Renewable and Energy Efficiency Technologies Overview

Mark F. Ruth

Joint ICTP-IAEA VIRTUAL Course on Nuclear–Renewable Integrated Energy Systems: Phenomenology, Research and Development

October 4, 2021

Outline

- Renewable energy technologies
- Energy efficiency technologies
- Growth of renewable electricity generation in the U.S.
- Impacts of renewable electricity generation on the grid

Photovoltaic Solar

Photons excite electrons on semiconductors (e.g., doped Silicon or Gallium Oxide) and they are forced to flow in one direction creating DC current

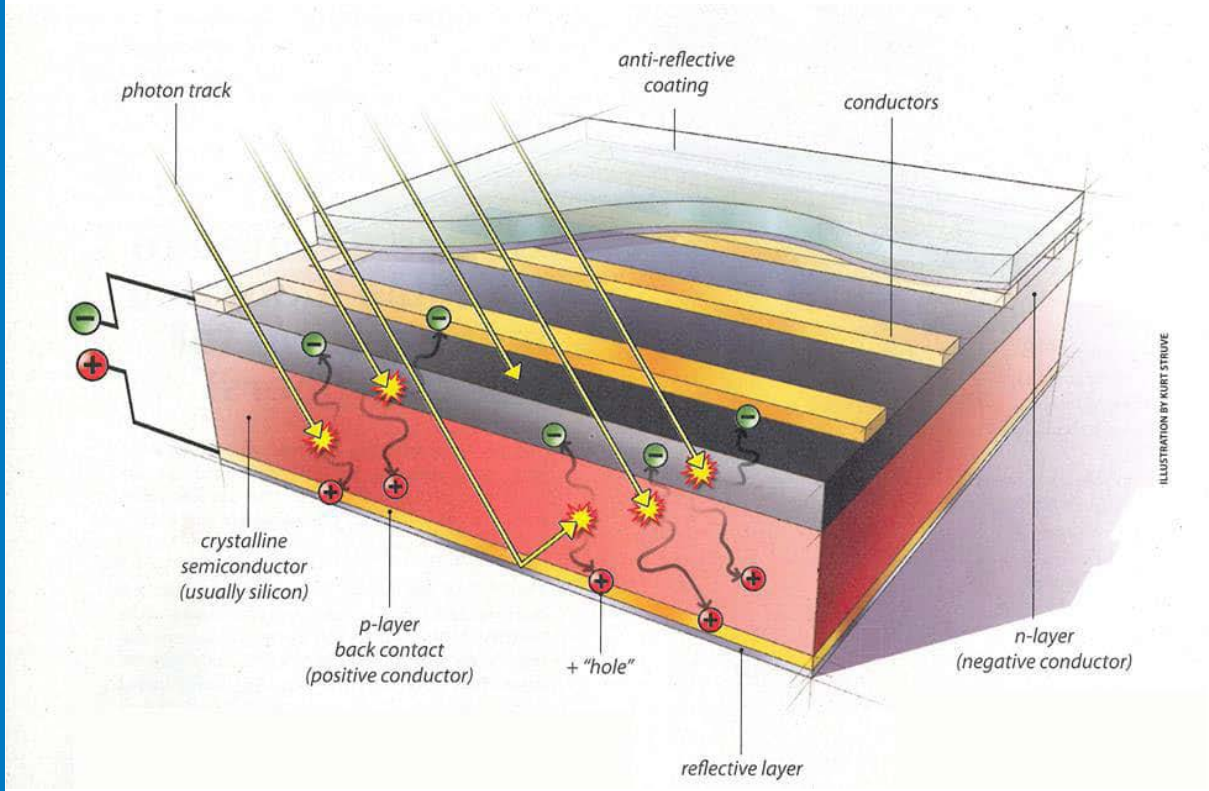


Image from https://www.seia.org/initiatives/photovoltaics

Concentrating Solar

Solar energy concentrated to heat fluid that then drives turbines directly or indirectly. Many fluids can be stored readily enabling generation when the sun is not shining.

Image Credit: Dennis Schroeder - NREL image: 46268

Solar Research

Areas of research include concentrating solar power, photovoltaics, grid integration, and market analysis.

Together, these areas will enable reliable, low-cost solar energy at scale—on the grid and beyond the grid.

Research Challenges

- Integrate large amounts of solar energy into the power grid while maintaining security and reliability, and enhancing resilience
- Improve the efficiency, lifetimes, and manufacturability of photovoltaic materials
- Develop technologies for a third generation of concentrating solar power plants to further reduce costs and improve thermal storage capabilities
- Capture surplus solar energy to provide heat and produce fuels and clean water
- Create flexible, highly efficient solar cells that can make low-cost power available without wires anywhere the sun shines
- Make solar an even better investment through work on bankability, reliability, and recyclability

Wind Power

Wind Power $P_w = \frac{1}{2} \rho A v^3$

- Density [kg/m^3]: Small changes with elevation & temperature.
- Area [m^2]: Squared effect of changes in radius.
- Velocity [m/s]: Cubic effect of changes in wind speed.

