Changes in the Electric Power Sector

Presented to

Sustainable Energy –
Choosing Among Options

Steve Fairfax

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Outline

- Who is Steve Fairfax?
- Introduction to the grid
- Bulk electric power marketplace
- Distributed generation

Steve Fairfax

MIT

- Course VIII 1978
- Course VI, VIII 1984
- 1988-94 Head of engineering Alcator tokamak
- Consultant, guest lectures 1994-present

1984-1986 Principal Engineer Cyborg, Newton MA

1986-1988 Principal Engineer KSI, Beverly MA

1994-1997 Failure Analysis Associates Inc.

1997-present President, MTechnology, Inc.

MTechnology, Inc.

- Founded 1996
- Applied quantitative risk assessment to 7x24 industries
  - Leverage techniques, tools from nuclear power
  - Evaluate mission-critical systems from 30 kW to 180 MW
- Power electronic systems development
  - 1200 kVA power plant for Rolls-Royce Fuel Cell Systems
  - 2 kA magnet protection system for proton beam therapy cyclotron

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Selected Clients

OEMs

- Active Power
- APC-MGE
- Cummins
- Emerson / Liebert
- Power One
- Rolls Royce Fuel Cell
- S&C Electric Company
- Siemens
- Still River Systems
- SustainX

Utilities

- First Energy
- Progress Energy
- Salt River Project
- NorthEast Utilities
- Detroit Edison

End Users

- Clean Energy Group
- Fidelity Investments
- First Solar
- Goldman Sachs
- Harvard Medical School
- Jones Day
- JP Morgan Chase
- Merck & Co.
- MIT

Consultants/Engineers

- CH2M HILL Industrial Design & Construction
- EPRI PEAC
- HDR
- EYP Mission Critical Facilities
- Jones Lang LaSalle
- Tishman Speyer

Introduction to the grid

Role of electric power

Power plants, transmission, distribution

As-built summary -
  power, plants, lines, miles, substations, etc.

Transmission system design requirements

Transmission voltages, stability limits

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Role of Electric Power

National Academy of Engineering:

Greatest Engineering Achievements of the 20th Century

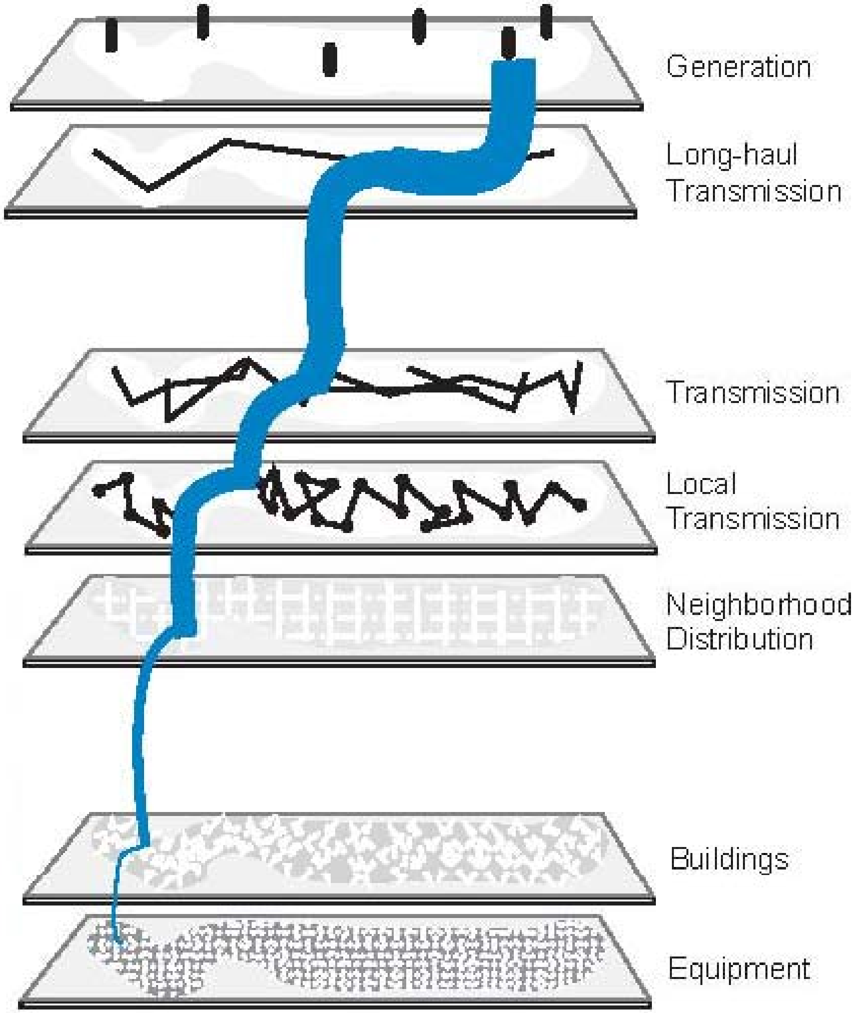
#1 - Electrification

Electric power is essential to modern society

Critical infrastructure relying on electric power:

- Information and communications
- Banking, finance, commerce
- Oil and gas production and transport
- Rail and air transport
- Water
- Sewage

The Tiers of the Electric Grid



Derived from "Distributed Energy Resources Interconnection Systems," U.S. DOE NREL (September 2002).

