JISEA Joint Institute for Strategic Energy Analysis

Clean Energy Technologies for Economic and Environmental Transitions

Air & Waste Management Association

EPA Region 8 Building

19 June 2019

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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

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:

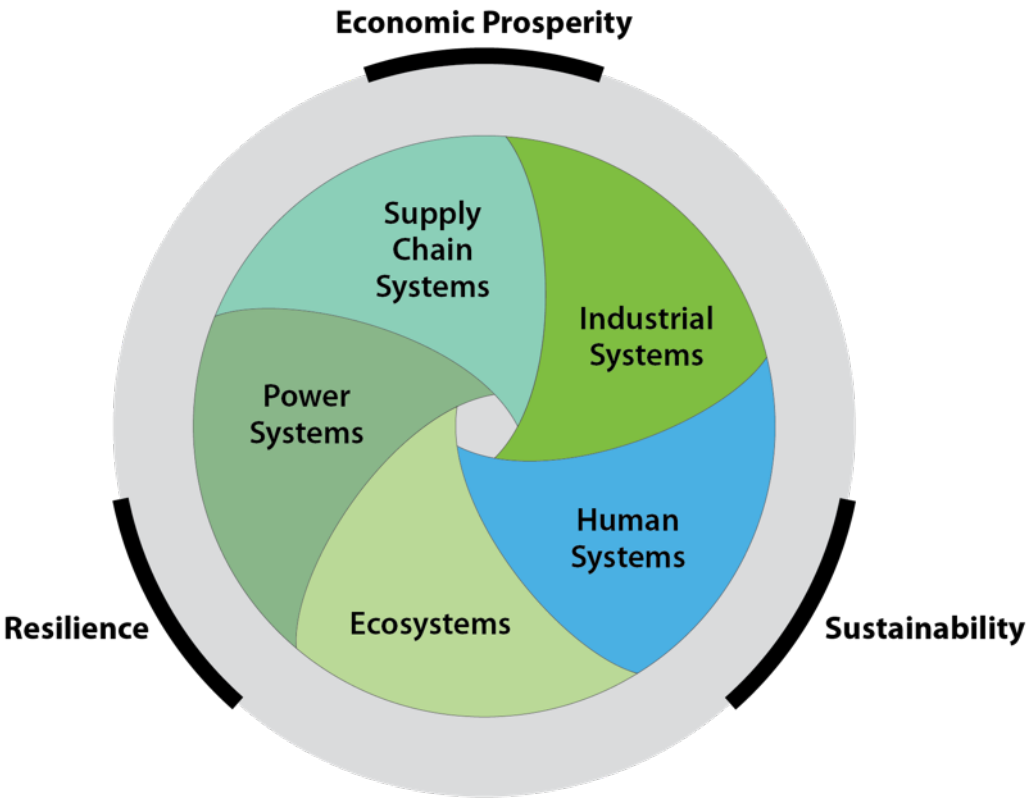
- 1800 employees, plus 400 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

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 Markets and Trends
- Clean Energy Technologies
  - Solar Photovoltaics
  - Wind Turbines
- Future Transitions and Discussion

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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