Currently commercial turbines are up to 8 MW

Image Credit: Werner Slocum - NREL image: 62958
Equation Credit: https://conwx.com/why-invest-in-high-quality-power-production-forecasts/

Wind Energy

Enabling low-cost and grid-supporting wind energy by joining forces with DOE, industry, and interagency and state partners to advance scientific knowledge and technological innovation.

Research Challenge

- Validate multiple wind technologies at scale to achieve an integrated energy system that can meet the complex energy challenges of the future.
- Develop taller wind turbines with larger rotors to capture greater wind resources at higher elevations and lower the levelized cost of wind energy.
- Develop innovations for offshore wind such as floating platforms, scaling solutions for larger offshore designs, advanced turbine controls, and lightweight drivetrains.
- Optimize total power output across the entirety of a wind plant instead of at the individual-turbine level.
- Enable sustainable manufacturing through new materials and new manufacturing processes.

Water-Power Research

Driving innovation in the design and utilization of next generation marine energy and hydropower/pumped storage systems through foundational research, tool development, and laboratory and in-water optimization.

Research Challenges

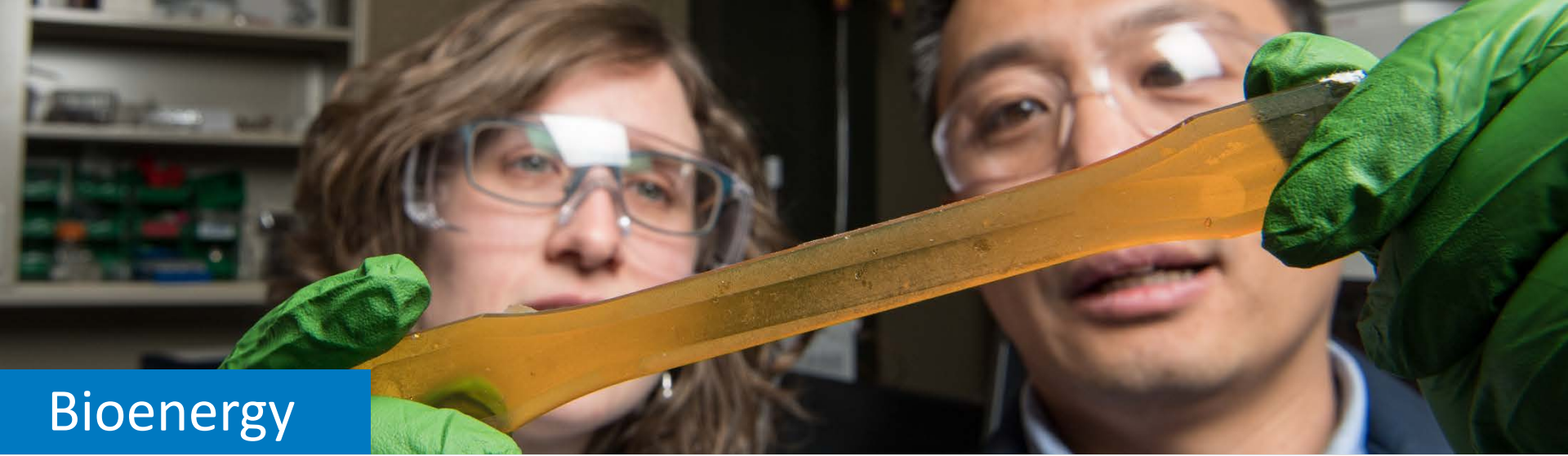
- Advancing scientific understanding to enable the full potential of hydropower/pumped storage hydropower to contribute to reliability, resilience, and renewables integration in our rapidly evolving power systems
- Developing technology to enable wave, tidal, ocean, and river current energy systems to provide reliable power to utility scale and blue economy markets (e.g., ocean observing)
- Transforming technology to drastically improve performance and reduce marine energy and hydropower generation costs.

Geothermal

Geothermal provides both heat and power—24 hours a day, 7-days a week—increasing grid reliability and security, with the smallest footprint of any renewable. Reducing costs and enabling geothermal anywhere can increase deployment nearly 26-fold by 2050.

Research Challenge

- Reduce well field development costs through increased drilling efficiency and drilling rates and reduced material construction costs.
- Enable development of geothermal anywhere through new technologies such as Enhanced Geothermal Systems (EGS) or Advanced Geothermal Systems (AGS).
- Economically recover lithium and other critical minerals from geothermal brines to meet U.S. and global demands.
- Identify the feasibility of hybrid geothermal-solar systems and subsurface thermal energy storage.



Bioenergy

Developing industrially relevant, cost-competitive, and performance-advantaged fuels, materials, and chemicals from renewable and waste carbon sources through foundational science, applied R&D, and industrial partnerships.

Research Challenges

- Produce biofuel molecules that confer benefits such as higher energy content, higher octane, and lower soot formation while meeting stringent cost targets.
- Develop industrially relevant bio-based materials and chemicals that provide performance advantages—such as recyclability, multifunctionality, and lower toxicity for chemicals.
- Use electricity to upgrade carbon from diverse “low energy” sources such as CO_2 and other waste gases to produce high-value fuels and chemicals at acceptable cost.
- Use foundational science to design, upcycle, and manufacture energy and carbon-efficient materials and processes.

