ANALYZING A CLEAN ENERGY FUTURE

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Overview

- Climate Context – why energy and electricity matter in the fight against climate change
- Renewable Energy Technologies
- Challenges Facing Renewables
- Local, State, and Federal Actions

Beyond analyzing only costs, you must consider other factors contributing to a technology's success.

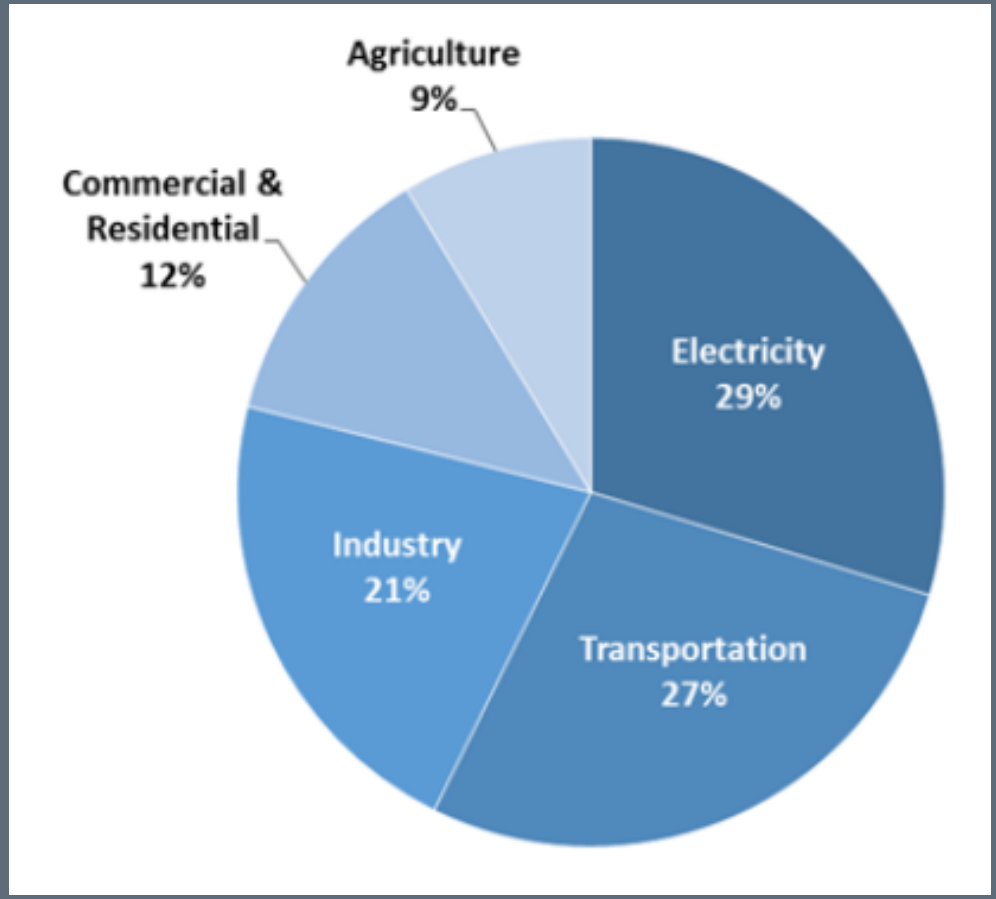
ENERGY & CLIMATE

Paris Commitments and Progress, as of 2015

Table 1. 2020 greenhouse gas reduction targets of the ten largest emitters (based on 2015 emissions) and IEA member countries[1]

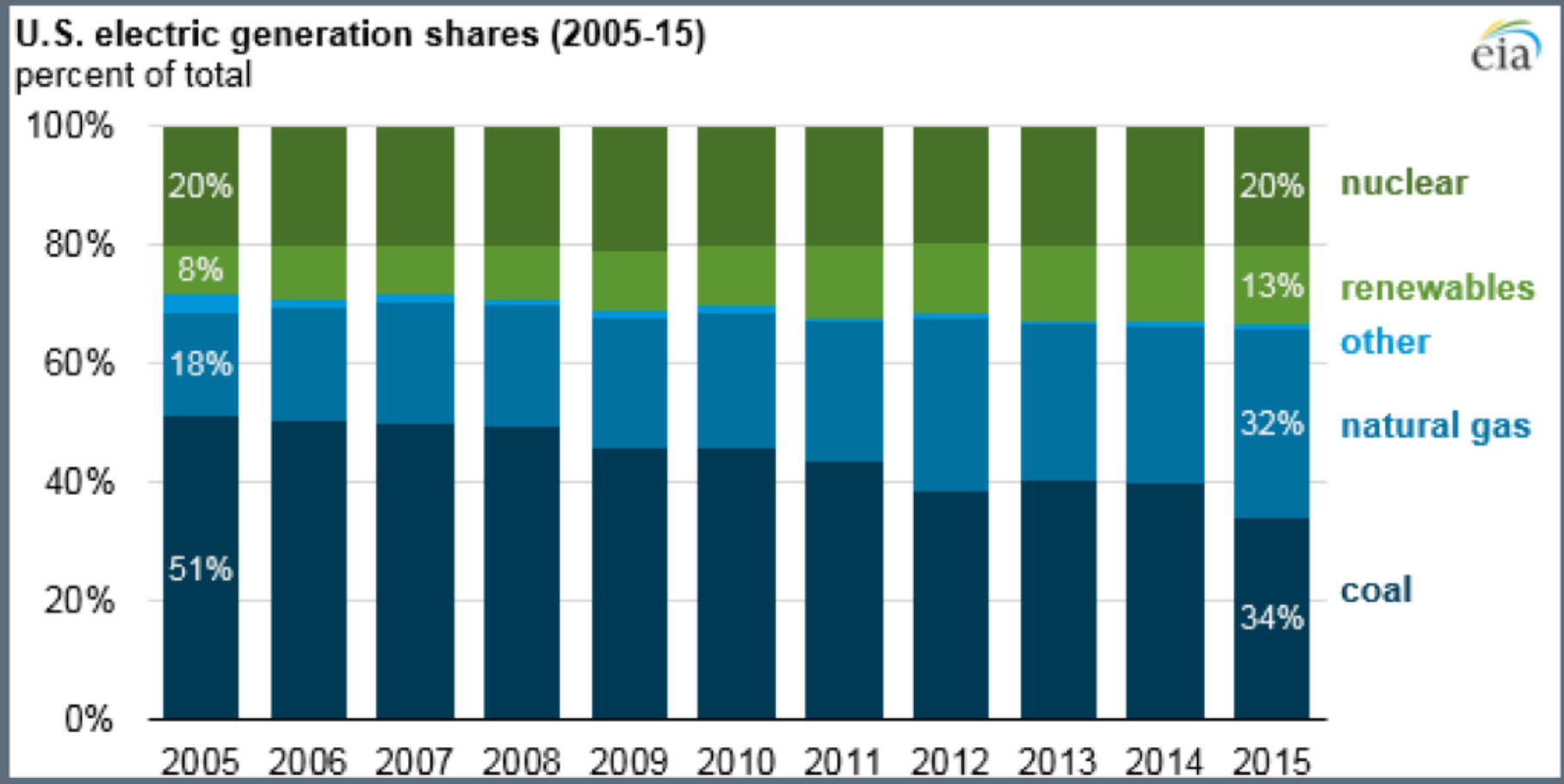
Ten highest emitting Parties (as per IEA estimates of CO_2 emissions from fuel combustion in 2015)							
	1990	2005	2015	2020 GHG target	base year level	2015 level	change %
	$MtCO_2$						
China (incl. Hong Kong, China)	2 109	5 399	9 084	Reduce CO_2 emissions per unit of GDP by 40-45% below 2005 levels.	0.72 $kgCO_2$ / 2010 USD PPP	0.49 $kgCO_2$ / 2010 USD PPP	-32%
United States[2]	4 802	5 702	4 998	In the range of a 17% emission reduction compared with 2005	5 702 Mt	4 997 Mt	-12%
European Union	4 028	3 921	3 201	20% averaged 2013-2020 reduction compared with 1990 under the Kyoto Protocol; 20% reduction in 2020.	4 028 Mt	3 160 Mt	-21%
India	530	1 080	2 066	Reduce the emissions intensity of GDP by 20-25% below 2005 levels.	0.30$kgCO_2$ / 2010 USD PPP	0.28 $kgCO_2$ / 2010 USD PPP	-6%
Russian Federation	2 163	1 482	1 469	15-25% below 1990.	2 16 Mt	1 469 Mt	-32%
Japan	1 042	1 178	1 142	3.8% below 2005.	1 18 Mt	1 142 Mt	-3%

Total US GHG Emissions by Sector in 2015



(EPA)

US Electricity Generation



(EIA)

The Carbon Content of Combustion

- Natural Gas – 0.502 kg CO_2/kWh
- Oil – 0.650 kg CO_2/kWh
- Coal – 0.987 kg CO_2/kWh
- All Others – 0 kg CO_2/kWh

EIA Wind Levelized Generating Costs, Annual Energy Outlook 2010 – 2017

Beyond combustion…

Different technologies vary in their use of land and natural resources and how they may impact the nearby environment

Chart 1: Land Use by Electricity Source in Acres/MW Produced

Electricity Source	Acres per Megawatt Produced
Coal	12.21
Natural Gas	12.41
Nuclear	12.71
Solar	43.50
Wind	70.64
Hydro	315.22

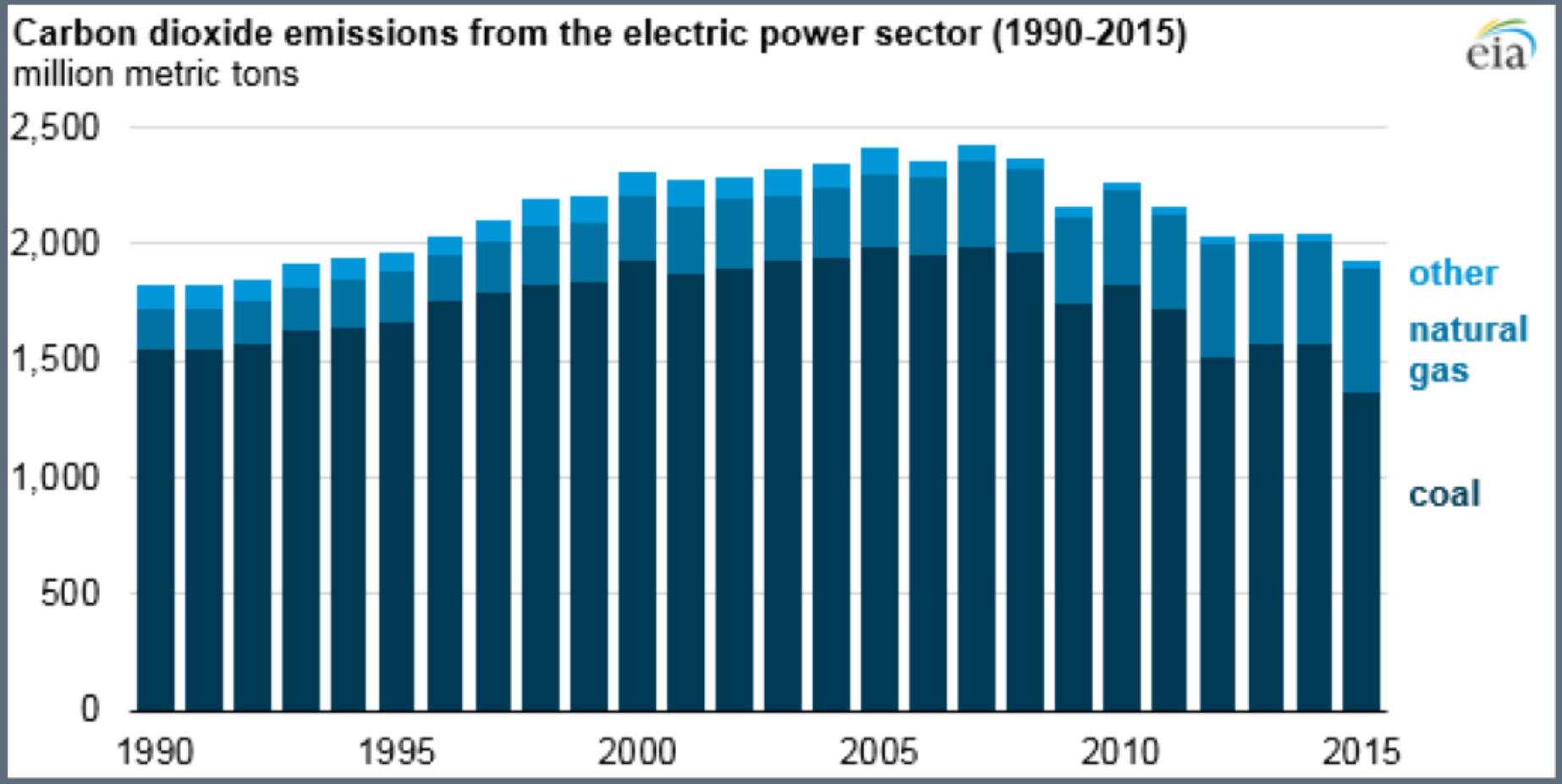
Life-Cycle Analysis of Carbon Content of Energy Generation Technologies

- Coal – 820 g CO_2/kWh
- NG – 490 g CO_2/kWh
- Solar PV – 48 g CO_2/kWh
- Geothermal – 38 g CO_2/kWh
- Hydropower – 24 g CO_2/kWh
- Nuclear – 12 g CO_2/kWh
- Wind – 11 g CO_2/kWh

Includes albedo effect (reflection into atmosphere), resource extraction, land conversion, construction materials, waste, etc.

