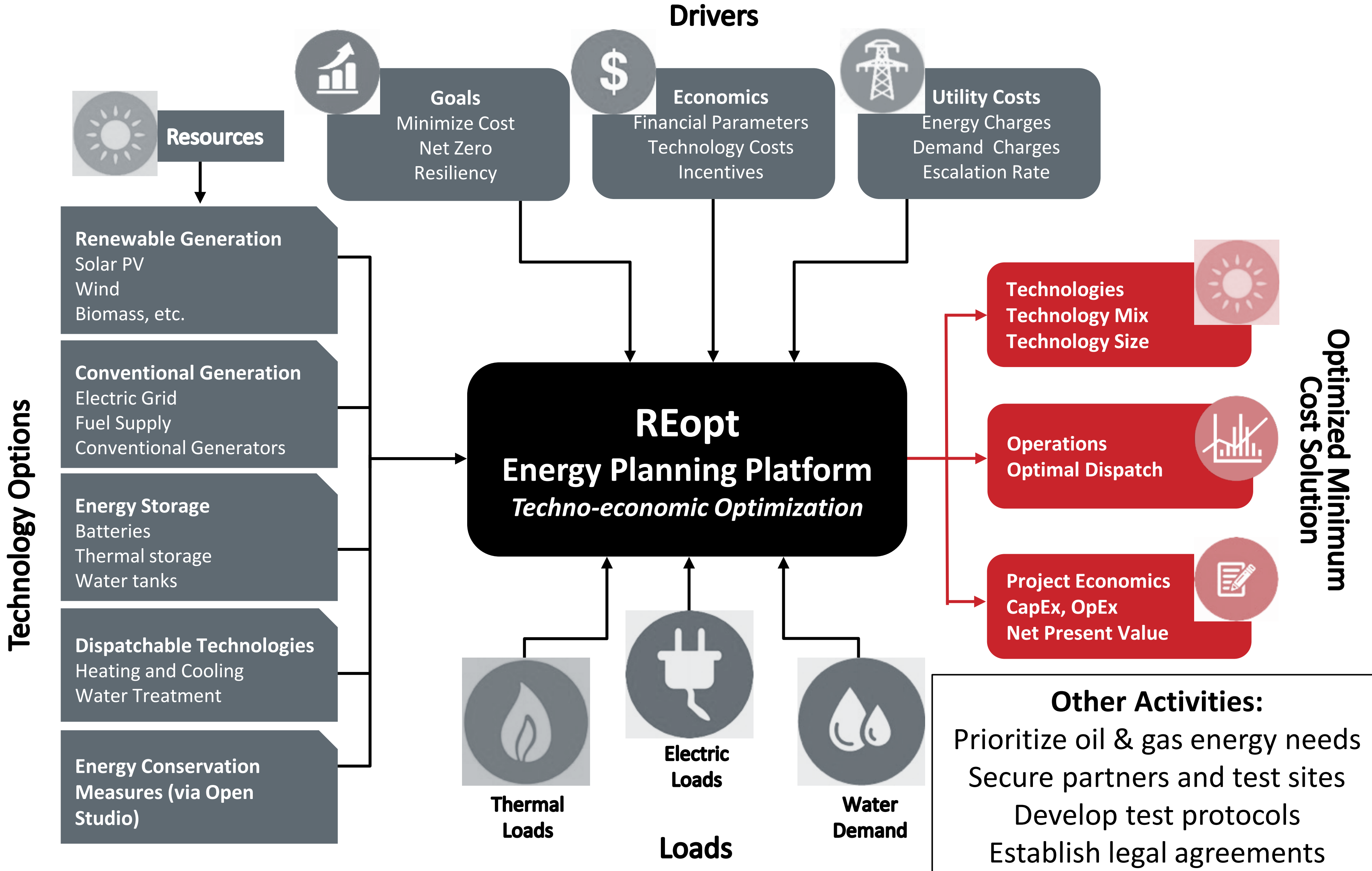
Source: JISEA project in progress.

