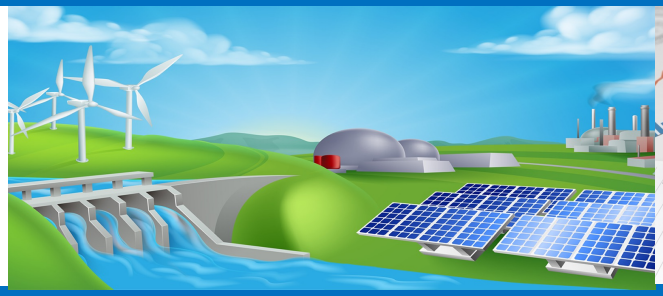



ECONOMICS OF MODERN POWER SYSTEMS

M3 - SG: How Electricity Generation Will Change

Prof. Luana Medeiros Marangon Lima, Ph.D.

Learning goals

- Shift to Generation side
  - Distributed Generation
  - Renewable Energy Sources
  - Electricity Mix
    - US
    - World wide trends
  - Challenges of integrating renewable resources
    - Balancing supply and demand

A Generation Paradigm Shift

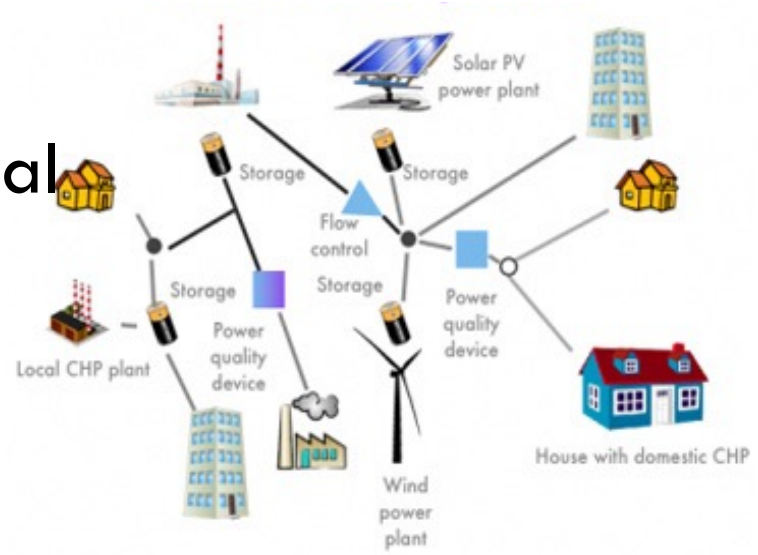
- Historically
  - Centralized generation
  - Fossil fuel, nuclear, large hydropower
- Current Situation
  - More dynamic
  - More distributed
  - More renewable generation
- But some aspects remain unchanged
  - Need for balancing supply and demand
  - High reliability standards





Defining Distributed Generation

- Generation of electricity from many decentralized, smaller than conventional, energy sources
- Connected to distribution grids
- Often based on renewable sources
  - Wind, solar, biomass
- Possibly based on conventional methods
  - Diesel, natural gas



Renewable Energy and Clean Energy

- Alternative energy

  Refers to sources of energy other than conventional nuclear or fossil fuels

- Renewable energy

  Type of energy that comes from renewable natural resources, such as wind, rain, sunlight, geothermal heat, biomass, and tides

- Clean energy

  Form of energy which is created with clean, harmless, and non-polluting methods

- Most renewable energy sources are also clean energy sources
  - some geothermal energy processes can be harmful to the environment
- NG is often praises as "clean" because it burns more cleanly than other fossil fuels
  - "bridge" fuel until zero-carbon-producing renewables can take over

Electricity Generation

Fossil Fuels

Nuclear

Renewable

Background (Energy Tech)

- Three major categories
  - Fossil fuels (coal, natural gas and petroleum)
  - Nuclear
  - Renewable energy
- Electricity can be generated with steam turbines using fossil fuel, nuclear, biomass, geothermal and solar thermal energy
- Others technologies
  - Gas turbines, hydro turbines, wind turbines, and solar photovoltaics

Conventional & Renewable Sources

Conventional Sources

Natural gas
Can be used in steam turbines and gas turbines to generate electricity

Petroleum
Mostly steam turbines

Coal
Mostly steam turbines

Nuclear
Use steam turbines to produce energy from nuclear fission

Renewable Sources

Hydropower
Uses flowing water to spin a turbine connected to a generator

Wind
Uses wind to spin a turbine

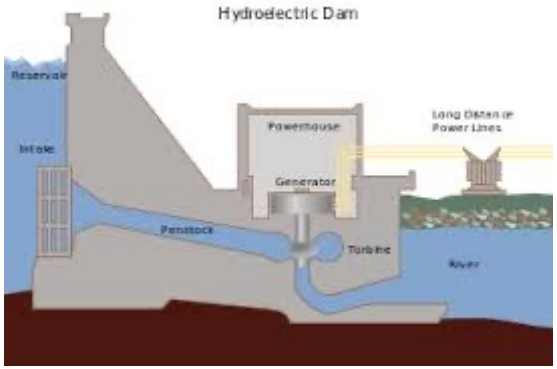
Biomass
Burned directly in steam-electric plants or converted to gas and burned in steam generators or gas turbines

Solar
PV produces electricity from sunlight in a photovoltaic cell (DC)
Solar-thermal uses steam turbine to generate electricity

Geothermal
Use steam turbines

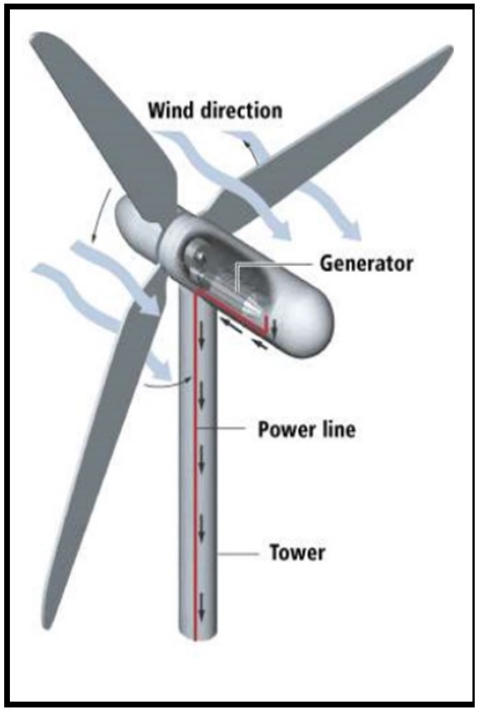
Hydropower

- Conventional hydroelectric - hydroelectric dams
- Run-of-the-river - captures the kinetic energy in rivers or streams, without a large reservoir and sometimes without the use of dams
- Small hydro projects are from 1 to 10 MW and often have no artificial reservoirs
- Micro hydro provide less than 1MW to isolated homes, villages, or small industries



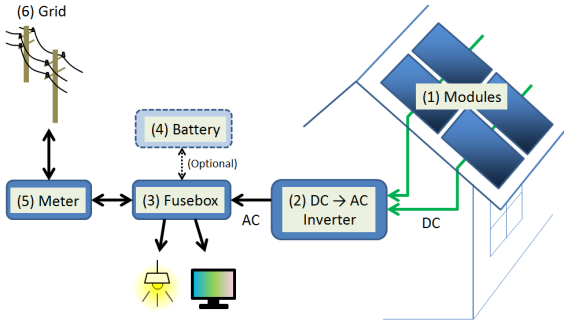
Wind Power

- Utility-scale wind
  - 100 kilowatts to several megawatts
  - electricity is delivered to the power grid and distributed to the end user by electric utilities or power system operators
- Distributed or "small" wind
  - below 100 kilowatts
  - used to directly power a home, farm or small business
  - not connected to the grid
- Offshore wind
  - wind turbines in large bodies of water
  - usually larger than land-based turbines and can generate more power

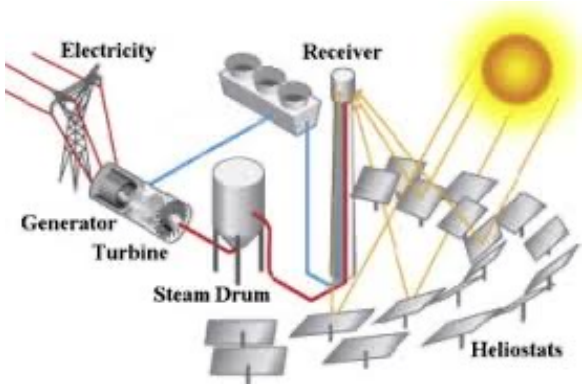


Solar Power

- Photovoltaic – solar panels
  - Utility-scale, community scale
  - Residential rooftops