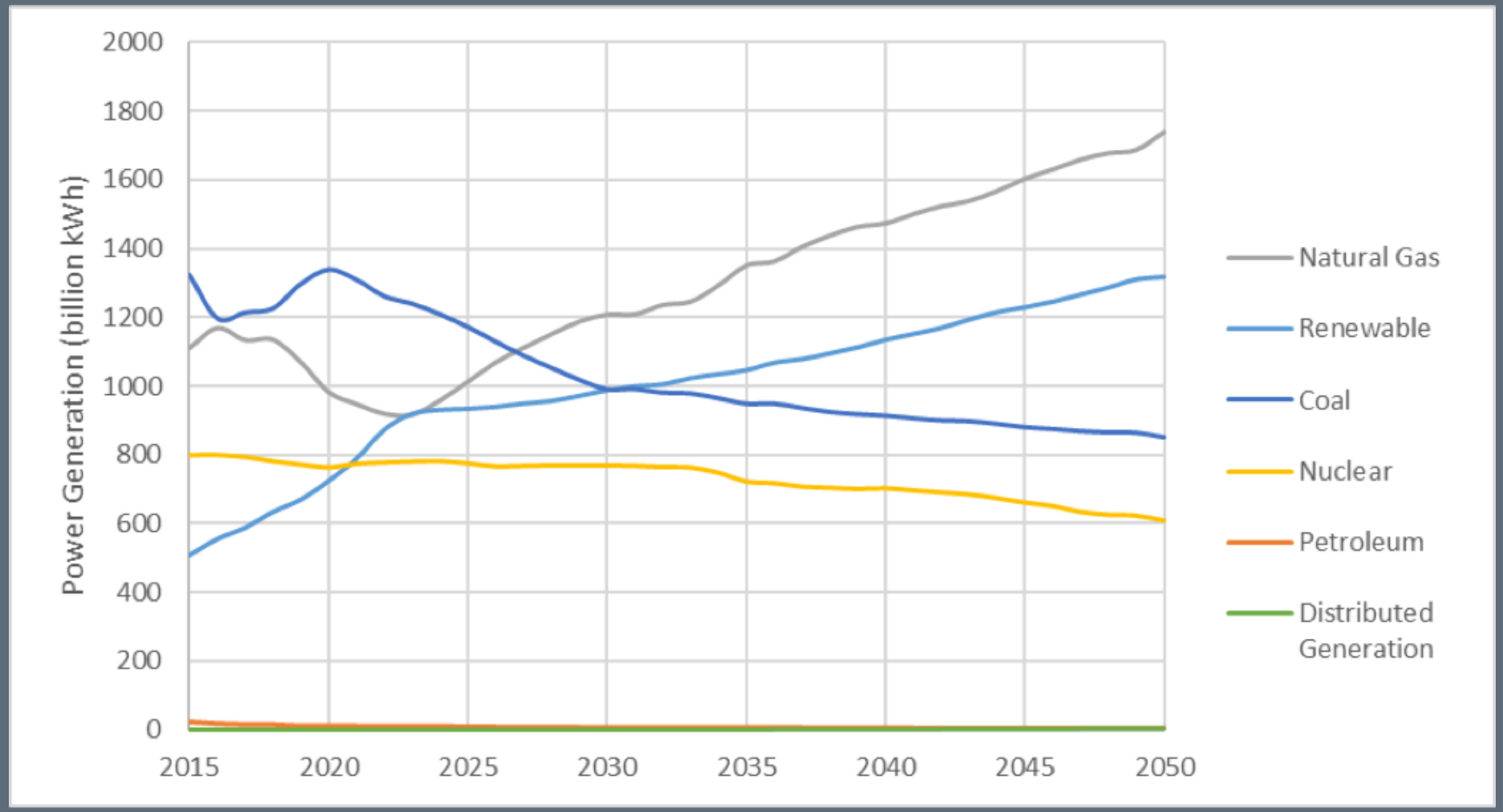
2014 IPCC, “Global Warming Potential of selected electricity sources”

CO_2 Emissions for US Electricity Generation



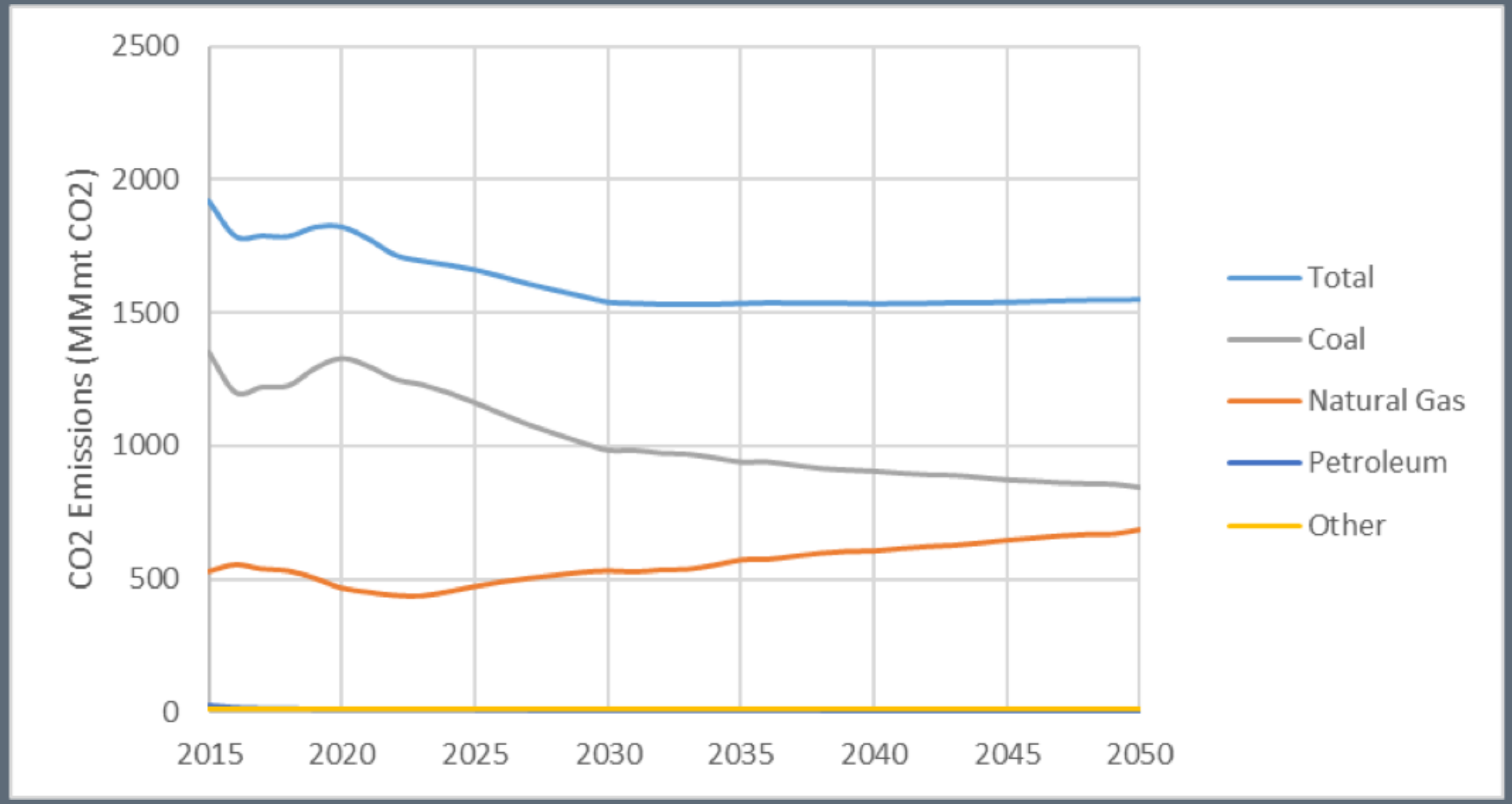
(EIA)

Projected Power Generation Shares



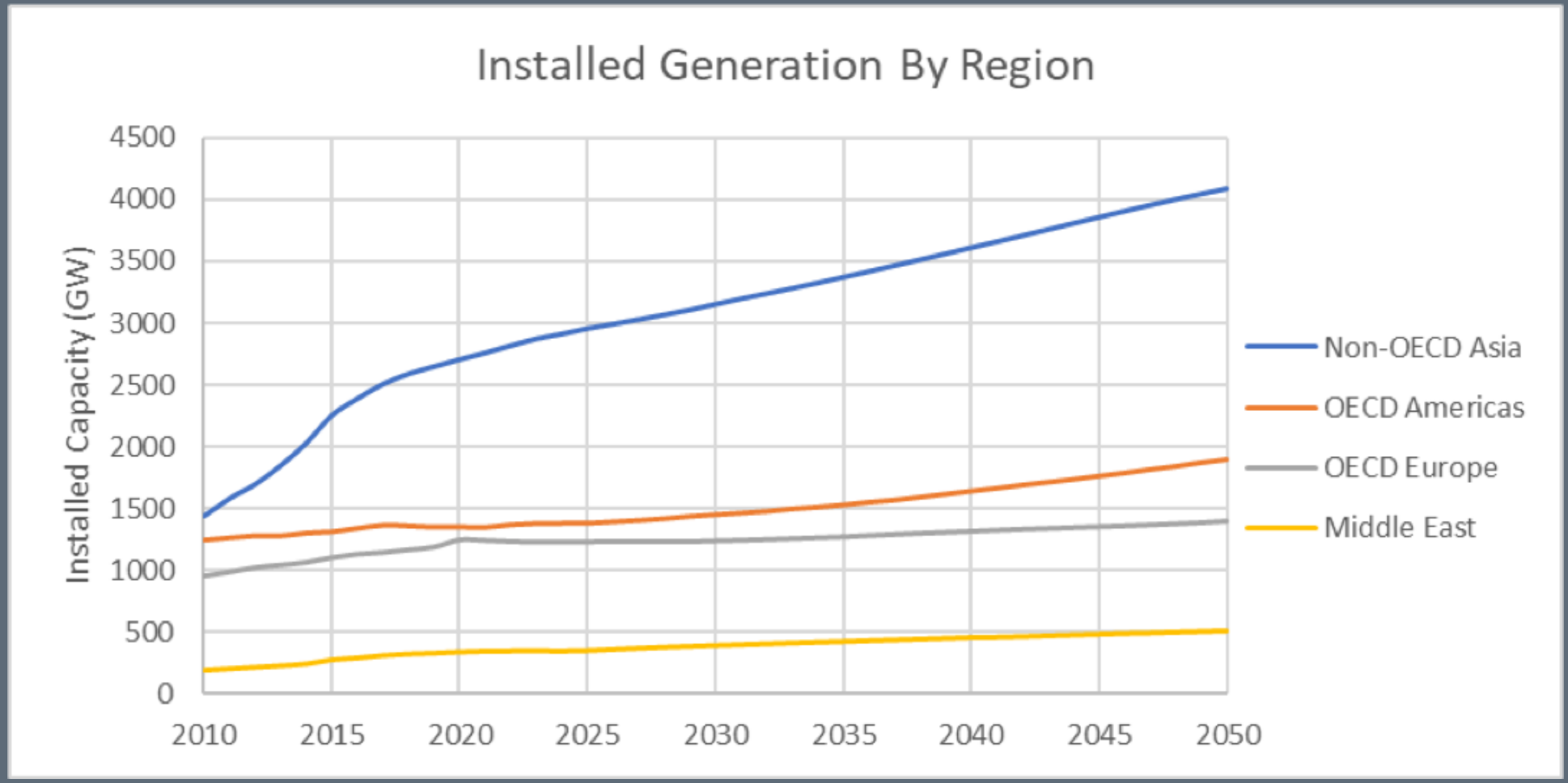
(AEO2017)