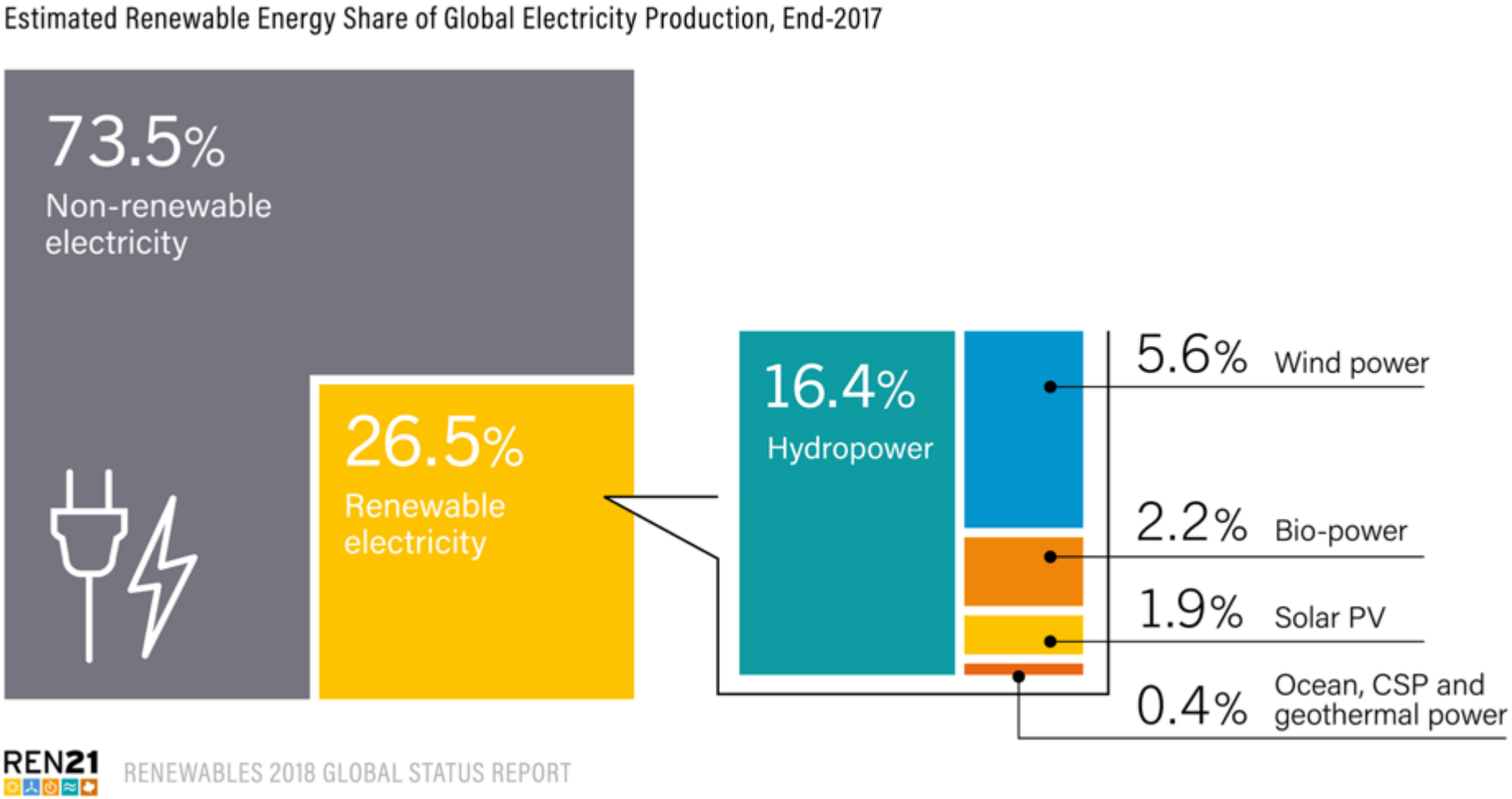
CONCENTRATING SOLAR

BATTERIES & STORAGE

EFFICIENCY & HEAT USE

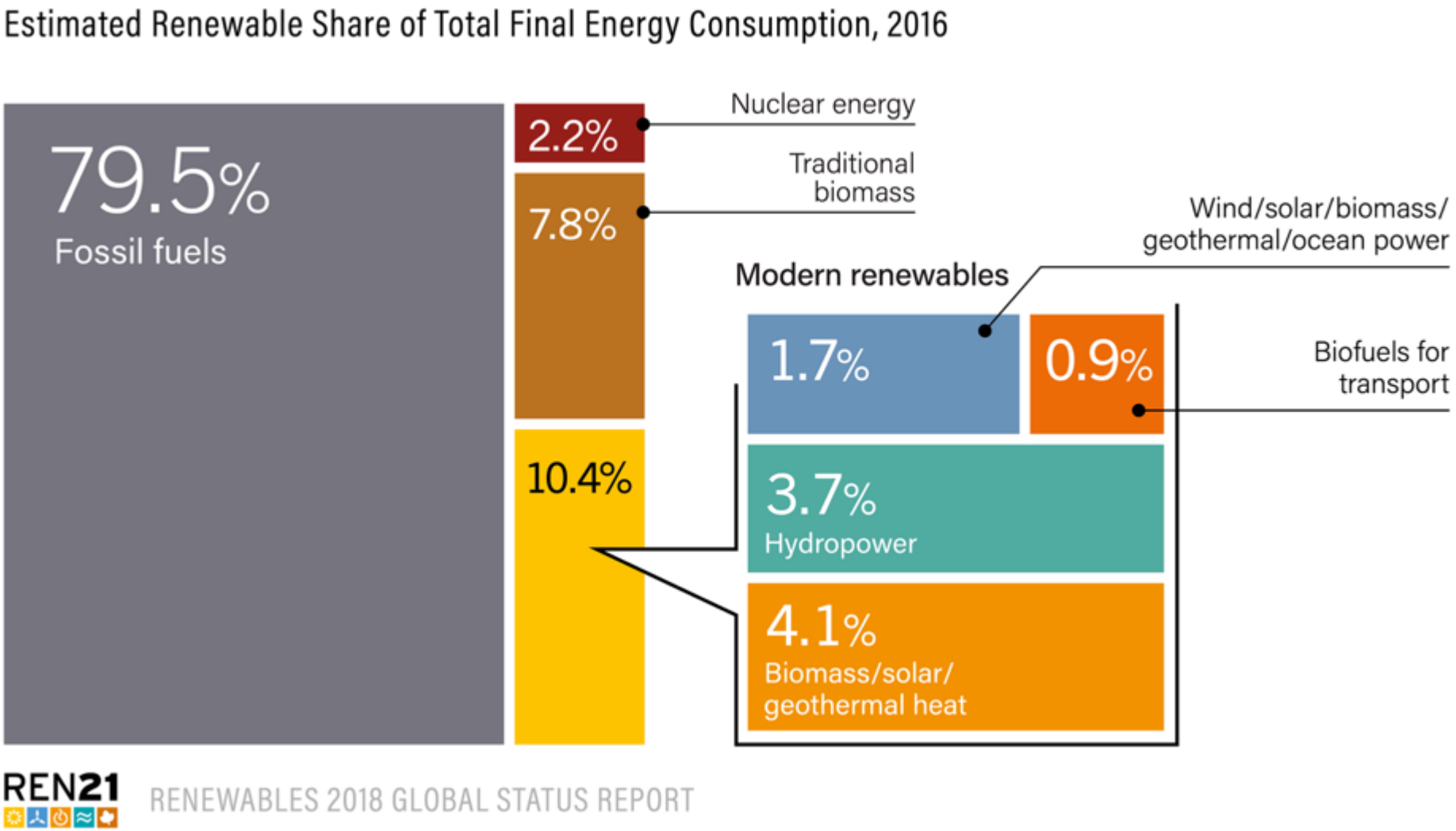
Images from https://images.nrel.gov/

Global share of renewable energy



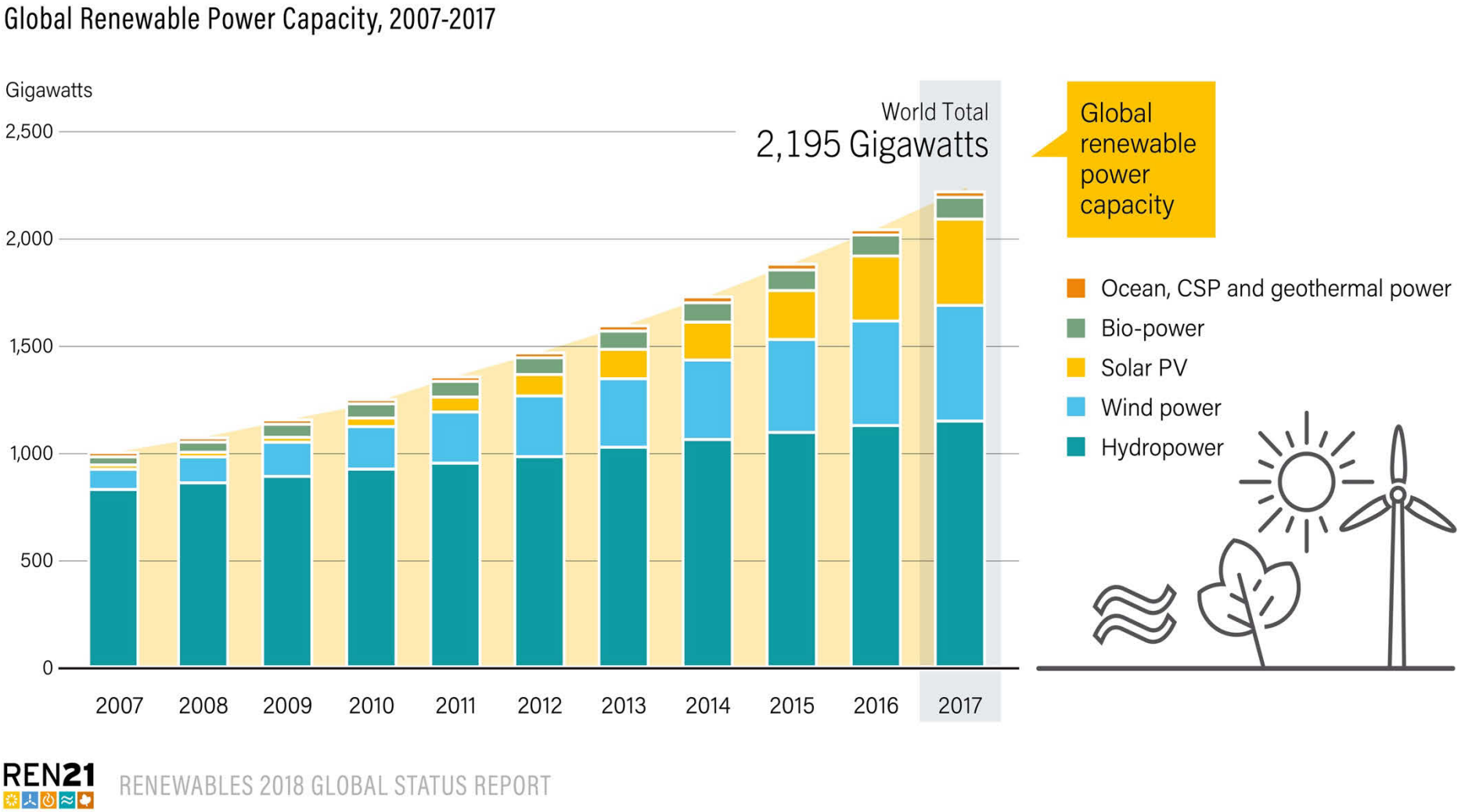
Source: REN21 Renewables 2018 Global Status Report, http://www.ren21.net/gsr-2018/

Global share of renewable energy



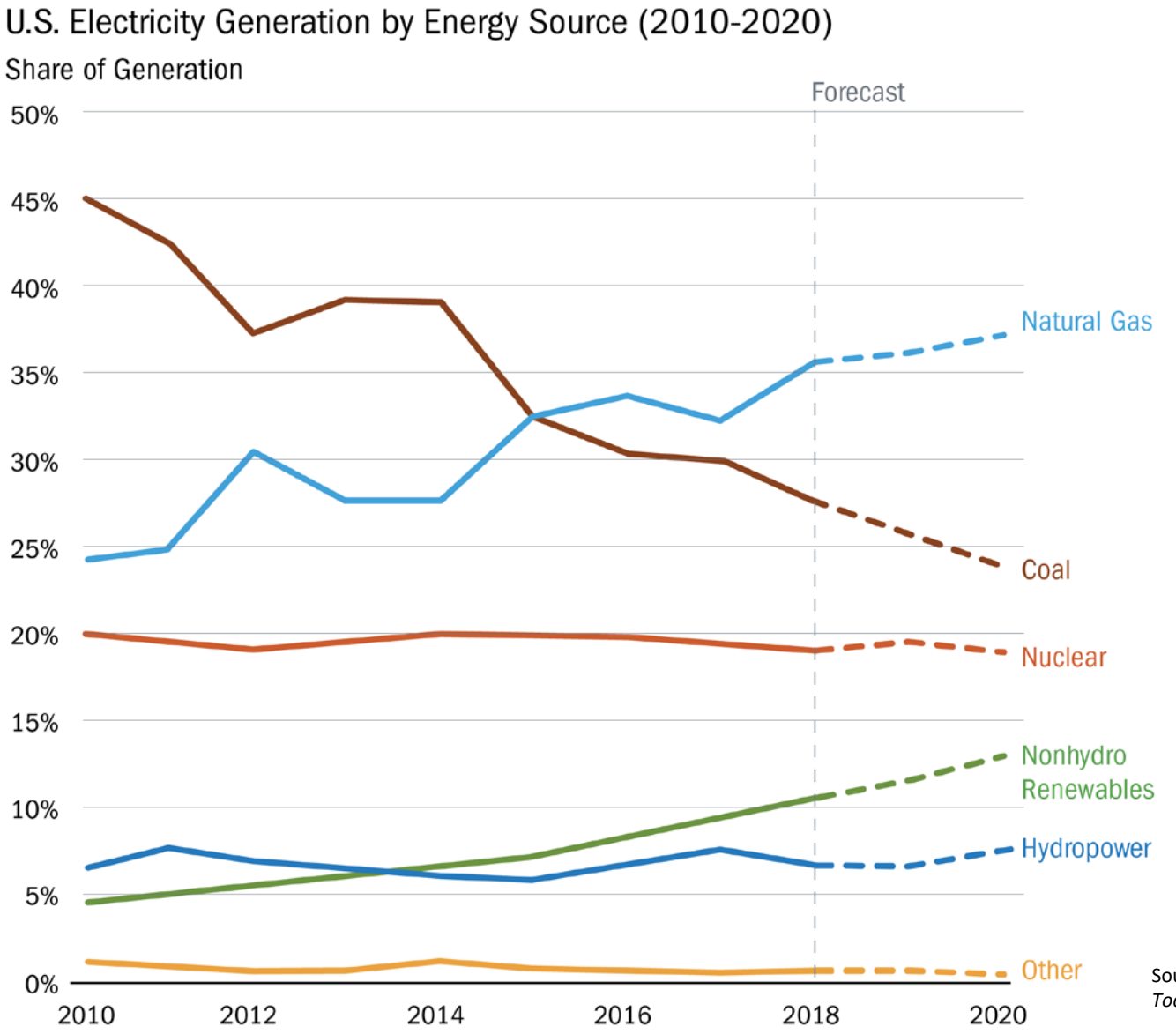
Source: REN21 Renewables 2018 Global Status Report, http://www.ren21.net/gsr-2018/

Global growth of renewable energy



Source: REN21 Renewables 2018 Global Status Report, http://www.ren21.net/gsr-2018/

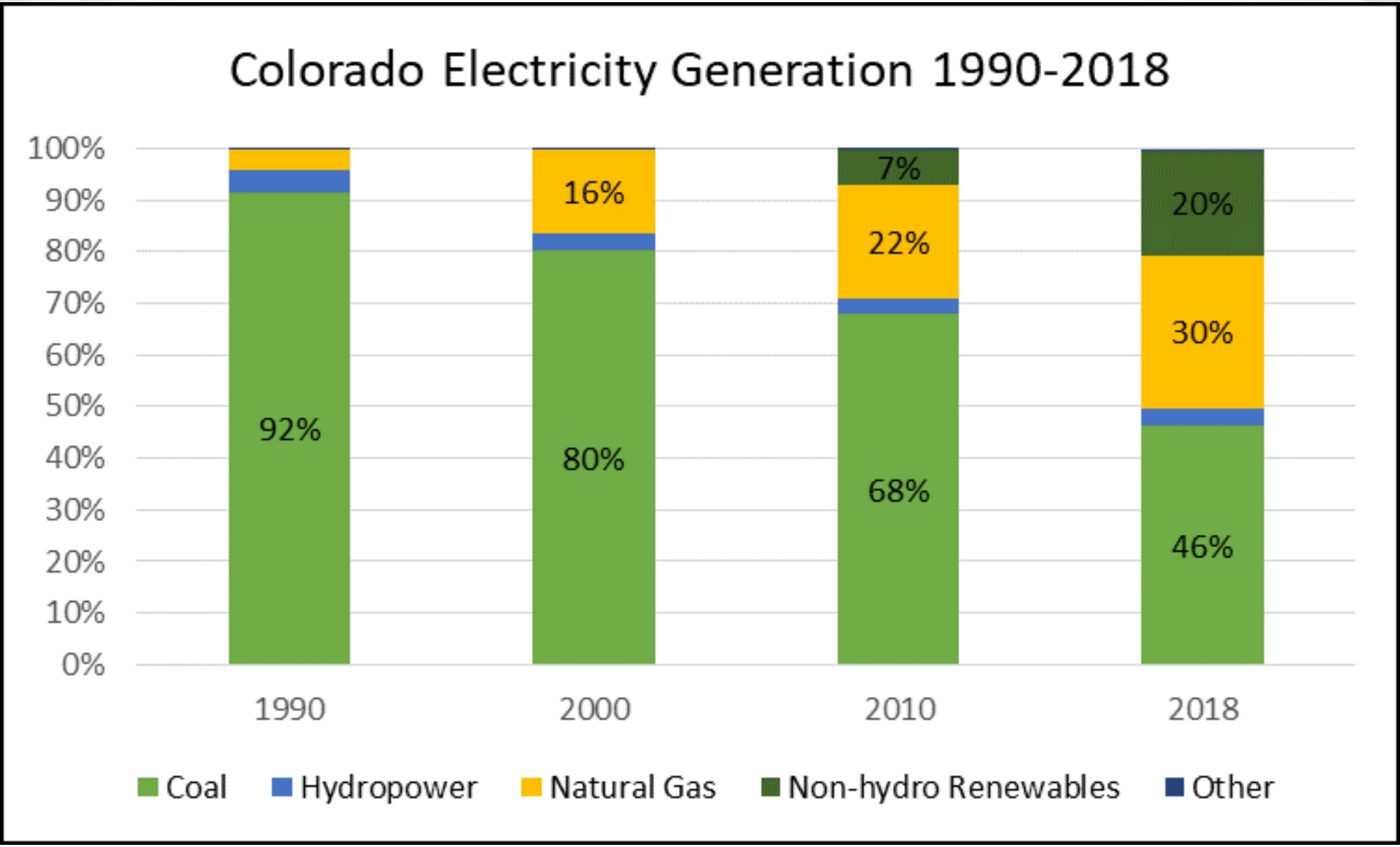
Electricity Trending to Gas and Renewables



Power sector is undergoing profound transformation, shifting from coal to natural gas and renewable power generation.

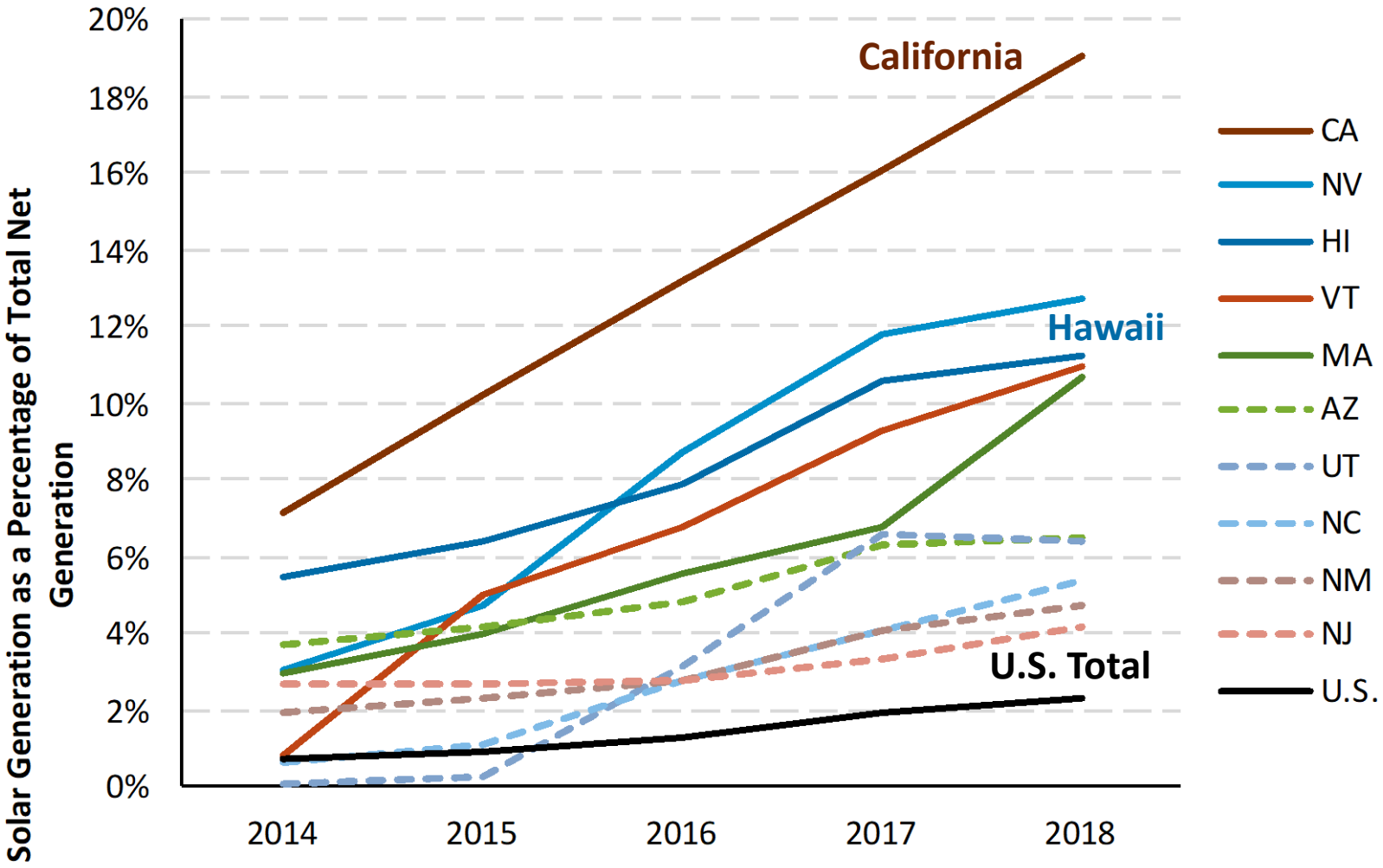
Source: United States Energy Information Agency, *Today in Energy,* 18 January 2019