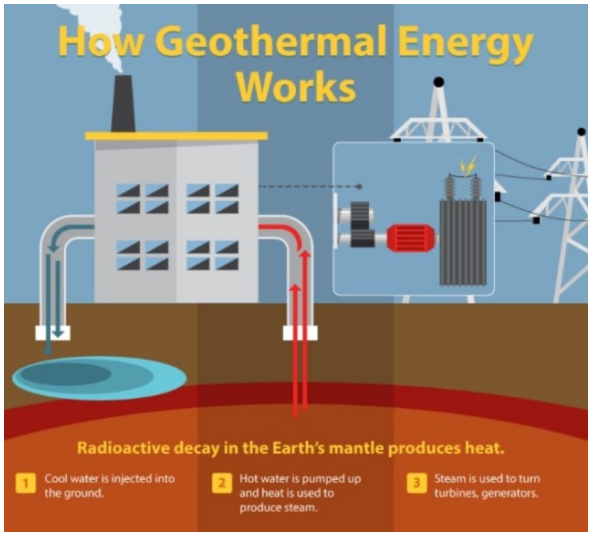


- Concentrated solar power or solar thermal



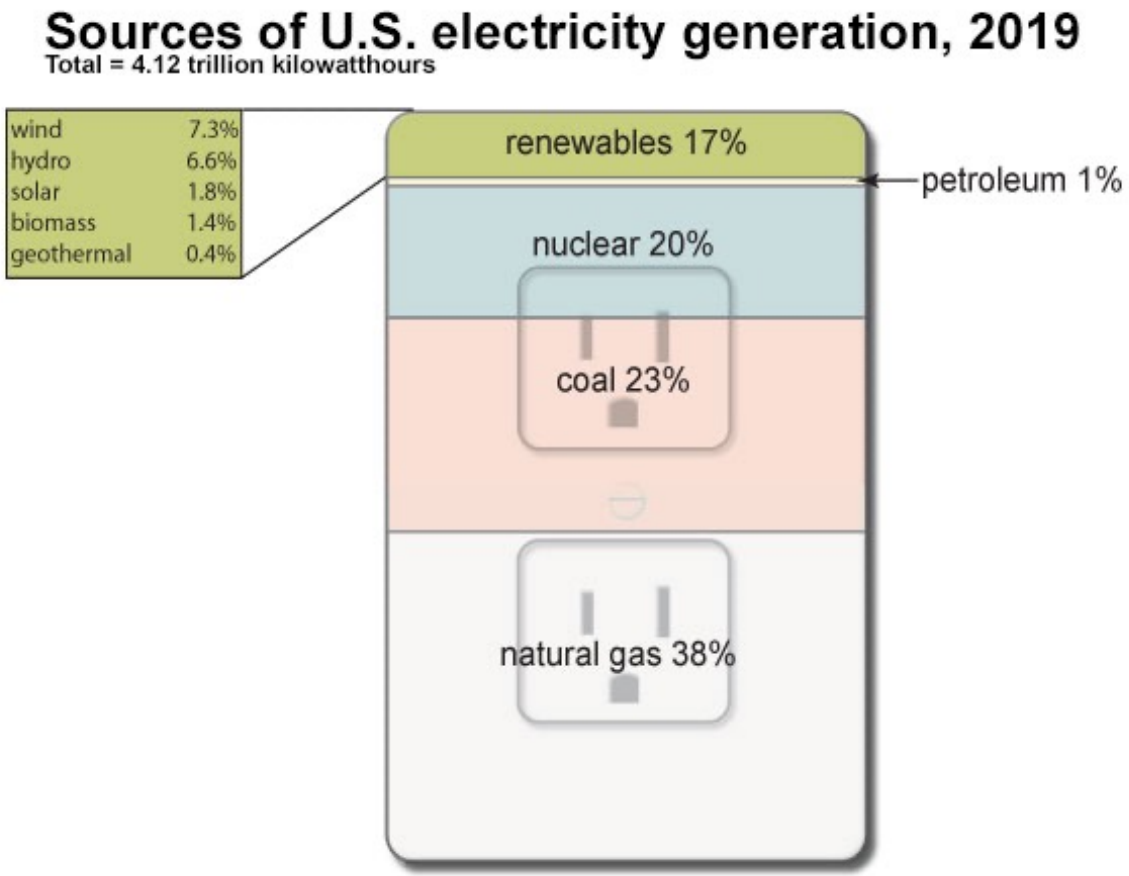
Geothermal power

- Geothermal energy is the heat from the Earth
- In the United States, most geothermal reservoirs of hot water are located in the western states, Alaska, and Hawaii
- Wells can be drilled into underground reservoirs for the generation of electricity



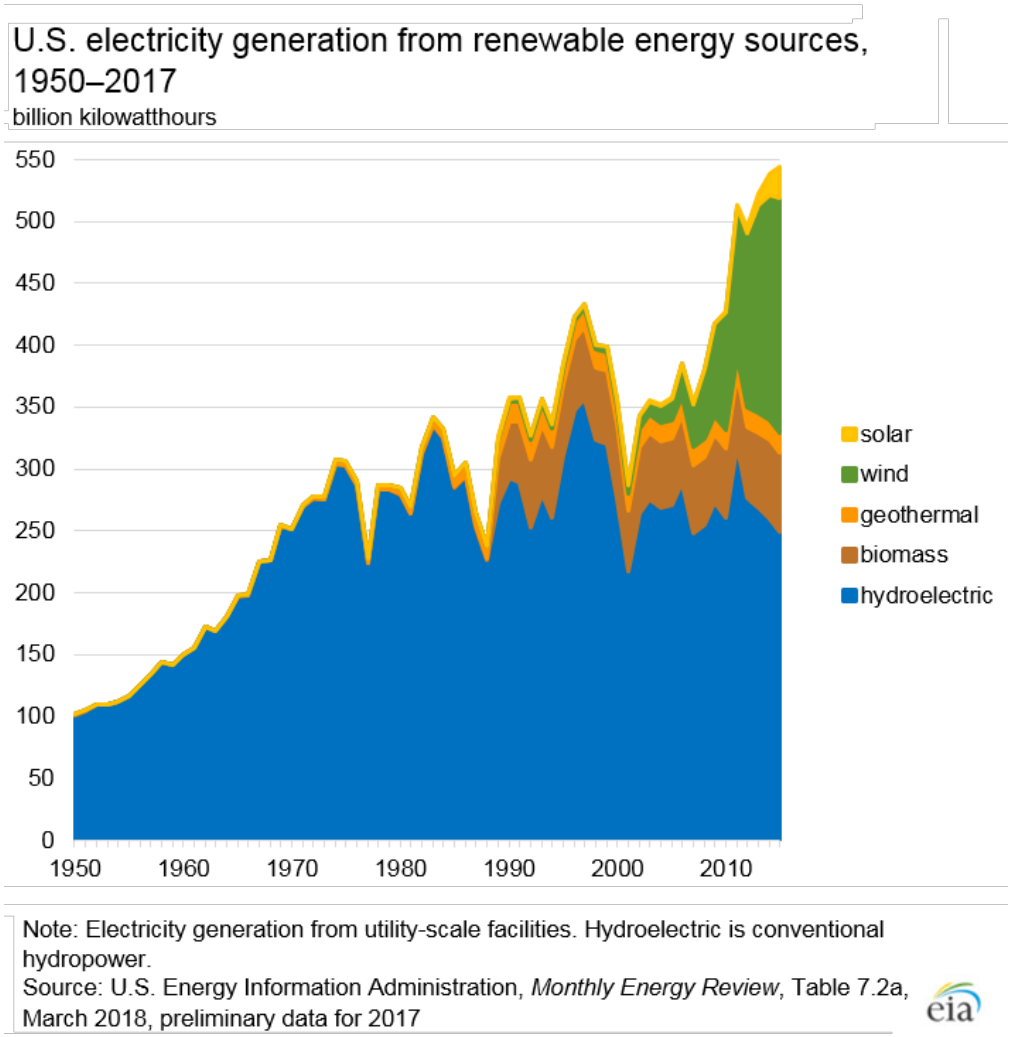
US Electricity Mix

US Electricity Generation Mix



Utility scale facilities

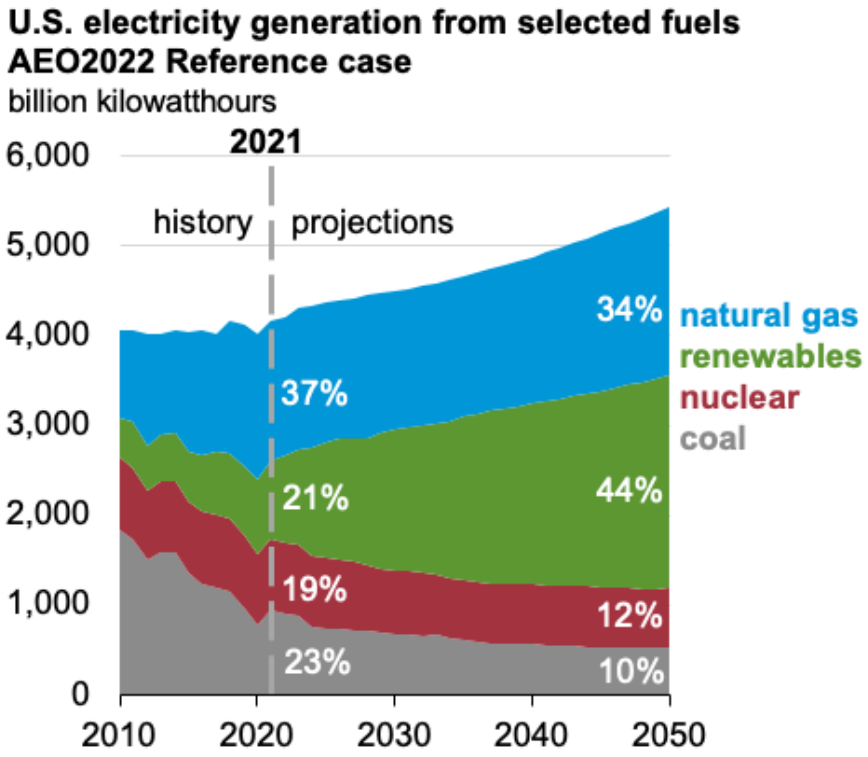
US Historical Electricity Generation from Renewables