Projected US CO_2 Emission Shares



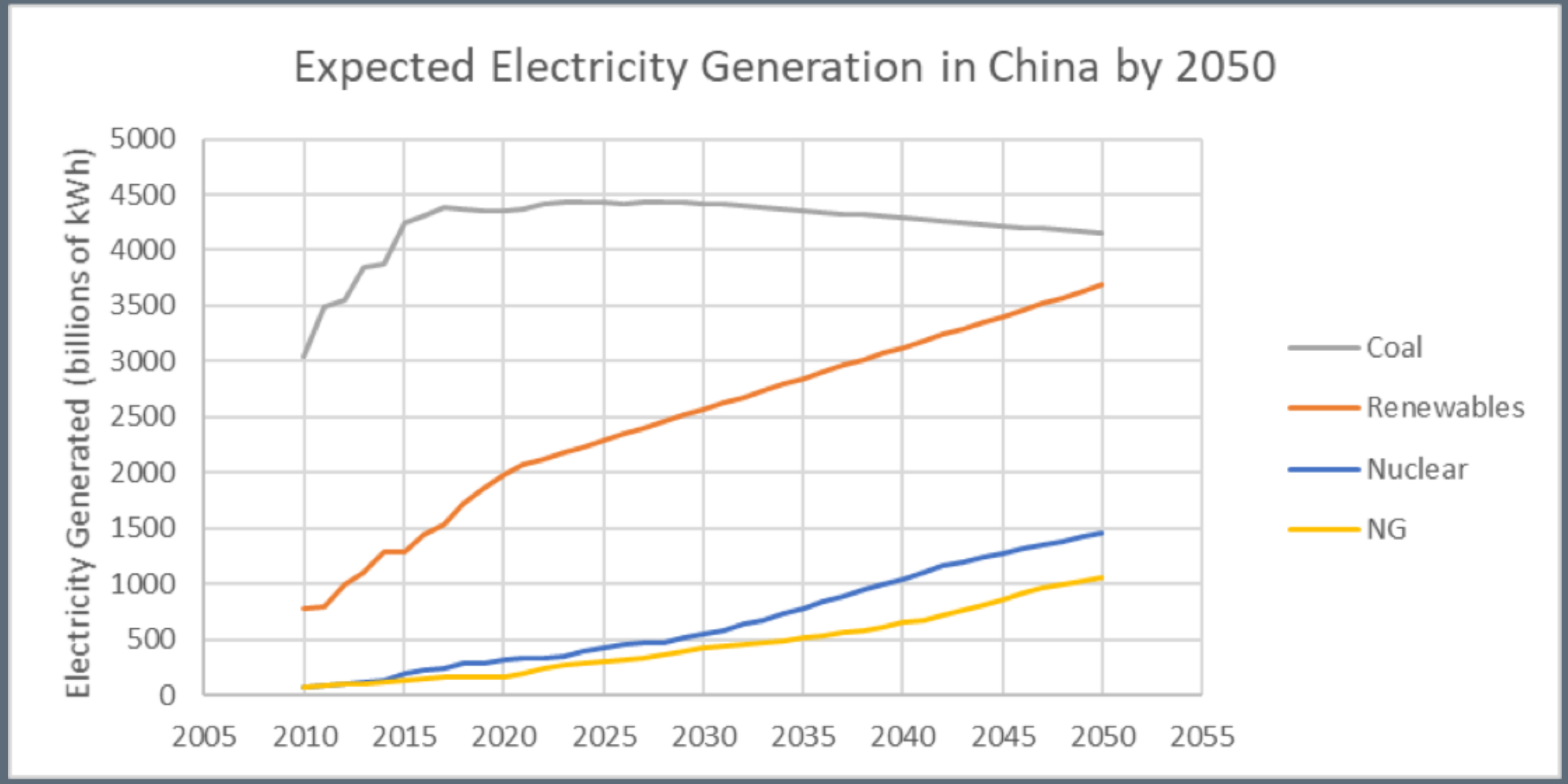
(AEO2017)

Projected International Generation



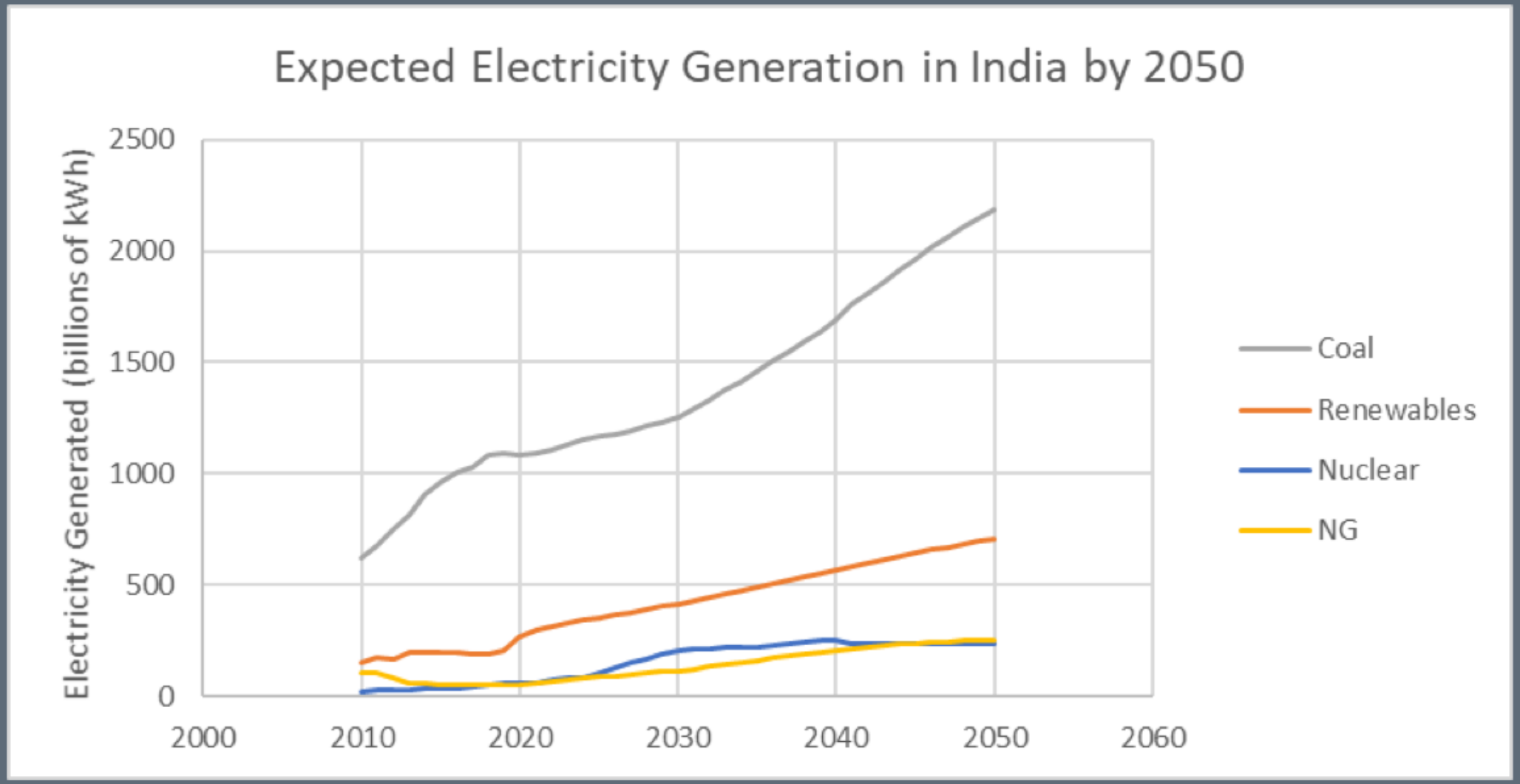
(International Energy Projections 2017)

China Electricity Generation through 2050



(International Energy Projections 2017)

India Electricity Generation through 2050



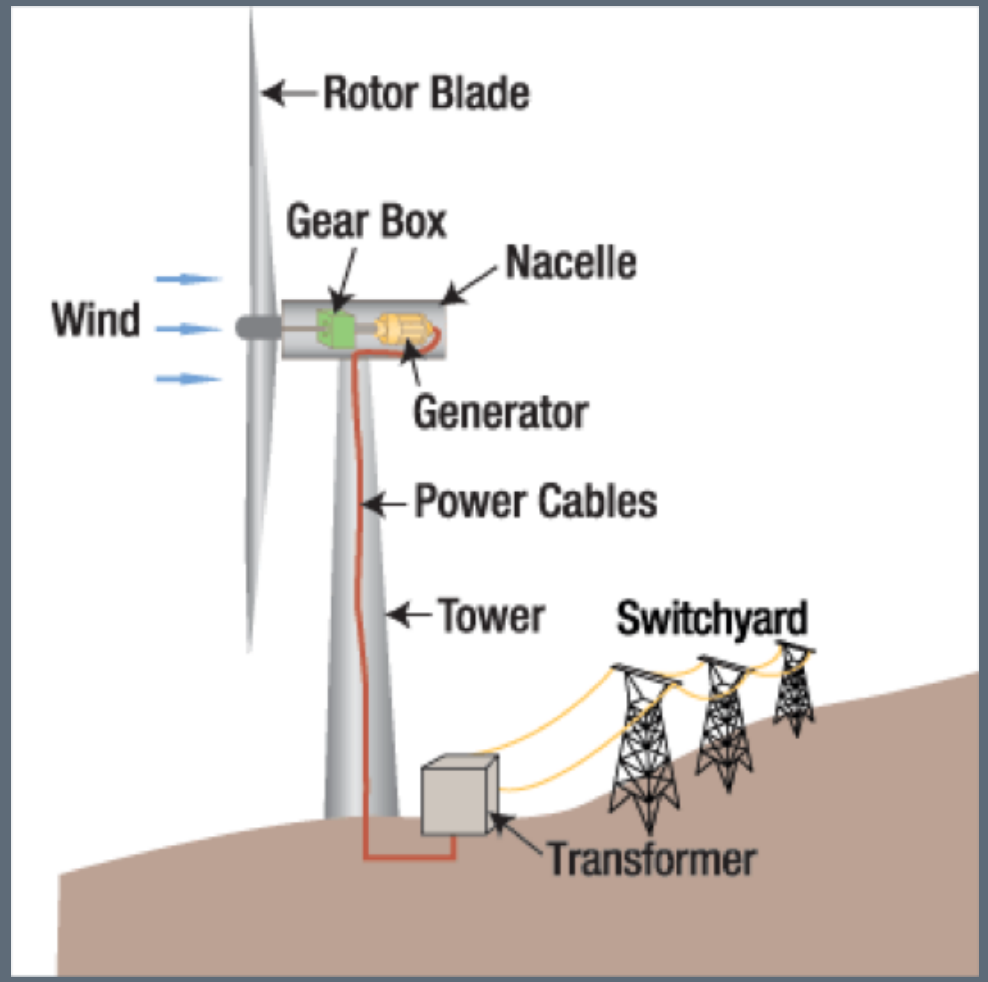
(International Energy Projections 2017)

Energy & Climate

- Possible solutions to reducing CO_2:
  - *Energy efficiency improvements*
    - Can reduce energy use and emissions per capita
  - *Decoupling energy and emissions*
    - Create energy without emissions
  - *Reverse emissions – biomass, CCS*

