

Climate Change
and
Clean Energy

**Renewables are necessary but not
sufficient**

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6:30-8:30

Jefferson County Library

Renewables are necessary but not sufficient

Necessary

- Very low costs
 - Installation
 - Electricity
- Feasible growth rates to make NetZero by 2050
- Minimal regulatory hurdles

Not Sufficient

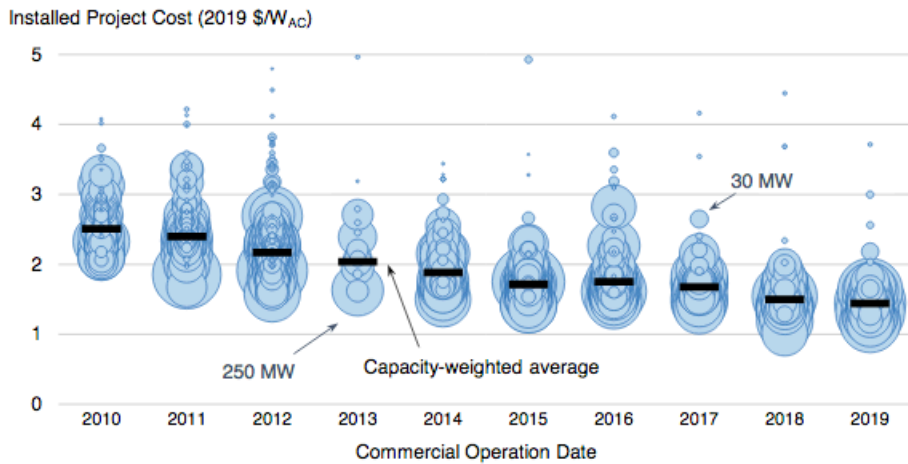
- Zero-emission electricity has been $\approx 37\%$ for 20 years
- Dispatchable Clean Energy (DCE)
 - Hydro
 - Batteries
 - Geothermal
 - Nuclear
- Process Heat
 - Decarbonize industry
 - Heat buildings
- Geographical regions
 - Like Alaska



Low Costs

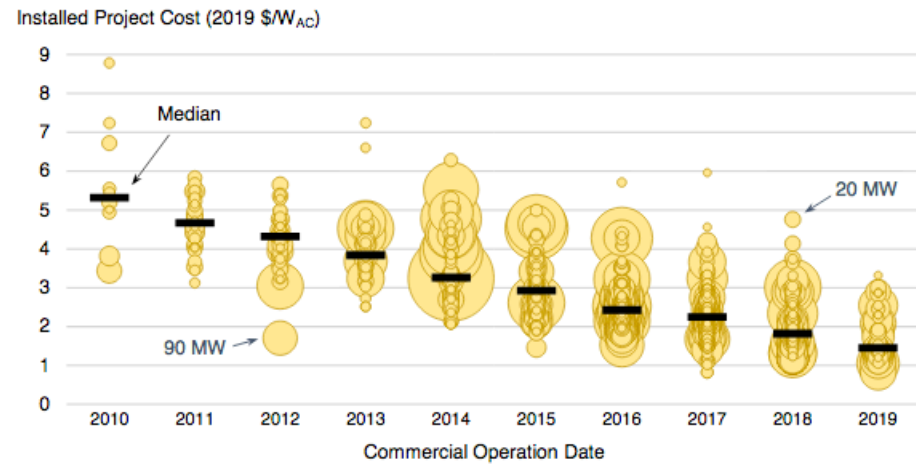
Since 2010, average installed costs have fallen by 40% (wind) and 70% (solar)

Wind Installed Costs



Wind's per-unit (\$/W) costs have declined despite significant turbine scaling aimed at improving performance (i.e., larger rotors and taller towers to boost energy capture and capacity factor)