Electricity Trending to Gas and Renewables



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

Solar Generation as a Percentage of Total Generation, 2014-2018, by U.S. State

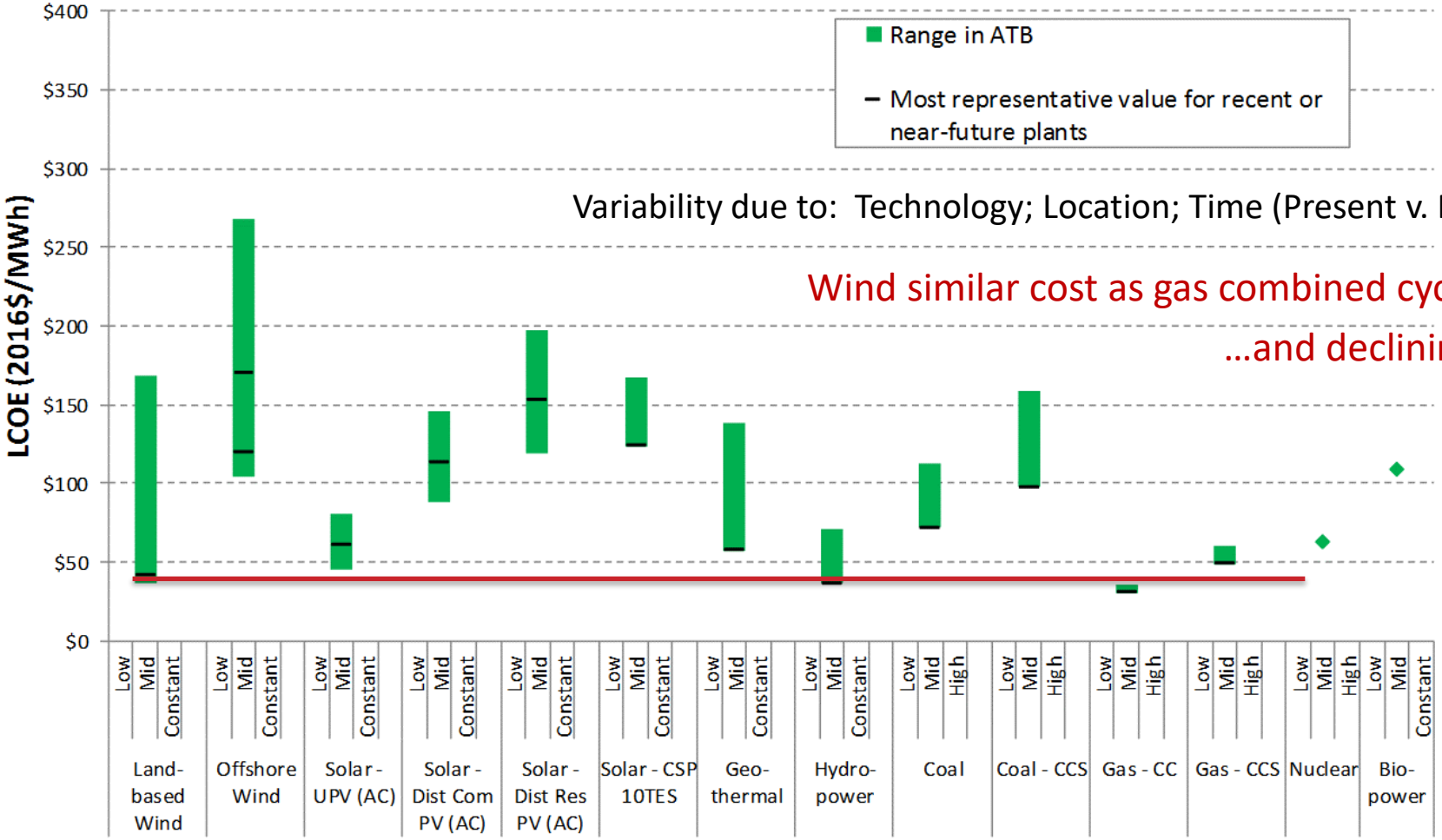


Note: EIA monthly data for 2018 are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore, a certain amount of solar data has not yet been reported. "Net Generation" includes DPV generation. Net generation does not take into account imports and exports to and from each state and therefore the percentage of solar consumed in each state may vary from its percentage of net generation.
Source: U.S. Energy Information Administration, "Electricity Data Browser." Accessed April 3, 2019.

Source: NREL, Q4 2018/Q1 2019 Solar Industry Update, May 2019.
https://www.nrel.gov/docs/fy19osti/73992.pdf

Cost of Renewable & Traditional Electricity Equalizing

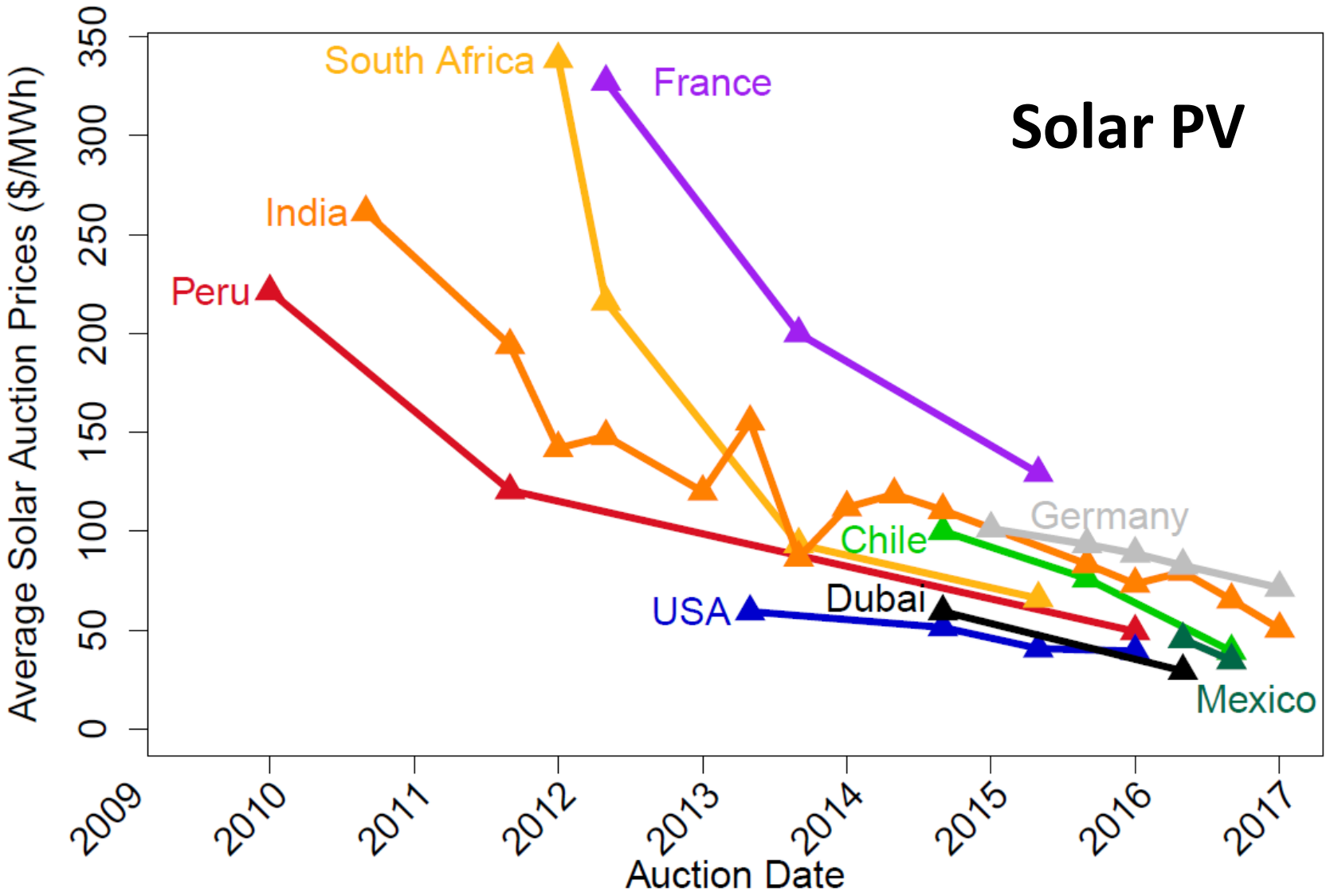
Levelized Cost of Electricity ranges by technology. Values are in 2016$.



2018 ATB LCOE range by technology for 2016 based on R&D financial assumptions

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

Cost of Renewable Electricity at Auctions Driving Decrease



Source: IRENA Renewable Energy Auctions: Analysing 2016 (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

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Solar energy is diverse

BATTERIES & STORAGE

SOLAR PHOTOVOLTAICS (PV)

