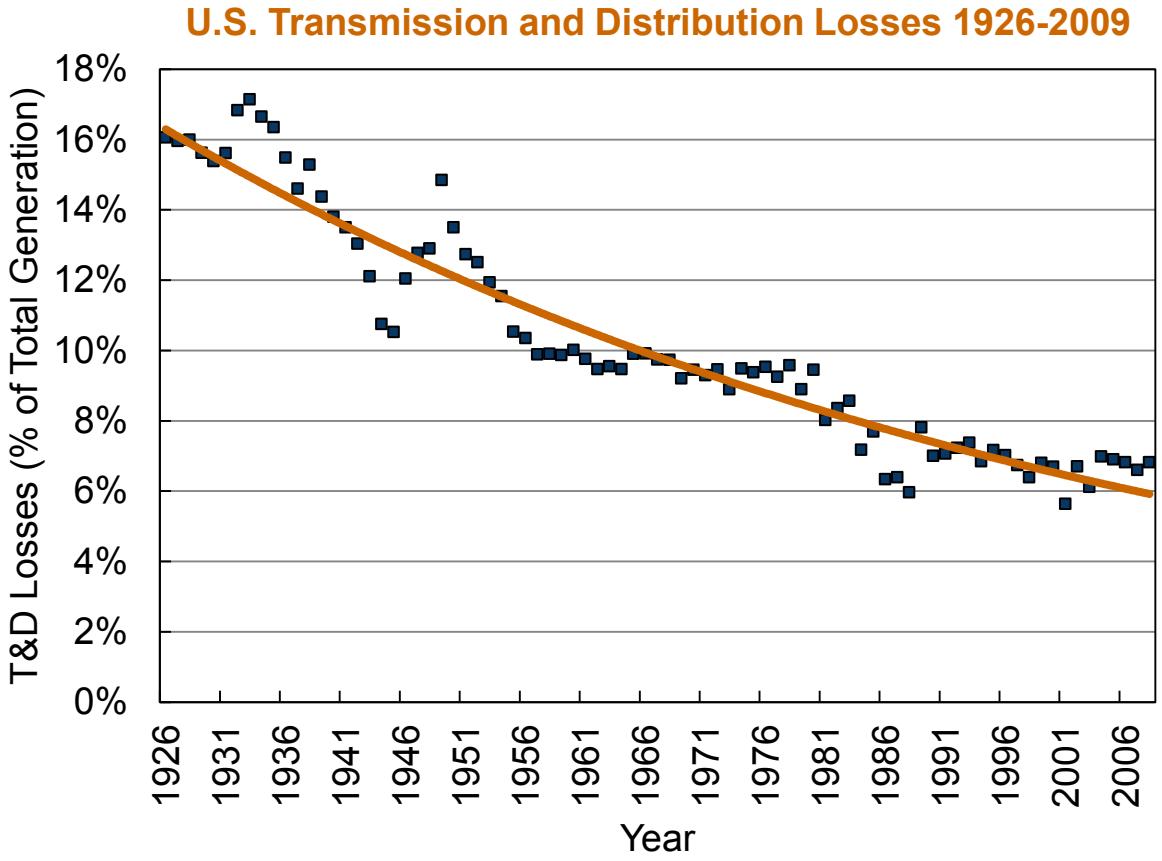
Tomorrow's Electric Power System: Challenges & Opportunities

Lecture 18

eDMP: 14.43 / 15.031 / 21A.341 / 11.161

Despite Complexity and Exceptional Policy & Institutional Fragmentation, the U.S. Grid Performs Well *Today*

- Losses have fallen over time, are in line with other nations'
- Reliability also seems in line with other developed countries
- **Performance data are very spotty! Why?**



Source: Data for all years prior to 1943 were reported by the Edison Electric Institute. Losses for the years 1943 to 1951 were calculated using Edison Electric Institute data on generation, net imports, company use, producer use, and sales to customers. Company and producer use data were not reported during this time period, so the average of these quantities from 1941 and 1942 was used. Data for all years from 1951 to the present are from the U.S. Energy Information Administration Annual Energy Reviews.

Future of the Grid Study: In 2030 Known Technologies Will Dominate, But Significant Challenges & Opportunities –

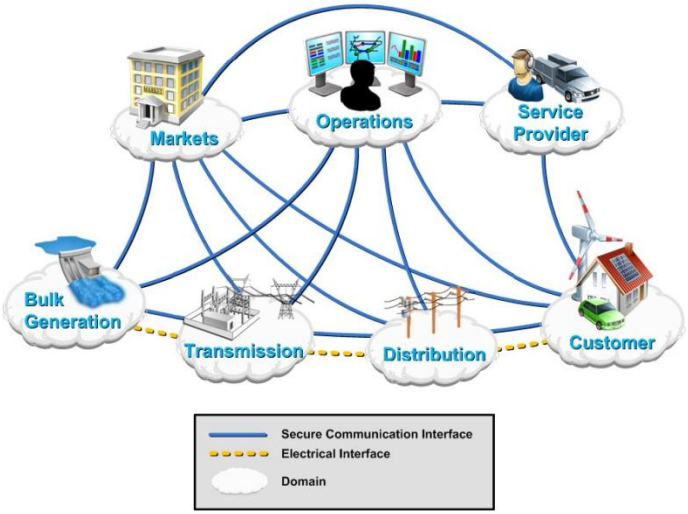
- New technologies with great potential
- More grid-scale wind and solar generation
- Plug-in hybrid & pure electric vehicles
- Increased deployment of distributed generation
- Increased connectivity → cybersecurity and information privacy concerns

Some Constraints to Keep in Mind

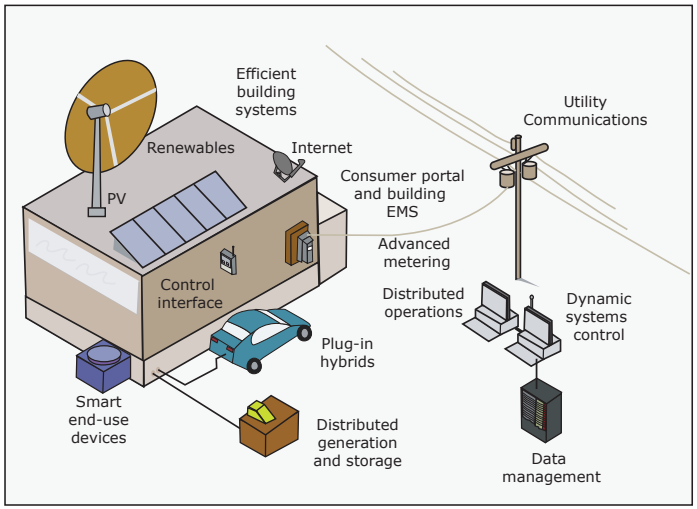
- No clear federal policy; states jealous of their powers (Texas the extreme case, but not by that much.)
- Little post-CA/Lehman appetite for reform/markets
- Institutionally diverse system with a variety of interests: coal states, rural coops, etc.
- Not much demand growth expected: 0.7%/yr. to 2035
- Very durable assets: EIA's forecast of generation retirements 2010 – 2035 as % of 2010 capacity?

6.7%

"Smart Grid" as a Means, Not an End



Source: National Institute of Science and Technology. *Smart Grid: A Beginner's Guide.* Washington, DC: Government Printing Office, 2010, p. 5.



