# The many challenges of
# Energy Transition

**AIEE Conference**

Rome, Italy

20 November 2025

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# Thank you for

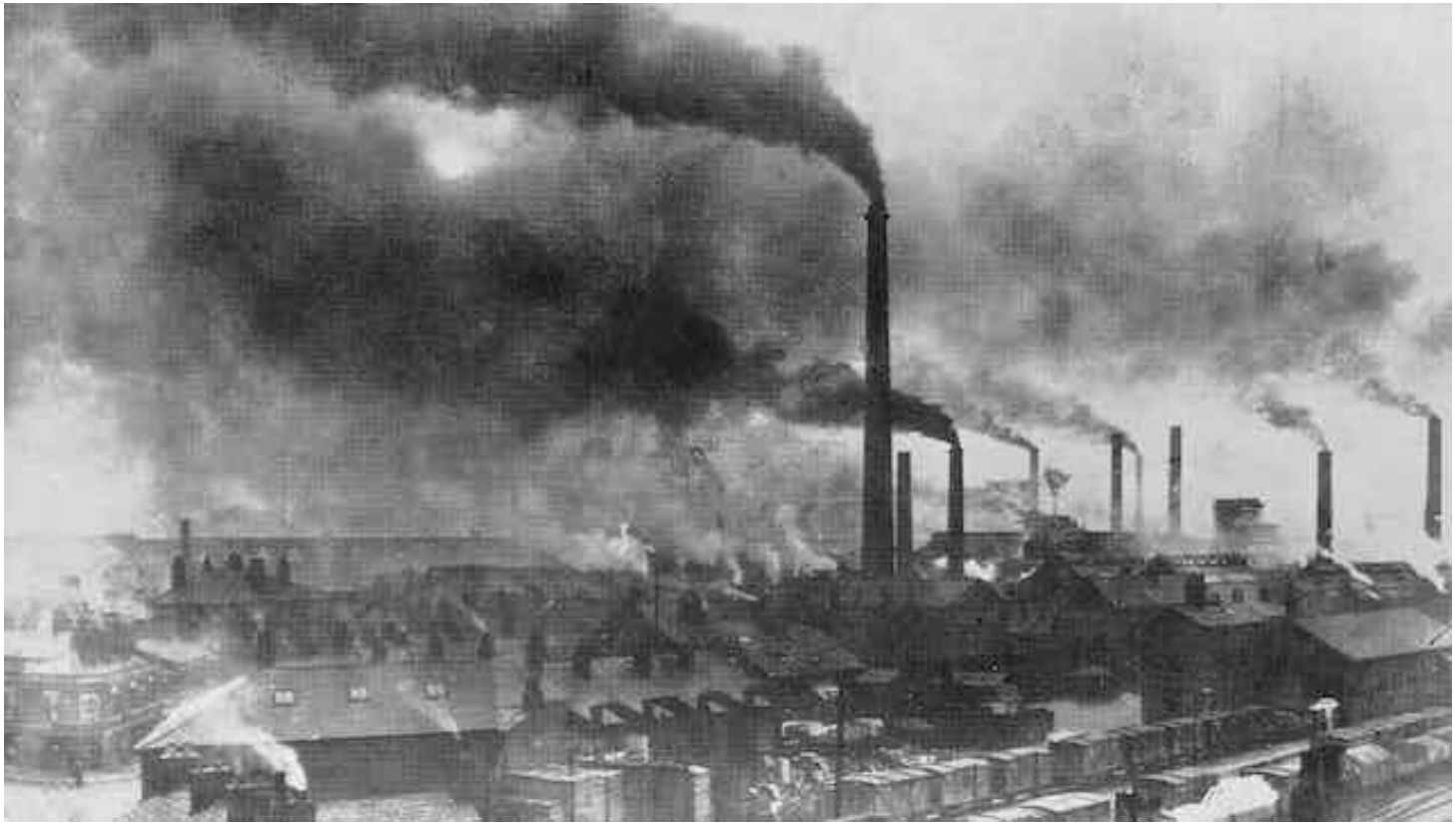
- The kind invitation
- Always a pleasure to visit beautiful Italy

# Outline

- How did we end up to where we are?
- What is the way out?
- Why is it so hard?

