AI's *Energy Crisis* Is Not What You Think

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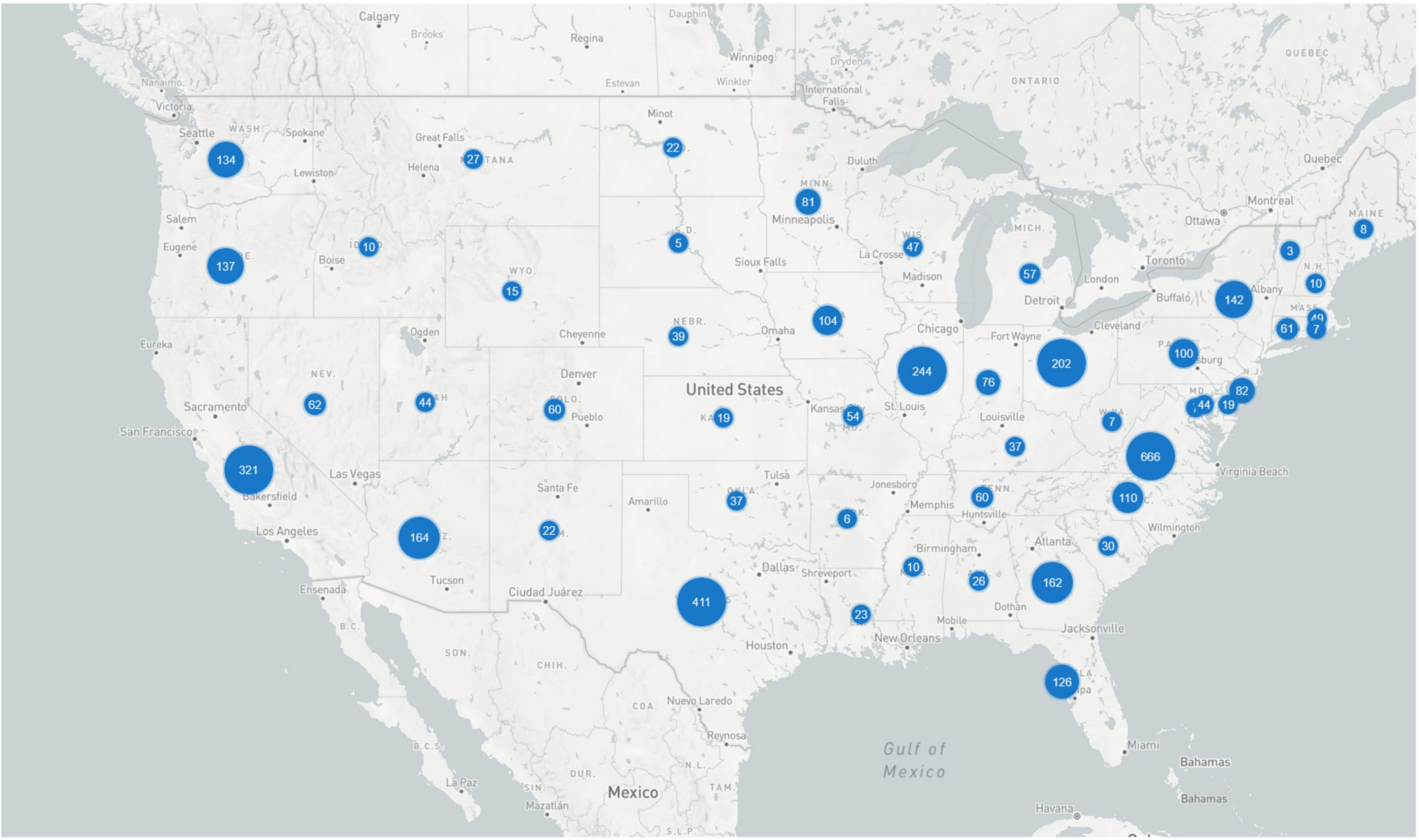
The AI “Energy Crisis”

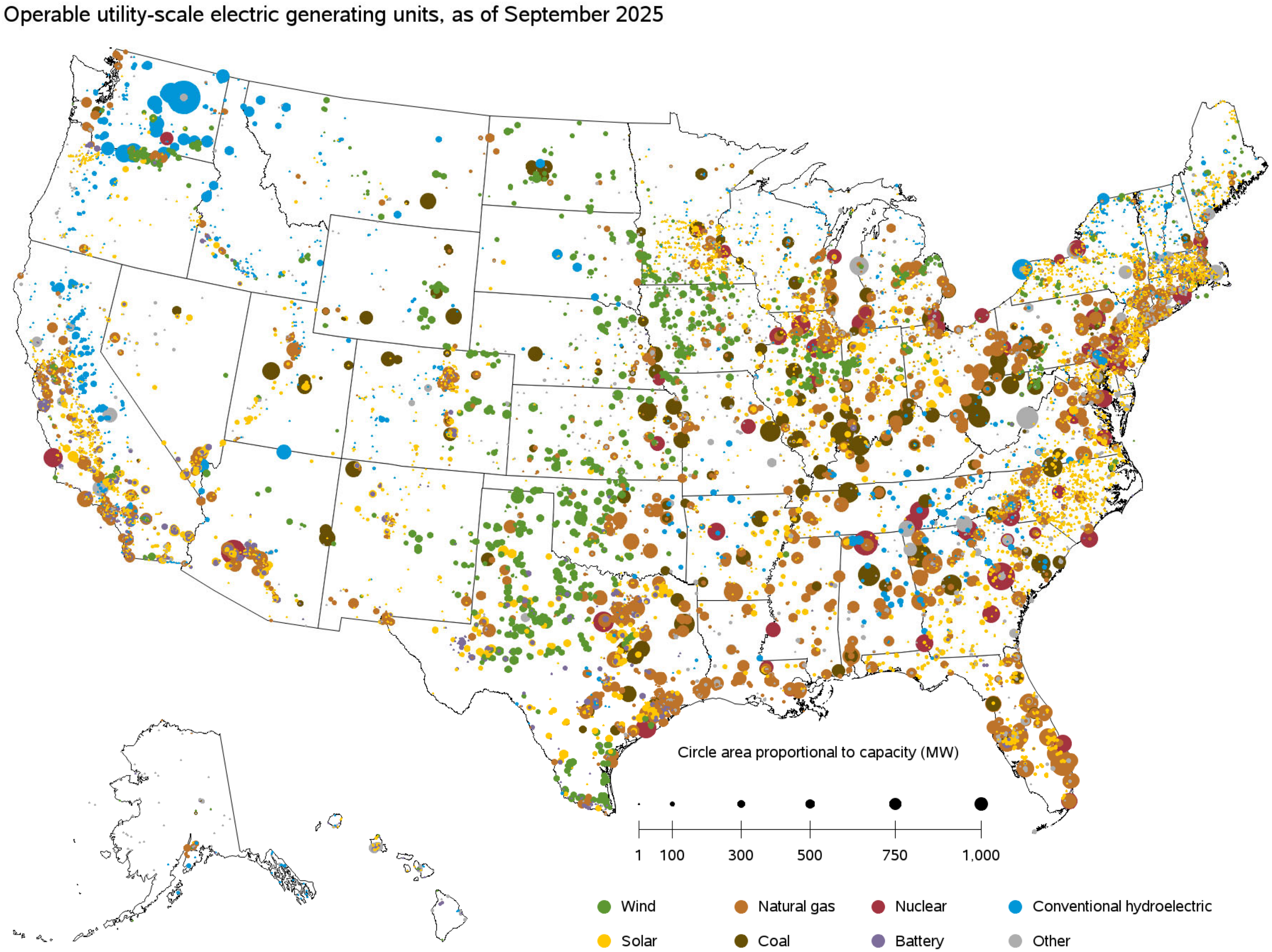
- Data Centers currently consume ~5 percent of grid supplied electricity in the United States
- Data Centers could consume more than 10 percent of US grid-supplied electricity in the United States within the next three years
- Many Data Centers have been and are planning to be built near major population centers
  - Loudoun County, VA (Data Center Alley)
  - Dallas, TX
  - Silicon Valley, CA
- Proximity to major internet exchanges, fiber optic networks, and power availability, drive data center location decisions
- AI Energy Crisis: Current generation capacity and transmission infrastructure in US cannot reliably support anticipated load growth at these types of locations

Number of Data Centers By State



Source: www.DataCenterMap.com/usa

Generation Units by Technology



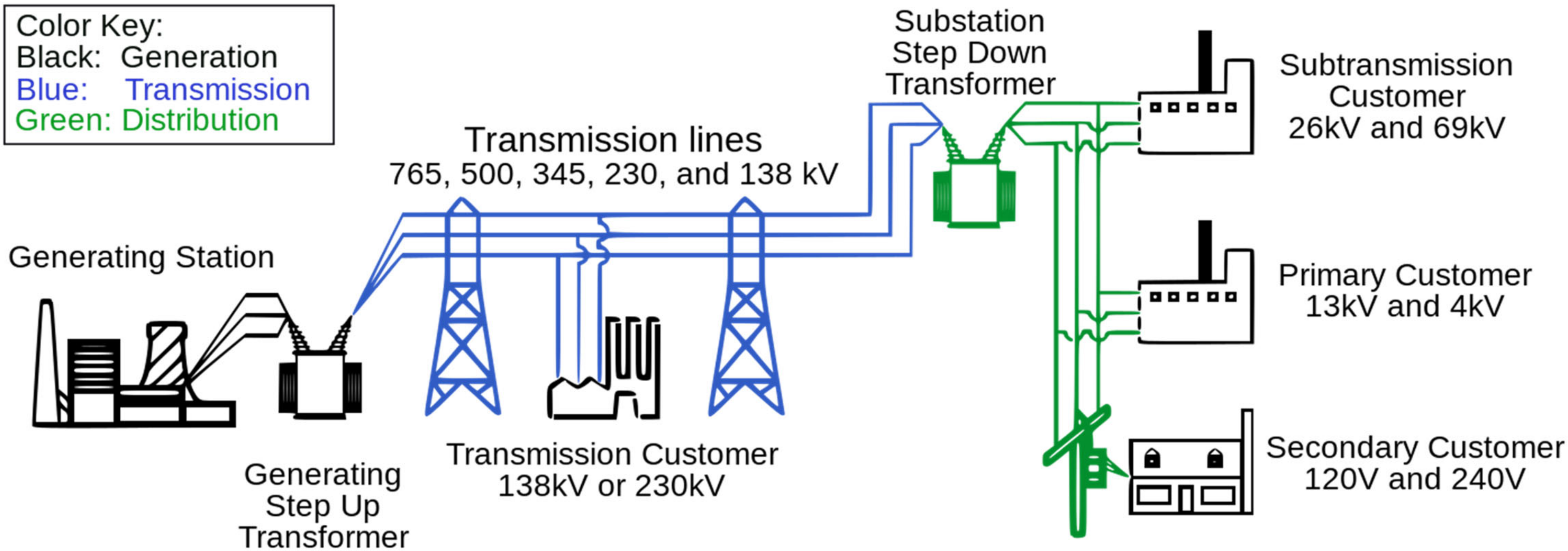
Data sources: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report' and Form EIA-860M, 'Monthly Update to the Annual Electric Generator Report.'

