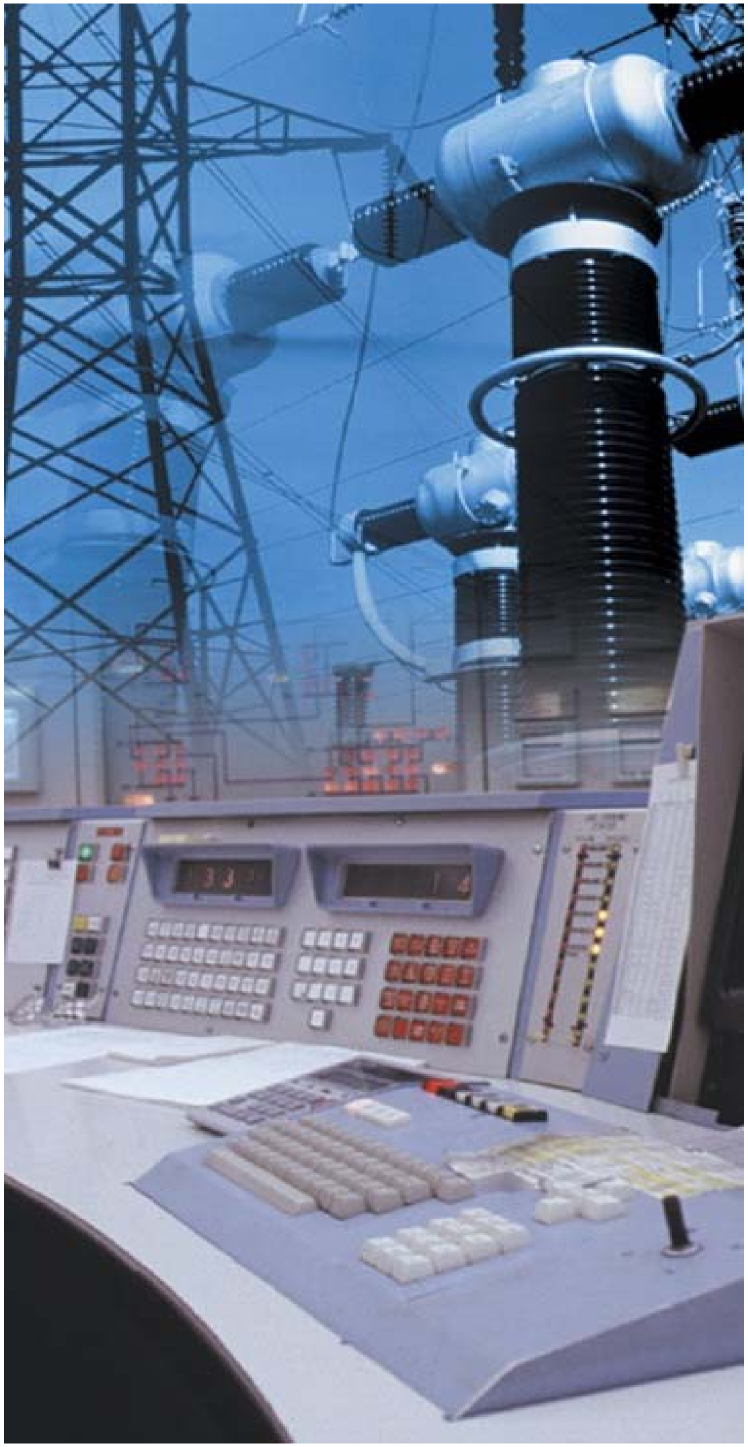

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The Smart Power Grid

Stephen Lee
Senior Technical Executive
Power Delivery & Utilization

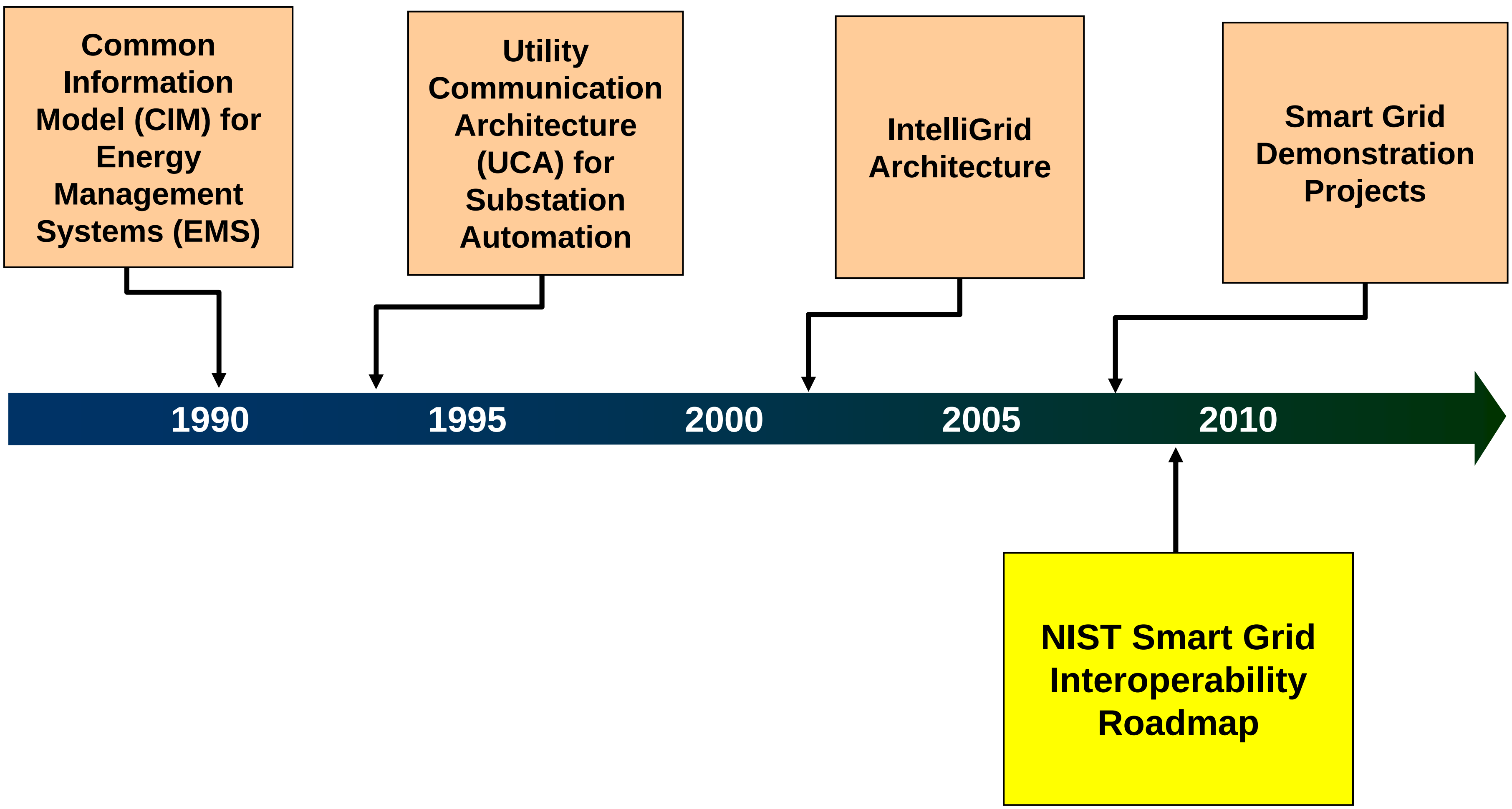
October 21, 2009

IEEE Power Electronics Society
Santa Clara Valley Chapter

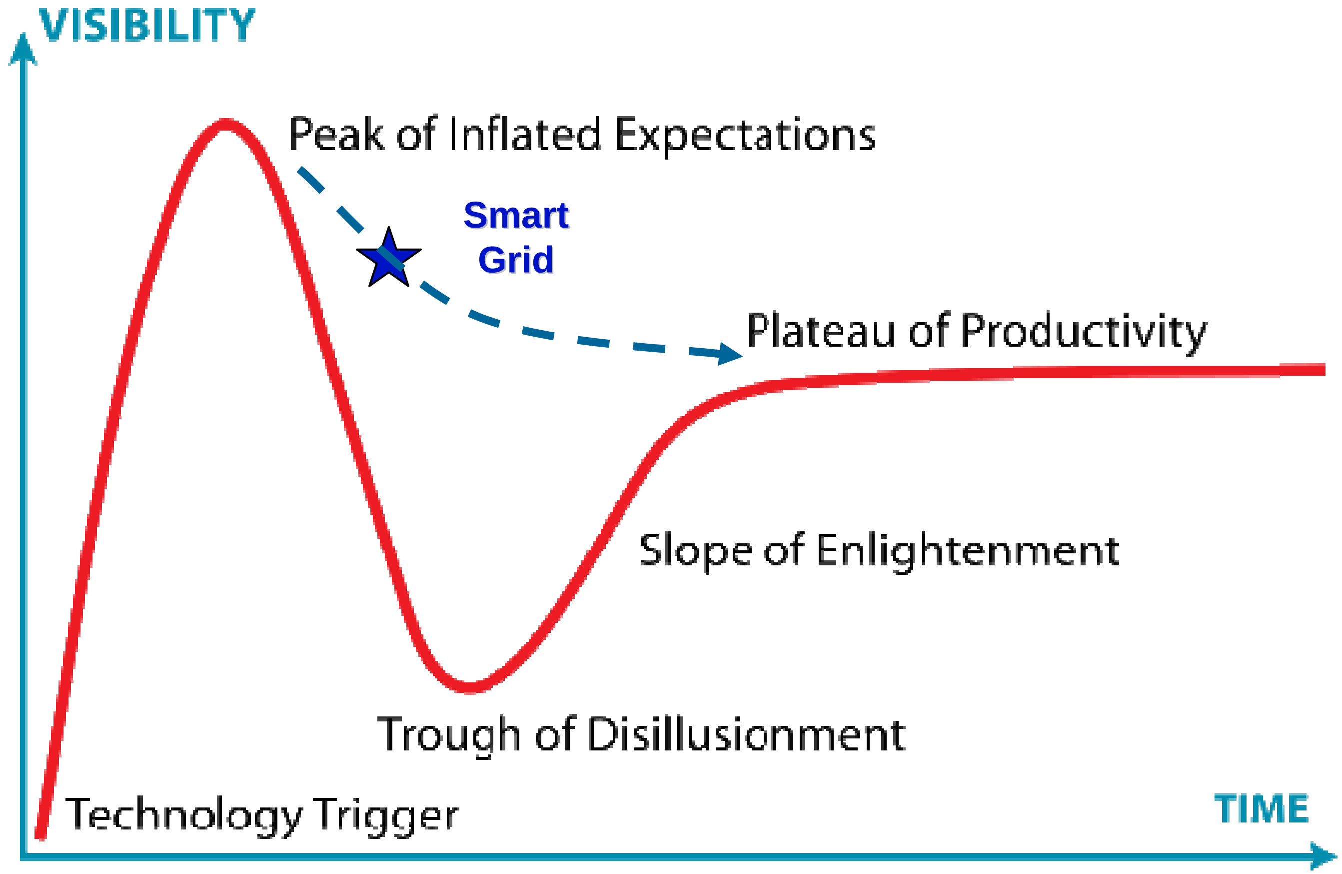
Outline Of Presentation

- Holistic Power Supply & Delivery Chain
- Smart Grid Standards (NIST)
- Smart Meters/Home Area Network
- Demand Response
- Electric / Plug-in Hybrid Electric Vehicles
- Highly Variable Renewable Wind and Solar Resources (Utility scale and distributed)
- Energy Storage Technologies
- Applications of Synchrophasors
- Conclusions