Utility-Scale PV Installed Costs

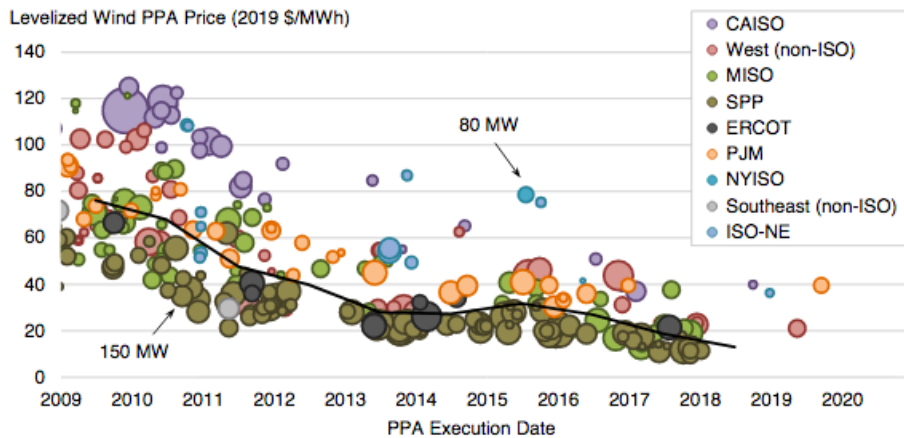


PV plants do not have this same performance-related scaling linkage—instead, efficiency improvements over time manifest almost exclusively in lower installed costs

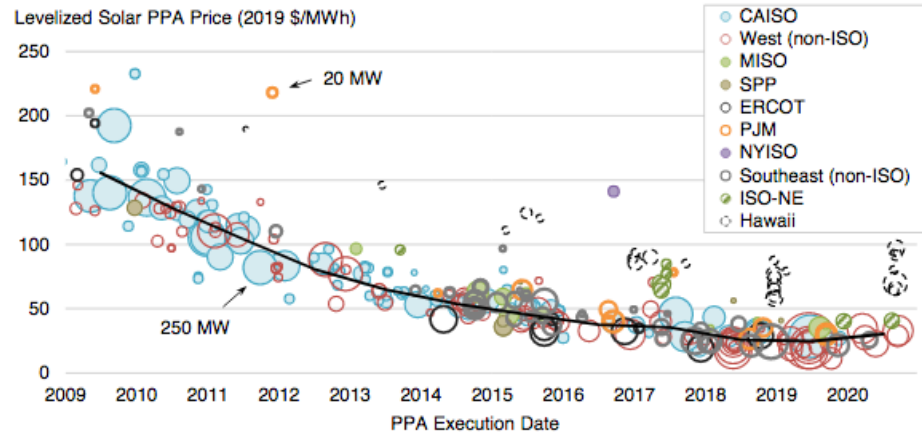
Real Purchase Prices

The combo of lower CapEx/OpEx/finance costs and higher capacity factors and longer lives has driven power purchase agreement (PPA) prices to all-time lows

