IES
Integrated Energy Systems

Introduction to Electricity Markets

FORCE Overview and Training

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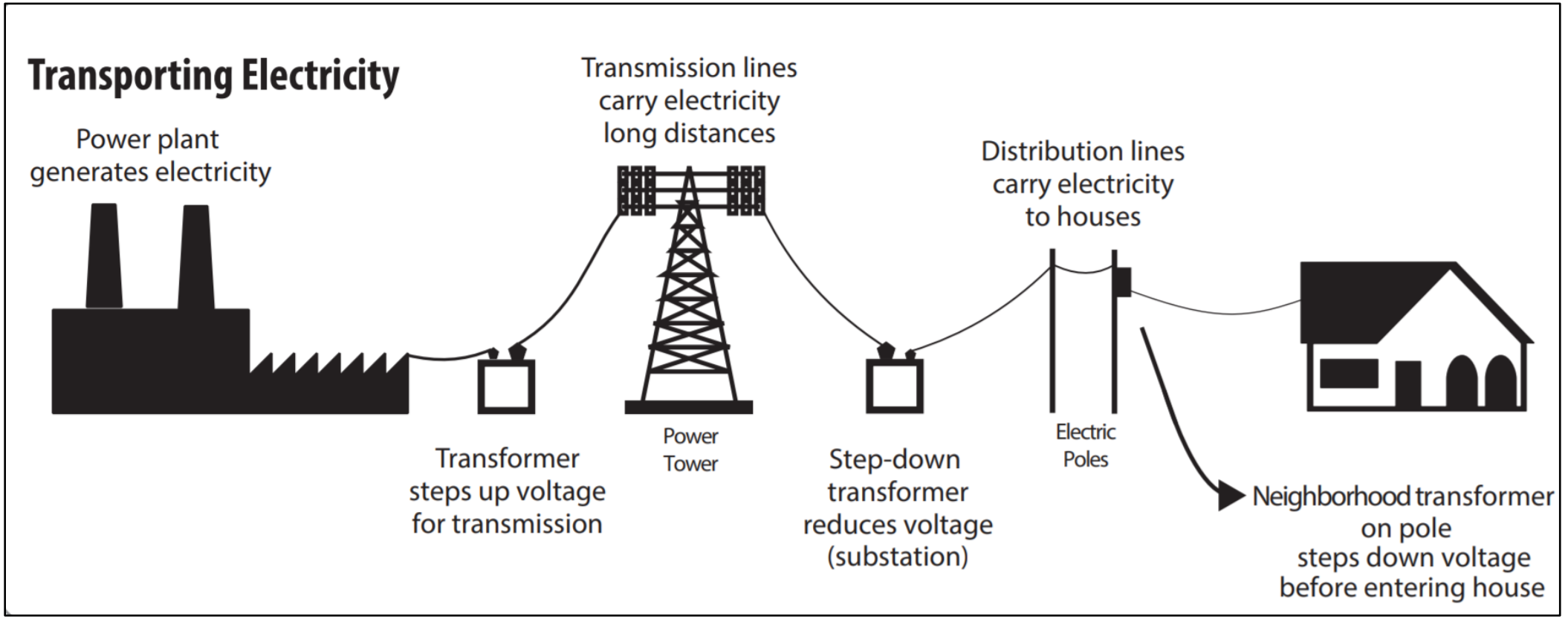
Economic Considerations in The Electricity System



Source: (NEED, 2020)

- **Technical** and **economic** considerations (i.e., exchange) along the **supply chain**
- **Organizational** structure matters: Regulated vs De-regulated

Outline

- The Electricity System
  - Deregulated vs Regulated
  - Wholesale vs Retail
- Wholesale Electricity Markets (ISOs/RTOs)
  - Two settlement system
  - Ancillary Services
  - Capacity Markets
- Competitive Position of Nuclear Industry
  - Competition in the energy portfolio mix
  - Impacts of recent legislation
  - Operating in the economic environment