Clean Power Technologies for Oil & Gas Industry Operations: Electrification of the Wellpad and Platform via Microgrids

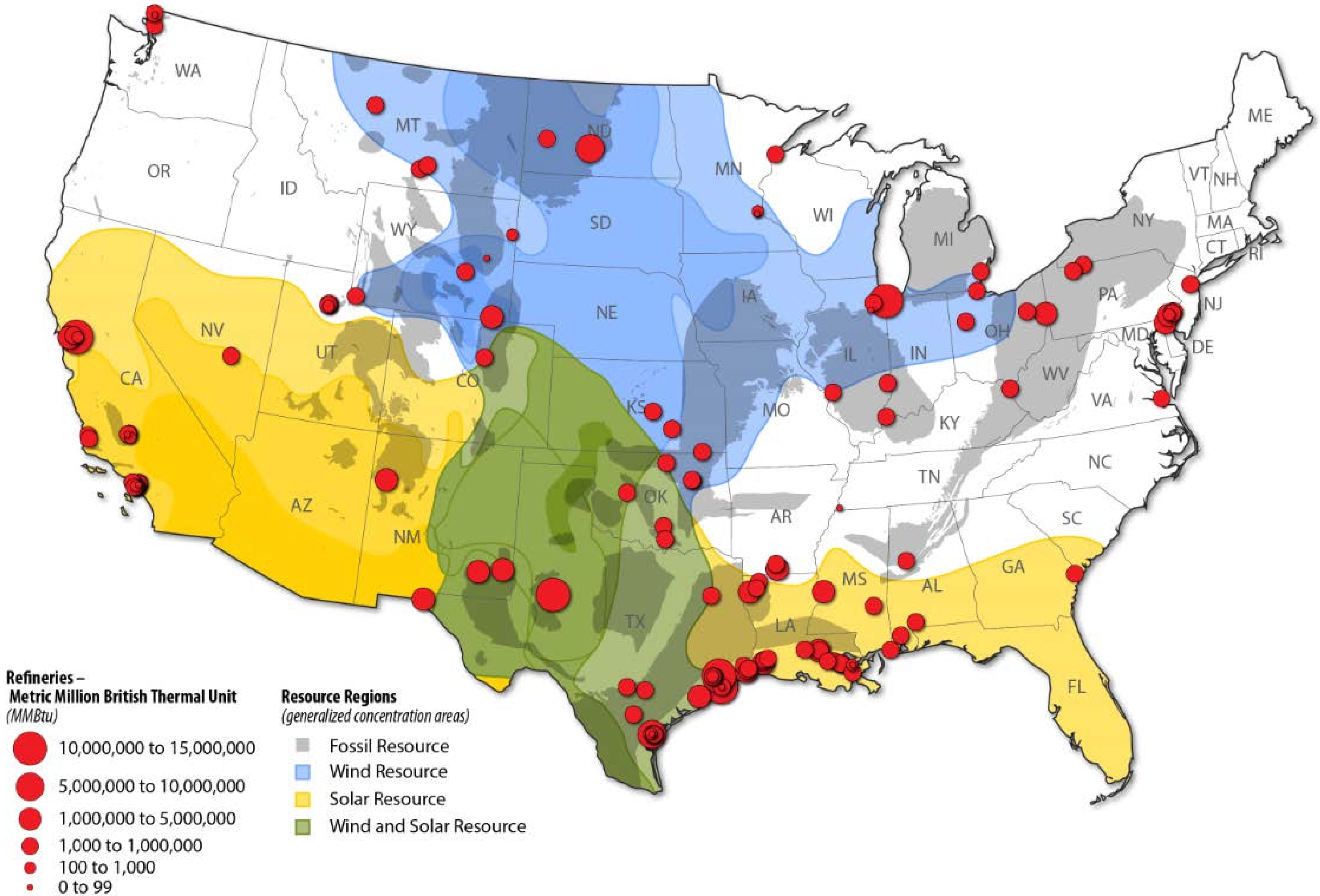
- Electrification of all equipment at wellpad connected via microgrid
- Power could consist of:
  - Field/Flare Gas fired generator
  - Solar PV/wind systems
  - Fuel cells
  - Energy Storage
    - Hydrogen
    - Batteries
  - Grid power (or offgrid)
- Benefits:
  - Resiliency during outages
  - Optimize for least cost
  - Reduce emissions
- Leverage work on
  - Remote bases & communities
  - Islands