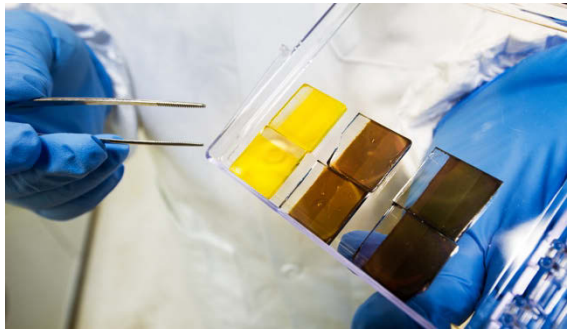
Residential: 1-10 kW scale

Commercial: 1-20 MW

Utility: 50-1000 MW

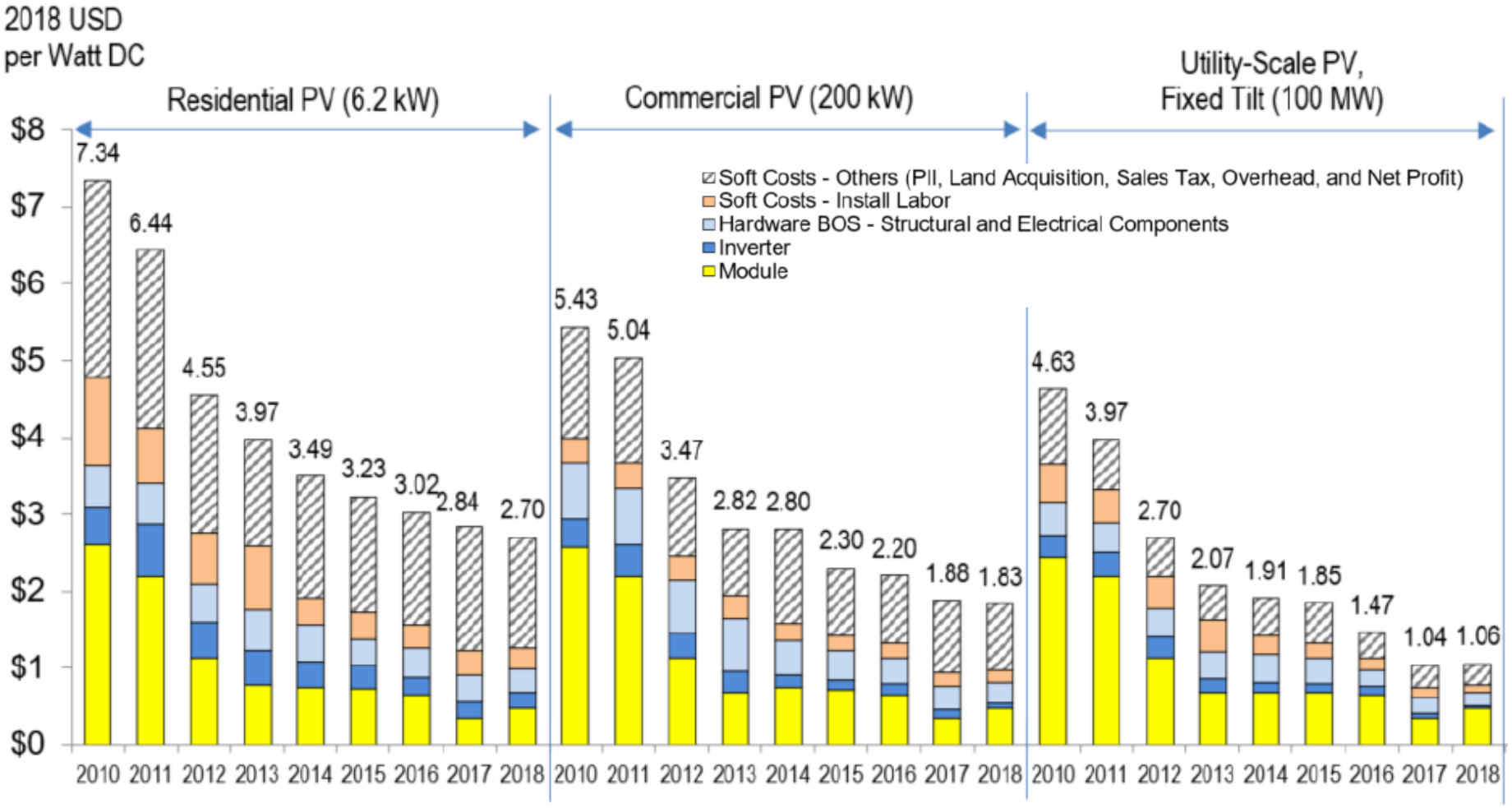
CONCENTRATING SOLAR

PEROVSKITES (New!)



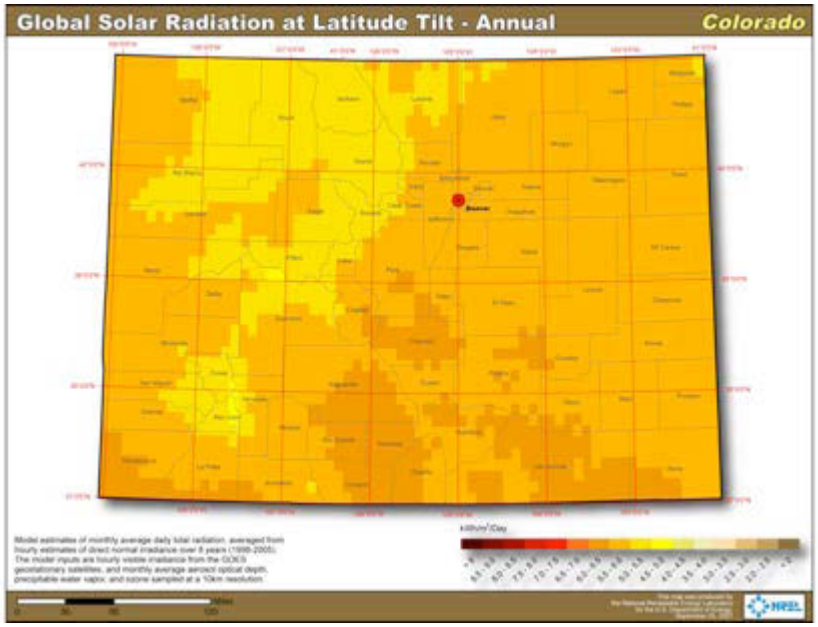
Images from https://images.nrel.gov/

PV System Installation Prices



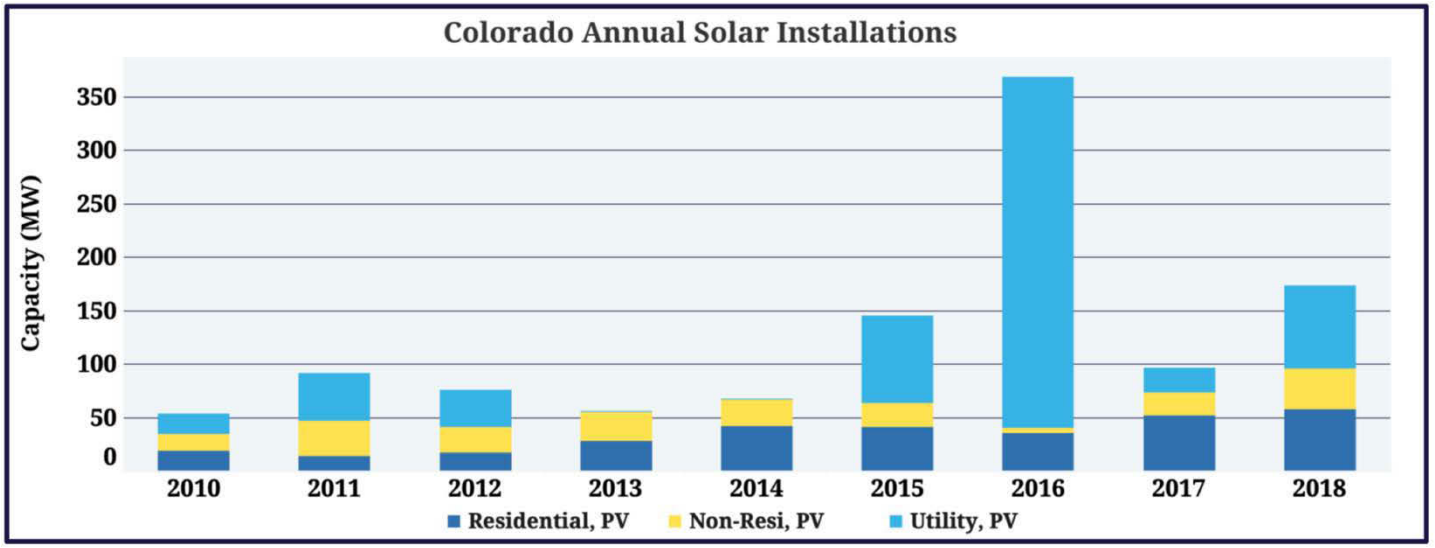
Source: NREL. The U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018, https://www.nrel.gov/docs/fy19osti/72399.pdf

Colorado Solar Development

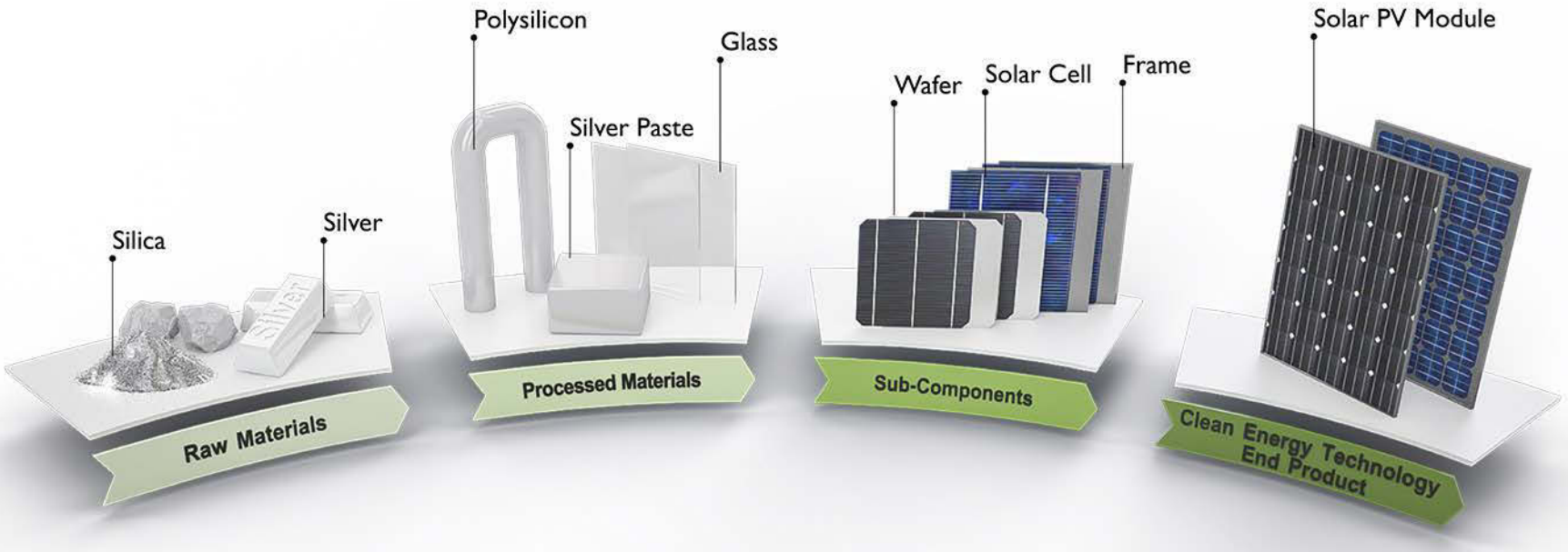


Colorado Rank – 12th
Installed: 1184 MW
Percentage of In-State Energy Production: 2.96%
Equivalent U.S. Homes Powered: 241,000
Manufacturers: 49. Installers: 231

Sources: NREL and SEIA,
https://www.seia.org/sites/default/files/2019-03/Federal_2019Q1_Colorado.pdf

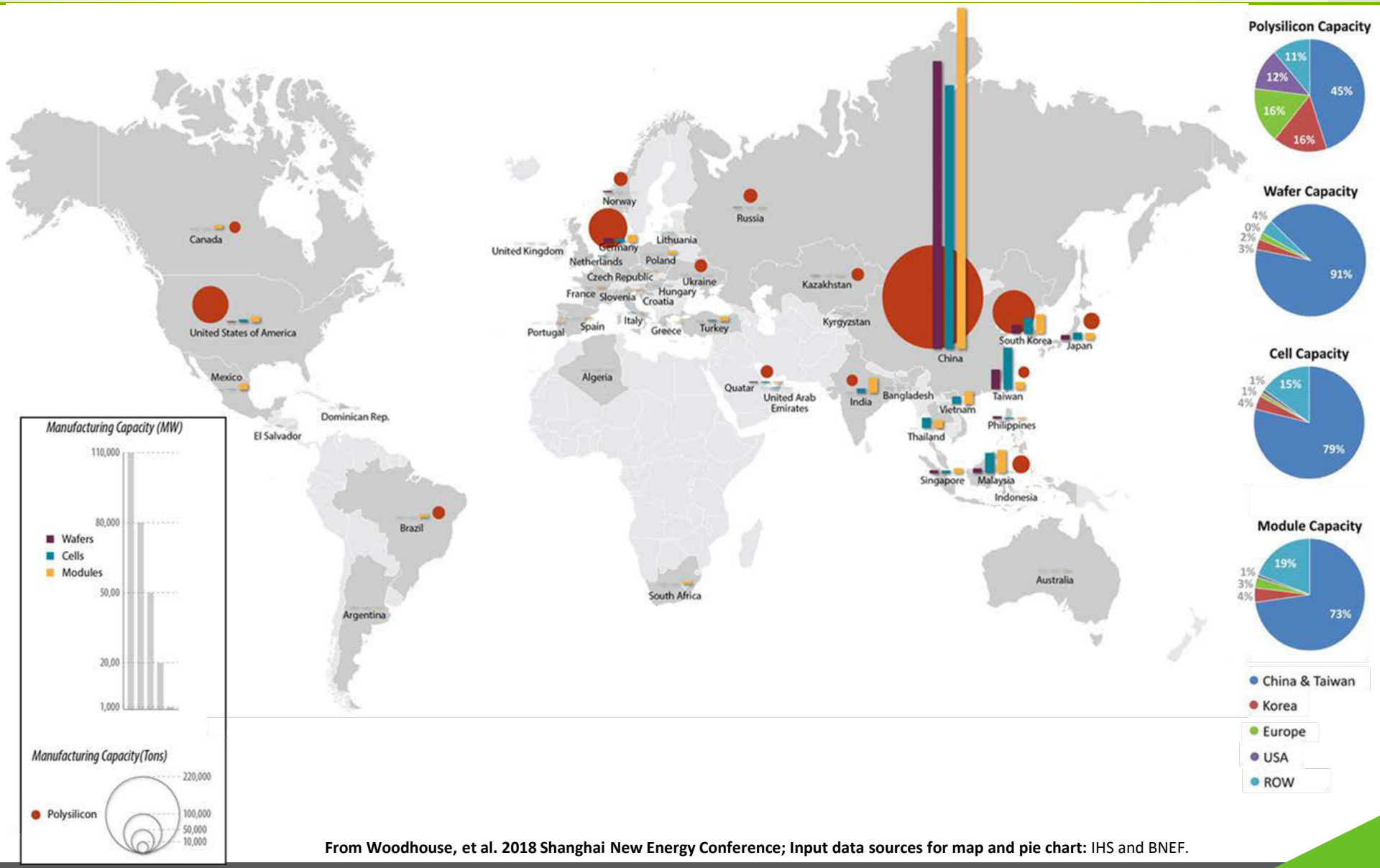


Supply chain of PV panels



Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2017, https://www.manufacturingcleanenergy.org/benchmark/.