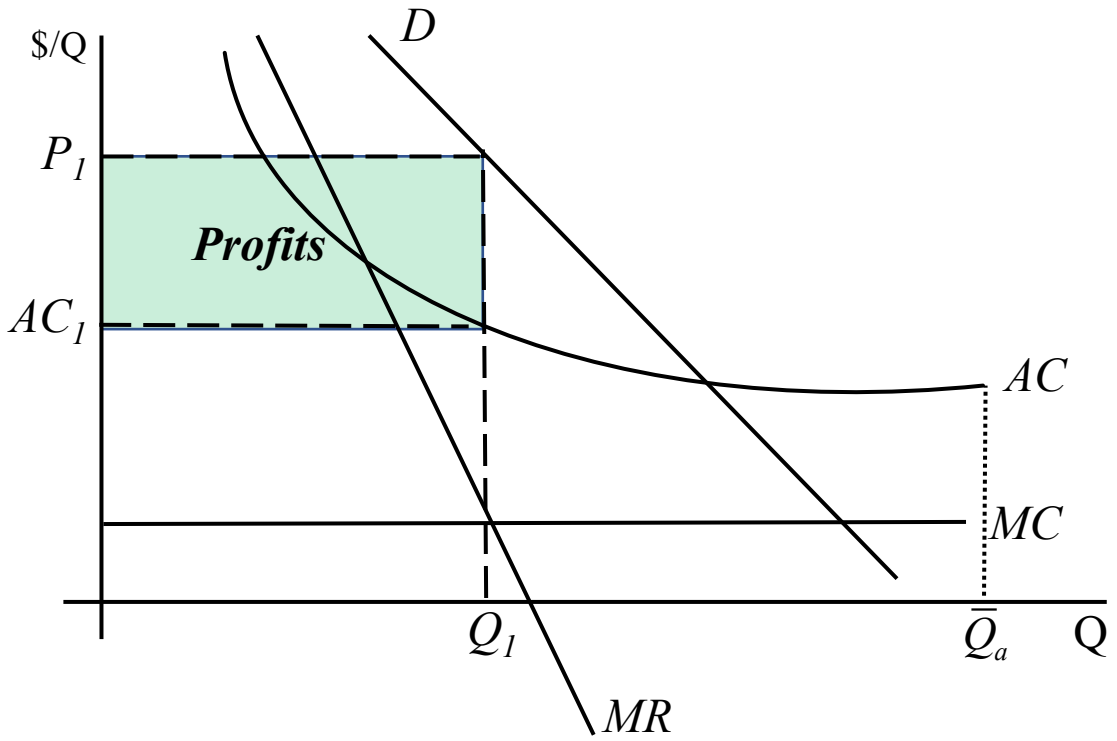
Restructuring

- Vertically integrated, regulated electric utilities prior to 1990
- This meant rate of return regulation of natural monopolies
- Early 1990s states deregulate electricity systems, create competition, lower costs
- Required electric utilities to sell generation assets, independent power producers
- Electric utilities retained ownership of transmission and distribution infrastructure
- Power producers – suppliers, load-serving entities – demanders
- Regulated then central, integrated resource planning. Deregulated, market forces. Financial risk transferred from end-use consumers to suppliers.

The Vertically Integrated Regulated Utility

- Single owner/operator structure of energy system means monopoly
  - one type of market failure
  - natural monopoly – large fixed costs
  - regulation to correct failure
- Rate of Return regulation
  - $\sum_{i=1}^{n} p_i q_i = \text{Expenses} + \text{sB}$
  - s = return on capital, B = investment expenses, rate base
- Subject to perverse incentives

Stylized Generator Cost Structure

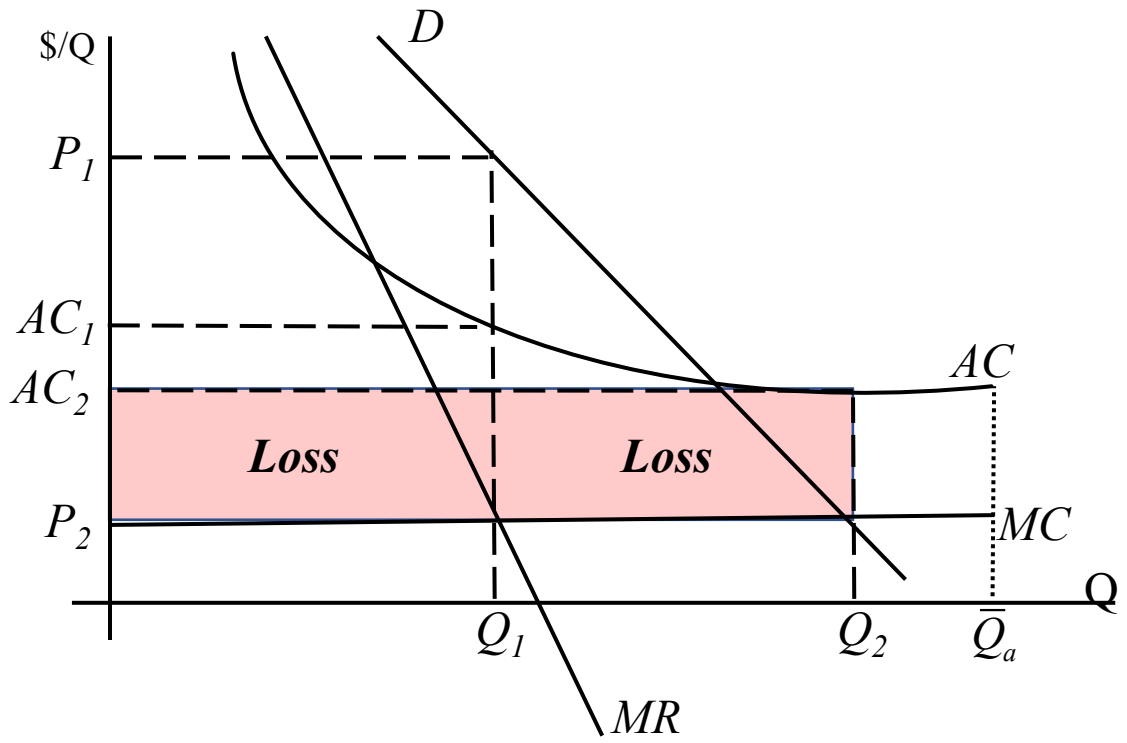


Source:(Viscusi, Harrington Jr, & Vernon, 2005)