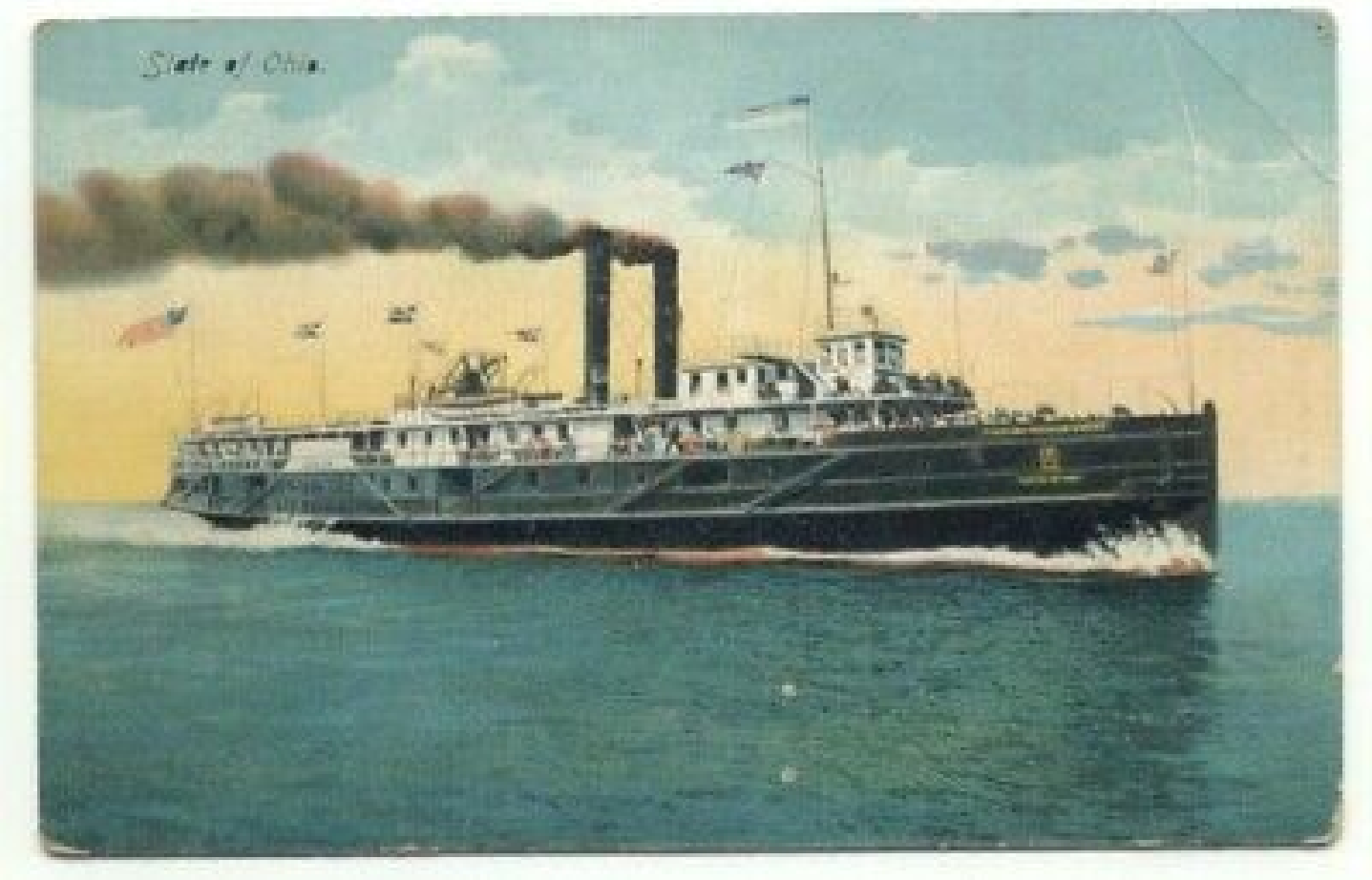
# 1. How did we end up here?