A Little Electricity and Energy Industry Background

Technology of Electricity Supply

- Four stages of production process
  - Generation
    - Production of electricity
      - Convert raw energy to electrical energy
        - » Heat, Water, Wind, Solar, Geothermal, Nuclear
  - Transmission
    - High-voltage transportation of electricity
    - High-voltage transmission reduces line losses
    - Bi-directional flows in network
  - Distribution
    - Low voltage distribution to final consumers
    - Uni-directional flows
  - Retailing
    - Purchase of wholesale electricity and sell to final consumers

Electricity Supply Industry



Four Stages of Electricity Supply

Generation—Production of Electricity

Transmission—Movement of Electricity at High Voltage over Long Distances

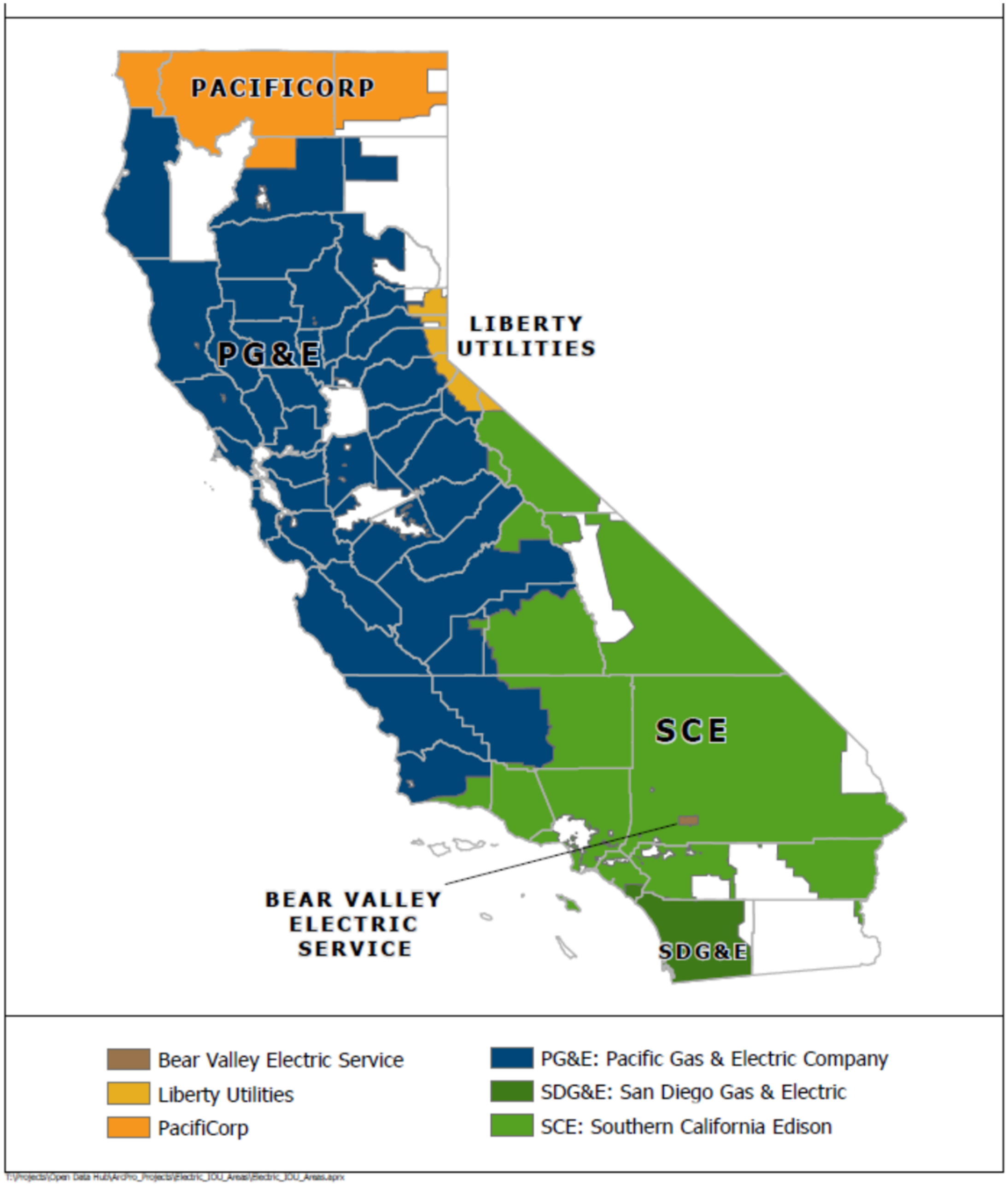
Distribution—Movement of Electricity at Low Voltage to Final Customers

Retailing—Sales of Electricity Delivered to Final Customers

US Industry Structure Until 1990s

- Vertically-integrated, geographic monopolies, regulated by state public utilities commissions (PUCs)
  - Vertically-Integrated--Single firm is responsible for all four stages of production process
  - Geographic monopoly—Legal monopoly to supply electricity for service territory
  - Output price and new investment regulated by state PUC
  - State PUC sets retail price of electricity firm can charge and determines whether generation investments are “prudent”
    - Prudent investment can receive cost recovery through “good utility practice”
- Regulatory Bargain—Firm required to serve all demand at price set by state regulator in exchange for regulator setting this price to allow the firm an opportunity to recover all prudently incurred costs