Generators with large fixed cost and low or constant marginal cost

- Generators bid their short run marginal cost
  - promise to provide Q capacity at P price at some time interval
- Bid covers variable costs but not fixed cost – "missing money problem"
- The scale of the missing money problem depends on the nature of generator cost structure (fixed costs)

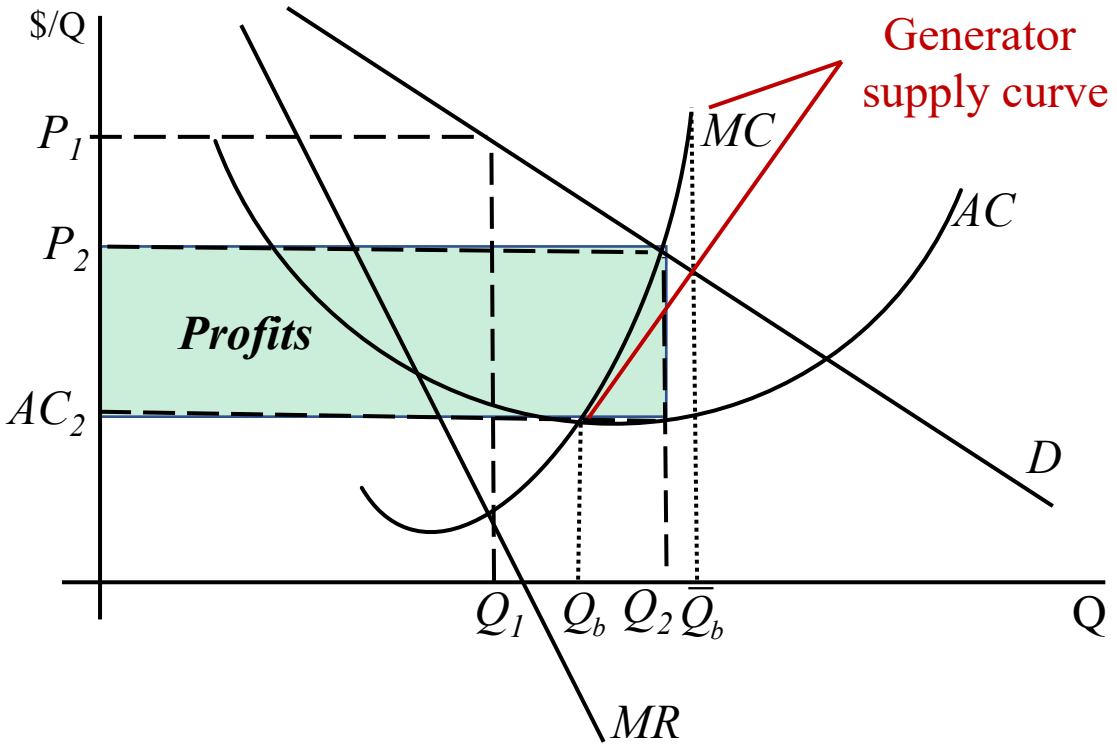
Stylized Generator Cost Structure



Generators with low fixed costs and increasing marginal cost

- Bids for generators with increasing marginal costs cover variable and fixed costs
- Generator supply curve is the marginal cost curve above average ***variable*** cost
- If generators can't cover variable cost in short run then shut down

