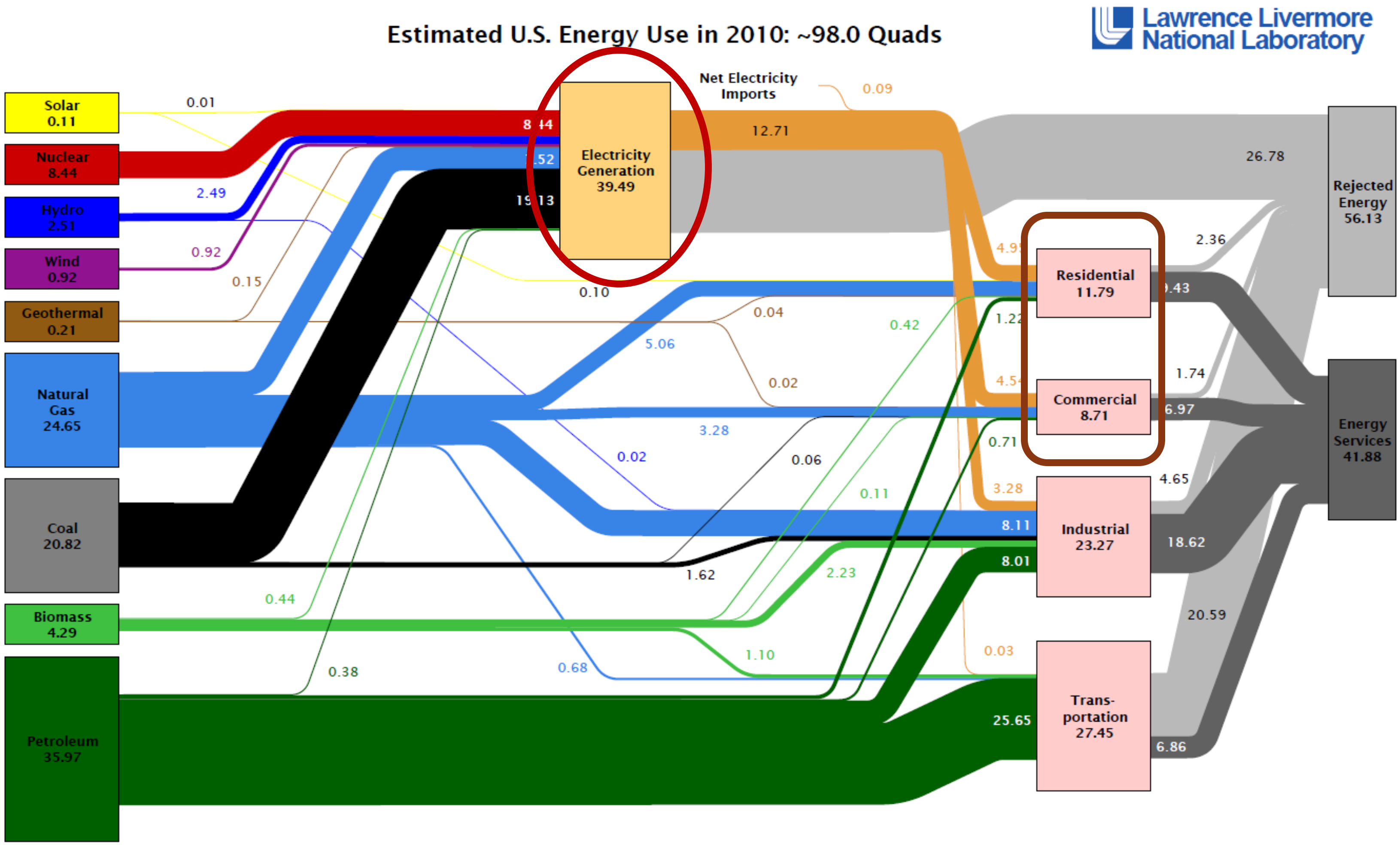
# (Yesterday's &) Today's Electric Power System

Lecture 17

# In 2010 Electricity Used 40% of Primary Energy, Produced About 40% of $CO_2$ Emissions; 74% to Residential + Commercial, Supplied 46% of Energy



# This Session and the Next

- Today:
  - Essential features of electric power systems
  - History & current status of the US system

- Next Monday:
  - Challenges facing the system looking forward
  - Opportunities provided by new technologies
  - Live policy issues, being debated now

# Key Features of Electric Power Systems

- Output is essentially not storable
  - Pumped hydro, compressed air are used, but expensive
- Demand varies over time, not perfectly predicable
  - Most US systems are now summer peaking, even NE

Graph of 2009-2010 peak forecast removed due to copyright restrictions.