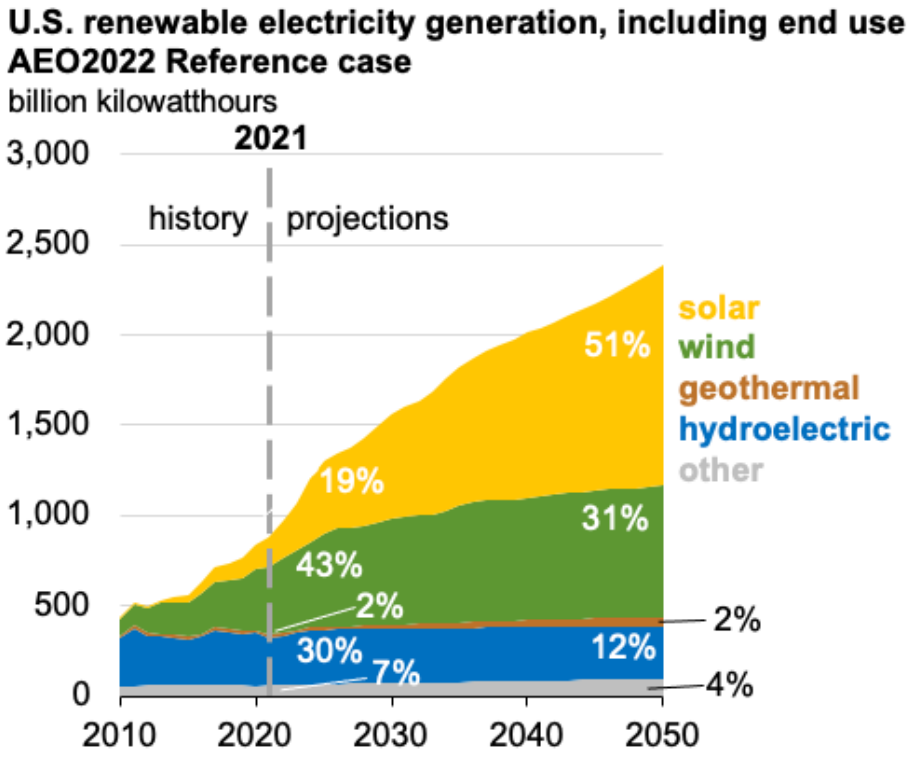


Note: This is electricity generation, not installed capacity!

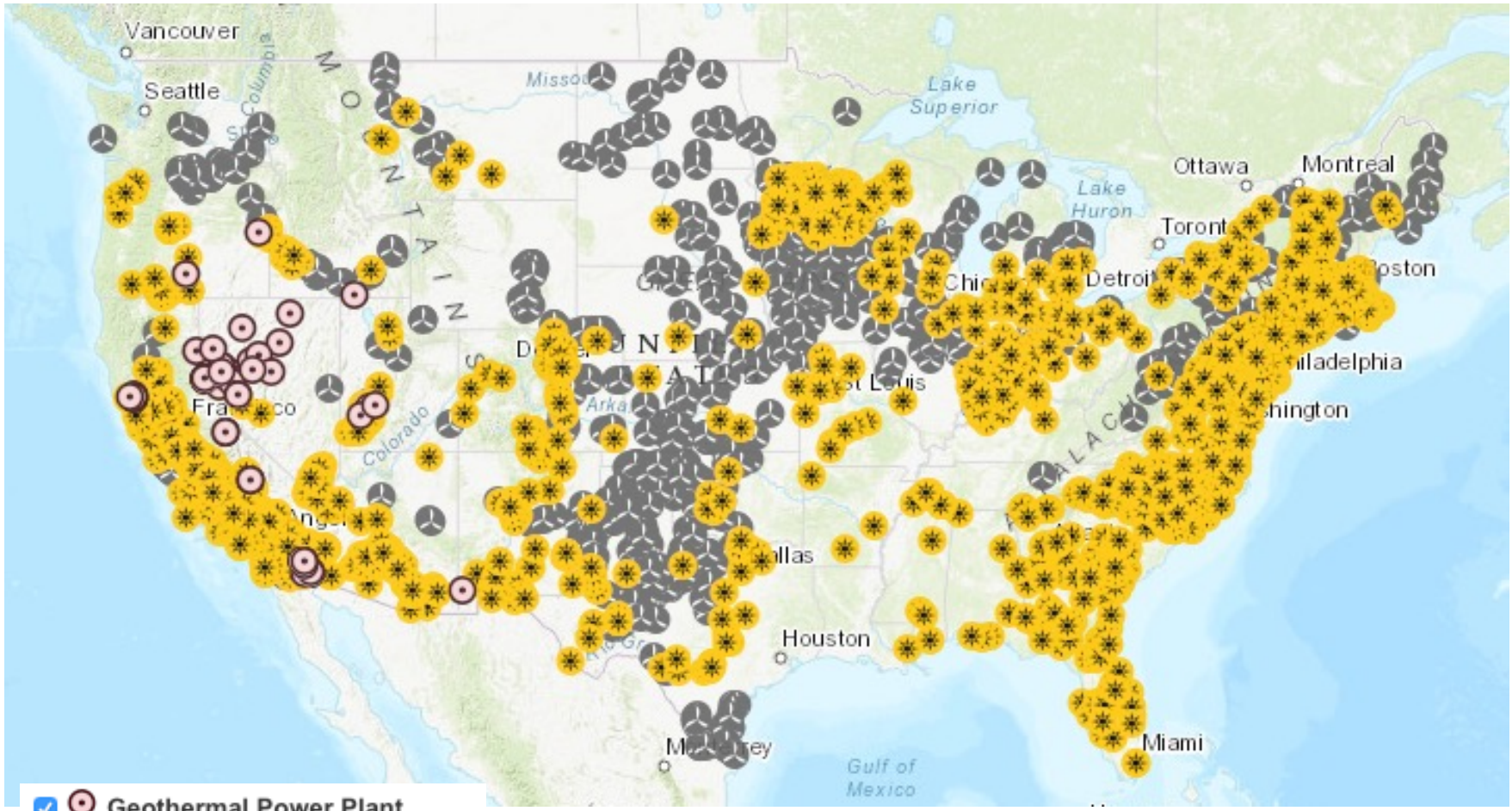
Significant increase in wind!

US Projected electricity generation



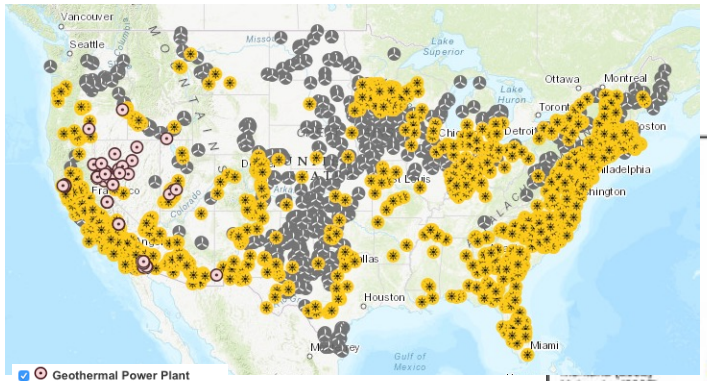


Solar, Wind and Geothermal



Source: https://www.eia.gov/state/maps.php

Wind Resources Map



Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
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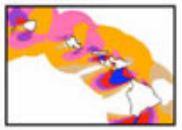
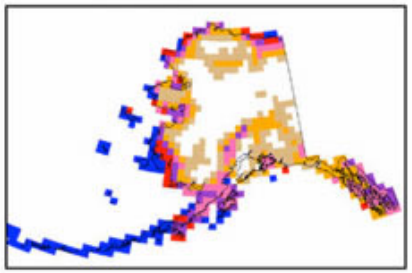
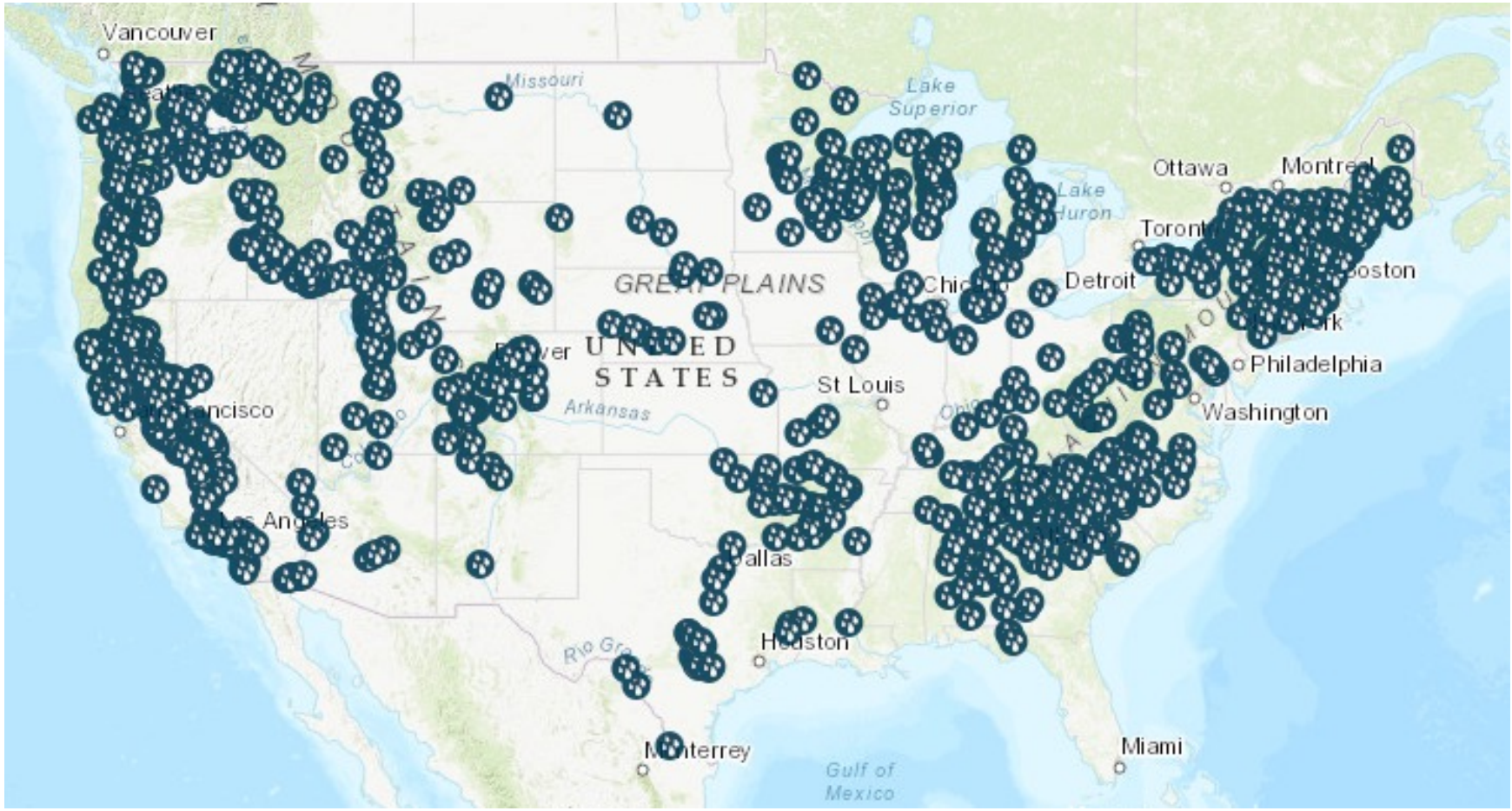
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)





