PennState
College of Earth
and Mineral Sciences

Earth and Mineral Sciences
Energy Institute

Initiative for
Sustainable Electric
Power Systems

Electricity and Water Interactions in the United States

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JGCRI Integrated Assessment Workshop

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Outline

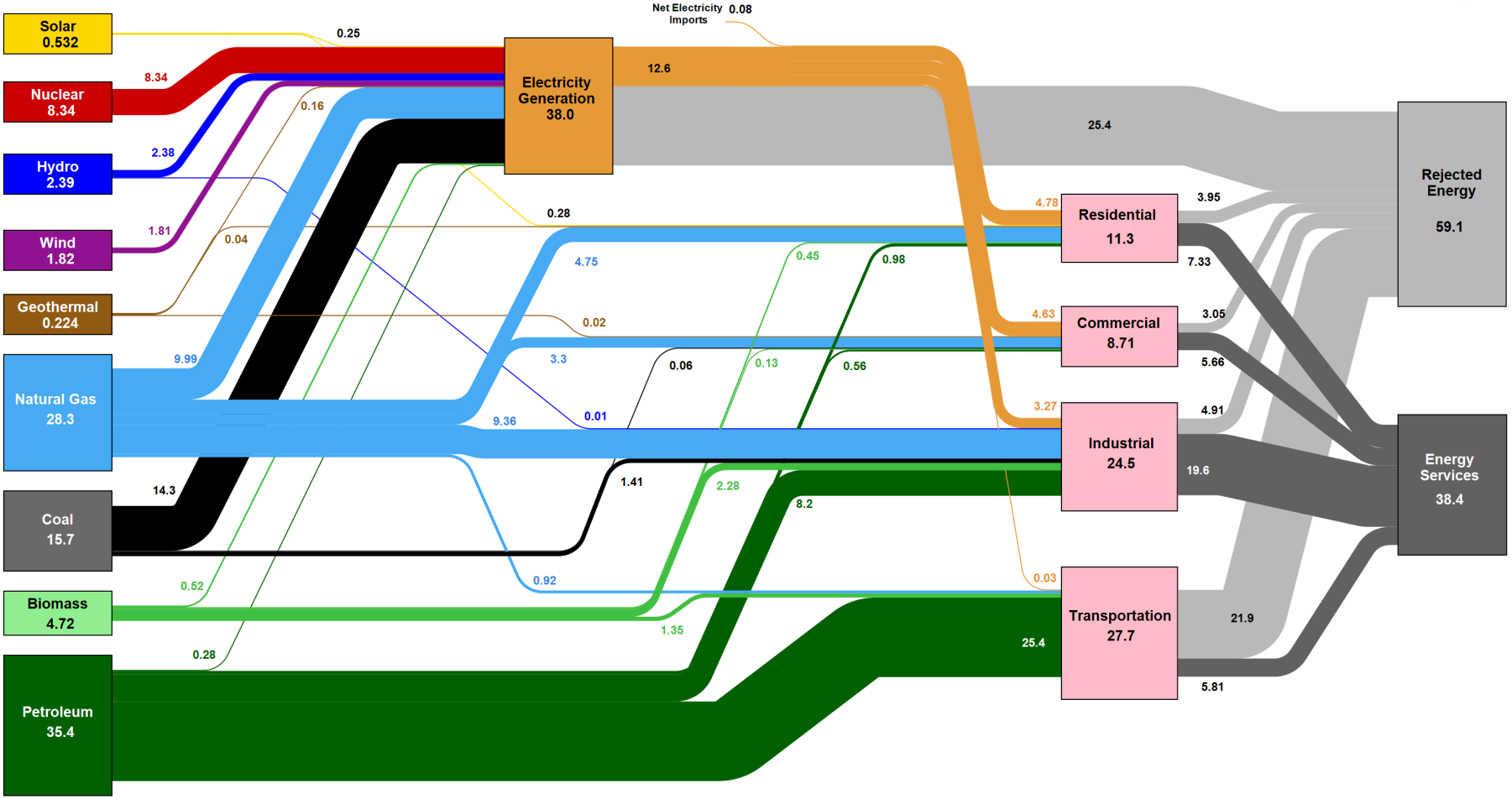
- Electric Power Sector Background
- Electricity and Water Interactions
- Illustrative Example
- Information Requirements
- Challenges to Coupling
- Discussion

Motivation

- Electricity:
  - Roughly 40% of Energy Flow in U.S.
  - May increase share in future…
- Impacts on/by Electric Sector
  - Carbon Emissions
  - Regional Air Pollutants
  - Water use for cooling and hydroelectric