Potential Energy Intermediate: Hydrogen

Hydrogen can be produced readily using electricity or other energy sources and can provide both chemical properties and energy to many applications

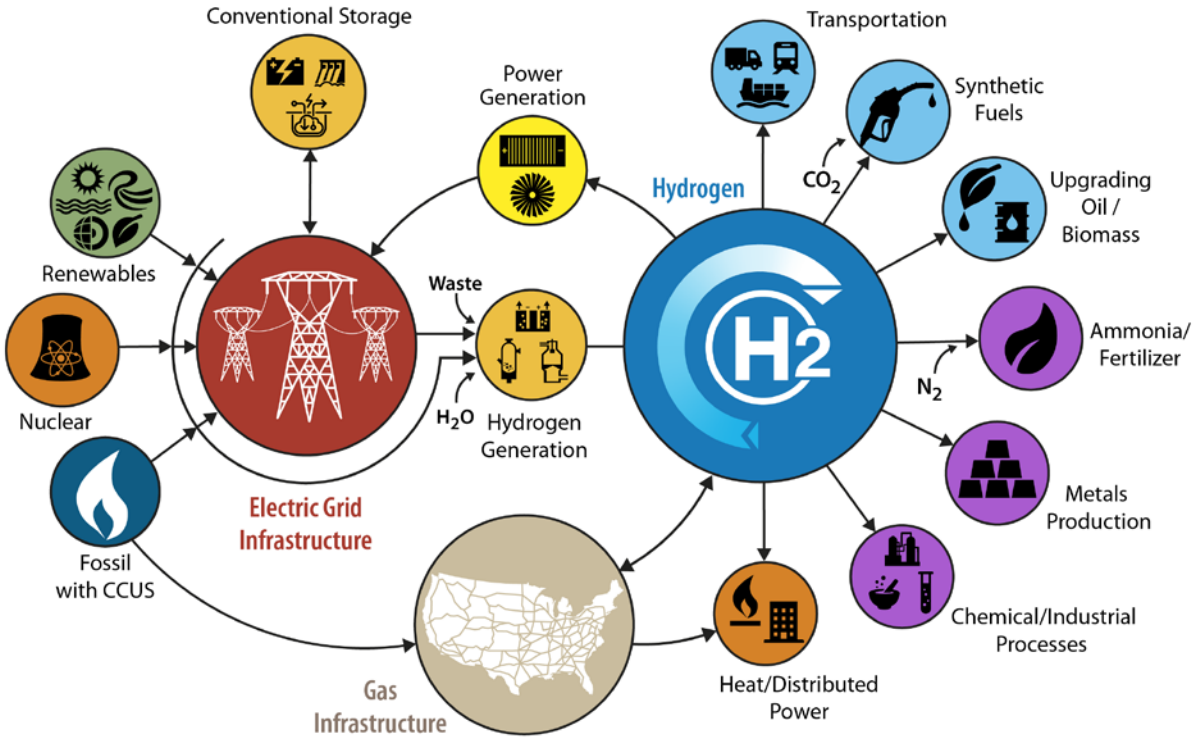


Image Credit: https://www.energy.gov/eere/fuelcells/h2scale

Hydrogen and Fuel Cell Research

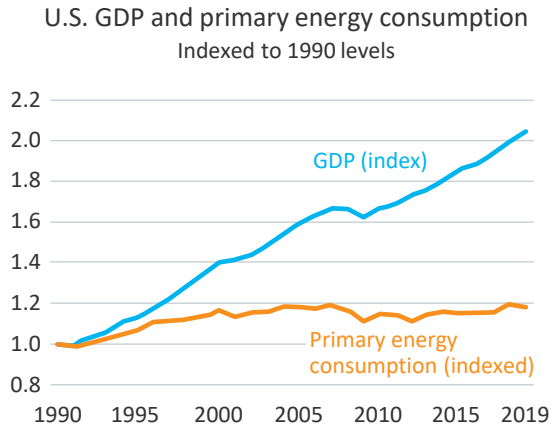
Enabling hydrogen to be a common means of transporting, storing, and transforming energy at the scale necessary for a clean and vibrant economy.

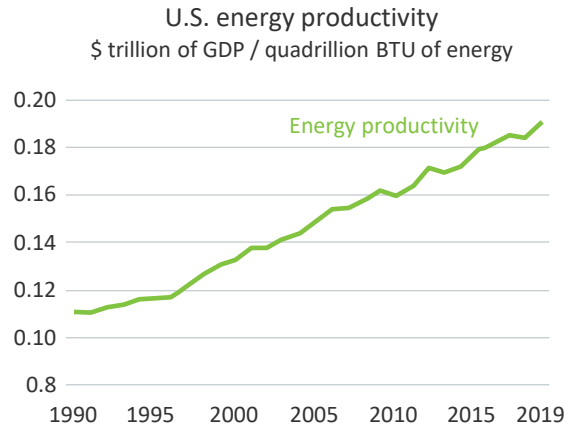
Research Challenges

- Improving the economics of hydrogen production to enable it to shift energy across time, sectors, and location—including providing electric grid support and energy storage
- Developing advanced materials for polymer electrolyte fuel cells and electrolyzers, focusing on the emerging markets of intermittent H_2 production and heavy-duty transportation
- Enabling safe fueling for heavy-duty hydrogen trucks, reducing the cost and improving reliability of fueling fuel cell electric vehicles
- Researching hybrid bio-electrochemical processes and advanced cell concepts.

