JISEA Joint Institute for Strategic Energy Analysis

Renewable Energy Technologies and Integrated Energy Systems

Energy Seminar Series, Colorado School of Mines

11 November 2020

Jill Engel-Cox, Director, Joint Institute for Strategic Energy Analysis




NREL Transforming ENERGY | COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT | 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 Nuclear Energy

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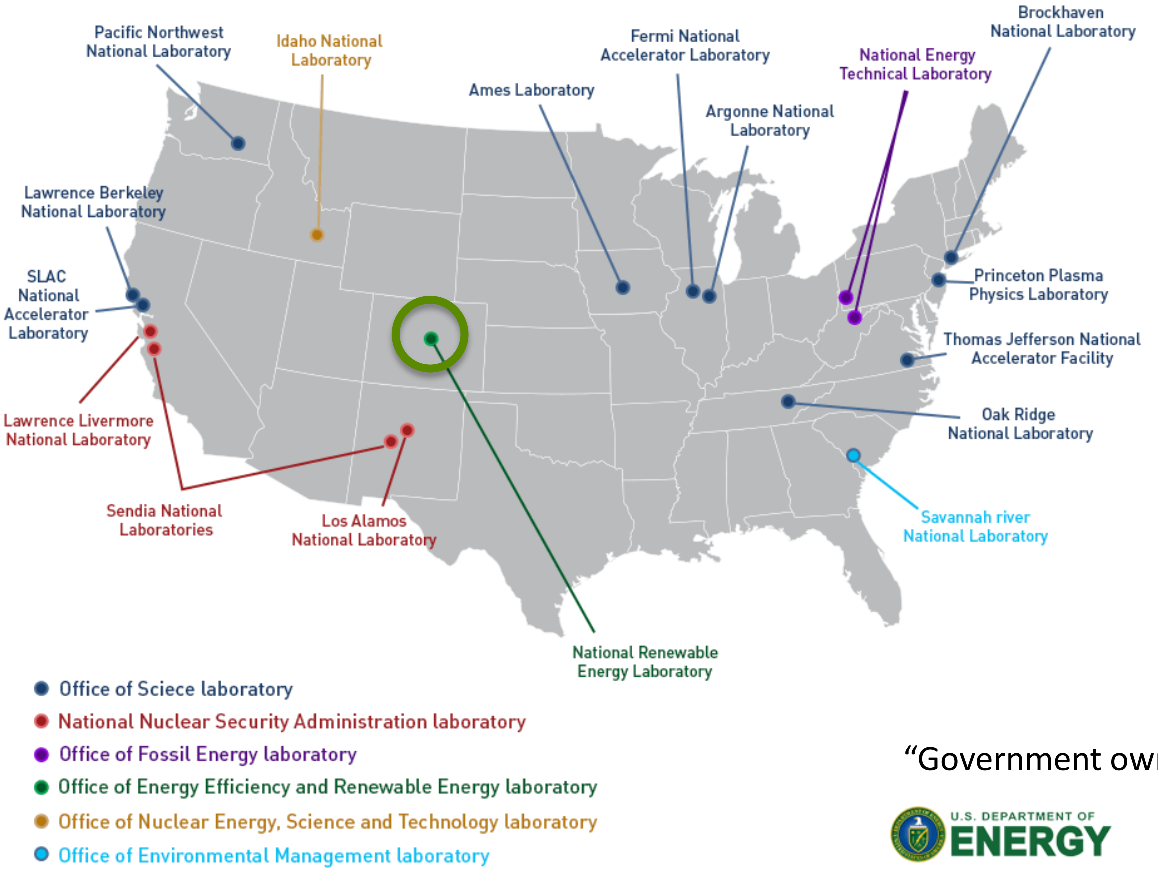
17 U.S. Department of Energy National Laboratories



"Government owned, contractor operated"

U.S. DEPARTMENT OF ENERGY

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:

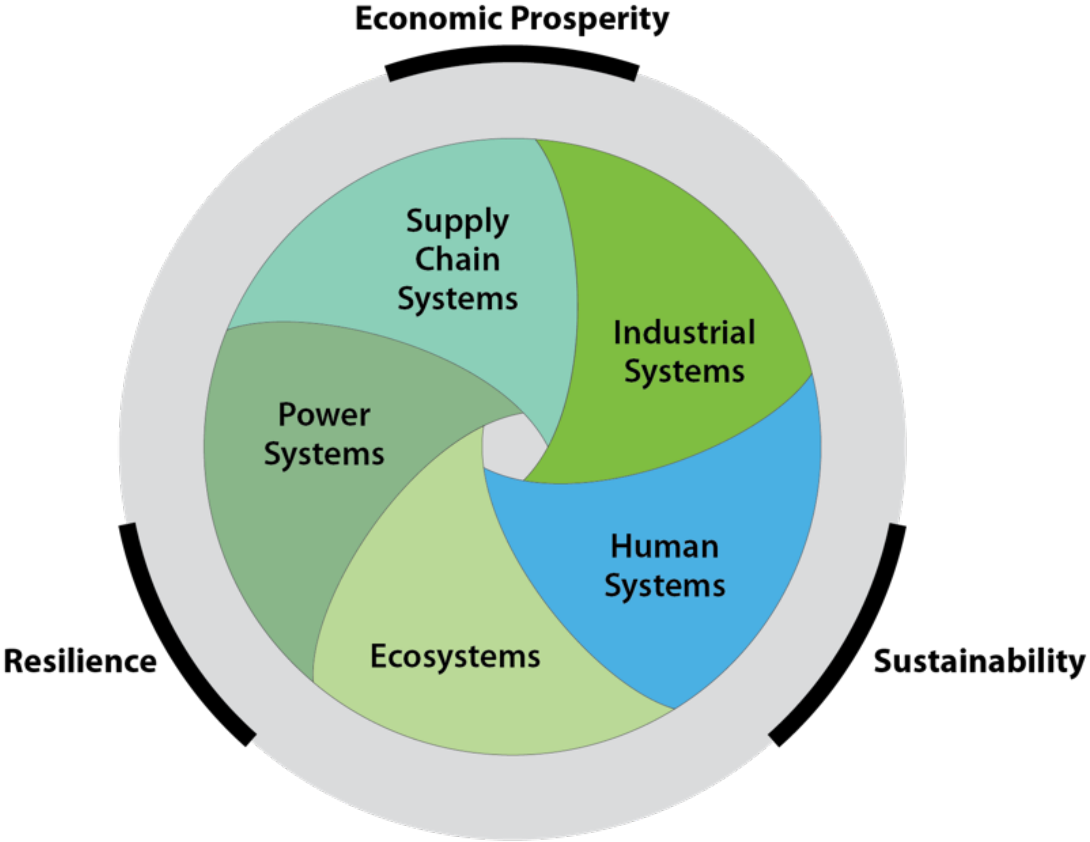
www.nrel.gov/about

- 2,900 employees and postdoctoral researchers, interns, and visiting professionals
- 327-acre main campus in Golden & 305-acre Flatirons Campus with National Wind Technology Center 13 miles north
- 69 R&D 100 awards. More than 1,000 scientific and technical materials published annually

JISEA

Joint Institute for Strategic Energy Analysis

Connecting technologies, economic sectors, and continents to catalyze the transition to the 21st century energy economy.



Founding Partners:

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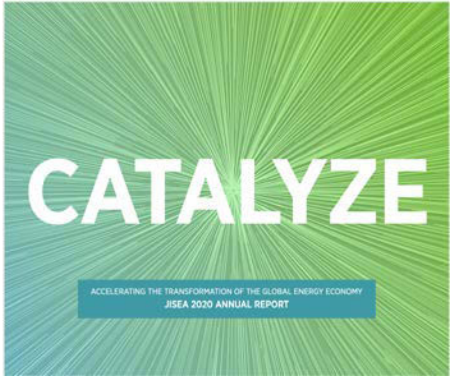
COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
COLORADO STATE UNIVERSITY
Massachusetts Institute of Technology
Stanford University
University of Colorado Boulder

JISEA Research Portfolio

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

Learn more on our website and in the 2020 Annual Report.



@JISEA1 www.jisea.org

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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