US Generation by Energy Source, 2008

Energy Source	Number of Generators	Nameplate Rating Megawatts
Natural Gas	5,467	454,611
Coal	1,445	337,300
Nuclear	104	106,147
Hydroelectric	3,996	77,731
Petroleum	3,768	63,655
Renewable	2,576	41,384
Pumped Storage	151	20,355
Other	49	1042
Total	**17,658**	1,104,486

http://www.eia.doe.gov/cneaf/electricity/epa/epat1p2.html

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US Generation, Change 2006-2008

Energy Source	Number of Generators	Nameplate Rating Megawatts
Natural Gas	-3	+11,666
Coal	-48	+1,470
Nuclear	0	+562
Hydroelectric	+8	+312
Petroleum	24	-663
Renewable	+753	+14,914
Pumped Storage	+1	+786
Other	-103	-2,497
Total	**+734**	+**28,809**

http://www.eia.doe.gov/cneaf/electricity/epa/epat1p2.html

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Transmission Voltages

- 765 kV – 2,426 miles
- 500 kV – 25,000 miles
- 345 kV – 51,025 miles
- 230 kV – 76,437 miles
- 230-450 kV DC (+/-) 1,351 miles
- 500 kV DC (+/-) 1,333 miles
- Total: 157,314 miles
  - Including 115 and 138 kV circuits: 680,000 miles
- Interstate highways: 46,677 miles

Source: North American Electric Reliability Council (NERC) 2001

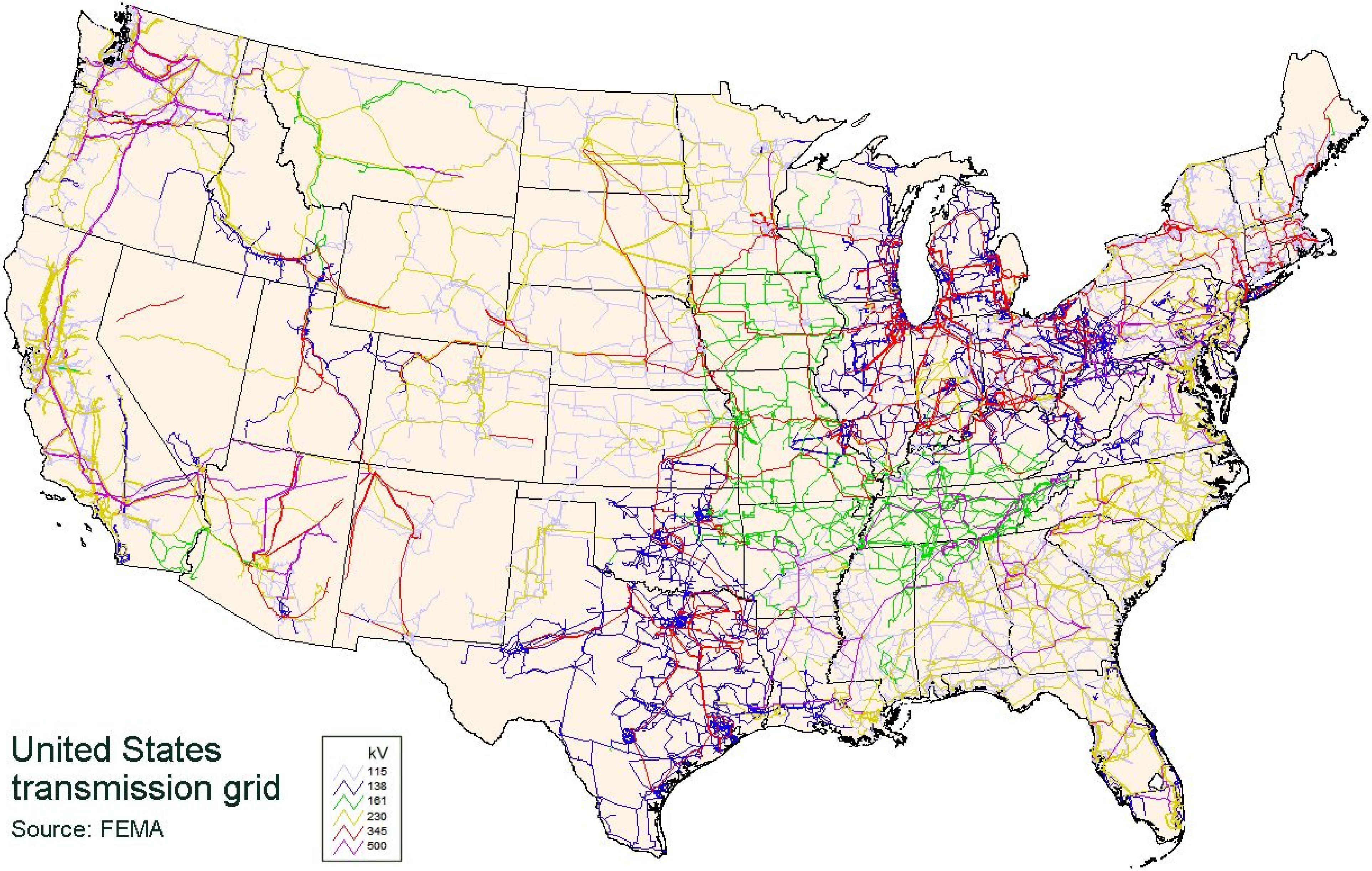

Image by Rolypolyman on Wikimedia Commons.

Distribution System 4160 to 69 kV

Facility Type	In Service
Transmission Substations	~7,000
Distribution Substations	>100,000
Distribution Circuit Miles	>2,500,000

Diagram of a typical substation removed due to copyright restrictions.Please see Figure 1 in "Illustrated Glossary: Substations." *Electric Power Generation, Transmission, and Distribution*. OSHA eTools, January 2010.