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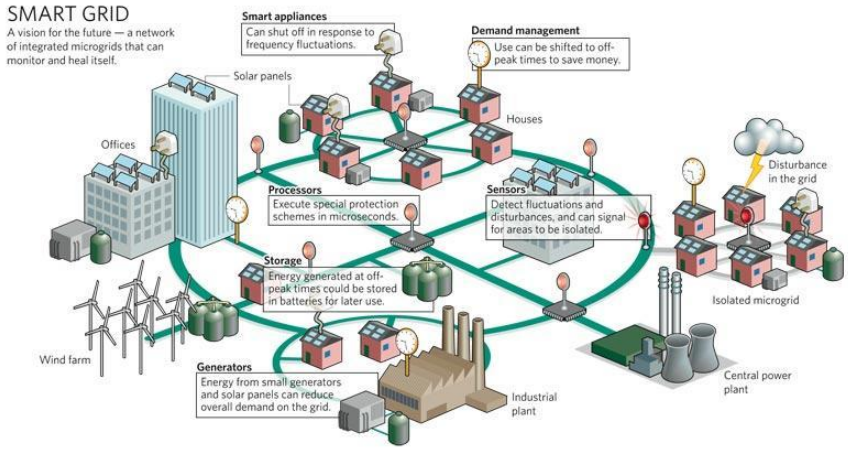

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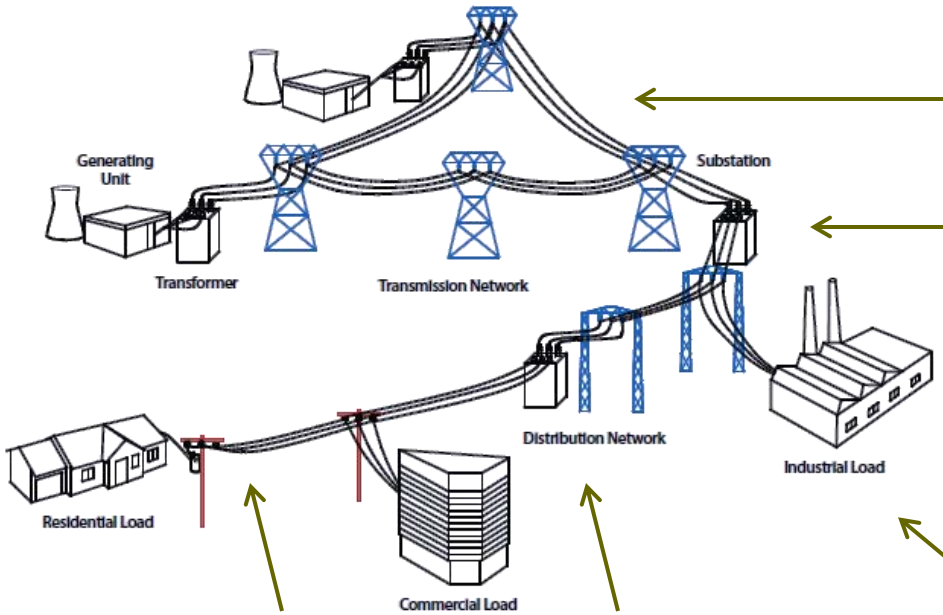
Source: U.S. Department of Energy

MITei MIT Energy Initiative

Policy *Mismatches* Could Have High Costs

- Lack of focus on grid technology innovation and RD&D
- More use of renewables requires significant changes
- Retail prices do not reflect time-varying nature of actual costs
- Per-kWh prices for distribution distort distributed generation incentives
- No clear authority for grid-wide cybersecurity

New Technologies Offer Great Opportunities



Transmission and Substations:

- Phasor Measurement Units (PMUs)
- Flexible AC Transmission Systems (FACTS)
- New Sensor Technologies
- High Voltage DC Lines
- Superconducting Lines
- Fault Current Limiters
- Dynamic Line Rating Systems
- Energy Storage

Distribution and Customers:

- Distribution Management Systems
- Outage Management Systems
- Volt/VAR Optimization
- Conservation Voltage Reduction
- Automated Fault Detection, Isolation, & Restoration
- Advanced Metering Systems
- Microgrids

Control Centers:

- Improved System State Estimation
- Phase Angle Monitoring/Alarms
- Improved System Simulation Models
- Oscillation Detection
- New System Control Approaches

Interconnection: the potential & challenge of PMUs

Florida Blackout simulation removed due to copyright restrictions.

Targeted RD&D Could Have Great Benefits

- PMUs could benefit the transmission network greatly, but….
  - …mechanisms for sharing data are immature (& resisted)
  - …tools that can generate actionable information from data acquired from PMUs are needed
- Flexible AC Transmission System (FACTS) devices can enhance transmission capacity, but have high costs.
- Need control schemes that use FACTS as well as other hardware, with information from PMUs.
- Complementarities among many *distribution system technologies* are not yet understood; results of ARRA demonstration projects could aid decision-making.

Industry-led RD&D Efforts Are Critical

RECOMMENDATION:

The electric power industry should fund RD&D projects to develop:

- **computational tools that will exploit the potential of new hardware to improve monitoring and control of the bulk power system**
- **methods for wide-area transmission planning**
- **processes for response to and recovery from cyberattacks**
- **understanding of consumer response to alternative pricing/response automation systems.**

Regulators' reluctance to approve RD&D or the use of locally new technologies: easy to understand, hard to fix

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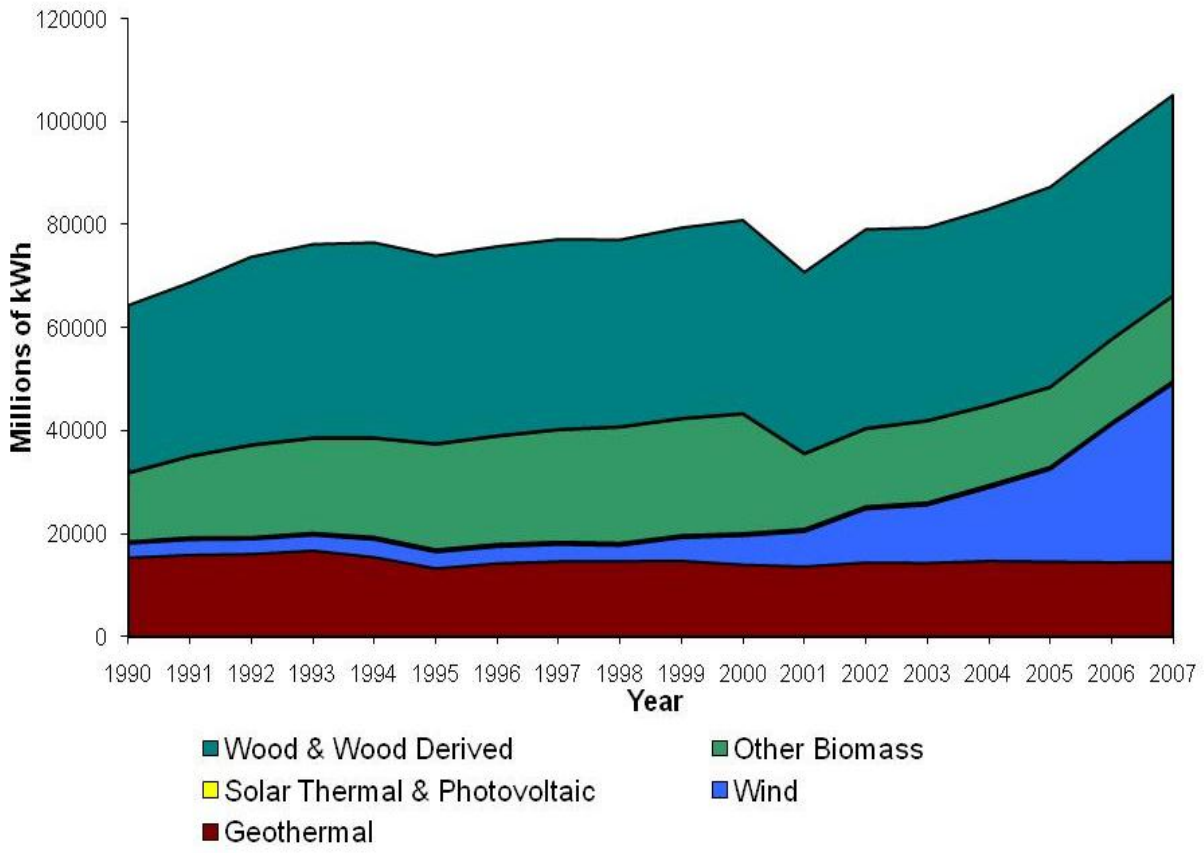
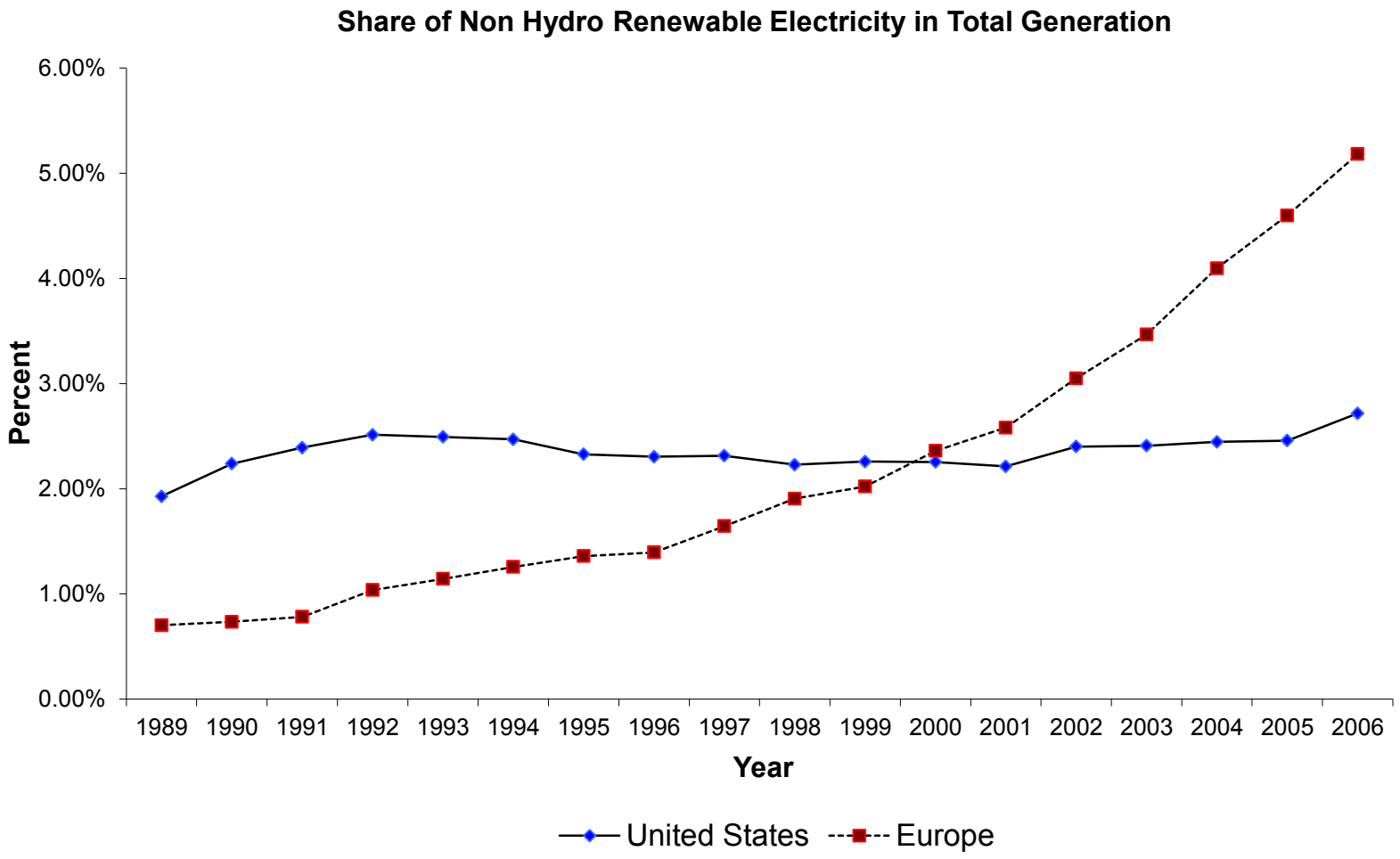
US Non-Hydro Renewable Generation:



- Rapid wind-driven growth has continued: total was 173,000M kWh in 2010
- 2010: Wind 55%, Municipal Waste 11%, Wood & Other Biomass 22%, Geothermal 9%, Solar 3%

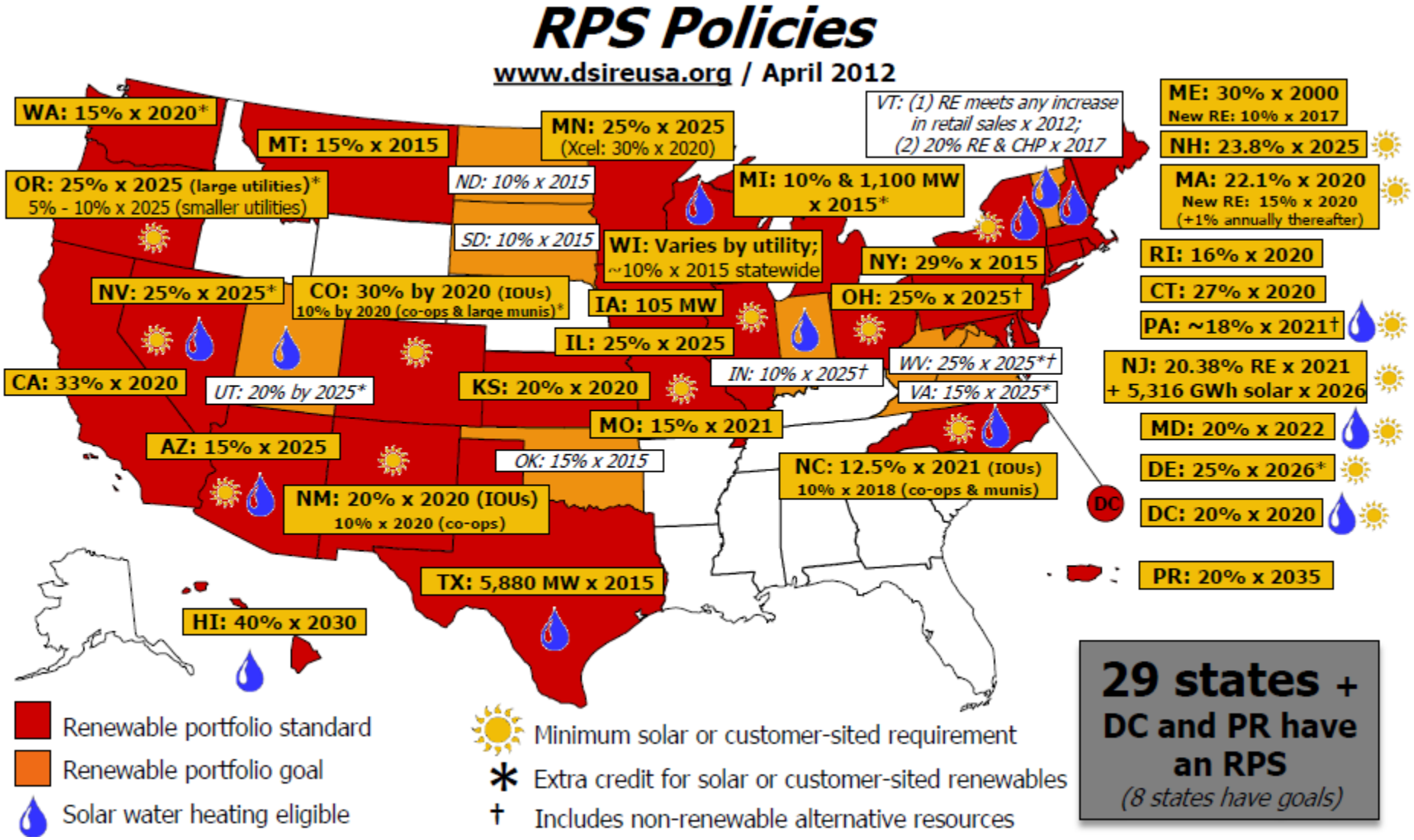
Europe Has Done More Recently



Some States Have Also Done More

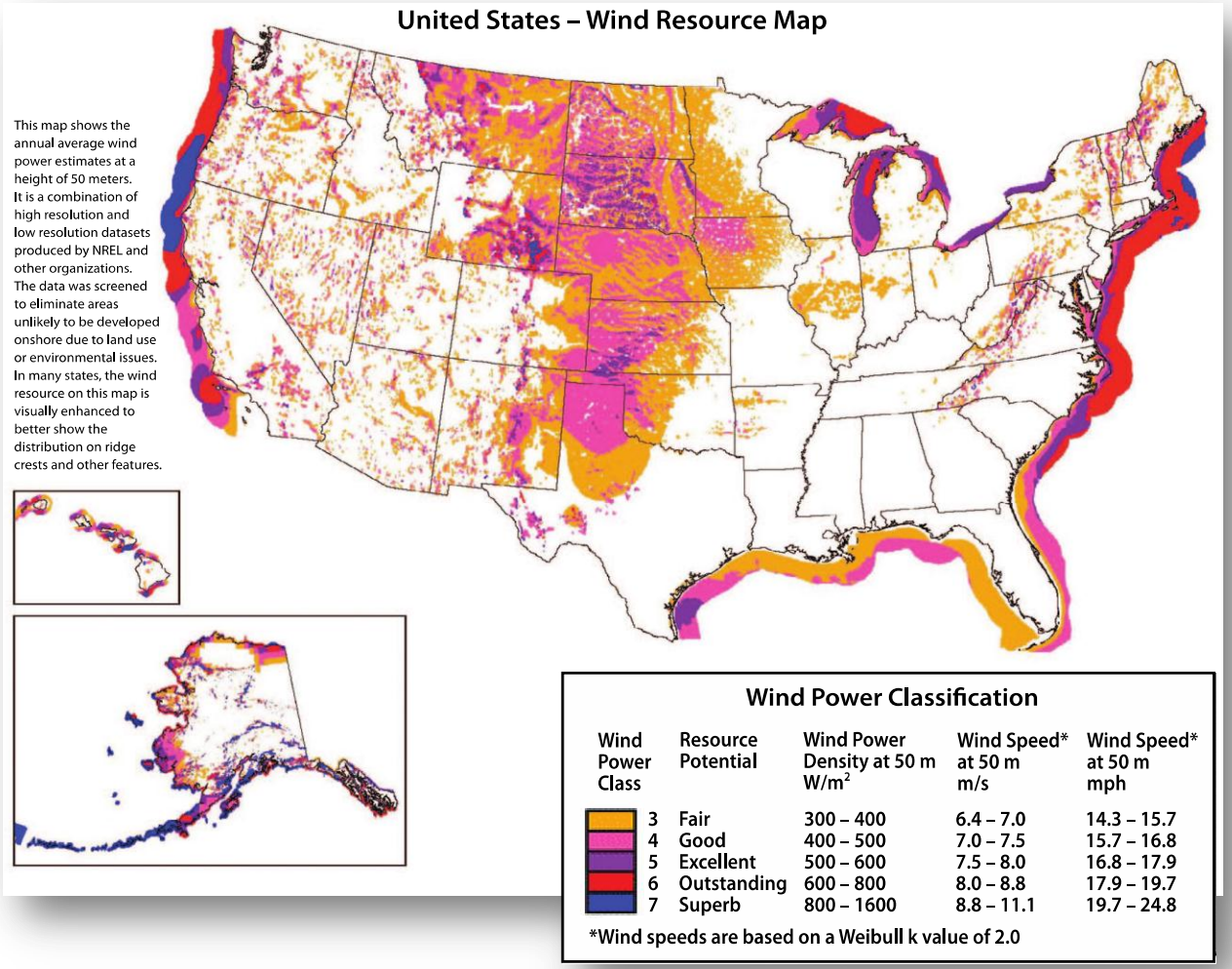
State	2007 NHR Generation		Main NHR Technology or Technologies
	Percent of State Total	TWh	
Maine	26.1	4.21	Wood/Wood Waste
California	11.8	24.85	Geothermal
Vermont	8.0	0.65	Wood/Wood Waste
Minnesota	7.2	3.93	Wind
Hawaii	6.6	0.75	Wind, Geothermal
Iowa	5.8	2.91	Wind
Idaho	5.7	0.65	Wood/Wood Waste
Texas	2.5	10.29	Wind
Florida	1.9	4.30	Wood/Wood Waste, Other Biomass

And State Policies Call for Lots More



Courtesy of Database of State Incentives for Renewables & Efficiency. Used with permission. The Database of State Incentives for Renewables & Efficiency (DSIRE) is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the N.C. Solar Center and the Interstate Renewable Energy Council.