EPRI's Smart Grid Leadership



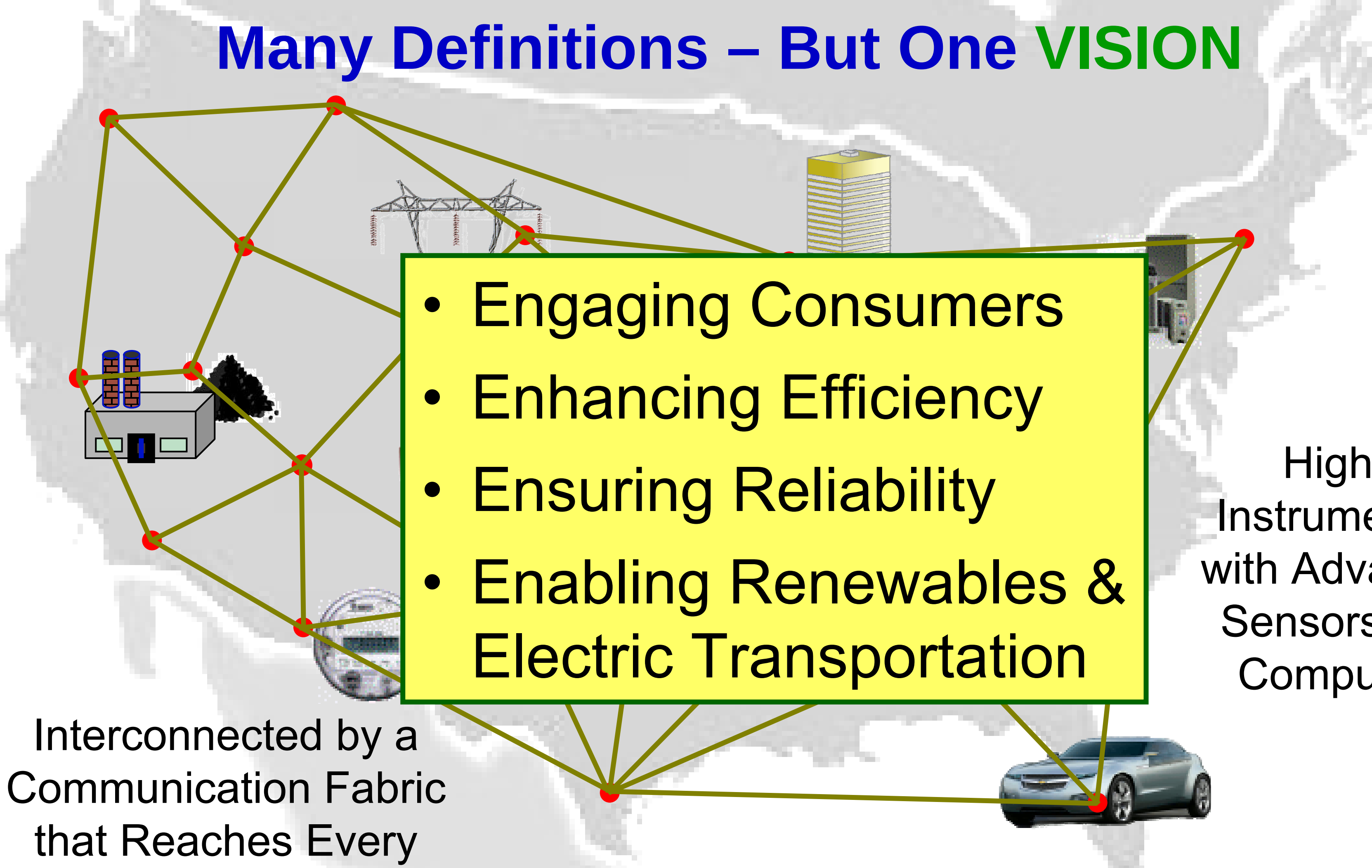
Smart Grid: Focus on What is Possible



Need an Objective Assessment of the Potential for Smart Transmission and the Path to Achieve it

What is The Smart Grid?

Many Definitions – But One VISION



- Engaging Consumers
- Enhancing Efficiency
- Ensuring Reliability
- Enabling Renewables & Electric Transportation

Highly Instrumented with Advanced Sensors and Computing

Interconnected by a Communication Fabric that Reaches Every Device

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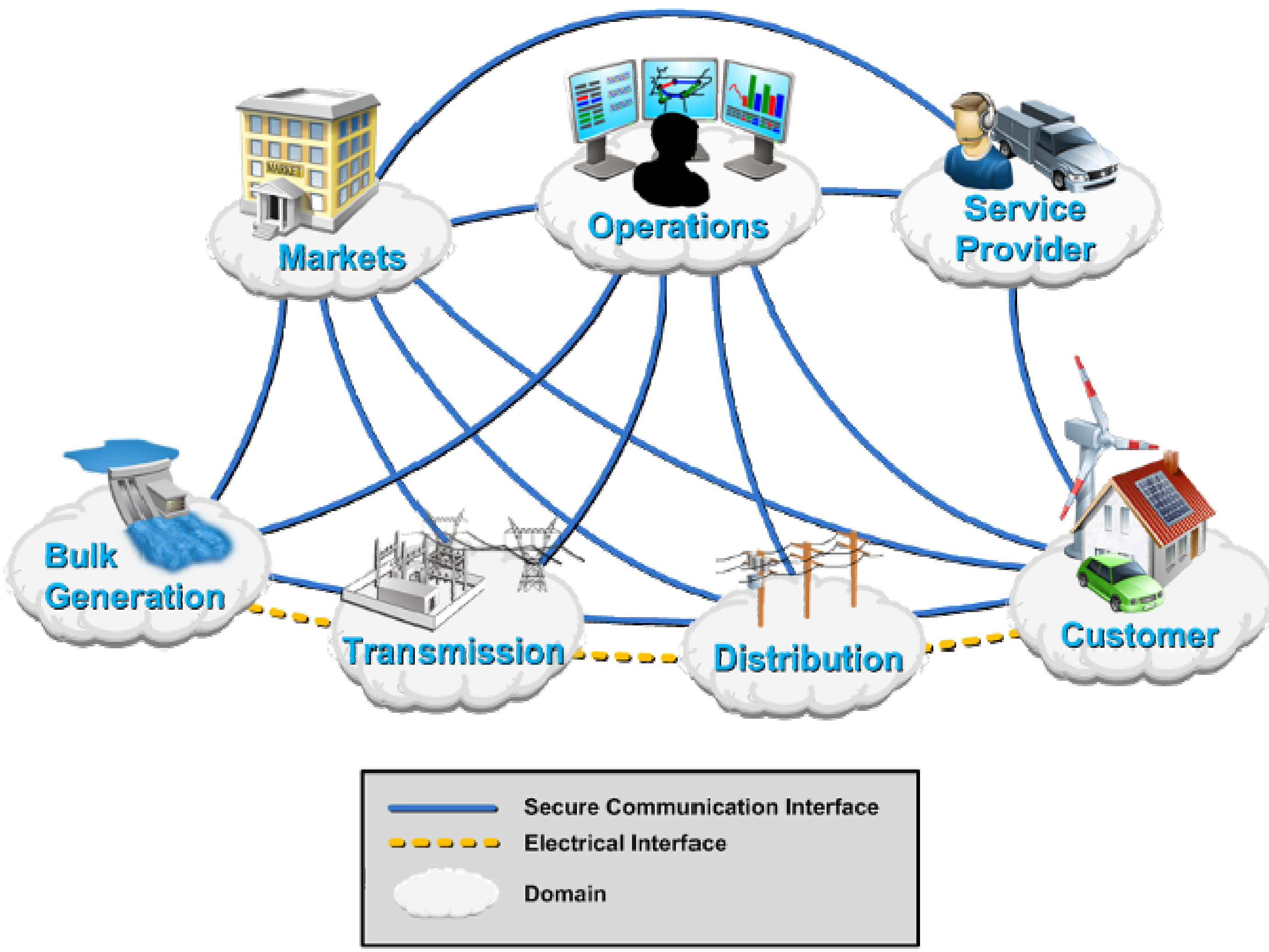
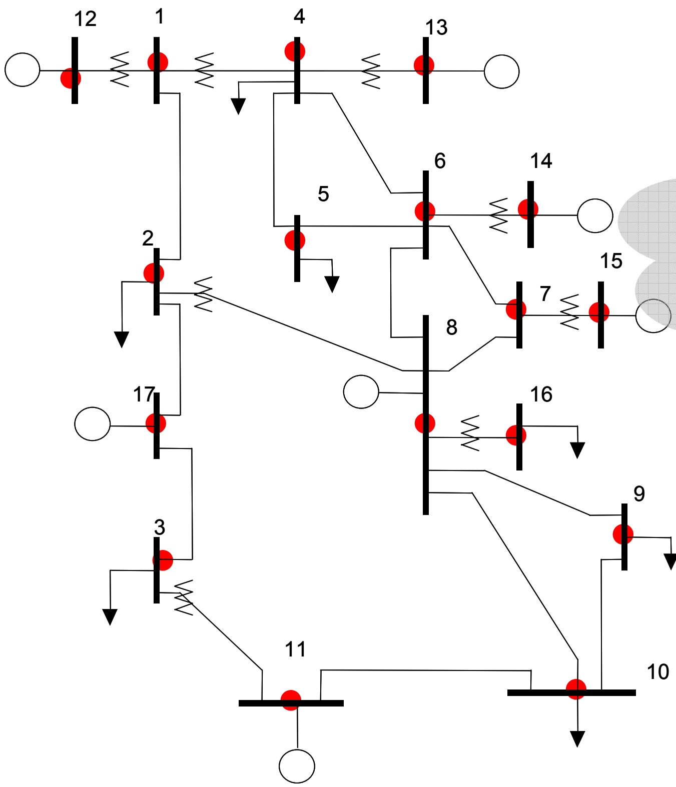
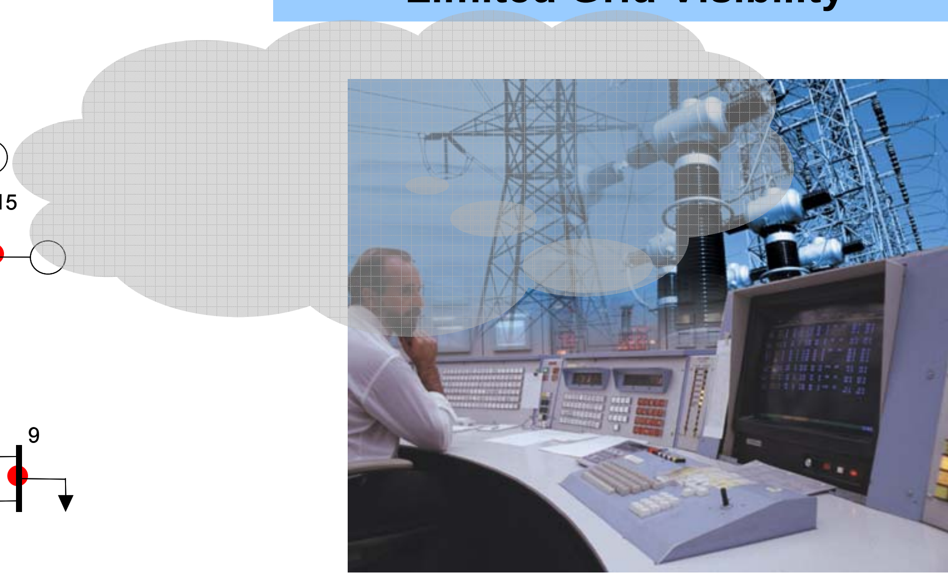
Smart Grid Domains