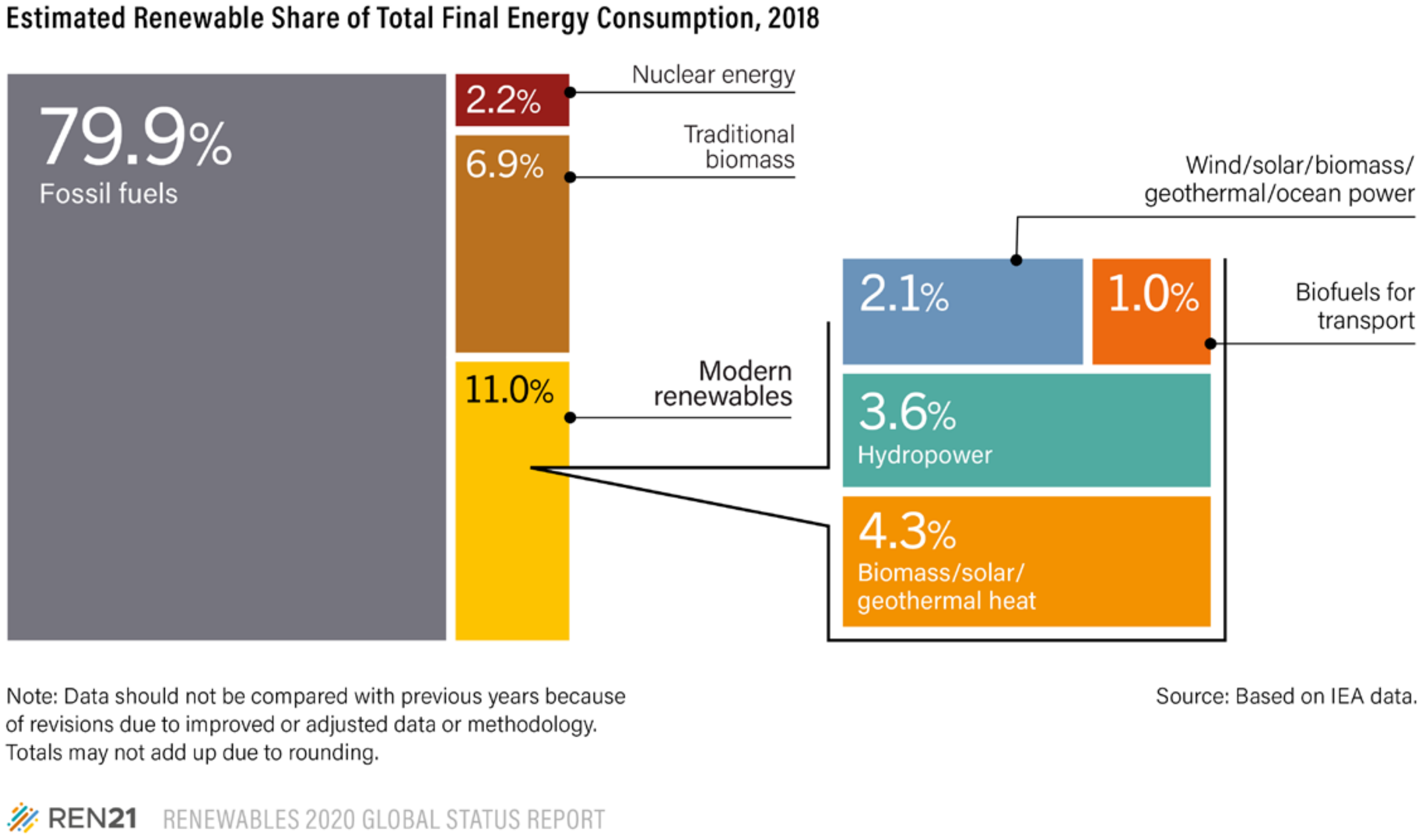
BIOMASS & WASTE

HYDROGEN & GAS

BATTERIES & STORAGE

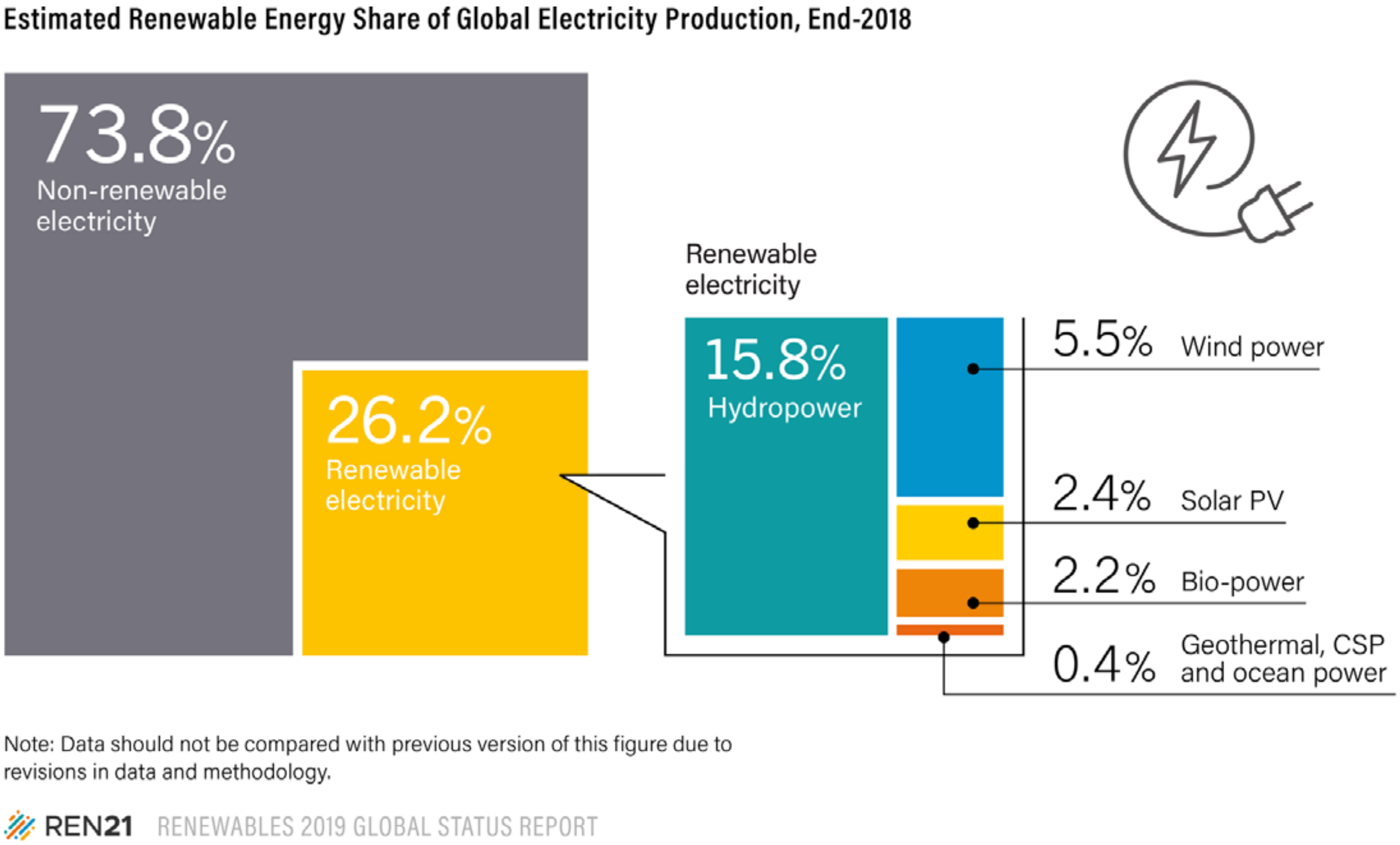
EFFICIENCY & HEAT USE

Global share of renewable energy



Source: REN21 Renewables 2020 Global Status Report, http://www.ren21.net/gsr-2020/

Global share of renewable electricity



Source: REN21 Renewables 2020 Global Status Report, http://www.ren21.net/gsr-2020/

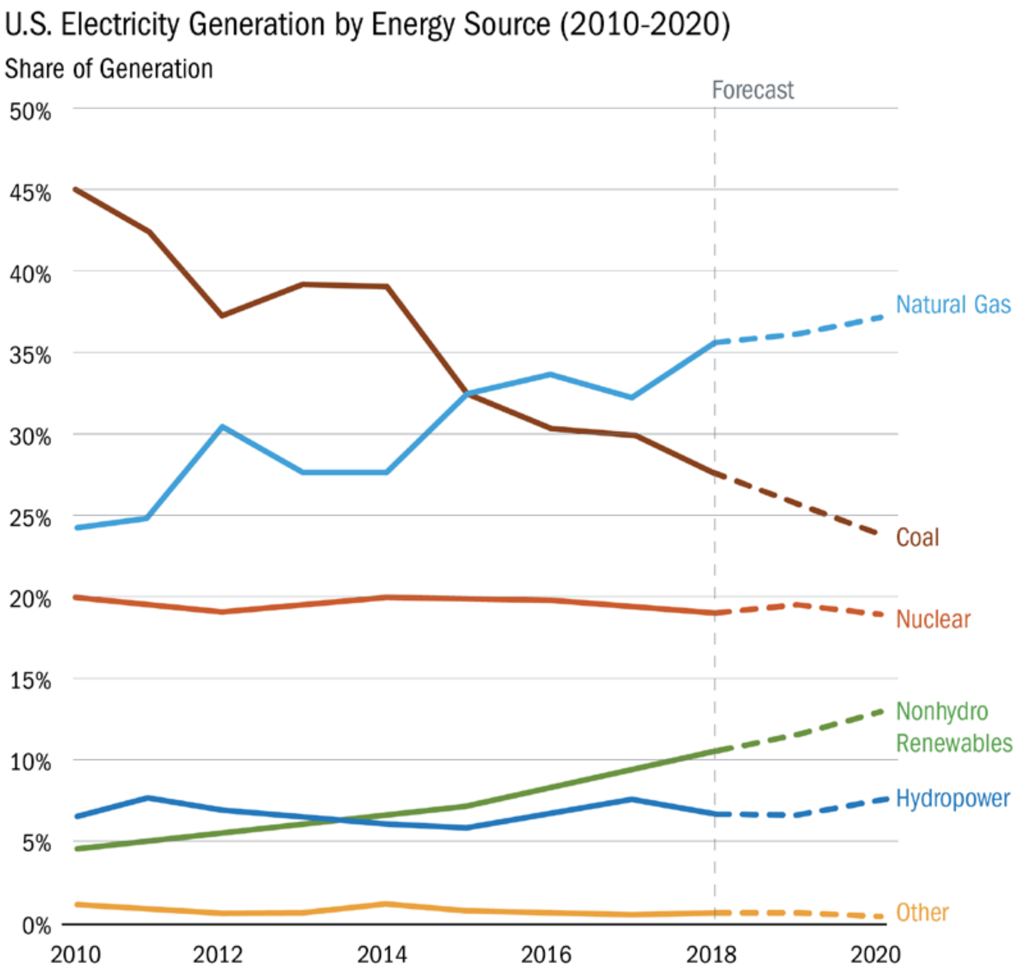
U.S. Energy Supply is Shifting

In 2019, renewable energy—not including hydropower—generates 11% of the total U.S. electricity (~7% wind, 2% solar, 1.5% biomass, 0.5% geothermal)

With hydropower, renewable electricity is ~18%

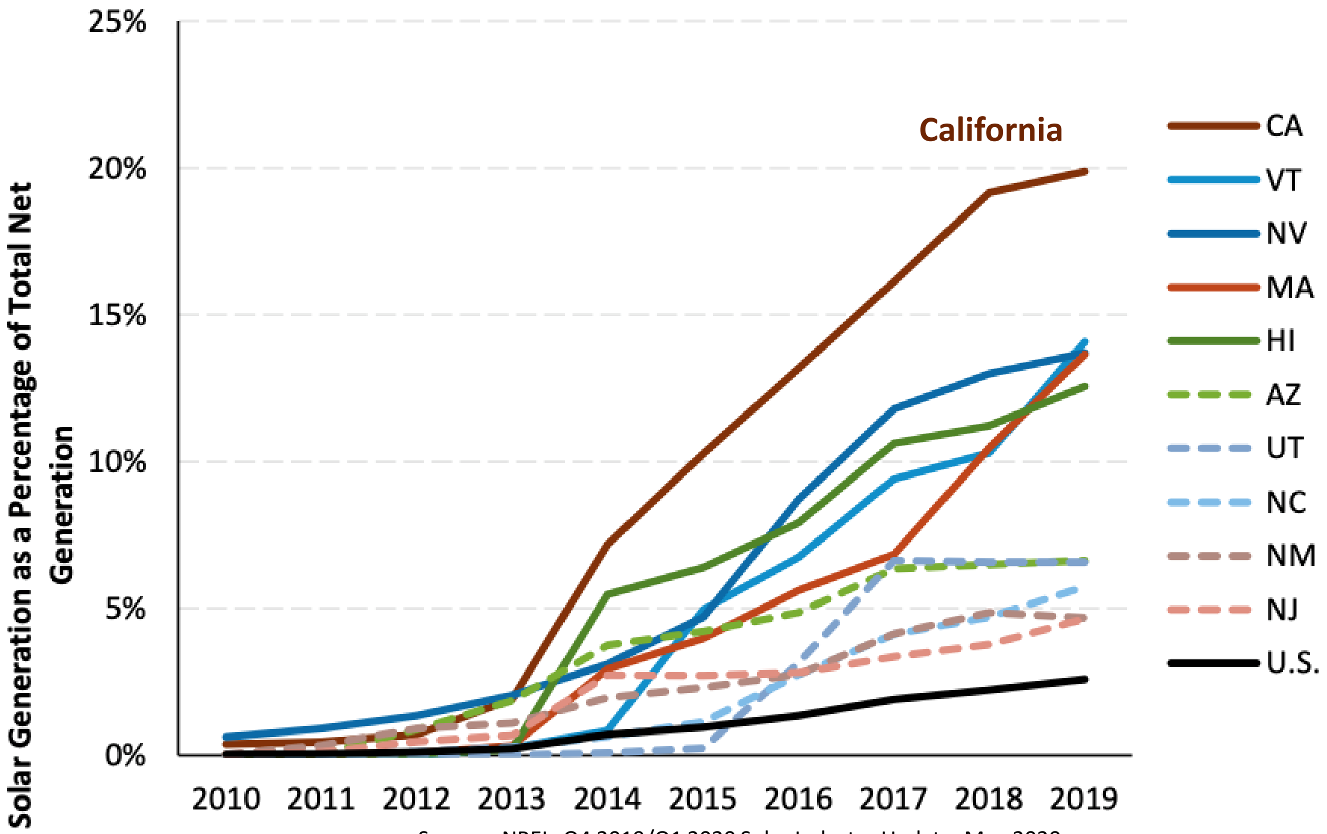
Natural gas power is ~38%

COVID Update: January-June 2020, renewable electricity = 22.2% (wind 9.1%, solar 3.4%) with natural gas = 39.2% and coal = 16.9%.



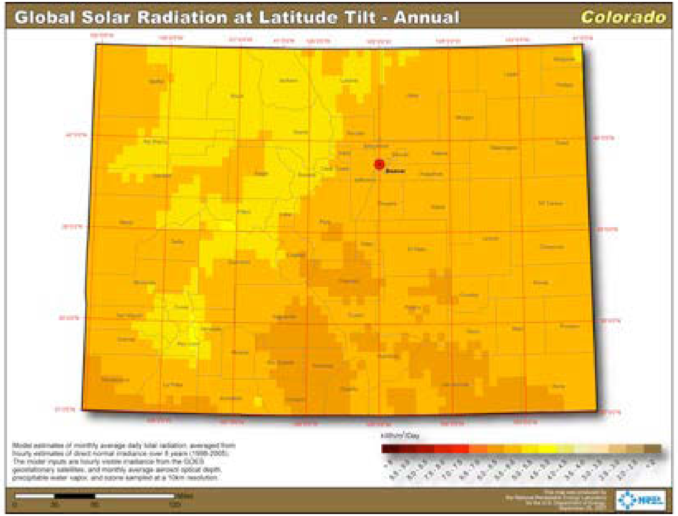
Source: United States Energy Information Agency, *Today in Energy*, 18 January 2019

Variation by Location: Solar Generation as a % of Total Generation, 2010-2019, by U.S. State

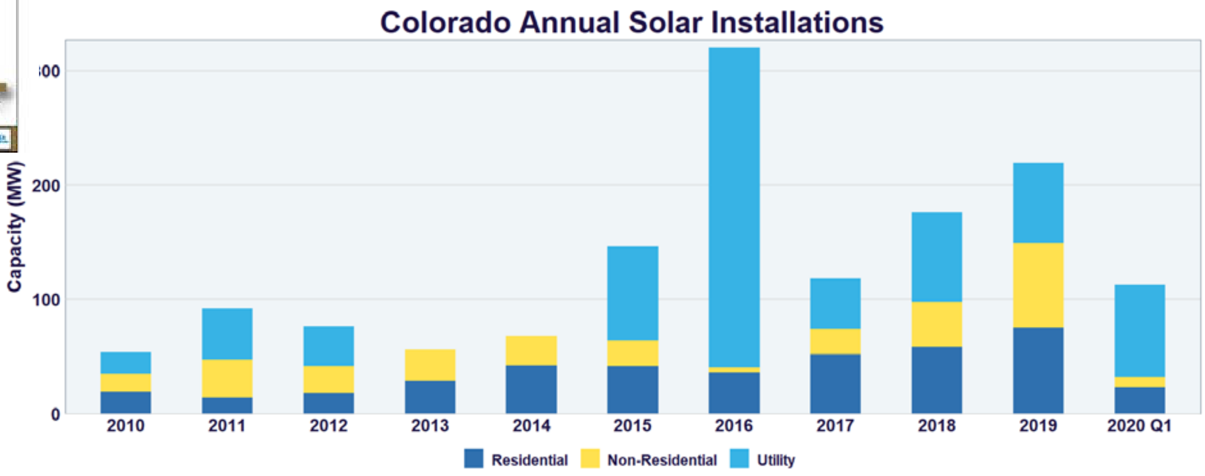


Source: NREL, Q4 2019/Q1 2020 Solar Industry Update, May 2020.