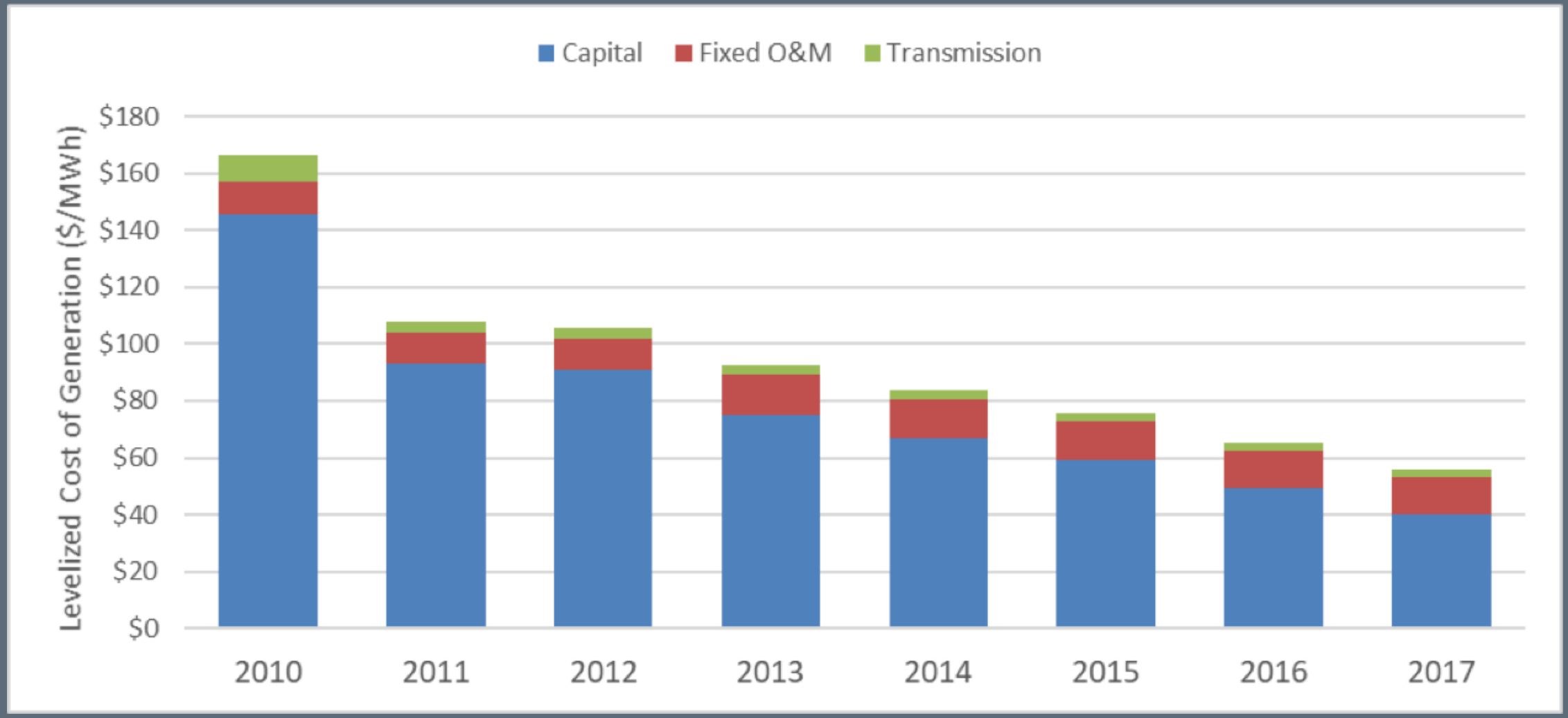
RENEWABLES

Wind Power



Energy Informative

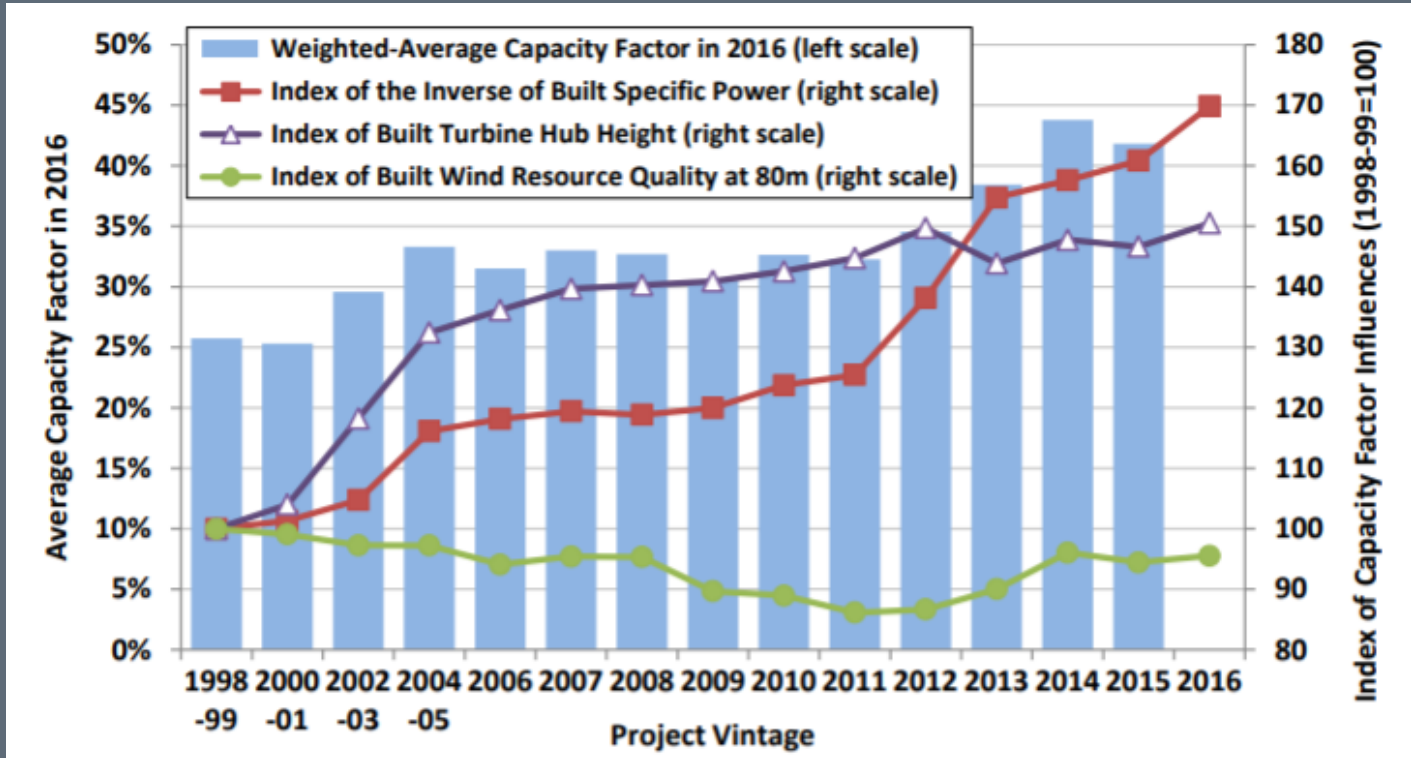
Wind has become cheaper…



EIA Wind Levelized Generating Costs, Annual Energy Outlook 2010 – 2017

Wind's increasing performance

Since 1998, nameplate capacity, hub height, and rotor diameter have all increased

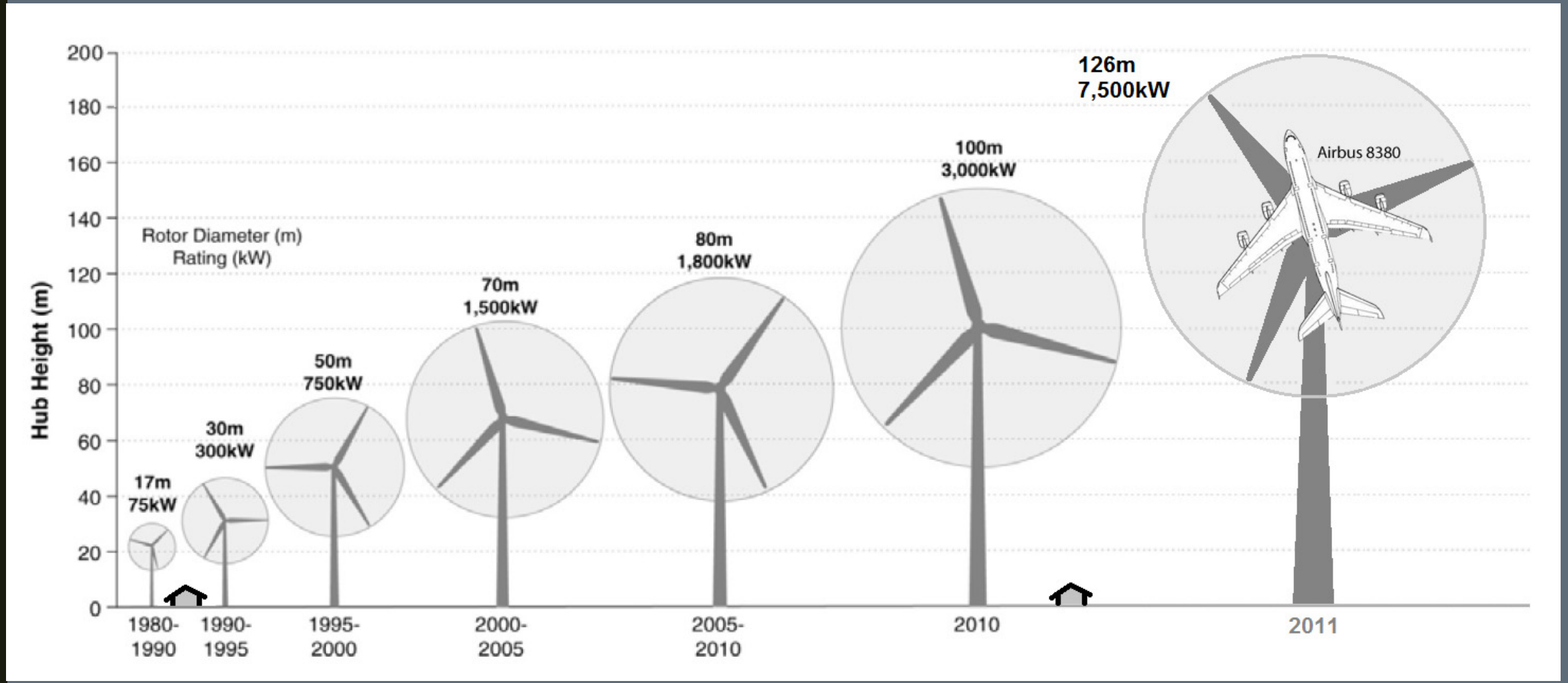


Note: In order to have all three indices be directionally consistent with their influence on capacity factor, this figure indexes the inverse of specific power (i.e., a decline in specific power causes the index to increase rather than decrease).

Source: Berkeley Lab

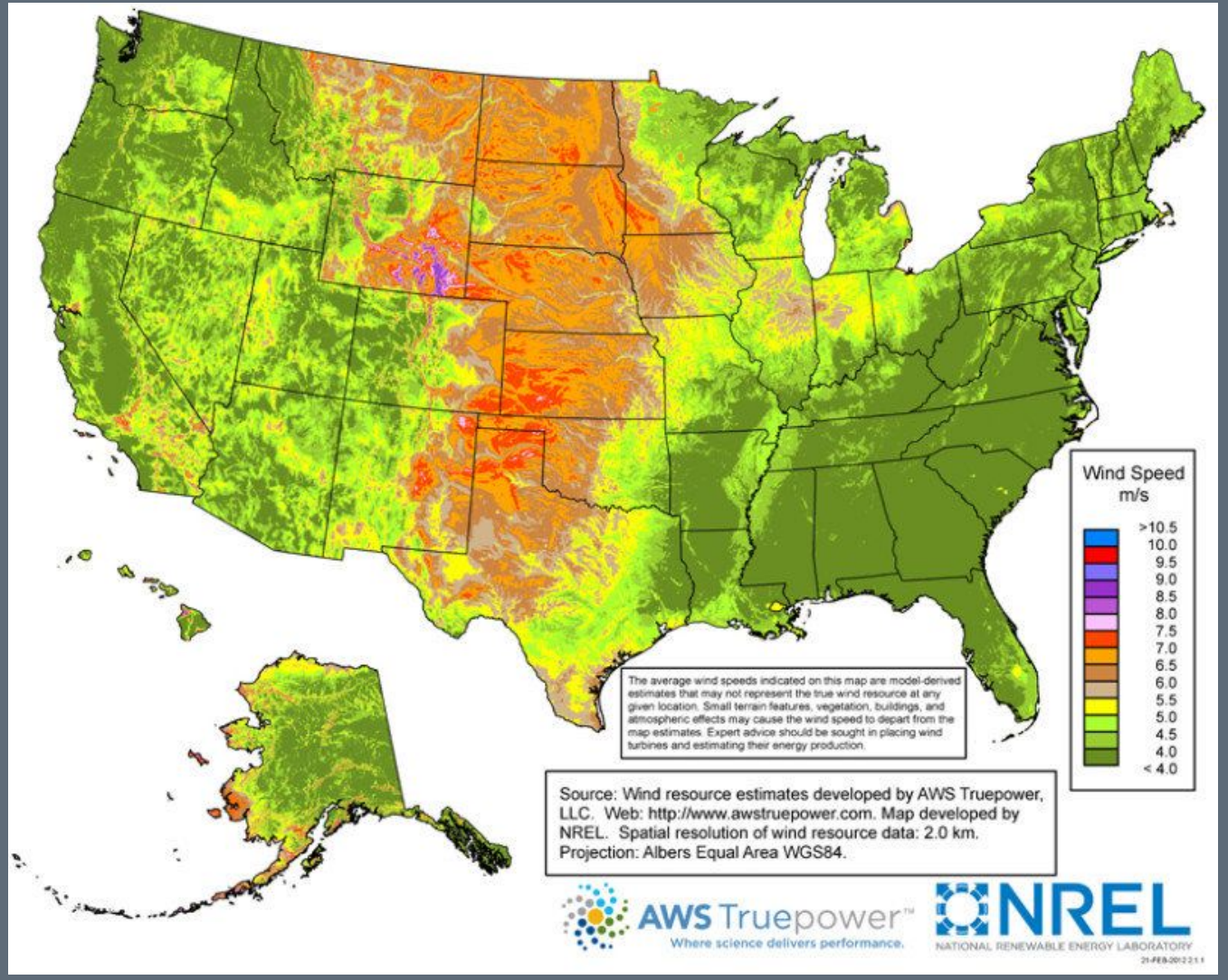
Figure 34. 2016 capacity factors and various drivers by project vintage

Wind's increasing performance

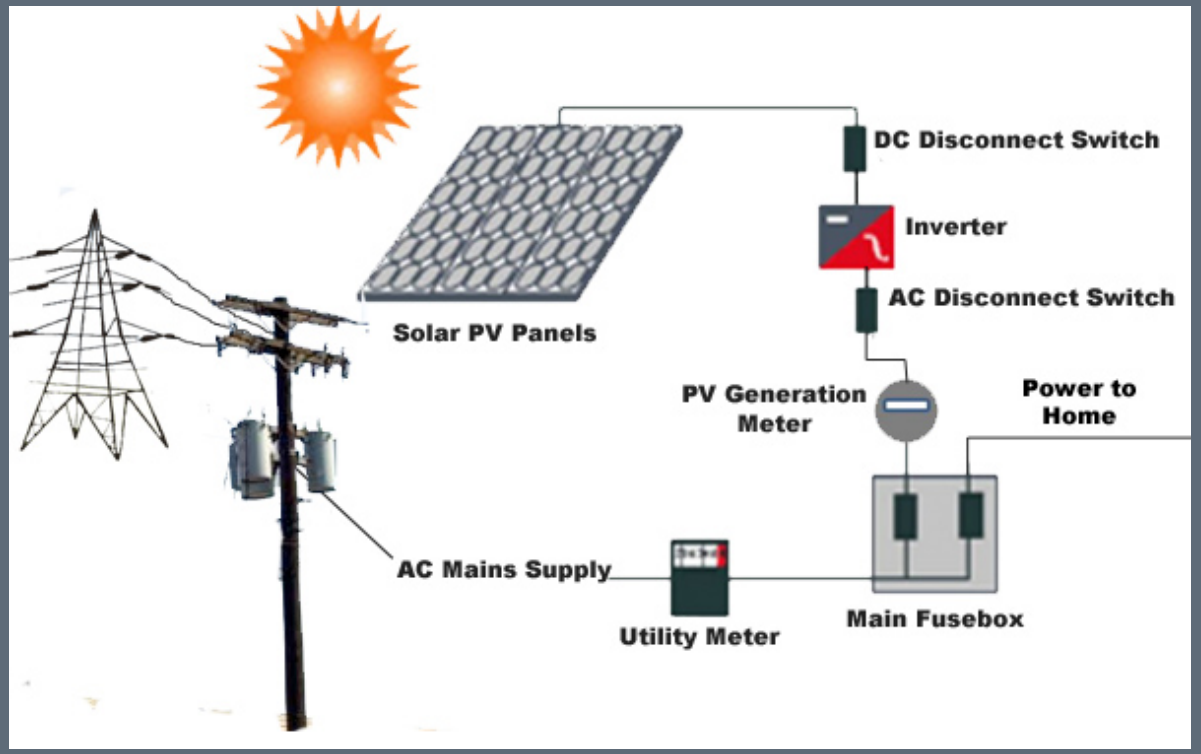


Wind's increasing performance

- Technological advancements have accompanied lower costs
- Better turbines have allowed for turbine placement in lower wind speed sites.