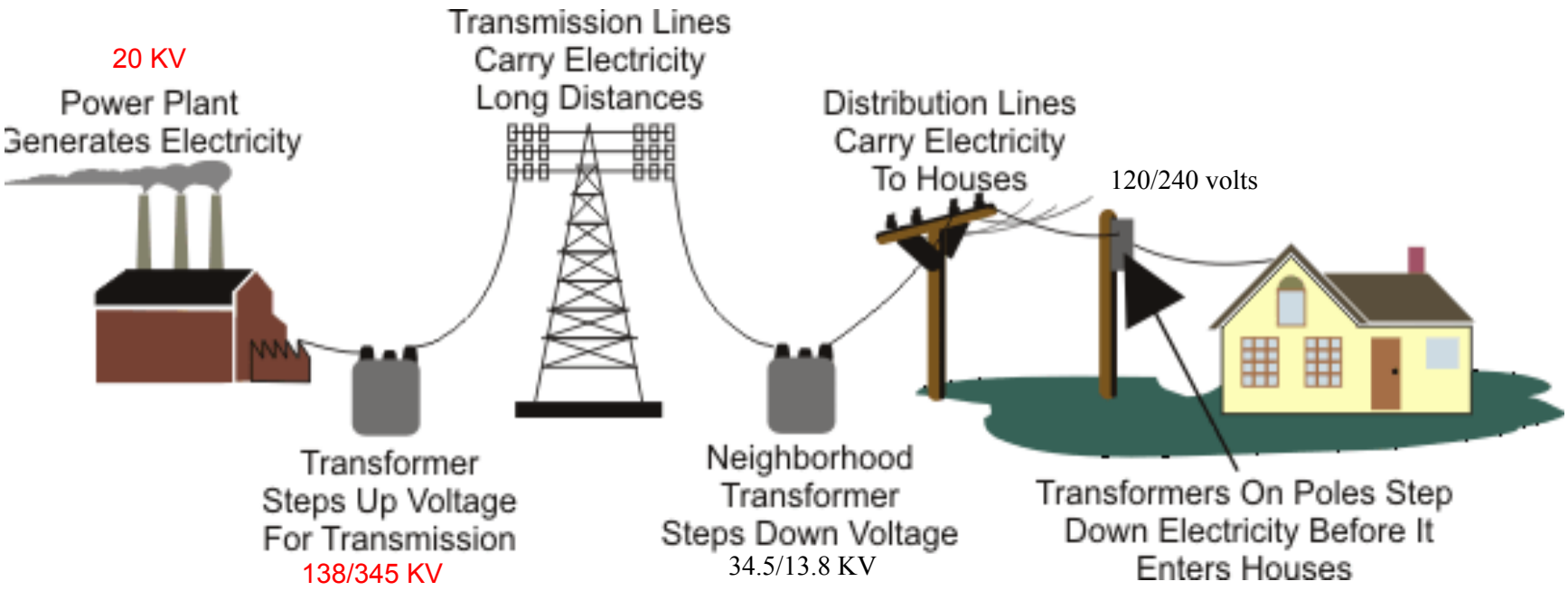
Estimated U.S. Energy Consumption in 2015: 97.5 Quads

Lawrence Livermore National Laboratory



Source: LLNL March, 2016. Data is based on DOE/EIA MER (2015). 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, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527