Wind PPA Prices



Utility-Scale PV PPA Prices

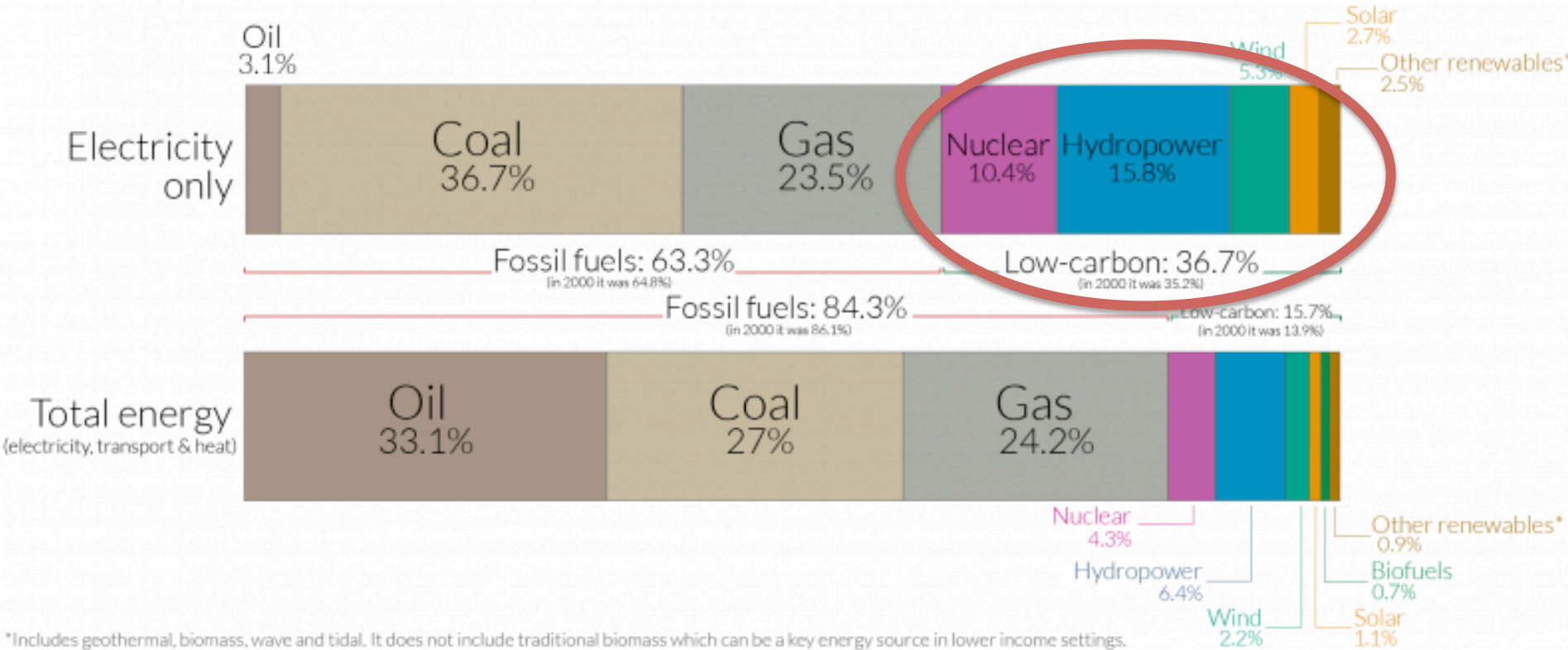


- Bubbles show levelized PPA prices by contract execution date (bubble size denotes PPA capacity)
- The black lines through the bubbles show generation-weighted average trend lines by calendar year
- Since 2009, average PPA prices have declined by ~80% for both wind and solar

Zero-emission Electricity 37% for 20 years



More than one-third of global electricity comes from low-carbon sources; but a lot less of total energy does



*Includes geothermal, biomass, wave and tidal. It does not include traditional biomass which can be a key energy source in lower income settings.

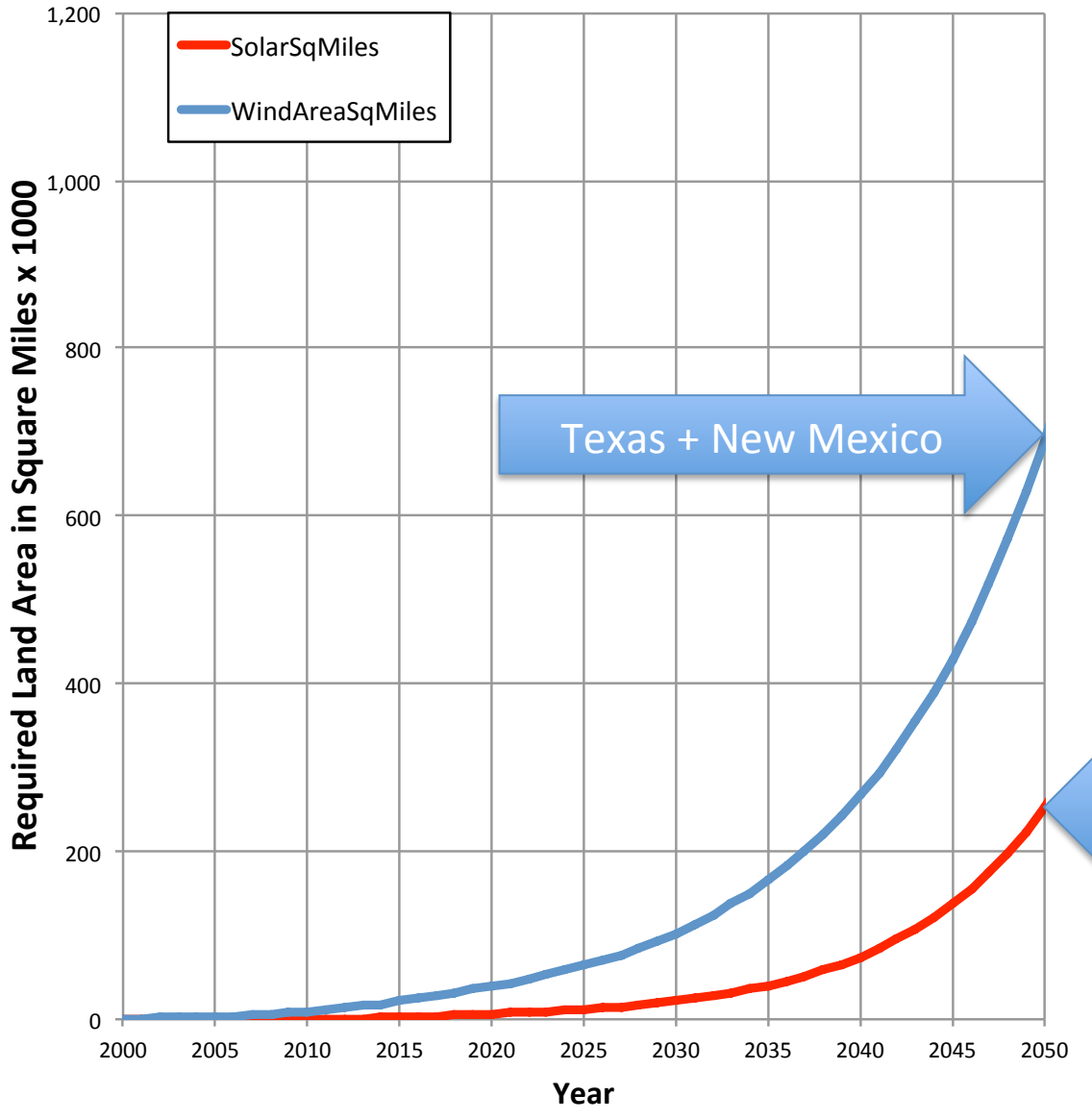
OurWorldinData.org - Research and data to make progress against the world's largest problems.