# The Industrial Revolution

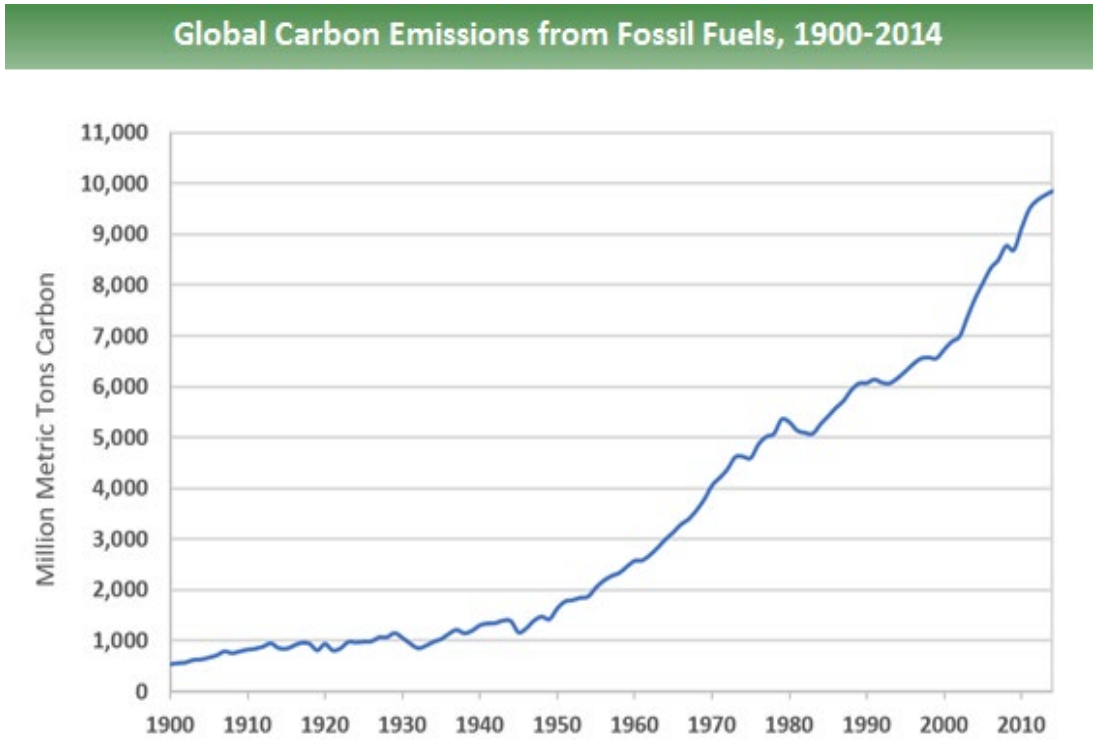


# The Iron Bridge
# 1781

# Smoke = Progress

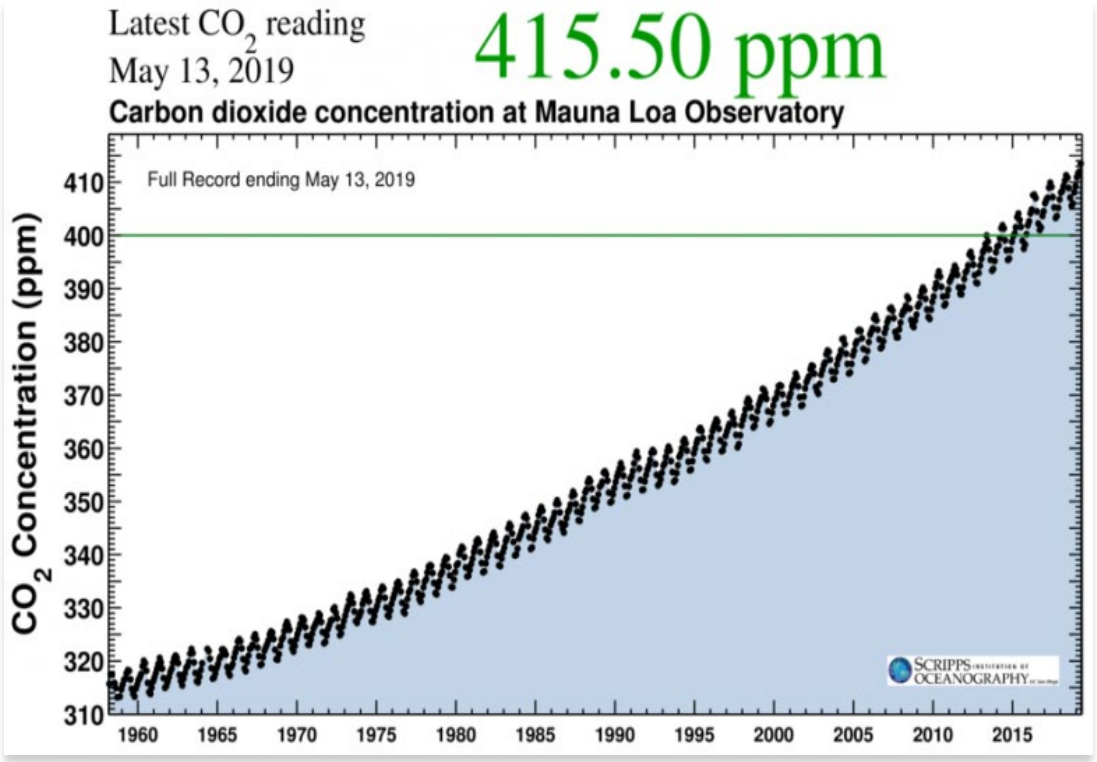


# What followed




Source: US DOE