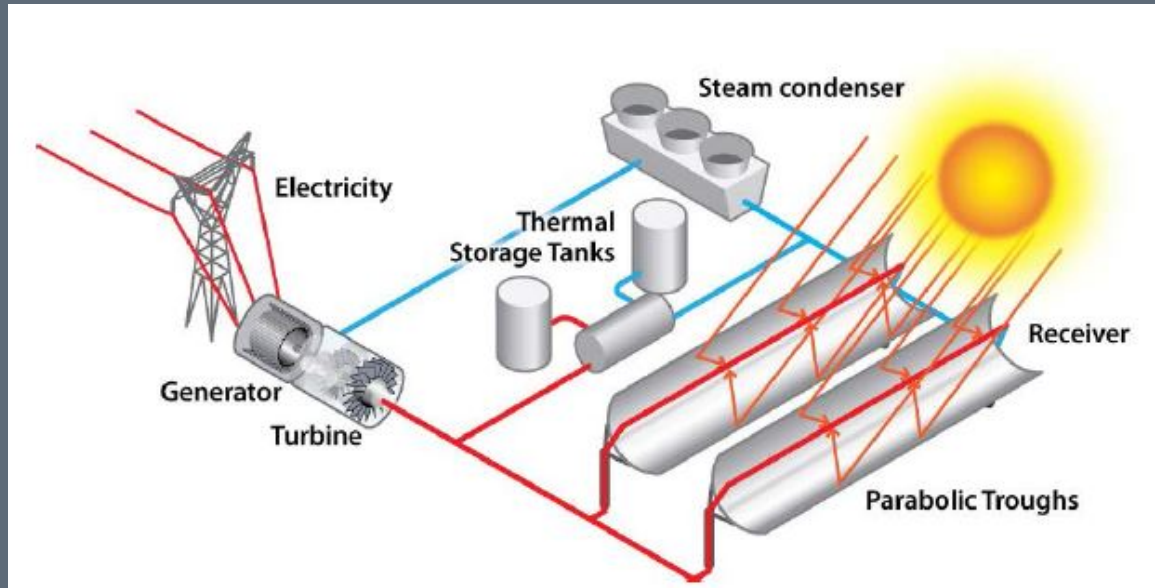


Solar Power



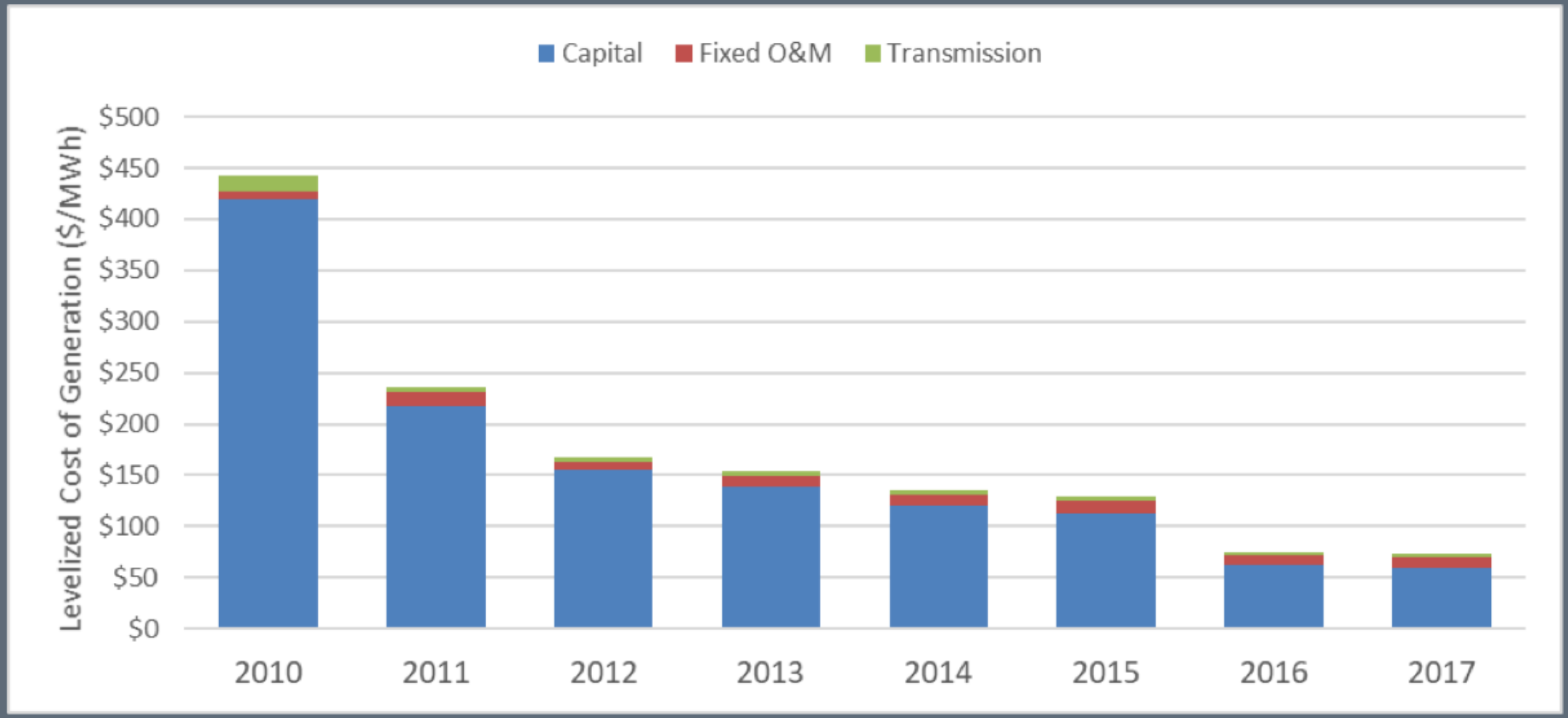
Solar PV

Concentrated Solar Power (CSP)



Energy Informative

Solar has become cheaper...



EIA Wind Levelized Generating Costs, Annual Energy Outlook 2010 – 2017

Both soft and hard costs decline.

- Installation Costs have decreased from approximately $6.5/W to $3/W from 2007 to 2015.
- Module prices have decreased significantly due to differences in supply and demand

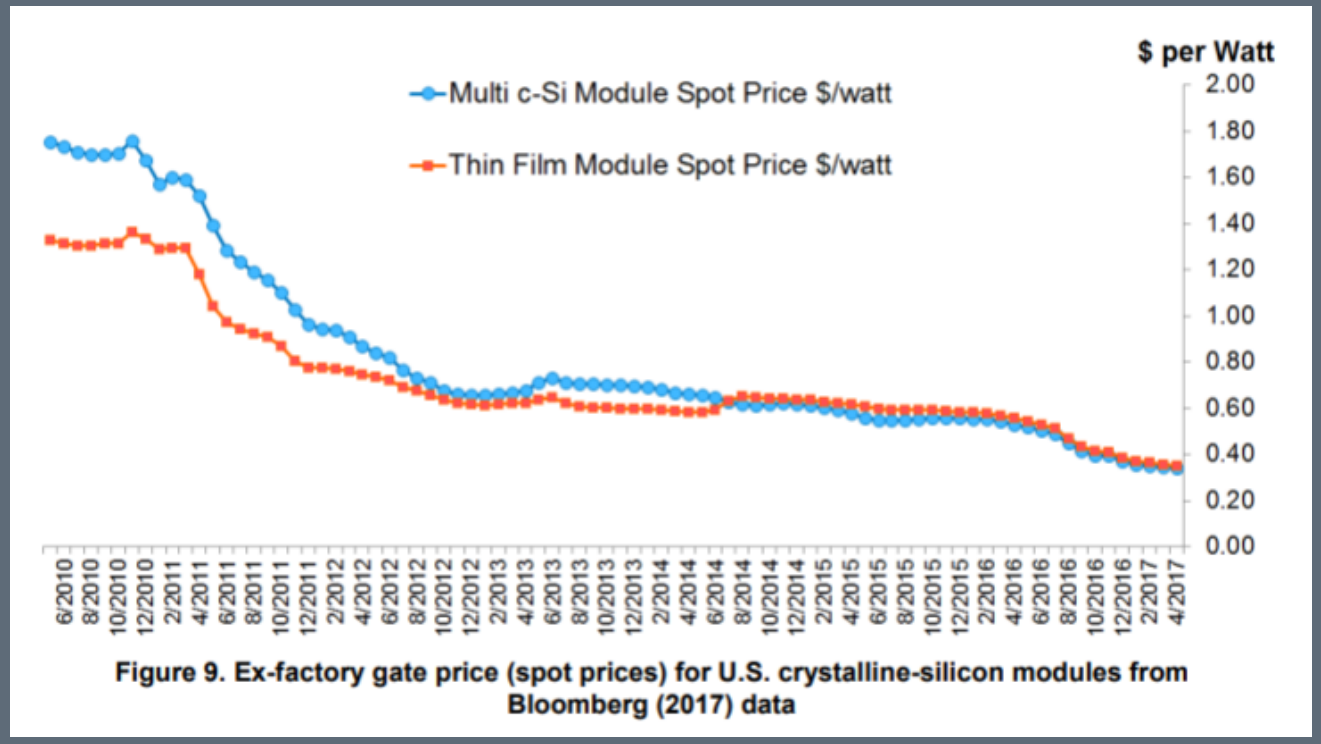
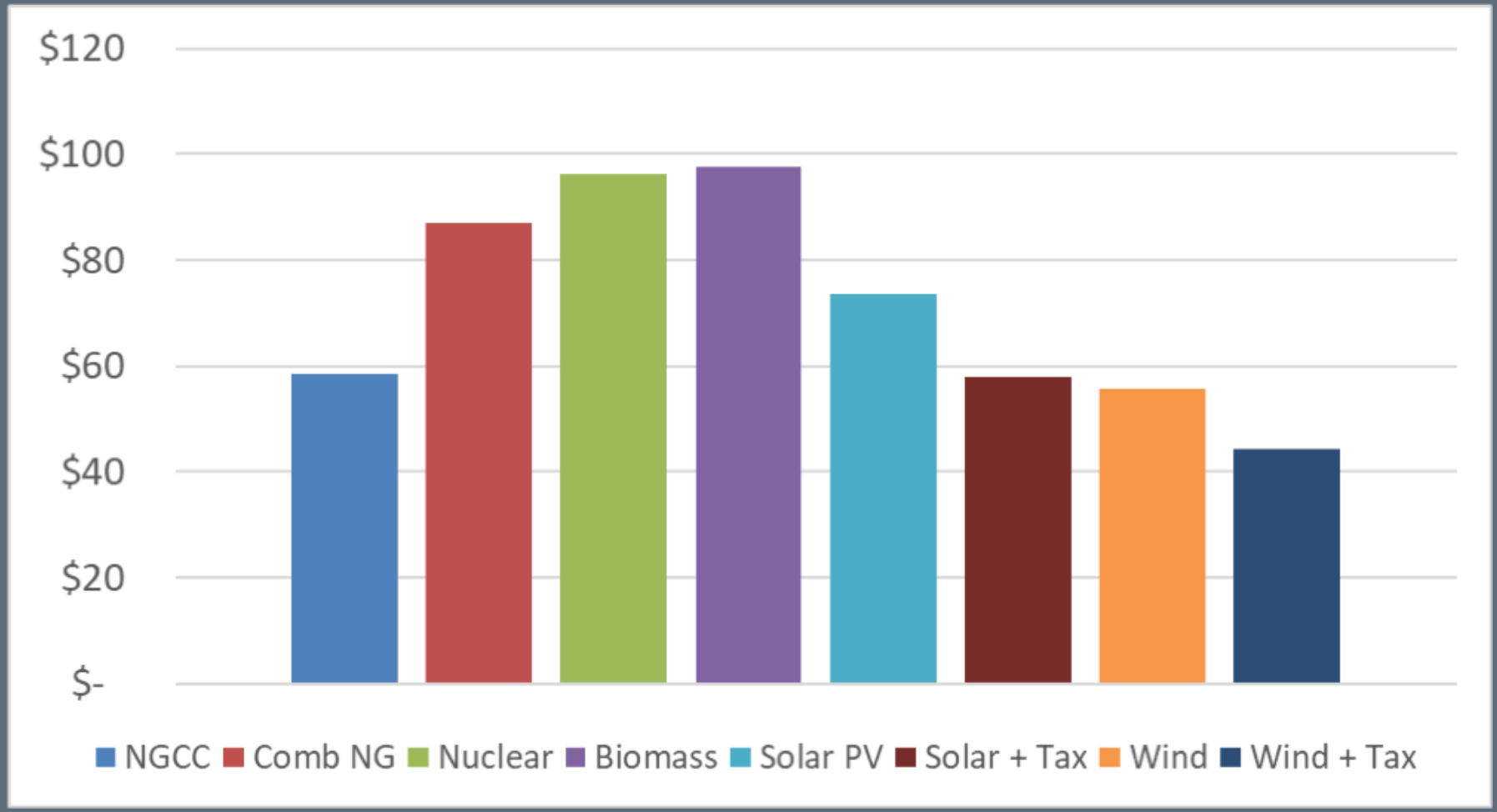


Figure 9. Ex-factory gate price (spot prices) for U.S. crystalline-silicon modules from Bloomberg (2017) data