Energy Productivity in the United States

Since 1990, the U.S. economy has nearly doubled as measured in gross domestic product (GDP), but primary energy consumption has increased only 19%. This represents a 72% improvement in U.S. energy productivity.





Source: *2019 Sustainable Energy in America Factbook*, Bloomberg New Energy Finance and the Business Council for Sustainable Energy, February 2019

Transportation Technologies

As the nation's premier facility for providing energy-efficient transportation R&D solutions, NREL collaborates with federal agencies, state entities, and private-sector companies to transform the movement of people and goods, while minimizing the impact to the environment.

Research Challenges

- Evaluating the energy, cost, and time impacts of new mobility technologies when deployed at scale.
- Identifying advanced lithium-ion battery and extreme-fast-charging technology solutions that will bring down the costs associated with electric drive transportation options.
- Optimizing fuels and engines as dynamic design variables that can work together to boost efficiency and performance, while minimizing emissions.

Energy Efficient Buildings

NREL's core R&D strengths are transforming energy by developing grid-interactive buildings that strengthen the resiliency, efficiency, and affordability of energy systems globally.

Research Challenges

- Developing integrated systems that include optimal design and operation.
- Making smart buildings the hub for electric vehicles, solar energy, battery storage, thermal storage, and intelligent building systems that address current industry needs.
- New materials and controls that enable future integration are needed.

Advanced Manufacturing Research

NREL's research is focused on the identification and application of energy-efficient manufacturing solutions through the exploration of unique materials and innovative processes that enable clean energy technologies.

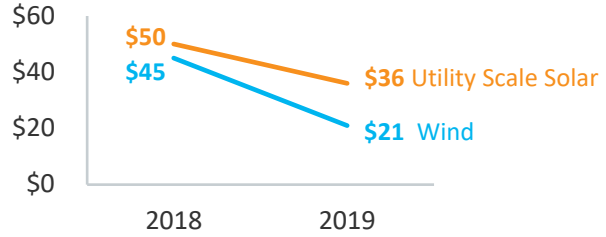
Research Challenges

- Enabling the circular economy in wind energy by researching novel recyclable and self-healing composite resins
- Understanding the intricacies of supply chain resilience through high-performance modeling and analysis
- Driving the manufacturing of robust multilayer, clean-energy technologies that improve energy efficiency and reduce costs
- Improving power electronic devices and reliability for stable grid connection of variable loads
- Investigating the science of desalination and other clean water technologies to open untapped water resources for broad use.

Cost for Renewables are Falling

Advanced energy technologies are providing real-world solutions by:

- Becoming increasingly cost-competitive
- Boosting the U.S. energy industry
- Providing jobs for American workers