# … and the result

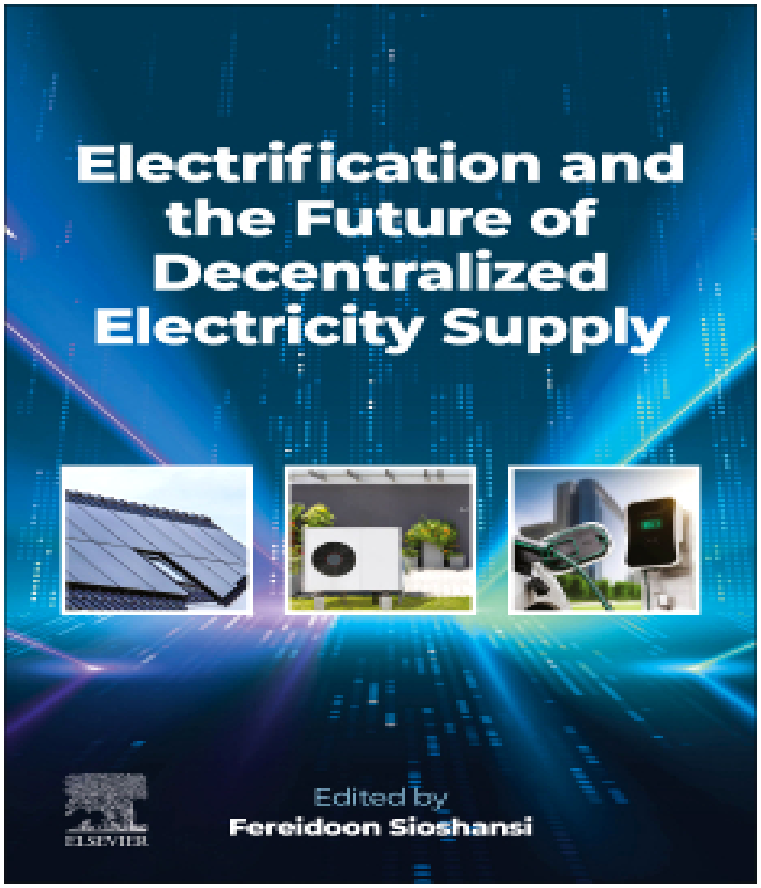



Source: Scripps CO2 Program at the Mauna Loa Observatory in Hawaii

# 2. How do we get out?

- Energy transition
  - Electrification
  - Supplied by renewables
- Different than the past