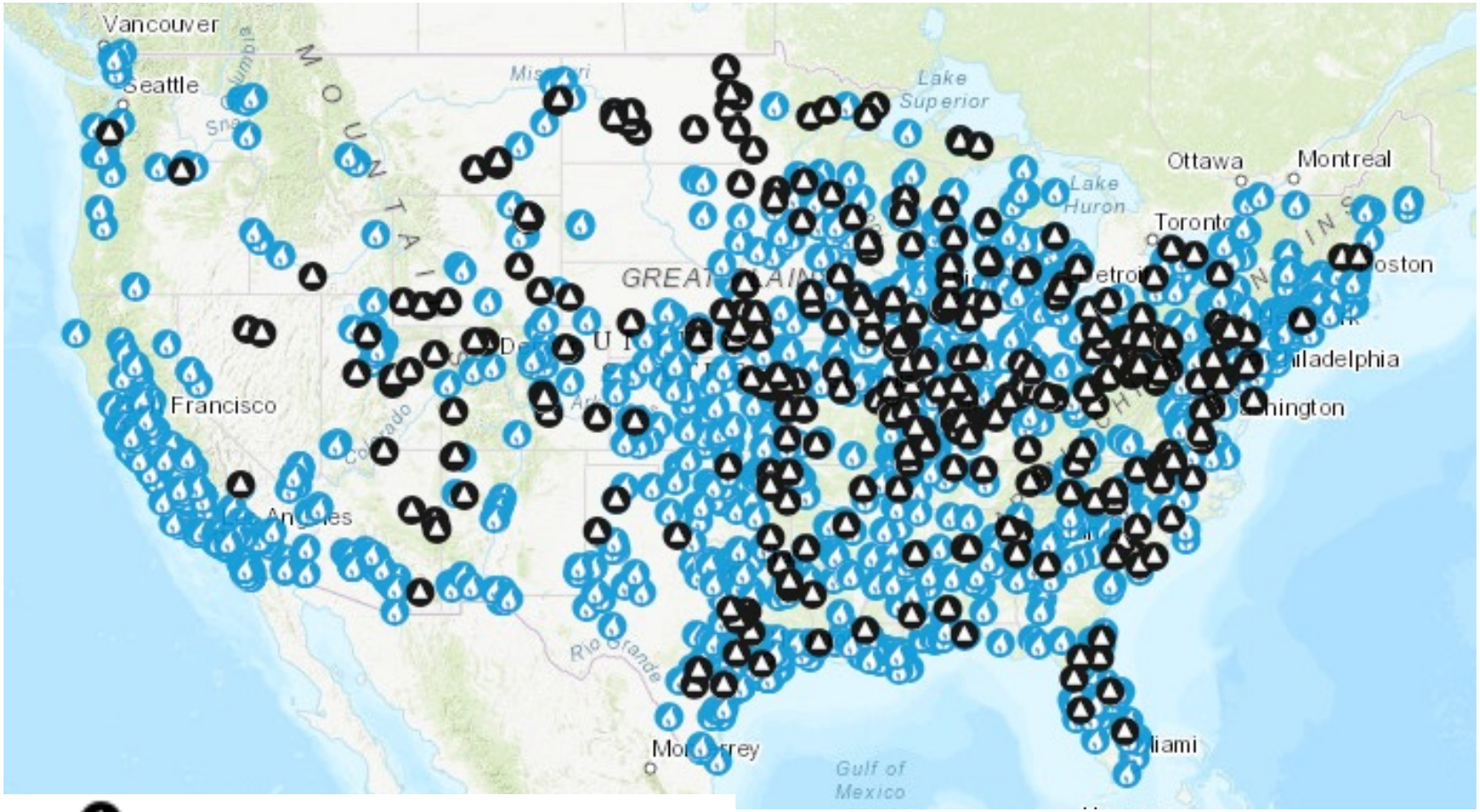
The remaining states use data from the 1987 "Wind Energy Atlas of the United States".

Hydro Power Plants



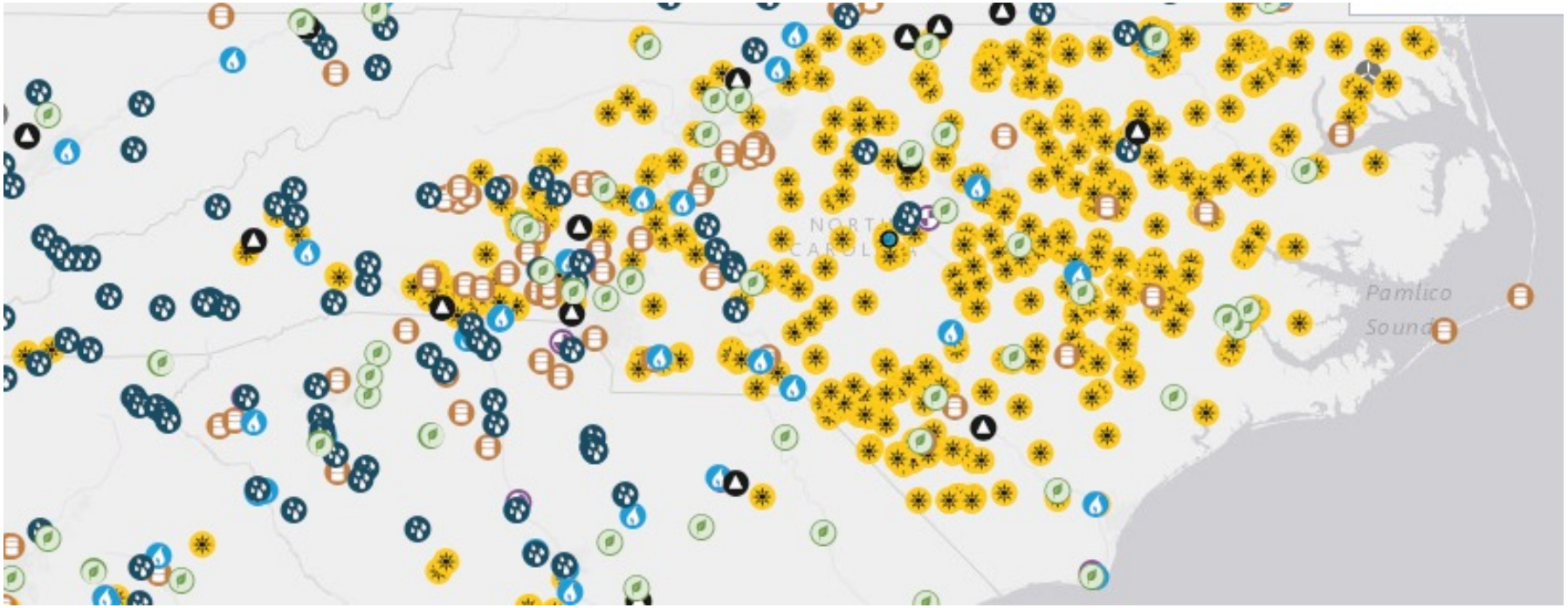
Source: https://www.eia.gov/state/maps.php

Natural Gas and Coal



Source: https://www.eia.gov/state/maps.php

North Carolina

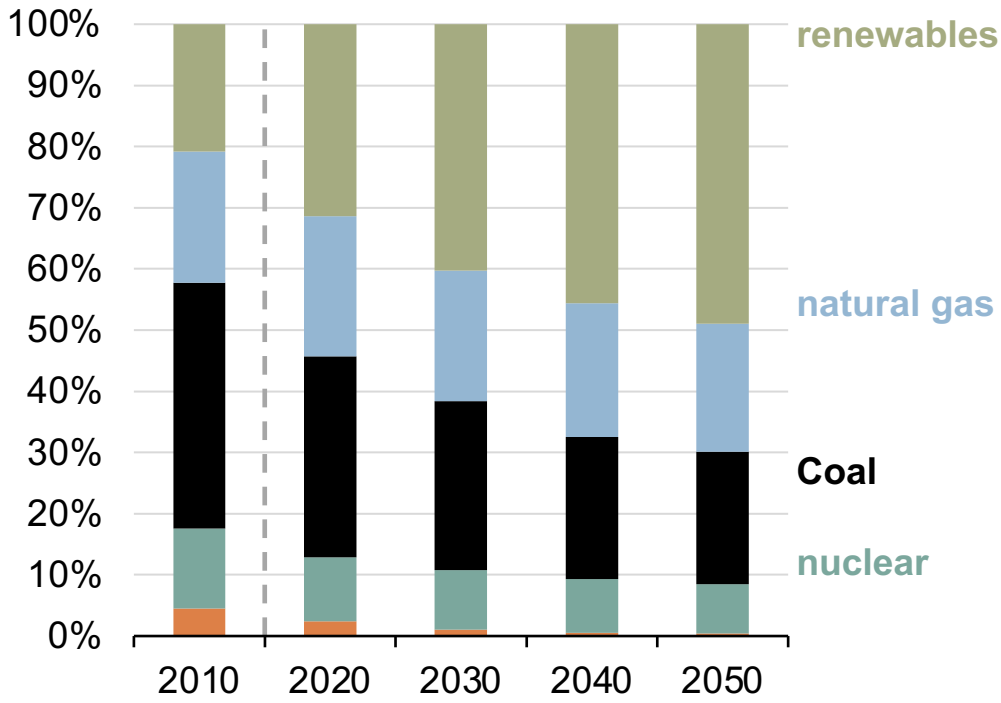


- Biomass Power Plant
- Coal Power Plant
- Geothermal Power Plant
- Hydroelectric Power Plant
- Natural Gas Power Plant
- Nuclear Power Plant
- Other Power Plant
- Petroleum Power Plant
- Pumped Storage Power Plant
- Solar Power Plant
- Wind Power Plant