Source: EPRI Report to NIST on Smart Grid Interoperability, June 2009

Current State – Power Grid Operations





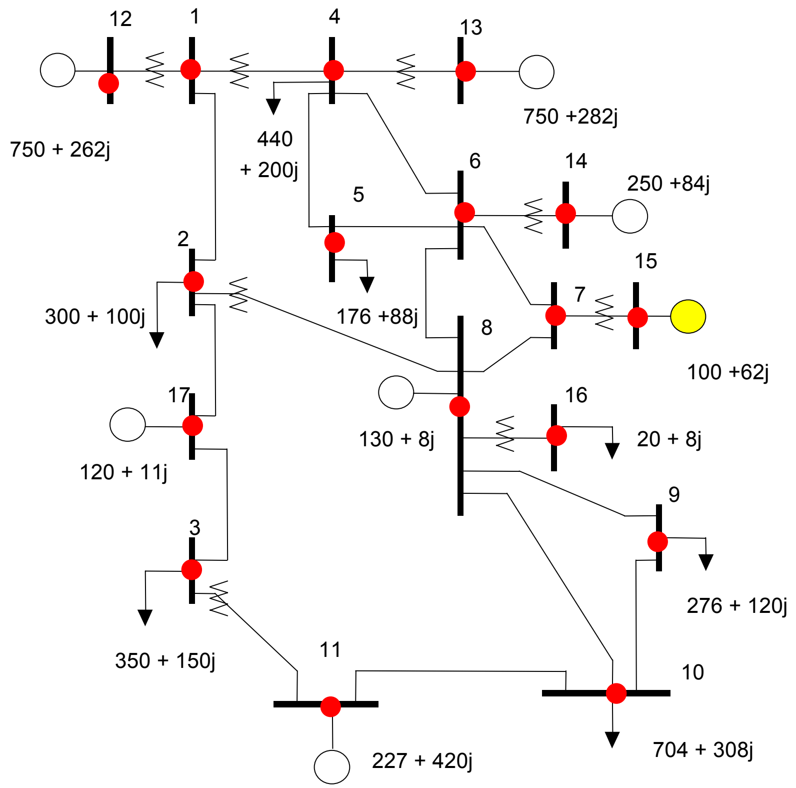
Limited Grid Visibility

2-4 Sec scan rates

Limited to info from lines and transformers at substations

MW, MVAR, KV breaker status

Smart Transmission State – Power Grid Operations

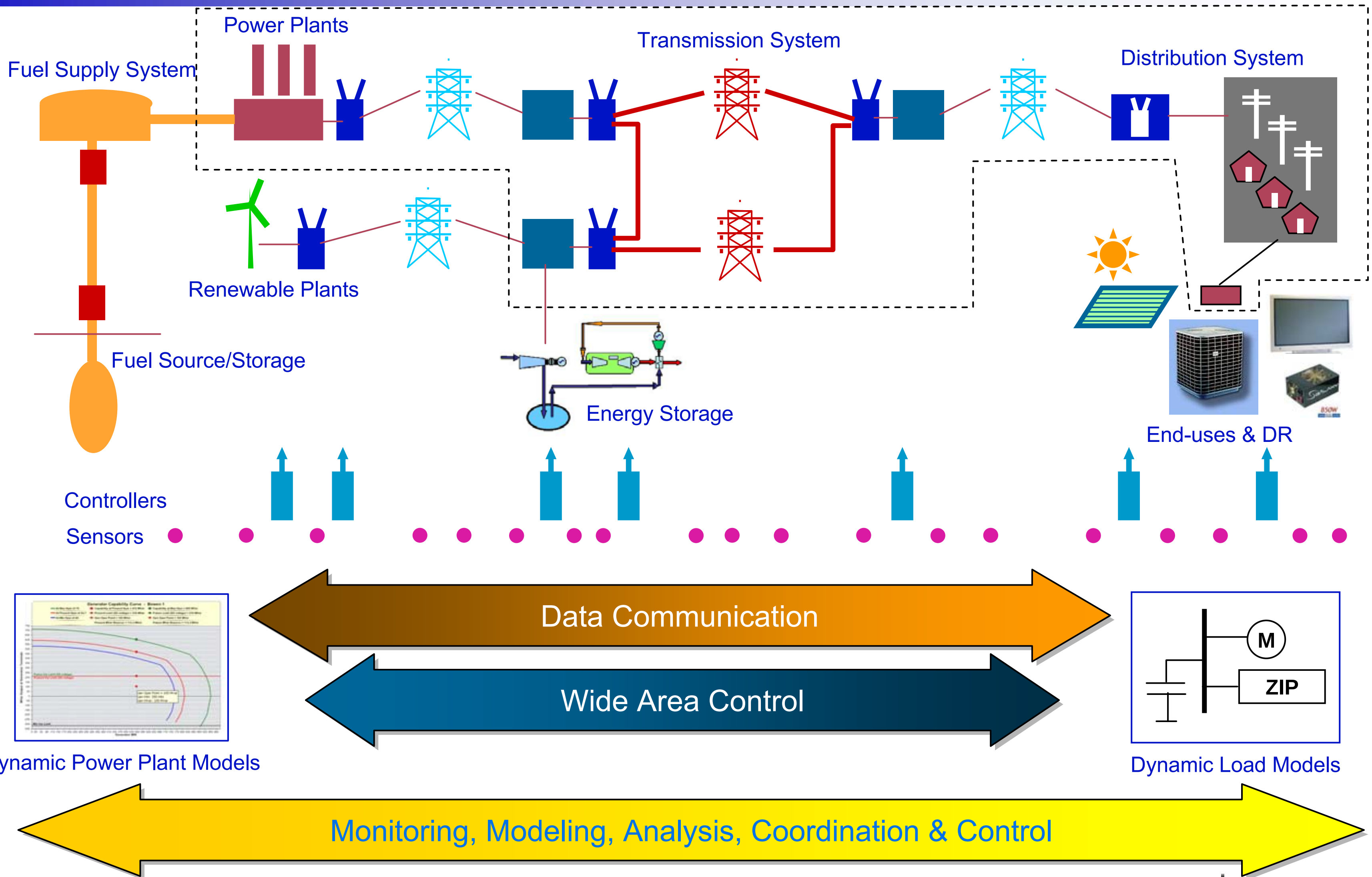


Enhanced Grid Visibility

Higher speed scan rates

Allows more frequent analysis of system state

End-to-End Power Delivery Chain Operation & Planning



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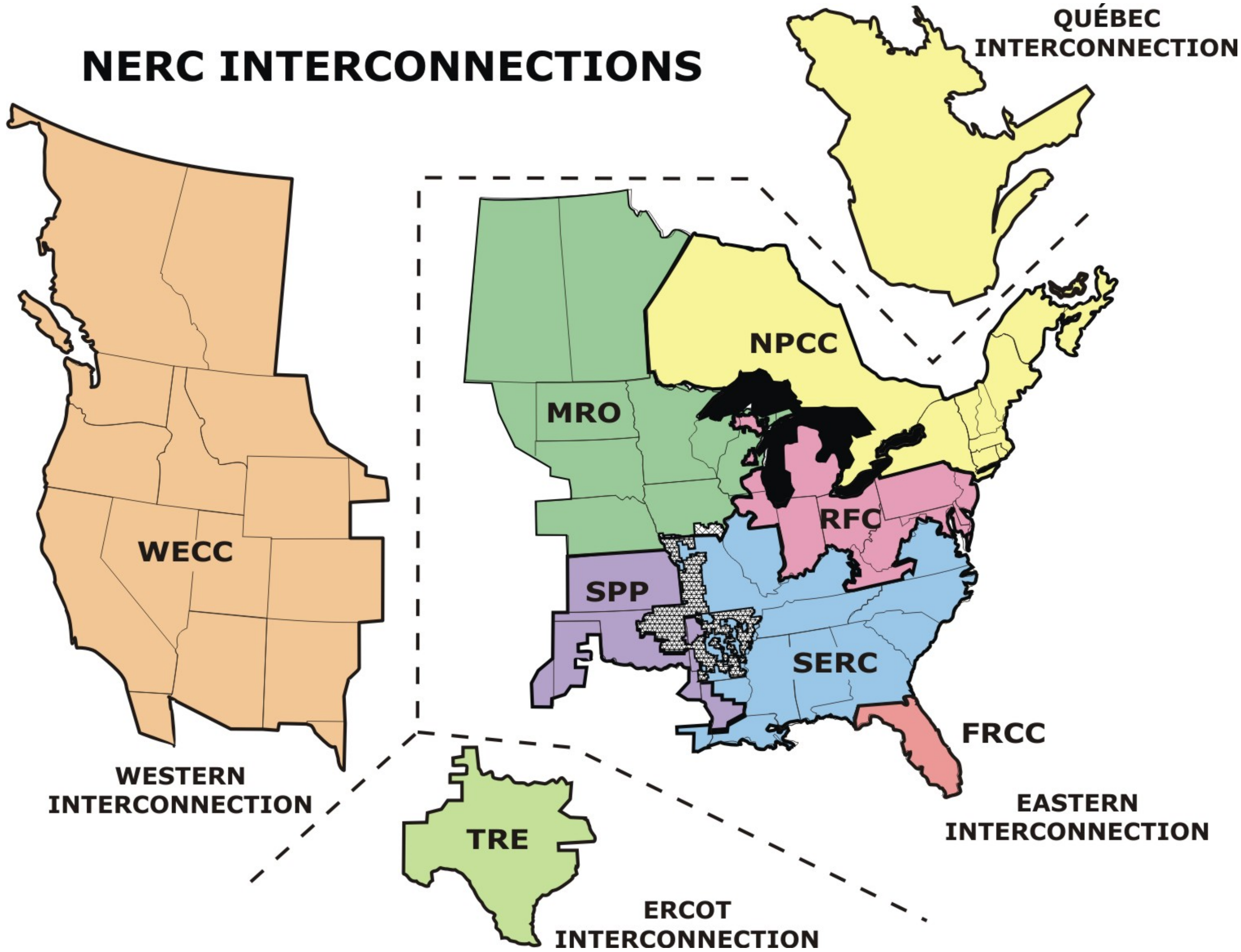
North America Electricity Interconnections



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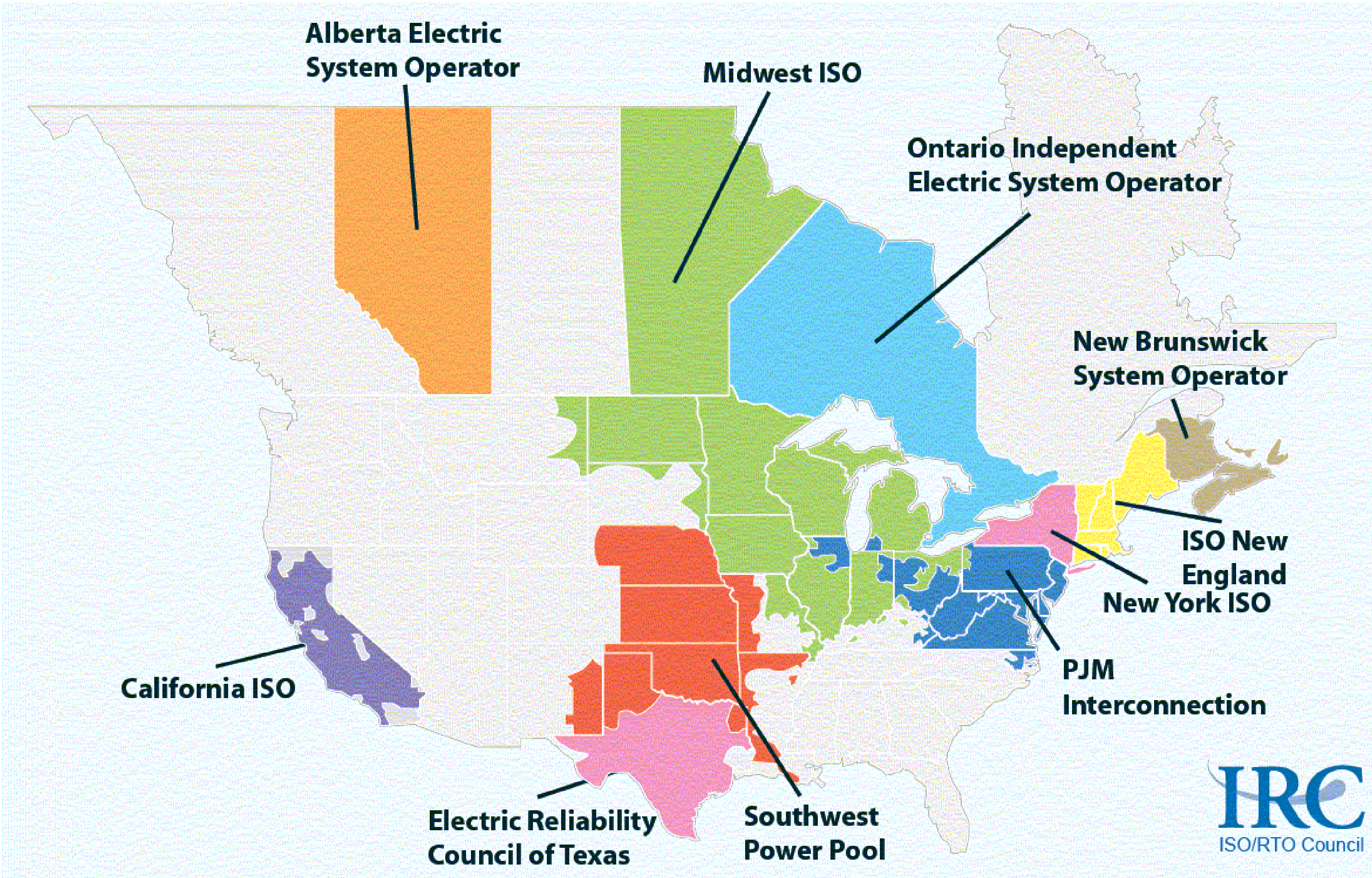
Independent System Operators / Regional Transmission Operators (ISO/RTO)