Source: Our World in Data based on BP Statistical Review of World Energy (2020). Based on the primary energy and electricity mix in 2019.

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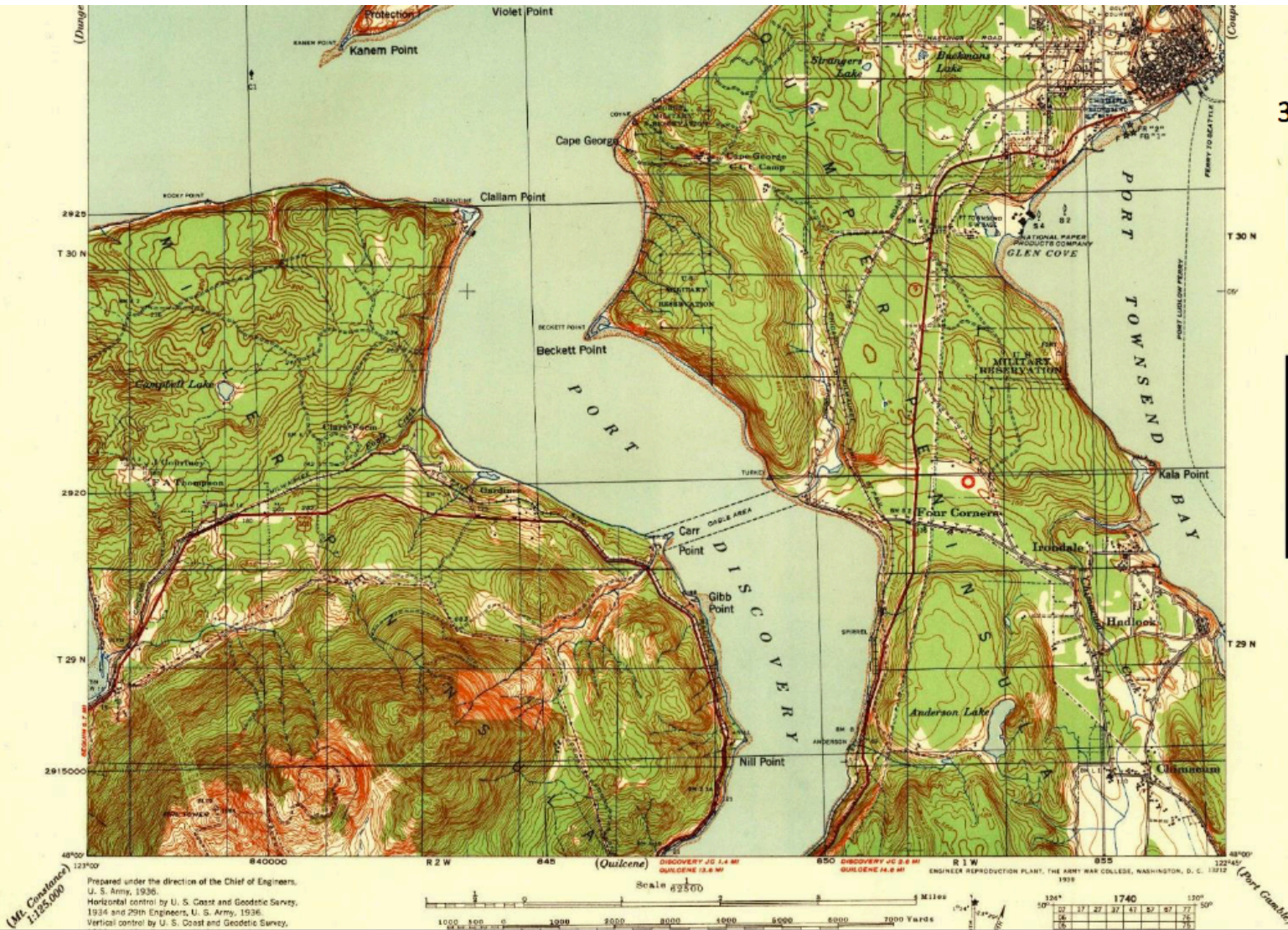
Land Areas
Alaska = 570,641 sq miles
Texas = 261,232 sq miles
New Mexico = 121,298 sq miles