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Purpose of HV Transmission System (as built)

- Transmit power from hydroelectric plants
  - Often long lines, subsidized by governments
    - James Bay to Montreal: 1,000 km, 11,000 MW
    - James Bay to Boston: 1,500 km, 2,200 MW
- Bulk supply of power to load centers
  - Cities, large factories
  - Lines typically short, <100 miles, essentially dedicated
- Interconnection between utility networks
  - Emergencies such as station or line failures
  - Share spinning reserves
  - Reduce required capacity margins

Fundamental Requirements of AC Transmission
Stability: Generators must remain in synchronism

- Stability decreases as lines are more heavily loaded
- Static Stability: Slowly increasing power will eventually cause generators to pull out of synchronization
- Dynamic Stability: System must return to stable operation after minor disturbance such as step load
- Transient Stability: System must recover after major fault, generator trip, transformer failure

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Fundamental Requirements of AC Transmission

Voltages must be kept near rated values

- Undervoltage can damage equipment
  - Induction motor current increases sharply - Rotor heating proportional to square of current
  - Electronic loads increase current to maintain constant power
    - Line and system losses increase as square of current
    - Negative resistance characteristic
- Overvoltage can damage equipment
  - Insulation failure on HV, EHV, UHV equipment
  - Transformer saturation causes
    - Increased losses
    - Harmonics
    - Potential ferroresonance
- Relatively small (5-7%) changes in transmission voltages cause large, unpredictable changes in power flow

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Transmission Lines are Transmission Lines!

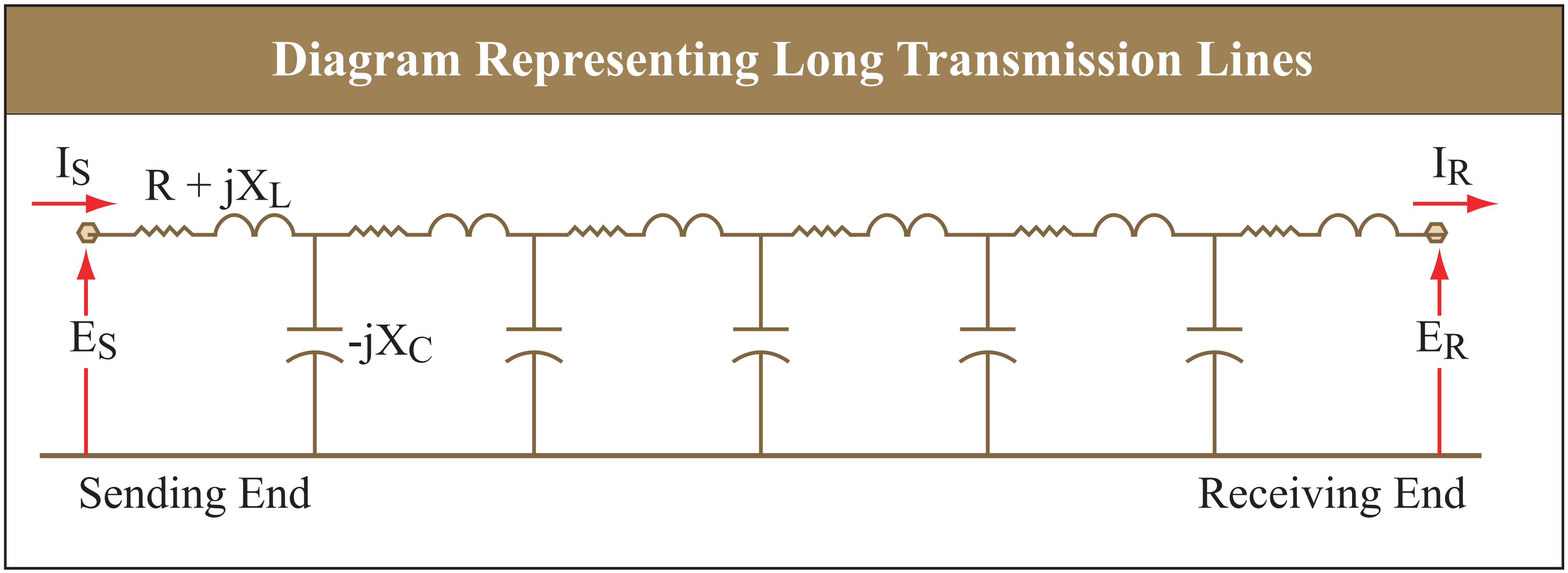

Image by MIT OpenCourseWare.

Typical values: R = 0.06 ohm per mile   Z = 300 ohms

X_L = 0.8 ohm per mile X_C = 0.2 megohm per mile

Capacity Limits for Transmission Lines

Graph removed due to copyright restrictions. Please see Fig. 7 in Hurst, Eric, and Brendan Kirby. "Transmission Planning for a Restructuring U.S. Electricity Industry." Edison Electric Institute, June 2001.

Source: *Transmission Planning for a Restructuring U.S. Electricity Industry*, Eric Hurst and Brendan Kirby, prepared for Edison Electric Institute, 2001

Changes in the Electric Grid

Demand

Regulation

Generation Mix

Transmission

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Changes in the Electric Grid - Demand

Electric utilities forecast demand to increase 2008-2017 by
17 percent (128 GW) in the United States
8 percent (6 GW) in Canada,

Generation resources* are forecast to increase by only
4.6 percent (42 GW) in the U.S. and by
1.1 percent (1 GW) in Canada.

Electric capacity margins will decline over the 2008–2017 period in most regions.

North American Electric Reliability Council.
2008 Long-Term Reliability Assessment.

*Net generating capacity resources (existing, under construction, or planned) considered available (net operable), deliverable, and committed to serve demand, plus the net of capacity purchases and sales.