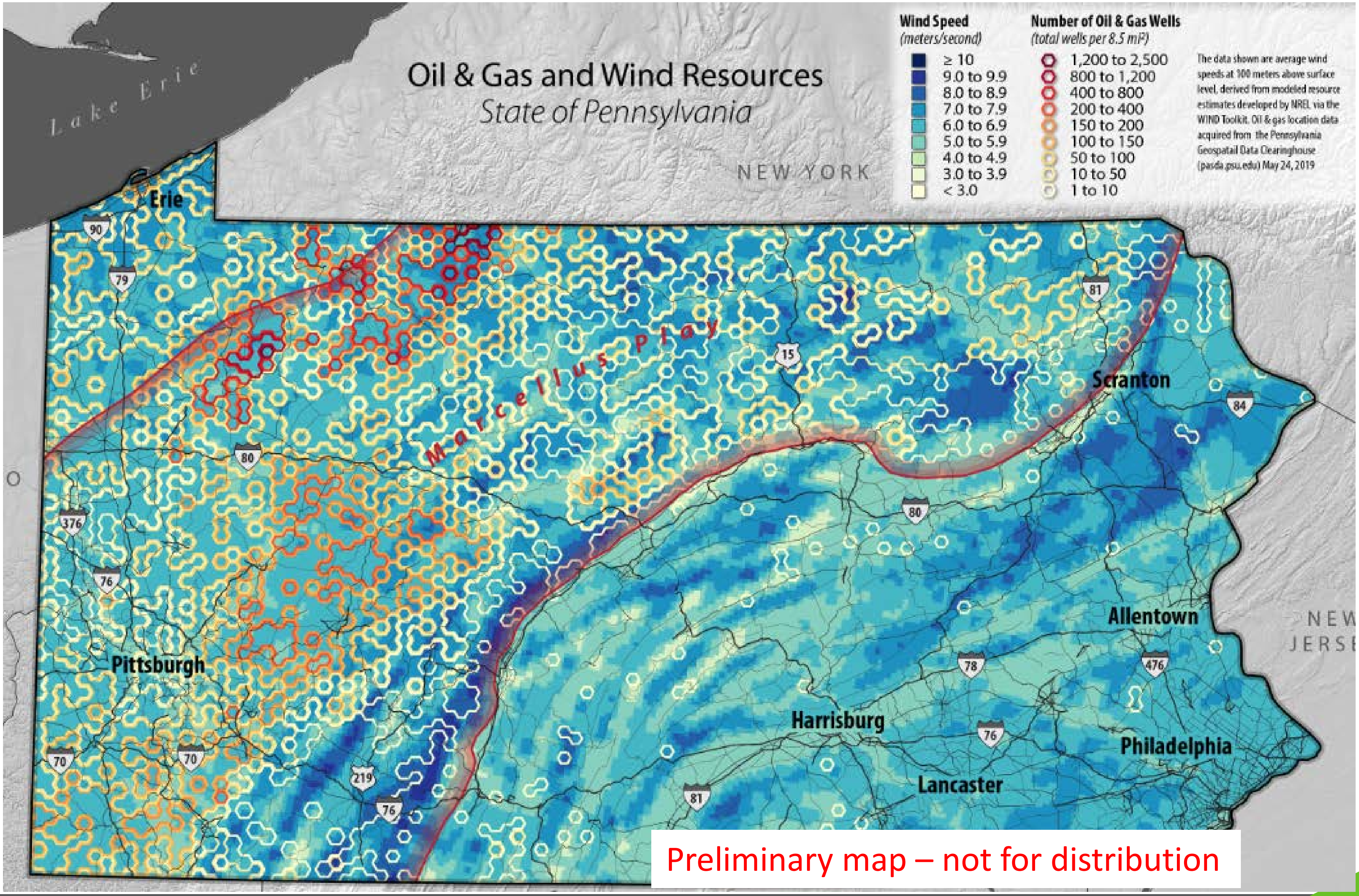
REopt: Optimizing energy at site scale



Many refineries may have great wind AND solar resources



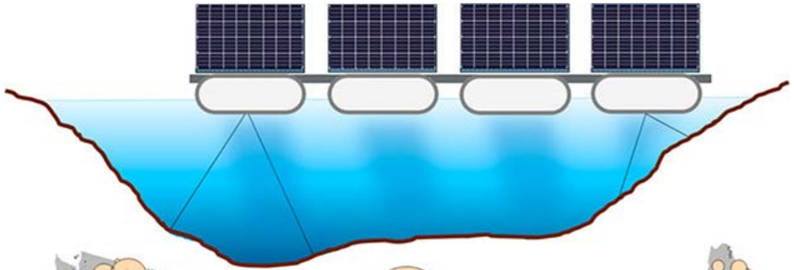
Marcellus Play: some wells near good wind resources (dark blue)