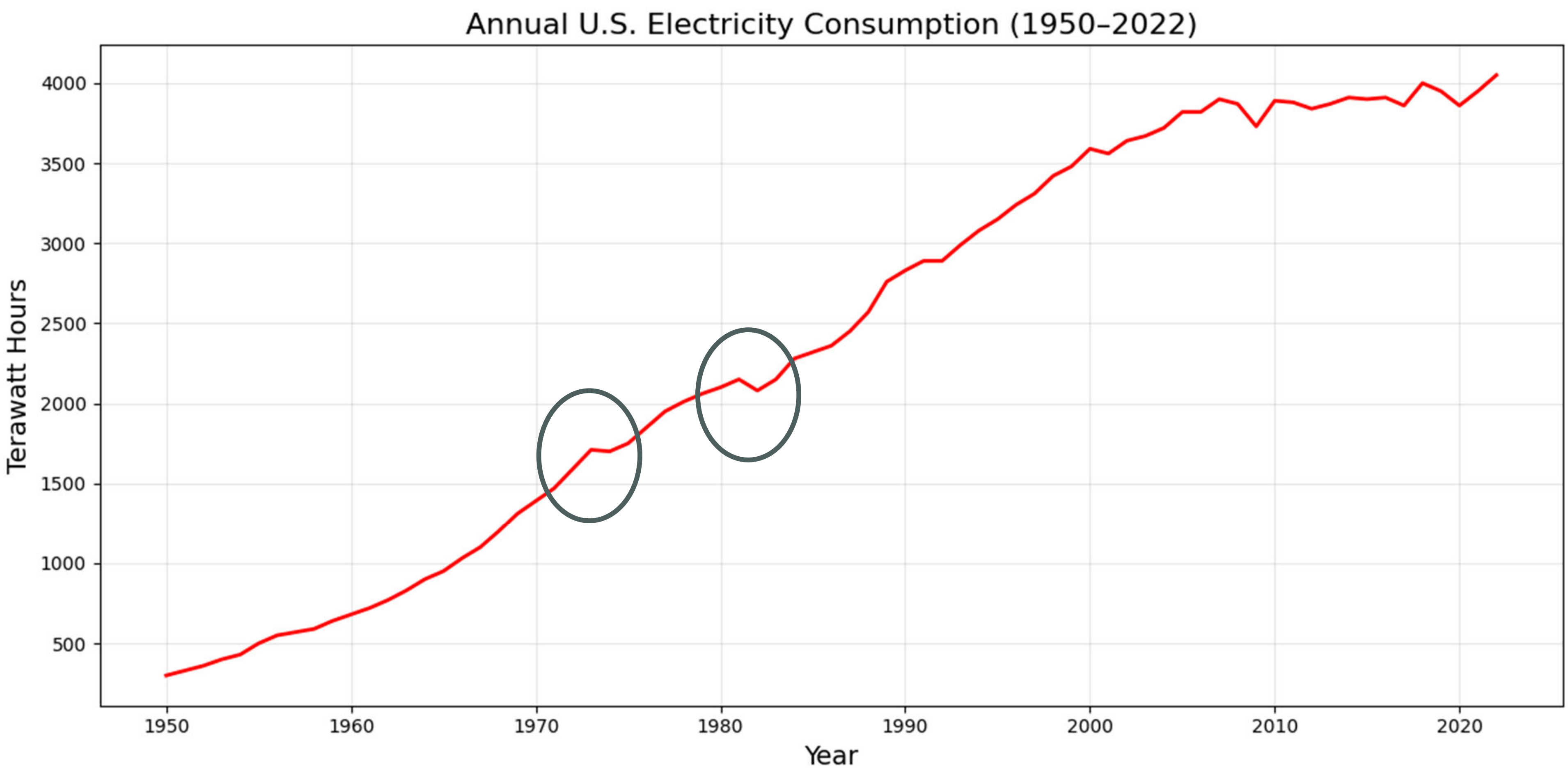
California Investor-Owned Utilities



Industry Outcomes Until Early 1970s

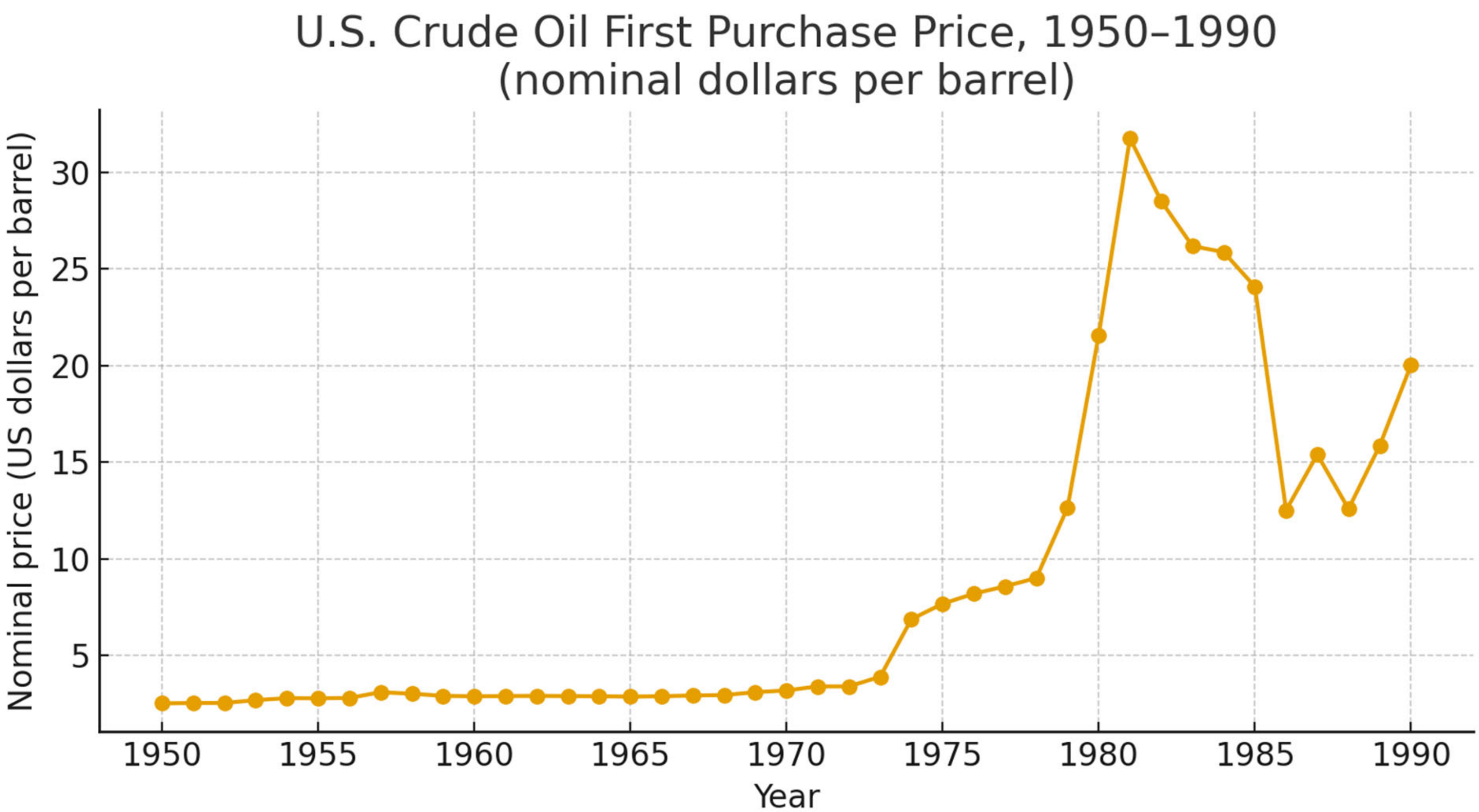
- Regulatory bargain and economic environment led to "world class" performance of US vertically-integrated geographic monopoly industry structure
  - Electricity supplied with very high level of reliability
  - New capacity growth matched and often exceeded demand growth
  - System losses (technical and theft) lower or comparable to other industrialized countries
- Nominal and real retail electricity prices fell continuously from early 1920s until early 1970s
- Electricity demand grew at an average rate of 7 percent per year from 1950 to 1979
  - Primarily fossil fuel fired generation—oil, natural gas, and coal--constructed to meet this load growth
  - Transmission network continuously expanded to accommodate demand growth where it occurred

Demand Growth Slowdowns in the Early 1970s and 1980s



Quiz Question: What happened in 1973 to early 1980s?

Oil Price Shock in the Early 1970s and 1980s



What Explains Success of Vertically-Integrated State-Regulated Monopoly?

- Very stable nominal fossil fuel prices, which was primarily fuel used to produce electricity
- Steady ~7 percent per year demand growth made new capacity planning relatively straightforward
- Key point: Vertically-integrated geographic monopoly can capture economies of scope between generation and transmission in investments and operations
  - Substitute construction of expensive generation unit near major load center for upgrade of transmission network and access to lower cost distant generation
- Regulatory process focused on achieving high level of reliability of meeting demands at all locations in service territory at low cost
  - No renewables mandates, no energy efficiency mandates
- State PUC knows exactly who to punish when "the lights go out"—Management of vertically-integrated geographic monopoly

State PUC Price Regulation

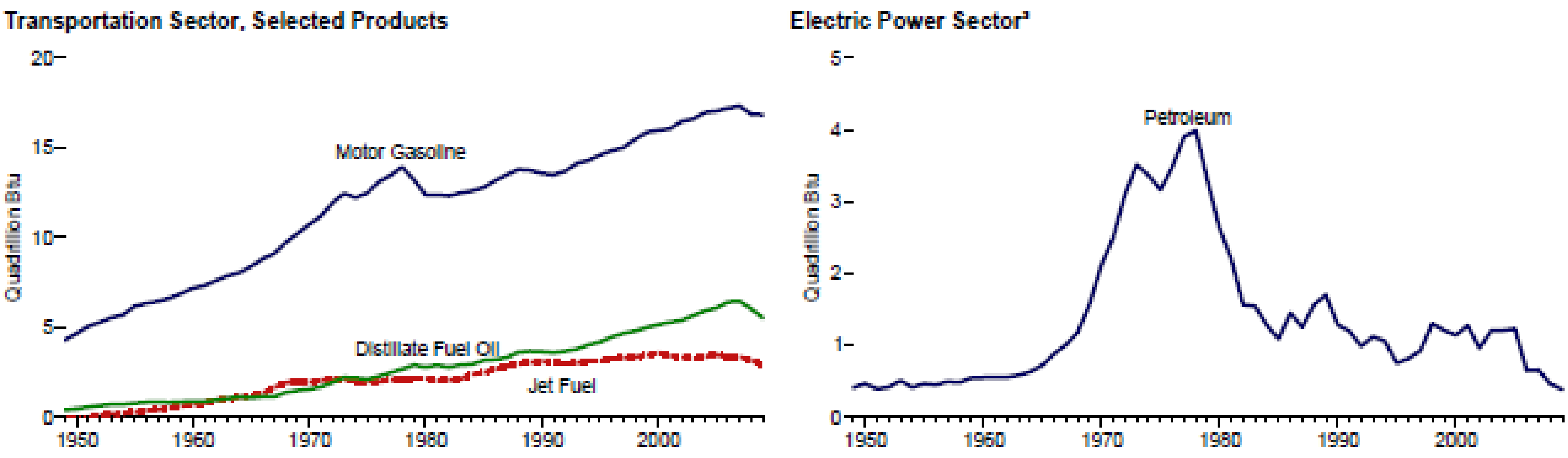
- Regulatory process dominated by
  - *Lawyers* managing administrative law process
  - *Accountants* enforcing standardized system of accounts for financial reporting
  - *Engineers* that understand technology of production and delivery of electricity
- Regulatory economics focused on rate design and cost allocation
  - Fixed charge, variable charges for each product sold
  - Allocation of fixed costs to different products supplied by monopolist
- This industry structure best suited to a stable and predictable economic environment
  - A prudently incurred cost in previous rate-setting cycle should be a prudently incurred cost in current rate-setting cycle

Response to Rapid Increase in Fossil Fuel Prices in 1970s

Much Higher Oil Prices Led to a Search for Substitute Sources of Electricity

(Coal and Nuclear)