# Electrification + Renewables



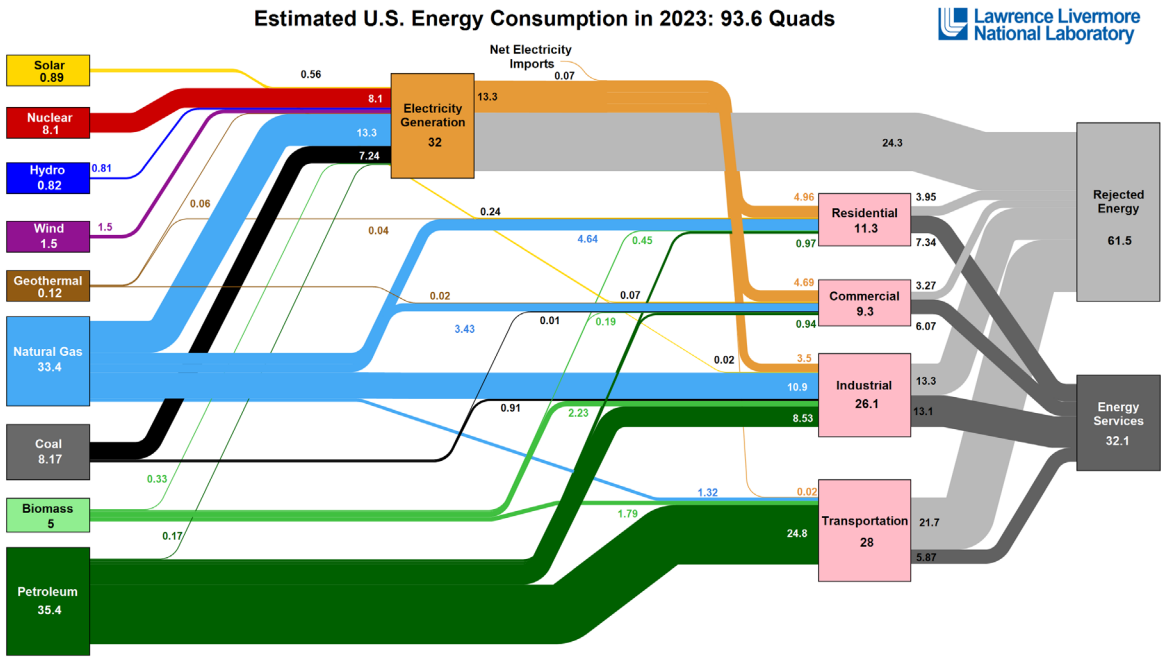
# Global GHG emissions, 2023

| | | |
|---|---|---|
| **Energy related** | | **68%** |
| ▪ Electric Power Generation | 26% | |
| ▪ Transport | 15% | |
| ▪ Industry | 11% | |
| ▪ Fuel production | 10% | |
| ▪ Buildings | 6% | |
| **Industrial Processes** | | **9%** |
| **Agriculture, forestry, land use, waste, other** | | **23%** |

# Electrification is key

- Power generation => Renewables
- 11% road transport => Electrify
- Industrial processes=> Electrify
- Fuel production=> Diminishing
- Buildings => Heat pumps, efficiency
- Agriculture, forestry, land use=> Hard to abate
- Resort to CCS for net zero

# US Energy Flow, 2023




Source: LLNL October, 2024. Data is based on DOE/EIA SEDS (2024). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 49% for the industrial sector, and, 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

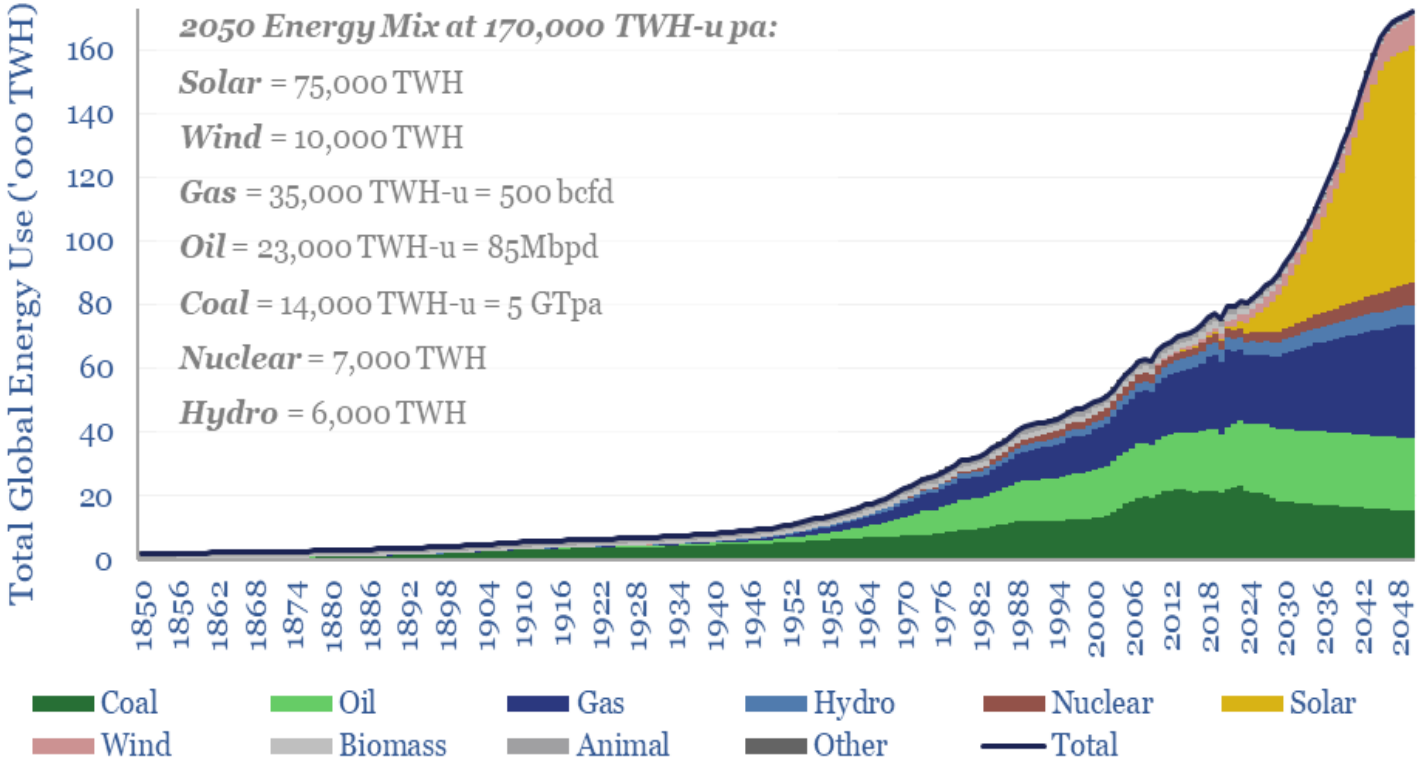
# Fossil fuel combustion
# Inherently inefficient