Potential Future Changes

- Extremely cheap Chinese imports have priced out producers of solar panels in the United States, EU, and India
- Chinese producers received subsidies from the Chinese government of 15% for solar panel production
- US responded with tariffs ~15%, but US-based producers are asking Trump for a 35% tariffs
  - *He will decide January 26.*
- This will likely double the cost of solar panels

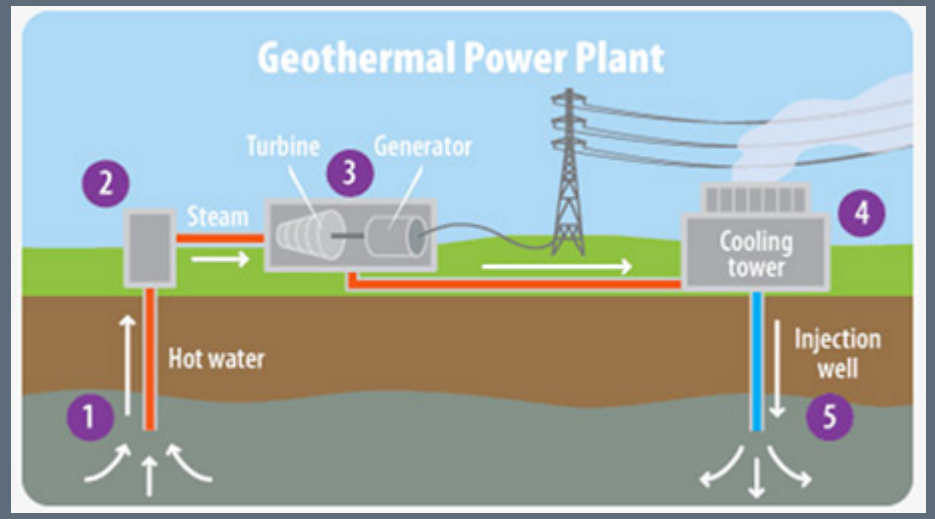
Solar and Wind are competitive with other technologies, even without tax incentives

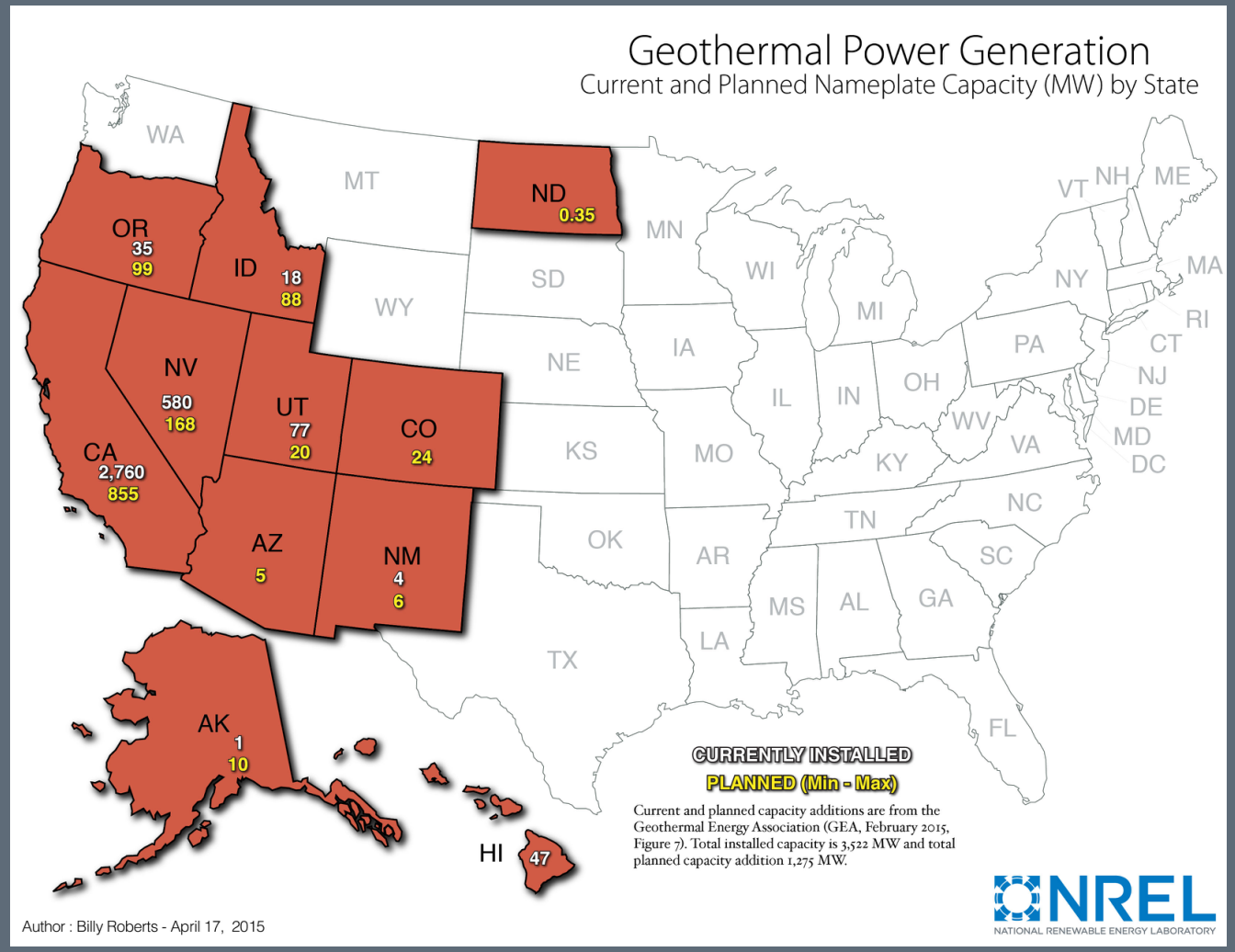


EIA Electricity Data, 2017

Geothermal Power Generation

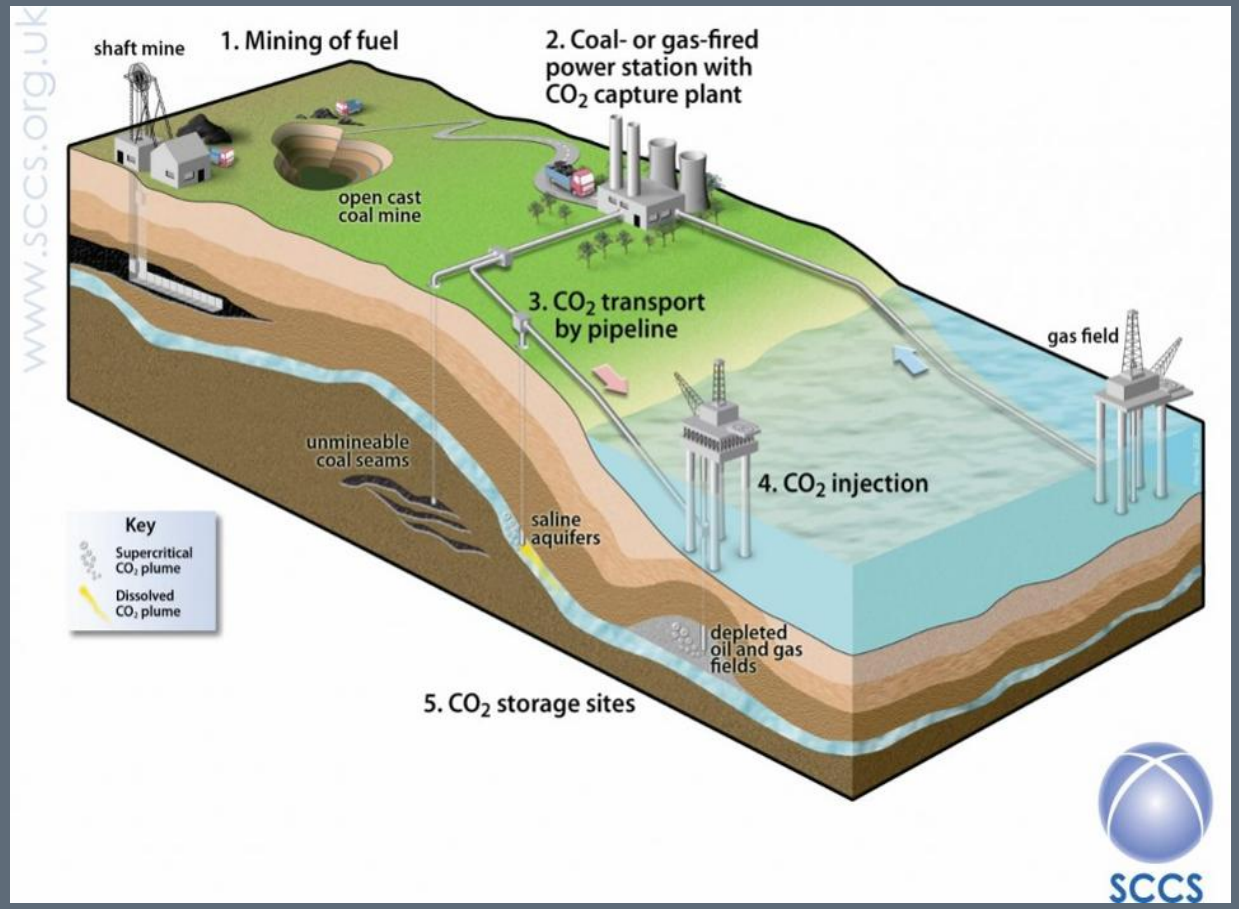
- 64 powerplants across the Western United States
- Generated 2,700 MW of power
- Dispatchable





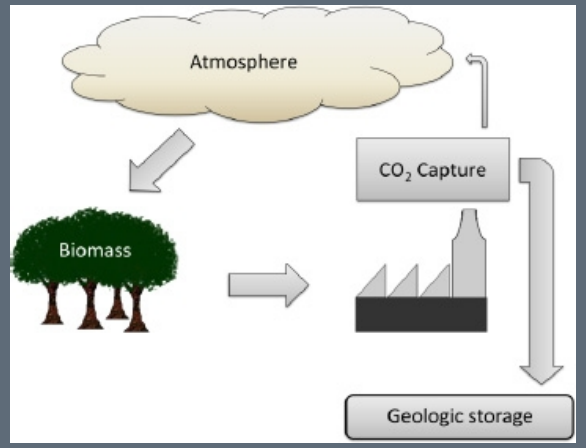
Carbon Capture and Storage

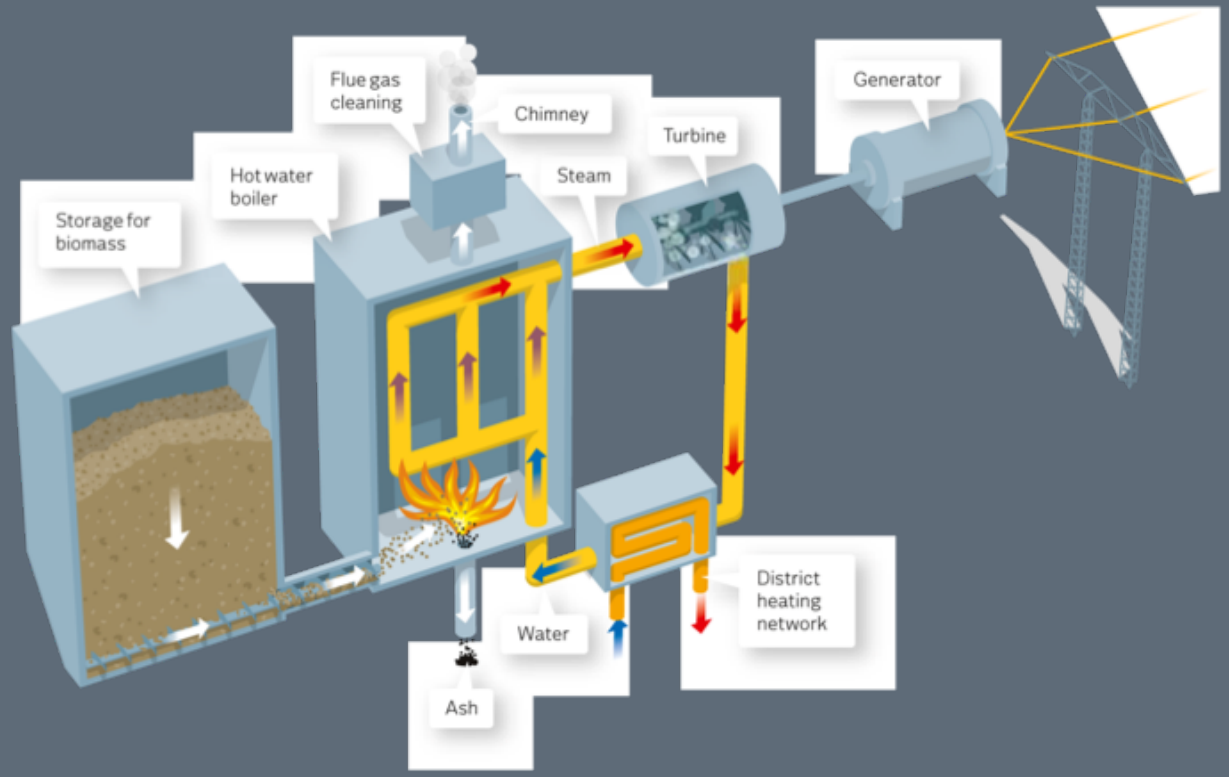
- Technology still in pilot/early stages of development
- Would allow for the capture of up to 90% of emissions from coal or natural gas powerplants
- Stores CO_2 permanently underground
- Would allow for some continued use of fossil fuels, possibly a bridging technology
- Currently 60-100% more expensive than fossil fuel plant.