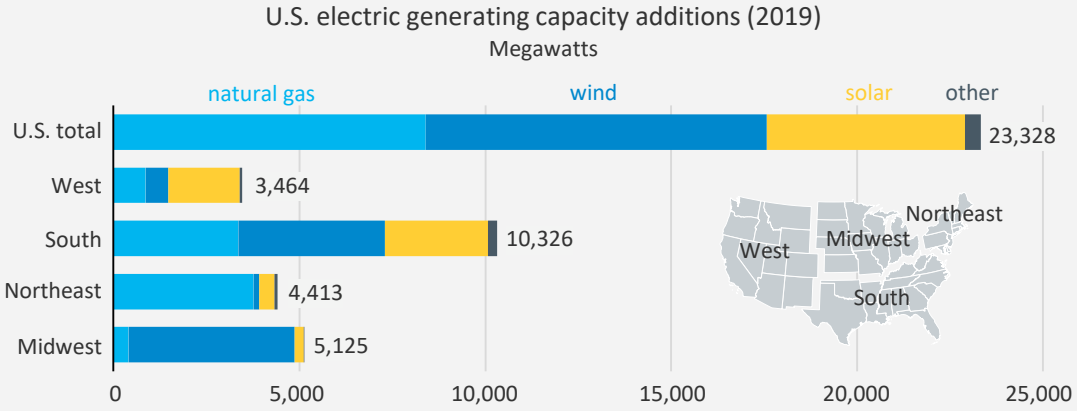


2019 Xcel pricing for projects due to go online in 2023

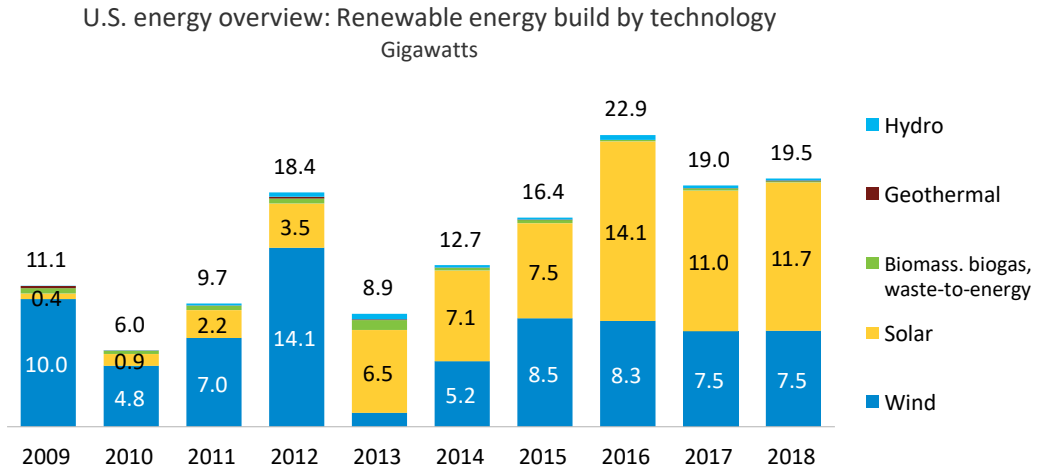
Source: *Lazard's 2019 Levelized Cost of Energy Analysis*

Growing U.S. renewable energy generating capacity

2018 was the second highest year on record for the installation of renewables and hydroelectric capacity with at a total of 19.5GW.



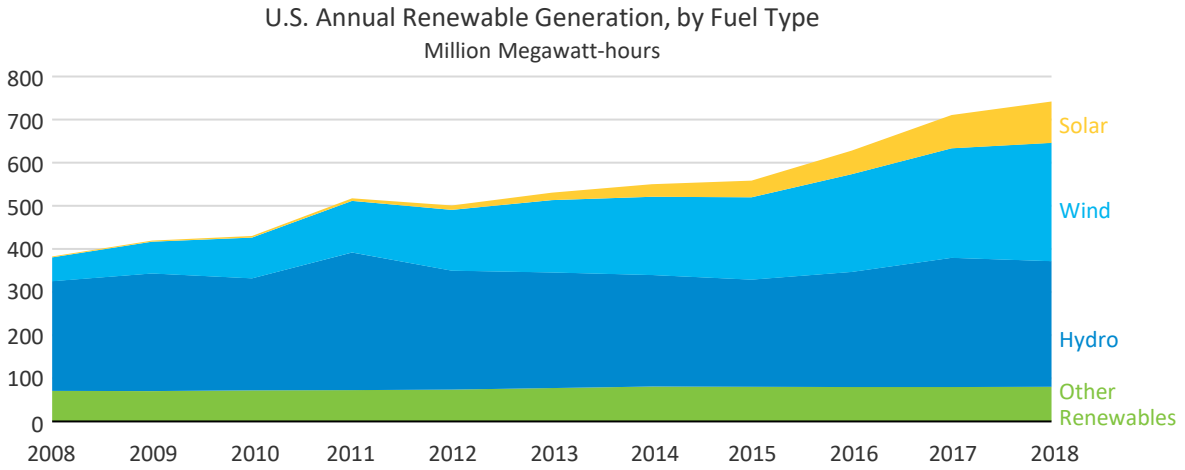
Source: *EIA Today in Energy*, April 21, 2020

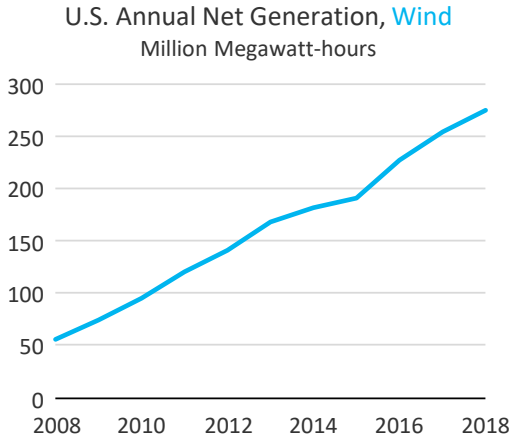


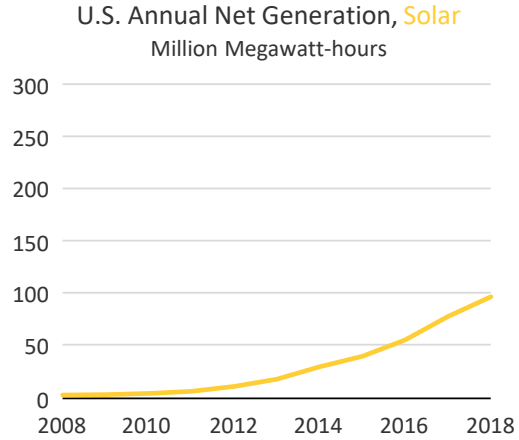
Source: *2019 Sustainable Energy in America Factbook*, Bloomberg New Energy Finance and the Business Council for Sustainable Energy, February 2019

Renewable Generation Haw Doubled in the United States Since 2008

Renewable generation provided a new record of 742 million megawatt-hours (MWh) of electricity in 2018, nearly double the 382 million megawatt-hours produced in 2008.