- Primary energy 93.6 quads
- Useful energy 32.1 quads
- Conversion efficiency? 34%
- Wasted? 61.5 quads
- Why?
  - Thermal power plants
    - 32 quads in; 13.3 quads out
    - Rest is wasted heat
  - Internal combustion engines
    - Most of energy is wasted as heat

# 82.5%

- Fossil fuels in US energy mix
- We have a LONG way to go
  - Many additional obstacles remain
- Technical, financial, political
- Especially now!

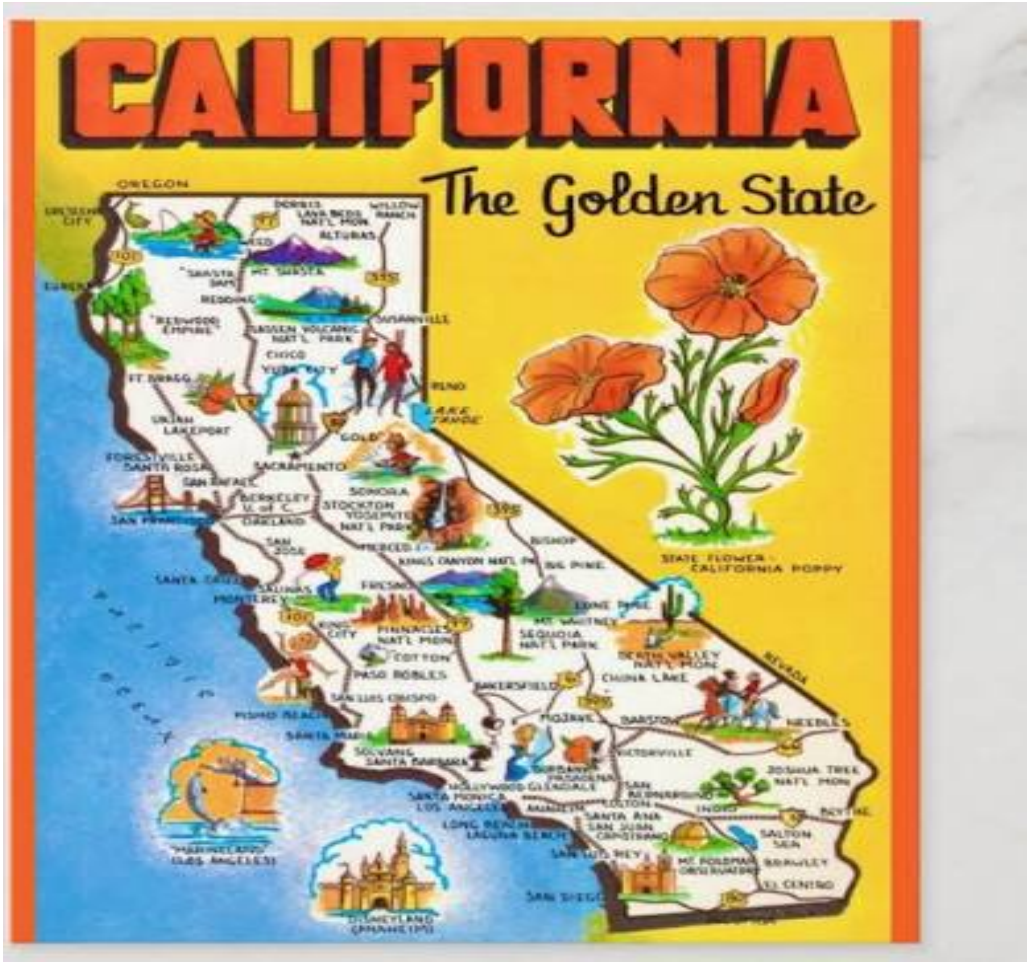
# Different transition needed



# 3. Why is it so hard?

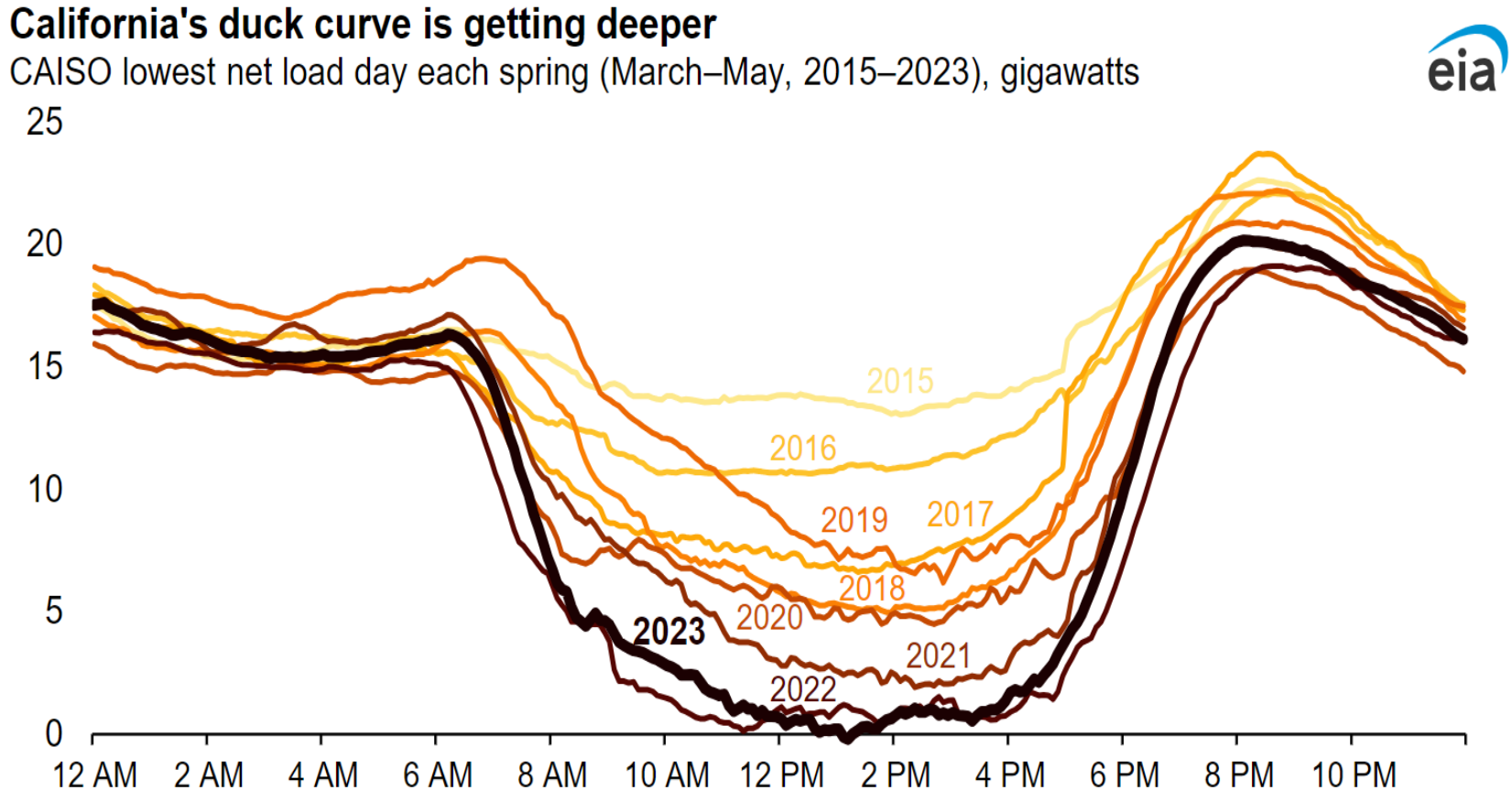
- Electrification is hard
  - E.g., electricity prices high
  - E.g., EV charging infrastructure inadequate
- Renewables are intermittent
  - Need storage, transmission grid
- Costs more & rakes long time
  - Transmission lines, permitting
- Powerful fossil fuel lobby
- Short-term pain vs. long term-gain