Colorado Solar Development

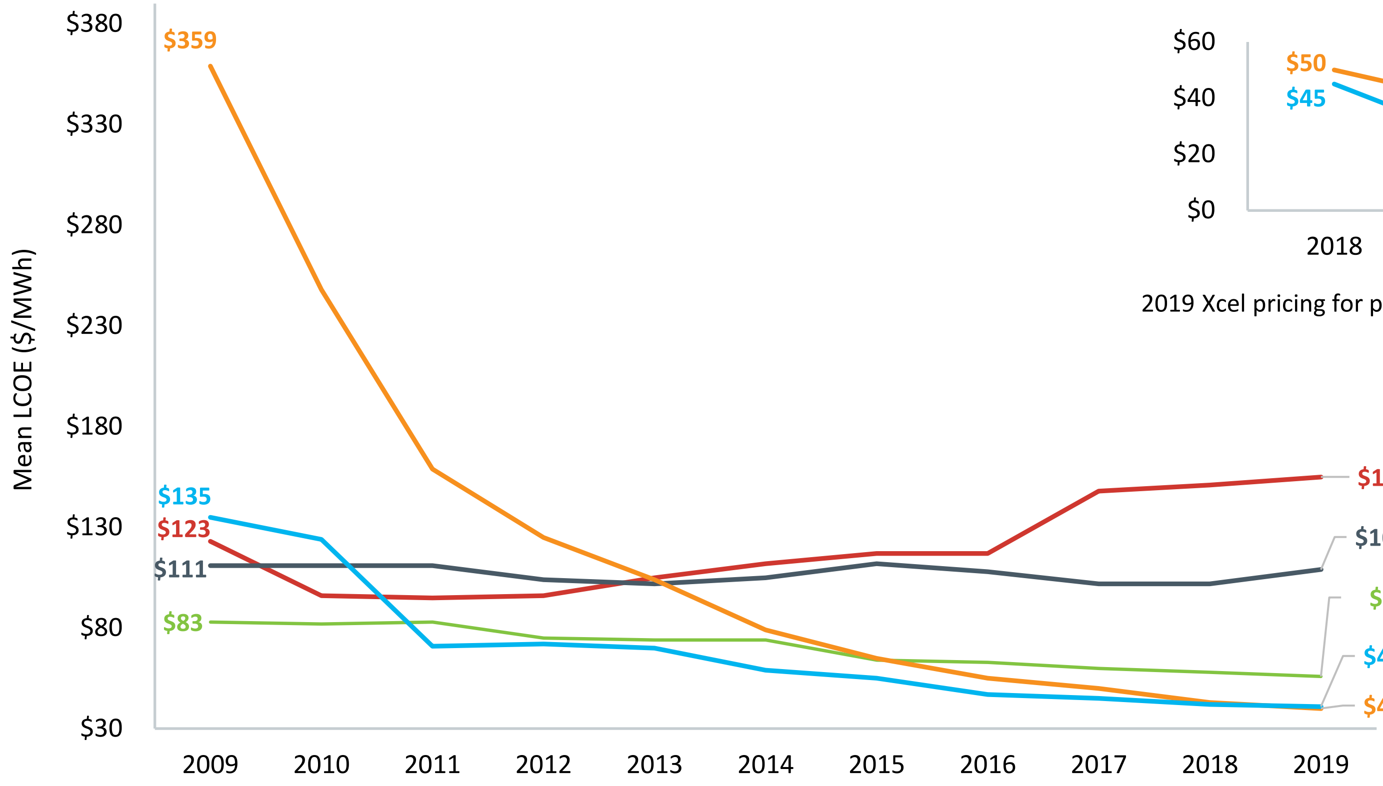


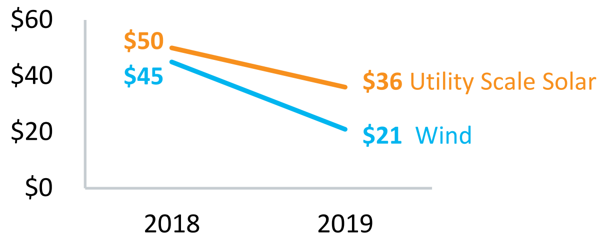
Colorado Rank – 12th
Installed: 1,490 MW
# of installations: 68,715
Percentage of In-State Energy Production: 3.33%
Equivalent U.S. Homes Powered: 301,000
Manufacturers: 62 Installers: 191



Sources: NREL and SEIA,
https://www.seia.org/state-solar-policy/colorado-solar

Costs for renewables are falling

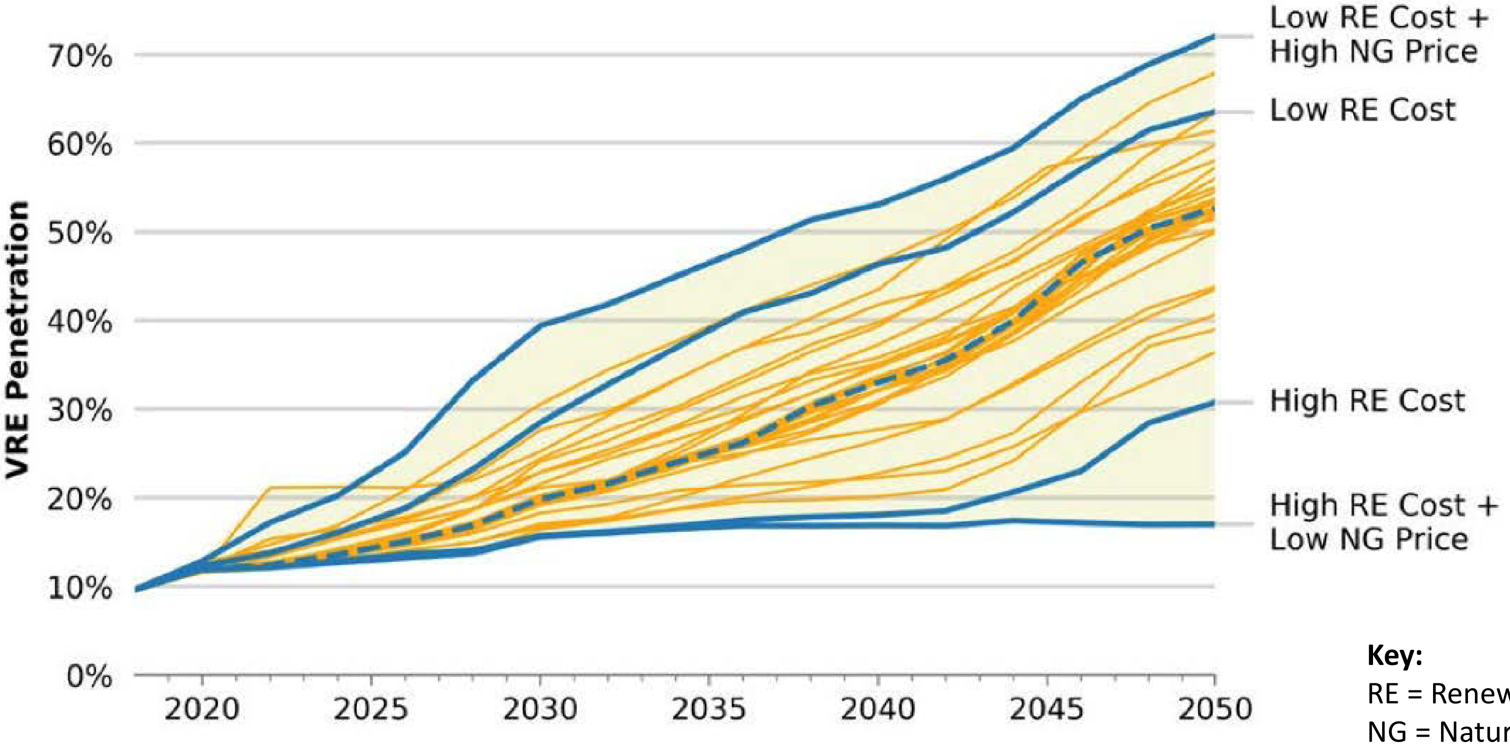




2019 Xcel pricing for projects due to go online in 2023

Source: *Lazard's 2019 Levelized Cost of Energy Analysis*

NREL models scenarios of future electricity generation

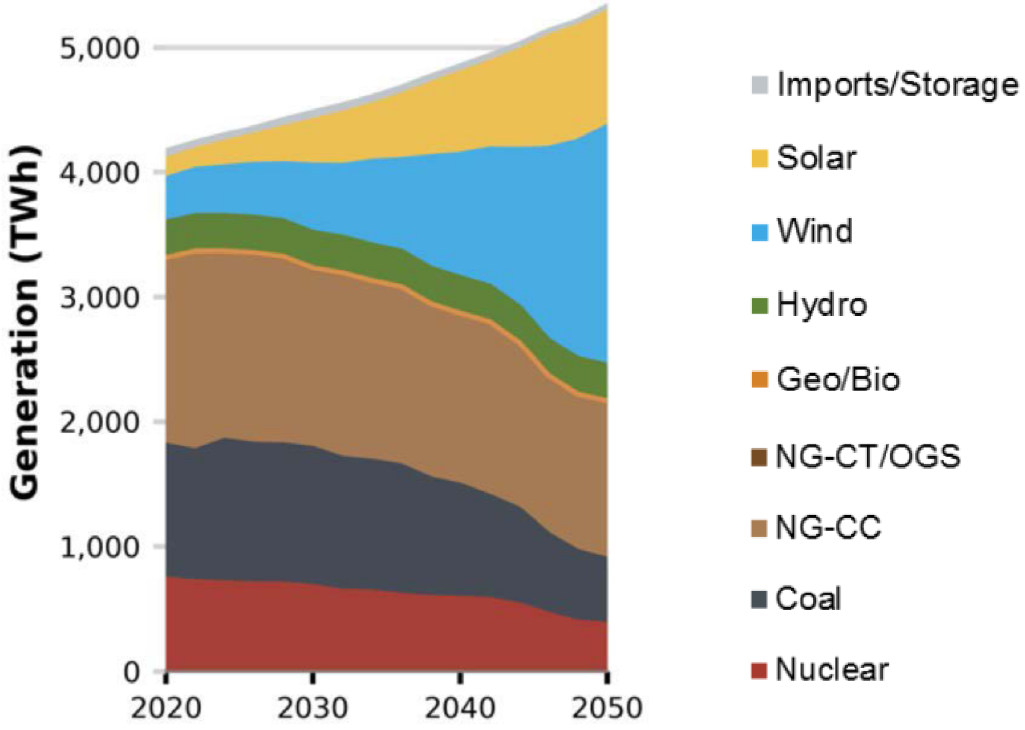


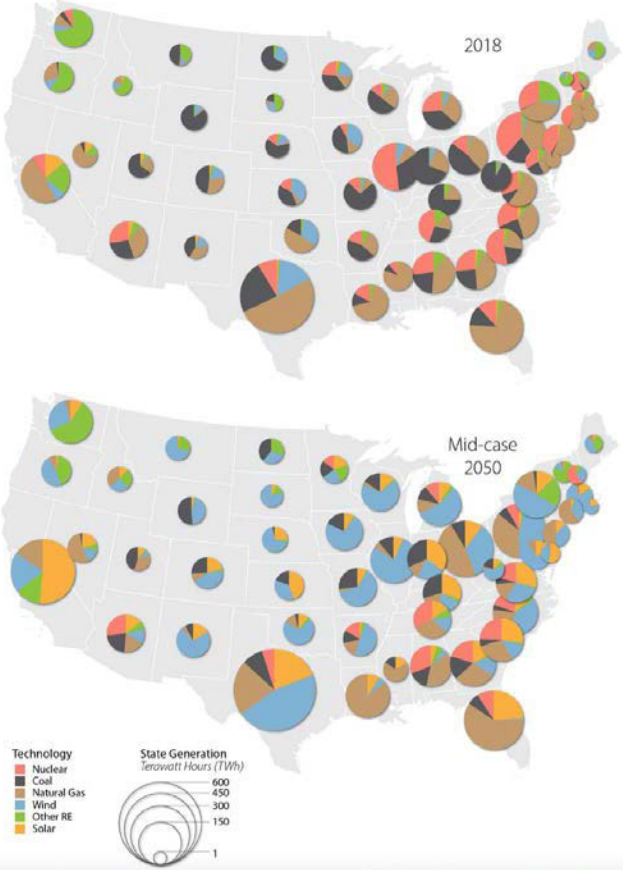
Key:
RE = Renewable Energy
NG = Natural Gas
VRE – Variable Renewable Energy

Generation projections across 36 scenarios: NREL 2019 Standard Scenarios Report: A U.S. Electricity Sector Outlook, https://www.nrel.gov/analysis/standard-scenarios.html