Biomass Power Generation

- Produces power from combusting biowaste, including wood chips, waste, and scrap
- Carbon neutral – the emissions from burning the waste were collected over its lifetime.
- Combined with CCS – carbon-negative

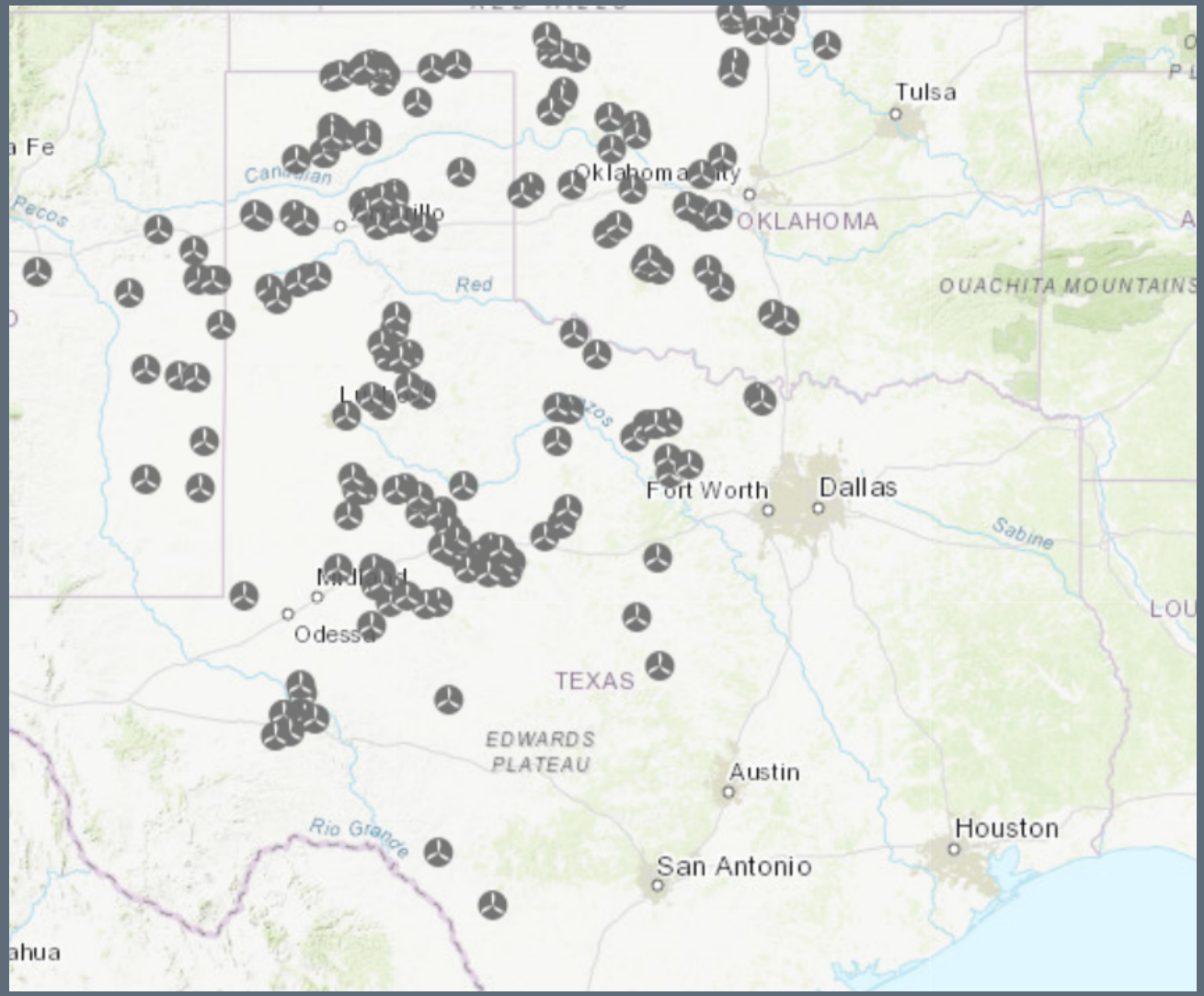




FUTURE CHALLENGES FOR RENEWABLES

Challenges facing Renewable Sources

- The locations of significant resources are sometimes far from load centers
- This requires large amounts of transmission lines
- If there is too much power on transmission lines, the powerplant must stop producing power



Challenges facing Renewable Sources

- This leads to curtailment (shutdown) of renewables
  - *This has decreased with transmission line upgrades (17% in 2009 to 1.6% in 2016)*

California invested heavily in solar power. Now there's so much that other states are sometimes paid to take it

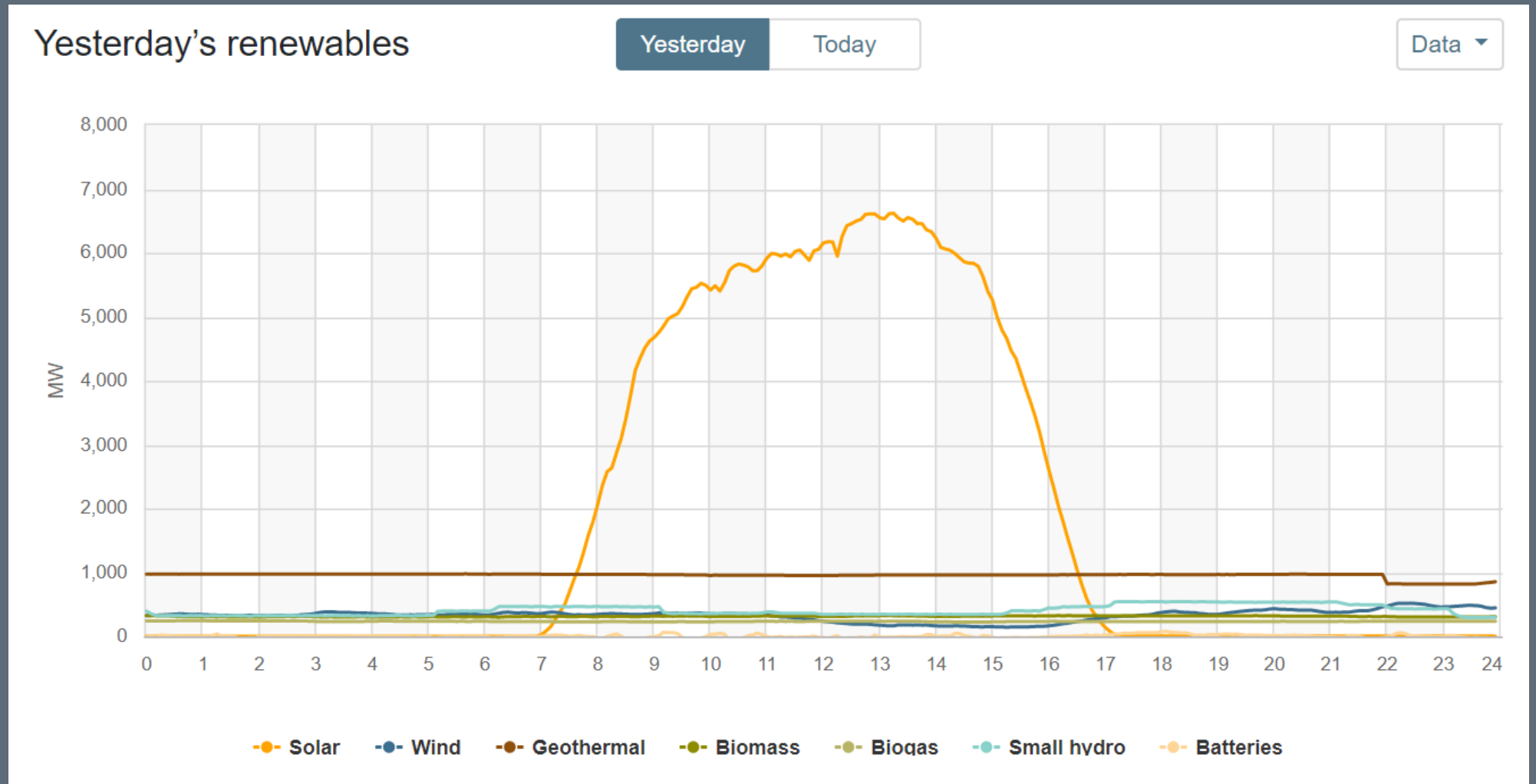
Midwest wind farms follow in the wake of new transmission lines