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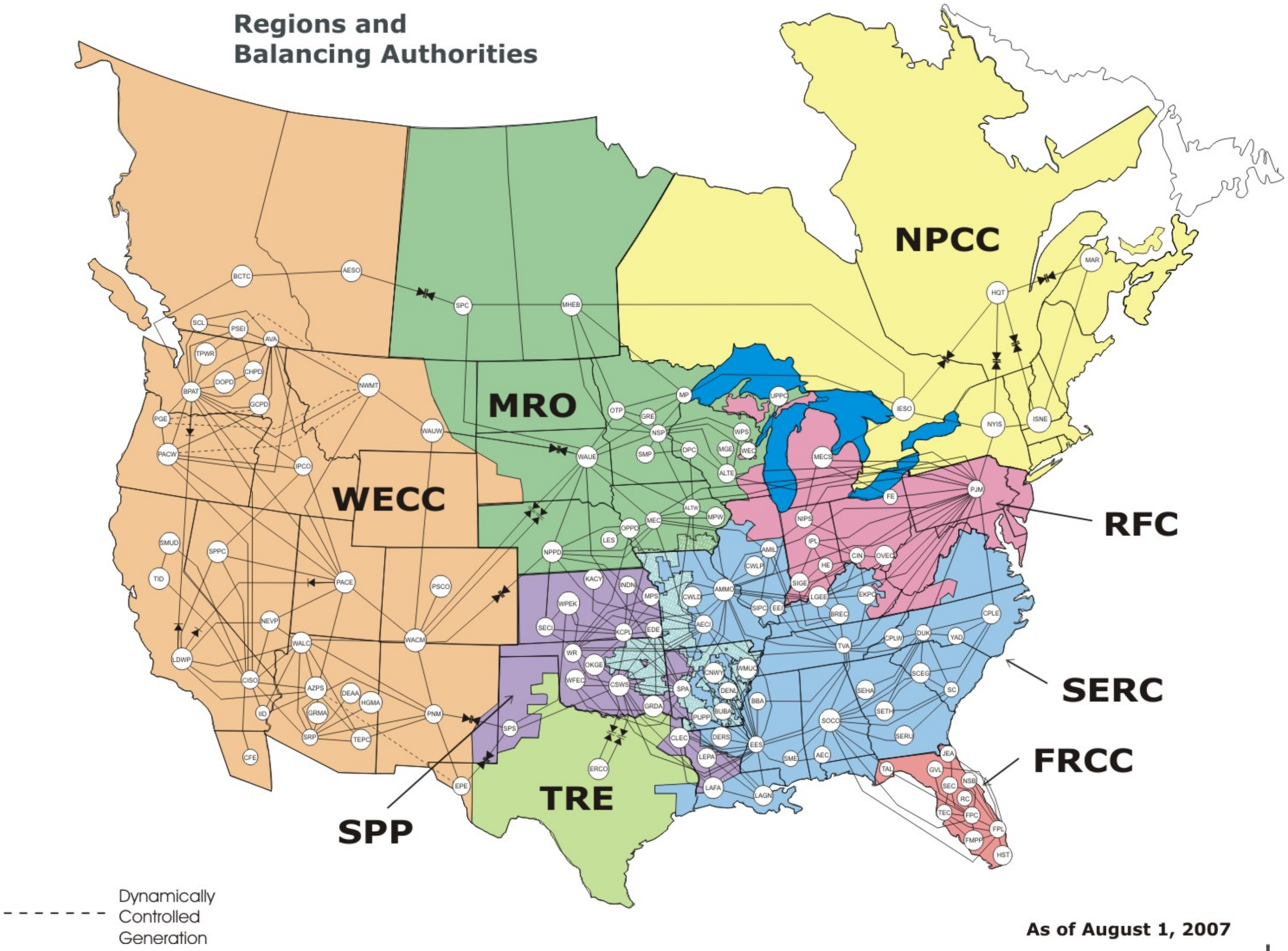
North America Electricity Balancing Authorities



As of August 1, 2007

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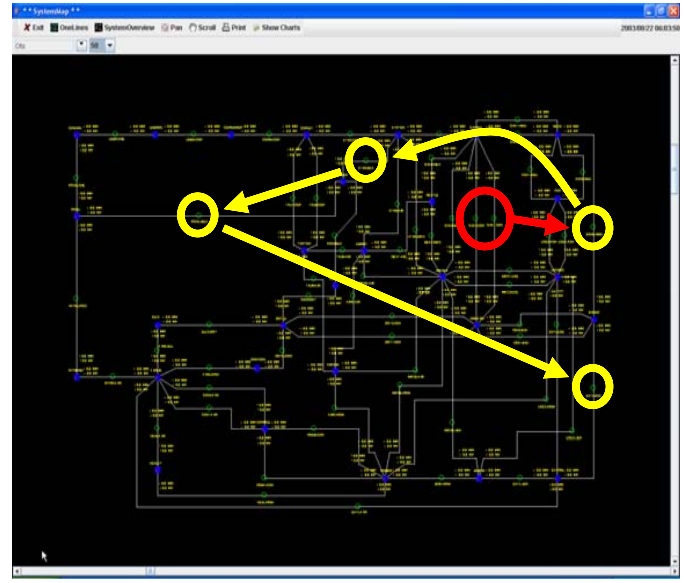
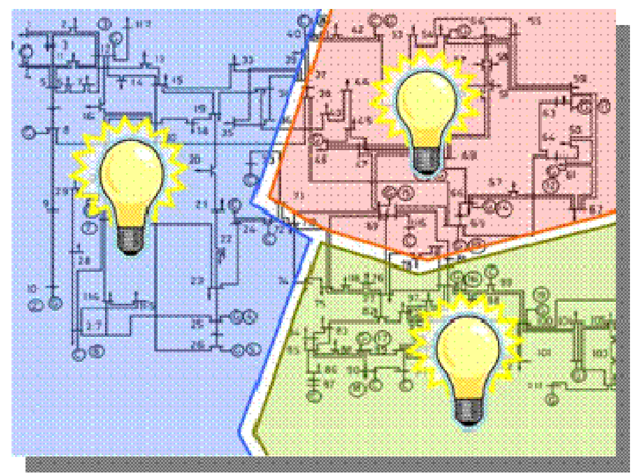
New Challenges for a Smart Grid

- Need to integrate:
  - Large-scale stochastic (uncertain) renewable generation
  - Electric energy storage
  - Distributed generation
  - Plug-in hybrid electric vehicles
  - Demand response (smart meters)
- Need to deploy and integrate:
  - New Synchronized measurement technologies
  - New sensors
  - New System Integrity Protection Schemes (SIPS)

Foundations Need Strengthening

- End-to-End Situational Awareness
- Alarm Management and Real-Time Root-Cause Diagnosis
- Dynamic Models of all Generators and Loads
- Faster System Restoration
- System Integrity Protection Schemes
  - Faster reflex actions on wide-area problems
  - Measurement-based safety nets to prevent cascading blackouts, e.g., load shedding, islanding/separation, damping





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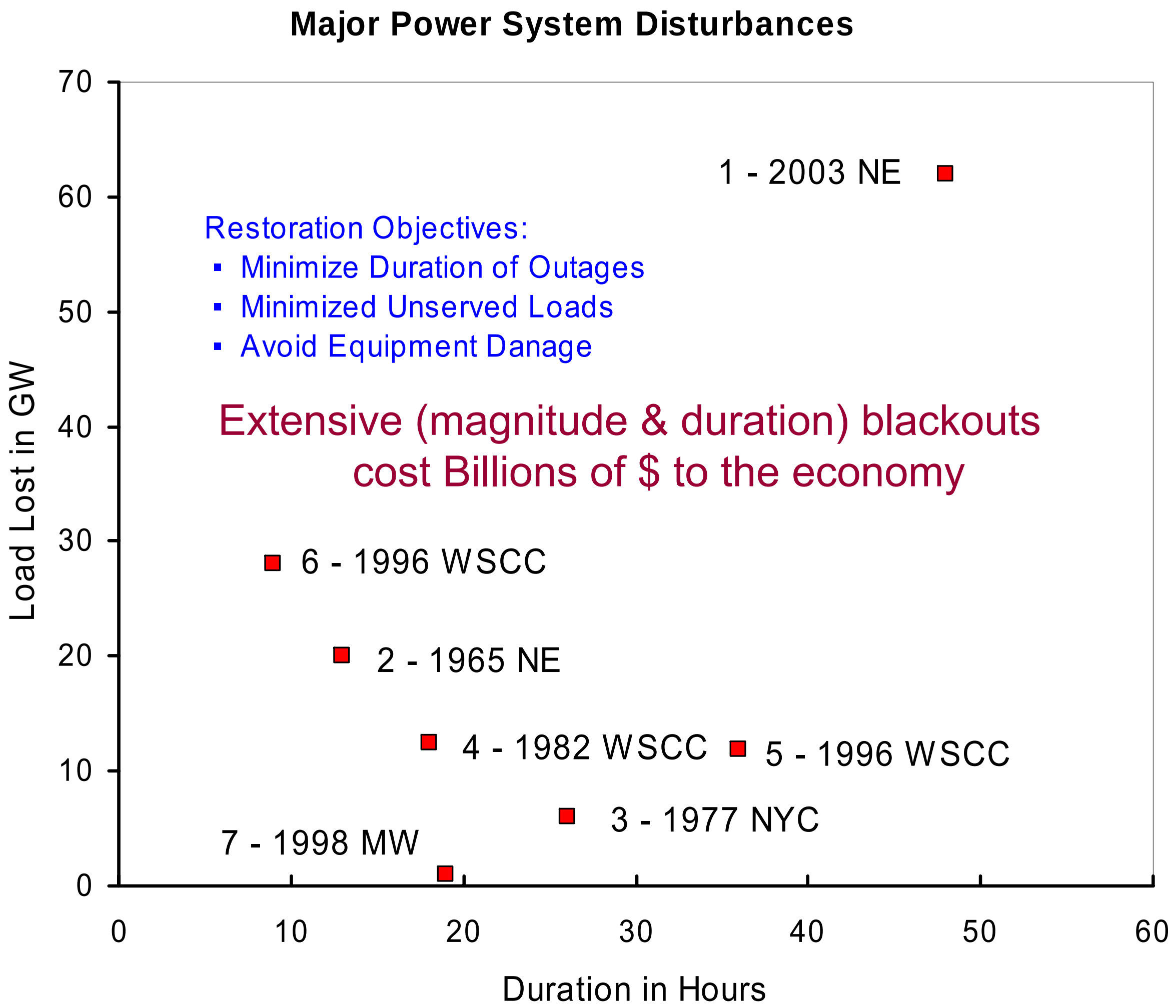
Effective System Restoration Can Reduce The Societal Impact Of Widespread Blackouts



Source: NSF/EPRI Workshop on Understanding and Preventing Cascading Failures in Power Systems, Oct 28, 2005.

New Solutions Are Needed

- Optimal end-to-end commitment and dispatch by ISO/RTO as backstop for system reliability
- Virtual Service Aggregators serving as Energy Balancing Authorities
  - Dispatch and control stochastic renewable generation
  - Dispatch and control (and own?) large scale energy storage plants
  - Manage demand response proactively
  - Manage smart electric vehicle charging

Role of National Institute of Standards and Technology (NIST) on Smart Grid Standards

Energy Independence and Security Act (EISA) of 2007
Title XIII, Section 1305
Smart Grid Interoperability Framework

- In cooperation with the DoE, NEMA, IEEE, GWAC, and other stakeholders, **NIST** has "primary responsibility to **coordinate development of a framework** that includes protocols and model standards for information management **to achieve interoperability of smart grid devices and systems**…"