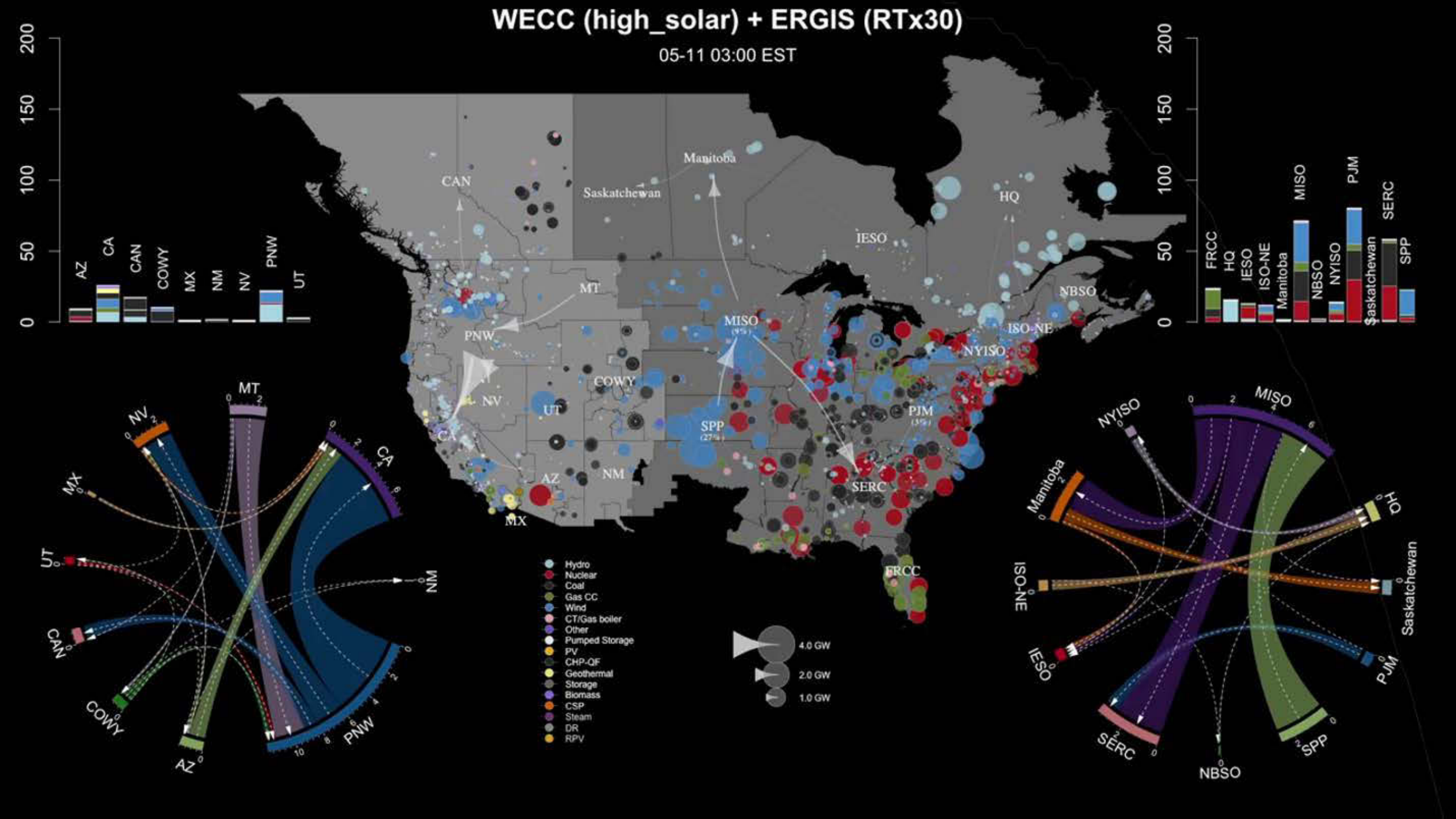
NREL models scenarios of future electricity generation

Example: Mid Case Scenario

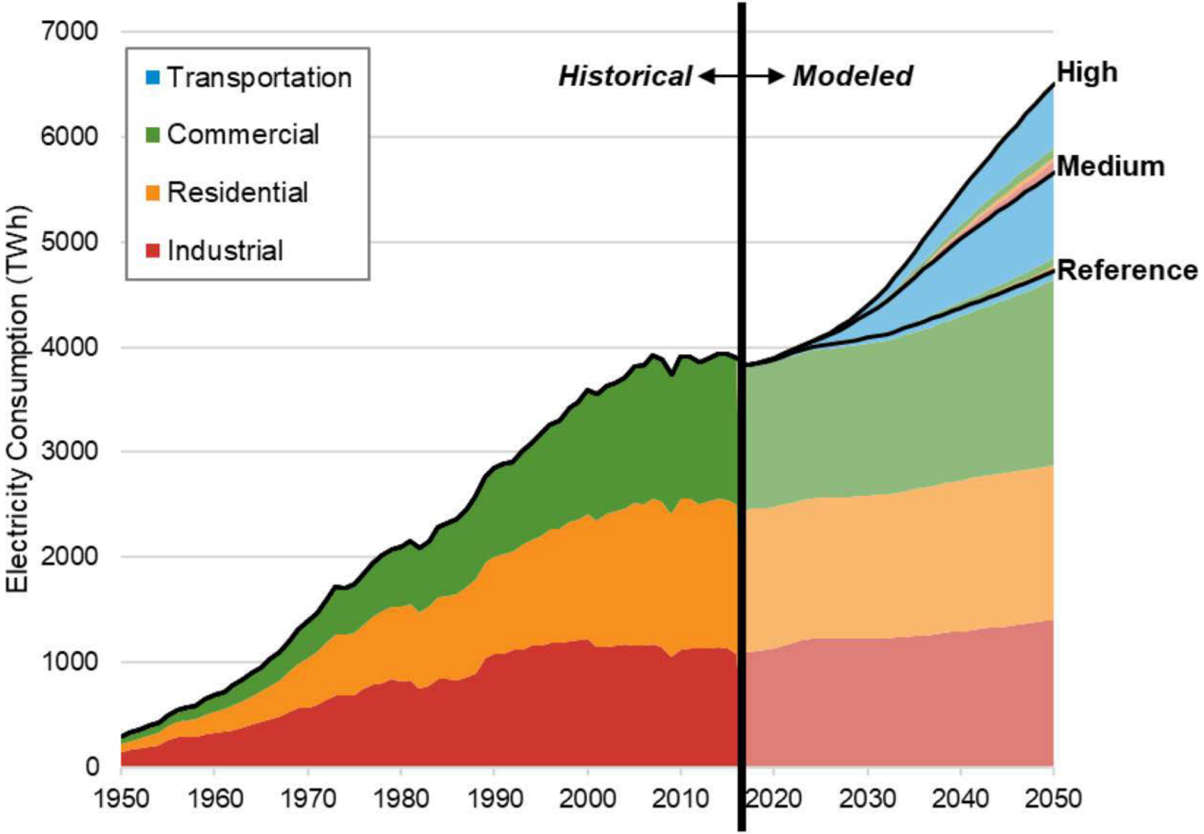


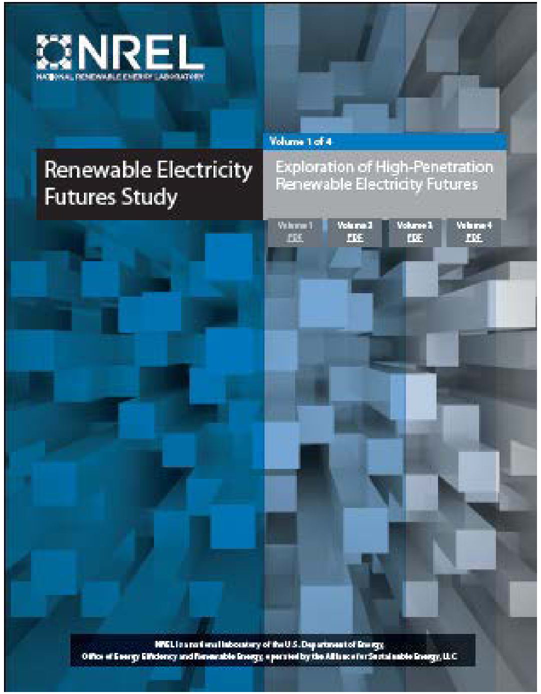


Generation projections across 36 scenarios: NREL 2019 Standard Scenarios Report: A U.S. Electricity Sector Outlook, https://www.nrel.gov/analysis/standard-scenarios.html


WECC (high_solar) + ERGIS (RTx30)
05-11 03:00 EST
AZ
CA
CAN
COWY
MX
NM
NV
PNW
UT
FRCC
HQ
IESO
ISO-NE
Manitoba
MISO
NBSO
NYISO
PJM
Saskatchewan
SERC
SPP
Hydro
Nuclear
Coal
Gas CC
Wind
CT/Gas boiler
Other
Pumped Storage
PV
CHP-QF
Geothermal
Storage
Biomass
CSP
Steam
DR
RPV
4.0 GW
2.0 GW
1.0 GW

Electrification Futures Study





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

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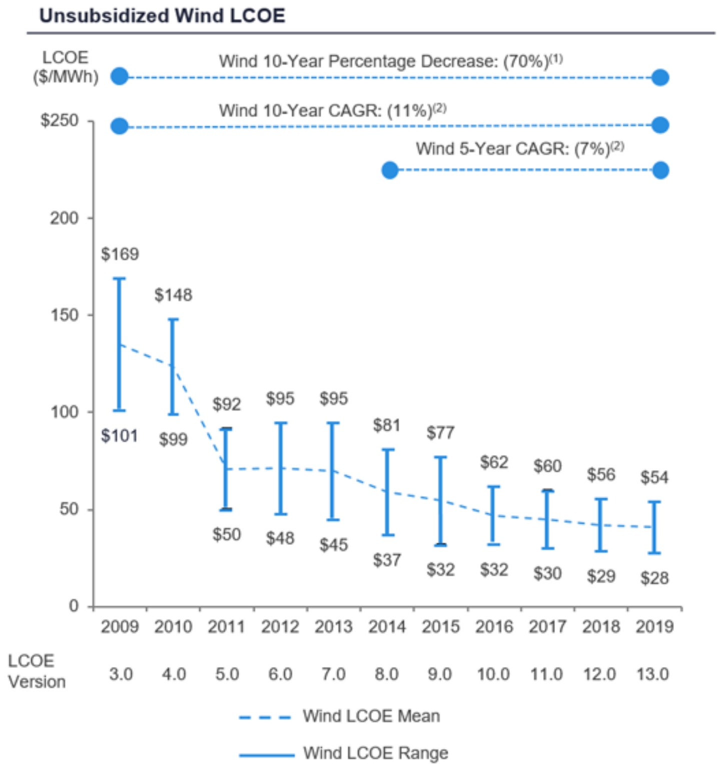
Wind Turbines – Onshore and Offshore

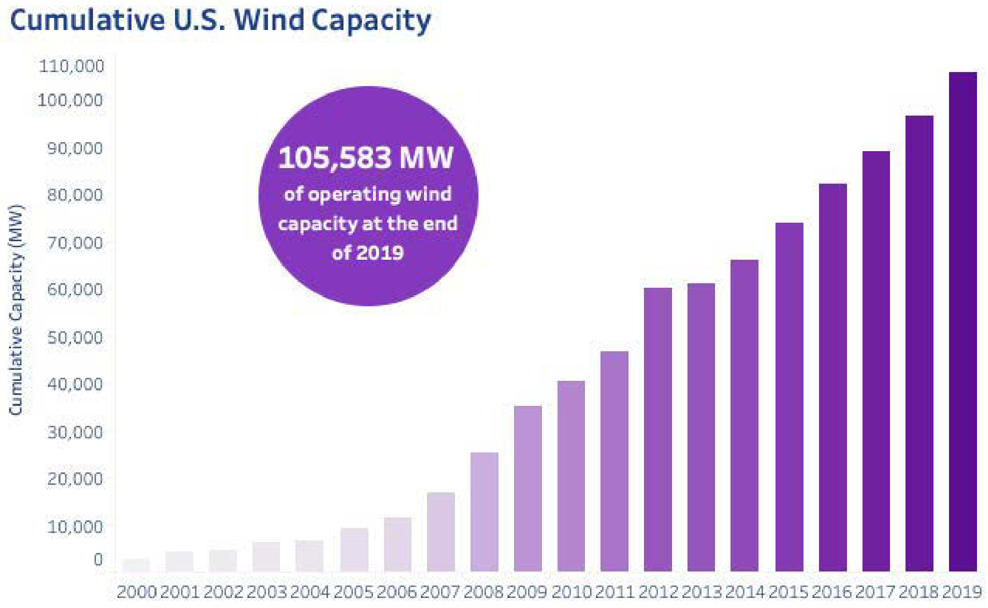
Peetz Table Wind Energy Center
- Peetz, Colorado
- 430 MW, 300 turbines
- Opened 2001, expanded 2007
- Capacity Factor 34.5%

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)

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.