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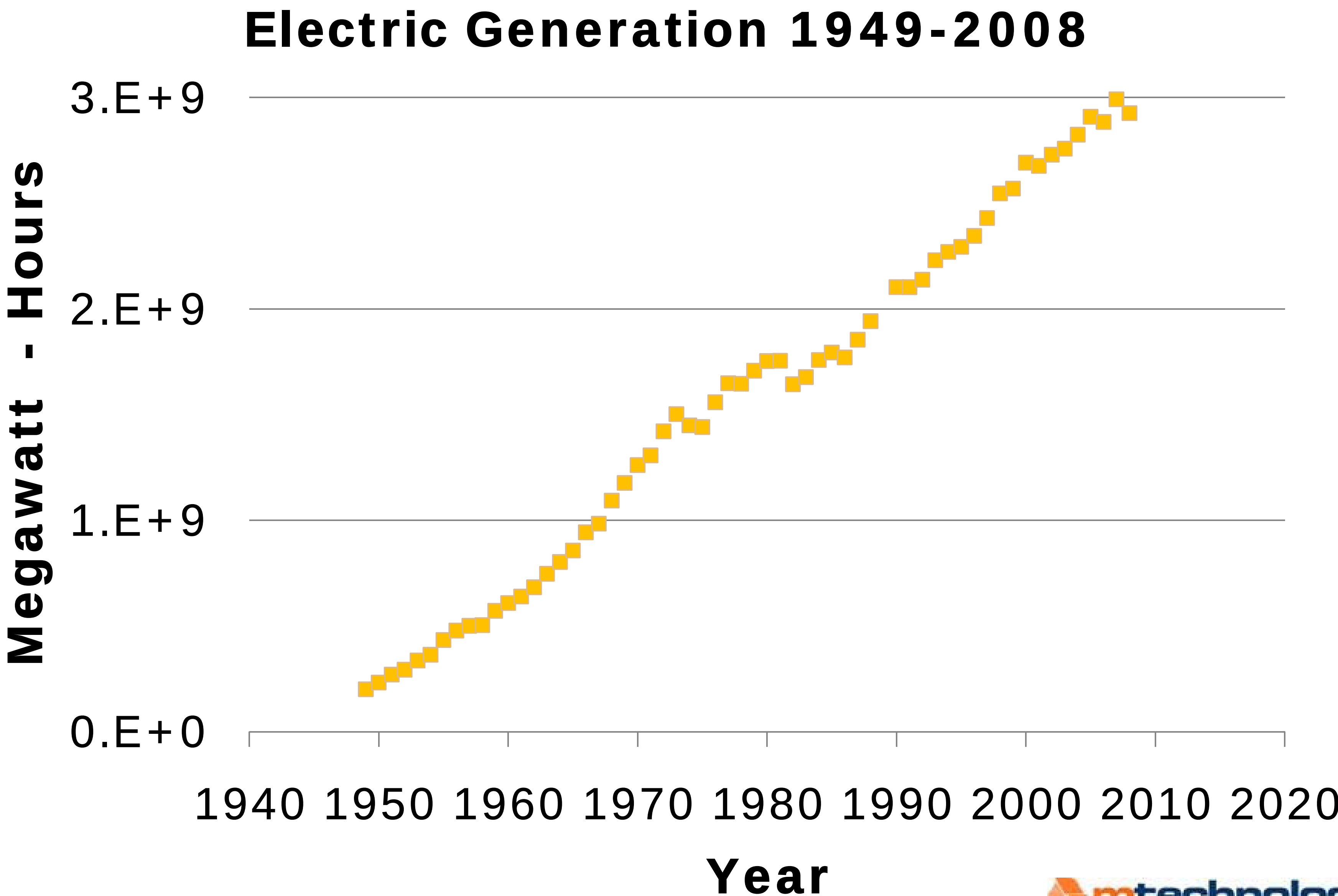
Demand for Electric Power Continues to Grow



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http://www.eia.doe.gov/emeu/aer/elect.html

Changes in the Electric Grid - Regulation

- Federal intervention accelerating in pace and scope
  - 1978 – PURPA, Public Utility Regulatory Policies Act – aka “deregulation” aka “re-regulation”
  - 1992 – Energy Policy Act – Federal Energy Regulatory Commission given broad powers over wholesale generation and transmission network
  - 1996 – FERC orders 888 and 889 – open access transmission
  - 2005 and 2007 Energy Acts - mandates on
    - Renewable energy
    - Demand management
    - Smart metering
    - Financial incentives
  - 2008 - Energy legislation in the bailout bill(s)
  - 2009 and 2010 – lost track