Will Need More Boundary-Crossing Lines



Source: This information was prepared by the National Renewable Energy Laboratory for the U.S. Department of Energy. This image has been reprinted from the National Renewable Energy Laboratory's GIS website http://www.nrel.gov/gis/pdfs/windsmodel4pub1-1-9base200904enh.pdf, accessed November 16, 2011.

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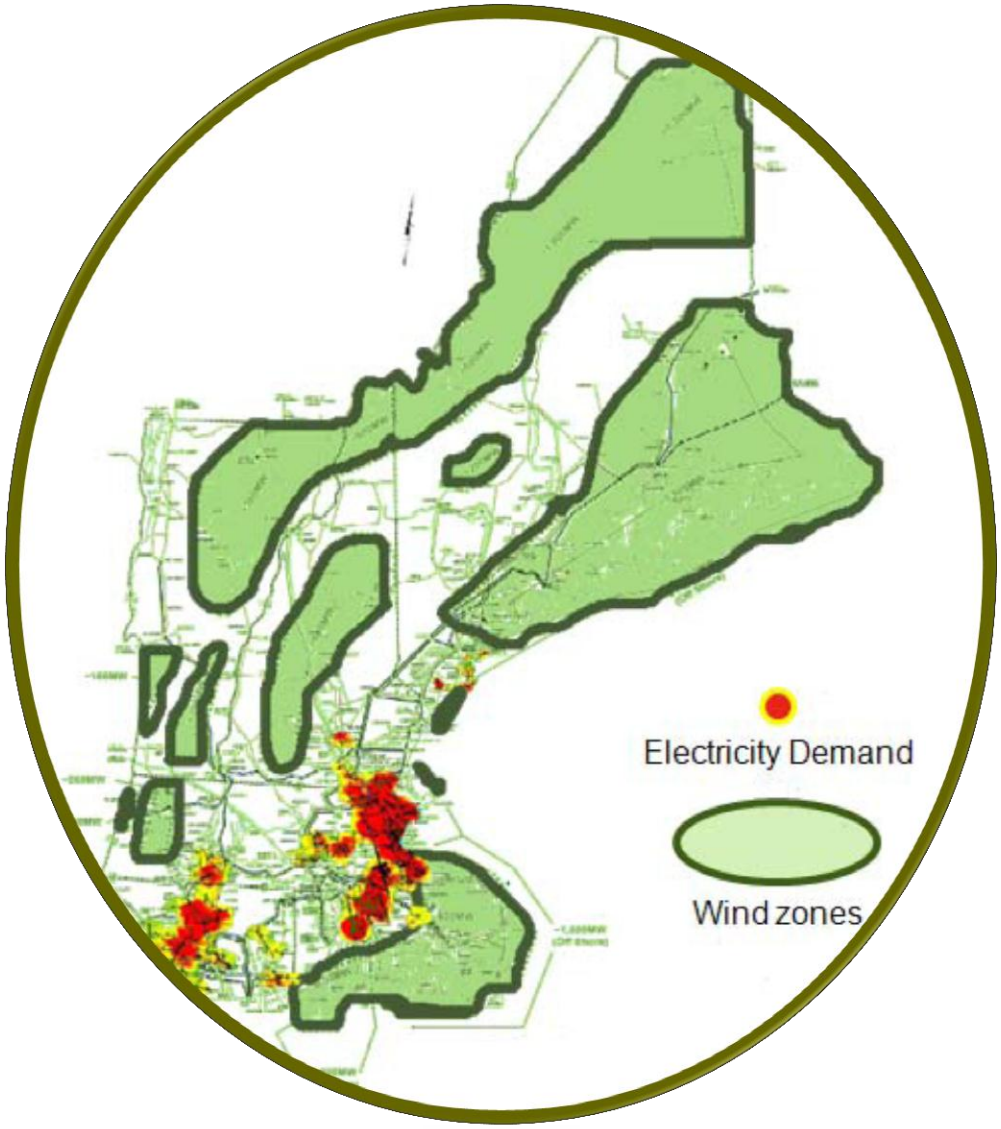


Northeast/New England:

A regional example of the mismatch between wind resources and demand centers

Transmission Siting Must Be Reformed

- States and federal agencies can and do block siting of transmission lines.
- No agency able to consider broad national interests and approve a boundary-crossing line.