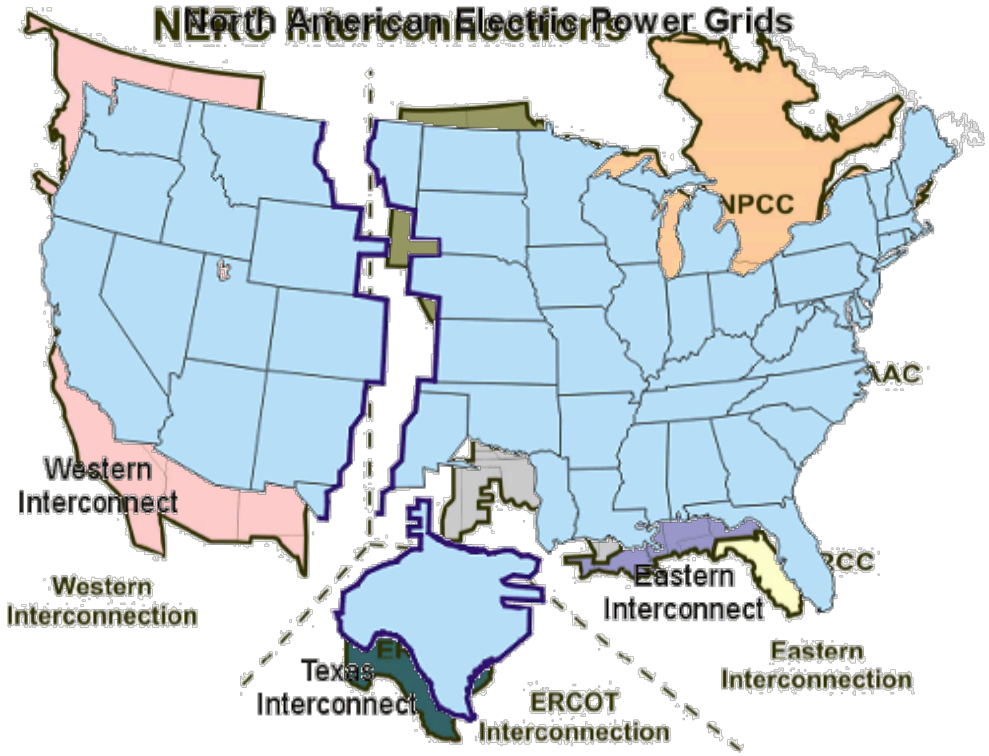
Electric Power System of Today



Source: Energy Information Administration

U.S. Electric Power Organization

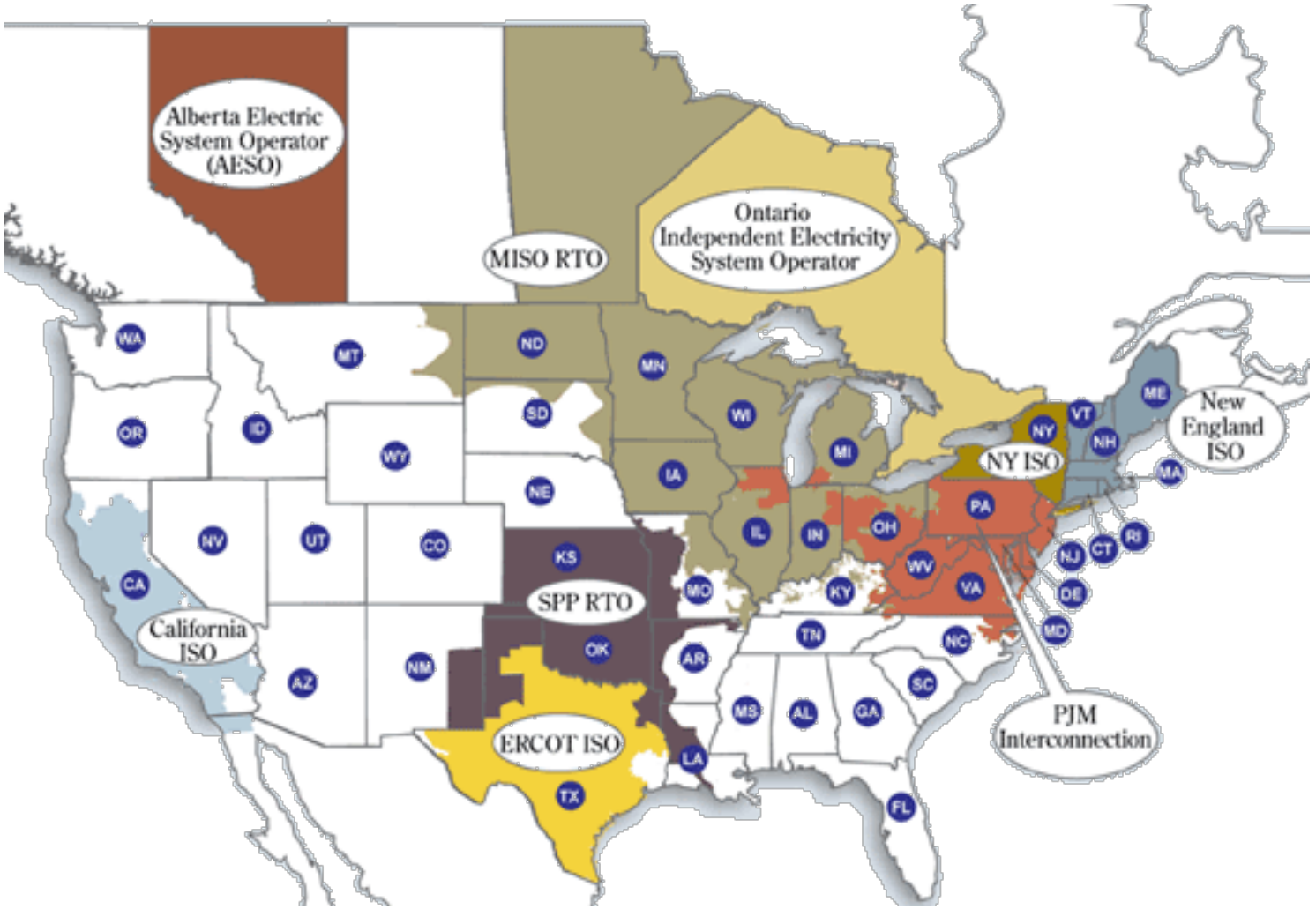
- Interconnections
  - Hums at different phases from one another
  - Requires DC Ties to connect them



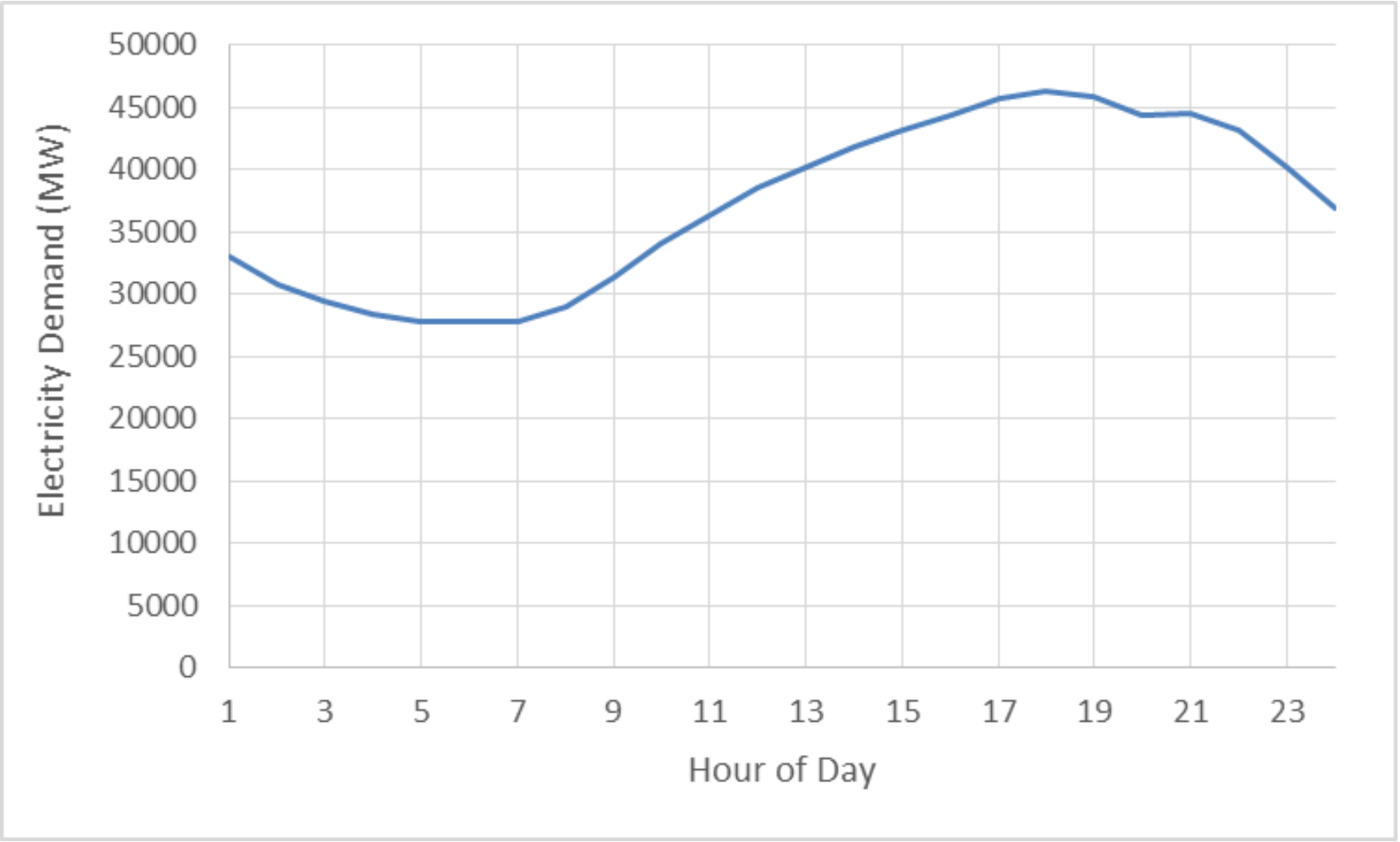
- NERC Reliability Areas
  - Regional Organizations in charge of electricity reliability in the region
  - Some organizations handle double-duty (e.g. WECC, SPP, ERCOT)