Changes in the Electric Grid - Regulation

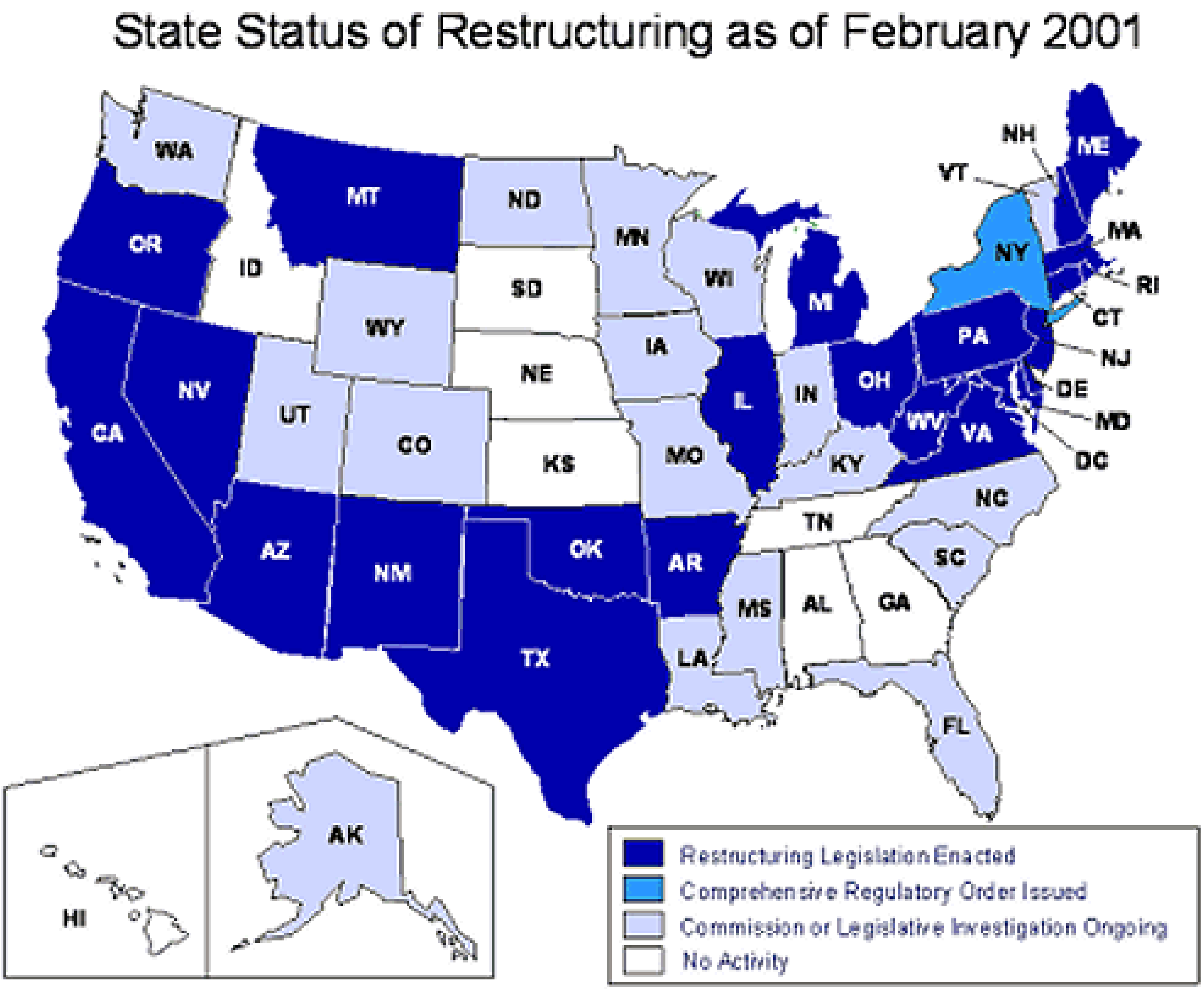

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Image from "Electric Power Industry Restructuring Fact Sheet." Energy Information Administration, U.S. Department of Energy, July 27, 2005.

Changes in the Electric Grid - Regulation

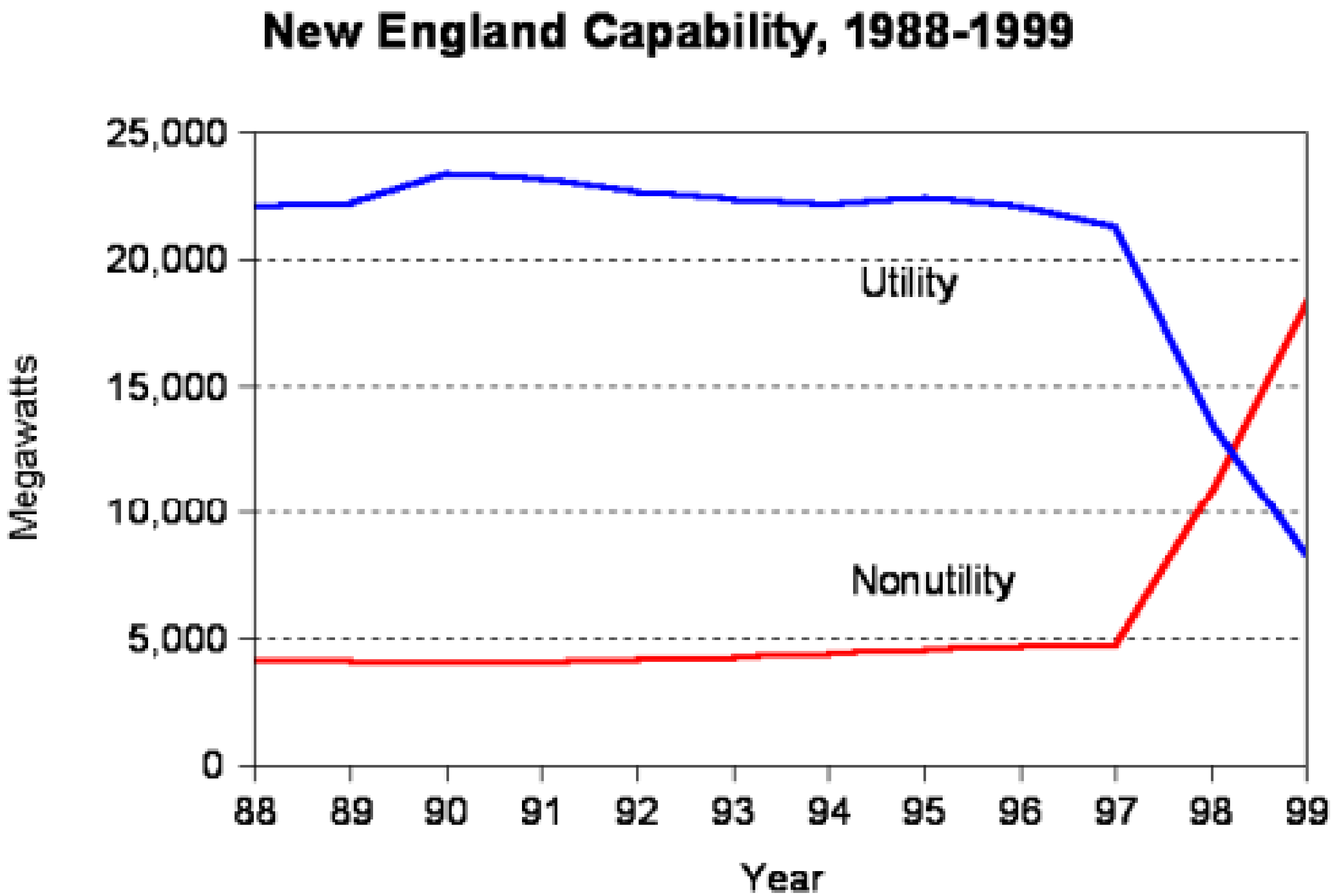

Image from "Electric Power Industry Restructuring Fact Sheet." Energy Information Administration, U.S. Department of Energy, July 27, 2005.