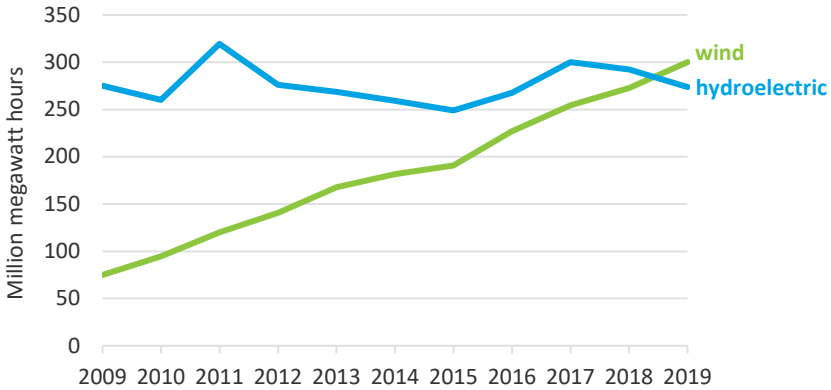




Source: United States Energy Information Administration, Today in Energy, March 19, 2019

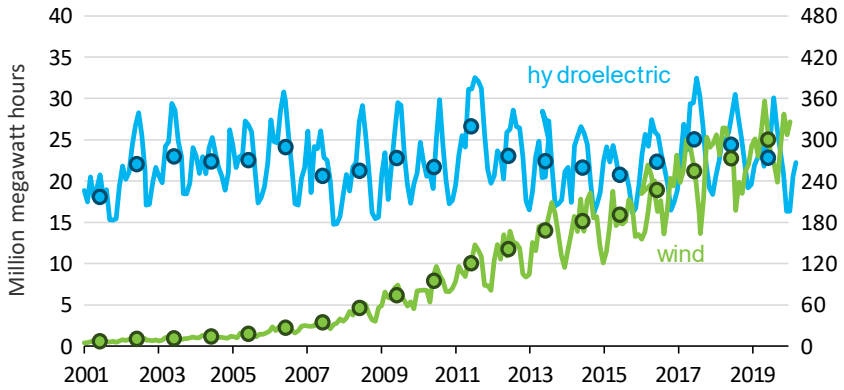
Wind Surpasses Hydro for U.S. Renewable Electricity Generation

2009 – 2019 Annual Electricity Generation from Wind and Hydro Sources



During the winter of 2019, wind became the top renewable source of electricity generation in the country, a position previously held by hydroelectricity.

2001 – 2019 U.S. Electricity Generation from Wind and Hydro Sources



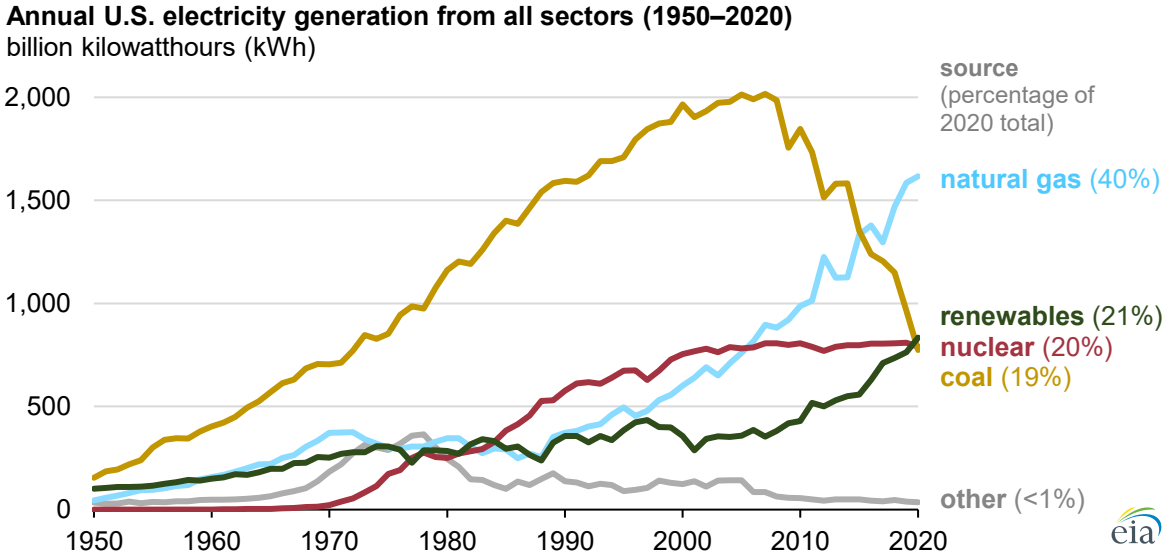
Capacity growth has been the predominant driver of annual changes in wind generation.

Source: United States Energy Information Agency, Today in Energy, February 26, 2020