U.S. Electric Power Organization

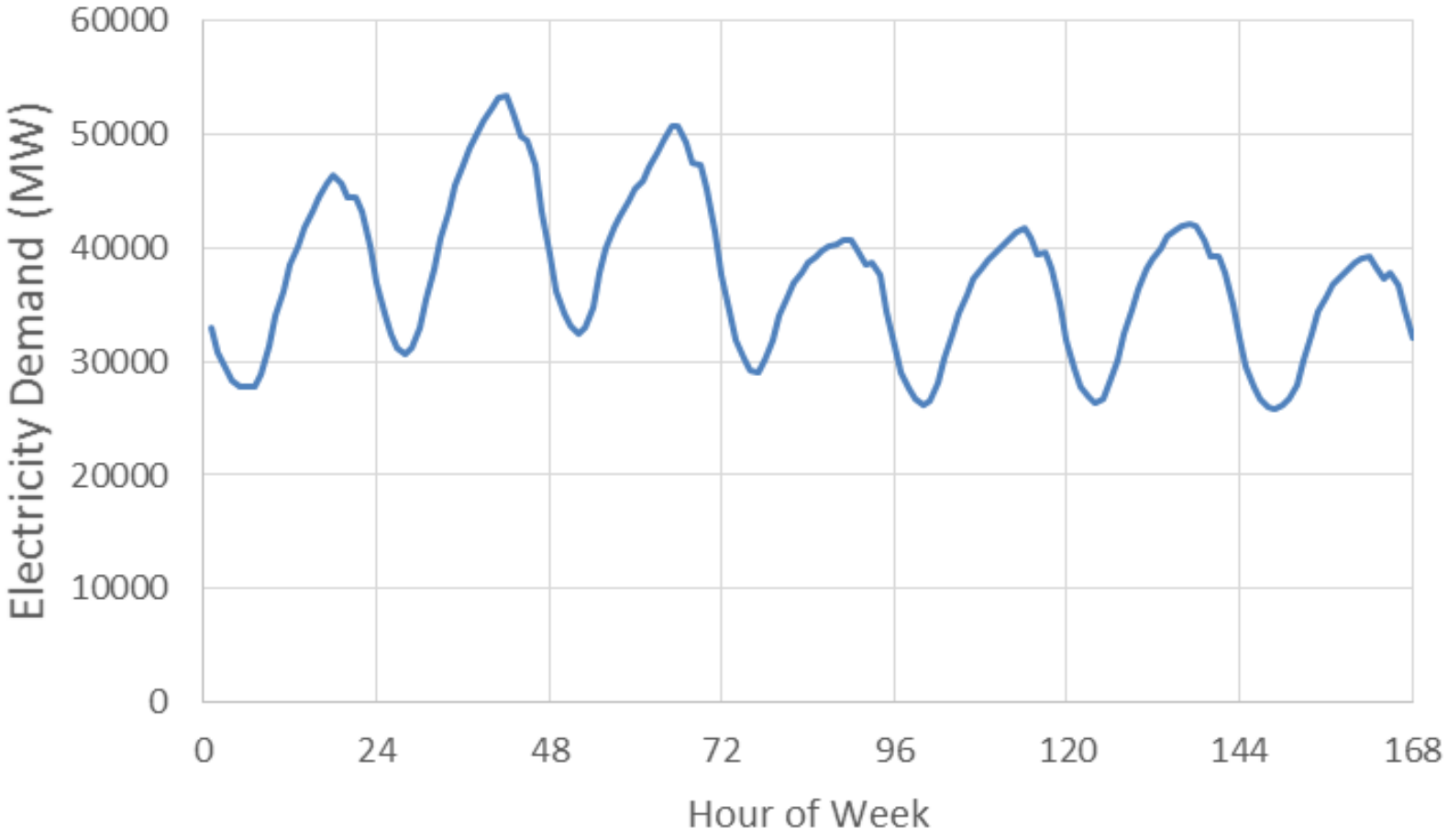
- Independent System Operators (ISOs), or Regional Transmission Organizations (RTOs)