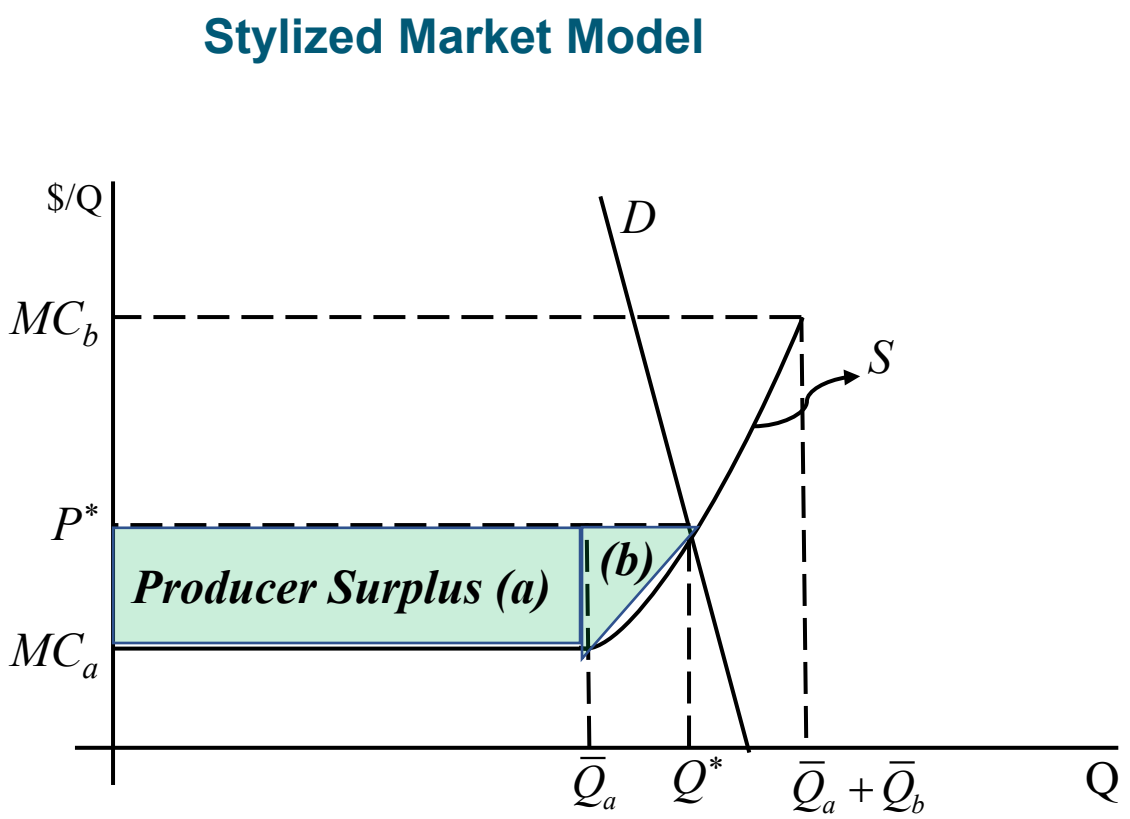
Stylized Generator Cost Structure



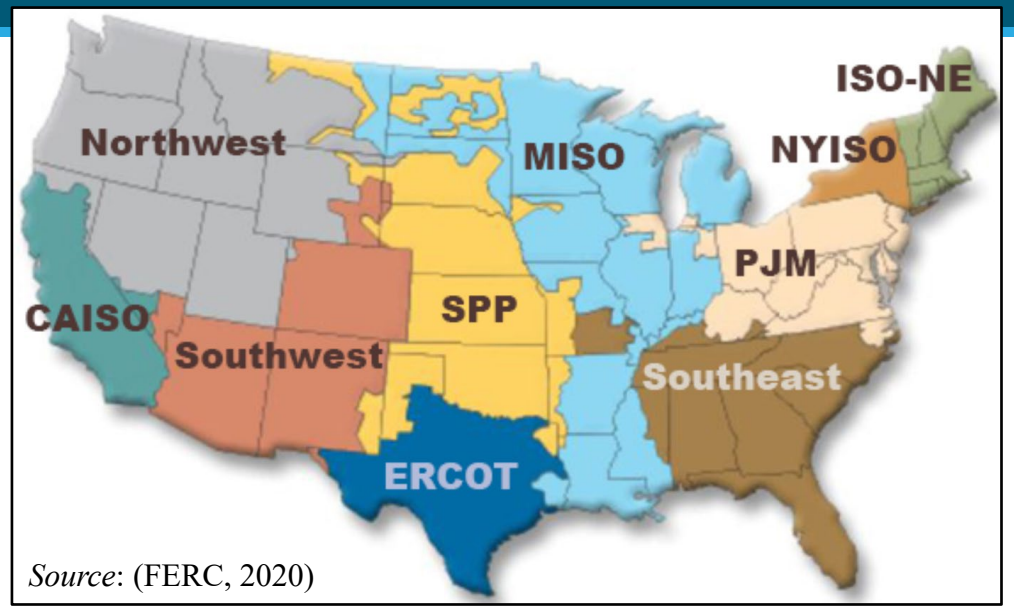
Developing the Bid Curve

- Market supply curve is the sum of the marginal cost curve across all generators in the market ("the stack")
- "marginal generator" is that for whom marginal cost intersects demand – "clearing price" P^*
- Dynamics of:
  - Production tax credit
  - Changing prices for natural gas
  - Carbon tax
- Note:

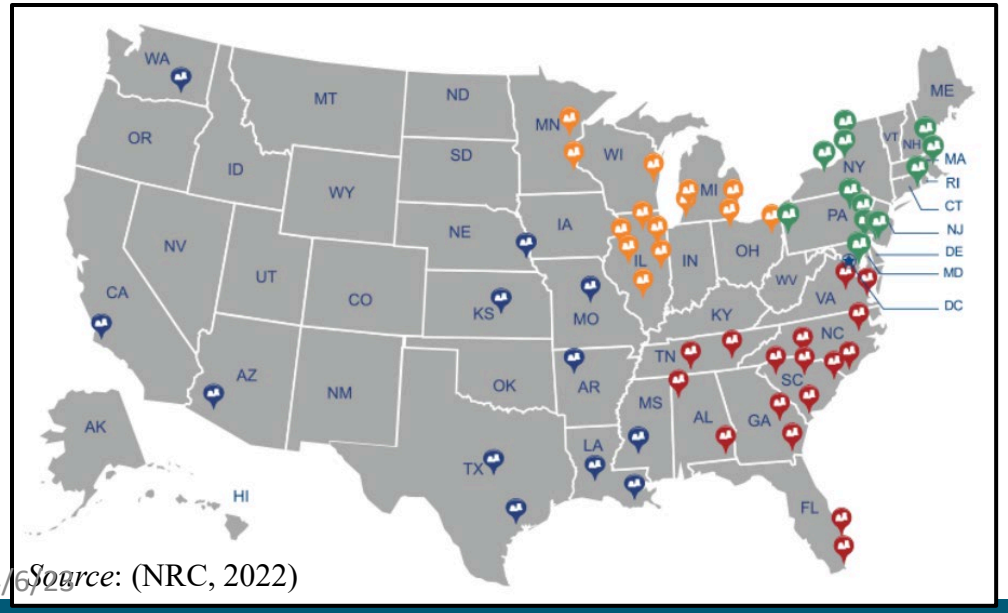
  Profits = Producer Surplus – Fixed Cost



US Wholesale Electricity Markets and Nuclear Plants



Source: (FERC, 2020)



Source: (NRC, 2022)

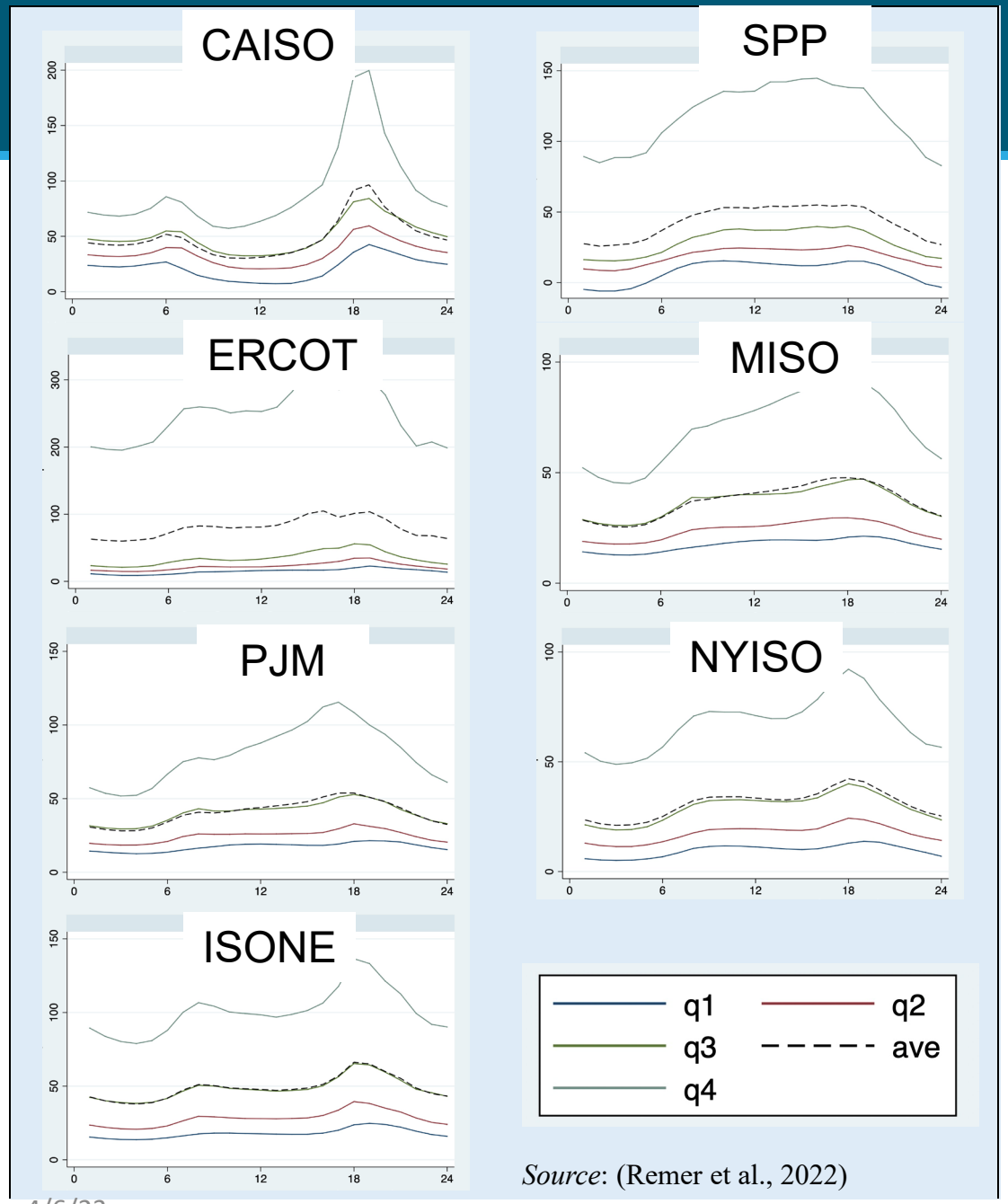
- In Northwest, Southwest, and Southeast, utilities operate in regulated markets
- In restructured markets, competitive market model used to allocate resources to:
  - Balance load
    - 2 settlement system
  - Regulation services
  - Expand capacity