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Graph of forecast load and actual load removed due to copyright restrictions.

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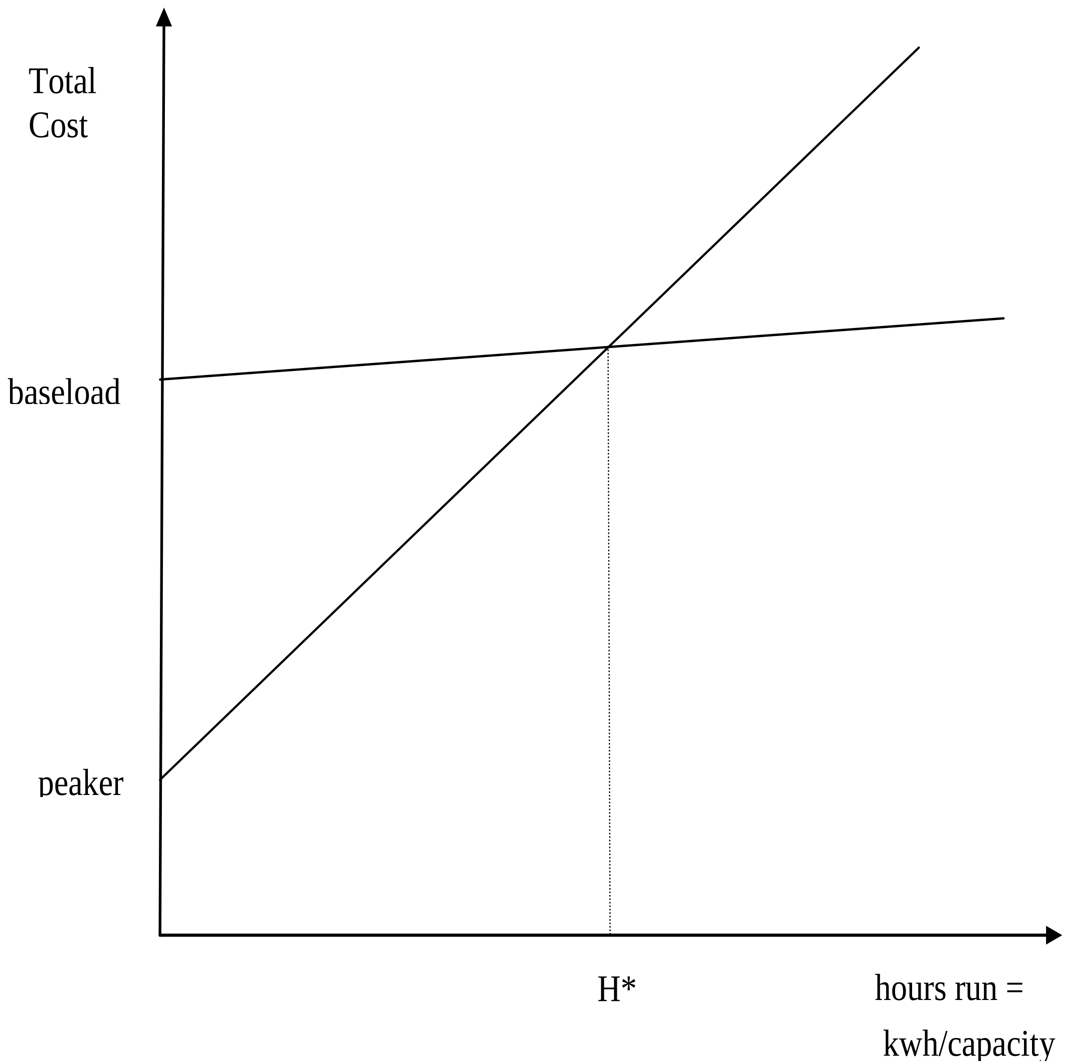
  - Considerable short-term variation within days
  - Frequency normally maintained by automatic control at designated “load-following” units – not nukes or coal
- Since capacity used varies, it is efficient to mix technologies. Suppose only two (classic) types:
  - *Baseload* units (nuclear, coal) have high fixed (capital) cost, low marginal (mainly fuel) cost – run as much as possible
  - *Peaking* units (gas turbine, diesel) have relatively low fixed costs, higher marginal cost – run only when needed