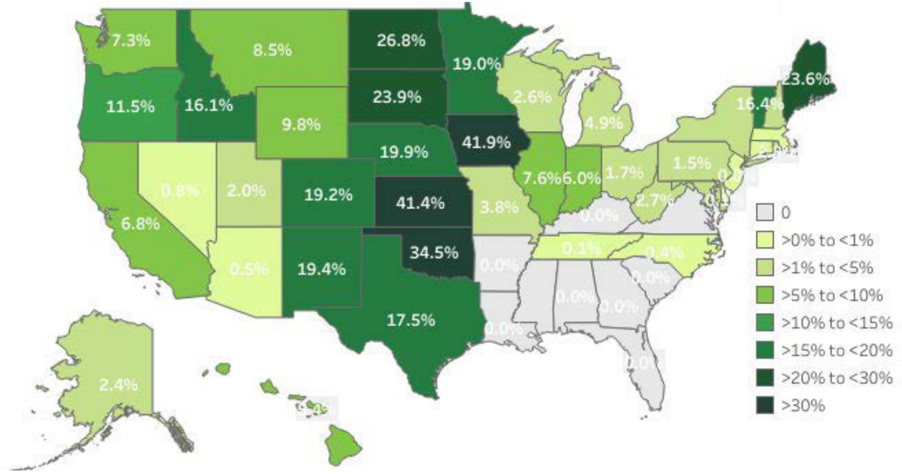


Source: Lazard, https://www.lazard.com/perspective/lcoe2019; AWEA, https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance.

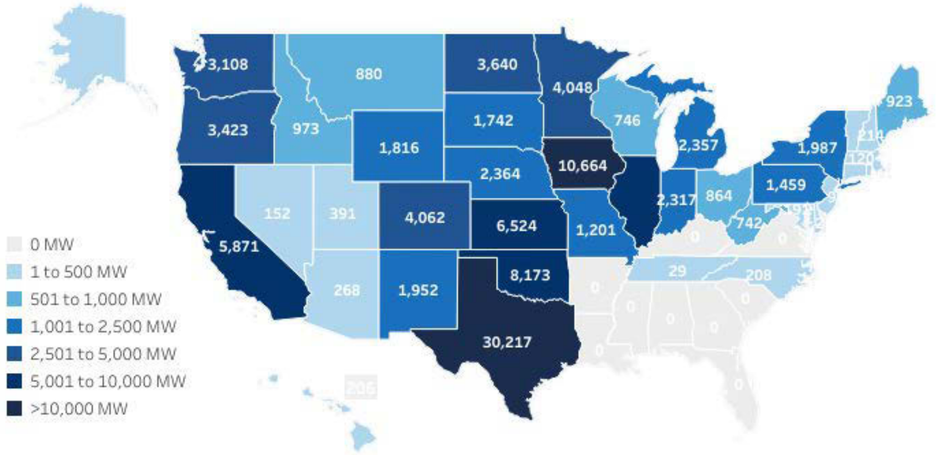
U.S. Wind Market (installed capacity, MW)

Wind capacity installed in Oklahoma, Iowa, and Kansas supplied >30% of all in-state electricity generation in 2019. 14 states were greater than 10%.

Wind Share of State Electricity Generation (2019)

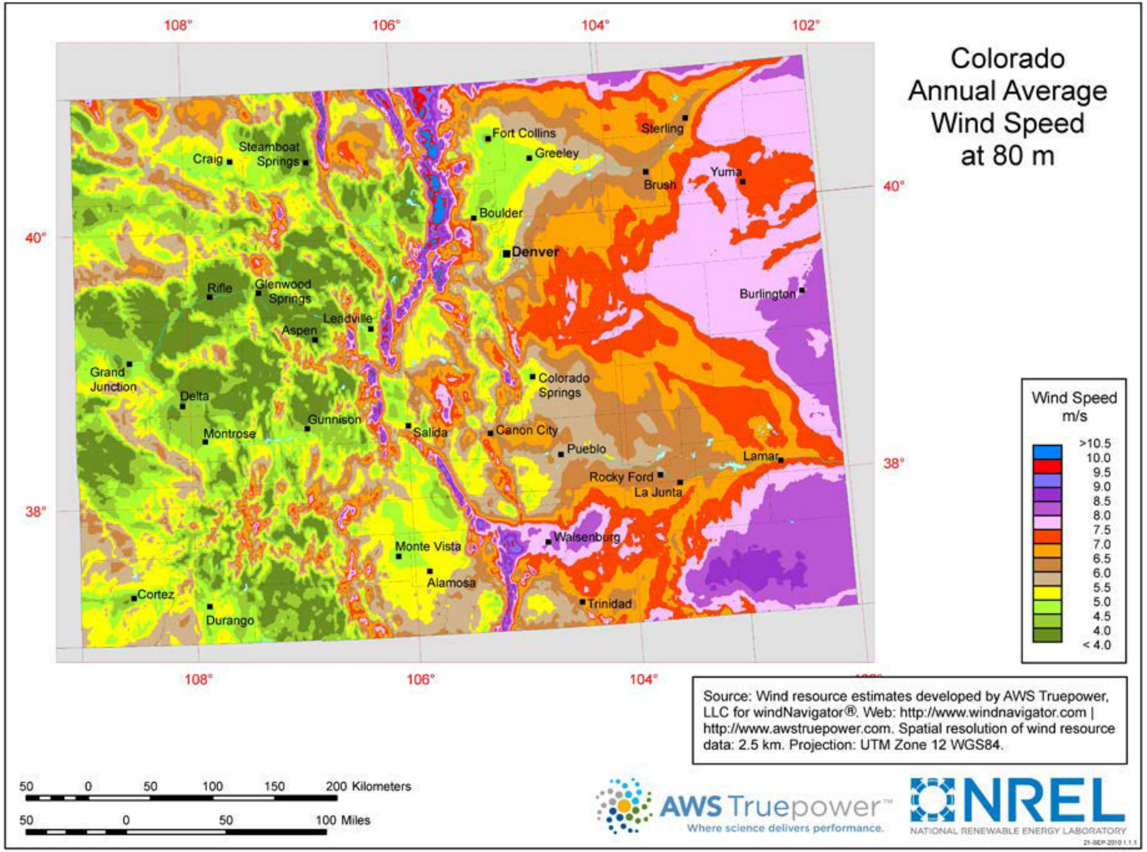


Wind Capacity by State



Source: American Wind Energy Association, https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance

Colorado wind energy



Colorado Rank – 7th
Installed: 4,062 MW
# of turbines: 2,383
Percentage of In-State Energy Production: 19.2%
Equivalent U.S. Homes Powered: 1,002,400
Manufacturers: 62 Installers: 275

Data Source: AWEA, https://www.awea.org/Awea/media/Resources/StateFactSheets/Colorado.pdf
Map Source: https://windexchange.energy.gov/maps-data/15

Wind Machines – Scale, capacity factor Increasing, Manufacturing costs declining

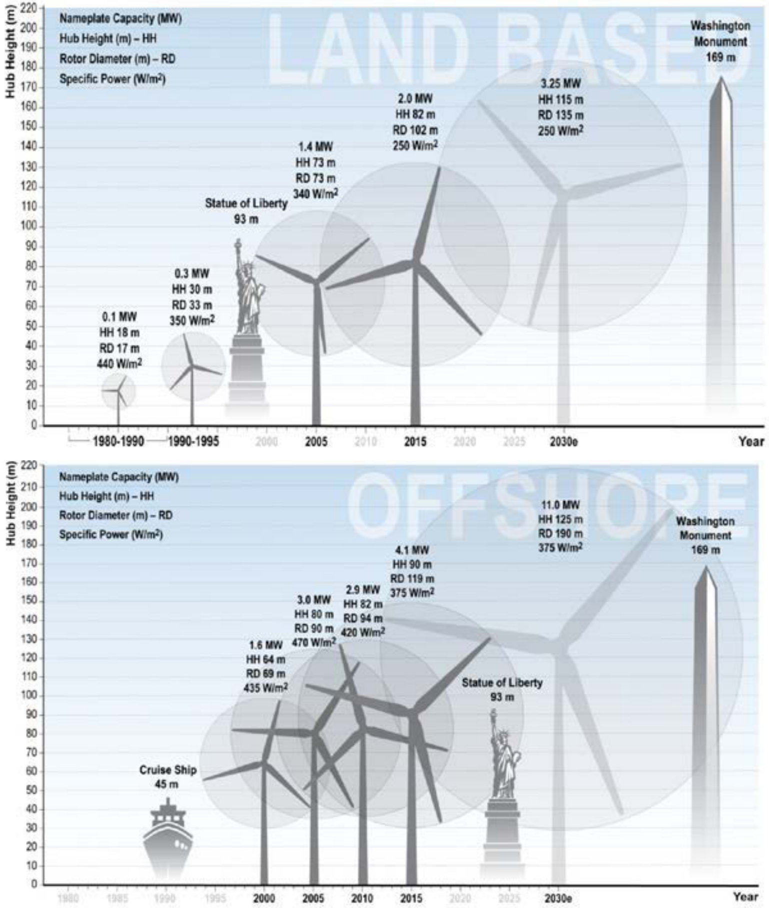
Avg. Wind Turbine Capacity Factors (% of capacity) by Build Year