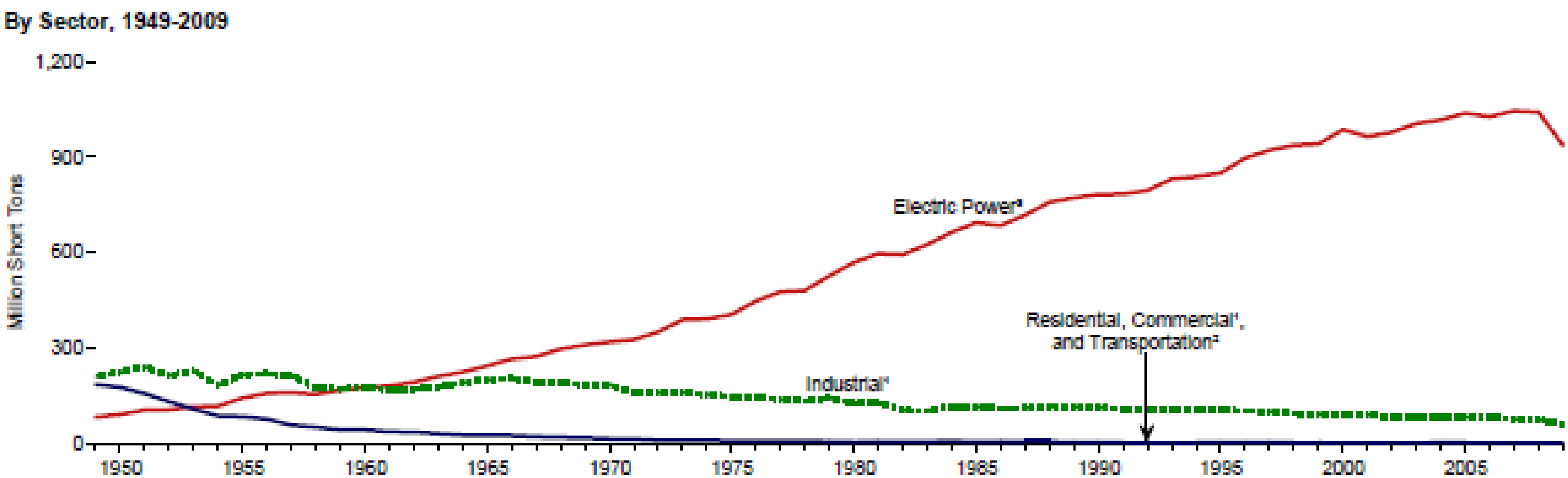
Changing Uses of Oil



Source: EIA, Annual Review of Energy

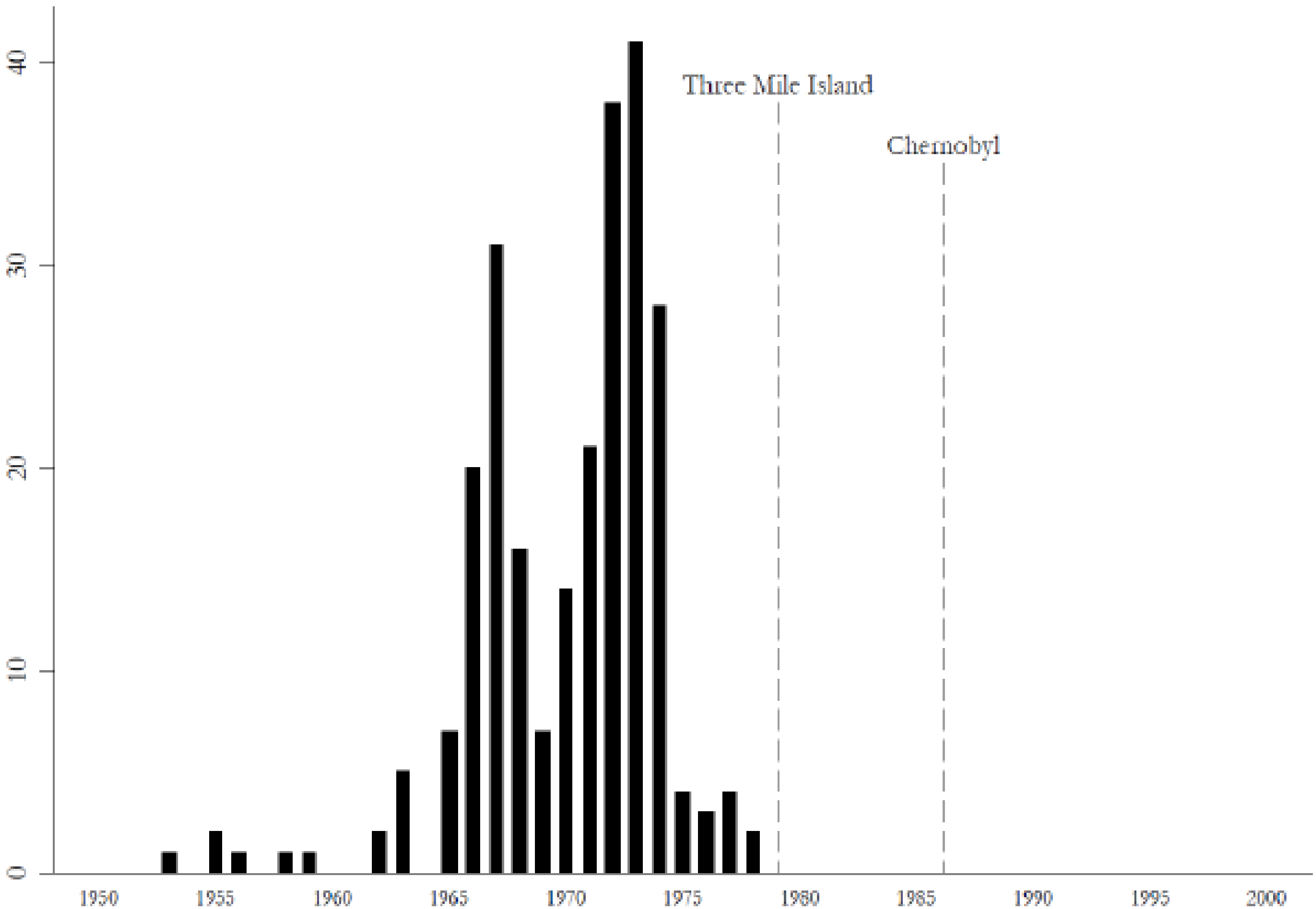
Coal Use By Sector

Consumption



Source: EIA, Annual Review of Energy

Figure 1: U.S. Nuclear Power Reactor Orders 1950-2000



Source: Author's tabulation based on U.S. DOE (1997).

Reproduced from Lucas W. Davis (2012) “Prospects for Nuclear Power,” *Journal of Economic Perspectives*, Volume 26, Number 1—Winter 2012—Pages 49–66

Rationale for Re-structuring

- Rapid run-up in fossil fuel prices and accompanying increase in real electricity prices slowed demand growth
  - Nuclear capacity (with long construction lead times made even longer by Three Mile Island event) was built in anticipation of 7% growth rate
    - Nuclear thought to be more economic than fossil fuel (except for coal-fired) plants, given expected future oil and natural gas prices at the time
  - Many nuclear power plants were not immediately needed at the time they were completed or expected to be completed
    - A large number were cancelled during construction process after enormous expenditures were already made
  - State-PUC regulatory process disallowed some of these expenditures putting investor-owned utilities (IOUs) in financial hardship
    - Some costs were passed on to consumers, which further increased real electricity prices
- Disallowances of new investments by state regulatory commissions slowed new investment
  - Fear of future disallowances caused IOUs to slow their investment plans
- Raised question of how anticipated load growth in major demand centers would be met

Figure 2: Construction Costs for U.S. Nuclear Power Plants Completed 1960-2000

Source: Federal Energy Regulatory Commission, Form 1.

Reproduced from Lucas W. Davis (2012) "Prospects for Nuclear Power," *Journal of Economic Perspectives*, Volume 26, Number 1—Winter 2012—Pages 49–66

Cost Overruns: Diablo Canyon

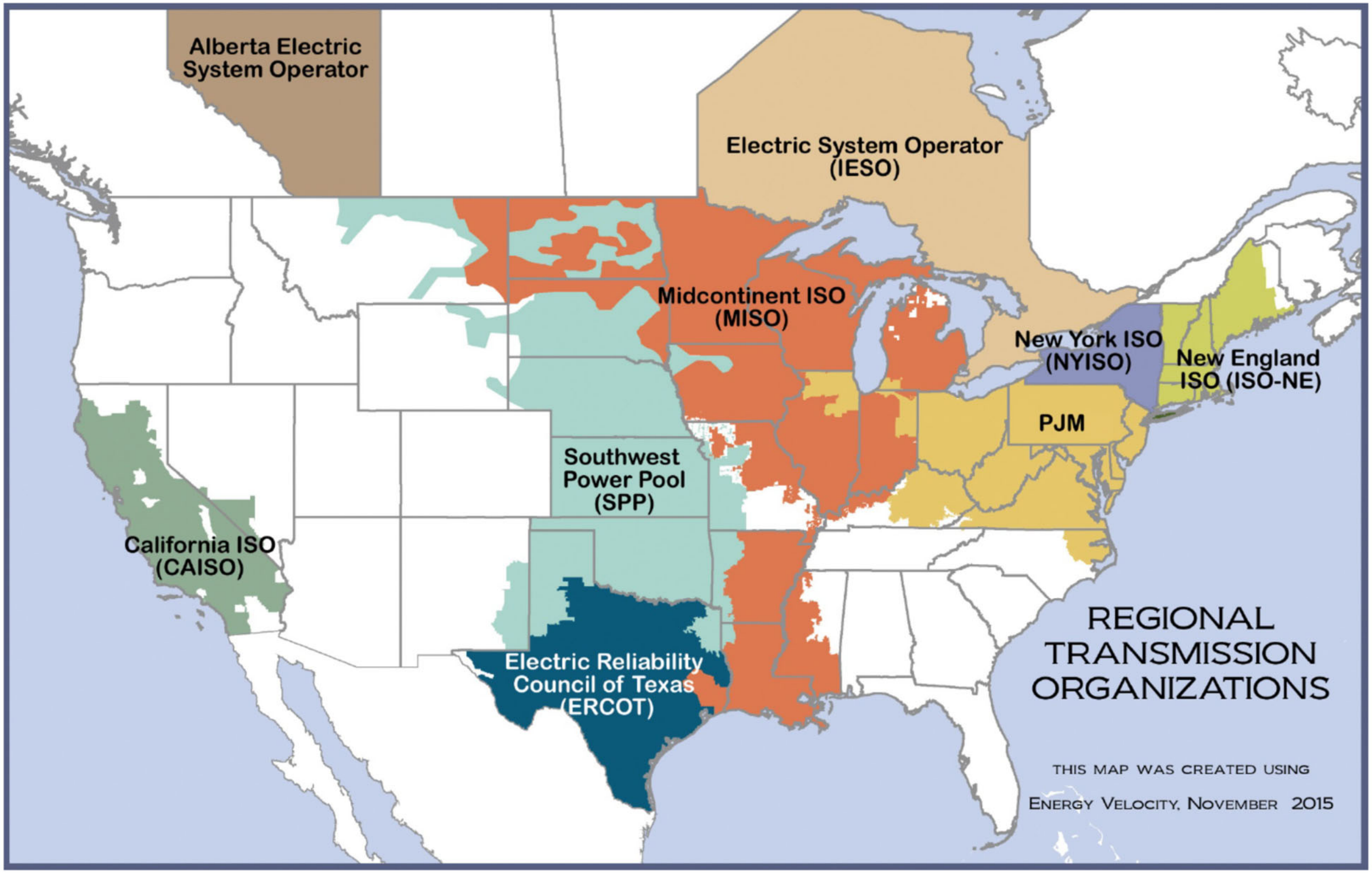
- Construction begins in 1966 with a projected cost of $1 billion
- Scheduled for completion in 1974
- Earthquake fault ‘discovered’ in 1971
- Nuclear Regulatory Commission orders redesign in 1976
- Three-Mile Island Accident in 1979 leads to additional redesigns, tighter regulations
- By 1981 Projected Costs were $2.4 Billion
- Operation begins 1985
- Final cost of construction was $5.7 billion

Effort by Federal Government to Address New Investment Problem

- Public Utility Regulatory Policy Act (PURPA) of 1978 enacted to encourage increased energy efficiency
  - Created market for electricity produced from renewable fuels and waste products
- PURPA required investor-owned utilities to purchase power from Qualifying Facilities (QFs)
  - QFs are primarily cogeneration and renewable sources
- Several rapid demand growth states signed a number of PURPA contracts at extremely high prices—CA, NJ, NY, PA, and TX
  - Note all of the above states subsequently formed or joined ISOs/RTOs

What is an Independent System Operator/ Regional Transmission Organization (ISO/RTO)?