# Coal/Nuclear baseload plants generally huge; CCGT/gas turbines can be small

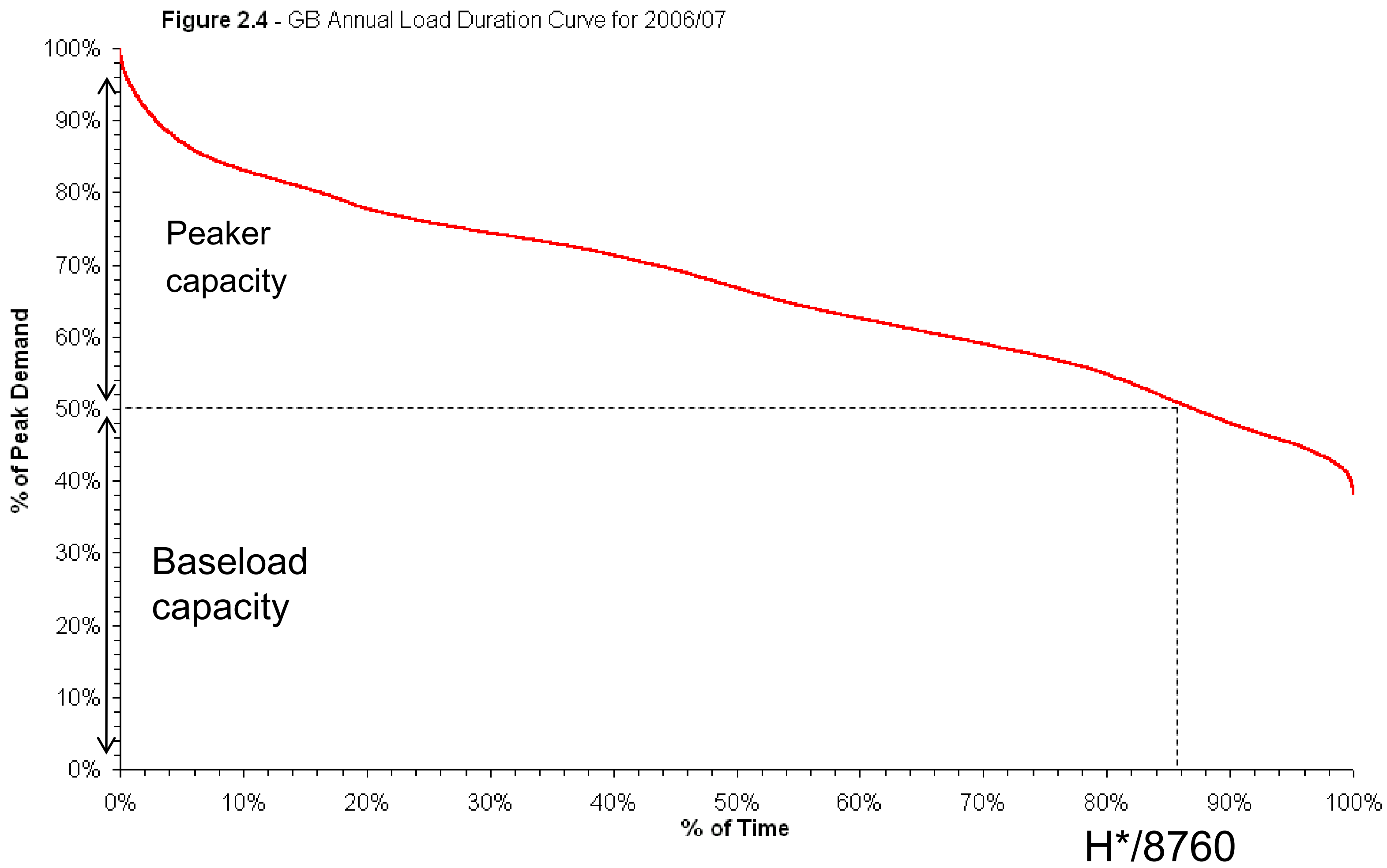
Generally baseload plants run flat out when they run; other plants can more easily vary output to follow load