Rest of the world…

Global Electricity Mix

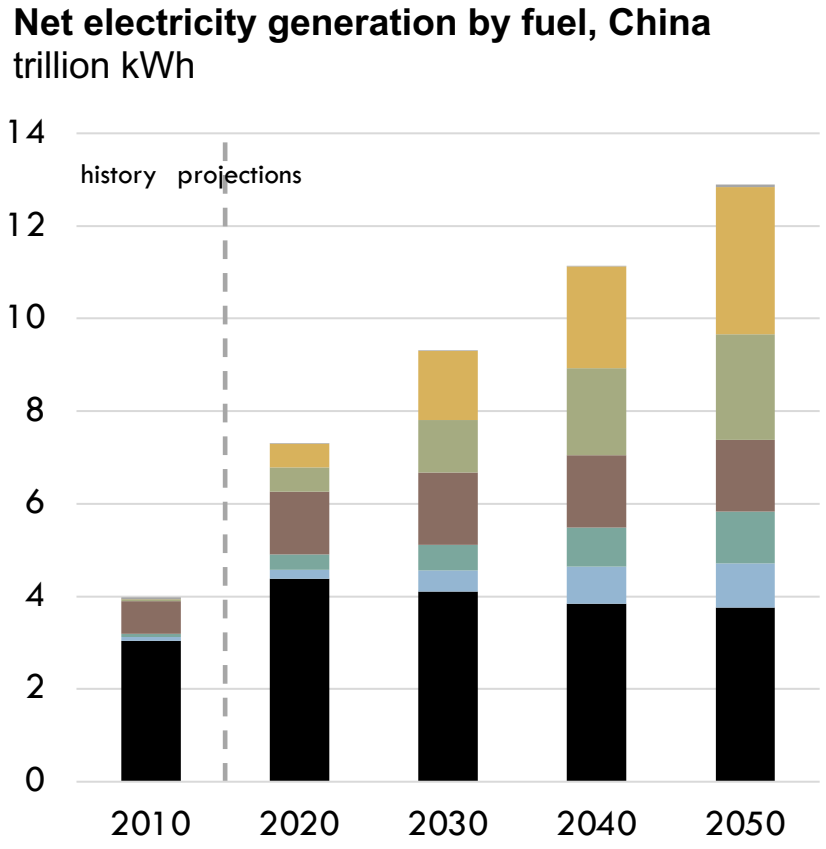
Share of net electricity generation, world
percent