Changes in the Electric Grid - Regulation
The California Experience

1996	California "deregulates"
Apr 1998	Spot market for energy begins operation.
May 2000	Significant energy price rises.
Jun 14, 2000	Blackouts affect 97,000 customers in San Francisco Bay area
Aug 2000	San Diego Gas & Electric Company files a complaint alleging manipulation of the markets.
Jan 17-18, 2001	Blackouts affect several hundred thousand customers.
Jan 17, 2001	Governor Davis declares a state of emergency.
Mar 19-20, 2001	Blackouts affect 1.5 million customers.
Apr 2001	Pacific Gas & Electric Co. files for bankruptcy.
May 7-8, 2001	Blackouts affect 167,000 customers.
Sep 2001	Energy prices normalize.
Dec 2001	Allegations that energy prices were manipulated by Enron.
Feb 2002	FERC begins investigation of Enron's involvement.
Oct 7, 2003	Governor Davis loses 1st recall election in state history
Nov 13, 2003	Governor Davis ends the state of emergency.

Lesson for Aspiring Politicians

Keep the lights on!

Changes in the Electric Grid - Generation Mix

- Natural Gas is the only large-scale generating technology that can be permitted in much of the US today
- States have begun denying permits for new coal plant construction by characterizing CO_2 as a “pollutant.”
- Renewable Energy Portfolio Standards mandate the use of certain generation technologies in 30 states
- 16 Combined Construction and Operating License applications to build 24 new reactors filed with NRC; 2-4 anticipated online by 2018

Changes in the Electric Grid - Transmission System

Designed, as-built purpose of transmission:

- Transmit power from hydroelectric plants
- Bulk supply of power to load centers
- Emergency interconnection between utility networks

Legislated new purpose of transmission:

- Enable wholesale trade and competition
- Provide equal access to all
- Enable wind farms

Changes in the Electric Grid - Transmission System

- 680,000 miles in service
- 7,100 miles planned additions through 2015
- Effective nationalization of transmission assets by FERC discourages private investment
- 330 MW 25-mile (small, short) Cross Sound Cable
  - lay dormant for 2 years after completion – activated via FERC emergency order after August 2003 blackout

Changes in the Electric Grid - Transmission System

The lack of adequate transmission emergency transfer capability or transmission service agreements could limit the ability to deliver available resources from areas of surplus to areas of need."

- North American Electric Reliability Council. *2006 Long-Term Reliability Assessment.*

Changes in the Electric Grid - Transmission System

Public opposition to new transmission facilities is deep and effective.

DOE announced in 2007 the draft designation of two National Interest Electric Transmission Corridors. The federal government has concluded that a significant regional transmission constraint or congestion problem exists – one that is adversely affecting consumers and that has advanced to the point where there is national interest in alleviating it. http://nietc.anl.gov/index.cfm

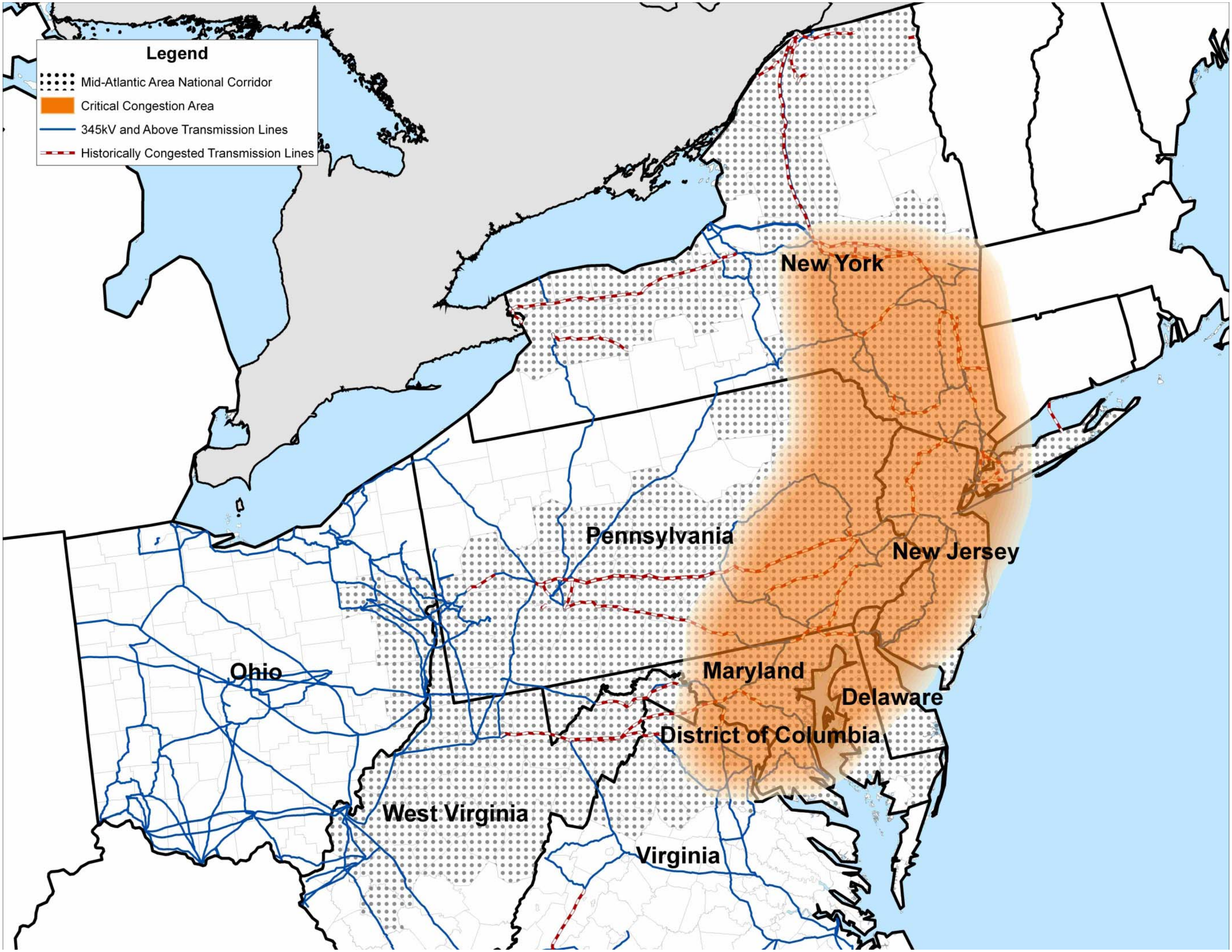

Image by Office of Electricity Delivery & Energy Reliability, U.S. Department of Energy.