Photo by NRC and Jim Champion on Wikipedia Commons.

# Consider two plants with equal capacities: If plan to run < H* hours, the peaker is cheaper



# *Load Duration Curve* for Britain, Continuing Two-Technology Example; Optimal Mix (Stylized!!)



# Many technologies, costs; “economic dispatch” = turn on lowest marginal cost units first

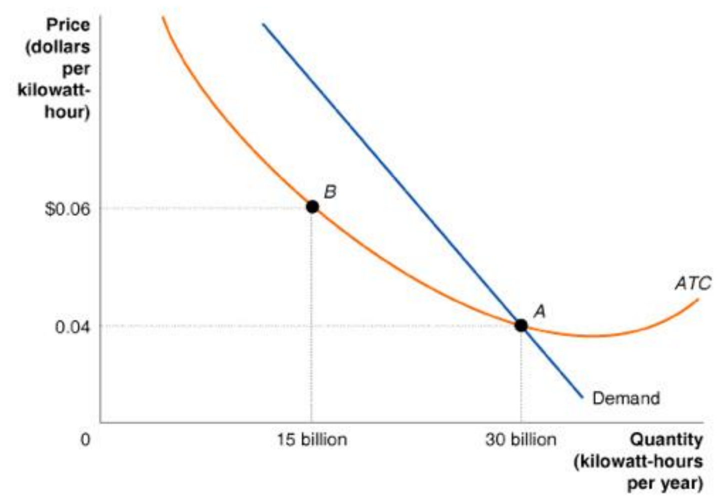
Graph of 2008 supply curve for lower 48 NERC regions removed due to copyright restrictions.

# Grid Architecture & Features

- Transmission & distribution generally viewed as natural monopolies; inefficient to have two systems

# Natural Monopoly & Its Problems

- *Natural monopoly*: having more than one supplier would raise costs (significantly)
  - Sub-additivity: $C(X_1 + X_2) < C(X_1) + C(X_2)$ for all X vectors
  - Global scale economies sufficient:
- What problems do natural monopolies pose?
  - Competition not viable (cable?)
  - Prices above costs (deadweight loss triangles)
  - Costs likely too high (rectangles, potentially larger)
  - If products are necessities, poor → rich transfers



# "Solutions" to Natural Monopoly

- Several policy types have been employed to deal with natural monopolies – **Examples? Characteristics?**
  - Government ownership (EU, LADWP, MBTA – eventually; incentives to control employment, costs?)
  - Regulation by local contract (early streetcars, buses, etc.)
  - Cost-plus or rate-of-return regulation (US early 20th century innovation; controls profits, but not costs)
  - "Incentive" regulation (RPI-X; gives incentives between infrequent reviews, but prices can get out of whack)
  - Franchise bidding (compete for the market, but hard to have fair bidding for renewals)
  - Cooperatives (like the COOP, owned by their customers)
- All these become "political" in practice; none perfect
  - Economists often argue for limiting their scope for efficiency

# Grid Architecture & Features

- Transmission & distribution generally viewed as natural monopolies; inefficient to have two systems
- Low-voltage distribution to customers: mainly a <u>tree</u> structure, one path from transmission to load
- High voltage transmission from generation: a <u>mesh</u> structure, generally many paths from A to B
  - Reliability (within & between utilities) a key motivation, but multiple paths cost more
  - Current flows on ALL paths from A to B, with loadings depending on impedance – Kirchhoff’s laws, not pipes
  - Individual lines have stability, thermal capacities: exceeding thermal capacity causes over-heating, sag, failure
  - Increasing generation at A and load at B may cause transmission lines elsewhere to congest – “loop flow”

# Transmission: 3 “Interconnects”, ≈170k Miles; Eastern 73%, Western 19%, ERCOT 8% of Sales

Map of power grids across the US in 2004 removed due to copyright restrictions.