RECOMMENDATION:

New legislation should grant FERC enhanced siting authority for major transmission facilities that cross state boundaries or federal lands.

Do state officials like this?

Wind & Solar are non-dispatachble, “intermittent” (& wind is often off-peak)

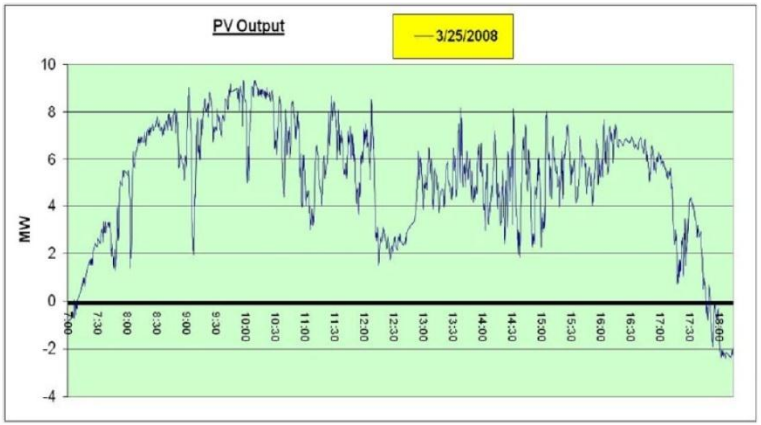
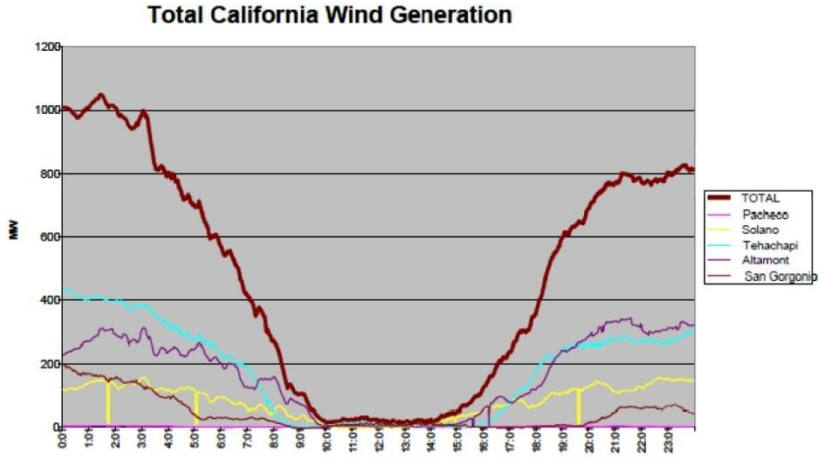


Figure 2.12: PV Plant output on a partly-cloudy day (Sampling time 10 seconds)



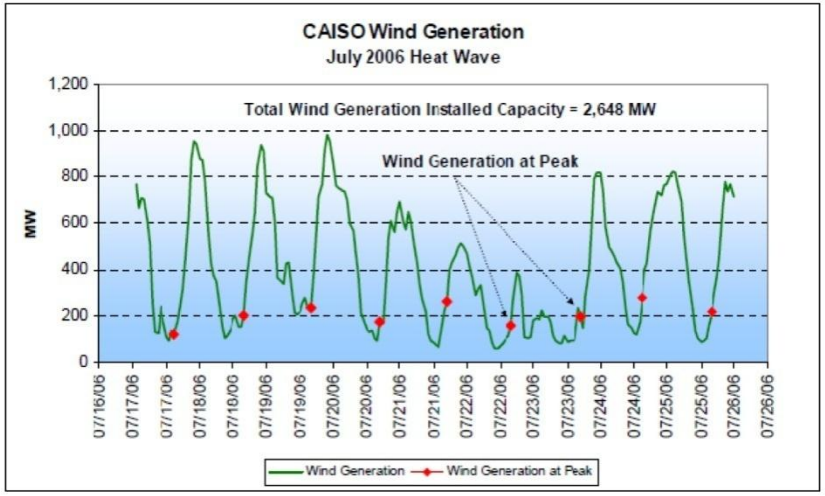
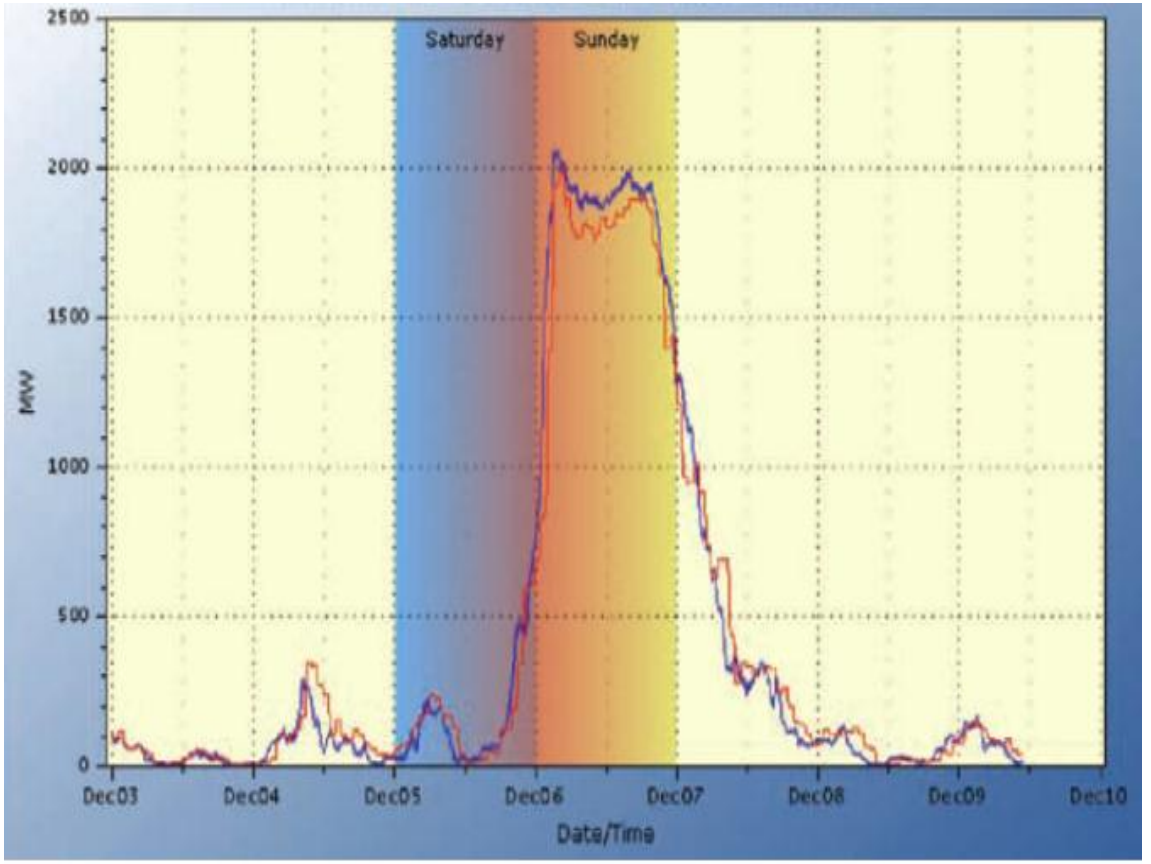