2017 Global PV Manufacturing: Top 373 Companies



From Woodhouse, et al. 2018 Shanghai New Energy Conference; Input data sources for map and pie chart: IHS and BNEF.

Balance of trade varies across supply chain (2016 data)

Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies.

Source: Benchmarks of Global Clean Energy Manufacturing, CEMAC, 2018, http://www.manufacturingcleanenergy.org/blog-20180326.html.

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Wind Turbines - Onshore

Peetz Table Wind Energy Center

- Peetz, Colorado
- 575 MW

Cedar Creek Wind Farm

- Grover, Colorado
- 550 MW

Wind Turbines – Offshore

Westermeerwind Wind Farm

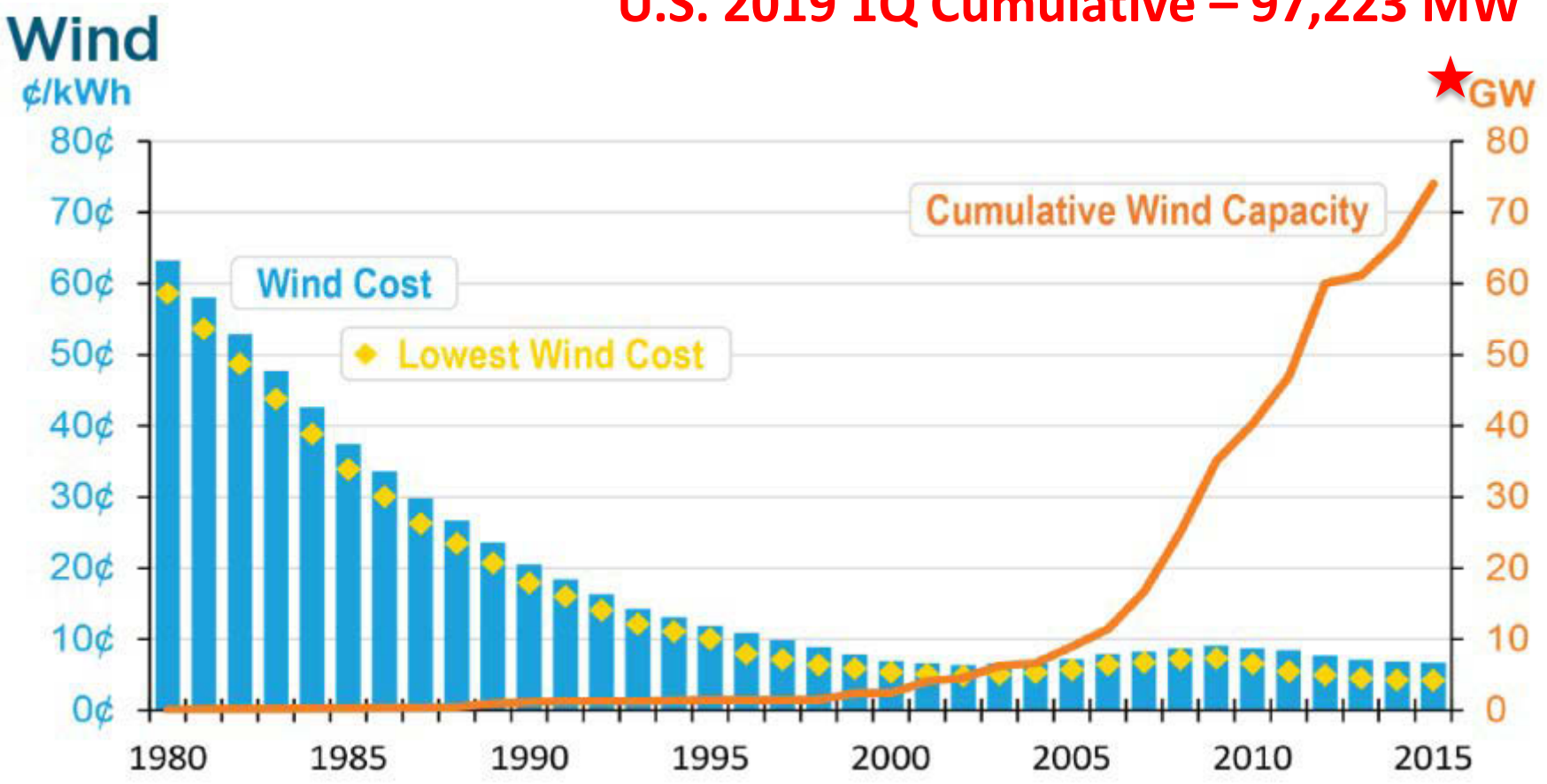
- Noordoostpolder, Netherlands
- 144 MW

Horn Rev Wind Farm

- West coast of Denmark
- 160 MW

Wind Market Growth Driven by Price Declines

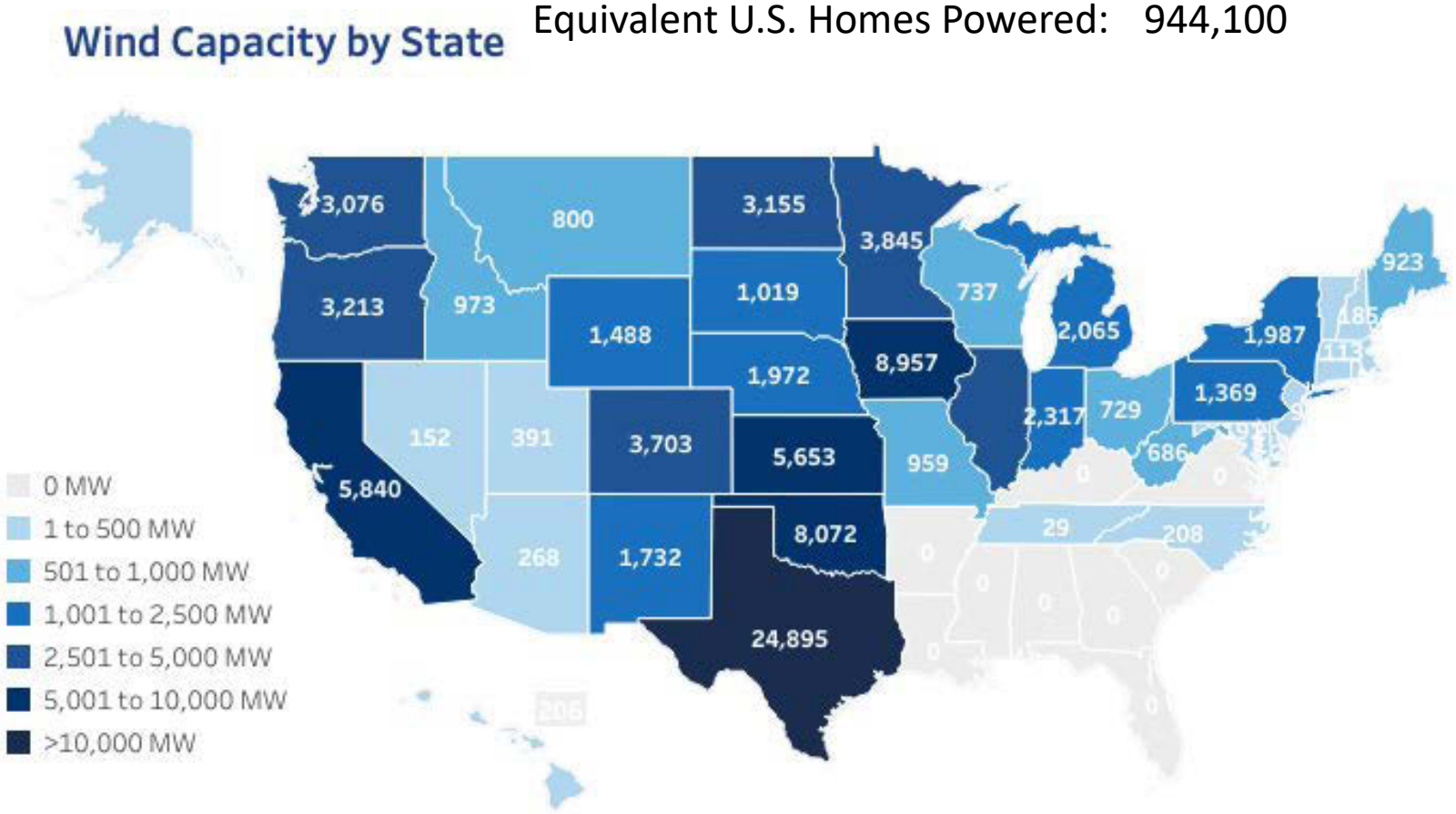
U.S. 2019 1Q Cumulative – 97,223 MW



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

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

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



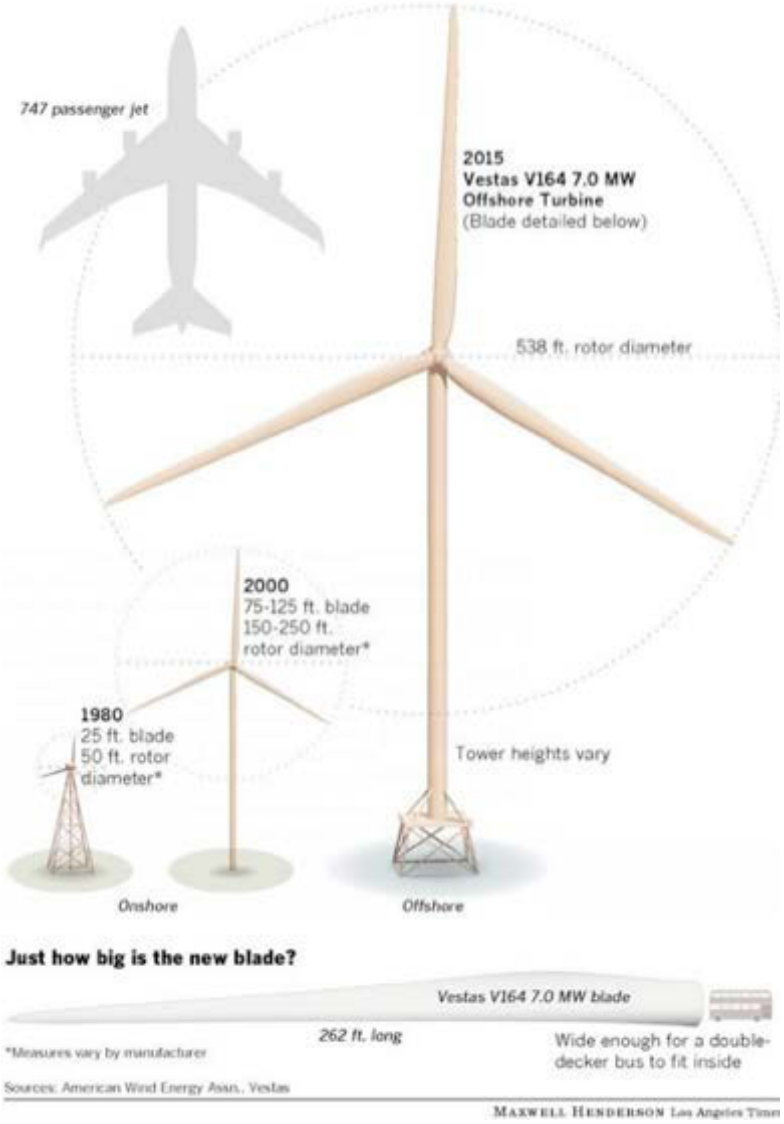
Source: American Wind Energy Association, https://www.awea.org/wind-energy-facts-at-a-glance/, https://www.awea.org/Awea/media/Resources/StateFactSheets/Colorado.pdf