U.S. Energy Supply is Shifting

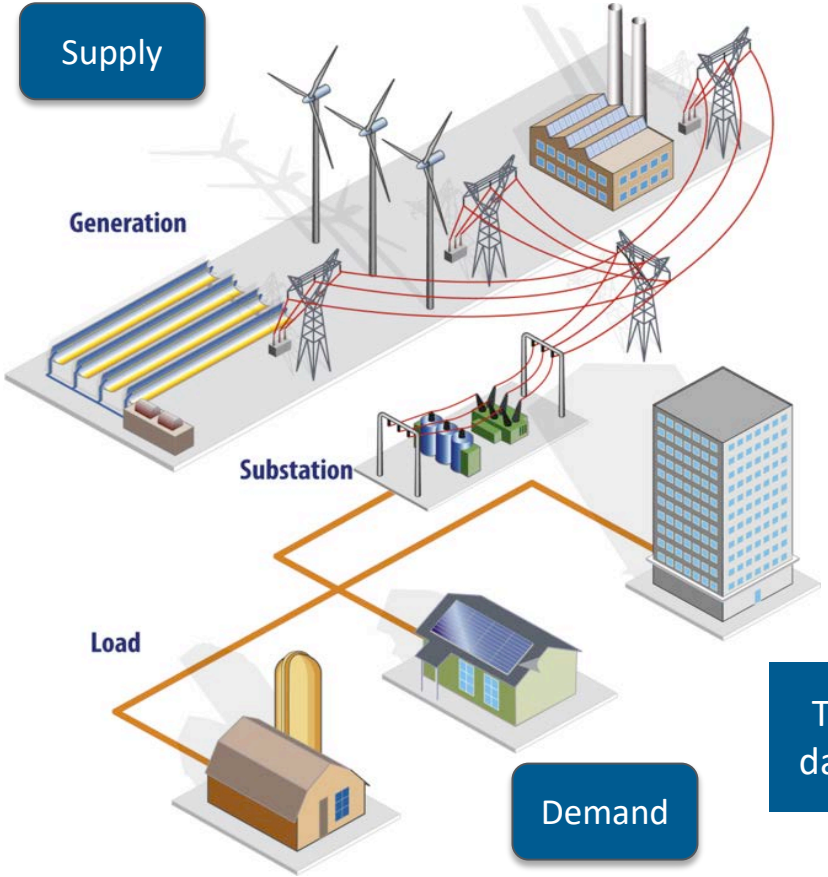
In 2020, renewable energy became the 2nd most prevalent source in the U.S.

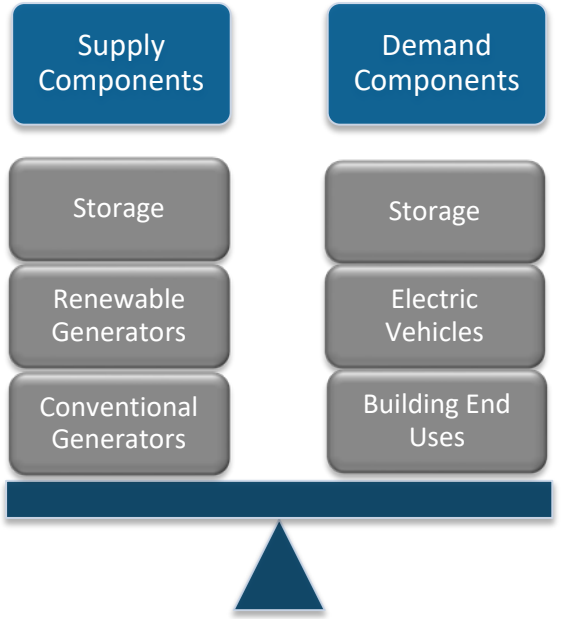
U.S. Generation Mix 1950 - Present



Source: United States Energy Information Agency, https://www.eia.gov/todayinenergy/detail.php?id=48896
Accessed October 2, 2021

Challenge for the Electricity Grid: supply and demand need to be balanced at all times





The electric grid operates at timescales from sub-seconds to days using assets that can take years to build and last decades