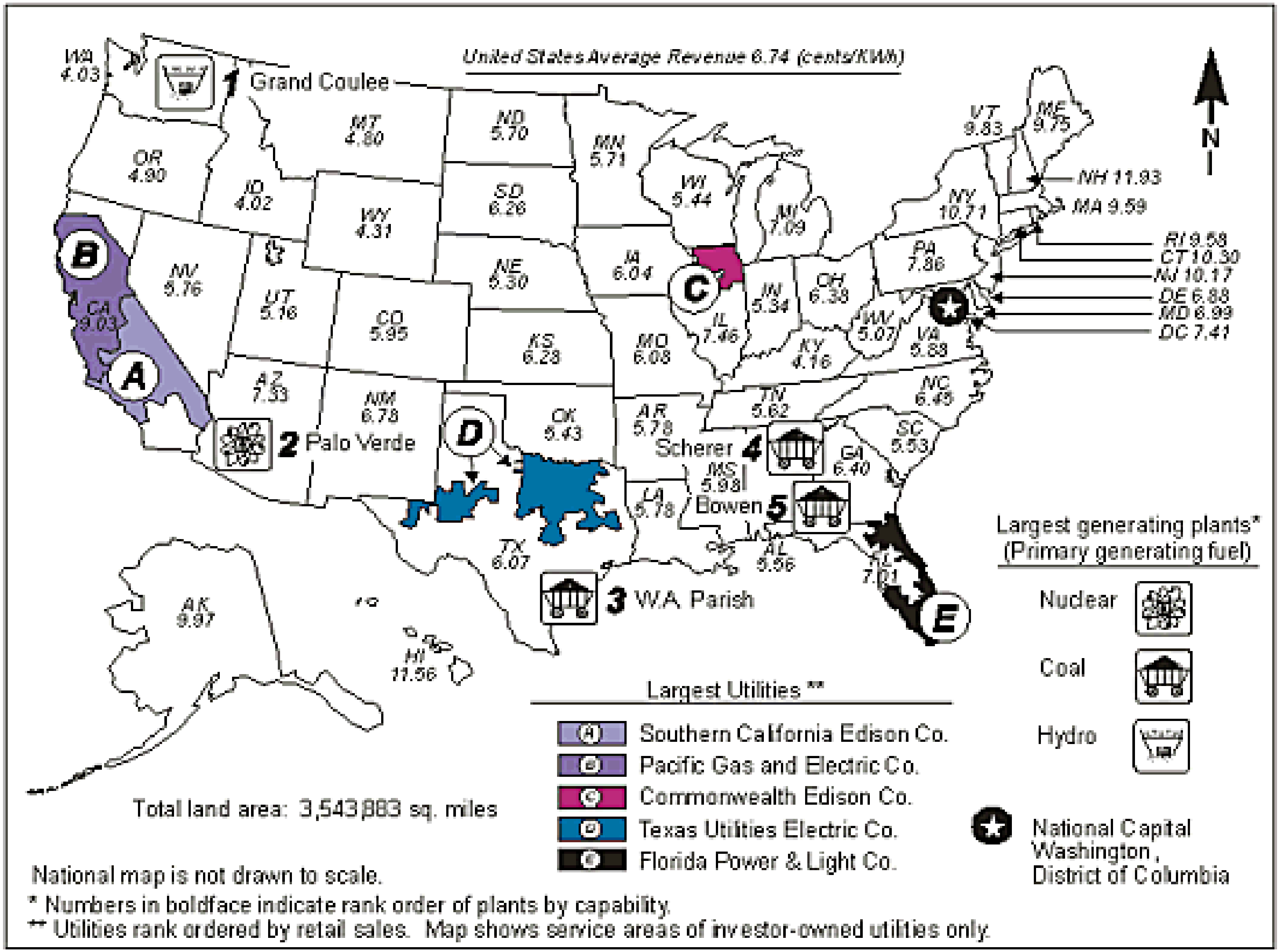
Current US ISO/RTOs



What is an ISO/RTO?

- Expands geographic footprint of transmission network over which generation units can be dispatched to serve locational demands
  - All current ISOs in US combine multiple service territories of vertically-integrated utilities, even in single state ISOs
- Replace explicit price regulation with market mechanisms to set wholesale prices and determine how electricity is supplied throughout control area of ISO/RTO
  - More generation unit owners capable of supplying energy to serve demand at all locations in larger transmission network
- Price-regulated open access to transmission network
- Individual states can elect to have price-regulated open access to local distribution networks—Retail competition

Why Might CA and Eastern States Think RTOs Would Lower Consumer Prices?



Potential Downsides of ISOs

- Significantly more difficult to capture economies to scope between generation and transmission
  - RTO's transmission network is operated as open access
  - RTOs transmission expansion process cannot favor certain generation investments
- In wholesale market regime no single entity is responsible for ensuring system demand is met under all possible system conditions
  - Independent System Operator (ISO) can only operate market and grid with resources offered into market
  - Generation unit owners can only supply energy from the generation units they control
  - Retailers can only withdraw energy supplied to wholesale market

Potential Downsides of ISOs

- Greater role for federal energy regulator
  - Participants in all ISOs except ERCOT are engage in interstate commerce
  - Market rules of all ISOs except ERCOT must be approved by Federal Energy Regulatory Commission (FERC)
- Former vertically-integrated utilities still own and maintain transmission grid in their service area
  - Transmission prices regulated by (FERC)
- ISO operates transmission grid and wholesale market
- Creates opportunities for disagreements about goals and methods to achieve them between State PUCs and FERC that can raise costs to consumers

Potential Downsides of ISOs

- **Unique feature of grid-supplied electricity**-—Currently a customer only gets a reliable supply with desired voltage and frequency if nearby customers do too
- Random curtailment will occur if aggregate supply is less than aggregate demand (rolling blackouts across distribution grids)
  - Implication: No customer faces full expected cost of failing to procure adequate energy in forward market
  - Cannot curtail specific customers during rolling blackouts, only all customers in a specific region of grid
- Conclusion: Because of existence of this “reliability externality” ISO markets have a *long-term resource adequacy (LT-RA) mechanism*
  - Ensure adequate supply of energy to meet system demand under all possible future system conditions and allowed short-term wholesale prices

Capacity-Based LT-RA

- Capacity-based LT-RA for ISO/RTO with dispatchable thermal resources
  - Coal, natural gas, fuel oil, and nuclear
- Major concern is sufficient generation capacity to meet system demand peak
  - Assign all retailers firm capacity obligations equal to multiple of annual peak demand
  - Between 110 and 120 percent of peak demand
- Firm capacity is the amount of **energy** generation unit can produce under stressed system conditions
  - For thermal resource this is typically equal to nameplate capacity times the availability factor of unit
  - Availability factor of a generation unit is percent of hours of the year unit is available to produce energy

Capacity-Based LT-RA

- Firm capacity construct with thermal resources based on assumption that availability (ability to produce energy) of individual thermal resources are independent random events
- Suppose region has peak demand of 1,000 MW and ISO composed of equal sized thermal units each with availability factor of 0.9 and outages are independent across units
  - With 100 MW units, then each unit has firm capacity of 90 MW and a 1.17 times peak demand firm capacity requirement ensures system peak is met with 0.96 probability with 13 units
  - With 20 MW units, then each unit has firm capacity of 18 MW and a 1.17 times peak demand requirement ensures system demand peak is met with 0.999 probability with 65 units
- Key assumption for this reliability outcome with thermal resources is independence of availability of individual generation units
  - This is a terrible assumption for intermittent hydro, wind and solar resources that have extremely high degree of contemporaneous correlation across units

Firm Capacity of Intermittent Renewables

- Firm capacity of hydroelectric resources is typically based on historical worst hydrological conditions, but this does not prevent energy supply shortfalls because of new records for low water conditions
  - For the case of Colombia see, McRae and Wolak (2016) "Diagnosing the Causes of the Recent El Nino Event and Recommendations" (on web-site)
- Firm capacity of a MW of wind or solar capacity declines with share of wind or solar energy in system demand because of high degree of contemporaneous correlation in output across locations
  - For an example from California, see Wolak (2016) "Level versus Variability Trade-offs in Wind and Solar Generation Investments: The Case of California" (on web-site)

Firm Capacity of Intermittent Renewables

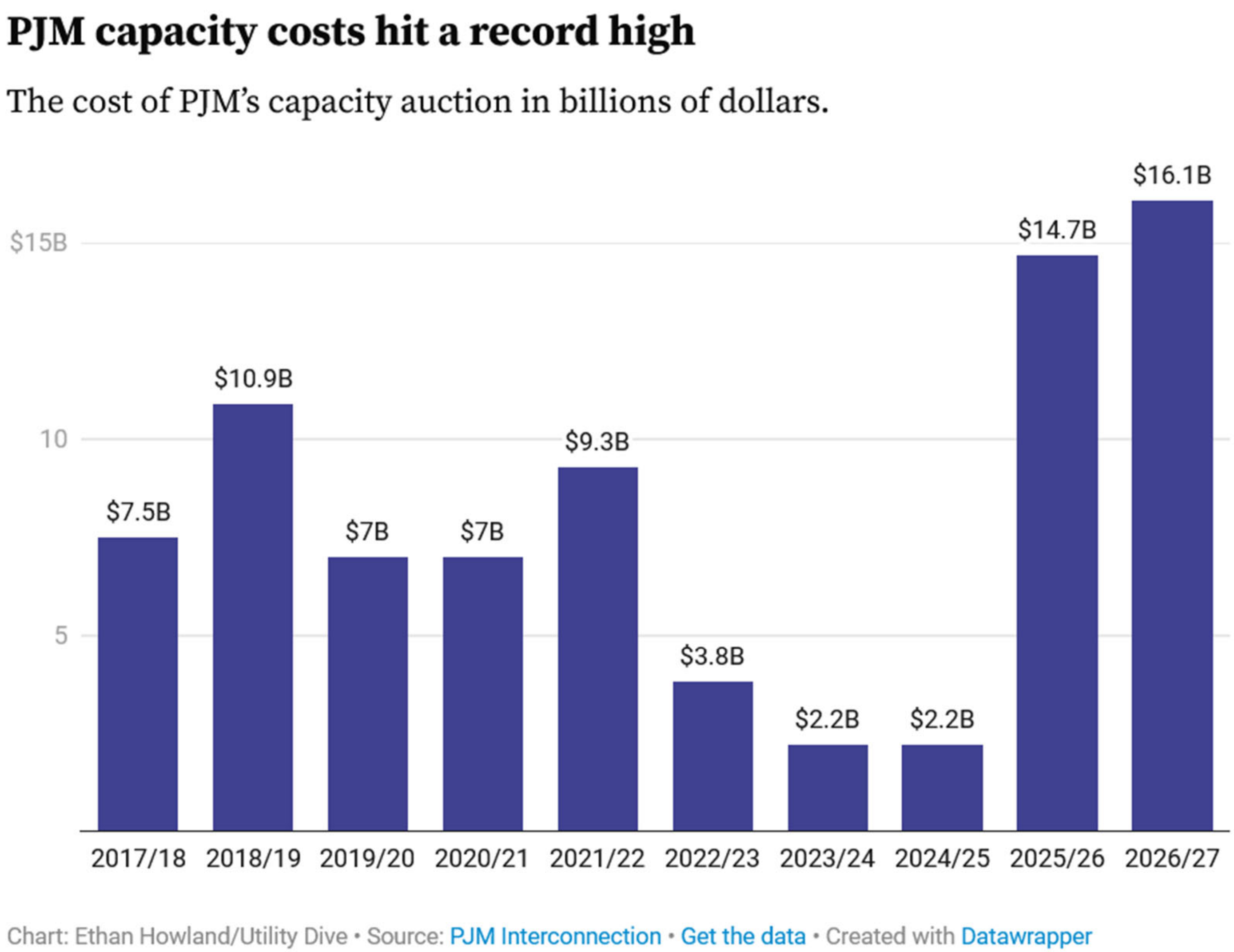
- In general, assignment of firm capacity to intermittent wind and solar resources involves ”engineering alchemy” and “political compromise”
  - If stressed system conditions occur when it is dark or when there is no wind, then firm capacity of solar and wind unit should be zero
- Supply shortfalls in August 2020 in California and February 2021 in Texas are cases for this point
  - See Wolak (2021) “Long-Term Resource Adequacy in Wholesale Electricity Markets with Significant Intermittent Renewables,” (on web-site)