Figure 3.2: CAISO wind generation during the 2006 heat wave

Changes to System Operation Will Be Critical

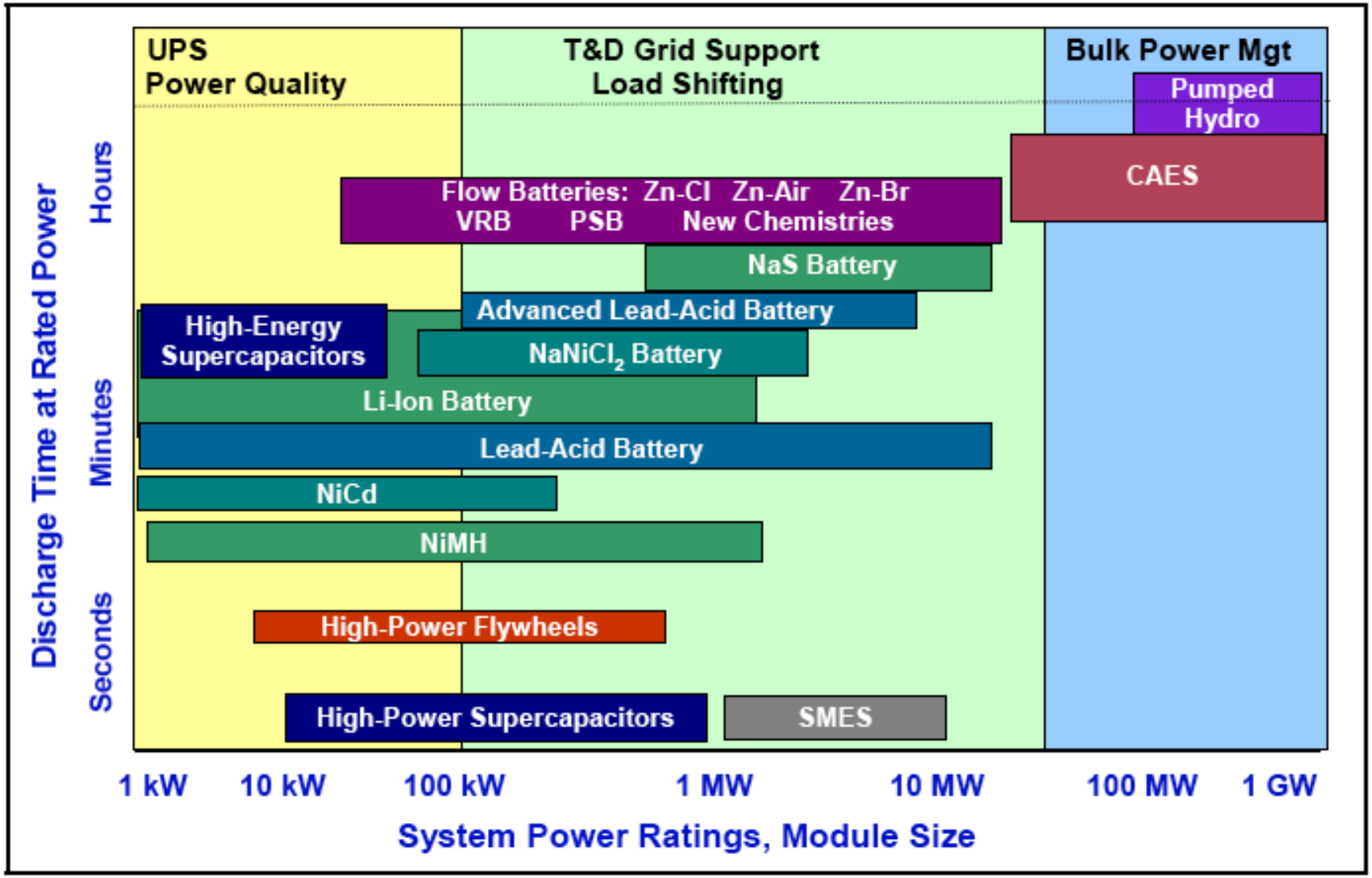
- Wind output more variable than load, imperfectly predictable.
- Work on better forecasting in progress.
- System operators studying, implementing other changes to facilitate more wind.
- **Few incentives currently exist for adding flexibility.**

BPA Total Wind Generation 12/3/2009 – 12/10/2009



Source: Bonneville Power Administration. "Balancing Authority Load and Total Wind, Hydro, and Thermal Generation, Near-Real-Time." http://transmission.bpa.gov/business/operations/wind/baltwg.aspx.

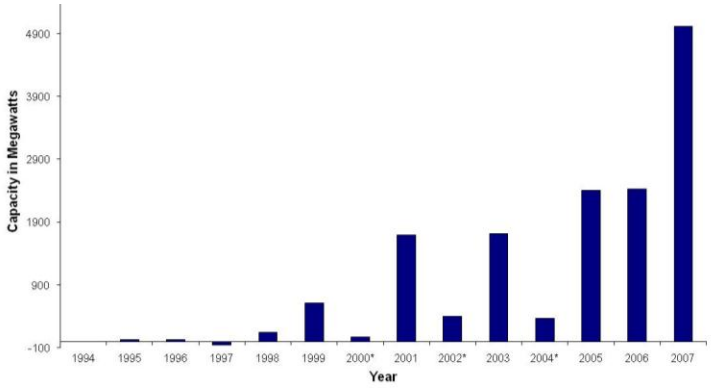
Many Storage Technologies, but…



Source: Electric Power Research Institute. *Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits (1020676)*. Figure ES-6. Washington, DC: Government Printing Office, 2010, p. 7.

What Can Be Done About Wind/Solar Cost?

- Clear case for R&D to lower cost; not much until now
- Rely on carbon price and/or subsidize renewables?
  - If the *right* carbon price, targeted subsidies make little sense
  - EU countries: stable "feed-in-tariffs,"utilities buy at fixed prices
  - US federal: unstable tax breaks (add complexity), boom/bust



US States: tax breaks, renewable portfolio standards: require purchases of minimum quantities, enforcement varies

- Why has the US adopted such an inefficient policy mix?

Because it makes costs less visible…?

Policy *Mismatches* Could Have High Costs

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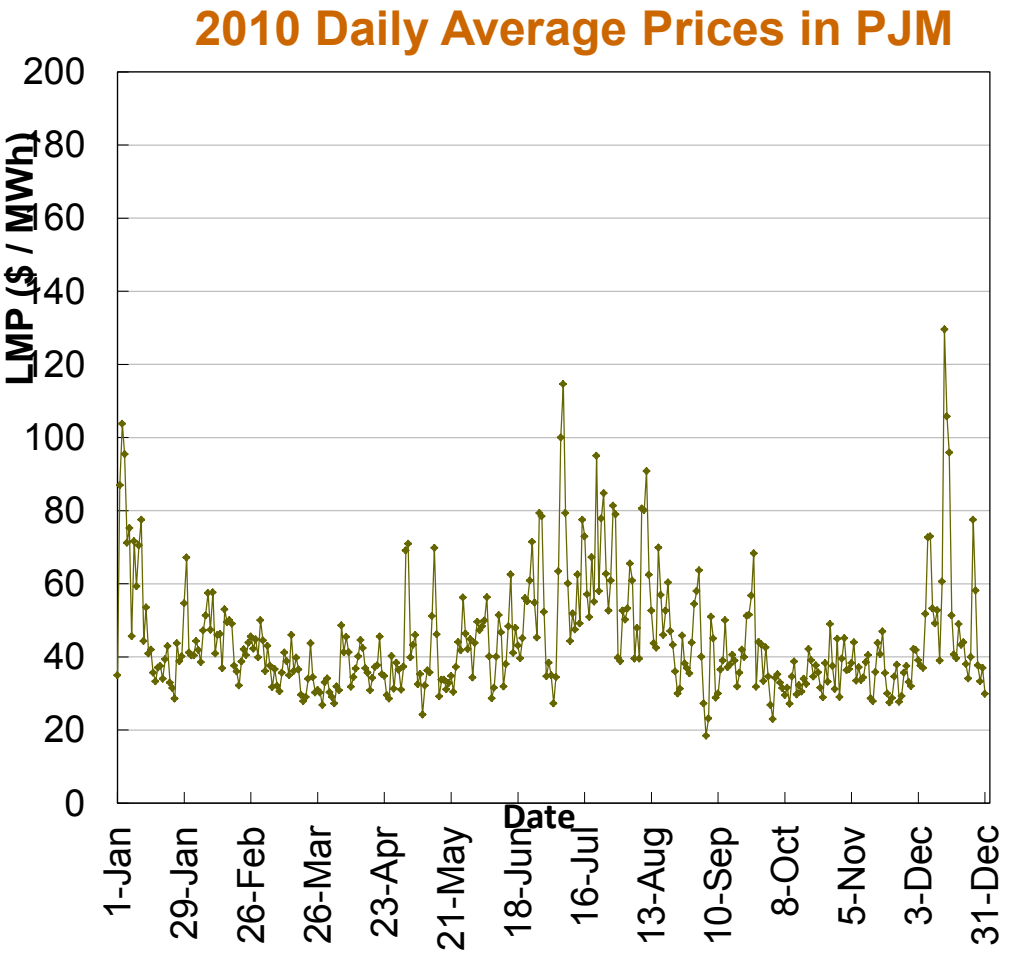
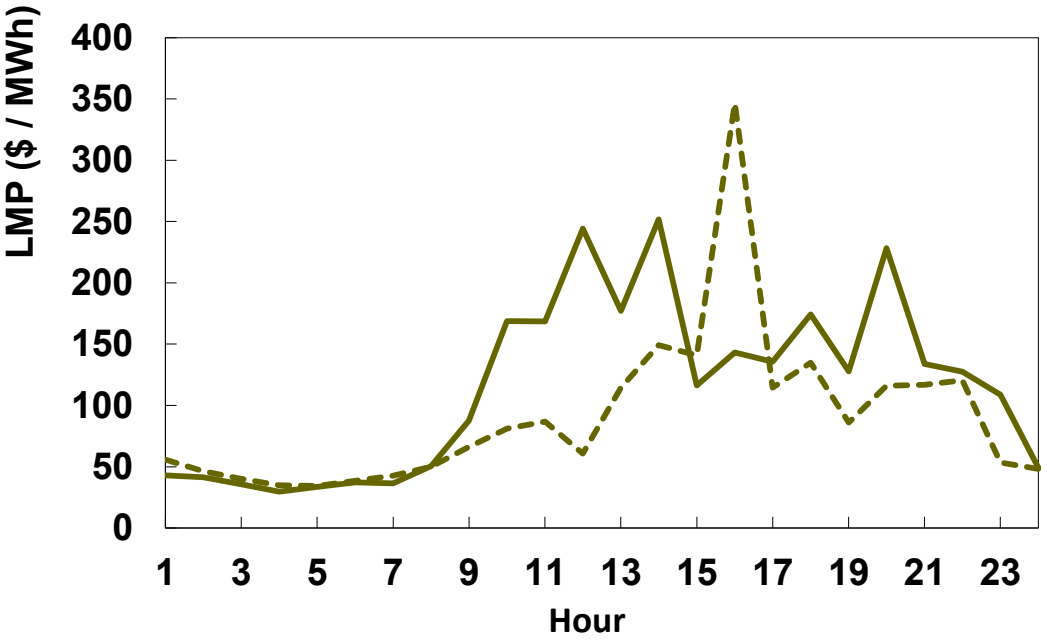
Varying Demand ⇒ Varying Marginal Costs