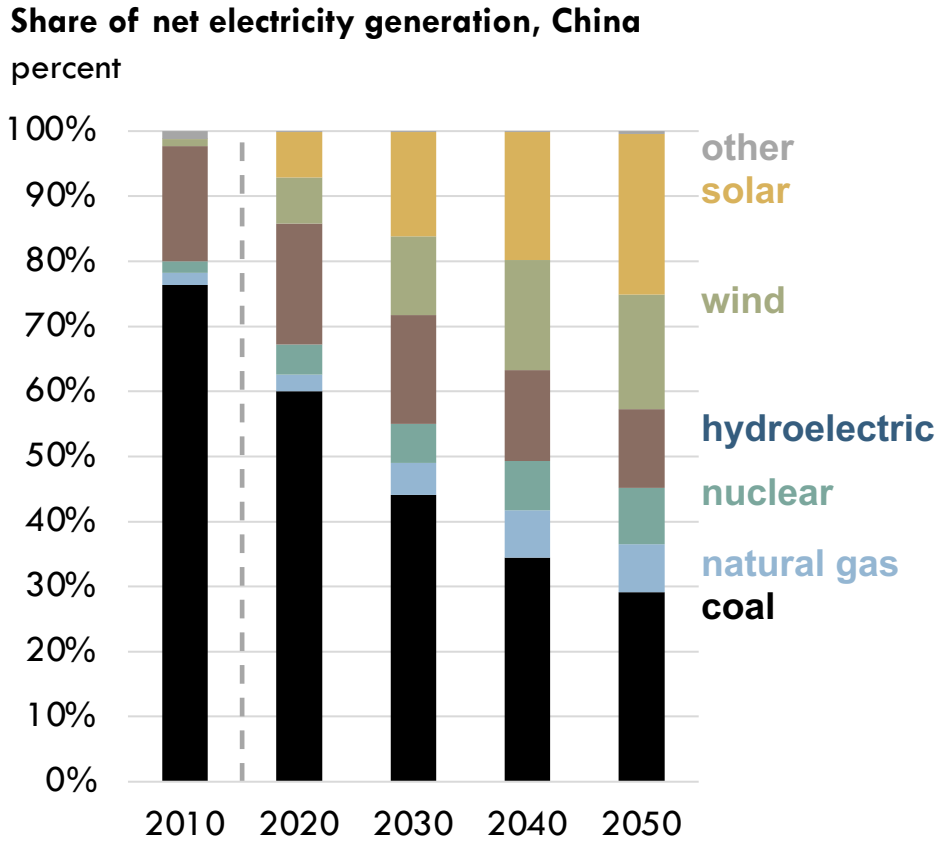


Share of renewable suppose to increase from 30 to 50% until 2050

Source: IEO 2019 - https://www.eia.gov/outlooks/ieo/

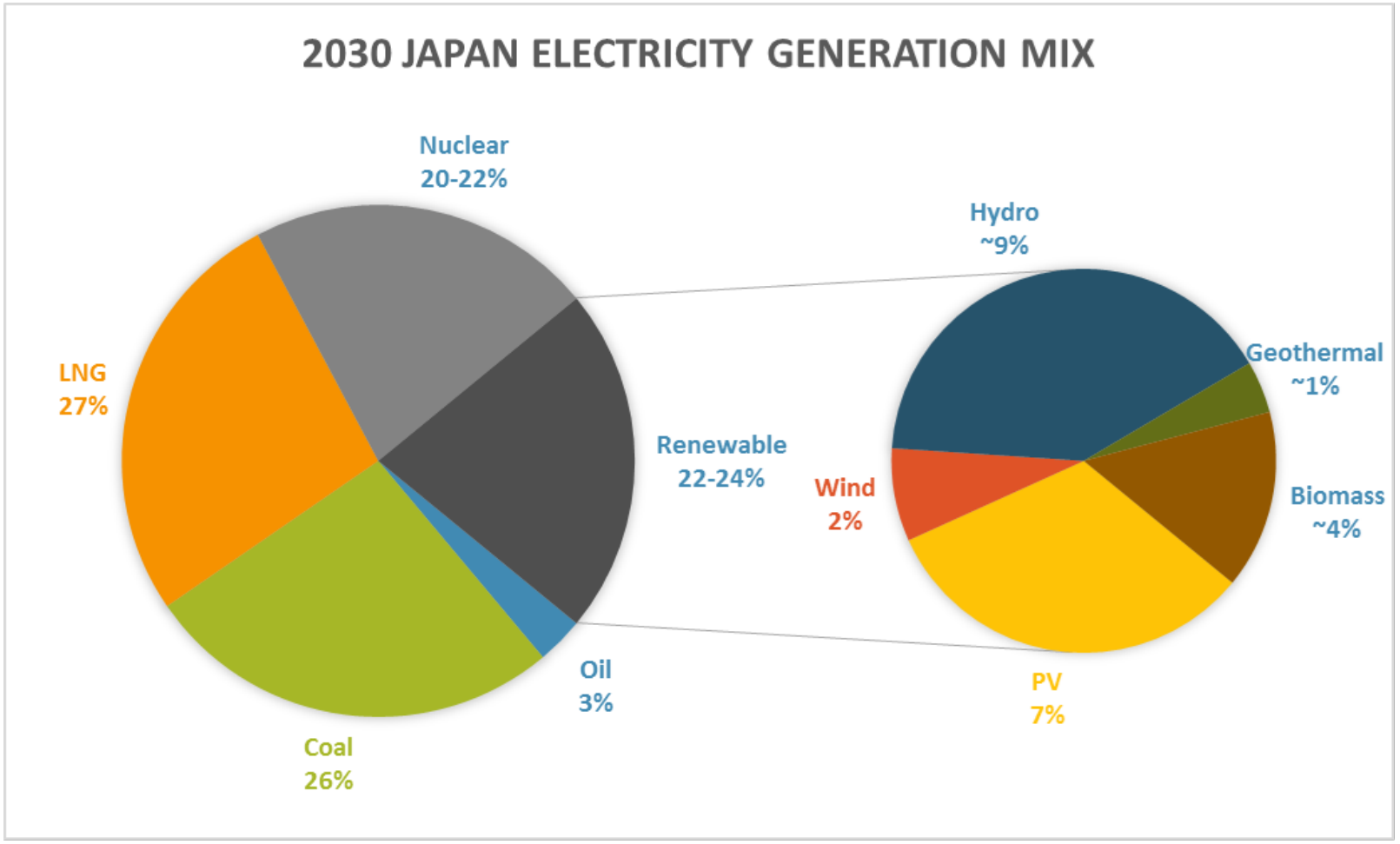
China Generation Mix



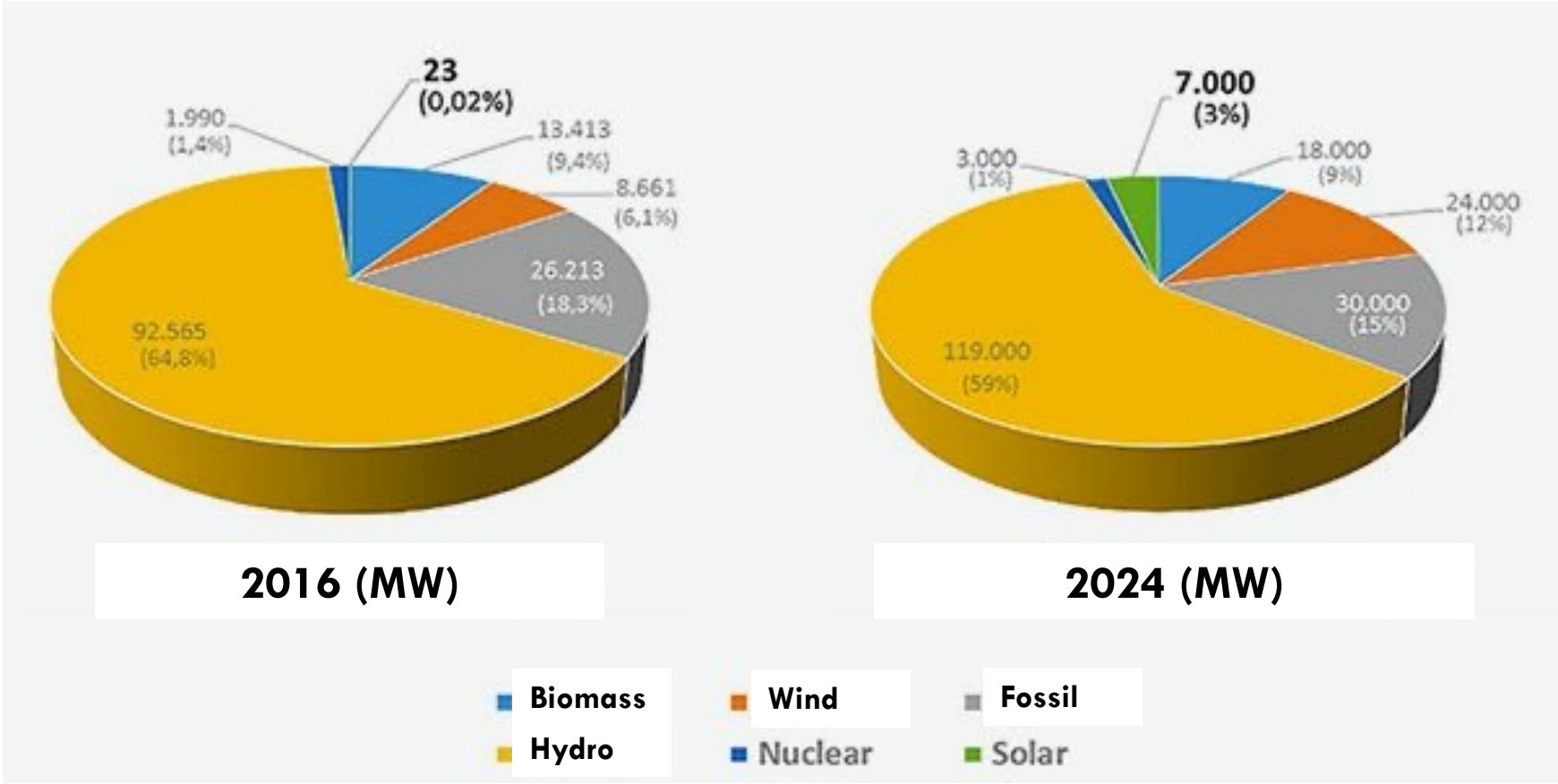


Coal expected to decrease to 30% as renewable increase

Japan Projected Mix

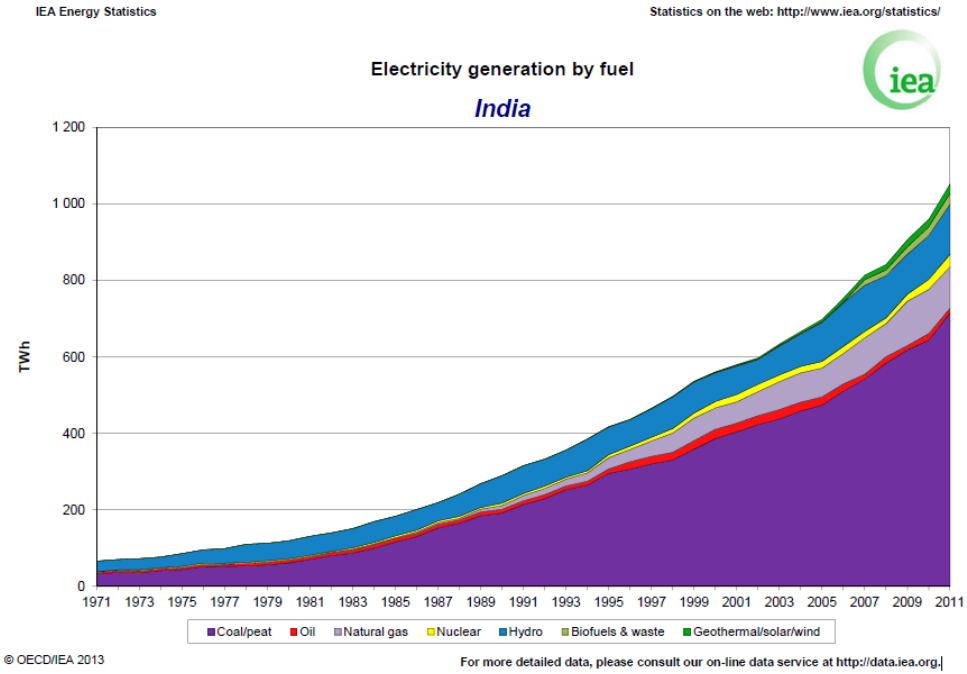


Brazil Electricity Generation Mix

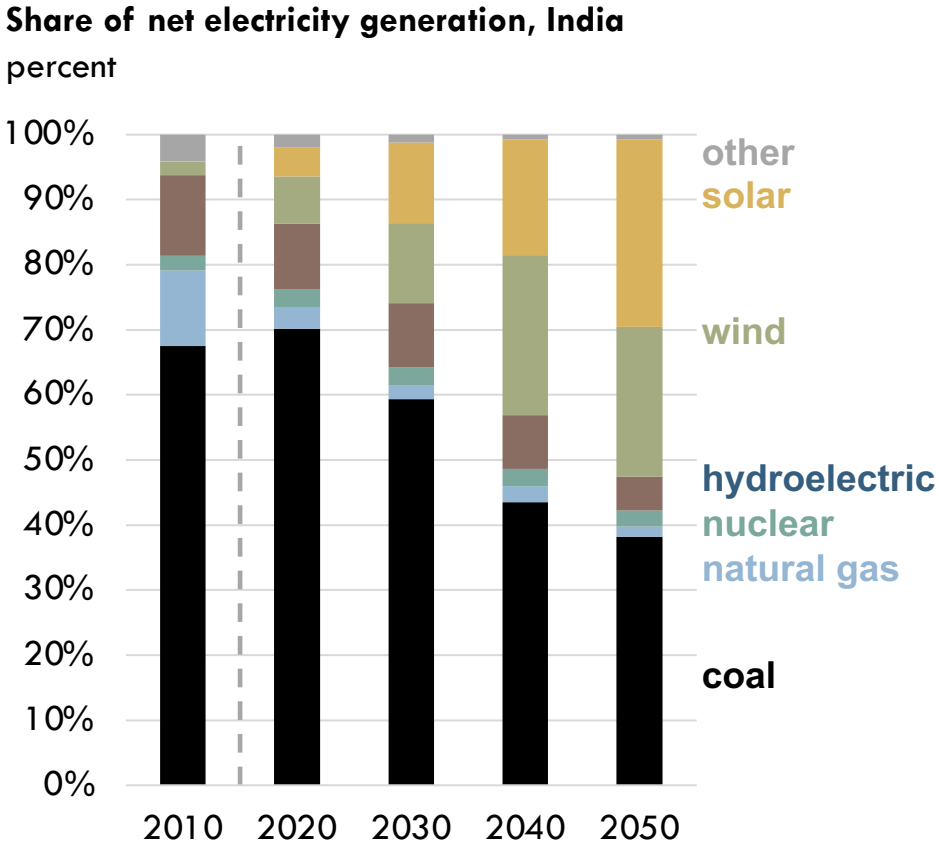


Investments in wind and solar!