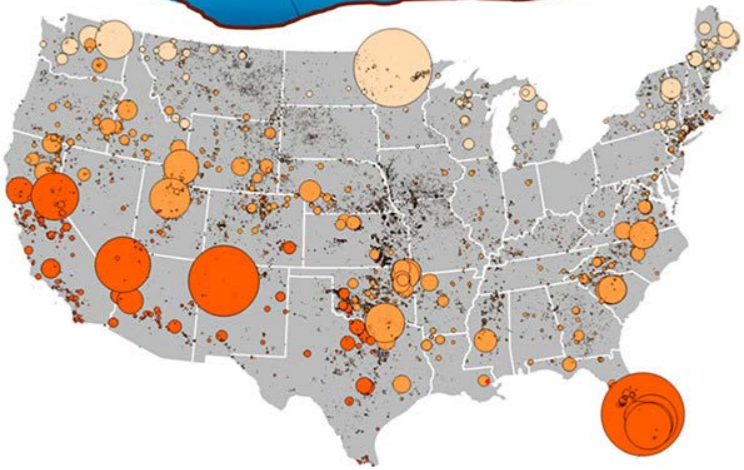


Co-location of Wind/PV and Agriculture

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



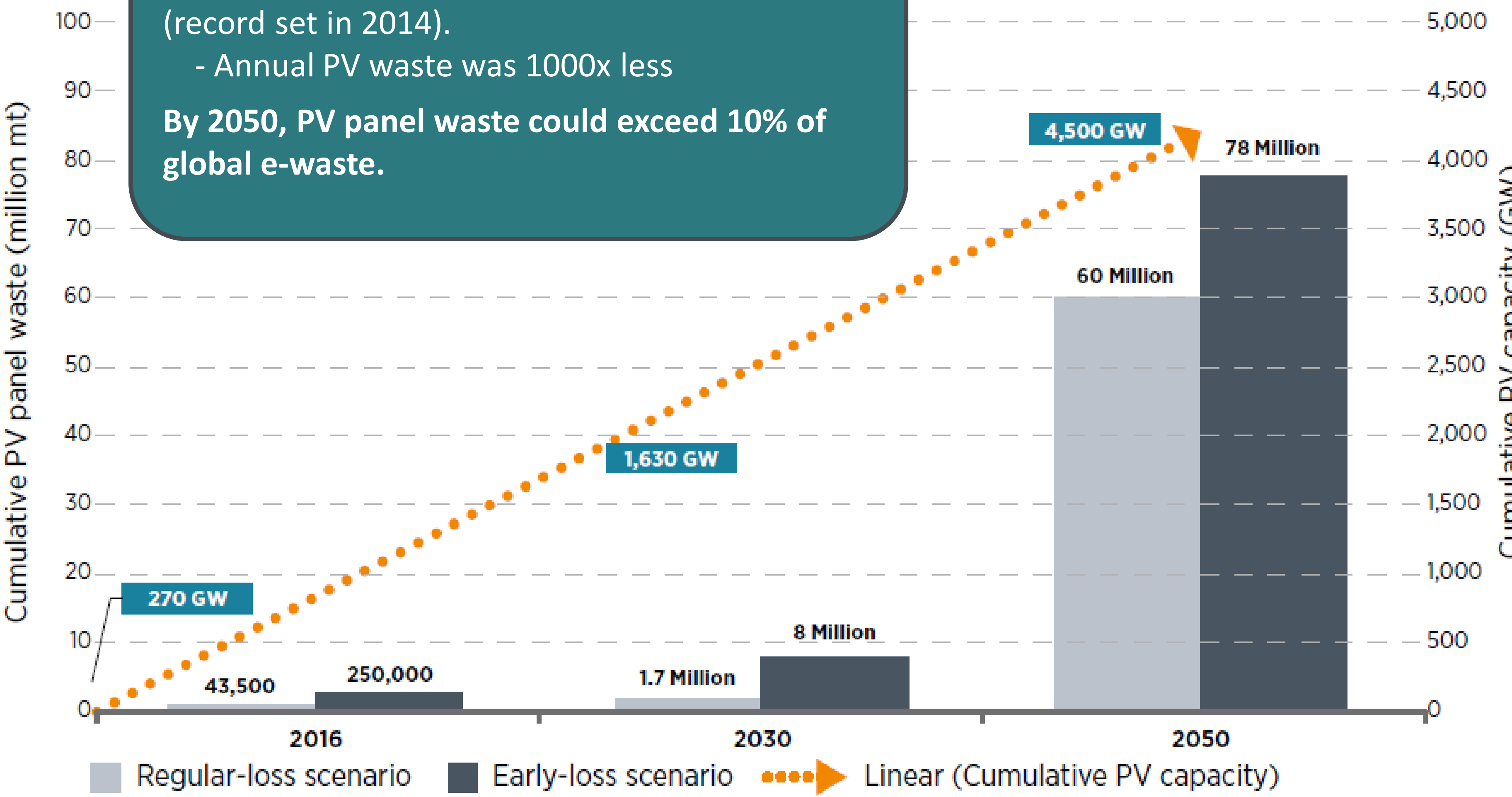


Top image from https://images.nrel.gov/
Source: Spencer et al. 2018, Environmental Science & Technology, https://www.nrel.gov/news/press/2018/nrel-details-great-potential-for-floating-pv-systems.html.