Electricity Markets by Market Size

ISO/RTO	Energy ($B)	Capacity ($M)	Ancillary Services ($M)
CAISO	10.6	N/A	189
ERCOT	13.4	N/A	603.5
ISO-NE	6.0	3,600	130.9
MISO	21	431	70.5
NYISO	6.38	1,800	491
PJM	29.61	11,000	654
SPP	7.5	N/A	76

Source: (Hansen and Rabiti, 2021)

Day-ahead Market



Source: (Remer et al., 2022)

- Based on generator bids, DAM schedules generators to produce 24 hours out
- Based on forecasted demand
- Generators can clear some capacity in DAM and hold out additional capacity in RTM
- About 95% of capacity exchanged in DAM
- Prices called LMP (locational marginal price)
- LMPs distributed across the grid
- Remaining capacity settled in real-time market

Ancillary Services

Table 3 Ancillary Services Summary (Average $/MW-hour, Requirement)

ISO/RTO	Spinning	Non-Spinning	Regulation
CAISO	3.61 10-minute response Min run time 2 hours	1.02	7.57 Immediate Response
ERCO	12.12 Response within minutes Min run time 4 hours 2 MW/min, up 3 MW/min, down	4.50 Response within 30 minutes Min run time 1 hour	8.5 Immediate Response 3 MW/min, up 4 MW/min down
ISO-NE	4.66 10-mintue response 1 MW/min up/down	26.63 10 to 30 minute response	18.38 Immediate Response
MISO	1.74 10-minute response	0.23 10-minute response	8.81 Immediate response, full response within 5 minutes
NYISO	3.61 10-minute response	3.08 10 to 30-minute response	6.07 Immediate response, full response within 5 minutes
PJM	3.17 10-minute response	8.11 10-minute response	13.47 Immediate response, 0.1 MW min response
SPP	5.36 10-minute response	0.73 10-minute response	7.28 Immediate

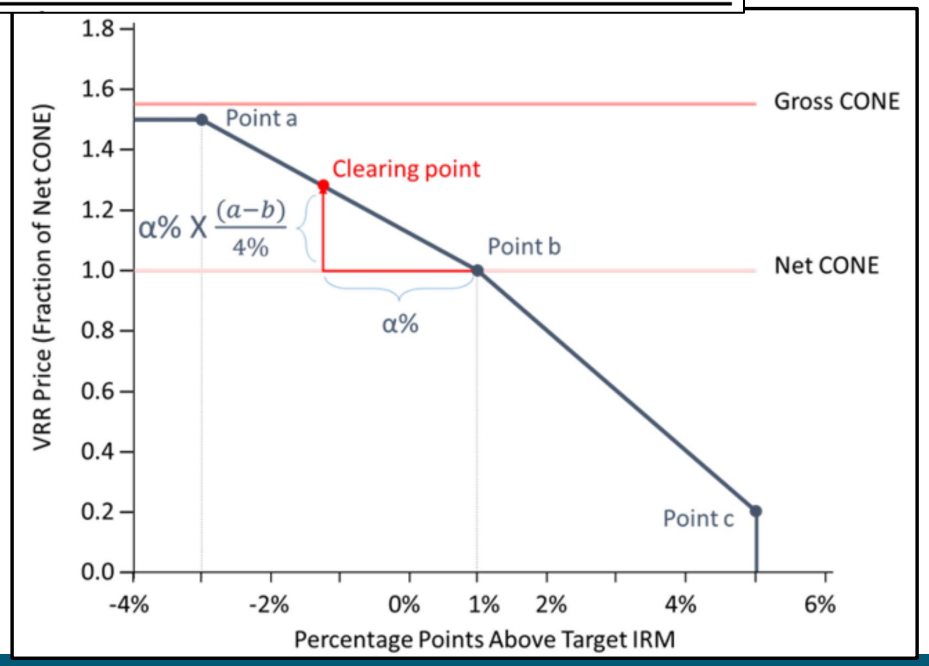
Source: (Hansen and Rabiti, 2021)

- Regulation
  - frequency control – adjustments within fractions of a second
  - Reactive power is the additional voltage needed to bring voltage and current into alignment and return to in phase power
- Reserves
  - spinning and non-spinning – adjustments within a few minutes
  - Generators commit to being willing and able to adjust by committed capacity amount
  - Paid capability price plus performance payment (electricity price from RTM)
  - Grid operator uses reserves when regulation control is not enough to bring system back into alignment