- Prices to most small commercial and residential consumers do not reflect this variation.
- Advanced Metering Infrastructure (AMI) makes dynamic pricing feasible.
- Much enthusiasm for AMI, but not for dynamic pricing.
- Behavior of residential consumers with dynamic pricing not well understood.

Varying Demand ⇒ Varying Marginal Costs

Hourly Real-Time LMPs – July 7 & Aug 11



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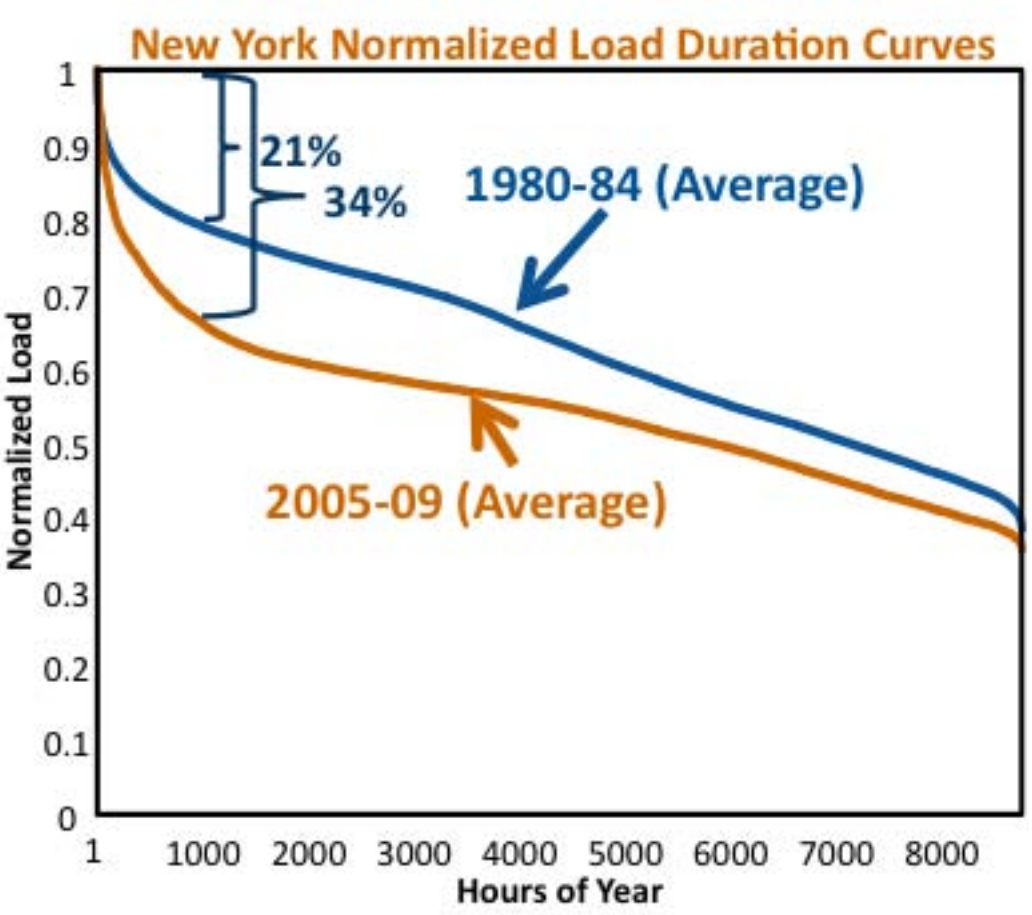
“Peakier” Load Duration Curves Raise MC Variability & Cost



Air conditioning, shift away from industrial load have reduced capacity utilization.

- Electric vehicles charged in late pm could make this worse.
- Moving charging, other loads off peak could flatten curve and lower cost.
- But most current demand response programs focus on emergencies, not load leveling.
- In principle, dynamic pricing can help smooth demand peakiness, lower costs.

Realizing the Potential of Dynamic Pricing

- Dynamic pricing + automated response can shift demand & lower costs, but more research on consumer behavior is needed.

- Substantial ARRA-supported, state-mandated AMI investments provide a very important learning opportunity.

RECOMMENDATION:

Utilities that have committed to AMI systems should begin a transition to dynamic pricing for all customers and publicly share data from their experiences.