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

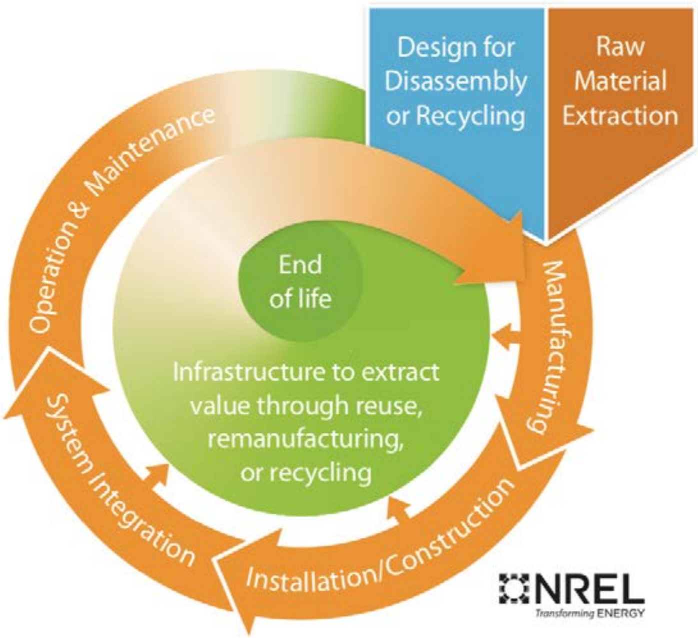
Global e-waste = 41.8 million metric tonnes (record set in 2014).
- Annual PV waste was 1000x less

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



Source: IEA/IRENA 2016

Transitioning from a Linear to a Circular Economy



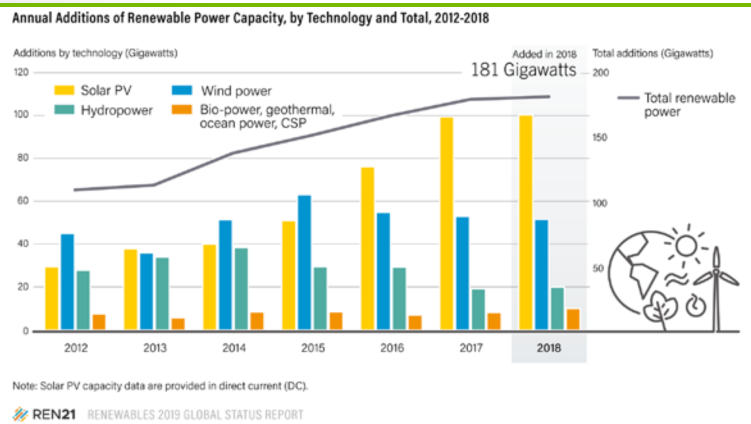
D R^n R Needs

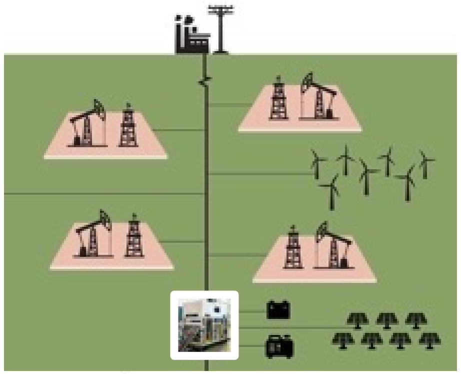
Design: Disassembly, recycle/reuse, materials/components/systems

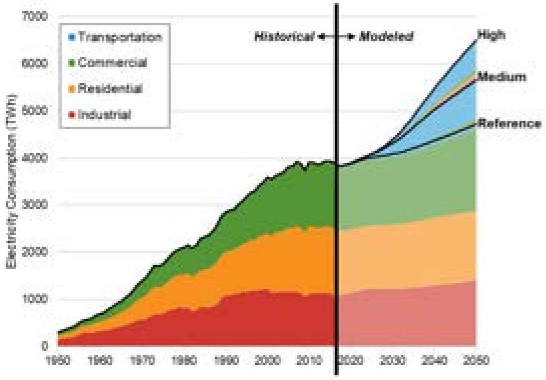
Recycle/Reuse: complex heterogeneous waste; collection, pre-treatment, separations
Repurpose/Remanufacture: components, materials
Reduce: thrifting, materials/element substitution

Reliability: validate performance, lifetime, predictability

Conclusion and Discussion







Trends and Potential Future Scenarios:

- Globally 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

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Questions and Discussion

Thank you!

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