Recall—
 Energy use has been growing at
 246 GW/year since 1965



Nuclear Growth 5%
 Hydro Growth 5%
 Solar Growth 13%
 Wind Growth 10%
 Wind 38.3 kW/Ac, 30 Ac/Windmill,
 WindCapFac 23% GE 5MW/turbine
 Solar 55.9 kW/Ac

Approximate Area for 45-100MW



□
300 MW reactor

1000
Acre

Solar panels, average

4000
Acre

Solar panels, max.

100 MW molten salt solar plant



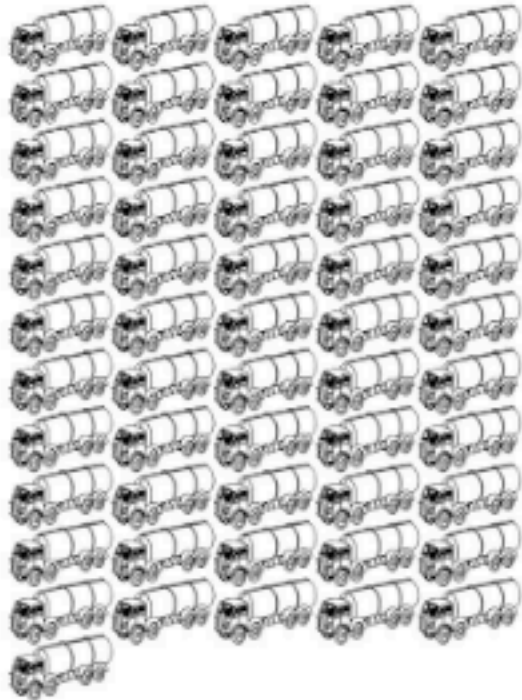
Over 200 of these per month

1 GW in under ½ Square Mile

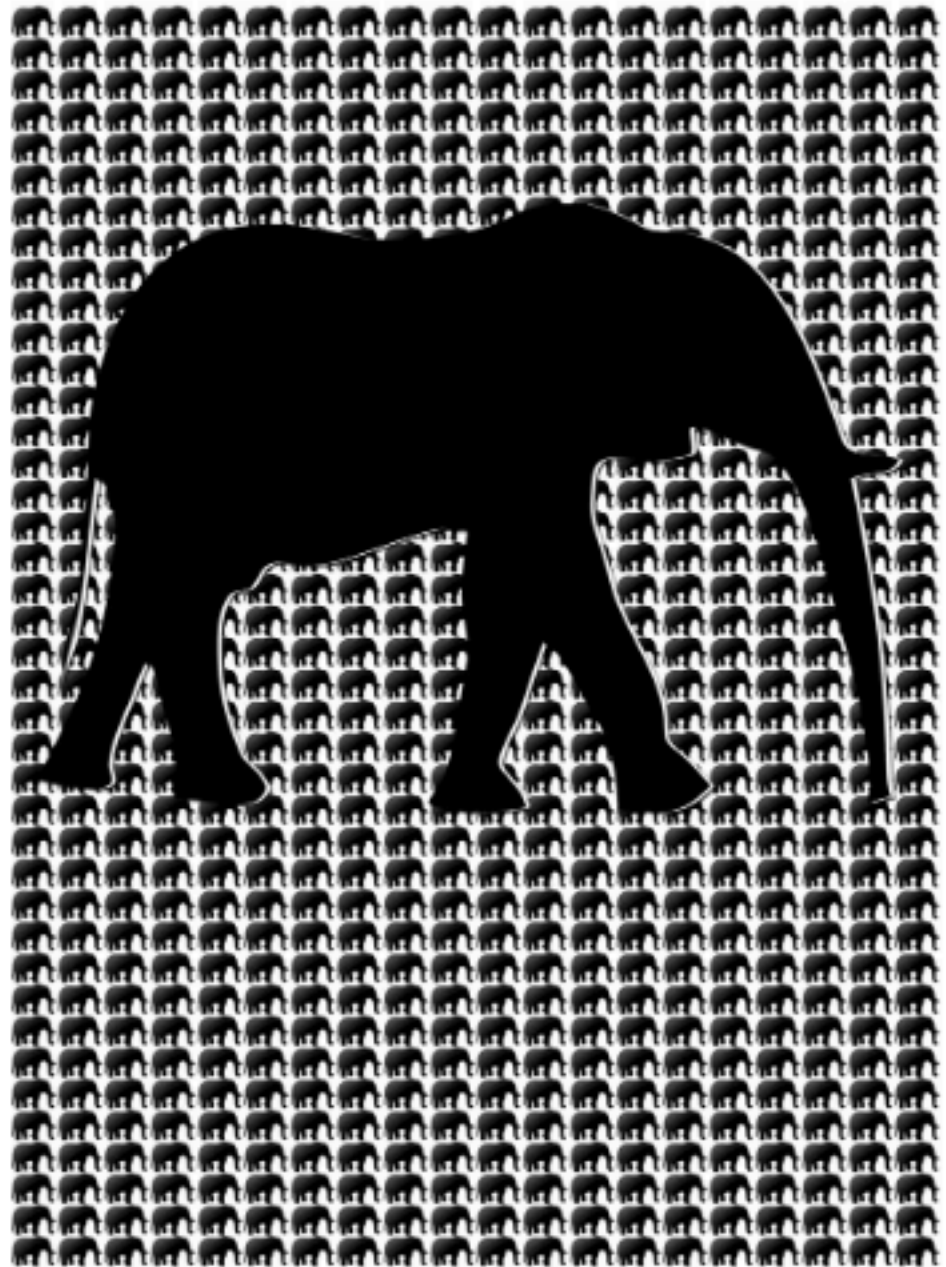




(a) uranium:
 $8.3 \times 10^6 \text{ kWh kg}^{-1}$



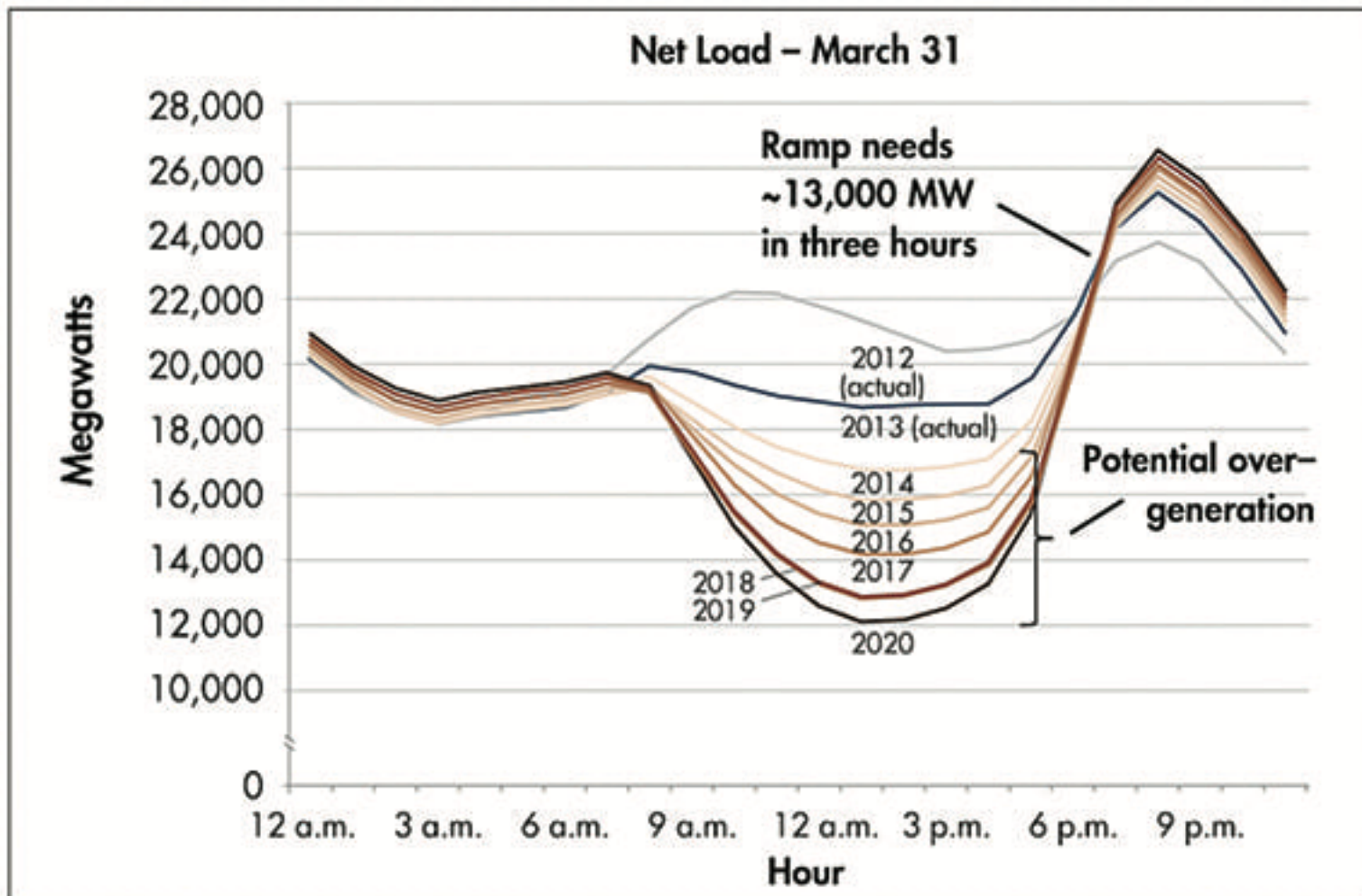
(b) CNG: 5.8 kWh L^{-1}



(c) coal: 2 kWh kg^{-1}

Necessary but not Sufficient

- NetZero by 2050 numbers are all annualized averages
- Doug showed us a movie about DUCK CURVE → daily performance



Variable Renewable Energy (VRE) + Smart Grid

Electricity Supply

VRE + Dispatchable Clean Energy

→ look at daily performance

Wind
Solar

Batteries
Hydro
Load Following Nuclear

= Demand
Response

Grid Operator or Aggregator
Sends messages to LOADS
Not NOW → Later