1998-2001: 24.5%

2004-2011: 32.1%

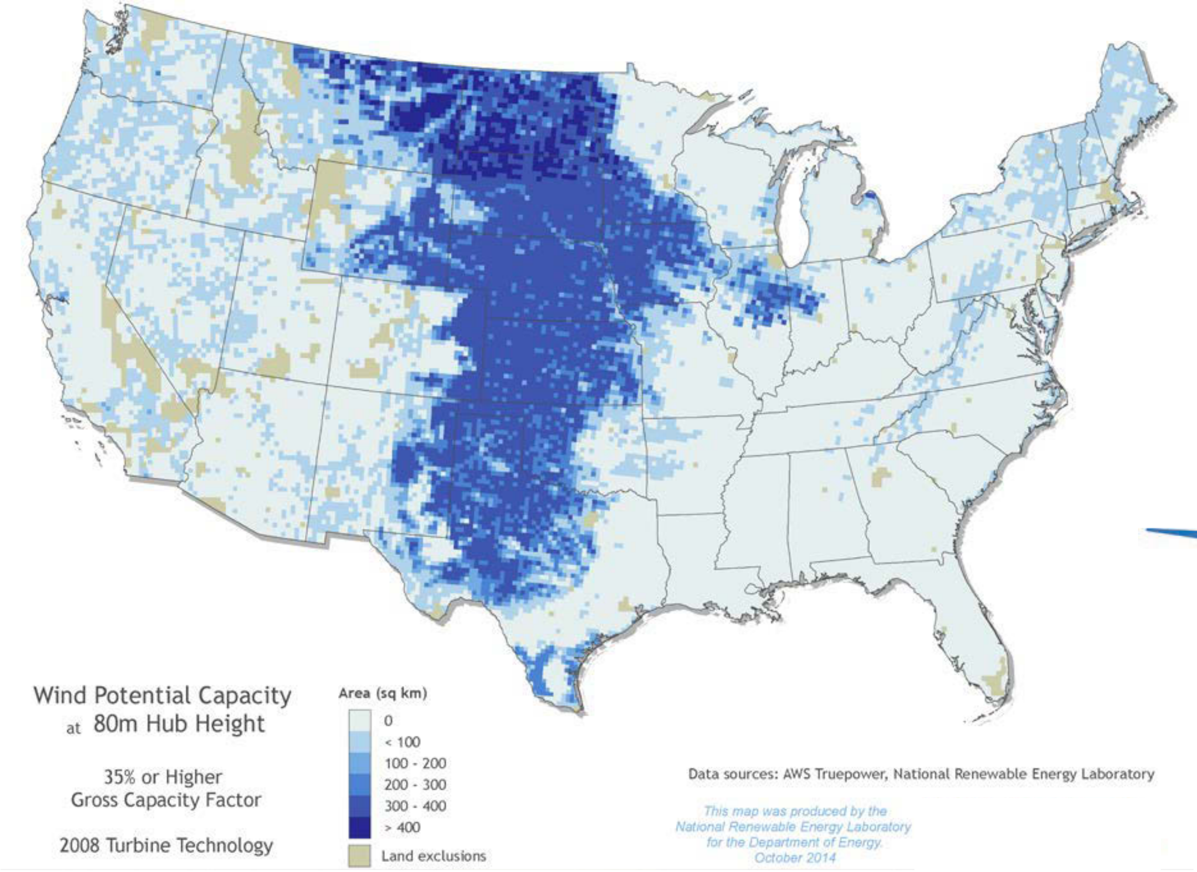
2014-2015: 42.6%

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

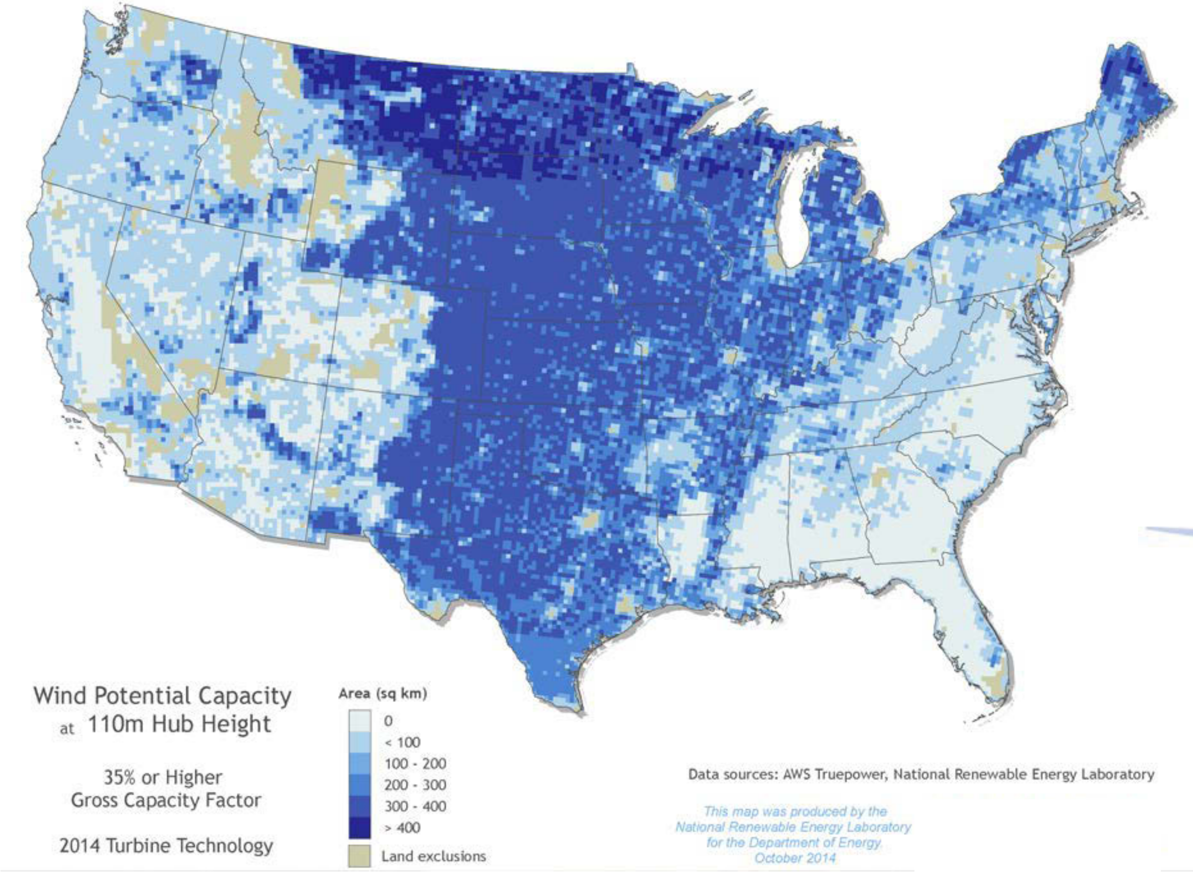


Source: LBNL, https://emp.lbl.gov/sites/all/files/scaling_turbines.pdf

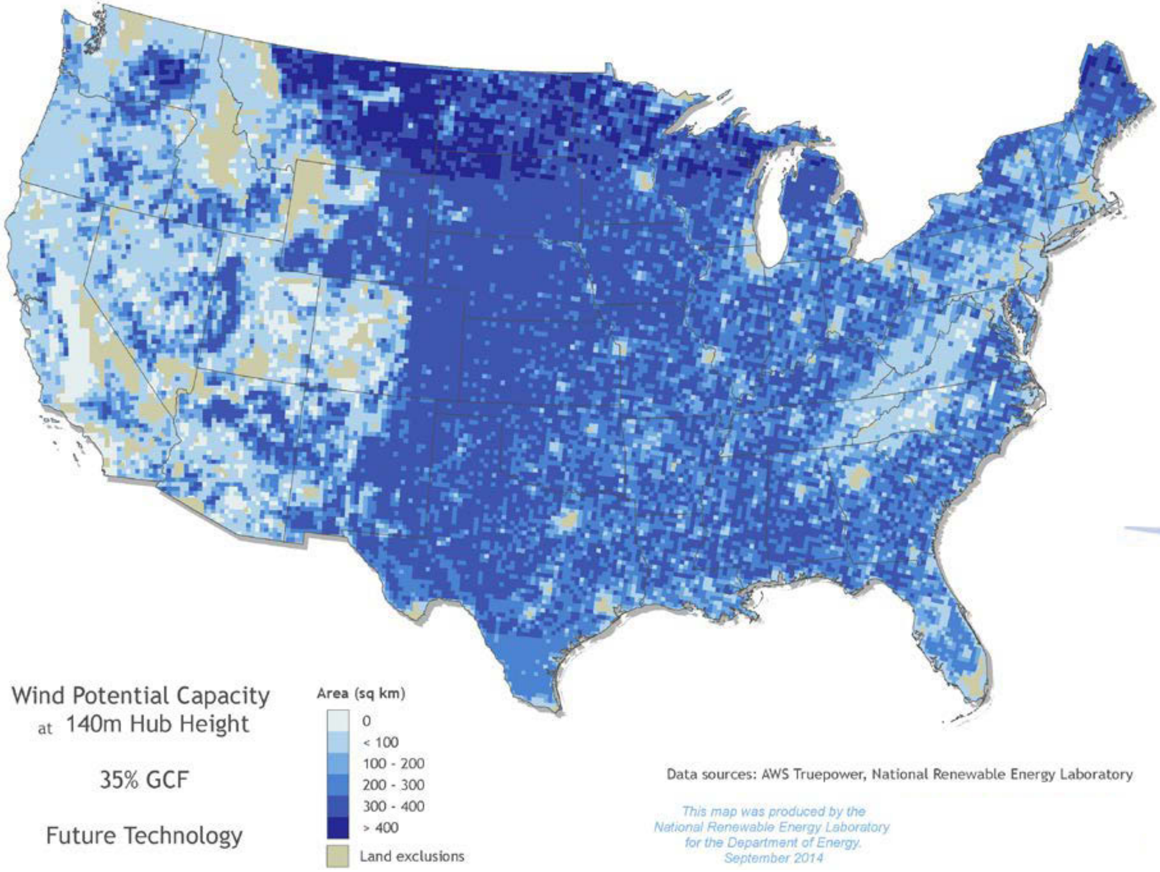
Wind energy potential capacity at 80m hub height

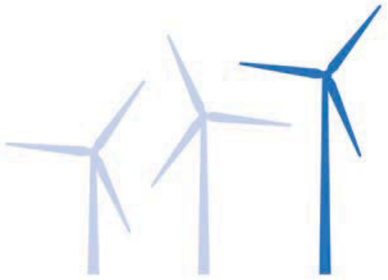


Wind energy potential capacity at 110m hub height



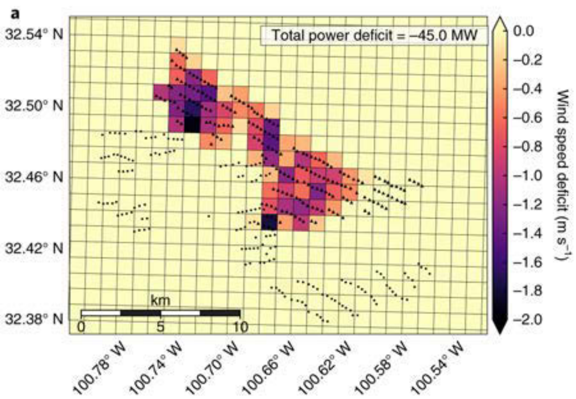
Wind energy potential capacity at 140m hub height

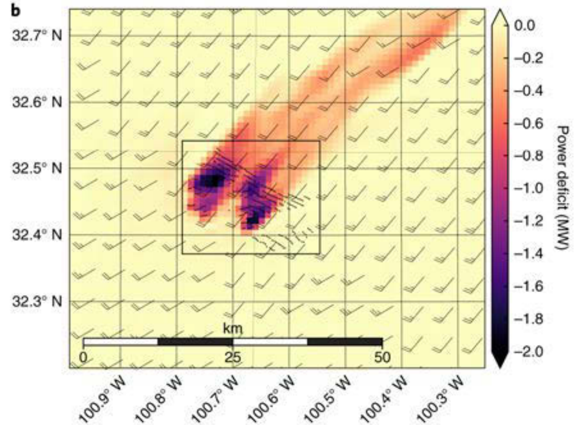


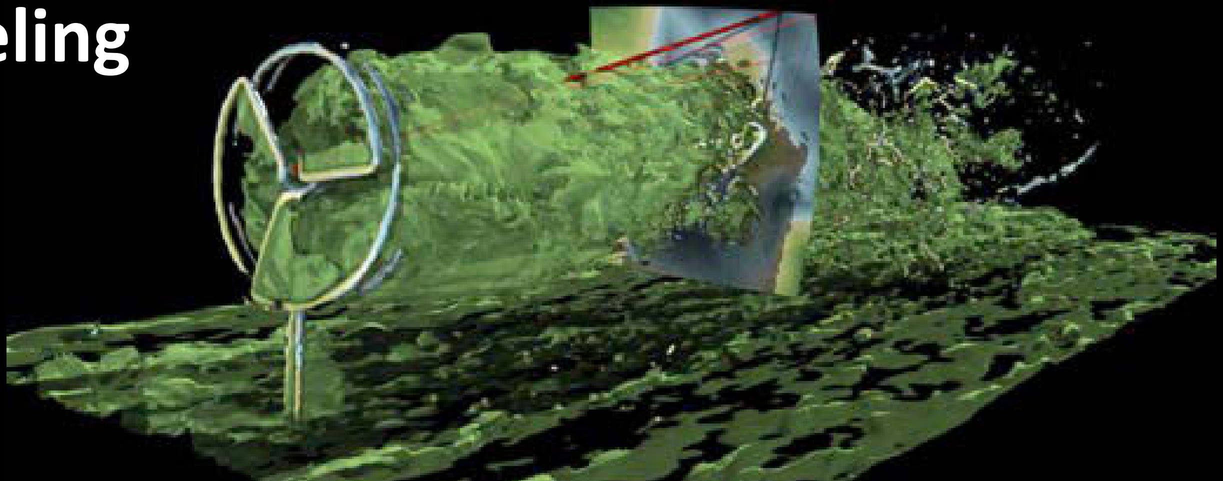


140m

Wind plant modeling







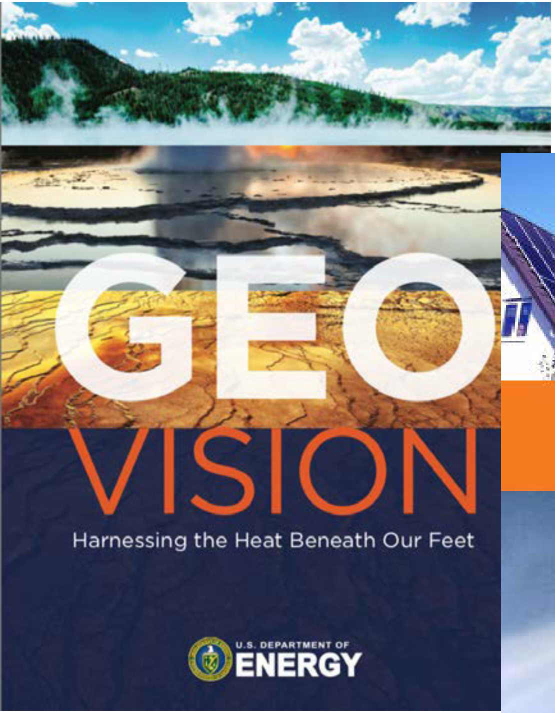
Blade-resolved simulations of whole wind plants

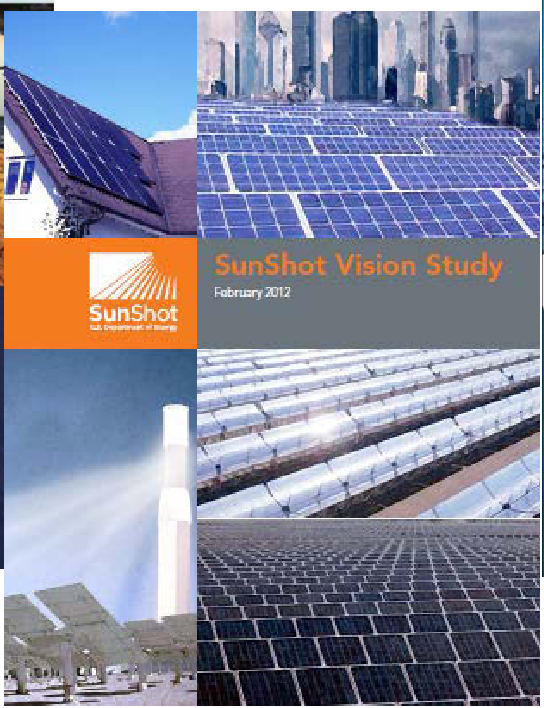
- Developing predictive capability to better understand complex fluid flow in wind plants with complex terrain, focus on turbine-turbine impacts, and address wind plant energy losses
- Growing fleet requires advanced sensors and simulation for improved reliability and energy security
- Inaccurate forecasts cost the industry $300M+/yr
- Simulations of single blade-resolved turbine exceed current ESIF HPC capabilities