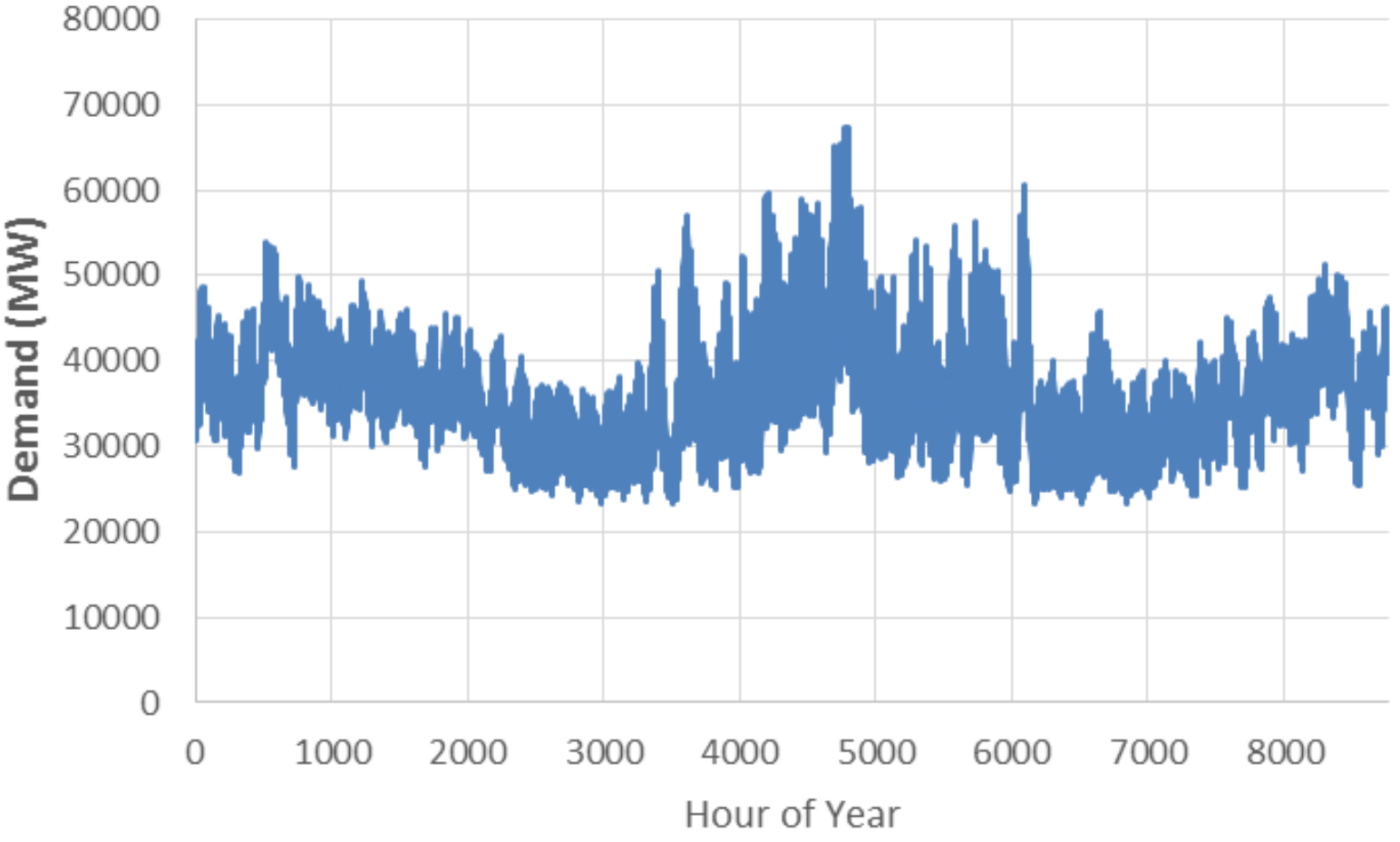
Electricity Demand – One Day
(August 11, 2013, PJM)



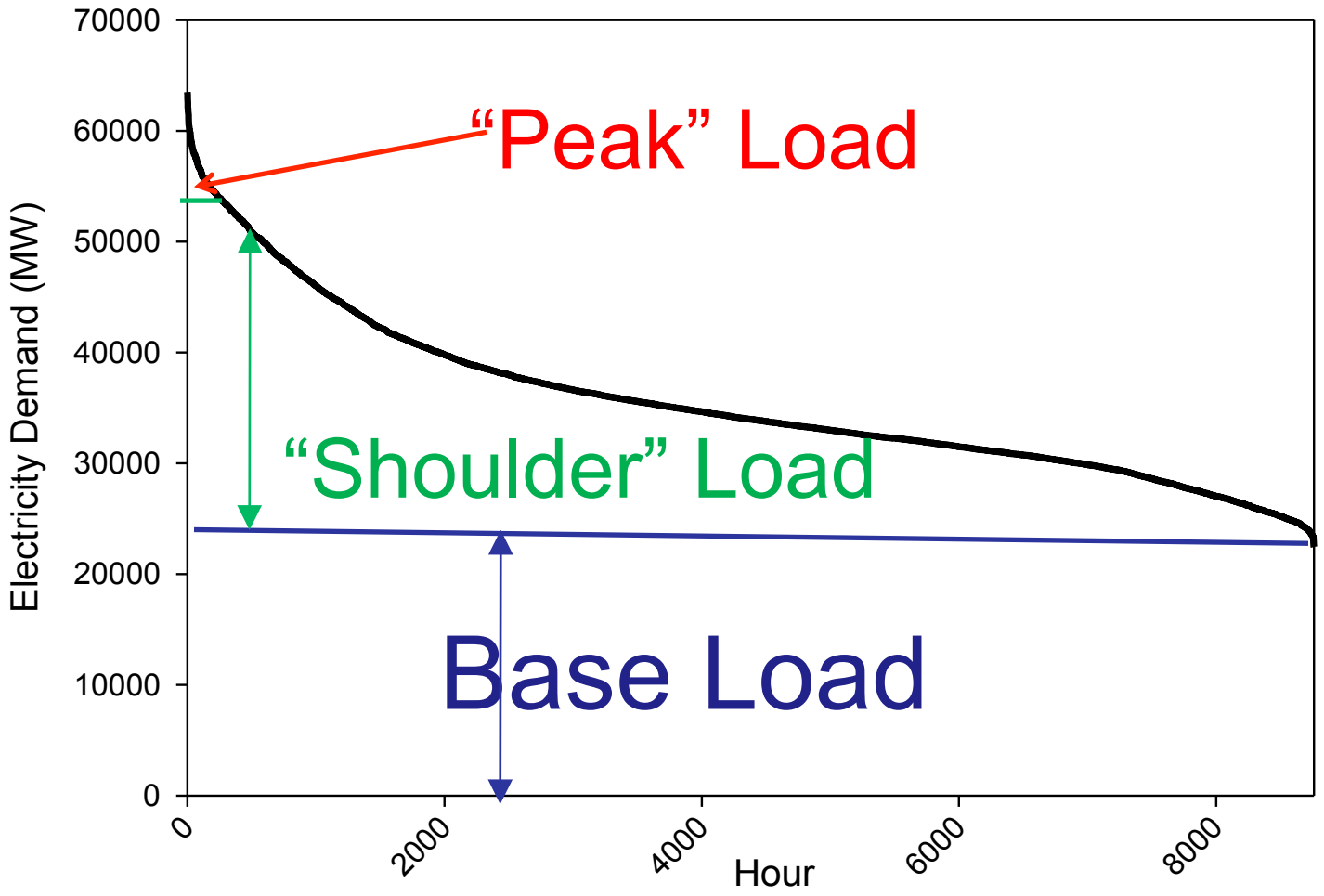
Electricity Demand – One Week
(August 11-17, 2013, PJM)