Shed the load NOW

- IF Supply < Demand → Brownouts or Blackouts
- IF Supply > Demand → Supplies must be Curtailed

California's Duck Curves

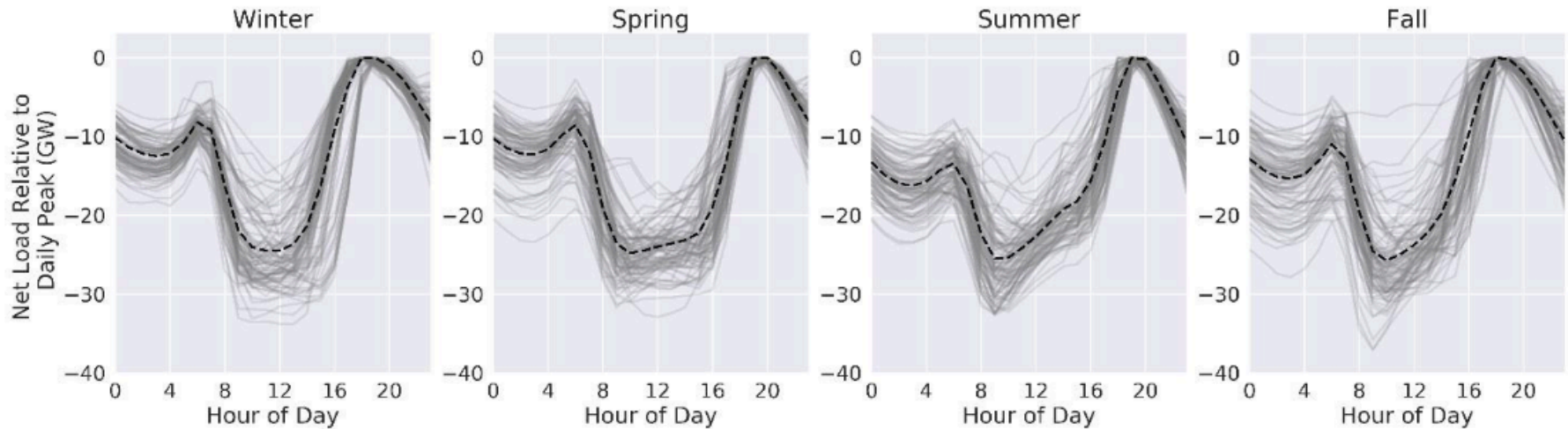


Figure 3-11. Forecasted system-level net load (gross demand less solar and wind generation) for 2030, normalized to each curve's peak value, in each day of the year (solid gray lines) and averaged by season (dashed black lines). There is evident variability in the size of the morning and evening ramps, both seasonally and from day to day within each season.