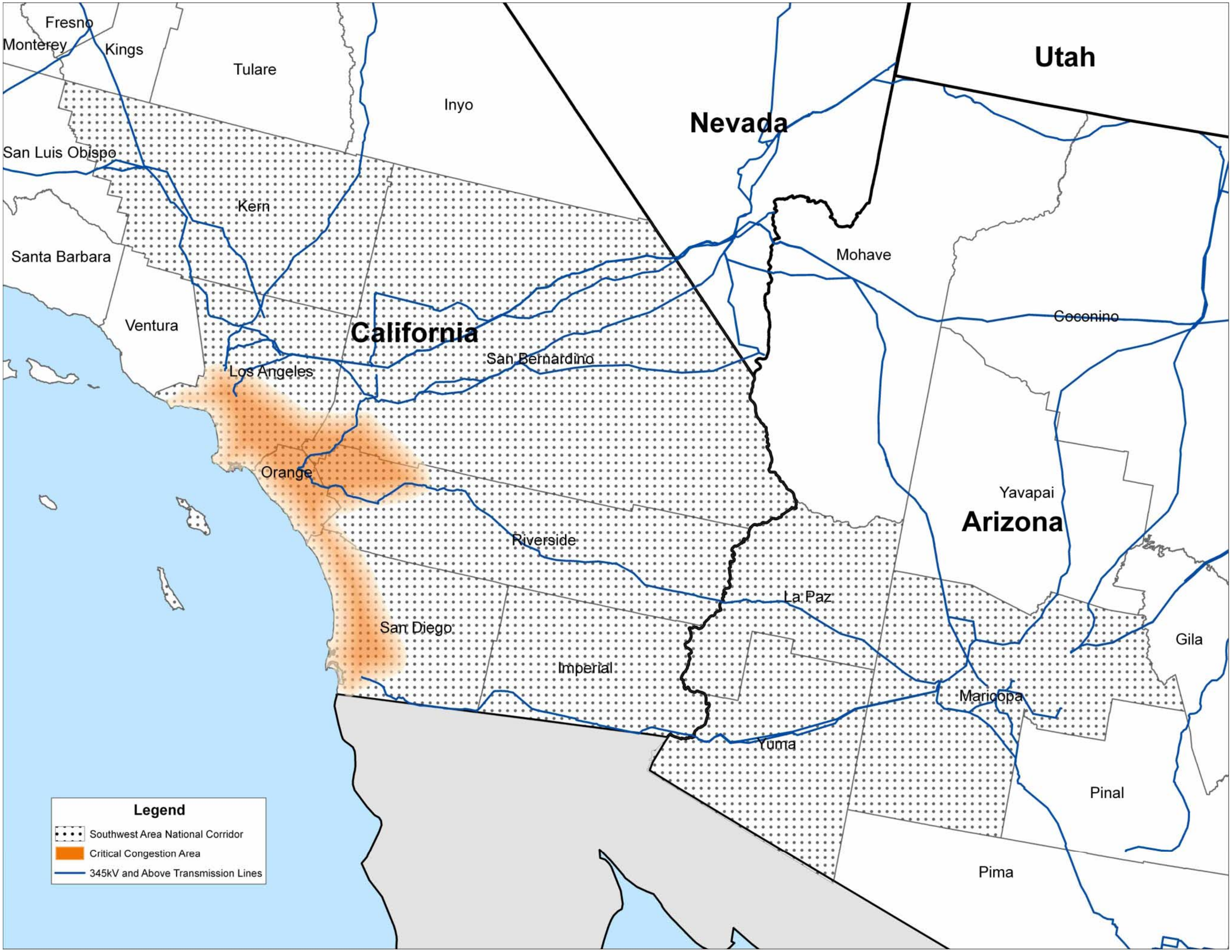

Image by Office of Electricity Delivery & Energy Reliability, U.S. Department of Energy.

Changes in the Electric Grid - Transmission System

Electricity follows the path of least resistance.

Changes in the Electric Grid - Transmission System

~~Electricity follows the path of least resistance.~~

Electricity follows all available paths, in inverse proportion to the impedance of each path.

Power flow obeys physics, not contracts

Power follows multiple paths

Loop flow consumes line capacity without delivering power

Image removed due to copyright restrictions. Pleases see Fig. 2 in Lerner, Eric J. "What's Wrong with the Electric Grid?" *The Industrial Physicist* 9 (October/November 2003): 8-13.

Source: *What's Wrong with the Electric Grid,* Eric Lerner, The Industrial Physicist, October 2003

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Changes in the Electric Grid - Technology

- Demand (customer) side
  - Growing dependency on computers and communications
  - Growing sensitivity to power quality, interruptions
- Generation side
  - Shrinking capacity margins and redundancy in generation, transmission
  - Growing dependence on unreliable, non-dispatchable renewable energy sources
    - February 2008 – drop in West Texas wind power caused
      - Interruptible customers to be curtailed
      - High probability of rolling "Davis recall" blackouts
    - Must-run cogeneration plants in Denmark requires much of winter wind energy to be sold to Sweden at bargain prices
    - Nellis Solar Plant in Nevada – 30 MW to 2 MW as clouds pass over
    - European ISOs increasingly limit wind power capacity that may be bid