# Early history, State Regulation

- 1882: Edison's Pearl Street Station, 100v DC to 59 nearby lighting customers
- 1880s: More local DC systems, "regulation" by municipal franchise; concessions for use of streets
- Municipal systems (LA, Belmont), peaked at 8% of generation in 1900 – like transit, water, etc
- 1896: Westinghouse uses AC + transformers (new) to send power from Niagara Falls to Buffalo; ***AC wins***
- Transmission enables geographic expansion, state "public utility" regulation spreads from 1907
- In Europe, government firms came to dominate – Why?

# A Federal Role Emerges

- 1906: Start selling (Cheap! Why?) surplus power from irrigation projects, preference for municipals
- 1900-29: *14%/year growth(!),* interstate holding companies formed to drive stocks, evade regulation
- 1920: FPC (now FERC) deals with hydro (waterways are federal), wholesale power regulation from 1935
- 1935: PUHCA outlaws multi-area holding companies, freezes vertically integrated monopoly structure
- 1930s: Rural electric coops created, get preferential access to cheap power from federal dams (e.g., TVA)
- 1950: Federal generation was 12% of US total

# Characteristics of State Regulation

- Utilities: monopoly service areas (esp. post-PUHCA); commissions: require “just & reasonable” rates
- “Rate of return” regulation: set prices so utility would earn “fair rate of return” on investment – cost plus
- How/why might this system perform badly?
  - Costs too high because no discipline
  - Gold-plating (A-J) because more capital ⇒ more profit
  - “Capture,” since utility is organized but consumers aren’t
  - No incentive to make prices reflect cost differences over time; differences among customers reflected politics not cost
- Why few complaints until the 1970s?
  - Rapid technical change drove real prices down until then

# An Alternative Model Appears

- 1970s: Pressures for change build
  - Deregulation of wellhead natural gas, airlines, railroads, interstate trucking lead to price reductions
  - Electricity: fuel cost increases slowed demand, led to excess generation capacity for which ratepayers must pay
- 1978: PURPA required utilities to buy from renewables, CHP units at regulated "avoided cost"
- Early 1980s: "Why not just deregulate electricity?"
  - Joskow & Schmalensee 1983,, *Markets for Power*: some scope for competition, special features mean care is needed
- 1990: Privatization, vertical disintegration in England and Wales: wholesale markets, independent grid!!