Firm Capacity of Imports

- Capacity-based approaches poorly suited to import-dependent regions
- Generation source of an electricity import to a region is a financial construct
  - Two connected bathtubs view of electricity imports–If more power poured into tub A than is draining from tub and less power is poured into tub B than is draining from tub, electricity flows from tub A to B
  - Impossible to know which generation unit in region A is producing energy flowing into region B
- **Conclusion:** Capacity-based construct for long-term resource adequacy is poorly suited to intermittent renewables and import-dependent regions
- Important Note: Because renewables must be produced where water, wind or solar resource exists, import share in most ISOs likely to increase as intermittent renewable share increases

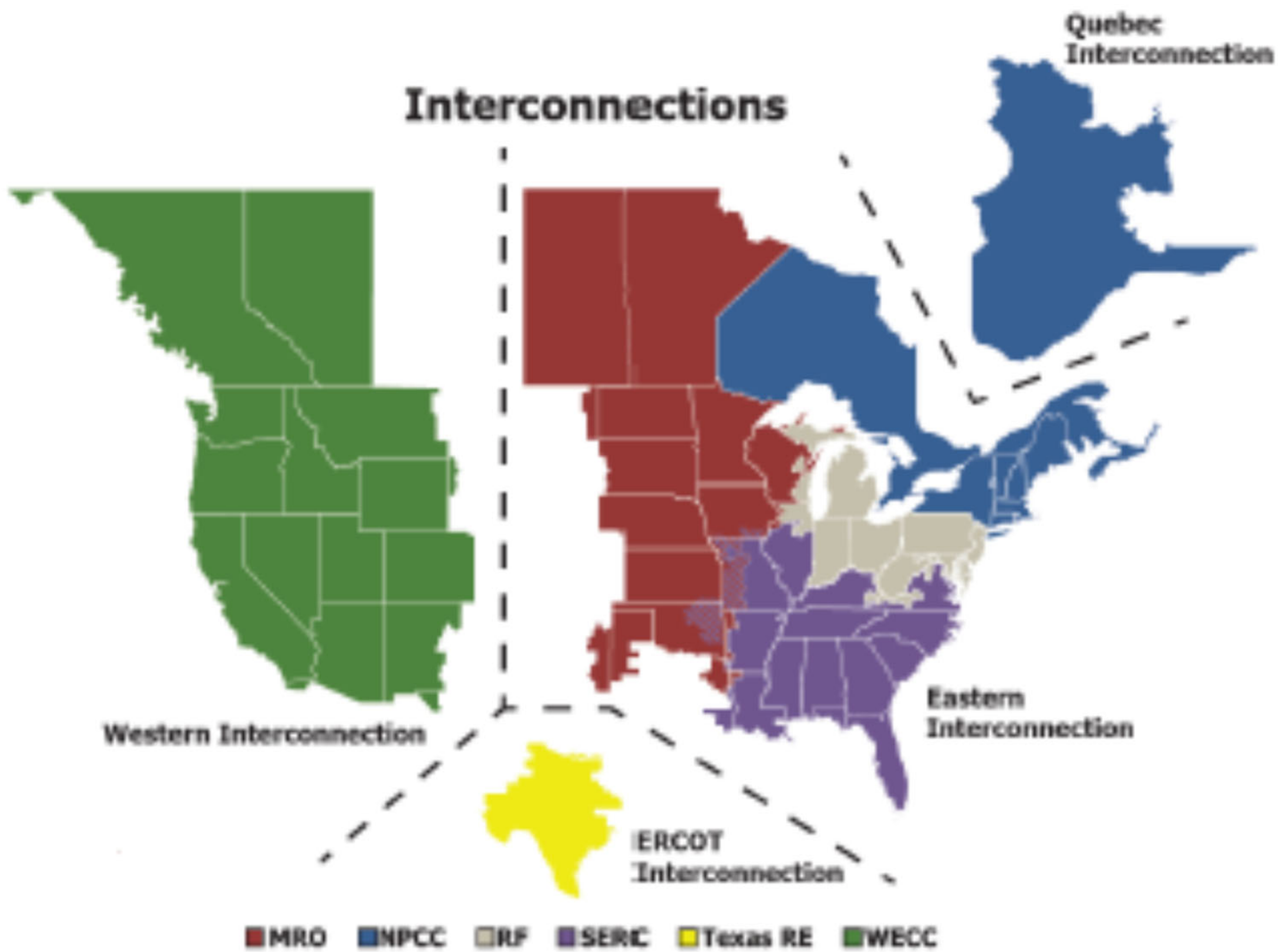
Capacity-Based LT-RA Mechanisms Can Be Expensive

- PJM's 2026/2027 capacity auction cleared 134,205 MW at a price of $329.17/MW-day

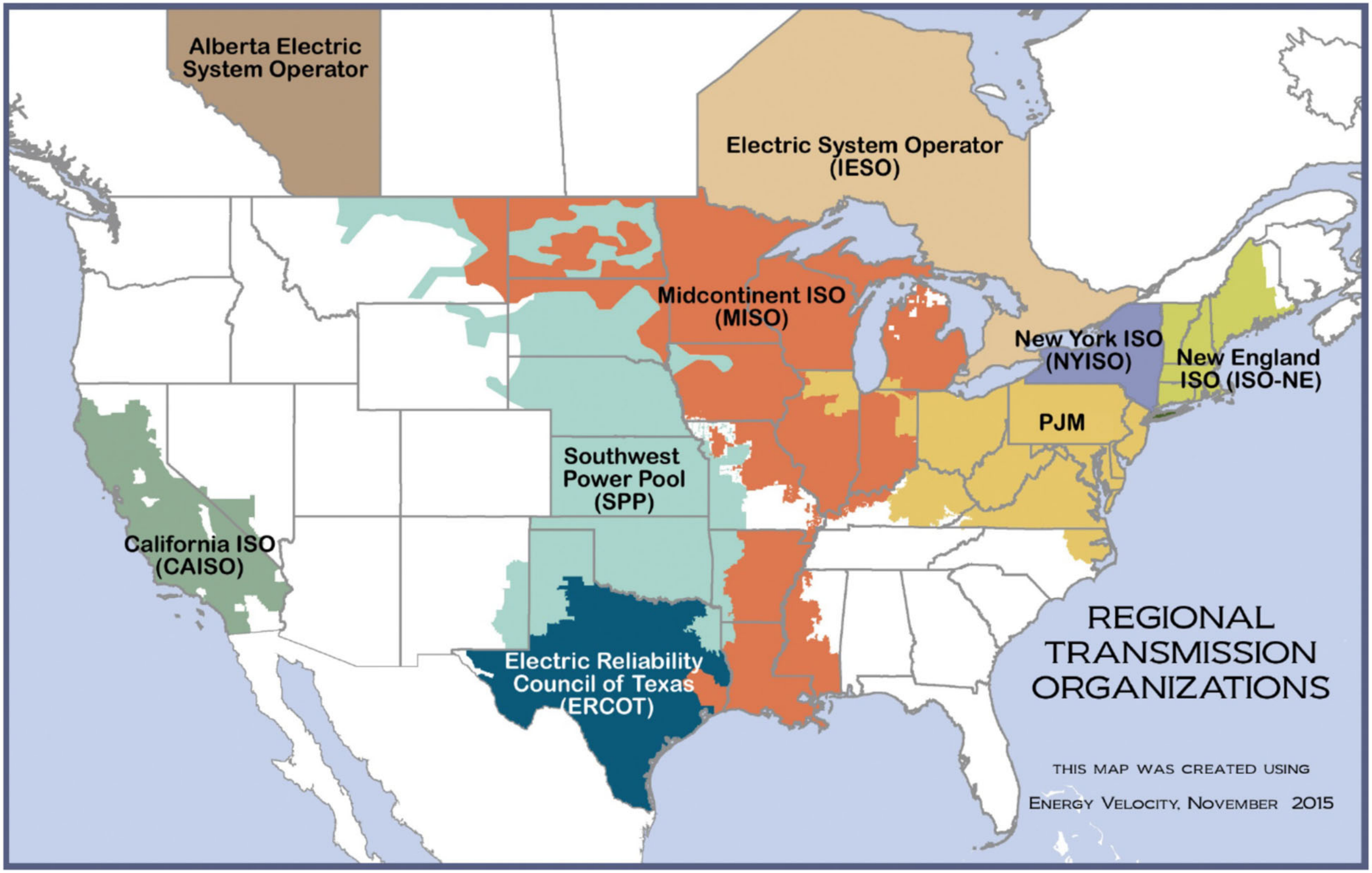


A Suggested Way Forward with Significant of Intermittent Renewables

North American Interconnections



Current US ISO/RTOs



Incomplete Coverage of US with ISOs

- All US ISOs/RTOs employ similar market designs
  - Day-ahead financial market and real-time imbalance market
  - Locational marginal pricing reflecting as-offered and as-bid cost of serving additional MWh of demand at a location in grid
- All boundaries or "seams" between ISOs represent potential costs to producers and consumers
  - Missed opportunity to optimize joint footprint in utilizing generation and transmission resources
- Expanding geographic footprint of existing US ISOs would make more efficient using of existing resources
  - Mansur, E.T. and White, M.W. (2012) "Market Organization and Efficiency in Electricity Markets," found significant evidence in favor of this outcome from PJM expansion (on Erin T. Mansur's web-site)