Electricity Demand – One Year
(2013, PJM)



Annual Demand: Load Duration Curve

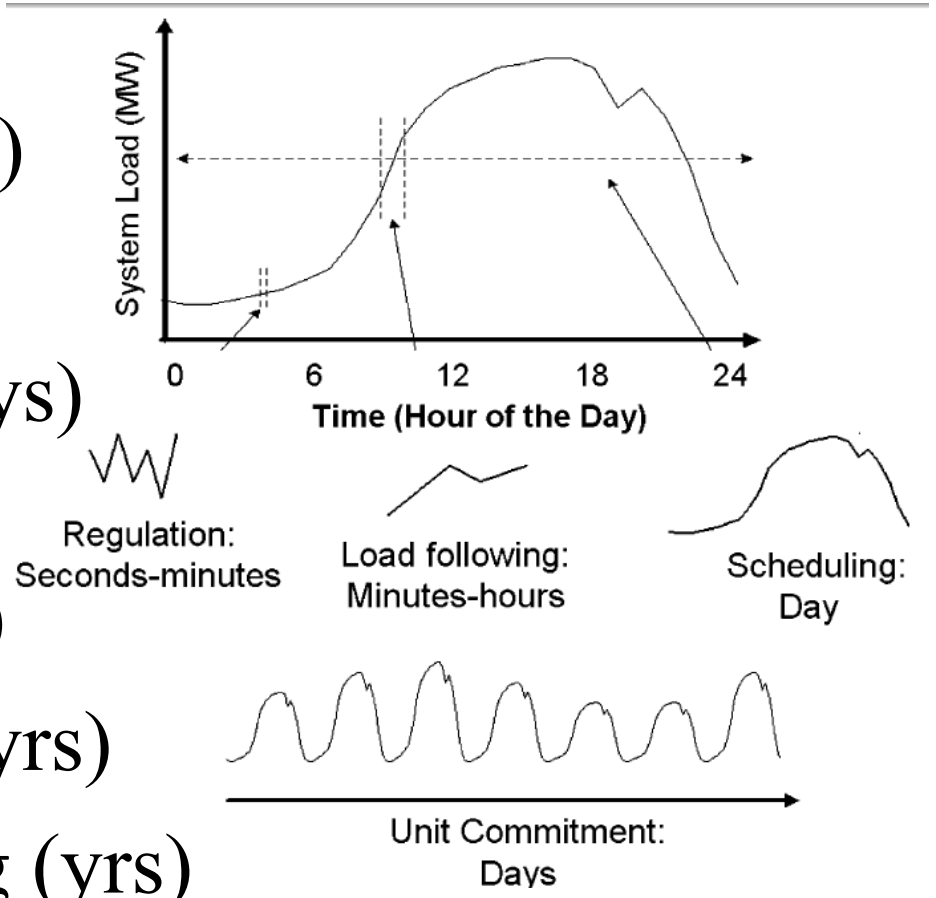


Electric Power System: Why is it Hard?