Huge Transmission Line Will Send Oklahoma Wind Power to Tennessee

High-voltage, direct-current lines could become the backbone of a U.S. supergrid

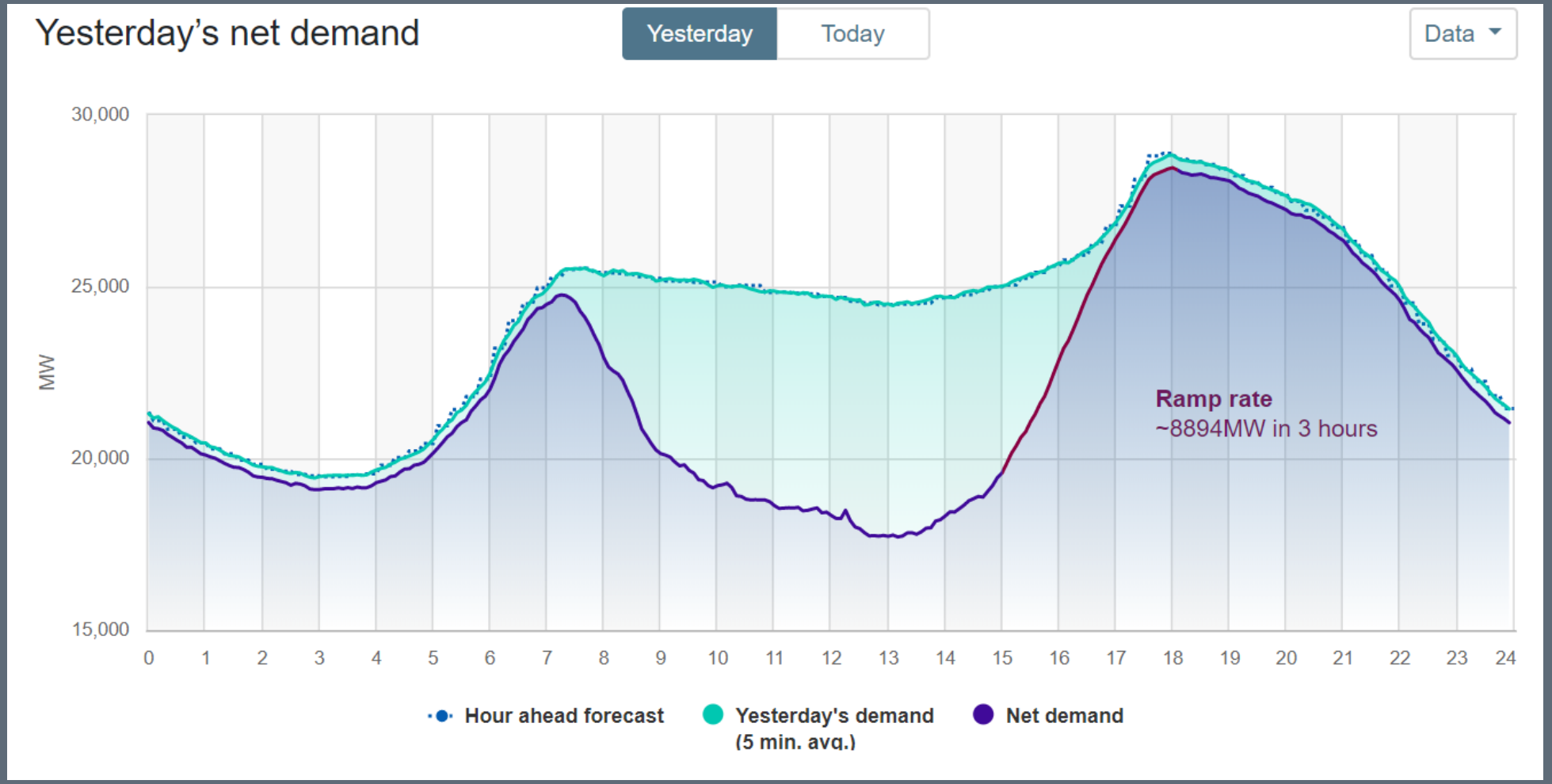
Challenges facing Renewable Sources

Excess Generation of Solar in Times of Low Demand

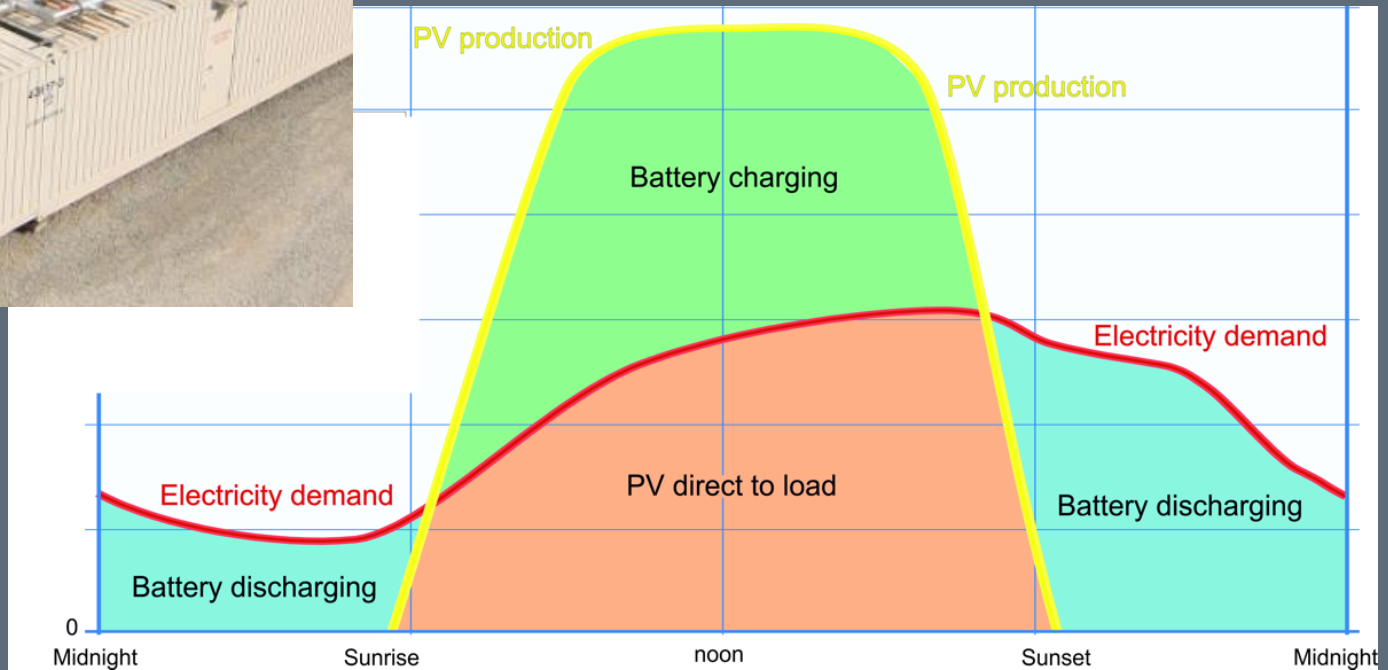


Challenges facing Renewable Sources

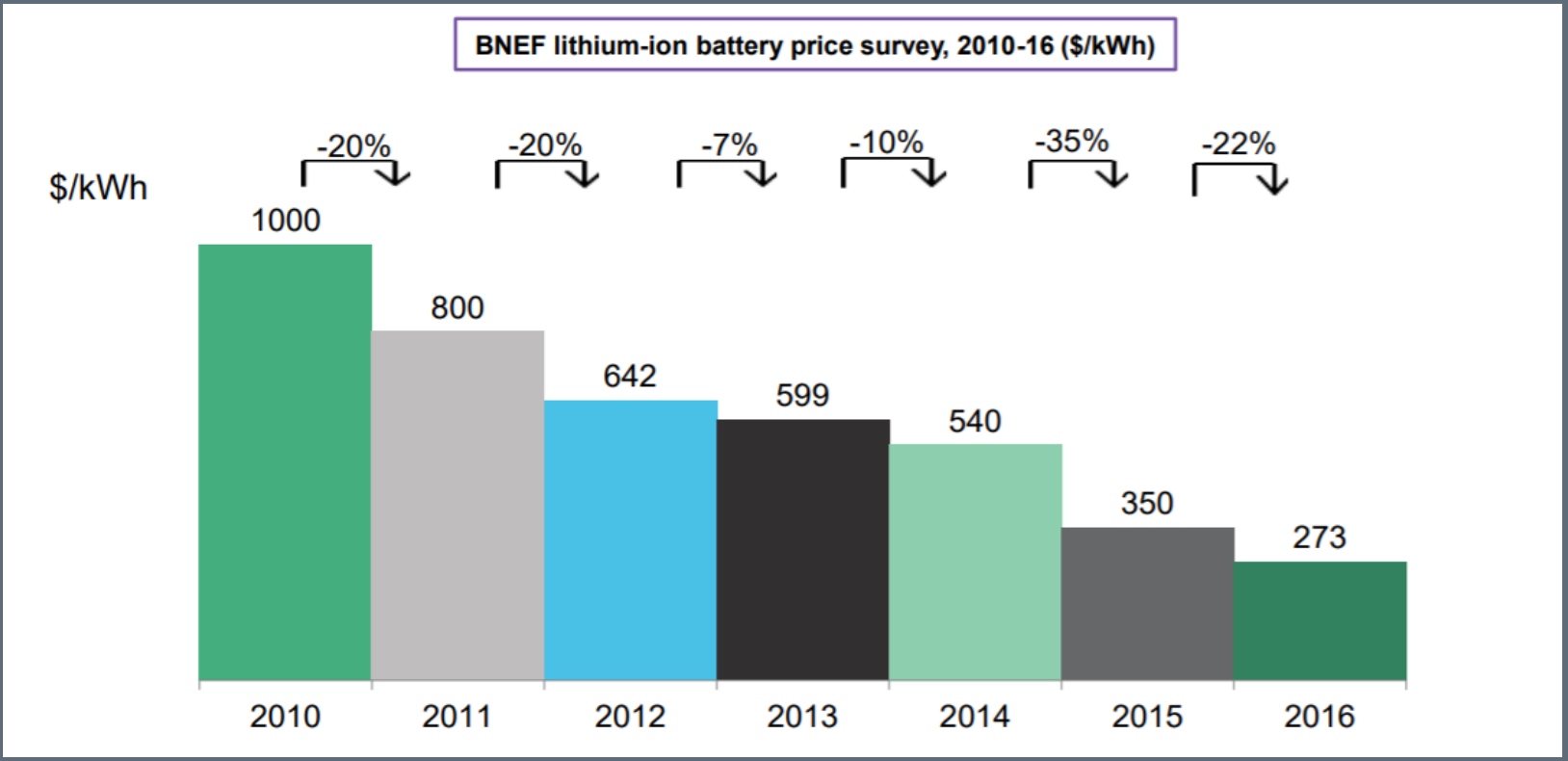
Net Demand (minus wind and solar)



Battery Storage



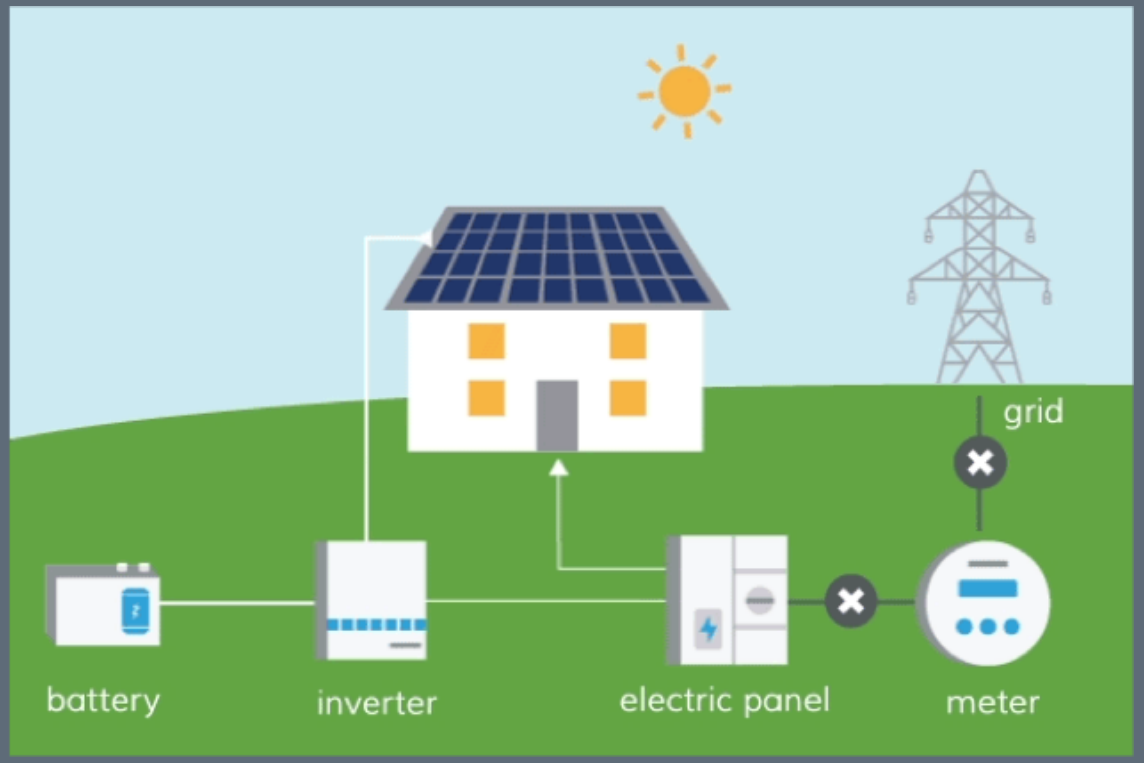
Battery Storage is also becoming cheaper



Markets expect prices to fall in 2017 to $173/kWh, with projections of $73/kWh by 2030.

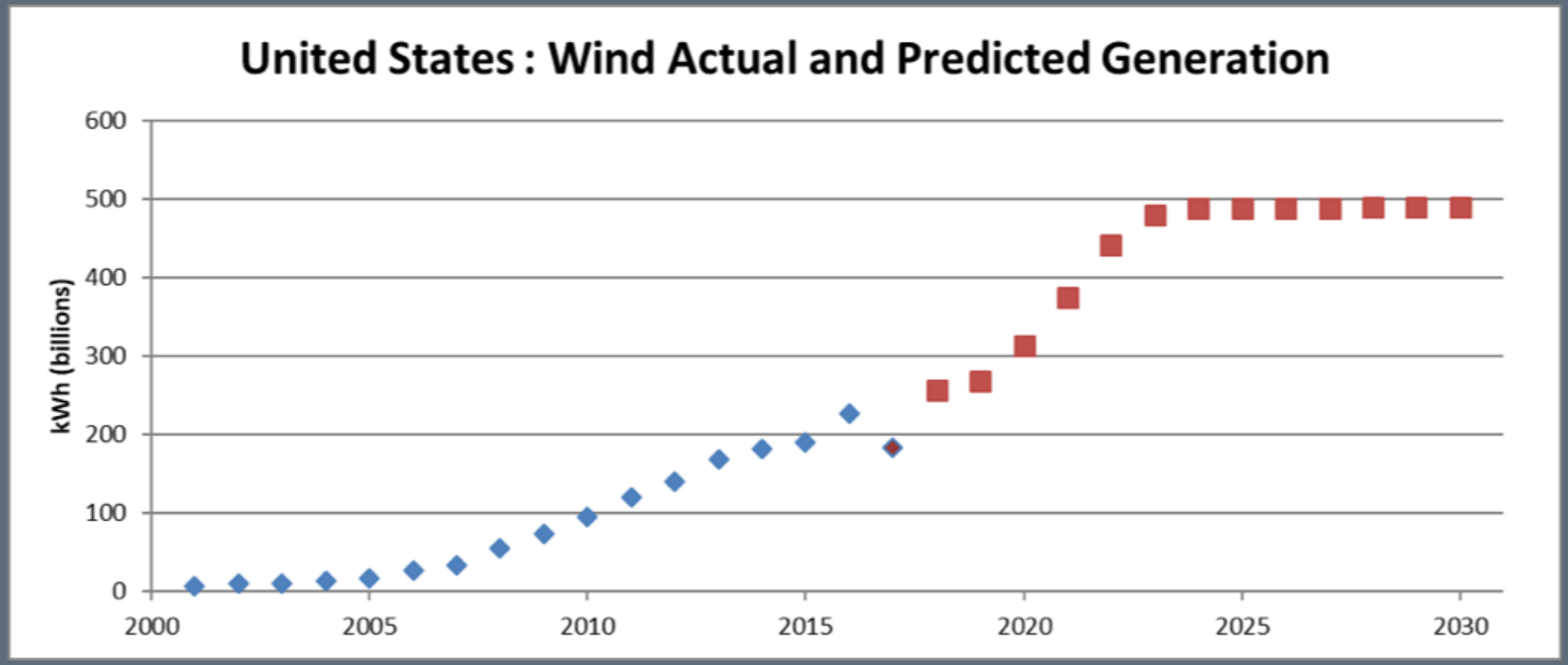
Additionally, distributed generation has grown rapidly in regions of the US.

Distributed generation allows for homeowners to use solar panels and battery systems to power their homes. In early 2017, over 1 million households in the United States had a household solar PV system, growing 29% annually



Challenges facing Renewable Sources

The Renewable Electricity Production Tax Credit (PTC) is set to expire December 2019, which provides an additional $0.023/kWh credit for all renewable energy producers



Despite the expiring tax credit…

- State-based Renewable Portfolio Standards (RPS) require a certain percentage of generation come from renewables
- In Massachusetts, 15% of electricity generation must come from renewables by 2020
- California has pledged to reach 50% renewable generation by 2030

Further incentives are needed to reach Paris Commitments, both in the US and internationally cont.

- Federal
  - *Carbon pricing on fossil fuels*
  - *Increased R&D support for innovative technologies (Carbon Capture and Storage)*

Trump Budget Proposes Deep Cuts in Energy Innovation Programs

NATIONAL ENERGY TECHNOLOGY LABORATORY

Further incentives are needed to reach Paris Commitments, both in the US and internationally

- Stronger Renewable Portfolio Standards at the state-level (80% by 2050)
- Potential state-level carbon pricing mechanisms
- City-wide initiatives to invest in renewable energy (25% by 2020)
- University-level purchases (32% by 2030)

MIT to neutralize 17 percent of carbon emissions through purchase of solar energy

GREENOVATE CITY of BOSTON

QUESTIONS?