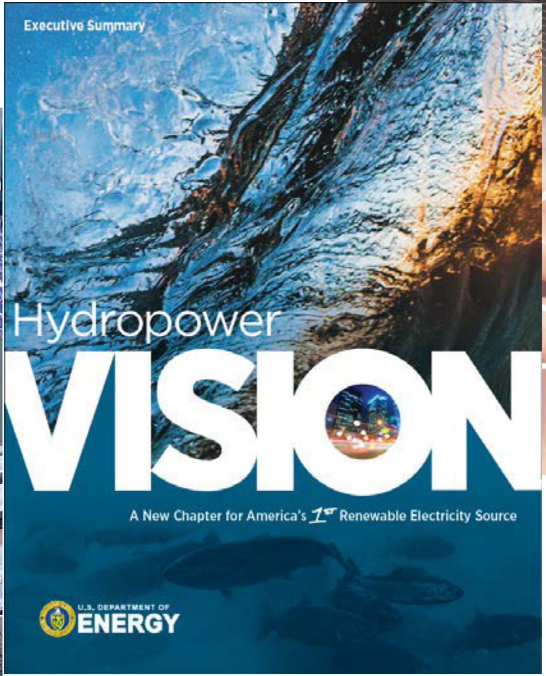
POTENTIAL IMPACT

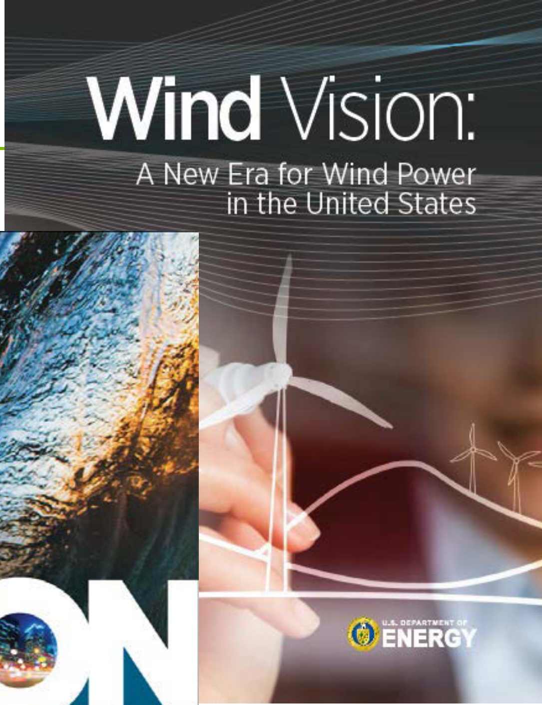
Improve wind plant efficiency **4%** to generate **$1 billion** in annual savings.

Technology vision studies









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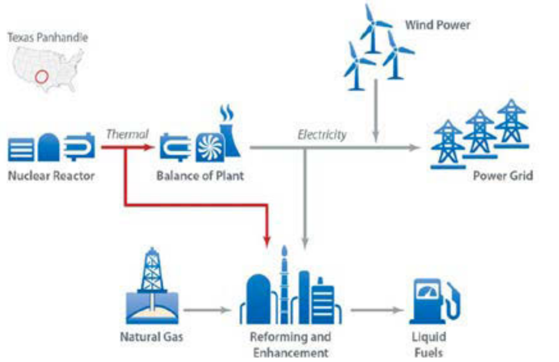
Nuclear-Renewable Hybrid Energy Systems

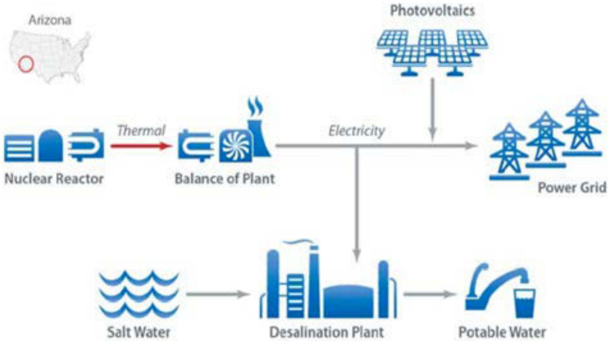
NREL and Idaho National Lab (INL) lead innovative analysis on nuclear and renewable energy and how they work together to decarbonize energy systems, including:

- System configurations
- Operations
- Product options (heat, power, fuels)
- Value streams
- Economics & investment

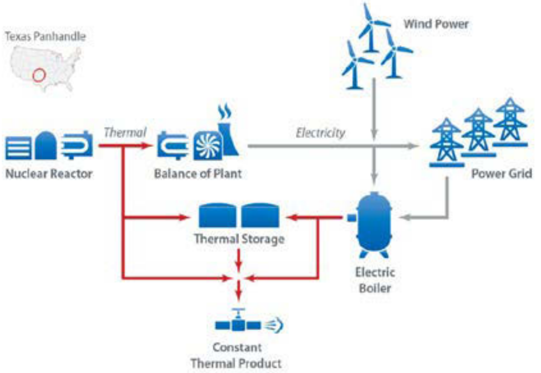
Liquid Transportation Fuels



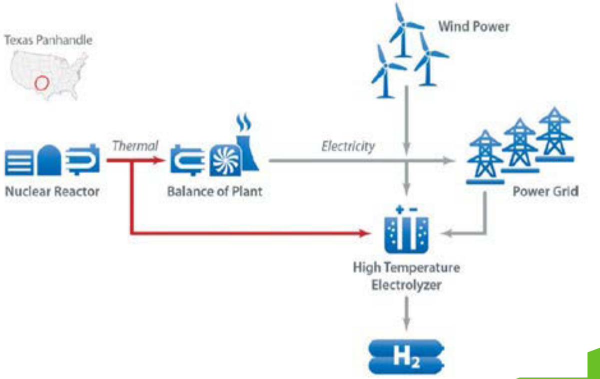
Reverse Osmosis Desalination



Thermal Energy in an Industrial Park

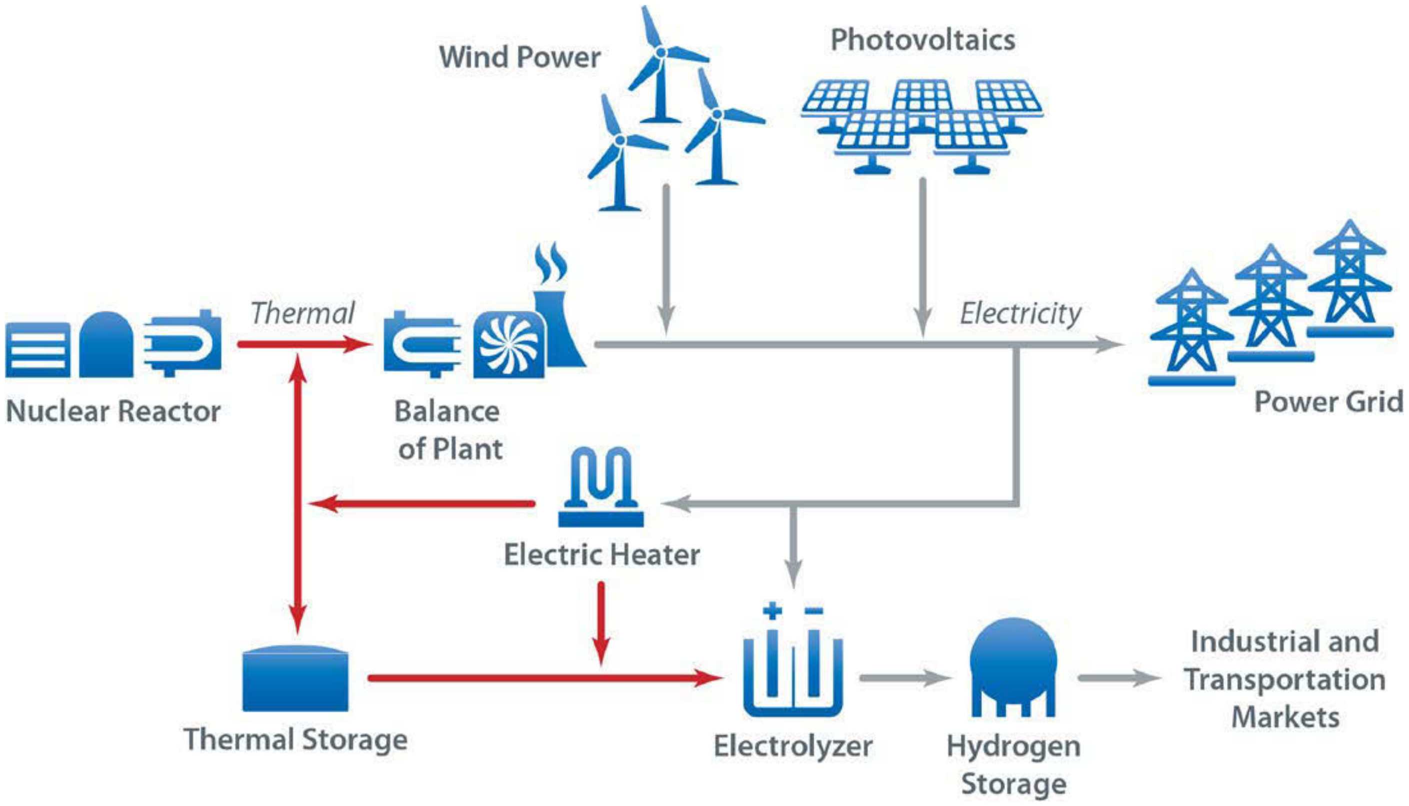


Hydrogen Production



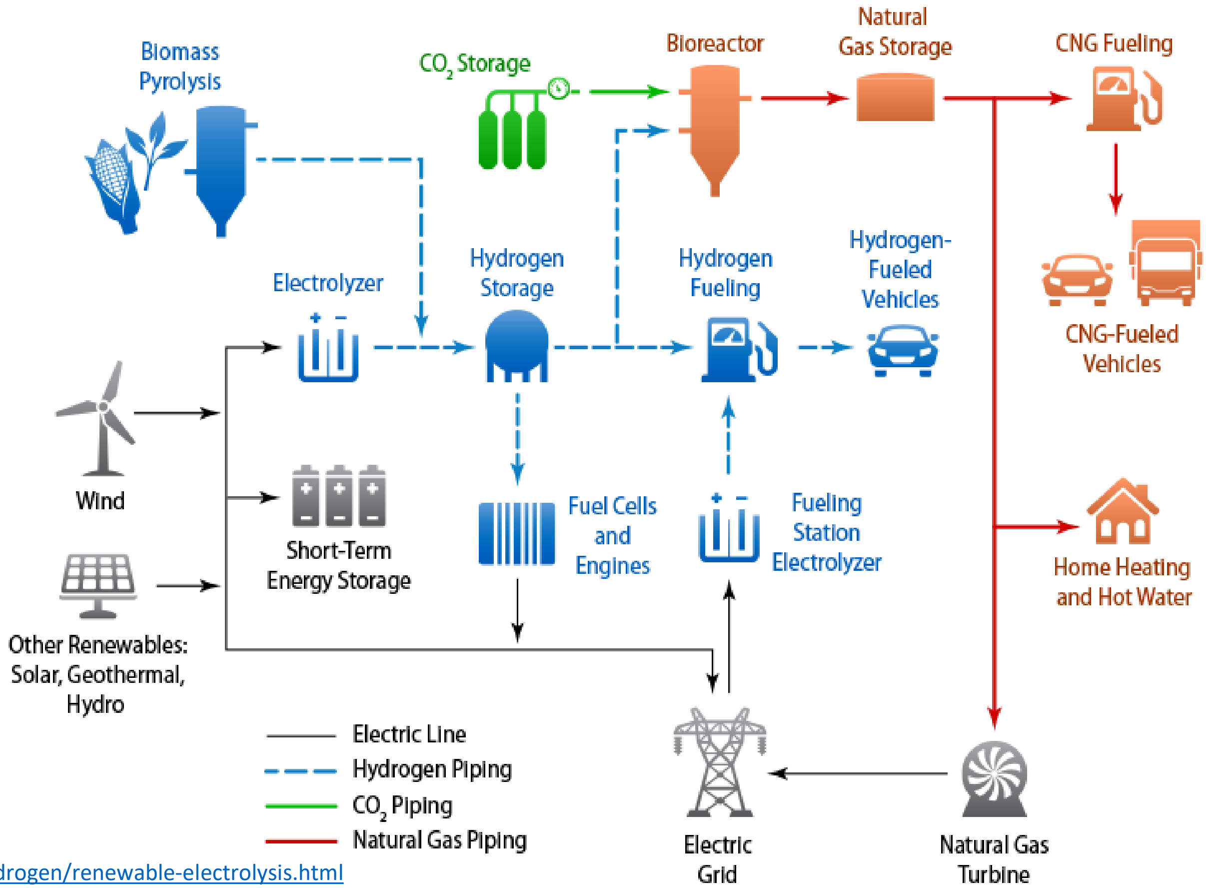
Sources:
Ruth, Mark, et al, *The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen*, 2017, NREL/TP-6A50-66764. https://www.nrel.gov/docs/fy17osti/66764.pdf.
The Economic Potential of Three Nuclear-Renewable Hybrid Energy Systems Providing Thermal Energy to Industry, 2016, NREL/TP-6A50-66745. https://www.nrel.gov/docs/fy17osti/66745.pdf
The Economic Potential of Two Nuclear-Renewable Hybrid Energy Systems, 2016. NREL/TP-6A50-66073. http://www.nrel.gov/docs/fy16osti/66073.pdf