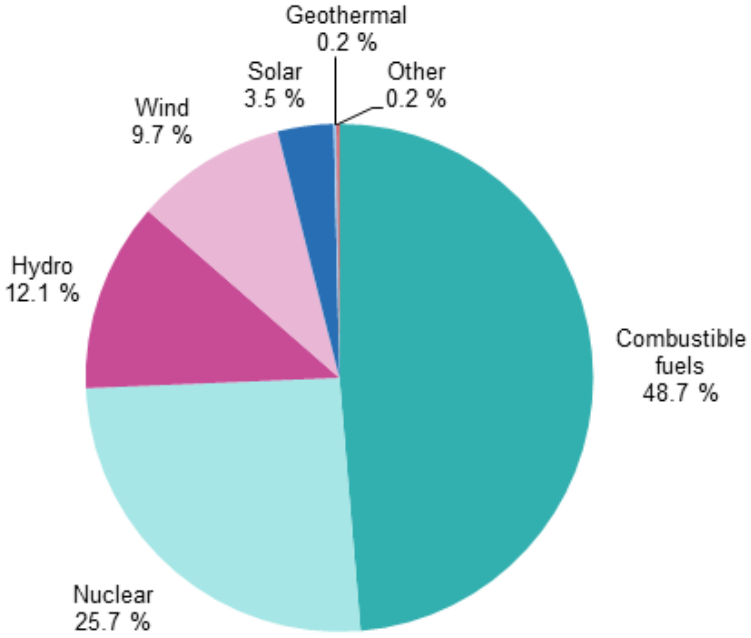
India electricity mix



Significant increase in demand!



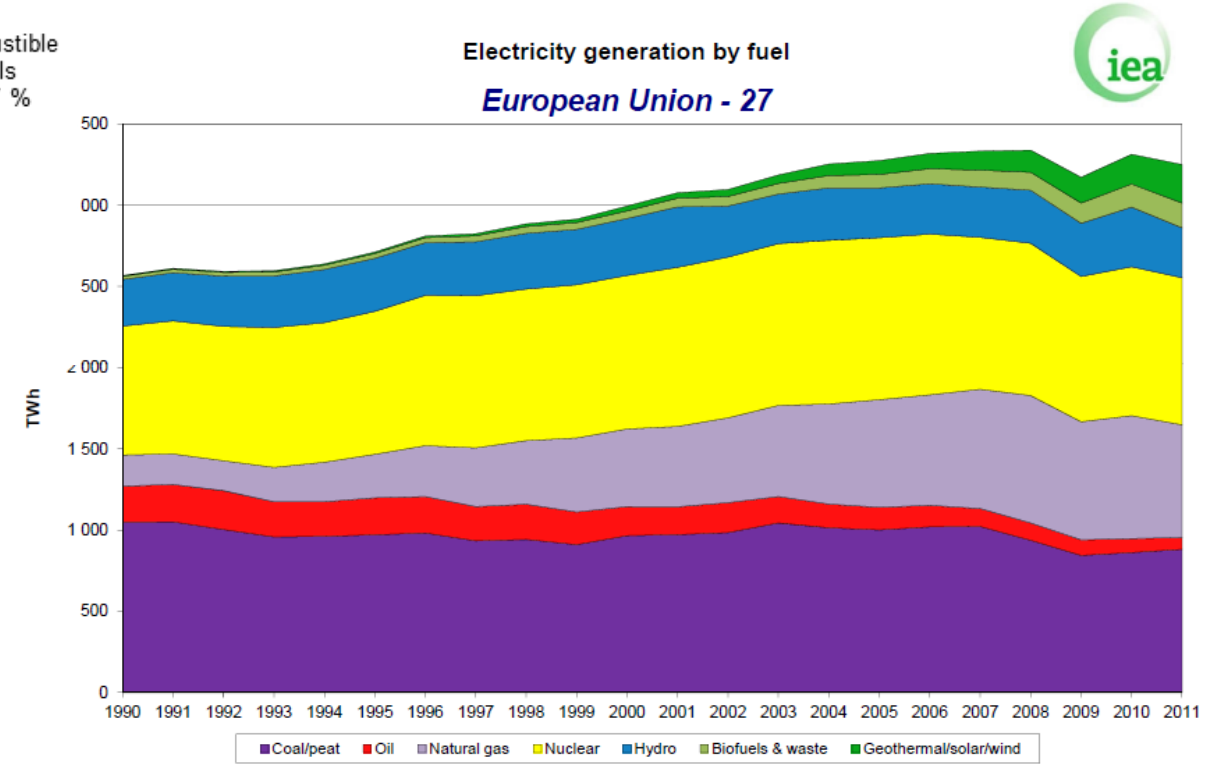
European Union



Net electricity generation, EU-28, 2016
(% of total, based on GWh)

Source: Eurostat

Trend: NG replacing Coal



For more detailed data, please consult our on-line data service at http://data.iea.org.

Learning goals

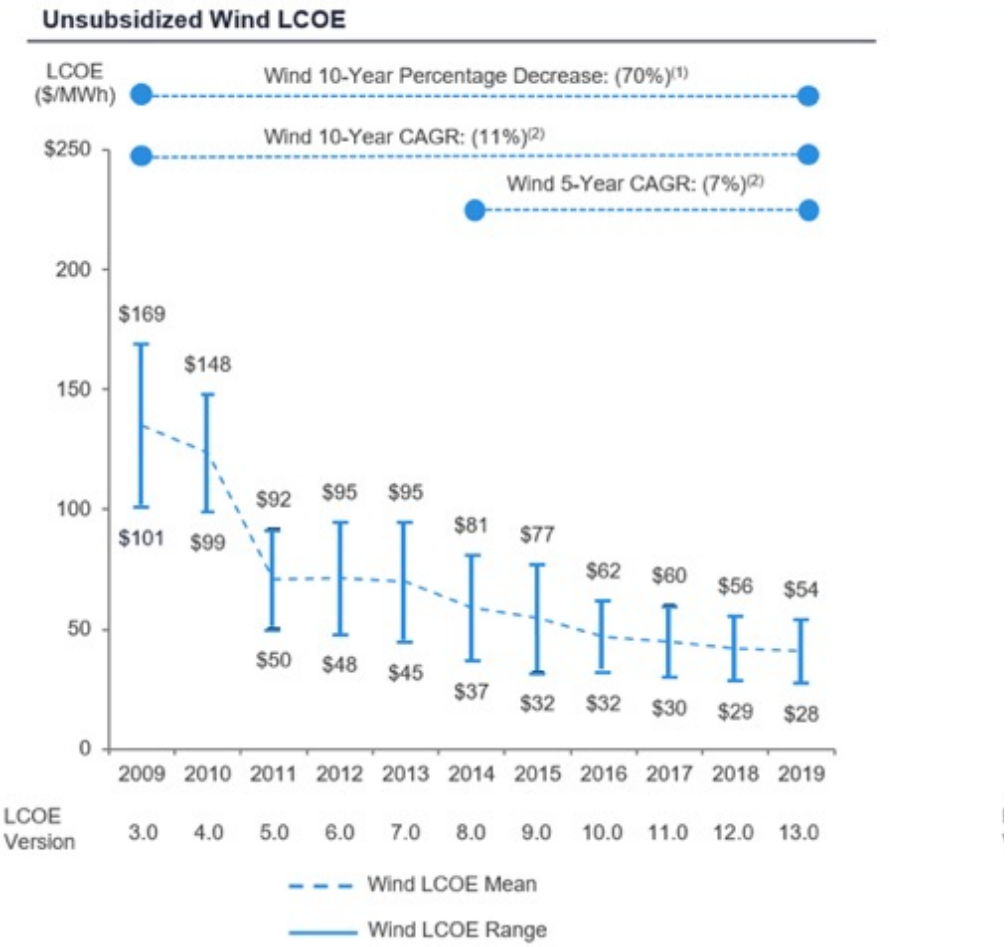
- Shift to Generation side
  - Distributed Generation
  - Renewable Energy Sources
  - Electricity Mix
    - US
    - World wide trends
  - Challenges of renewable resources
    - Balancing supply and demand

Economics of Renewable Energy

Cost Comparison

- World gets most of its energy supplies from fossil fuels
  - Provide energy at the lowest cost
- Cost advantage of fossil fuel over renewable has been decreasing
  - Fossil fuel cost are increasing
  - And renewables are decreasing
- A lot of uncertainty regarding future fuel prices

Closer look at Wind and Solar Costs



- The LCOE accounts for all lifetime costs of the system including operation, maintenance, construction, taxes, insurance, and other financial obligations of the project.

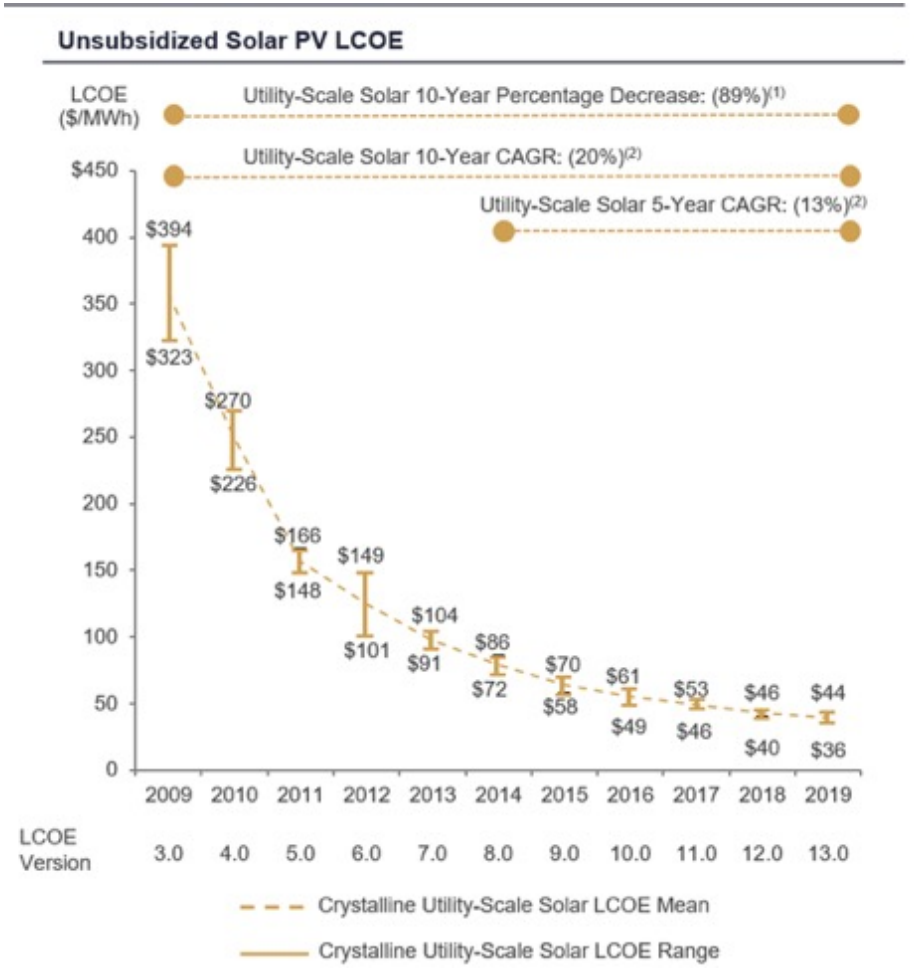
- According to Lazard's report in 2009 the levelized cost of electricity for wind ranged from 100 to 170 $/MWh and in 2019 from $28 to $54 – it's a 70% decrease in 10 years.