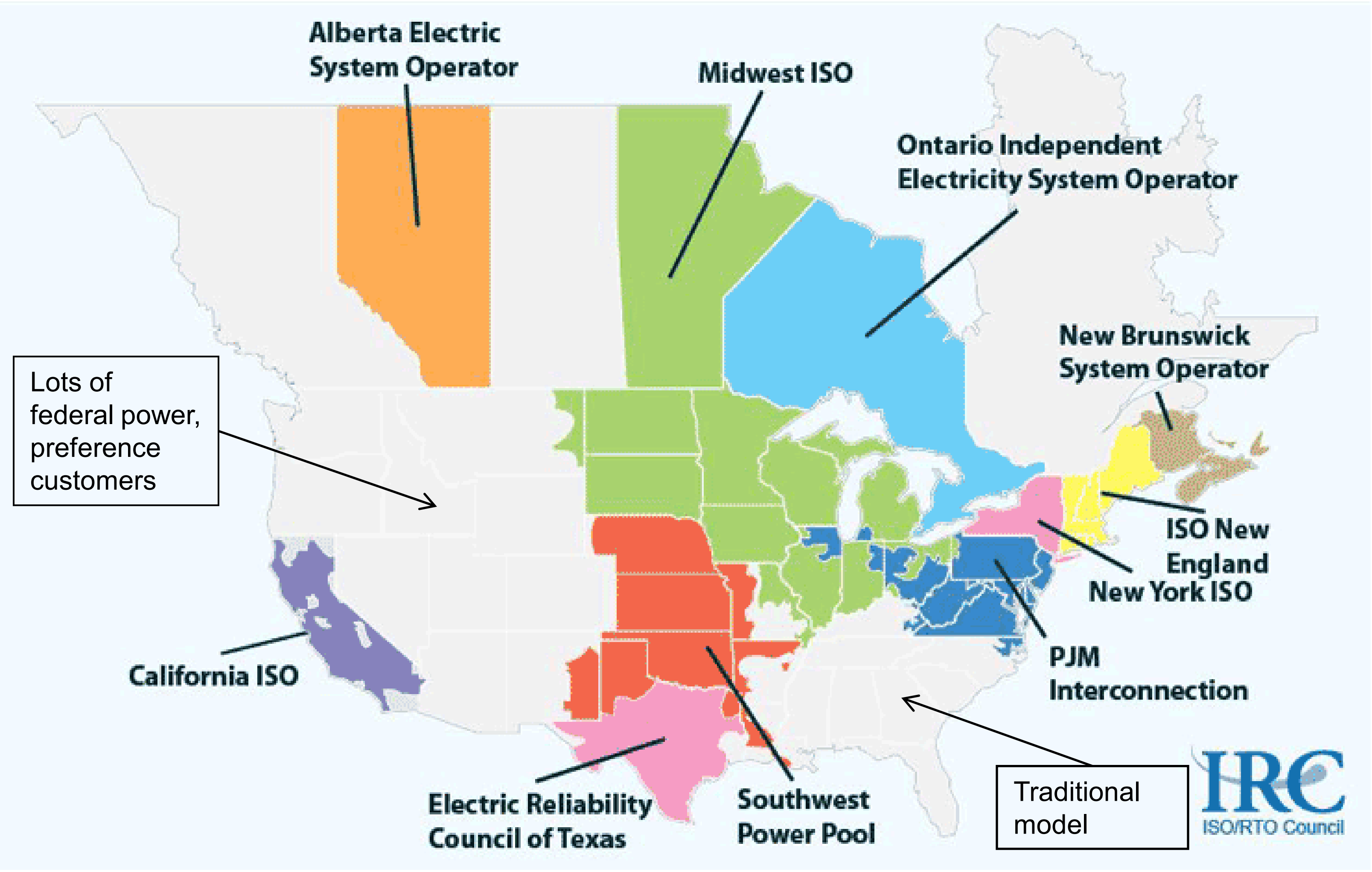
# The US Starts to Follow, But Hits a Wall

- 1992-96: EPA expands FERC authority, FERC requires transmission systems to be "common carriers"
- 1999: FERC enables independent grid operators (ISOs & RTOs) with wholesale markets, some implement
- **2000-01: Prices in the CA market, which began in 1998, explode; blackouts; Enron…**
- Post-California: Movement toward reform stops; pressure to reverse in areas where capacity is tight
- Will discuss current state of play next time

# The New, Market-Centric Model

- Competition in generation has worked elsewhere, though need to deal with market power
  - Has continued in England & Wales, now the core EU policy, in several Latin American countries (Chile since 1982!),
  - And for about 2/3 of US consumers, including New England

# Coverage of ISO/RTO Markets (Approx)



Graph of average wholesale prices removed due to copyright restrictions.

# The Current Structure (Approx)

- 2/3 of US customers & load in ISO/RTO areas
- **Transmission:** about 450 entities own parts; 66% investor-owned
- **Distribution:**
  - 2,200 publicly owned (munis, feds), 16%
  - 820 cooperatives, 10%
  - 242 Investor-owned, 66%
  - Retail competitors (no wires), 8%
- **Generation** (huge change since 1980):
  - Govt systems (incl. TVA) & coops, 16%
  - Investor-owned utilities (with retail sales), 42%
  - Independent producers (without retail sales), 42%