- Dispatchable Energy includes CO₂ emitting GAS
- Need Dispatchable Clean Energy (DCE) for ramps

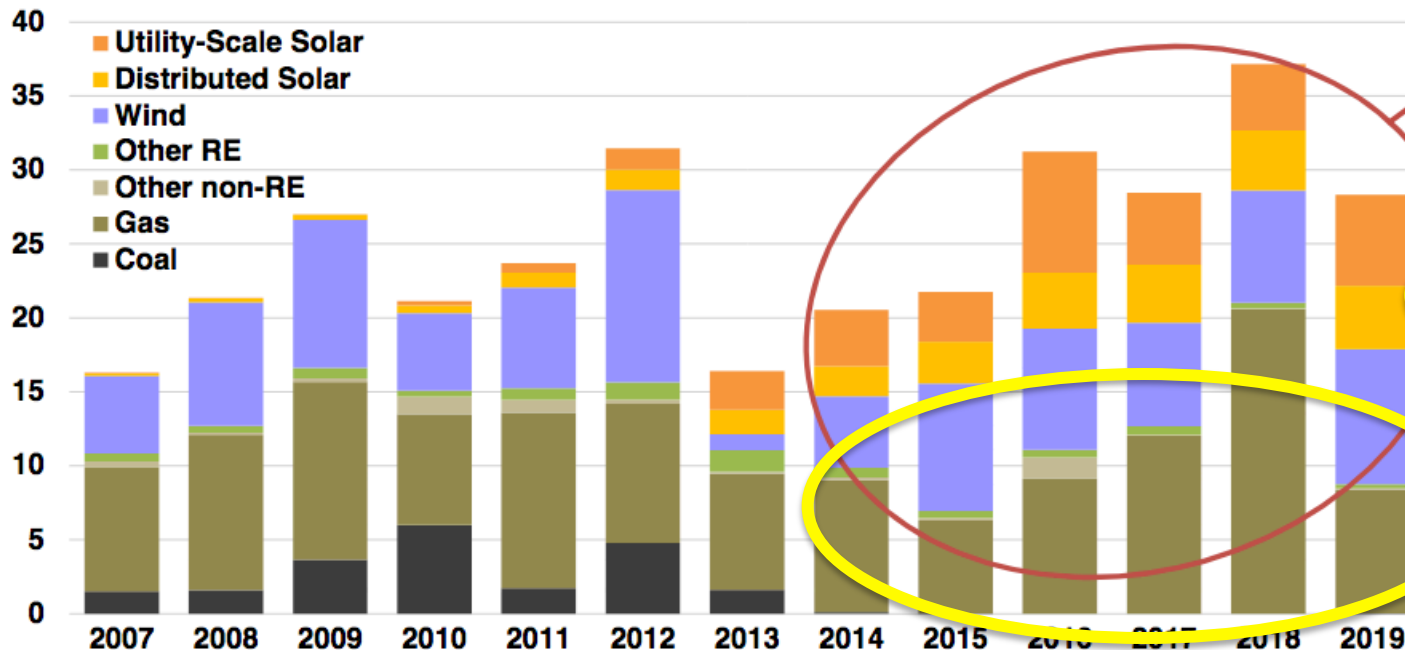
It's actually getting worse in every dimension



Natural Gas Helps Ducks

Over the past six years, natural gas, wind, and solar have accounted for 97% of all new capacity added to the U.S. grid

Annual Capacity Additions (GW_{AC})



- In aggregate from 2014-2019, wind (27%) and solar (31%) contributed 58% of all new generating capacity added to the U.S. grid (with gas at 39%)
- Wind has been a consistent, significant contributor all the way back to 2007, but solar not until 2013

Our Position

- Fossil Fuel Combustion → CO₂ in atmosphere
- International agreements for NetZero by 2050
- What is the correct GOAL?
 - Replace Fossil Fuels with Clean Energy
- What is Clean Energy?
 - Renewables, Hydro, Geothermal, Tidal
 - Nuclear
- Goals of 100% Renewables by <any date>
 - Confuse a technology with the real goal

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