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

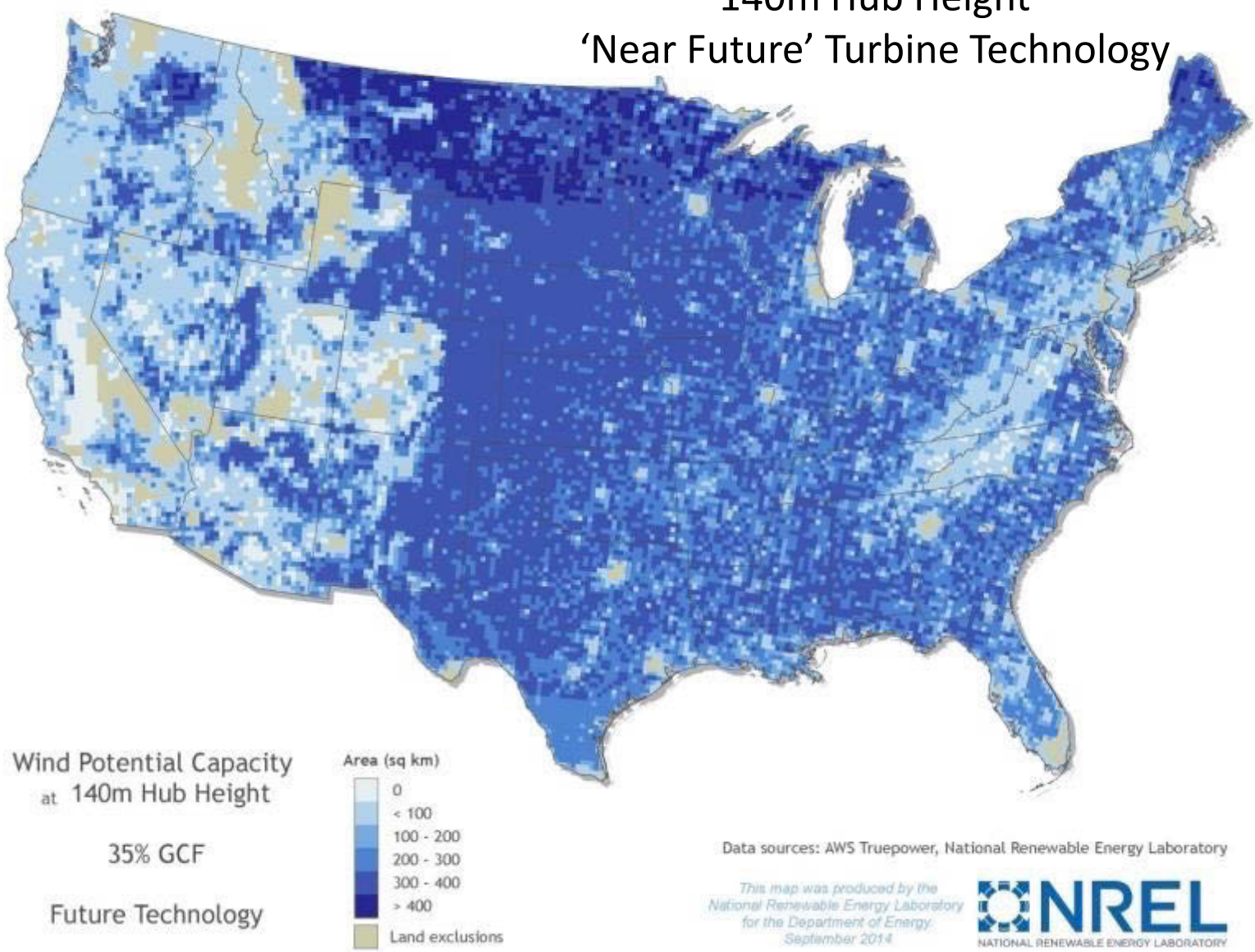
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

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



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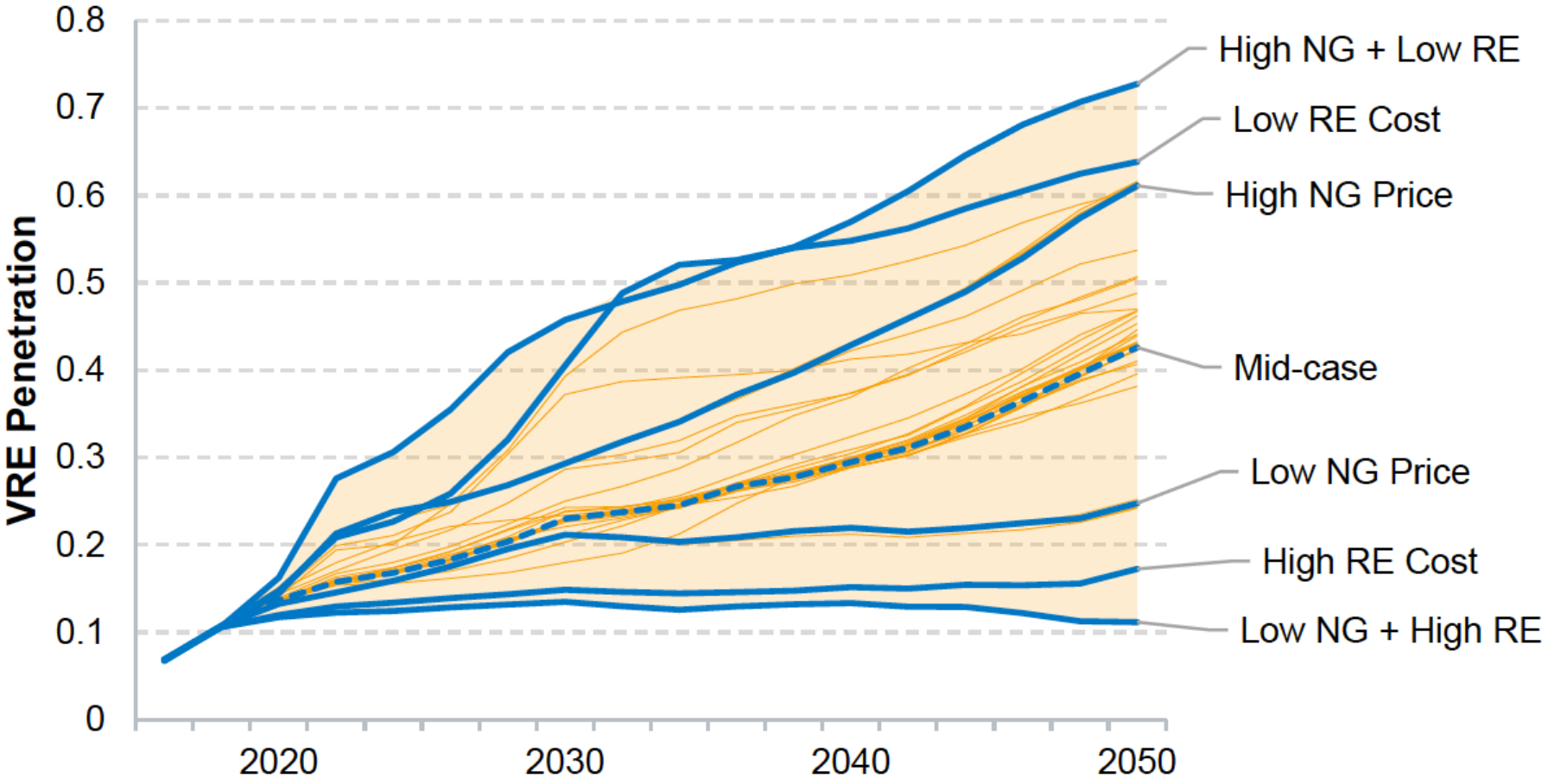
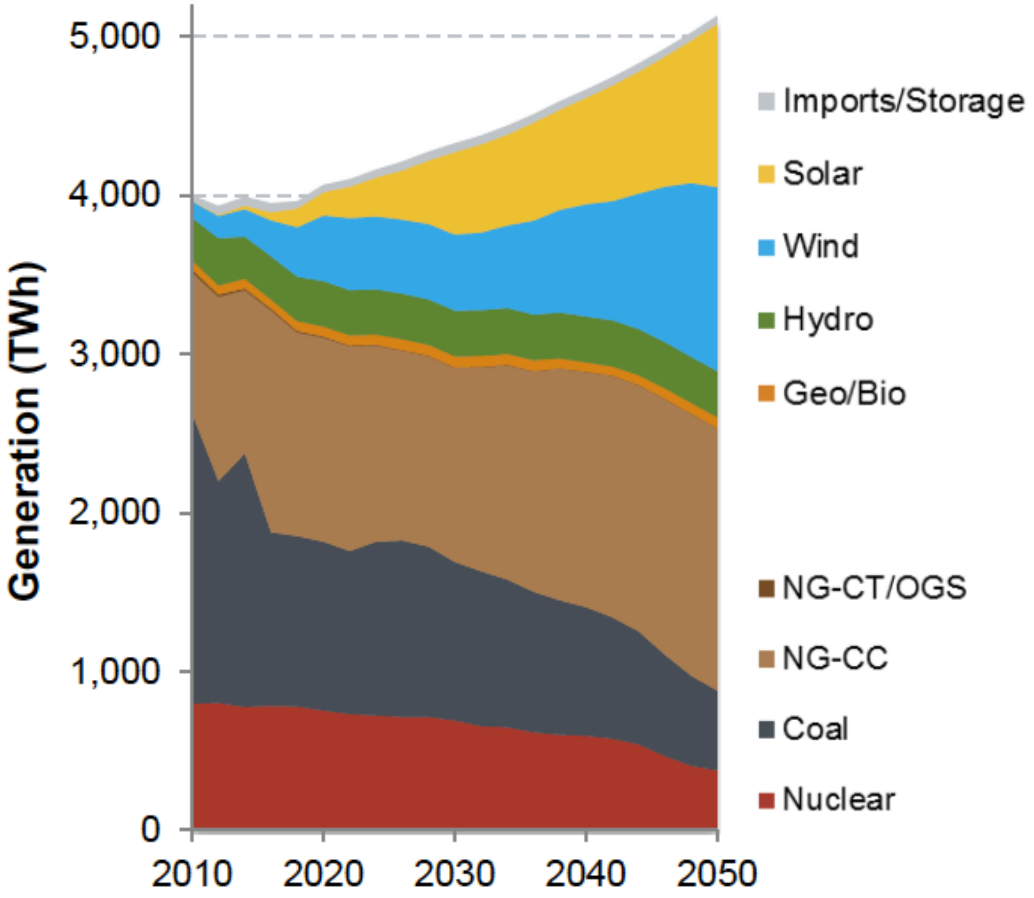
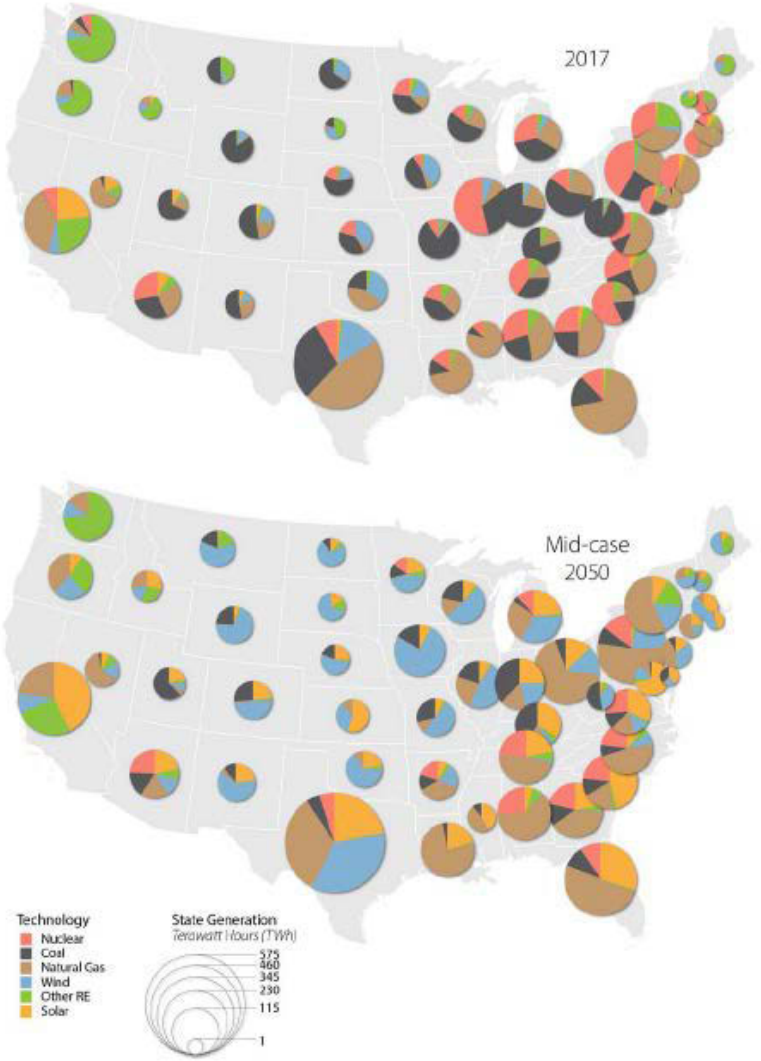
Future: NREL electricity generation scenarios