Source: https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf

Closer look at Wind and Solar Costs

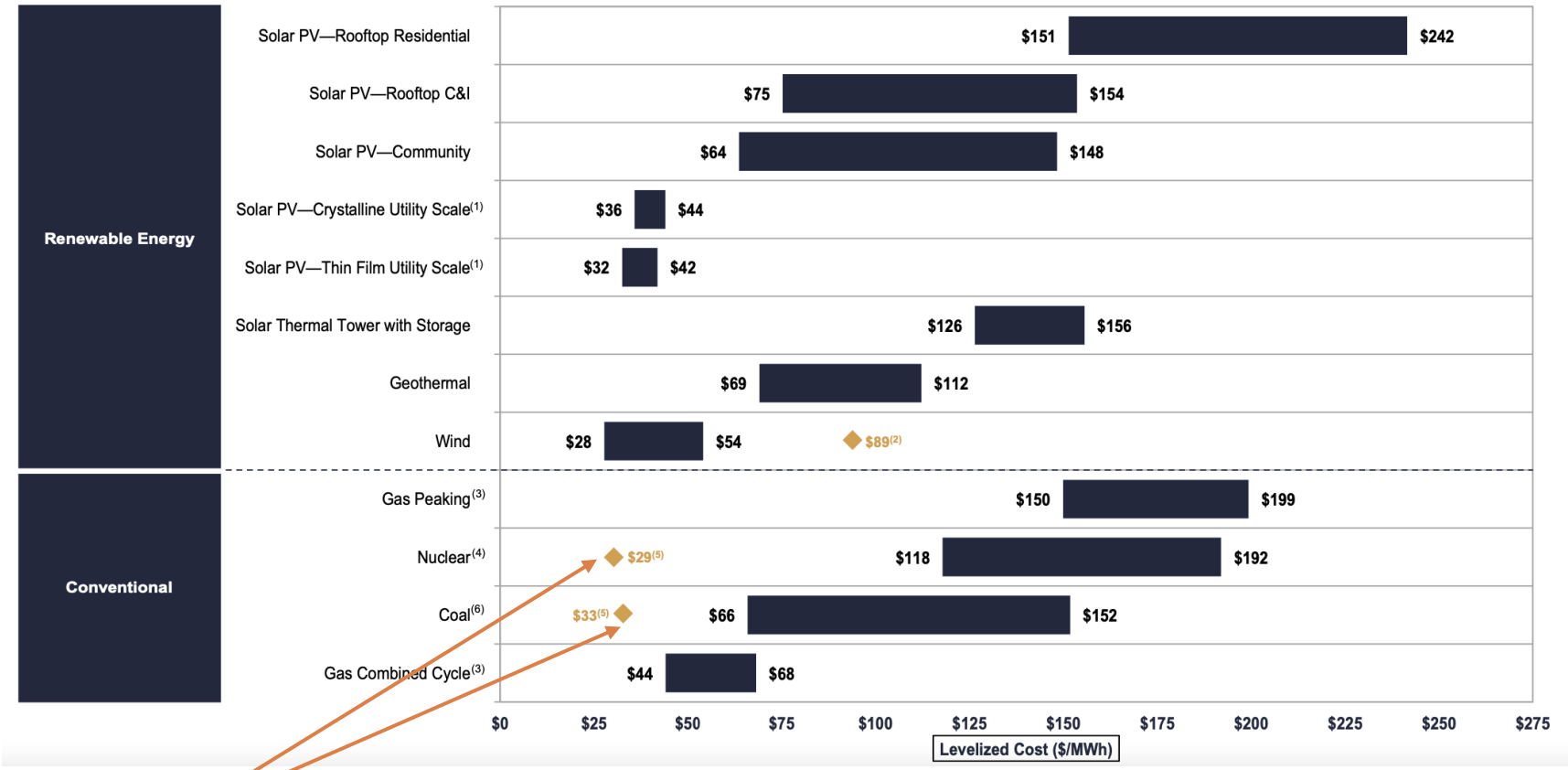
- Costs for utility-scale solar have been falling even more rapidly. In 2009 LCOE for utility scale solar PV ranged from 323 to 394 $/MWh and in 2019 36 to 44 $/MWh – a 89% decrease in 10 years

- The costs for wind & solar declined mainly due to
  - material declines in the pricing of system components (e.g., panels, inverters, racking, turbines, etc.)
  - improvements in efficiency



Source: https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf

LCOE comparison with other technologies



Marginal Cost

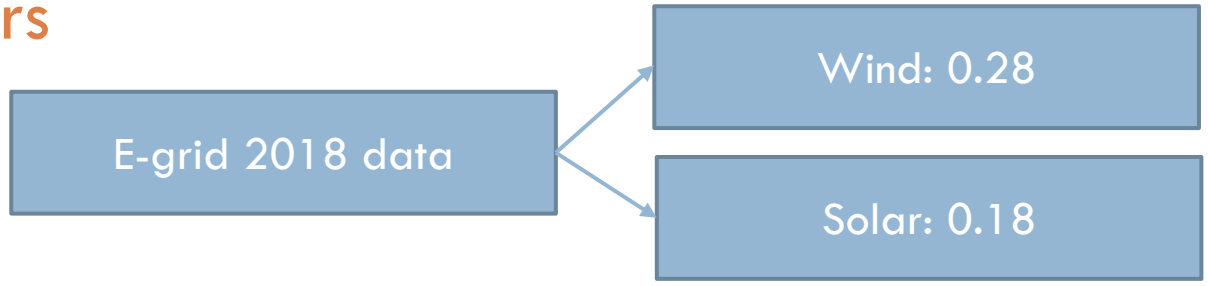
Utility scale solar and wind have on average lower LCOE's than nuclear, coal and natural gas.

Source: https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf

So the cost is down, what's the challenge now?

Renewable Energy Challenges

- Most renewable energy supplies cannot be matched to demand as easily as fossil fuel
  - Wind may not blow
  - Sun may not shine
  - Hydropower may not be available during drought
  - Biomass crop can experience crop failure
- Most renewable energy sources have low capacity factors



Matching supply and demand

- From Power Markets: supply must match demand EVERY moment

- Demand can be "predicted" and fossil fuel plant can be scheduled to start and stop at times of anticipated demand change
- Plants that start and stop quickly are held in as reserve
  - Mainly fossil fuels

Matching supply and demand

- Hydropower may be regulated to accommodate demand if reservoirs are adequate
- Biomass is similar to fossil fuels
- Geothermal is the most constant of renewable sources and can be started and stopped on demand
- Renewable sources such as wind and solar do not have this characteristic

How do we deal with energy source intermittency?

Energy Source Intermittency

- One approach: energy diversity
  - e.g. solar is strongest in summer while in most places wind is strong in winter
  - Combination of the two can provide more consistent year-round generation

Energy Source Intermittency

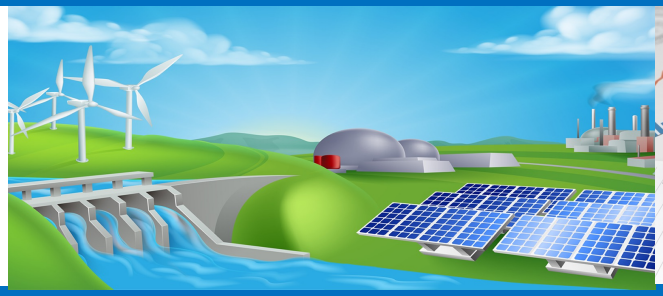
- Other approach: store electricity
  - solar + batteries
  - On-premise battery storage
  - Cost of delivery would be cost of production plus the cost of battery storage
  - On a grid scale could also use pumped water storage
    - Water is pumped from a lower to a higher reservoir
    - When electricity is needed water is allowed to flow back down

Energy Source Intermittency

- Other approaches
  - Energy source redundancy
    - building excess generation capacity
  - Robust national electric grid
    - The grid can take energy from where it is generated to where it is needed

Additional Challenges to Energy Source Intermittency

- Marginal cost will clearly vary depending on ambient conditions
  - At times of low water, wind and solar, marginal cost of energy will be very high
- Variable pricing implemented with smart meters could charge consumers a higher price at times when supply is limited
- Customers could make choices to limit electricity use
  - Program appliances to operate only at certain price points
  - e.g. water heater could operate only in low-price time periods, insulated tank can hold hot water for hours




THANK YOU !

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