Renewable-nuclear hybrid energy solutions



Source: Ruth, Mark, et al, 2016. The Economic Potential of Two Nuclear-Renewable Hybrid Energy Systems, NREL/TP-6A50- 66073. https://www.nrel.gov/docs/fy16osti/66073.pdf

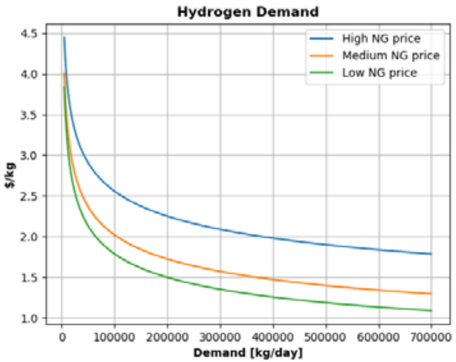
Integration of renewable & carbon capture systems



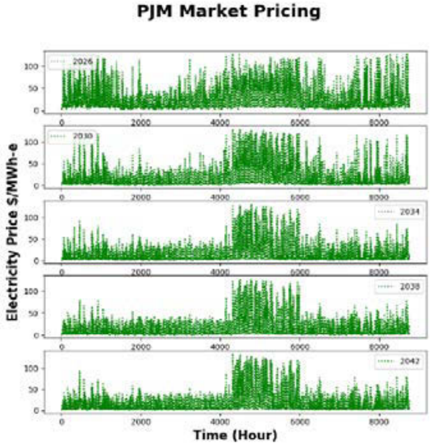
Source: https://www.nrel.gov/hydrogen/renewable-electrolysis.html

Nuclear-hydrogen System Cross-Sectoral Analysis

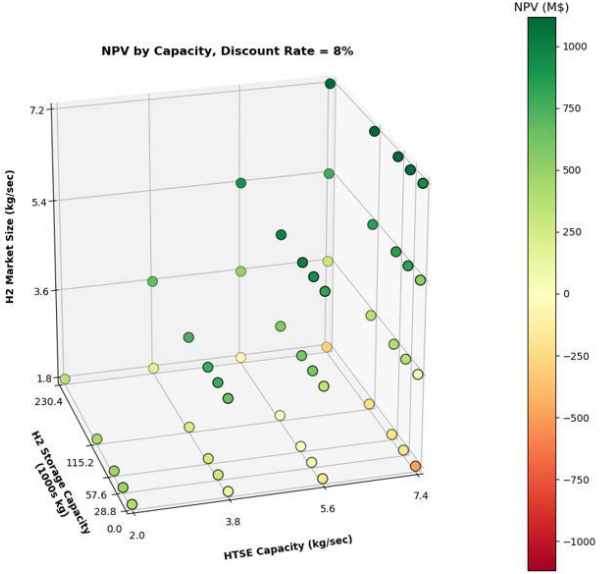
H_2 Market Assessment



Electricity Price Estimation



Design and optimization (both capital and operating) for a hybrid nuclear-H_2 system to maximize profitability



Findings (so far):

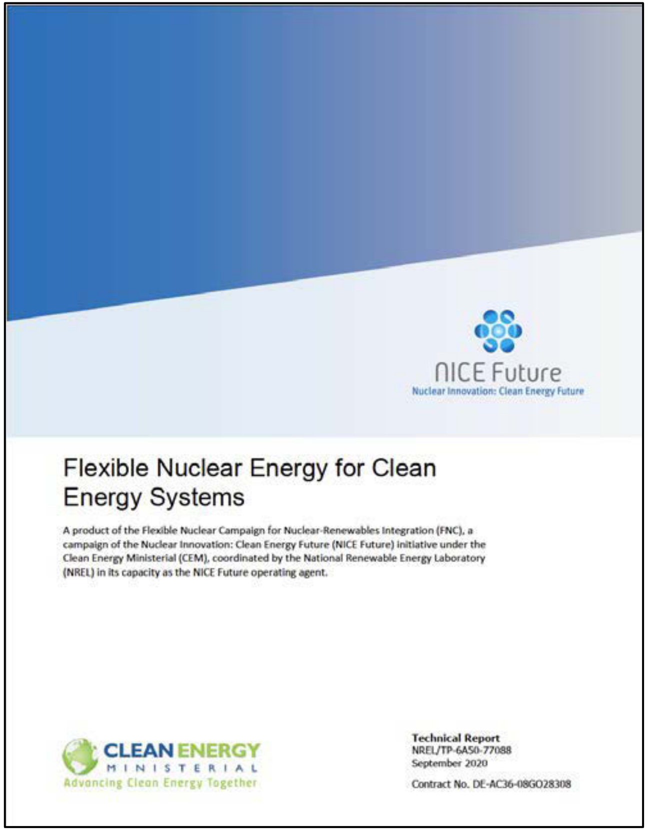
- 3 variables: H_2 market size, H_2 storage capacity, electrolyzer size
- Profitability depends on:
  - hydrogen vs. electricity market prices
  - Aligning electrolyzer size with H_2 demand
  - Proper sizing of H_2 storage
- Nuclear power plants have the *potential* to substantially increase current profit margins by hybridizing and producing H_2

Techno-economic Analysis and Net Present Value (NPV)

Source: Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

Flexible Nuclear Energy for Clean Energy Systems

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together


NICE Future
Nuclear Innovation: Clean Energy Future

Flexible Nuclear Energy for Clean Energy Systems

A product of the Flexible Nuclear Campaign for Nuclear-Renewables Integration (FNC), a campaign of the Nuclear Innovation: Clean Energy Future (NICE Future) initiative under the Clean Energy Ministerial (CEM), coordinated by the National Renewable Energy Laboratory (NREL) in its capacity as the NICE Future operating agent.

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

Technical Report
NREL/TP-6A50-77088
September 2020

Contract No. DE-AC36-08GO28308

NICE Future
Nuclear Innovation: Clean Energy Future
An Initiative of the Clean Energy Ministerial

FNC FLEXIBLE NUCLEAR CAMPAIGN FOR NUCLEAR-RENEWABLES INTEGRATION
A CAMPAIGN OF THE CLEAN ENERGY MINISTERIAL

- The purpose of the NICE Future initiative and Flexible Nuclear Campaign is to pool international experience with continued advancements in nuclear technologies and share this experience with the broader CEM community.
- The Flexible Nuclear Campaign is an exploration of the potential for nuclear to fit into an energy system to create a clean-energy future that will sustain the planet and allow its citizens to thrive.
- Development of a technical report engaged experts from nine ministries, five multi-governmental organizations, and 14 other organizations.

- Full report available at https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems

Key Findings: Flexible Nuclear Energy for Clean Energy Systems

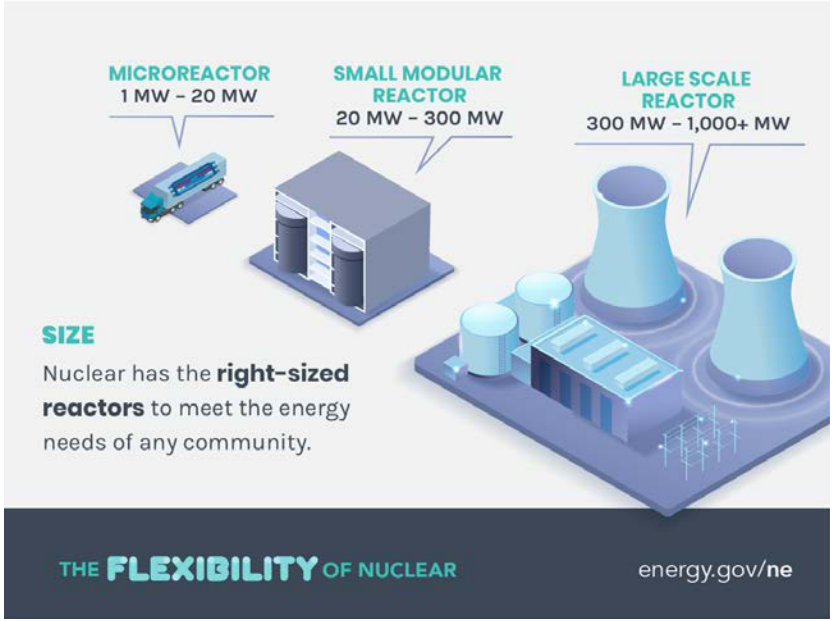
Nuclear Energy Flexibility: *"The ability of nuclear energy generation to economically provide energy services at the time and location they are needed by end-users. These energy services can include both electric and non-electric applications utilizing both traditional and advanced nuclear power plants and integrated systems."*

- ***Operational* flexibility:** There is an established body of knowledge surrounding current sources of flexible nuclear energy and its constraints.
- ***Product* flexibility:** Innovation can increase the flexibility of existing nuclear reactors to produce both clean electricity and beneficial non-electric products.
- ***Deployment* flexibility:** Advanced reactors will present even more opportunities for flexibility in nuclear systems at various scales.

Nuclear flexibility can enable other clean energy generators.

FNC FLEXIBLE NUCLEAR CAMPAIGN FOR NUCLEAR-RENEWABLES INTEGRATION

A CAMPAIGN OF THE CLEAN ENERGY MINISTERIAL



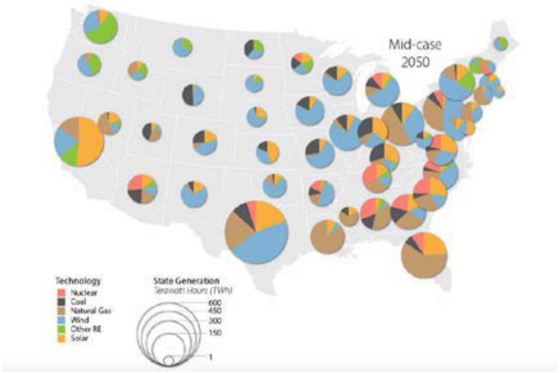
https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems

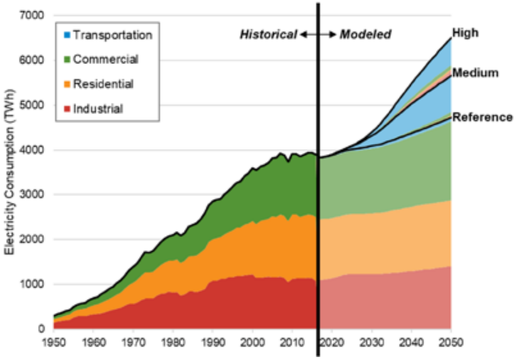
Reimagining Nuclear-Renewable Systems with Innovation

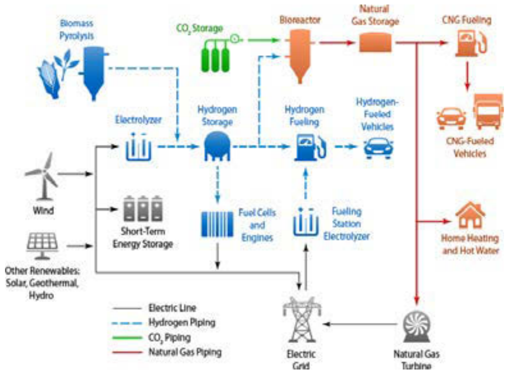
Integrated nuclear-renewables	Desalination for drinking water	Process heat	Flexible electricity grids	Hydrogen production and energy storage	Advanced smart designs (SMRs/Gen IV)	Nuclear waste reduction

Images courtesy of GAIN and Third Way, inspired by the *Nuclear Energy Reimagined* concept led by INL. Source: thirdway.org/blog/nuclear-reimagined

Conclusions and Discussion







- Trend is toward cleaner and lower cost energy (renewables and gas) that is more distributed
- Potential for increased electrification resulting in higher demand for power
- Renewable and other clean energy technologies can be enhanced when considered as a system with power, heat, fuels
- Renewable and nuclear power hybrids could enable a low-emissions future, but need research and demonstration of flexible operations

Thank you! Questions?

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JISEA Joint Institute for Strategic Energy Analysis

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