It's Not Just Data Center Demand

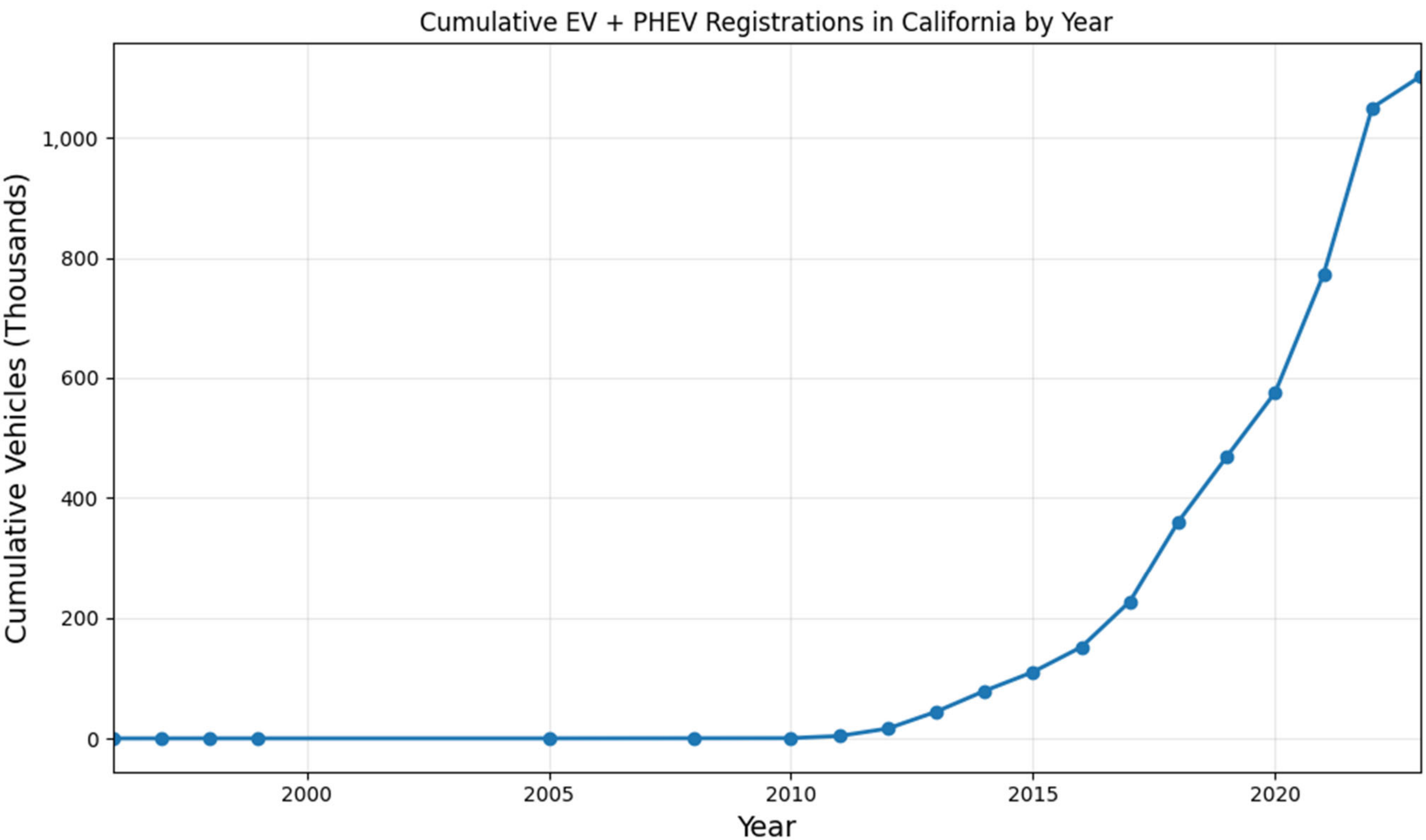
Particularly in California

Solving the AI "Energy Crisis"

- Roughly 40%-50% of electricity used at a data center is used for cooling and airflow systems and lighting
  - Remaining electricity demand is for servers, storage and network equipment
- Locating data centers in cooler climates can reduce cooling needs
  - Desire for proximity to major internet exchanges and fiber optic networks works against this desire
- Electricity demand flexibility at Data Centers is possible
  - On-site electricity storage to shift demand when grid is less stressed
  - Shift workloads to other data centers to reduce electricity consumption at stressed data center
    - Could be enabled by Data Center build out at diverse locations, because of climate, and locational power prices, and investment in Internet infrastructure at that location

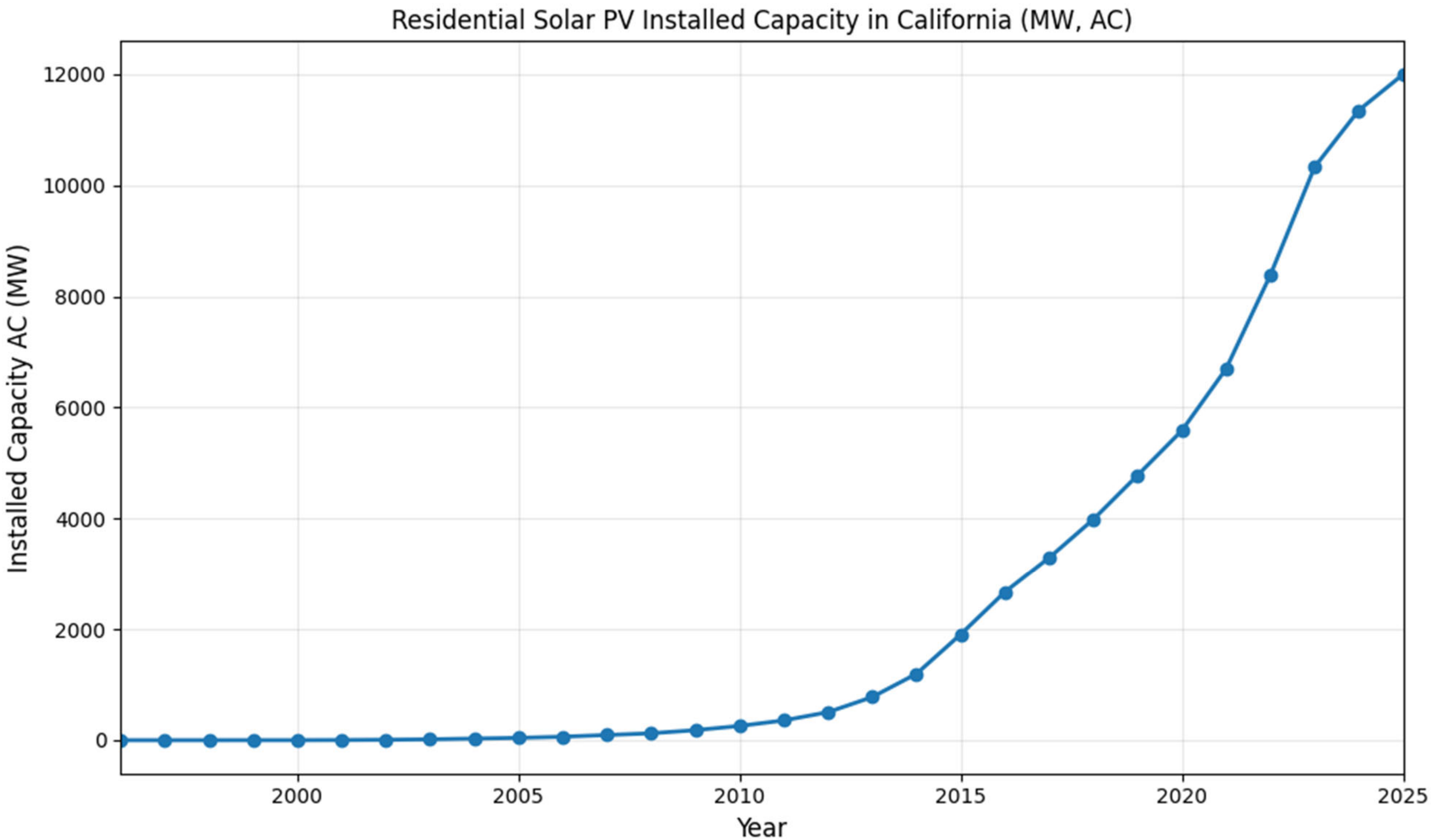
It's Not Just Data Center Demand

Electric Vehicles (EVs) and Plug-In EVs have created an annual demand for electricity to comparable to CA data center demand



It's Not Just Data Center Demand

Residential rooftop solar systems located behind the meter have created a substantial annual supply of electricity



Other Sources of Demand Reductions

- Shopping malls, which use roughly 50 percent of the electricity they consume for cooling, are exiting
  - An average of 1,170 shopping malls closed every year between 2017 and 2022.
  - US now has approximately **1,200** malls and it is projected that by 2028, there may be as few as *900* malls still in operation.
  - Projected that up to **87%** of large shopping malls may close over 10 years.
- Closed malls are empty for an average of **3 years and 11 months**.
- The number of malls declined **16.7%** per year from 2017 to 2022.
- The nationwide mall vacancy rate is **248%** higher than the overall average retail vacancy rate as of the fourth quarter (Q4) of 2024.

Information on slide taken from: https://capitaloneshopping.com/research/mall-closure-statistics/

It’s Not Just Data Center Demand

Despite having 321 data centers in California

- Annual demand for grid-supplied electricity in the CAISO control area has fallen each year from 2019 to 2023
- Annual peak demand for grid-supplied electricity has fallen three out of five years

Table 1.1 Annual system load in CAISO: 2018 to 2023

Year	Annual total energy (GWh)	Average load (MW)	% change	Annual peak load (MW)	% change
2019	214,955	24,541	-3.9%	44,301	-11.6%
2020	211,919	24,128	-1.7%	47,121	6.4%
2021	211,020	24,092	-0.1%	43,982	-6.7%
2022	210,879	24,059	-0.1%	52,061	6.4%
2023	203,268	23,207	-3.5%	44,534	-14.5%

Source: 2023 Annual Report of Market Issues and Performance, Department of Market Monitoring, California ISO, July 2024.