Options to Balance Generation and Demand

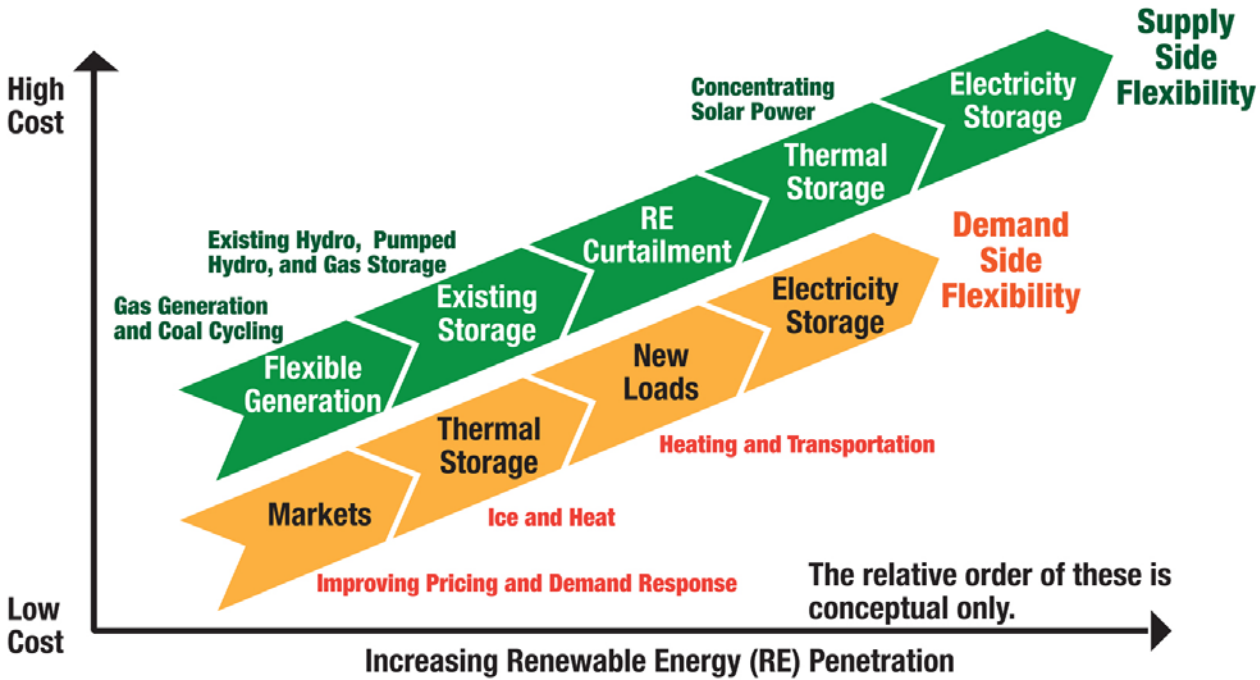
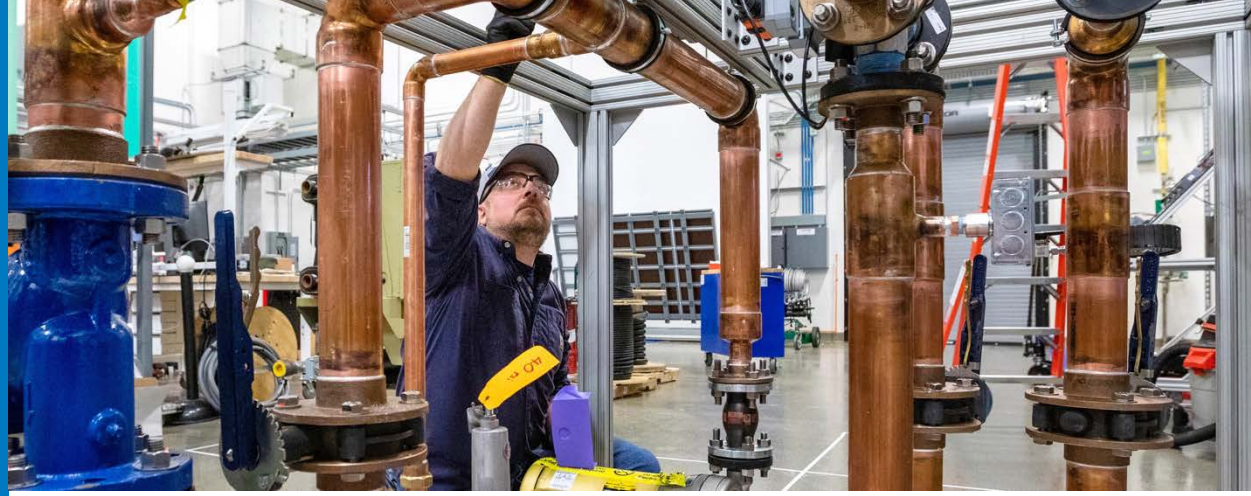
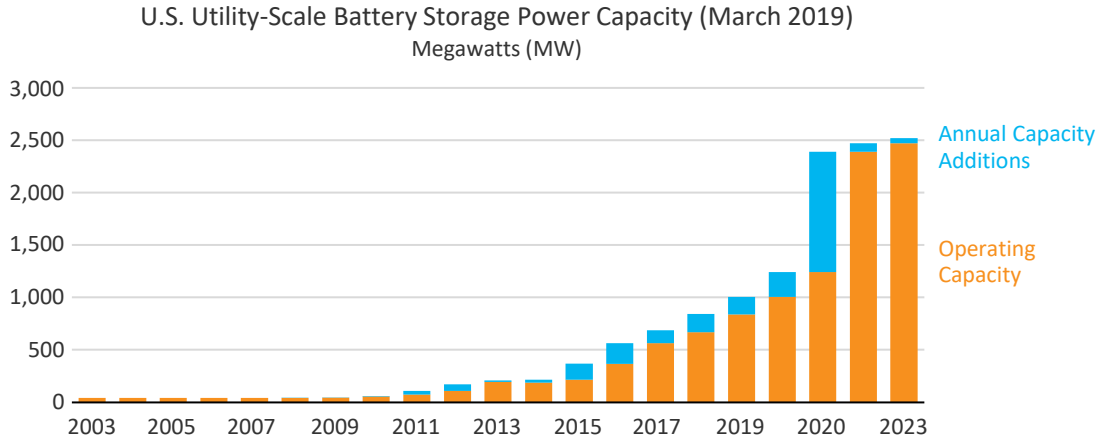


Image from Paul Denholm. 2016. *Do We Really Need Storage to Operate the Renewable Grid of the Future? . NREL (National Renewable Energy Laboratory)*. NREL/PR-6A20-66104. https://www.nrel.gov/docs/fy16osti/66104.pdf

Utility-Scale Battery Storage Power Capacity

Operating utility-scale battery storage power capacity has more than quadrupled from the end of 2014 (214 MW) through March 2019 (899 MW).





Source: United States Energy Information Agency, Today in Energy, July 10, 2019

Thank You

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This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by NREL planning and assessment funds. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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