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

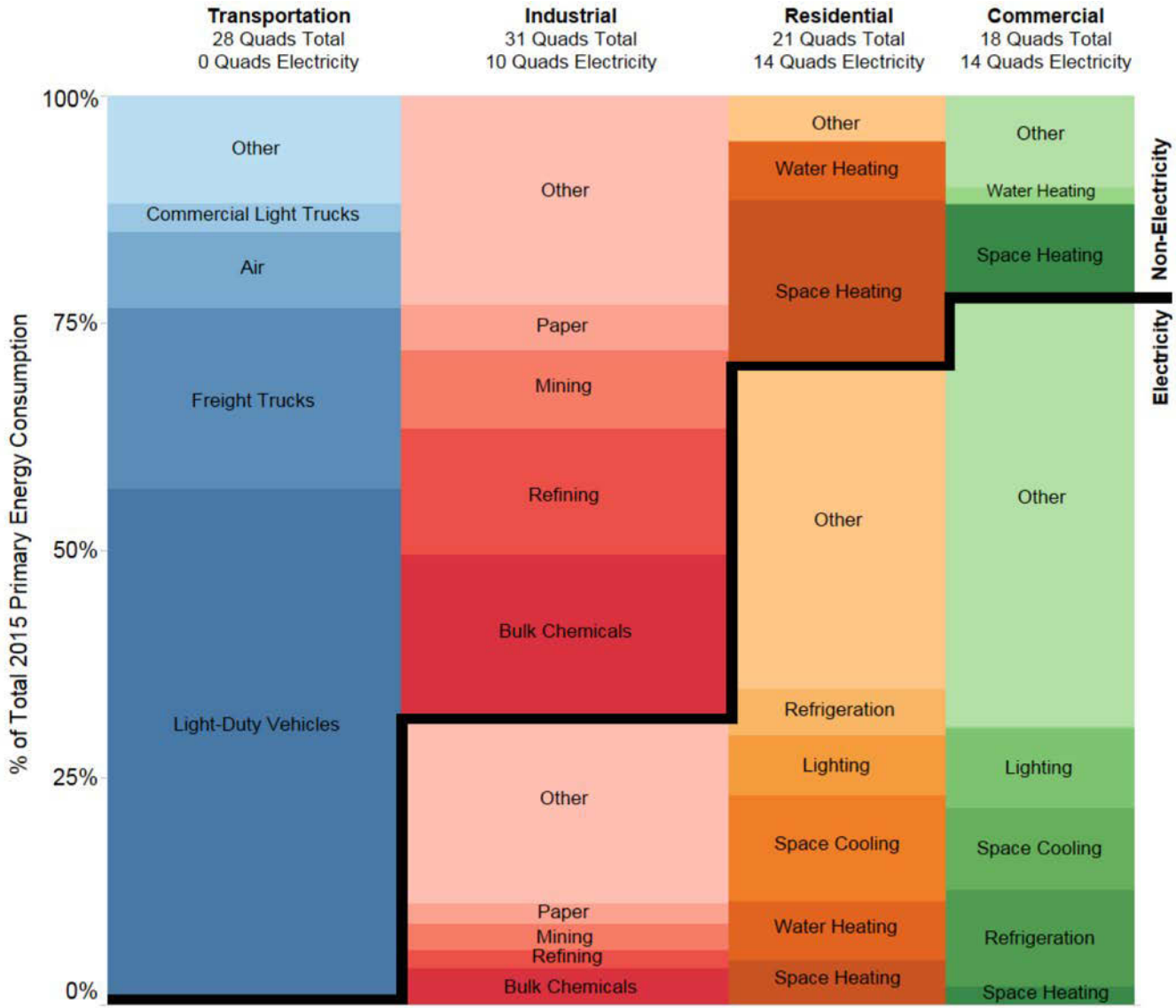
NREL electricity scenario mid-case generation mix





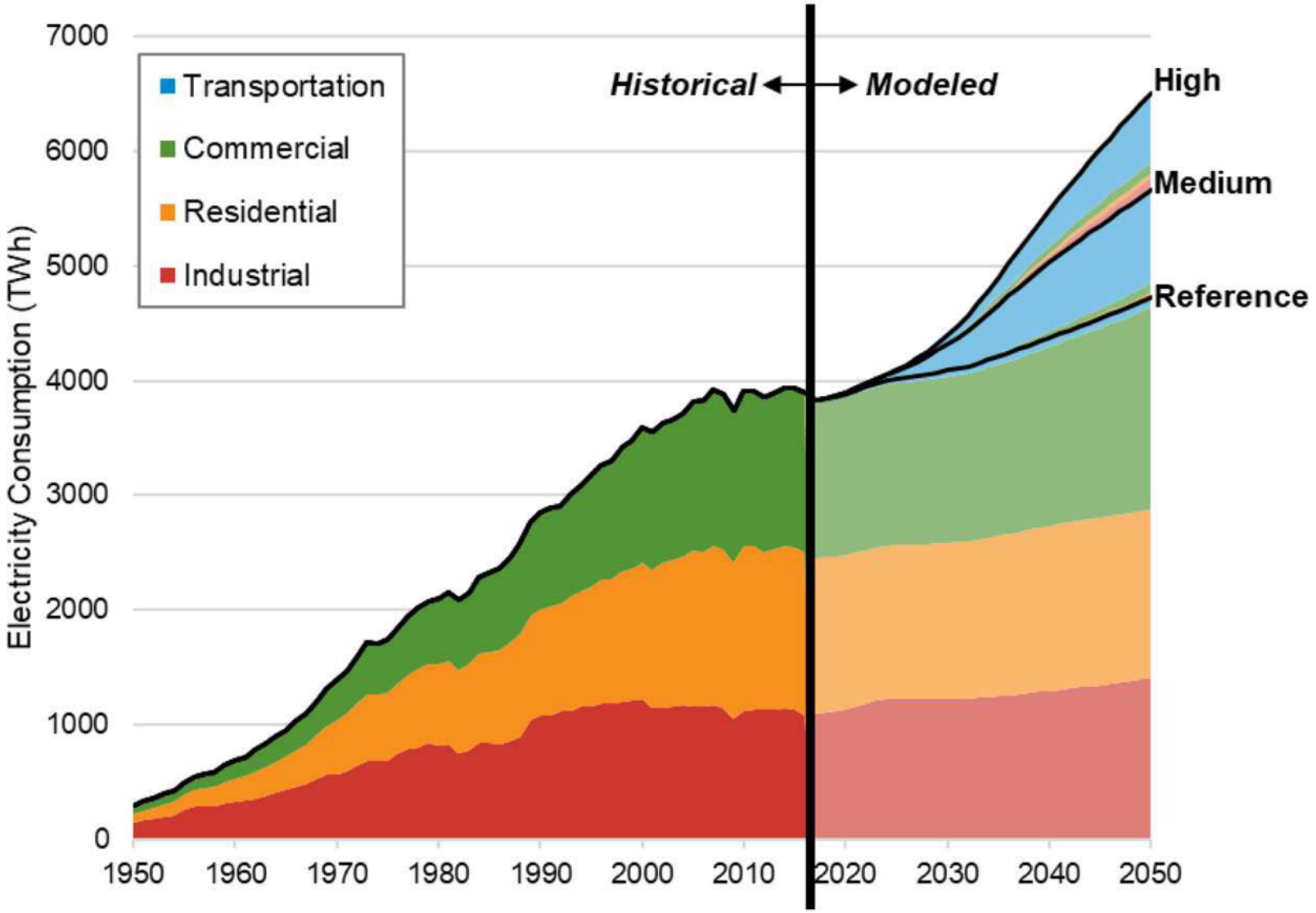
Generation by technology type in the Central Scenario, from: NREL 2018 Standard Scenarios Report: A U.S. Electricity Sector Outlook, www.nrel.gov/analysis/data_tech_baseline.html