Regulatory Oversight is a Team Sport in ISO Regime

Summary: “Modern Regulation”

- Regulation changes from setting “just and reasonable prices” to setting “just and reasonable market rules”
  - Market rules that cause the actions of market participants to yield market prices that are “just and reasonable” for consumers and producers
- Modern Regulation is an economist and engineer-intensive process, not as lawyer and accountant intensive as “old school” regulation
  - Requires an understanding of how all firms are likely to behave given market rules
  - Power system engineering and economic incentives can interact to cause large winners and losers

Proactive Transmission Planning and Development

- Wholesale market regime has no entity with a financial interest in building out transmission network
  - Recall economies to scope between generation and transmission in former vertically-integrated monopoly regime
- Network expansions improve performance of imperfectly competitive wholesale market, but can also massively change financial position of market participants
  - Can increase amount of low-priced power than can displace high-priced power at load centers in a locational marginal pricing market
- Transmission network planning becomes more straightforward in intermittent renewables dominated market
  - Connect loads centers to rich renewable resource locations because different from fossil fuel units or nuclear units, power must be produced where renewable resource is located

Proactive Transmission Planning and Development

- Transmission planning and development process is major regulatory function in wholesale market regime
  - Configuration of transmission network impacts where generation units locate and what they are paid in short-term market
  - Similar logic applies to large loads, such as data centers
- All parties should therefore be involved in transparent transmission planning process and the implications of different transmission network configurations for their financial bottom line
  - All parties must have access to necessary data to perform analysis
- For more on these points see Wolak (2022) “Transmission Planning and Operation in the Wholesale Market Regime,” (on web-site).

Smart Sunshine Regulation

- Public release of all data submitted to and produced by system and market operator necessary to operate market and system and determine transmission upgrades and operation
  - Bids, schedules, real-time production, and consumption
  - Network model used to compute LMPs
- Public data release allows other entities to perform their own analyses
- Mechanism for regulator and market operator to commit to a transparent market design process
  - Any prospective entrant has same advantage as existing firm
- Because changes in transmission network and distribution network configuration can result in massive change in financial positions of different stakeholders
  - All relevant stakeholders should be equal participants in process

Monitor Market Performance

- Construct and compute intuitive indexes measuring “health of market” that can be publicly released
  - Vital signs of market, similar to pulse and blood pressure for human health
  - Competitive benchmark prices compared to actual prices
    - Borenstein, S., Bushnell, J. and Wolak, F.A. “Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market” (Dec. 2002) (on web-site)
- Indexes help to identify market design flaws before they because large problems

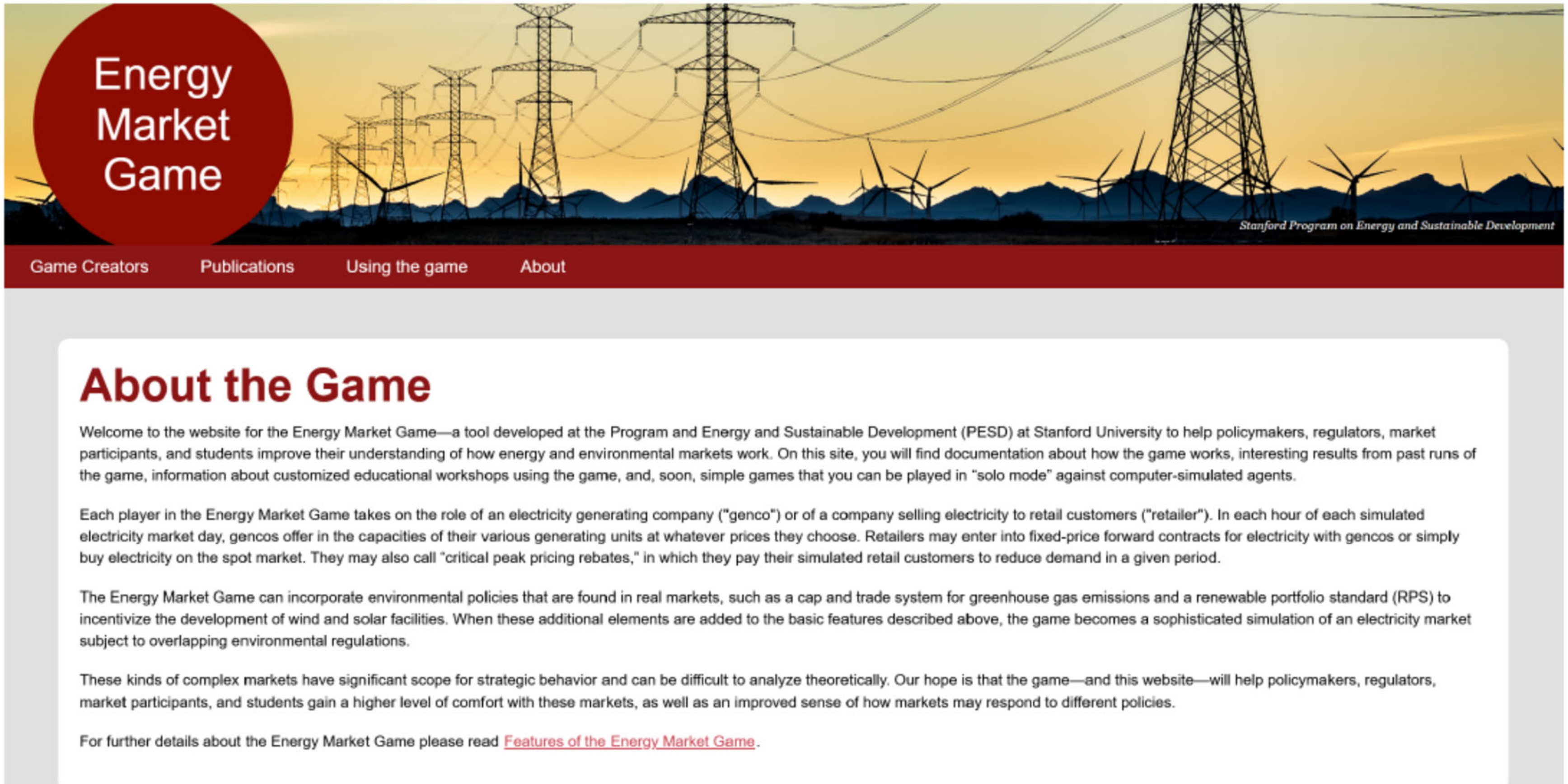
Process of Continuous Improvement

- All wholesale electricity markets must adapt to changing technology, policy goals, and market participant behavior
- All regulators and stakeholders must fully engage in transmission planning and expansion process in new ISO regime to ensure their voice and expertise is heard
- Transmission network modeling to determine impact of upgrades is technically challenging
  - Involves many assumptions that may or may not be true, but are deserving of debate among stakeholders
  - See (2010) “Using Market Simulations for Economic Assessment of Transmission Upgrades: Application of the California ISO Approach” (on web-site)

Productive Stakeholder Engagement

- Regulators and their staffs and electricity consumers face challenges in understanding financial implications of these decisions
  – Recall discussion of old school versus new school regulation
- Simulated market training using own behavior and that of other participants
  – Provides opportunities for policy-prototyping
- Research group at Stanford has taught short-courses using its Energy Market Game (EMG)
  – WIEB-Western Interconnection
  – CRE-France
  – PUCT—ERCOT
  – CPUC-CAISO
  – ANEEL—Brazil

Energy Market Game for Regulation and Policy Prototyping



Energy Market Game

Stanford Program on Energy and Sustainable Development

Game Creators | Publications | Using the game | About

About the Game

Welcome to the website for the Energy Market Game—a tool developed at the Program and Energy and Sustainable Development (PESD) at Stanford University to help policymakers, regulators, market participants, and students improve their understanding of how energy and environmental markets work. On this site, you will find documentation about how the game works, interesting results from past runs of the game, information about customized educational workshops using the game, and, soon, simple games that you can be played in "solo mode" against computer-simulated agents.

Each player in the Energy Market Game takes on the role of an electricity generating company ("genco") or of a company selling electricity to retail customers ("retailer"). In each hour of each simulated electricity market day, gencos offer in the capacities of their various generating units at whatever prices they choose. Retailers may enter into fixed-price forward contracts for electricity with gencos or simply buy electricity on the spot market. They may also call "critical peak pricing rebates," in which they pay their simulated retail customers to reduce demand in a given period.

The Energy Market Game can incorporate environmental policies that are found in real markets, such as a cap and trade system for greenhouse gas emissions and a renewable portfolio standard (RPS) to incentivize the development of wind and solar facilities. When these additional elements are added to the basic features described above, the game becomes a sophisticated simulation of an electricity market subject to overlapping environmental regulations.

These kinds of complex markets have significant scope for strategic behavior and can be difficult to analyze theoretically. Our hope is that the game—and this website—will help policymakers, regulators, market participants, and students gain a higher level of comfort with these markets, as well as an improved sense of how markets may respond to different policies.

For further details about the Energy Market Game please read Features of the Energy Market Game.

www.energymarketgame.org

E-Learning Modules

- Establish common understanding of basic engineering and economic concepts
- Interactive on-line training modules with short exam at the end to ensure that participant understands concepts
- Currently six modules (`https://pesd.fsi.stanford.edu/e-learning`)
  - Fixed and Variable Costs
  - Offer-Based Markets
  - Uniform-Price versus Pay-as-Bid Auctions
  - Unilateral Market Power
  - Transmission Network Pricing
  - Fixed-Priced Forward Contracts for Energy
  - Multisettlement Markets (Day-ahead and Real-time) Under Development

A Key Role for Munis and Coops

- Municipal utilities are owned by local government jurisdiction they serve
  - Palo Alto, Sacramento, Los Angeles
- Rural Cooperatives are owned by their customers
- Providing a common understanding of new regime to relevant staff and board members, particularly for transmission network expansions, could pay significant dividends to their customers

Concluding Comments

- Regulating wholesale market much more challenging than regulation of monopoly services
  - Prudency review to ensure “just and reasonable” prices
    - Accounting and administrative law intensive process
  - Set market rules to ensure “just and reasonable” prices
    - Economist and engineer intensive process
  - Determine where and when transmission expansions will take place and who will pay for them
- A large part of overseeing wholesale market is smart sunshine regulation
  - Compile and make market data available for internal and external analysis
  - Develop and produce measures of “vital signs” of market for public and regulatory process
  - Assist with process of continuous improvement in regulation and market operation and process determining expansion of transmission and distribution networks

Thank you
Questions/Comments?