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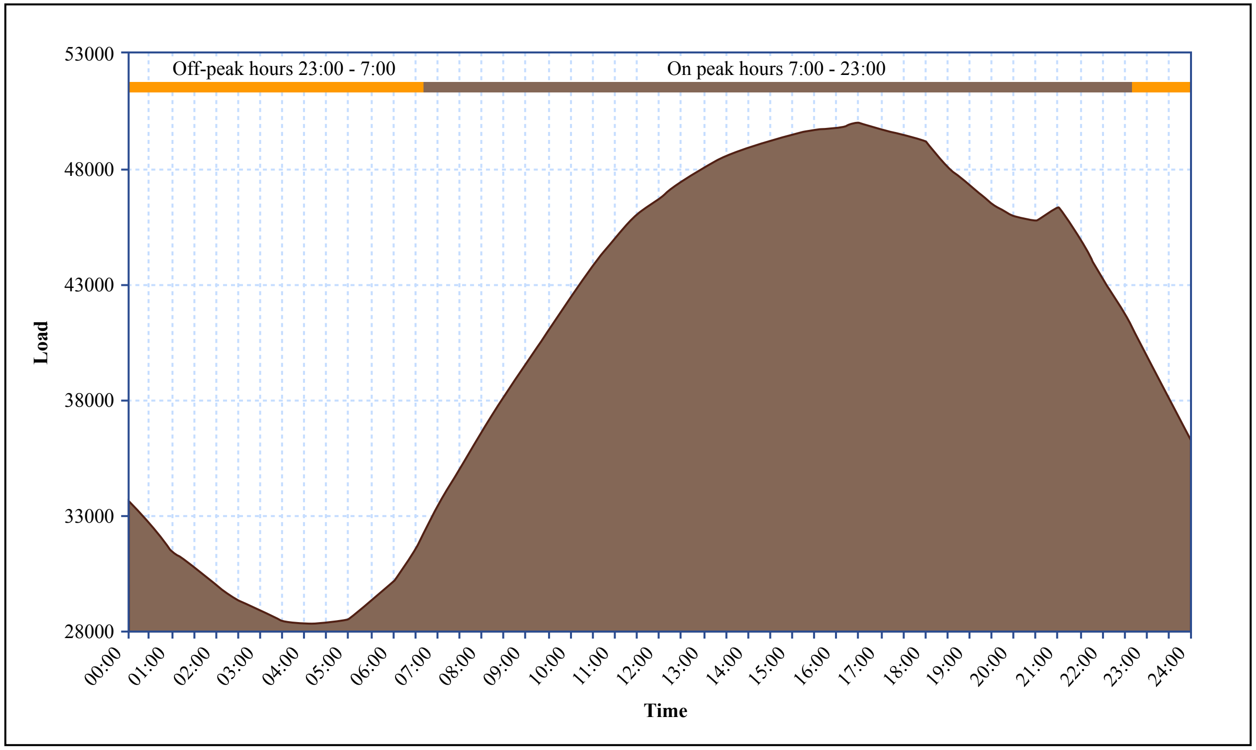
Power requirements historically determined by demand

Typical Summer Load Curve for PJM



Predictable, correlated with calendar, weather

Image by MIT OpenCourseWare. Data from www.pjm.com.

New mix results in rapid changes in generation

- Wind power can start or stop in minutes
- Solar power changes in seconds
- Large gas turbines take several minutes to ramp up or down
  - Reduced life expectancy from rapid cycling
- New market for frequency stabilization
  - Formerly su pplied by excess spinning capacity
  - Transmission operators generally limited to 4-second response time
  - Technologies that are too expensive for wholesale competition find a niche in frequency stabilization
    - Flywheel energy storage
    - Advanced battery energy storage

Demand Response

- Central planning vision: reduce demand when load is high, capacity is low.
- Requires detailed metering and remote control of millions of appliances
- Consumer’s perception: Turn off my air conditioner during a heat wave.
- Subject matter expert: Former California Governor Gray Davis

Distributed Generation

Generation connected at the distribution system level

Generally more expensive, less safe, higher polluting but

Only possibility to meet growing demand without new transmission and large central generation facilities

Distributed Generation

Results in very large (10-100x) increase in number of sources connected to network

Violates basic design assumptions regarding the direction of power flow

Significant technical problems remain unsolved

- Safety of linemen
- Coordination during faults
- Interaction with existing voltage regulation infrastructure
- Stability
- Reliability
- Reactive power supply
- - and many more

Changes in the Electric Grid

Demand – strong and growing. Recession/depression will reduce rate of growth. Projected 1% decrease in MWh generation 2008-2009 is only the third decrease since 1949. Some areas (e.g. Detroit) are experiencing significant reductions in load.

Regulation – strong and growing. Increasing intervention into markets, political selection of favored technologies,

Generation Mix – Less fuel diversity (more reliance on natural gas) plus new "plants" that cannot be dispatched and fail frequently with little warning.

Transmission – Extremely sophisticated system built in 1950s-70s being used for unforeseen purposes. Operating outside design assumptions and limits. Nationalization of assets have drastically reduced incentives for private investment. Nimby, Banana and Nope.

Technology – Consumer and commercial power requirements trending towards higher quality and reliability, while grid systemic trends are opposite.

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Tremendous business and employment opportunities

Sustainable Energy – no opinion.

Sustainable profits – impossible in free markets.

Profit and loss are generated by success or failure in adjusting the course of production activities to the most urgent demand of the consumers. Once this adjustment is achieved, they disappear. - Ludwig von Mises, *Profit and Loss*

http://mises.org/books/profitloss.pdf

Transient profits, quantity unknown – almost certain.

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Conclusions

- Electric power has not been a major career choice for the past 3 decades.
- Aging of the electric power industry workforce is a growing concern and recognized by NERC as a potential threat to the reliability of the grid.
- Financial engineering is unlikely to be hiring again soon.
- The demand for electric power remains strong.
- The present supply system is being stressed by age, legislation, re-purposing, and new generation sources with new and different characteristics.
- New technology, new rules, new consumer requirements are creating major new opportunities.

Thank you.

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