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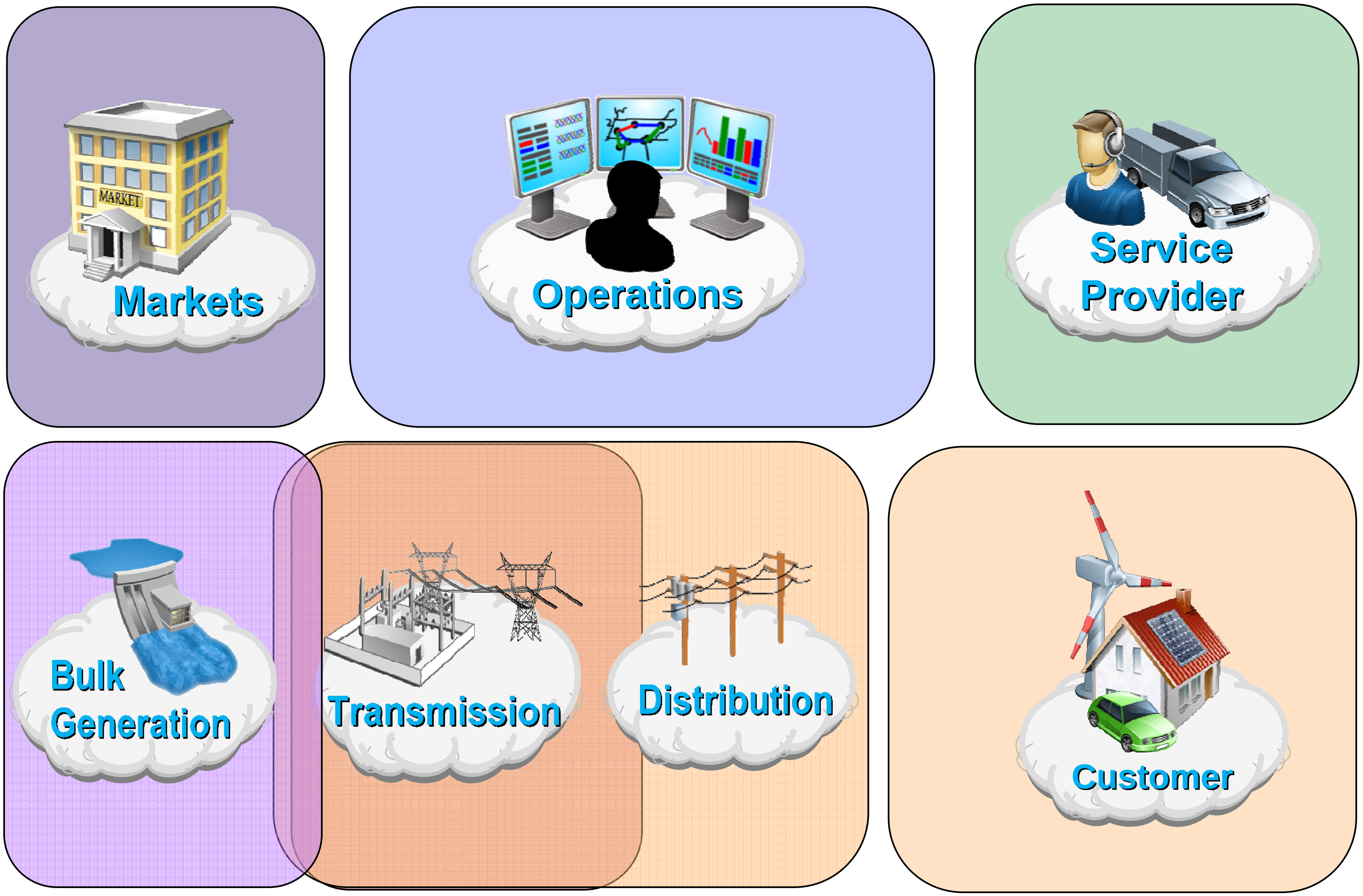
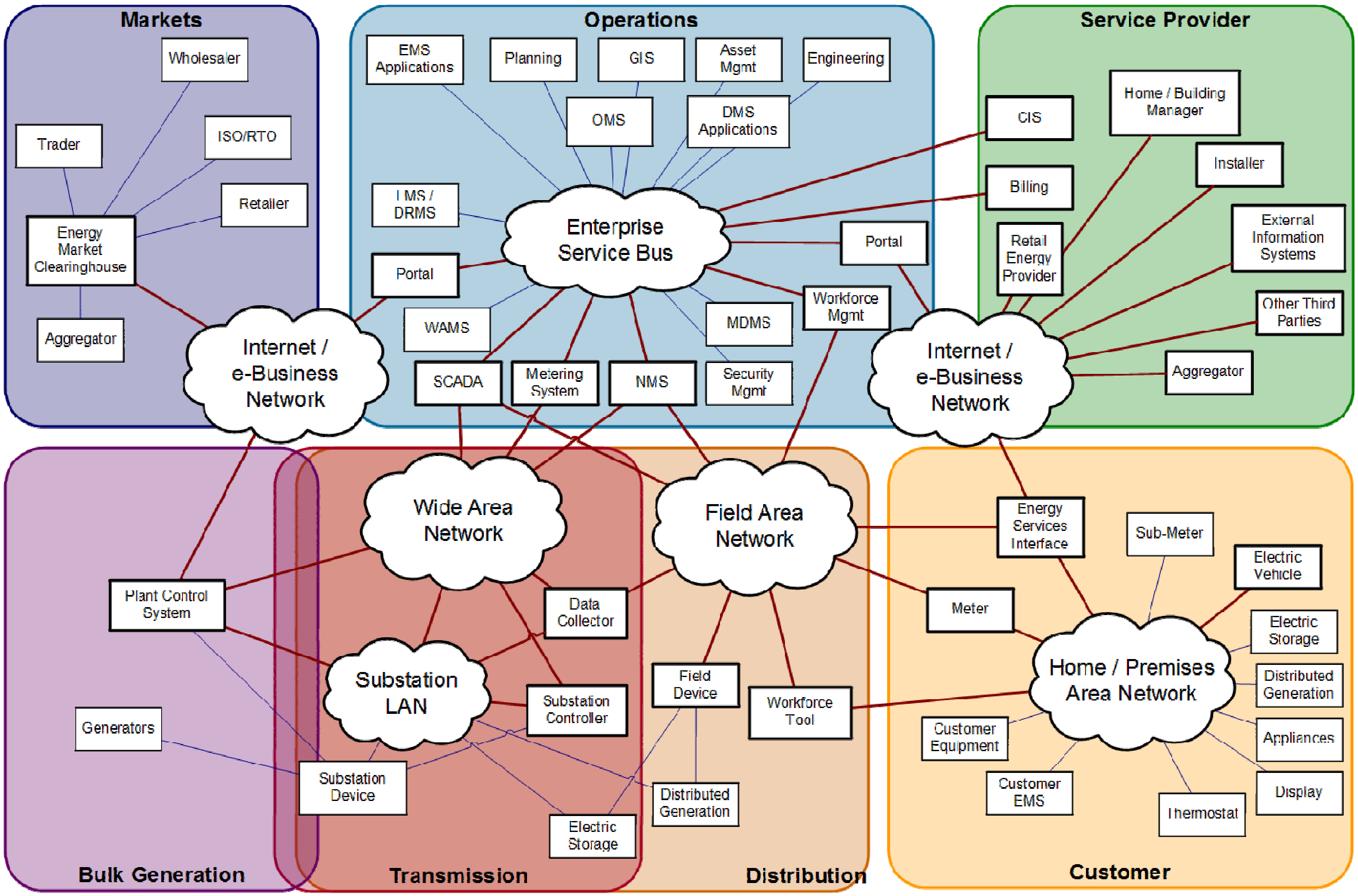
Smart Grid Domains



Smart Grid Networks



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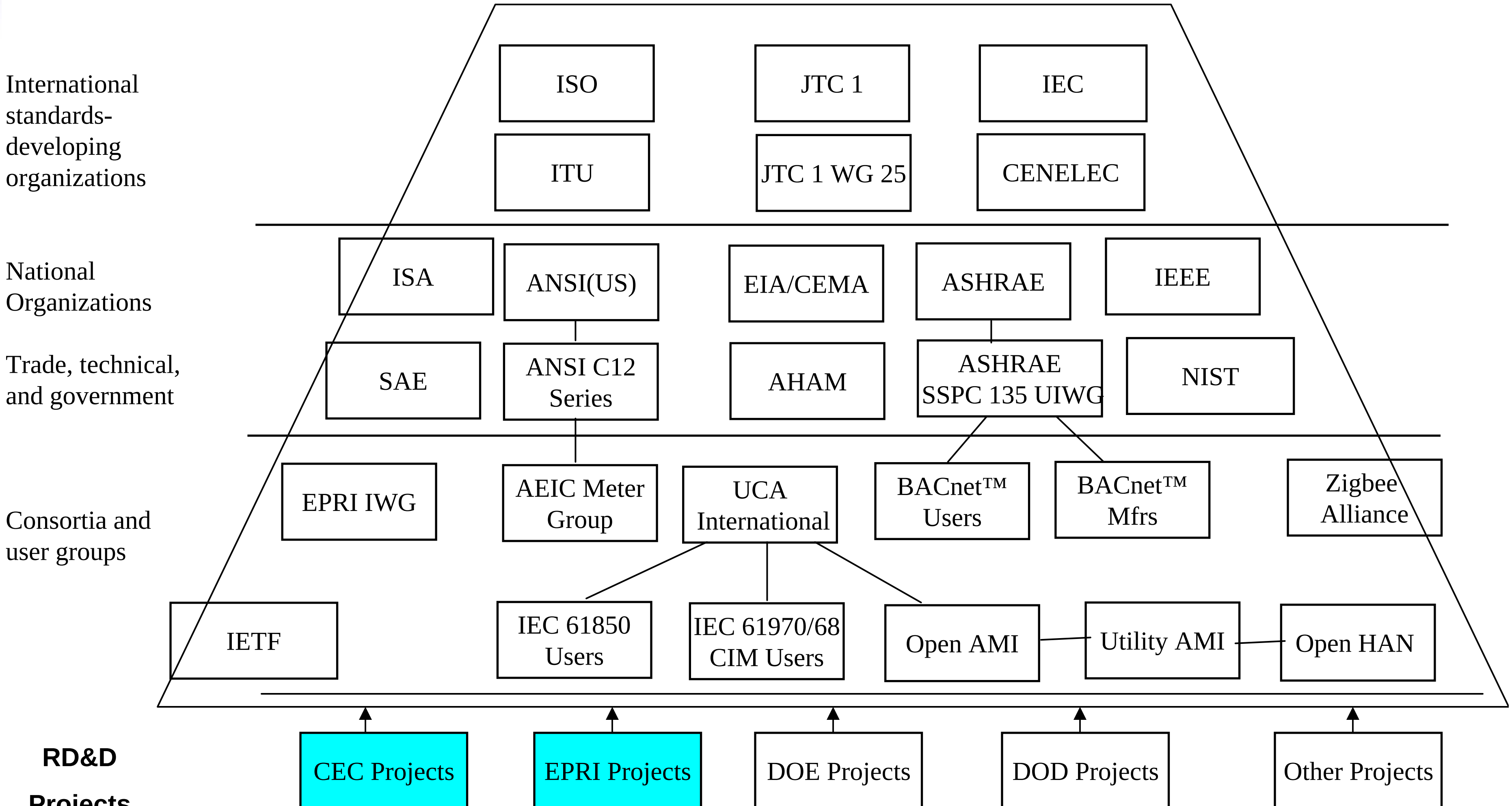
Key Standards Organizations Involved in the Development of “Smart Grid” Infrastructure



*Representative Sample

NIST Phase 1 Plan

2009

March ← → September

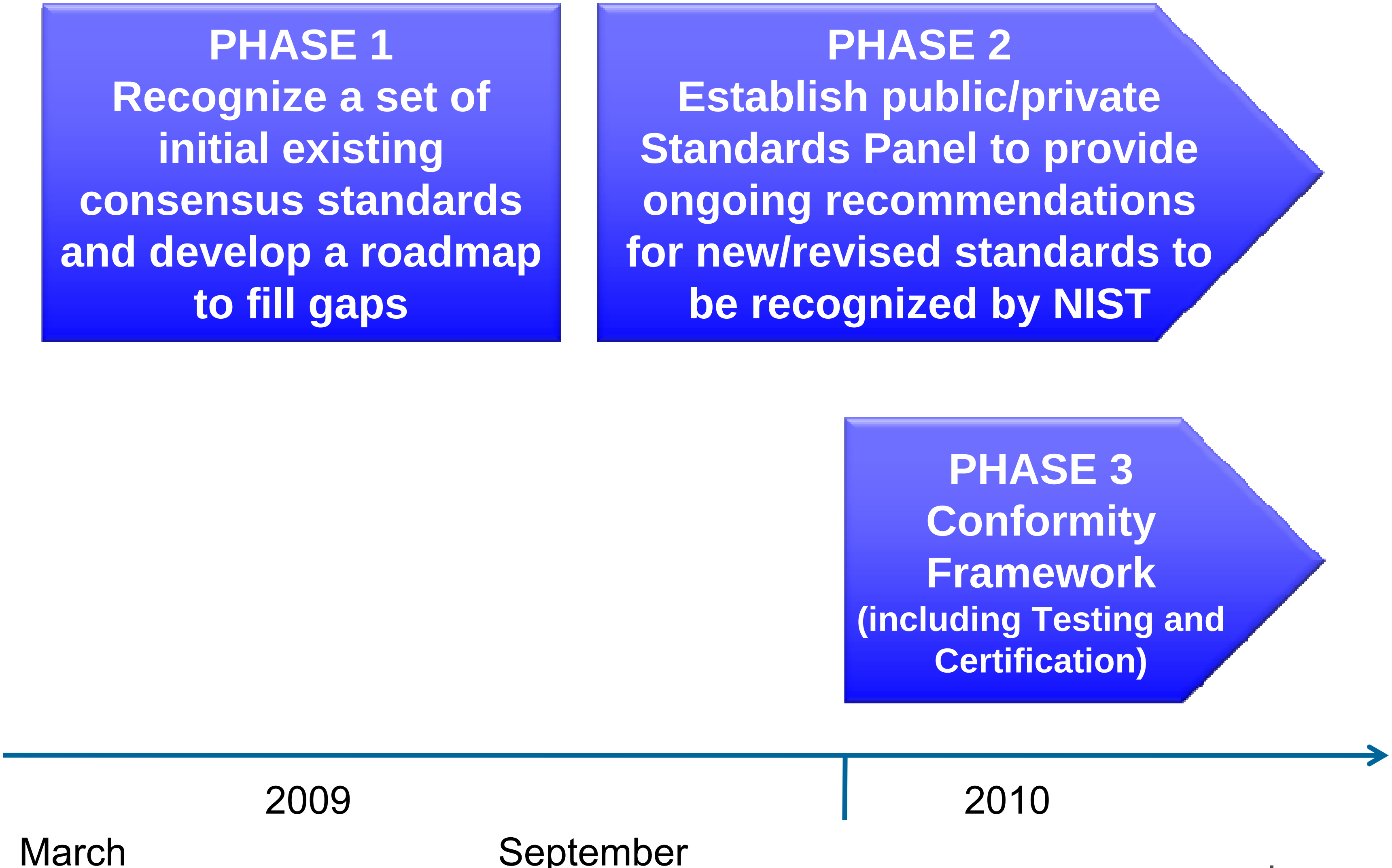
EPRI Project Objectives:

- Develop an Interim Roadmap that describes the high-level Smart Grid architecture, principles and interface design.
- Describe the current status, issues, and priorities for interoperability standards development and harmonization including an action plan that addresses these issues.
- Rapidly build consensus for the Interim Roadmap among the various Smart Grid stakeholders.