Capacity Market

Table 2 Capacity Market Summary

ISO/RTO	Length of contracting period	Average Capacity Prices and CONE[1/]
CAISO	1-year forward contract	Average Capacity Price: $100/MW-hour CONE: $208/MW-day
ISO-NE	3-year forward contract	Average Capacity Price: $9.63/MW-hour CONE: $309.59/MW-day
MISO	3-year forward contract	Average Capacity Price: $1.27/MW-hour CONE: $257.53/MW-day
NYISO	30-day delivery contract	Average Capacity Price: $5.04/MW-hour Net CONE: $366.94/MW-day
PJM	3-year forward contract	Average Capacity Price: $7.17/MW-hour Net CONE: $285.5/MW-day
SPP	Incrementally as needed	Average Scarcity Price: $439/MW-hour[2/] Average Make-whole Payment: $0.22/MW-hour (DAM), $18.94/MW-hour (RTM)[2/] CONE: $234.55/MW-day

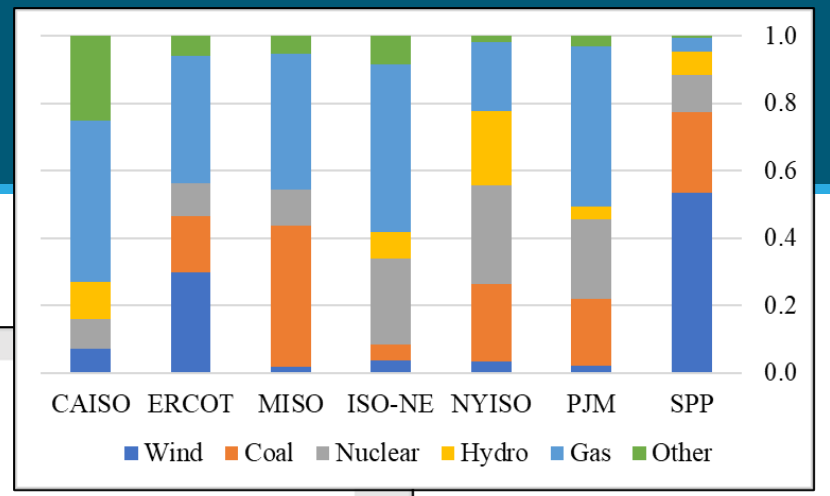


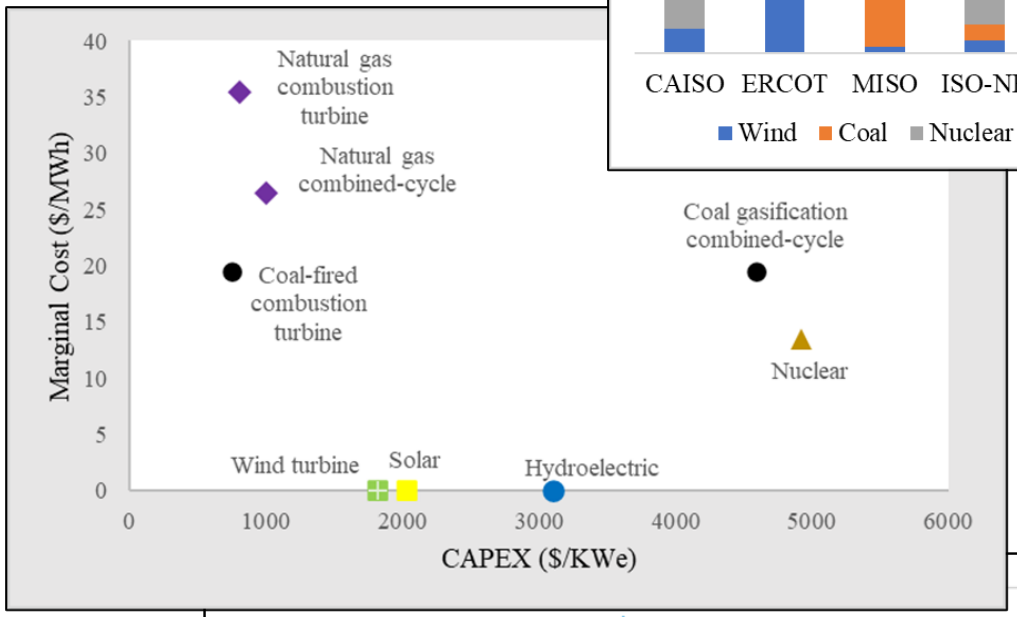
- Capacity markets are a way for power producers to generate revenue for providing electricity capacity to the energy grid.
- ISOs set a price-cap called the CONE (cost of new entrant)
- Net CONE reflects generator revenue need to make up for shortfall from electricity revenue, estimate of missing money
- Cost of new generating capacity must fall below the CONE to bid in the capacity market
- The ISO sets a capacity target then generators bid based on their net CONE