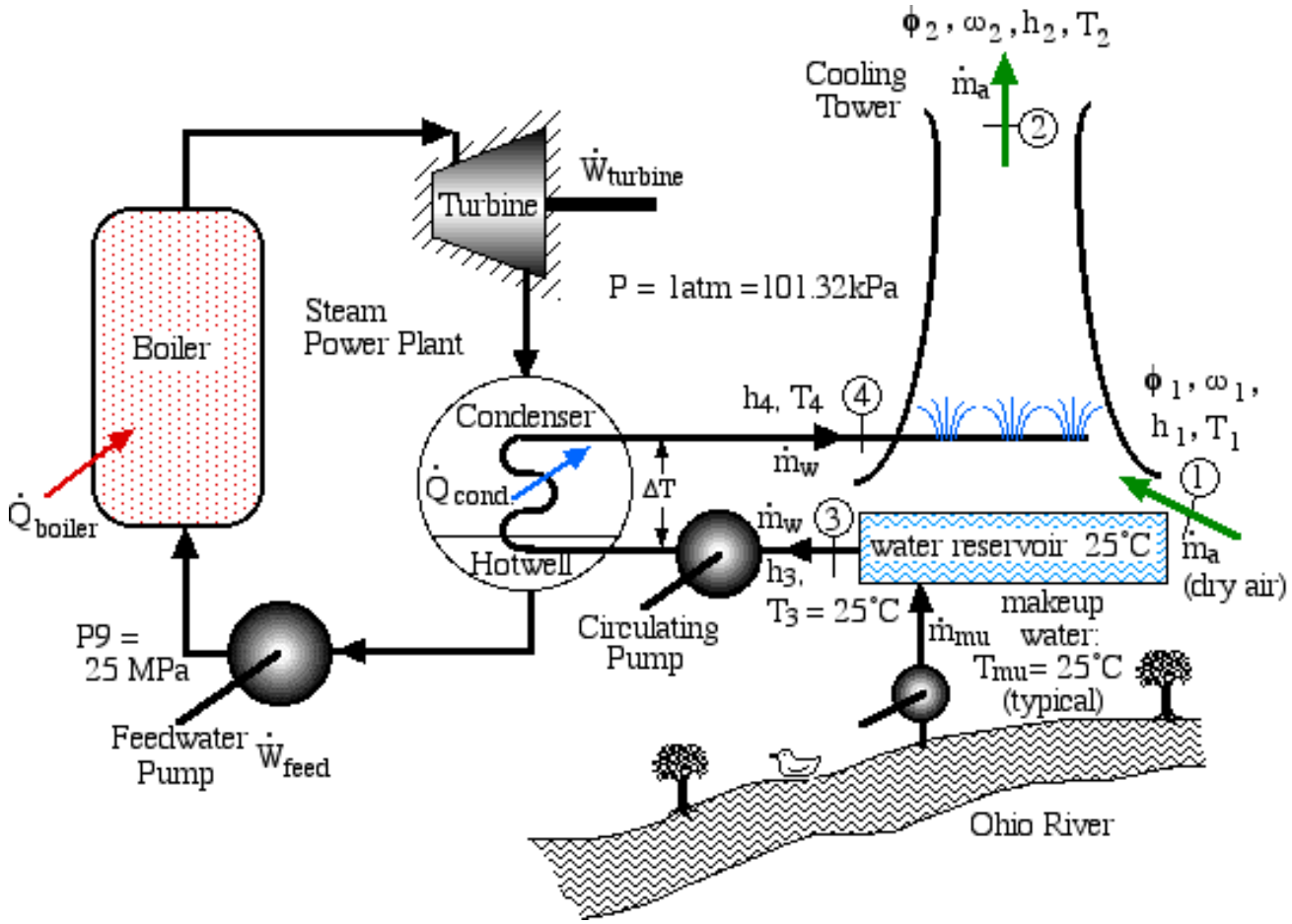
Must spin at 60 Hz
± 5% or else….

Planning/Operations Tasks in Electric Power

- Regulation (secs)
- Load-Following (mins)
- Dispatch (hrs)
- Unit Commitment (days)
- Hydro-Thermal Coordination (months)
- Generation Planning (yrs)
- Transmission Planning (yrs)



Water for Cooling Electric Power Generation



Reasons for interruption of power:

- Water volume too low

- Water Temperature too low

Impacts of Drought on Power Systems

- Hydroelectric Generation
  - Run-of-River: lower power output
  - Large Hydro: lower reservoir levels

- Thermoelectric Generation
  - Lower water levels limits withdrawals for cooling
  - Higher water temperatures also limit use for cooling

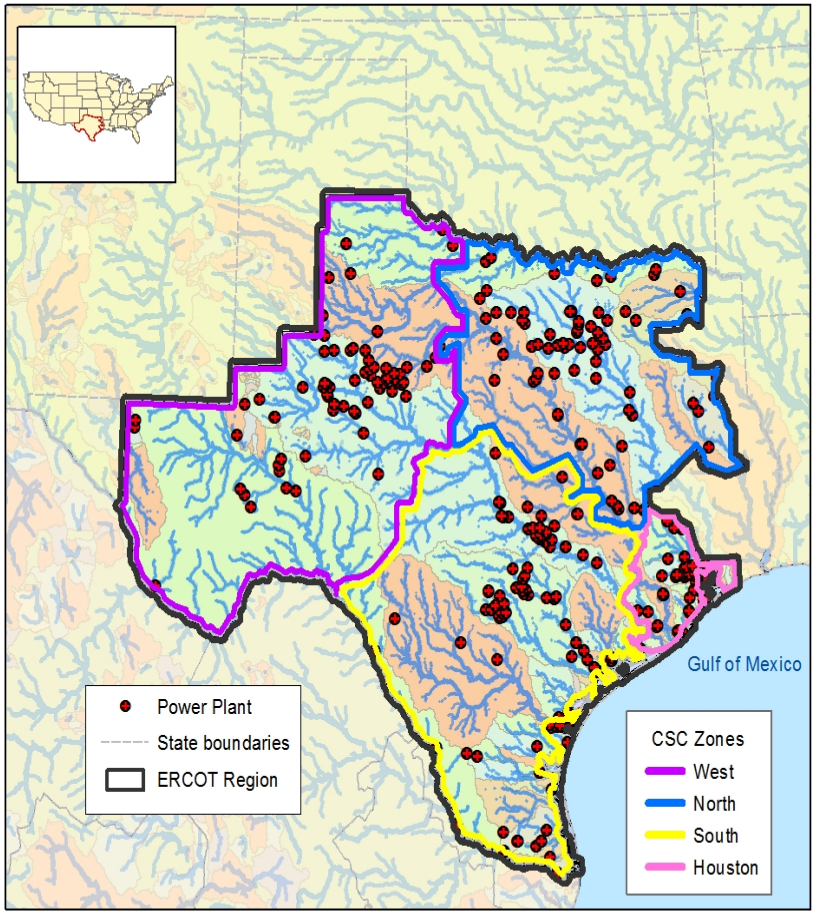
Recent Examples in U.S.