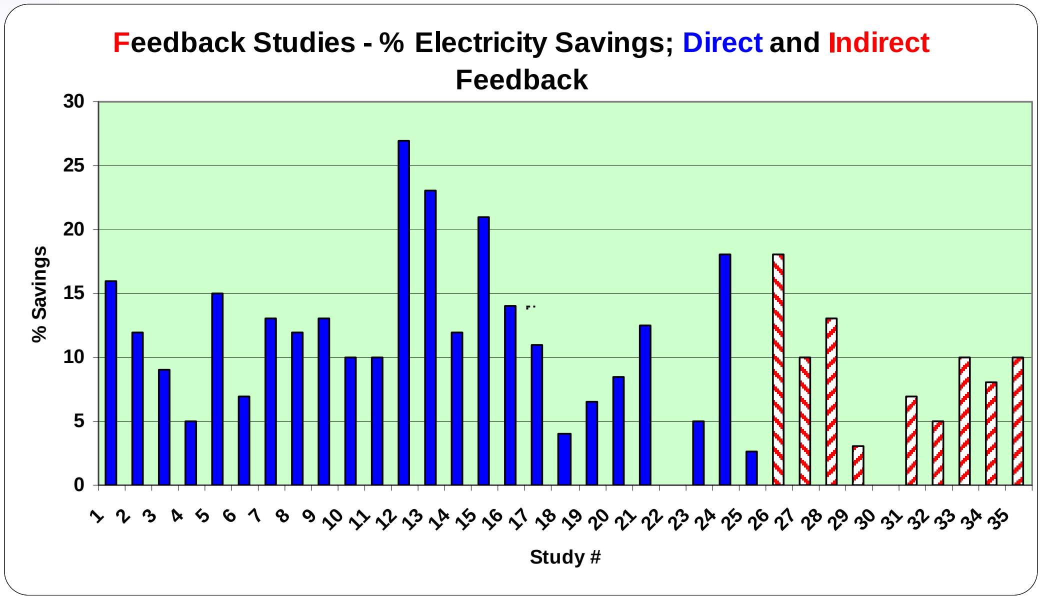
Key Milestones:

- Stakeholder workshops April 28-29 & May 19-20
- NIST Recognized Standards Release – May 08
- EPRI delivers Interim roadmap to NIST – Wednesday, June 17
- Standard Development Organizations workshop – August 3-4
- NIST smart grid interoperability report – September 2009

NIST Phase 2 and Phase 3 Plan



Smart Grid
Enabling Consumers to be More Efficient

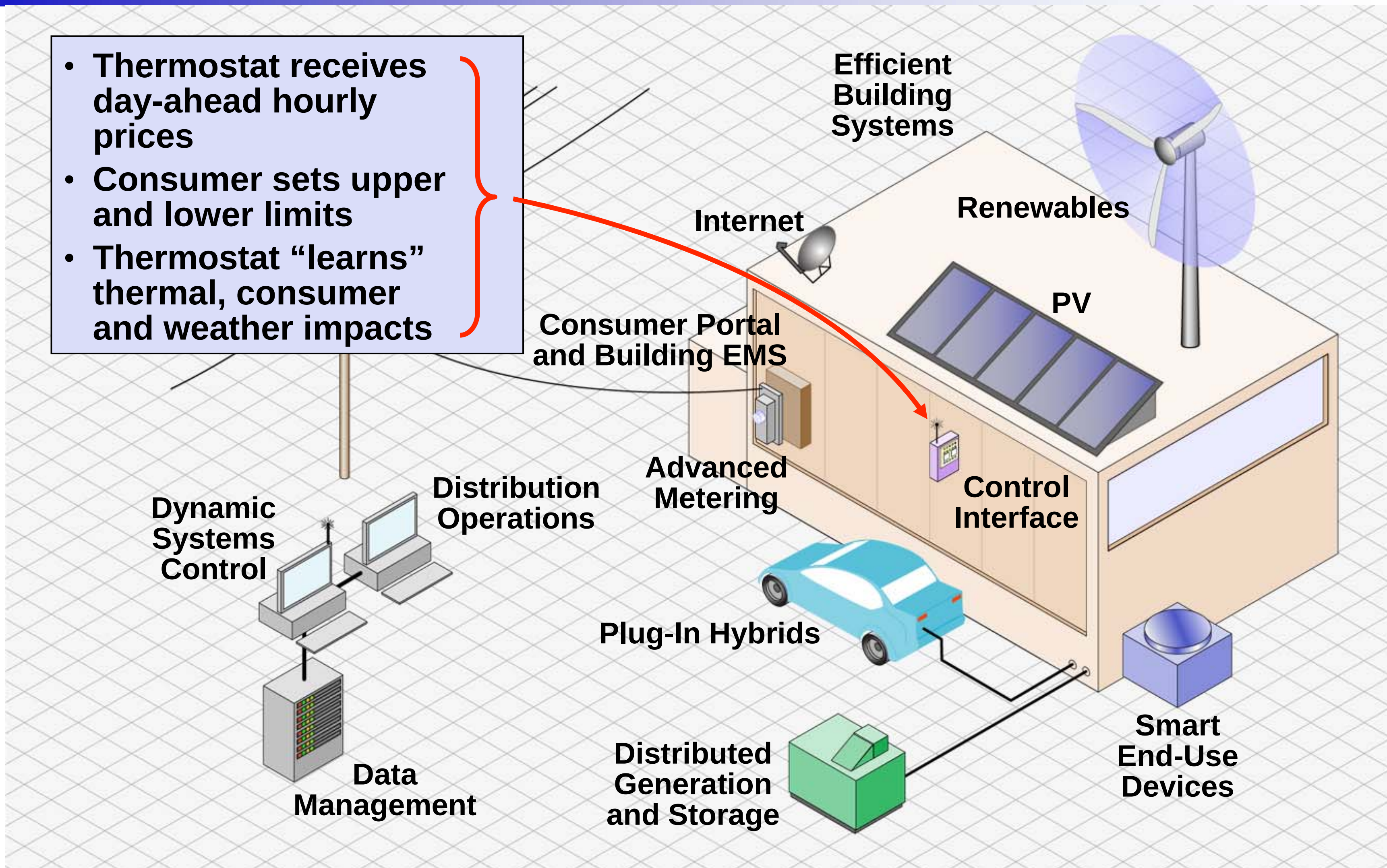


Numerous studies have been conducted to quantify the impact of information on electricity consumption

Making Consumers Energy Aware

Prices to Devices
Tomorrow's Smart Pricing

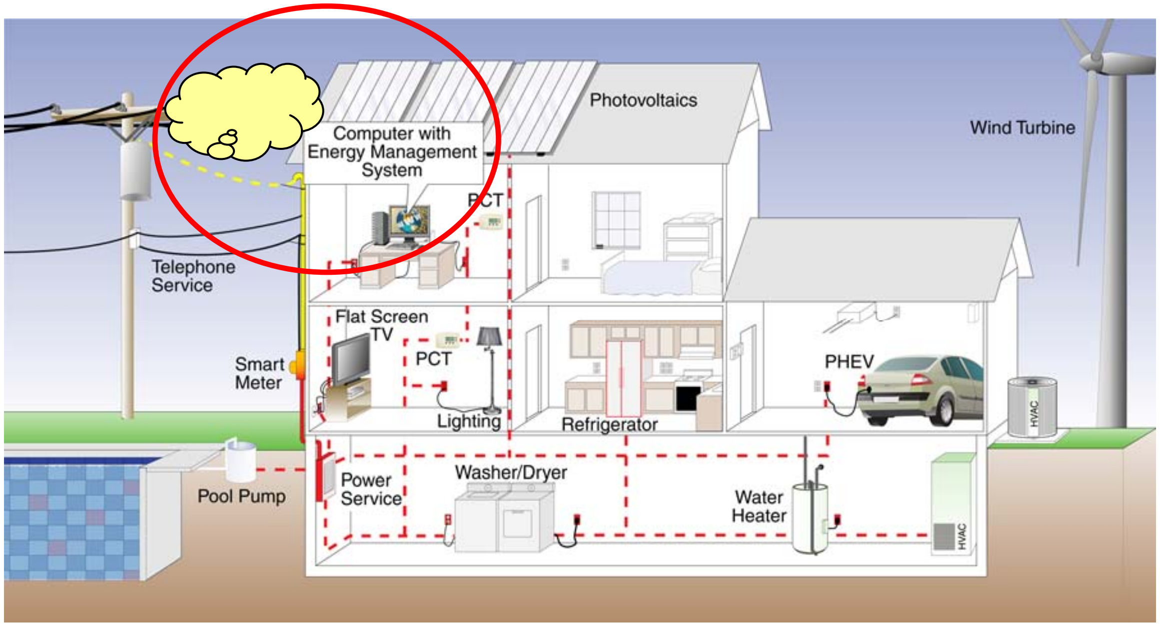
- Thermostat receives day-ahead hourly prices
- Consumer sets upper and lower limits
- Thermostat "learns" thermal, consumer and weather impacts



Future HAN Applications for Energy Management

Smart Energy Application Profile 2.0

- **Zigbee**
- **HomePlug**
- **Wi-Fi**



Air Conditioner	Pool Pump	Water Heater	Refrigerator
Computer/Laptop		Flat Screen TV	Washer/Dryer
Plug-in Hybrid Electric Vehicle		Wind Turbine	Solar Panels

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What is Demand Response?