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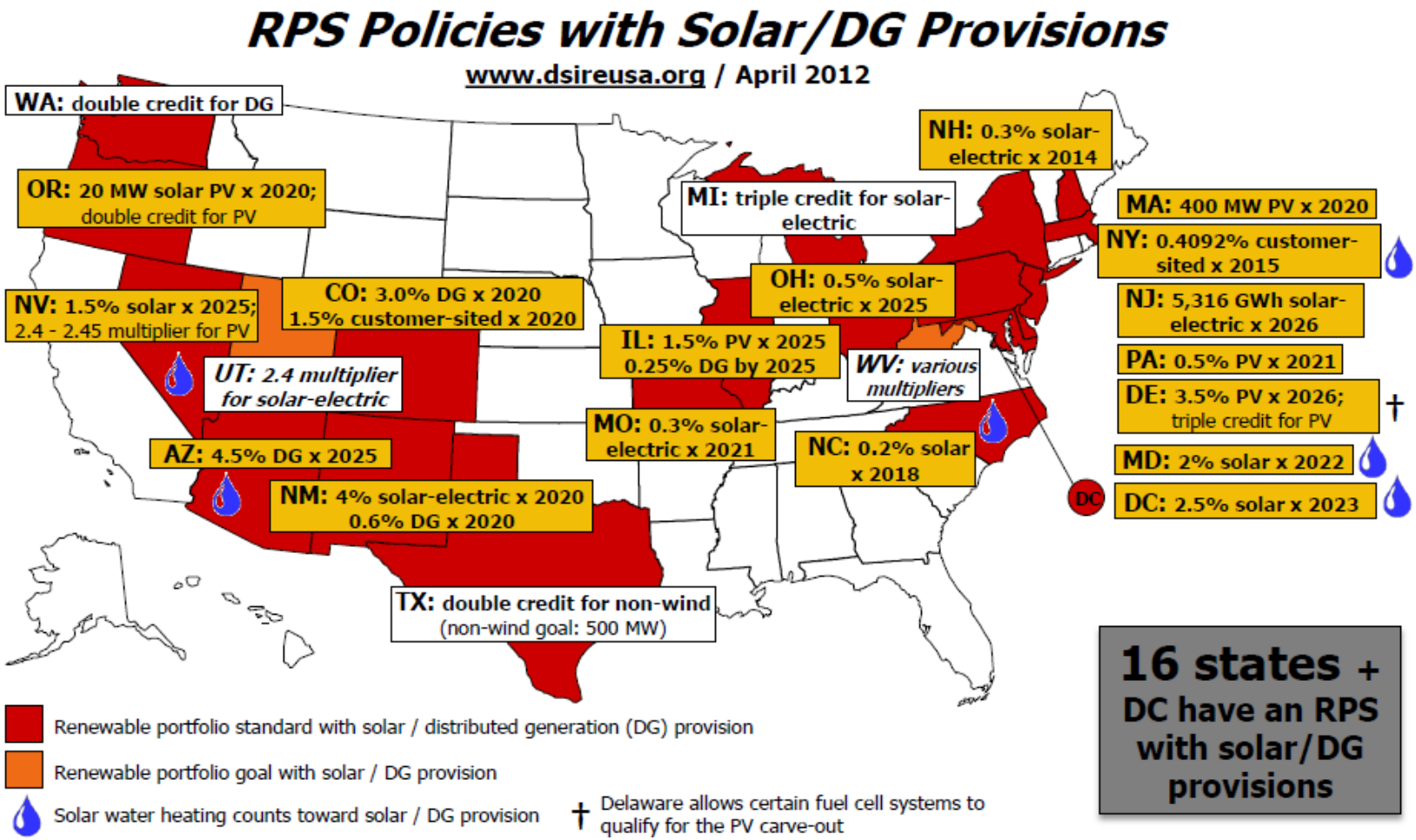
States Support Distributed Generation:



+CA "Million Solar Roofs" & Other Subsidy Programs

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"Per kWh" Prices Distort Incentives/Subsidize DG

- Distributed generation requires changes to grid planning and operations that are being actively managed.
- Recovery of largely fixed network costs through $/kWh charges + *"net metering":* subsidizes distributed generation, incents utilities to resist it.
  - Generator gets retail price; utility saves only wholesale price

RECOMMENDATION

Fixed network costs should be recovered primarily through customer charges that may differ among customers but should not vary with kilowatt-hour consumption.

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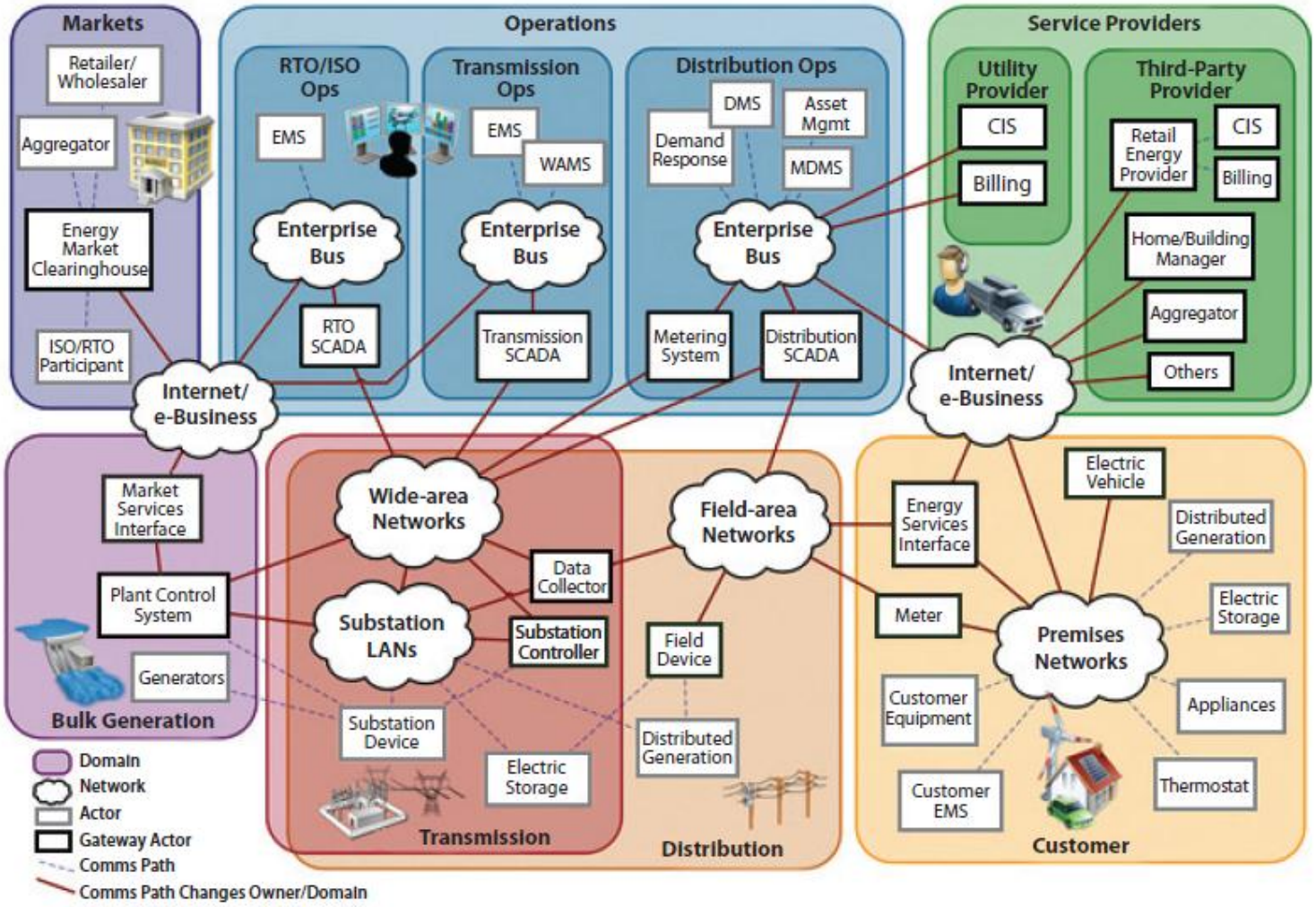
More Communications ⇒ More Vulnerability



Source: National Institute for Standards and Technology, *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0*, special publication 1108 (Washington, DC: U.S. Department of Commerce, 2010), 35, http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf.

Cybersecurity Regulation Is Disjointed

- Real, growing risks widely understood, but response is fragmented.
  - NERC: bulk power cybersecurity standards development and compliance.
  - NIST: coordinating smart grid standards development generally (including cybersecurity) but has no operational role.
- No national development and coordination of cybersecurity standards for distribution systems.
- No agency with clear authority over cybersecurity preparedness, response, and recovery for the grid as a whole.

Fixing the Cybersecurity Mismatch

RECOMMENDATION:

The federal government should give a single agency the responsibility for working with industry and the necessary regulatory authority to enhance cybersecurity preparedness, response, and recovery across the entire electric power

Not controversial, but big fights over which agency!

Conclusions

- The grid will face significant challenges and opportunities in the next two decades; its evolution is not predetermined.
- Policy and regulatory changes in key areas are needed:
  - Focused, industry-led RD&D efforts & information sharing are necessary.
  - FERC should be granted effective transmission siting authority.
  - There should be toughtful movement toward retail prices that reflect actual costs.
  - Fixed network costs should be recovered primarily via fixed customer charges.
  - A single agency should be in charge of grid-wide cybersecurity.

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