# California is trying

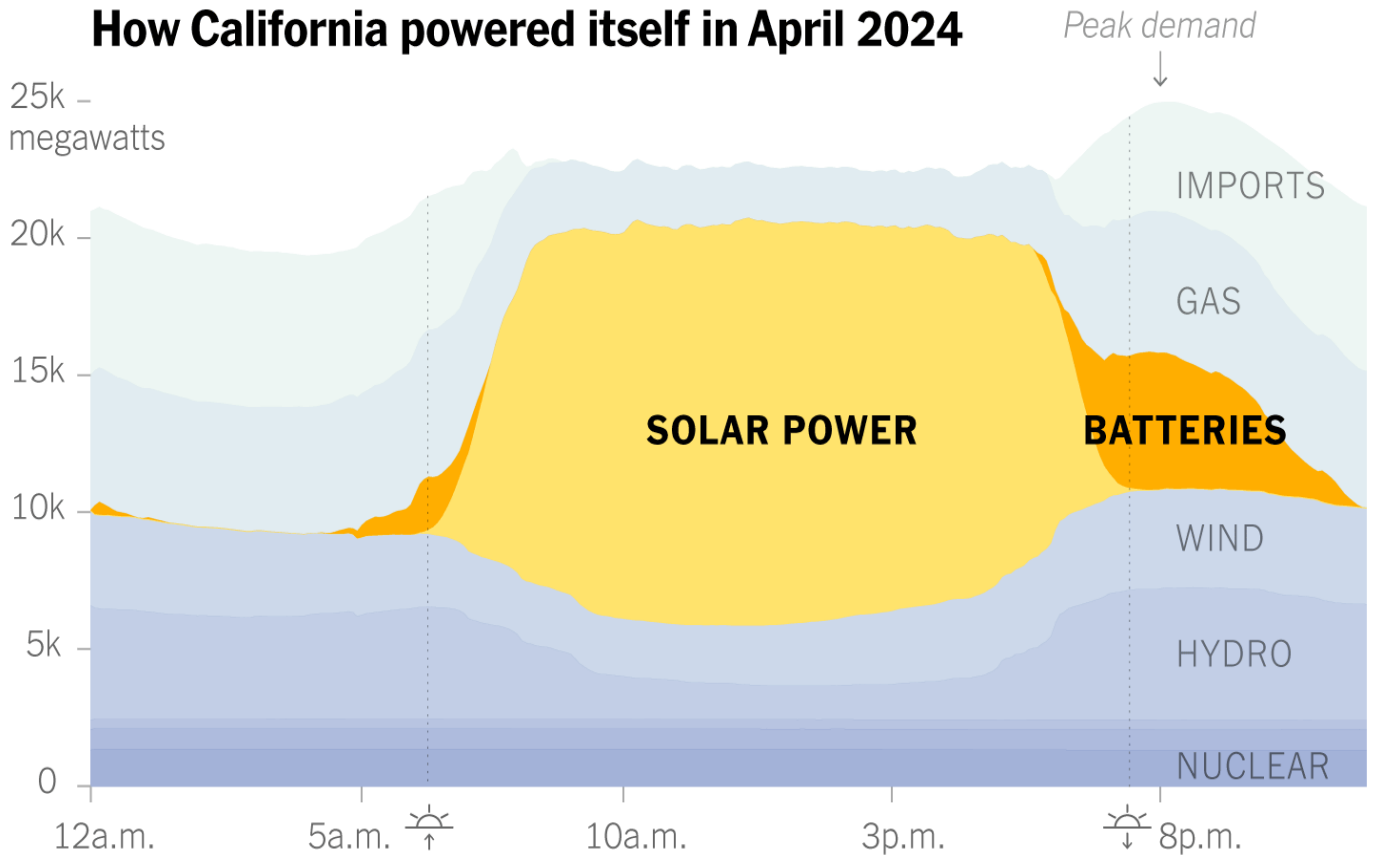


# California Duck Curve

## The actual earlier & worse then predicted



# And it is NOT easy



# Thank you

- Happy to answer questions