- Southeast U.S. in 2007
  - Nuclear and coal-fired plants in TVA system were forced to shutdown or curtail operations. Intake water exceeded 90F for 24 hours.
- Mississippi River in 2006
  - Affected nuclear plants in Illinois and Minnesota. Drought and heat wave warmed intake water
- Texas, 2011
  - A large power plant was forced to reduce operations at night because of extreme heat and insufficient water for cooling

(Sources: Argonne, 2012; Galbraith, 2011)

A Case Study Simulation

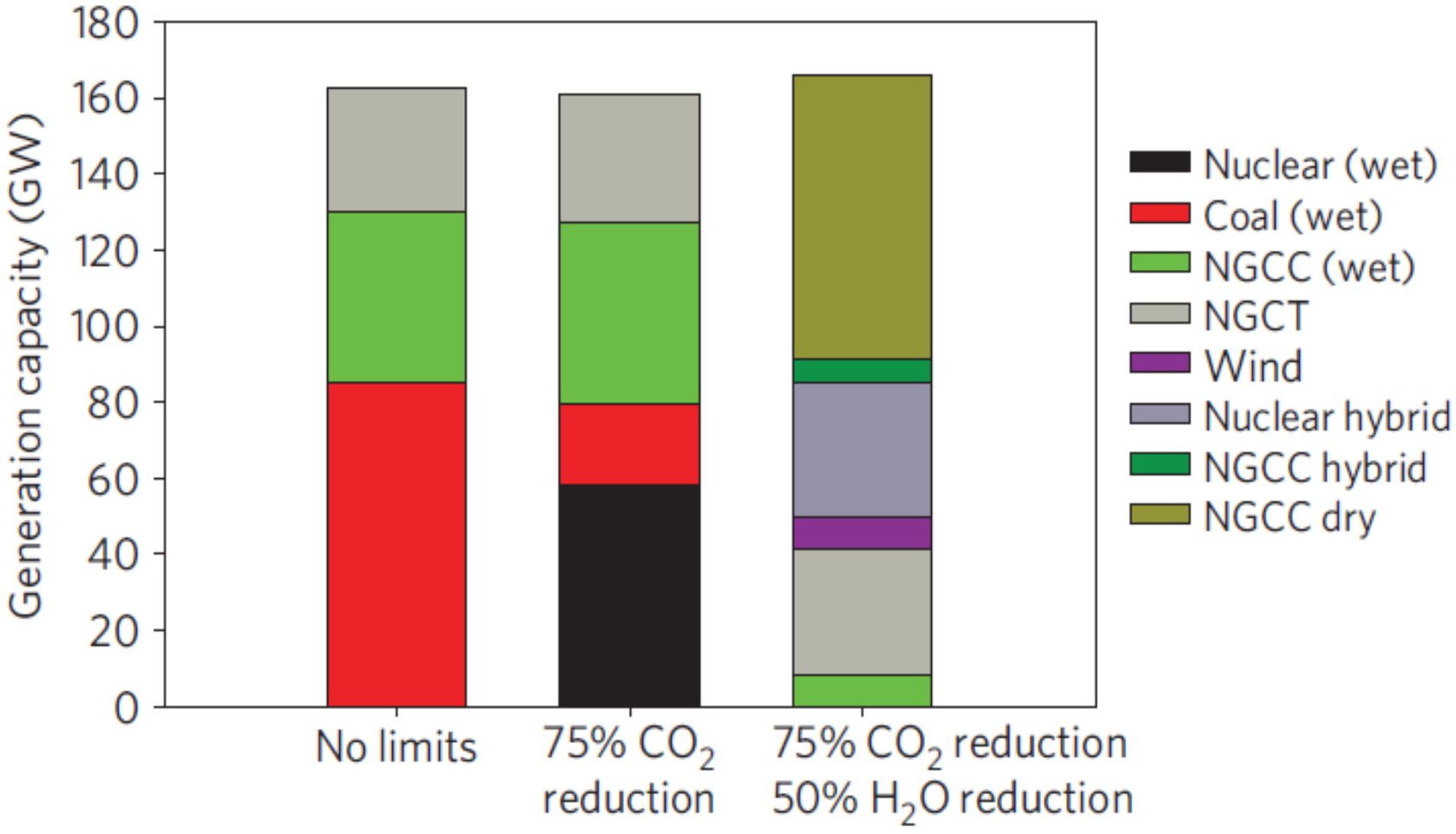
- Case Study: Texas (ERCOT)
- Historical week: August 14-20
- Assume drought conditions (e.g., 2011) cause 9 units (13 GW) with once-through cooling to go offline
- Impacts:
  - Cost increase of $28M for week (14%)
  - Unmet demand of 0.6% in North and Houston (transmission constraints)
- If No Transmission Constraints
  - Cost increase only $8M (9.5%)
  - No unmet demand



Alternatives for Adaptation

- Lower-Water Generation Technologies
  - Thermal units with low-water or dry cooling
  - Non-thermal technologies (wind, solar, etc)
- Increase the capacity of transmission grid
  - Droughts rarely hit all water basins
  - Excess capacity could exist elsewhere in grid
- Reduce Electricity Demand During Droughts

Generation Mix: Water vs. CO_2



Research Questions

- What combination of strategies is lowest cost?
  - New low-water generation units
  - New transmission lines
  - Adaptive demand
- … Under Uncertainty?
- Interactions and tradeoffs with other sectors
  - Agriculture/irrigation?
  - Water Sector?

Challenges (I)

- Multi-Scale Problem:
  - Model changes in gen/trans over decades
  - Model hourly constraints on generators

- Appropriate Regional Scale
  - National? Interconnect? NERC regions? ISOs?
  - Need to resolve generation units, transmission lines, waterbasins and subbasins
  - Must interact with regional/national economic model

Challenges (II)

- Uncertainty Treatment
  - This is a decision under uncertainty
  - This problem confounds most known techniques
- Mitigation and Adaptation Synergies
  - “Decarbonize the electric sector”
  - The SAME infrastructure
  - What should the design/operations/market look like?

Questions?