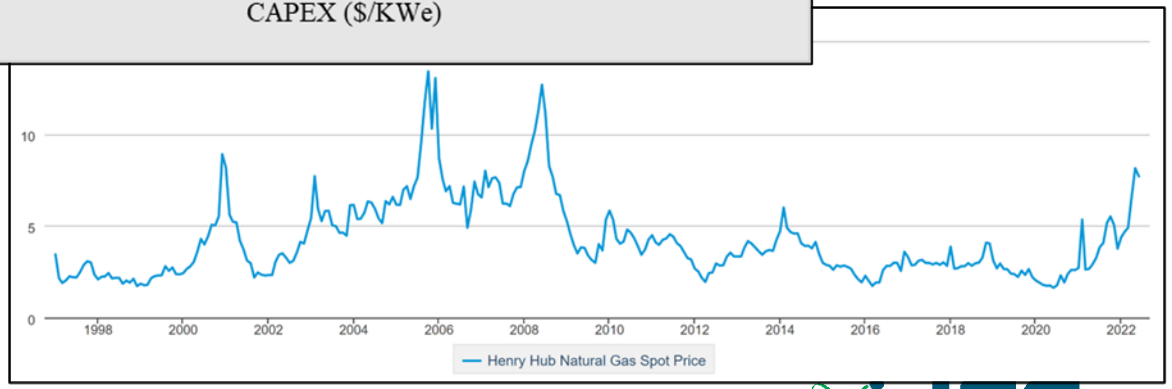
Source: (Blumsack, 2020; Hansen and Rabiti, 2021)

Competitive Position: Energy Mix

- Keep in mind technology competition
- Cost structure impacts market outcomes – fixed vs variable costs
- Average correlation in electricity prices and natural gas prices estimated at ~0.9!







Source: (Remer et al., 2022)

Competitive Position: Inflation Reduction Act

- 45U – Production tax credit for operating nuclear plants
  - Up to $15/MWh
  - Adjusts for prices above $25/MWh
  - Merchant and regulated plants
  - 2024 - 2032
- 45Y – Clean electricity production credit
  - Up to $30/MWh for 10 yrs
  - ITC or PTC, not both
  - Plants entering service 2025 or later
  - Adjustments available, energy communities, domestic content
- 48E – Clean electricity investment tax credit
  - 30% of construction expense when plant enters service
  - ITC or PTC, not both
  - Plants entering service 2025 or later
  - Adjustments available, energy communities, domestic content
- 45Q CO_2 capture and storage credit
  - Up to $85/t$CO_2$ captured with bonus
  - 12-year eligibility
  - Construction before 2032
  - Cannot stack credits with others
- 45V – H_2 production tax credit
  - Up to $3/kg with 10-year eligibility
  - Construction before 2032
  - Stack with 45Y and 48E
  - Size of credit based on emission intensity
- Thoughts on H_2 and IES applications
  - Additionality
  - Regionality
  - Time matching
  - Accounting for average vs marginal emissions

Competitive Position: Economic Conditions

Energy Industry	Cost of Equity	Share of Equity	Cost of Debt	Tax Rate	Share of Debt	WACC
Non-Renewable	4.84	51.38	3.0	0.0	48.62	4.21
Renewable	5.56	60.95	3.0	1.74	39.05	5.02
Utility	4.42	57.24	1.92	9.74	42.76	3.74

Source: (STERN, NYU)

- Inflation running at 40-year historic highs
- Rising interest rates, stock market volatility, . . . recession risk
- Lazard (2021) shows that a 1% change in WACC increases LCOE by ~8.4%

Summary

- Significant differences in modeling regulated utility versus restructured (“deregulated”) utility
- Shape of (or assumptions on) marginal cost curve impacts firm profitability – large fixed costs vs large variable costs
- In restructured markets a competitive market model is used to allocate resources formerly accomplished by a single entity
- Markets for ancillary services and capacity provide additional value for utilities, although not as strong as electricity market
- The competitive position of the nuclear industry may be a point of consideration on modeling assumptions

References

- Blumsack, S. (2020). *Introduction to Electricity Markets*. Retrieved from https://www.e-education.psu.edu/ebf483/
- FERC. (2020). *Electric Power Markets*. Retrieved from https://www.ferc.gov/industries-data/market-assessments/electric-power-markets
- Hansen, J., & Rabiti, C. (2021). *Characterizing US Wholesale Electricity Markets*. Idaho Falls, ID: Idaho National Laboratory.
- Hytowitz, R. B., Ela, E., Kerr, C., & Bernhoft, S. (2020). *Economic Drivers for Nuclear Flexible Operations*. Retrieved from Palo Alto, CA:
- Lazard. (2021). *Lazard's Levelized Cost of Energy Analysis -- Version 15.0*. Retrieved from https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf
- NEED. (2020). *Electricity*. Retrieved from https://7ad3lz9zmyhppfq26wugt151-wpengine.netdna-ssl.com/Files/curriculum/infobook/ElecI.pdf
- Remer, S. J. (2022). *Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation*.
- *STERN, NY. http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm*
- Viscusi, W. K., Harrington Jr, J. E., & Vernon, J. M. (2005). *Economics of regulation and antitrust*: MIT press.

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