- *Voluntary*, *temporary* adjustment of power demand by end-user or counter-party in response to market signal (e.g. price, emergency, etc.)
- Three basic forms
  - Direct Load Control
  - Price Response
  - Interruptible Tariff
- Enabling technology → automation → ubiquity → DR magnitude & reliability
- Still subject to human behavior
  - Even with automation, overrides possible
  - Persistence a question

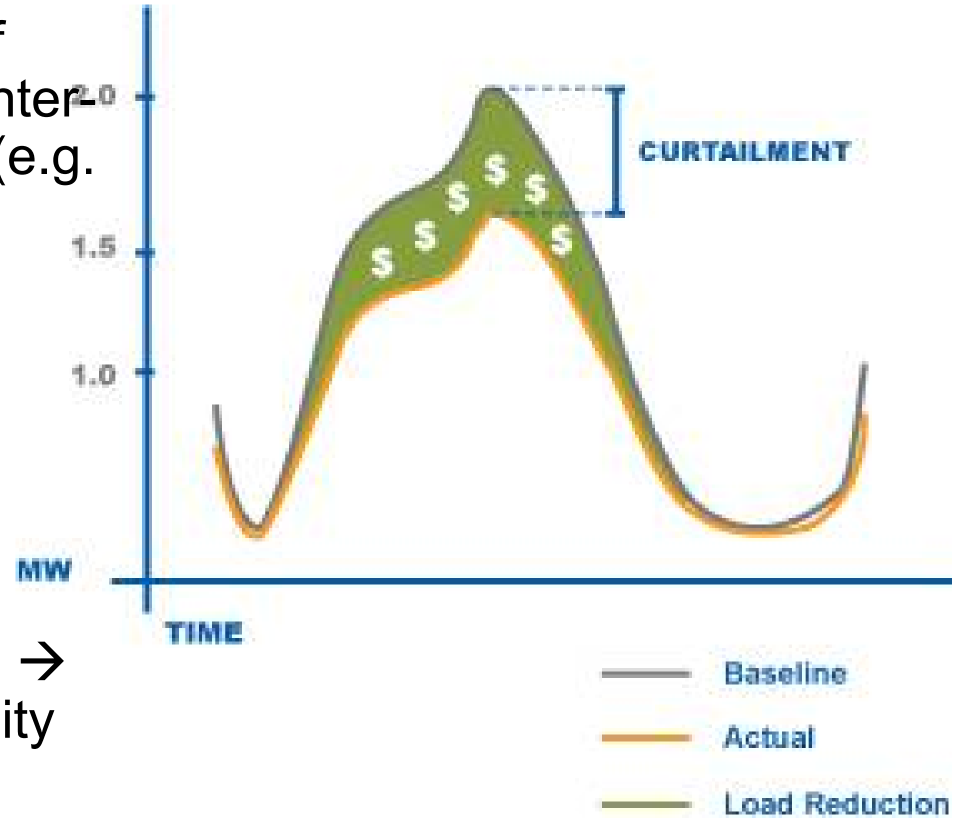
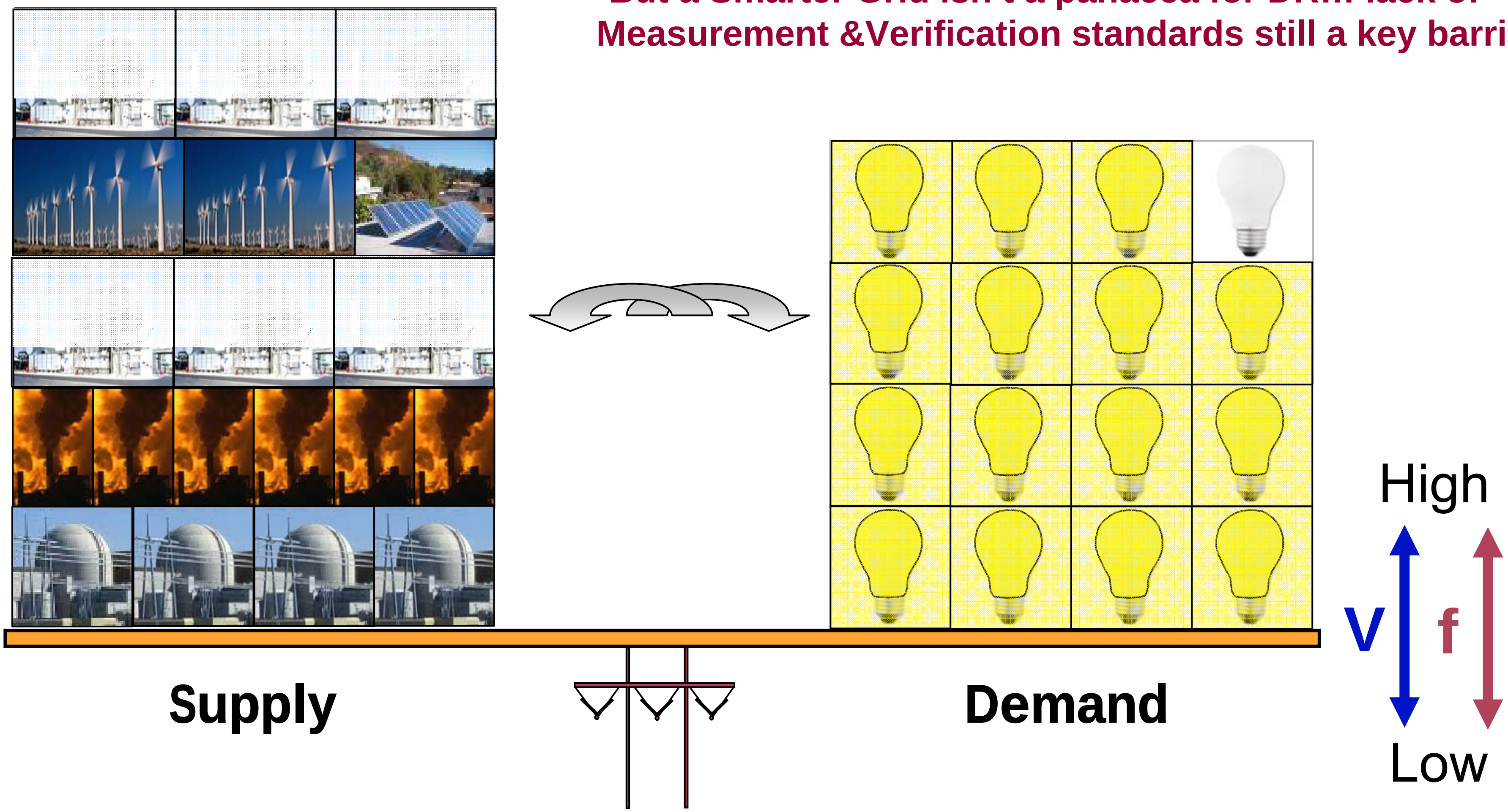


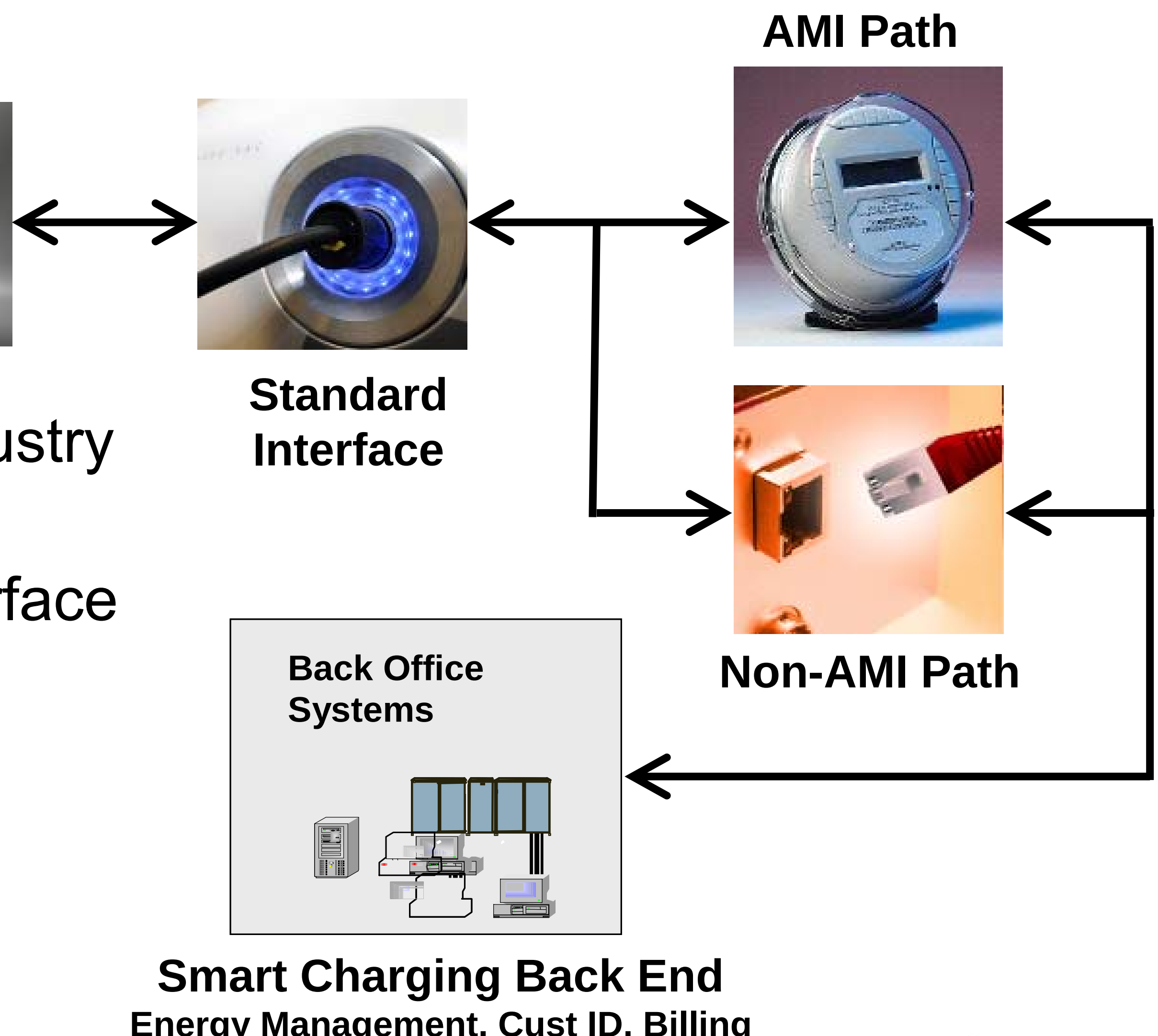
Image source: GDF Suez

…and DR will be needed to help balance increasing intermittent resources on the Grid…

But a Smarter Grid isn't a panacea for DR… lack of Measurement &Verification standards still a key barrier