Electrification Futures Study



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

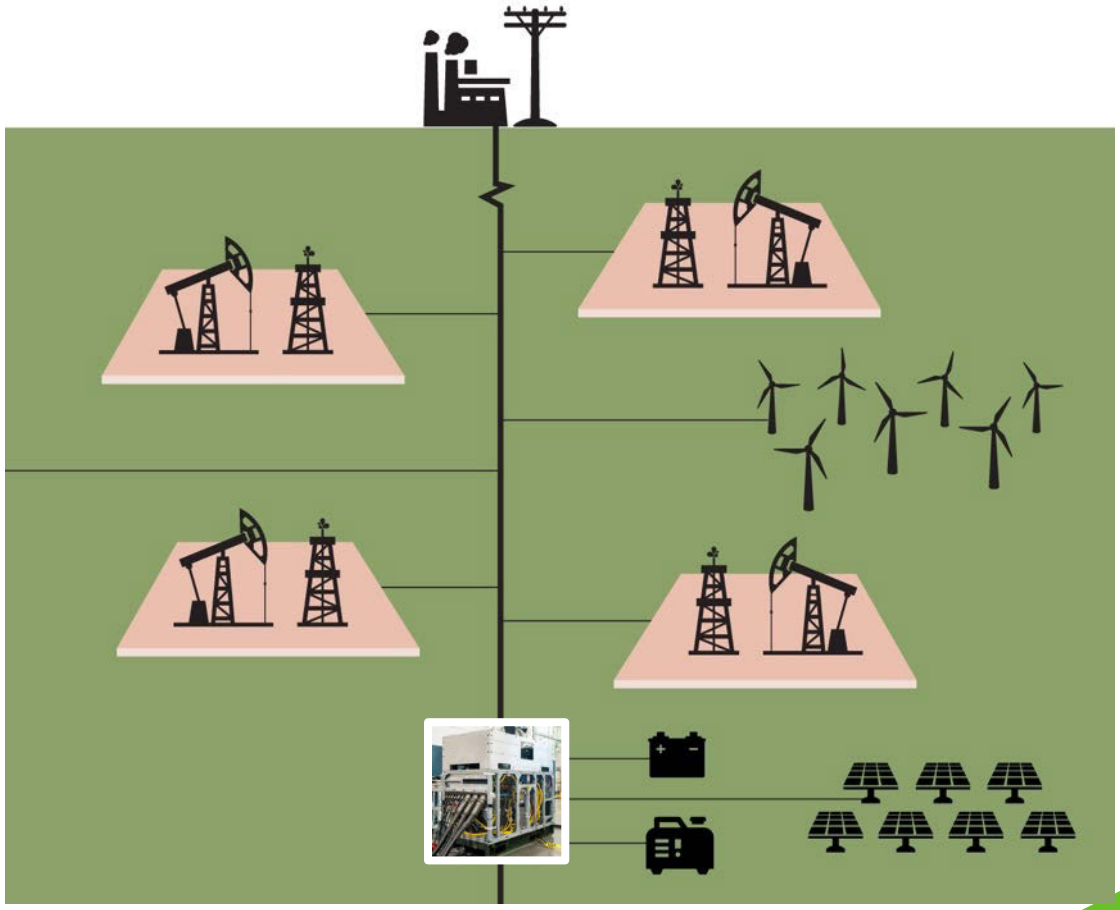
Electrification Futures Study



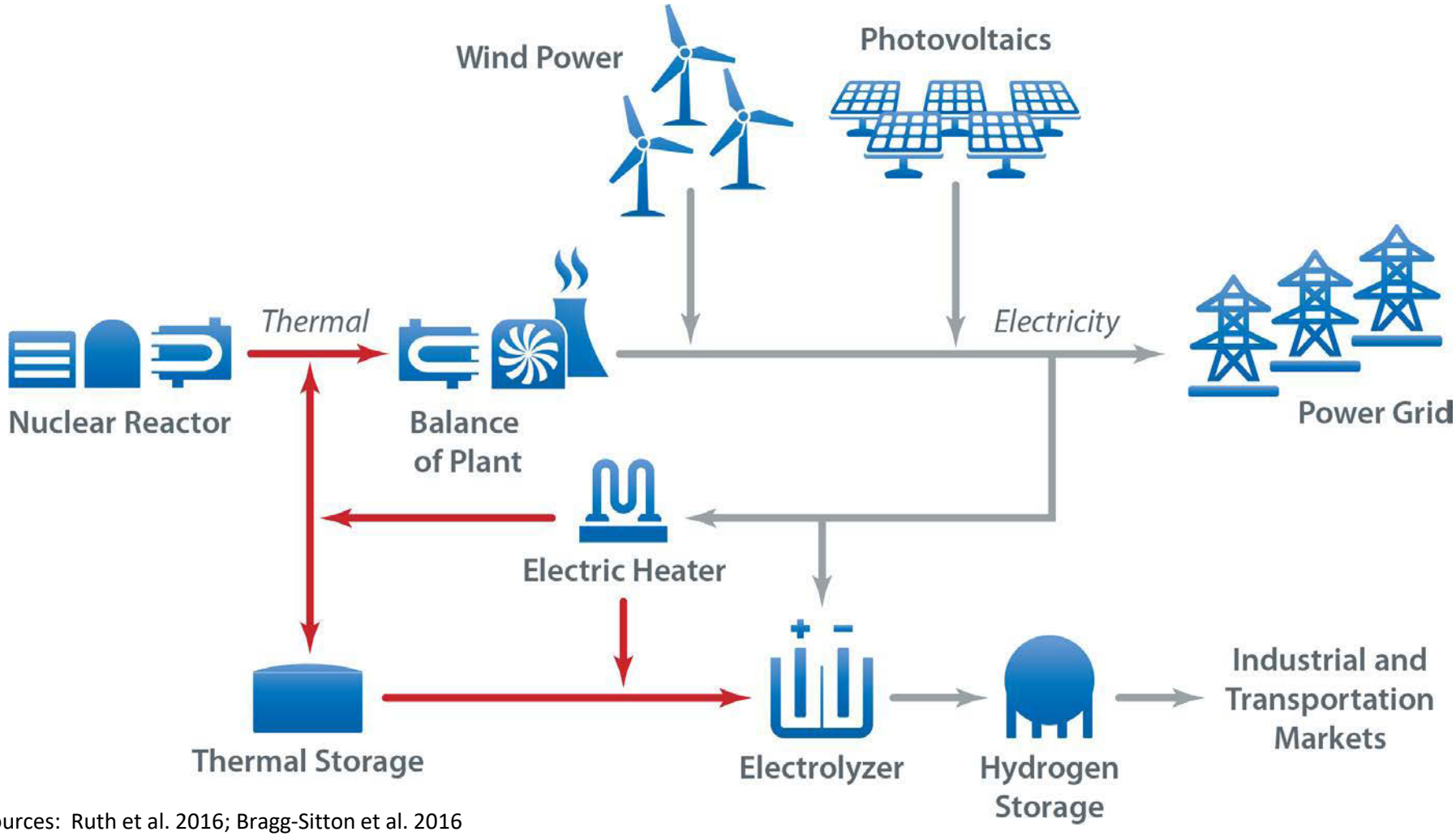
All Figures from NREL's Electrification Futures Study: www.nrel.gov/efs

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



Renewables and Nuclear Hybrid Energy Solutions

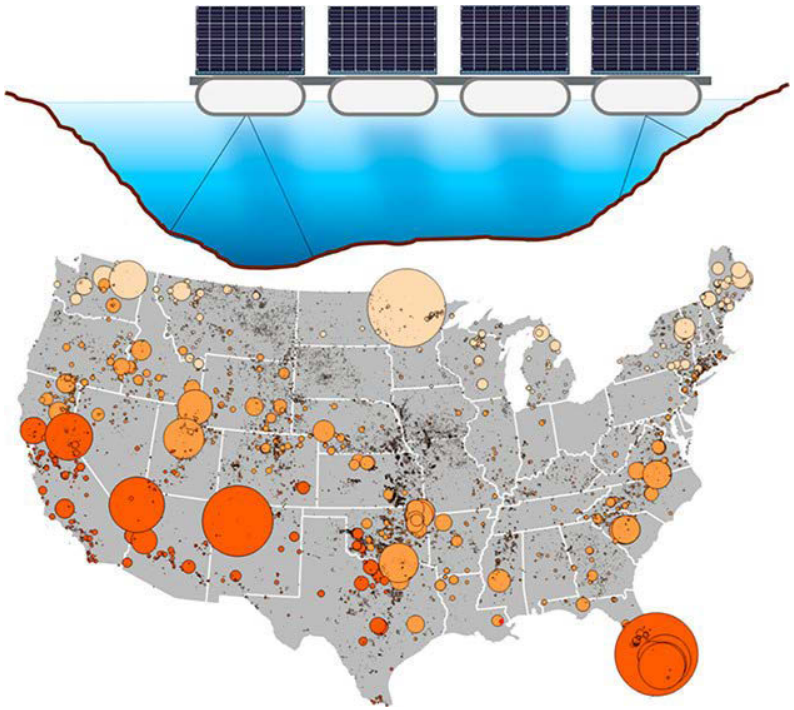


Sources: Ruth et al. 2016; Bragg-Sitton et al. 2016

Co-location of Wind/PV and Agriculture

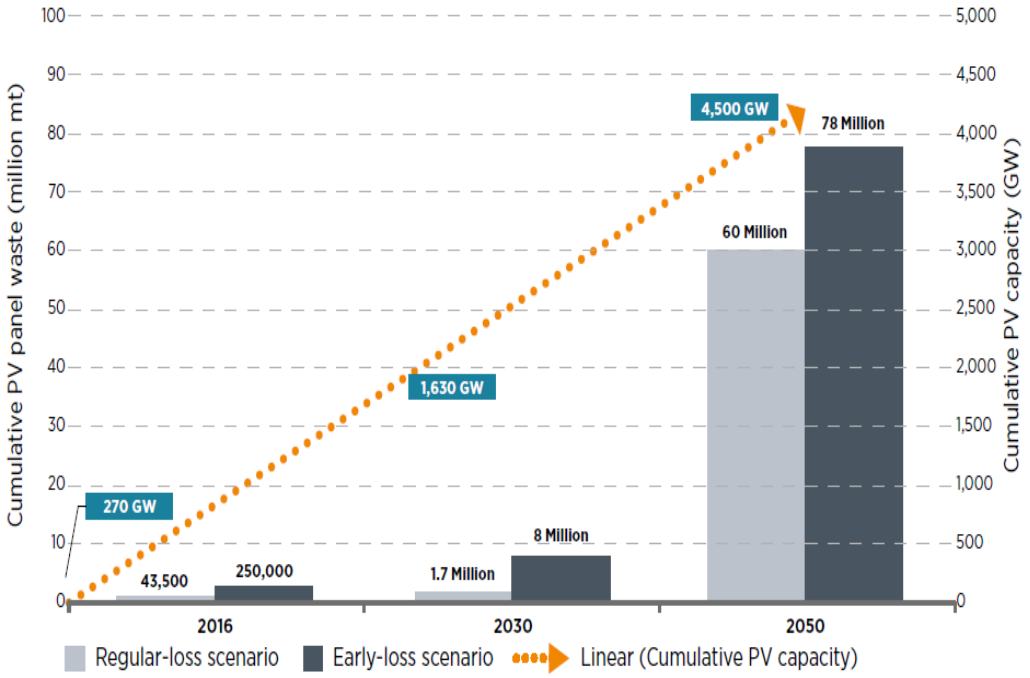
Floating Solar PV (FPV)

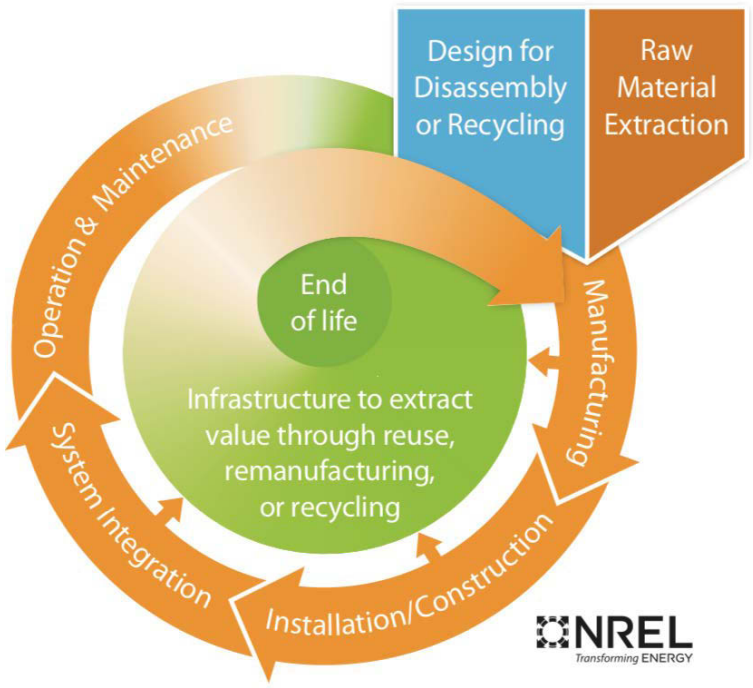
- Analysis of cost, siting, and O&M tradeoffs
- GIS-based technical/market potential analysis for the U.S.
- Installing floating solar photovoltaics on the more than 24,000 man-made U.S. reservoirs could generate about 10 percent of the nation's annual electricity production
- Reduces evaporation and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

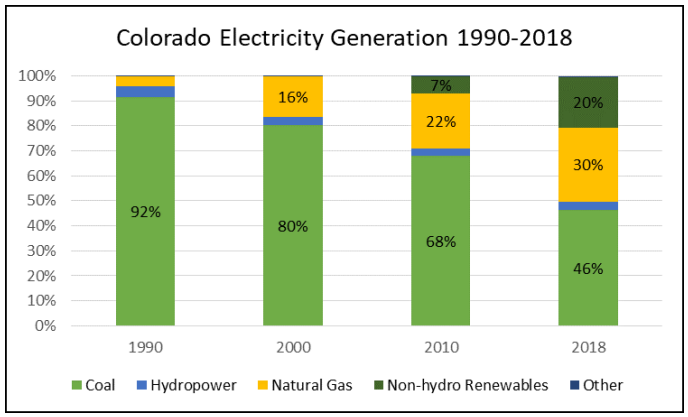
Circular Economy: Growing PV Waste Will Need Technology and Policy Solutions

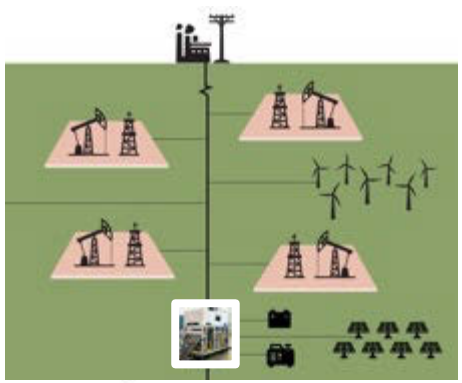


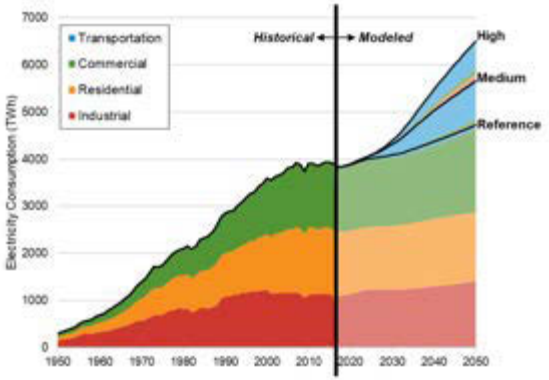


Source: IEA/IRENA 2016

Conclusion and Discussion – Colorado







Trends and Potential Future Scenarios:

- Colorado 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




Questions and Discussion

Thank you!

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