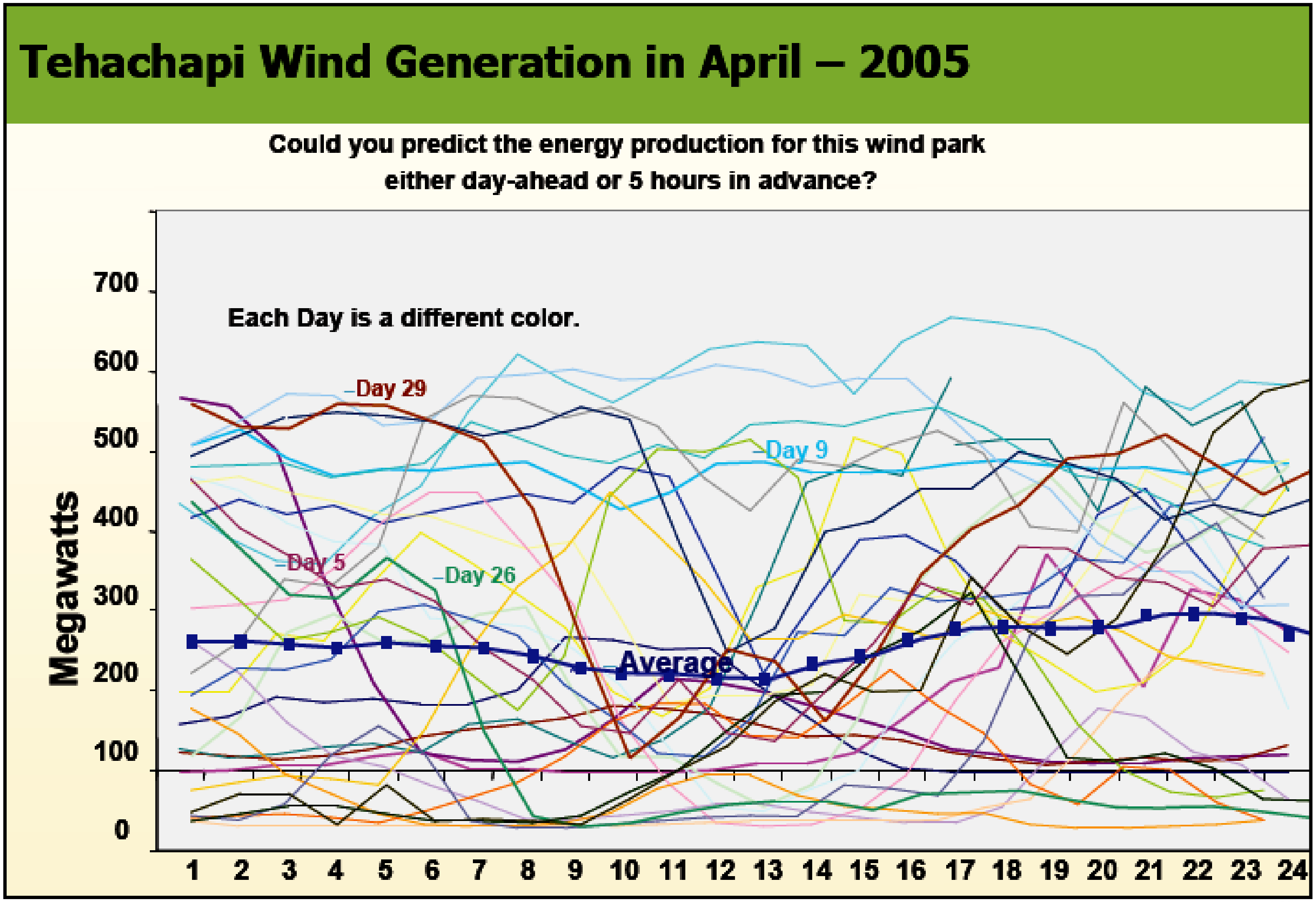


Smart Grid
Enabling PHEV Through Smart Charging



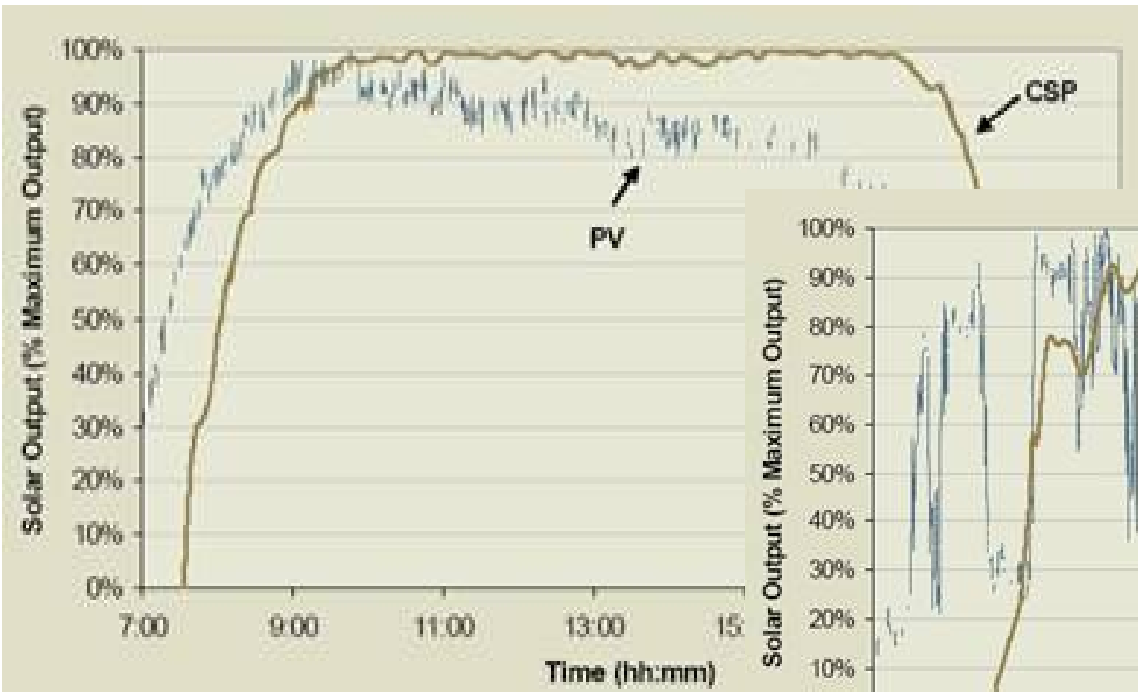
- Utility – Auto industry collaboration
- Standardize interface vehicle-to-grid
- Open systems

Variability of Wind Generation

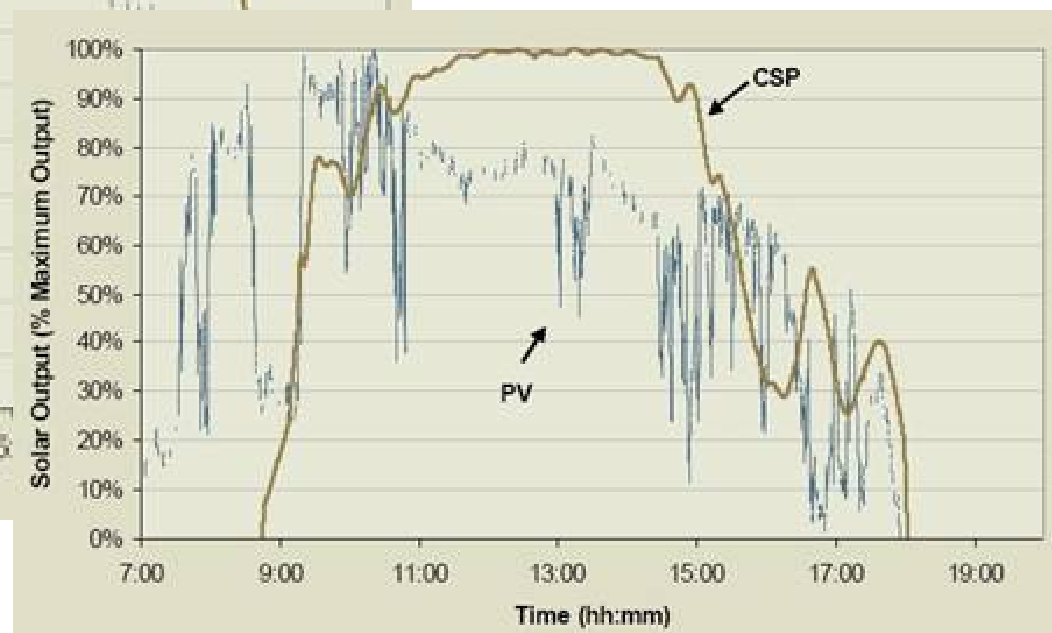


Solar Thermal (CSP) vs Photovoltaic (PV) Output

Sunny Day

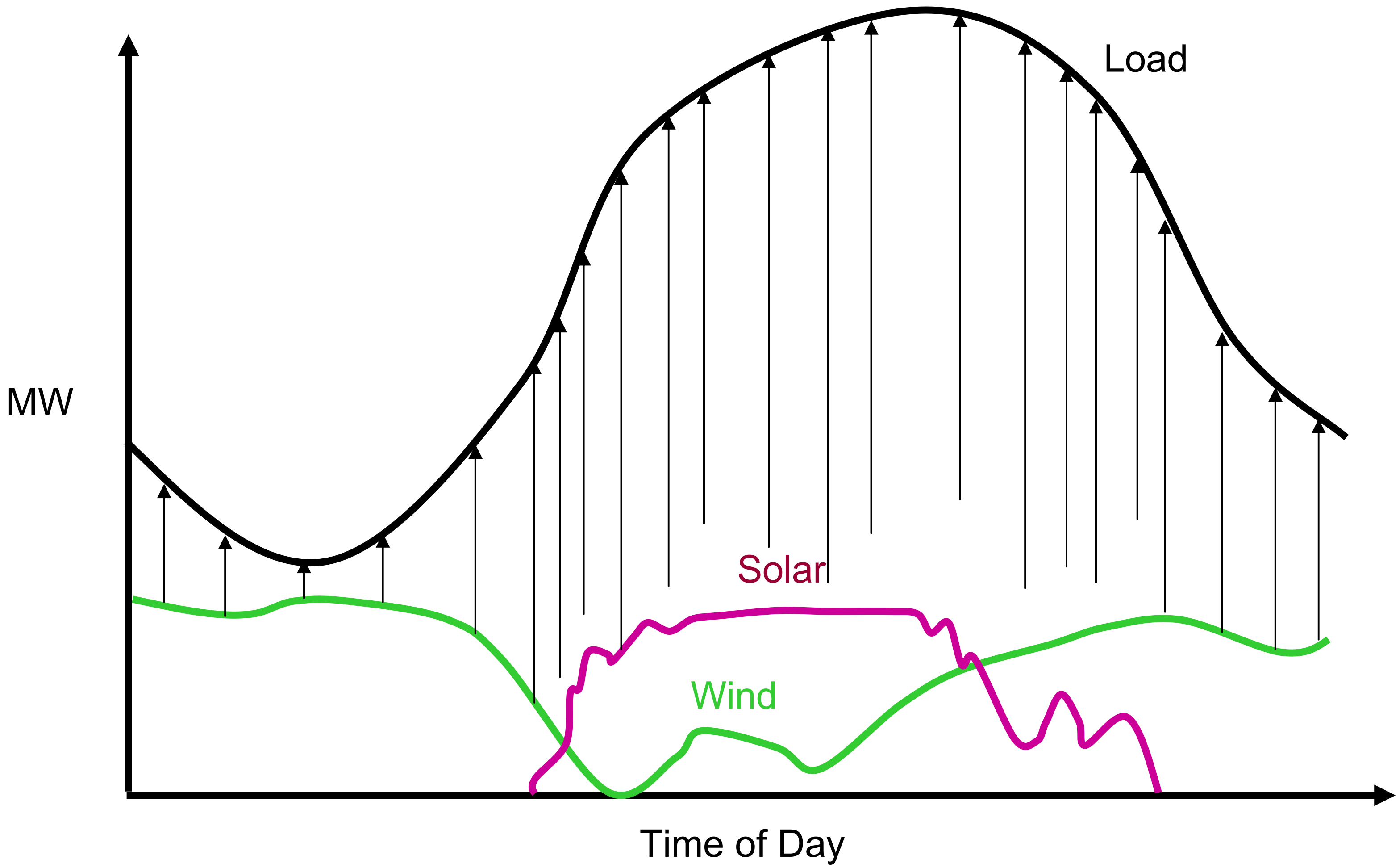


Cloudy Day

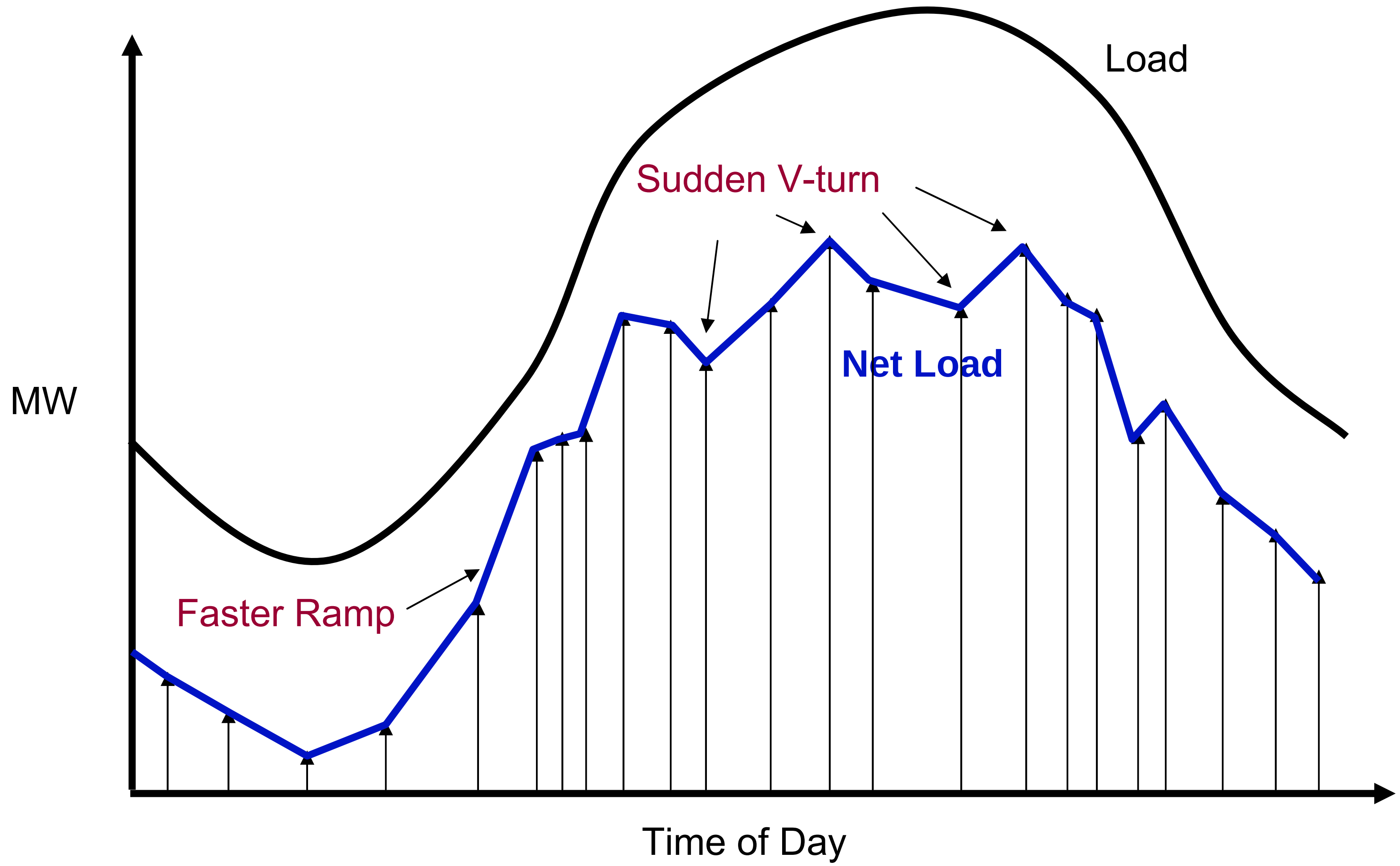


Source: Larry Stoddard, Black & Veatch

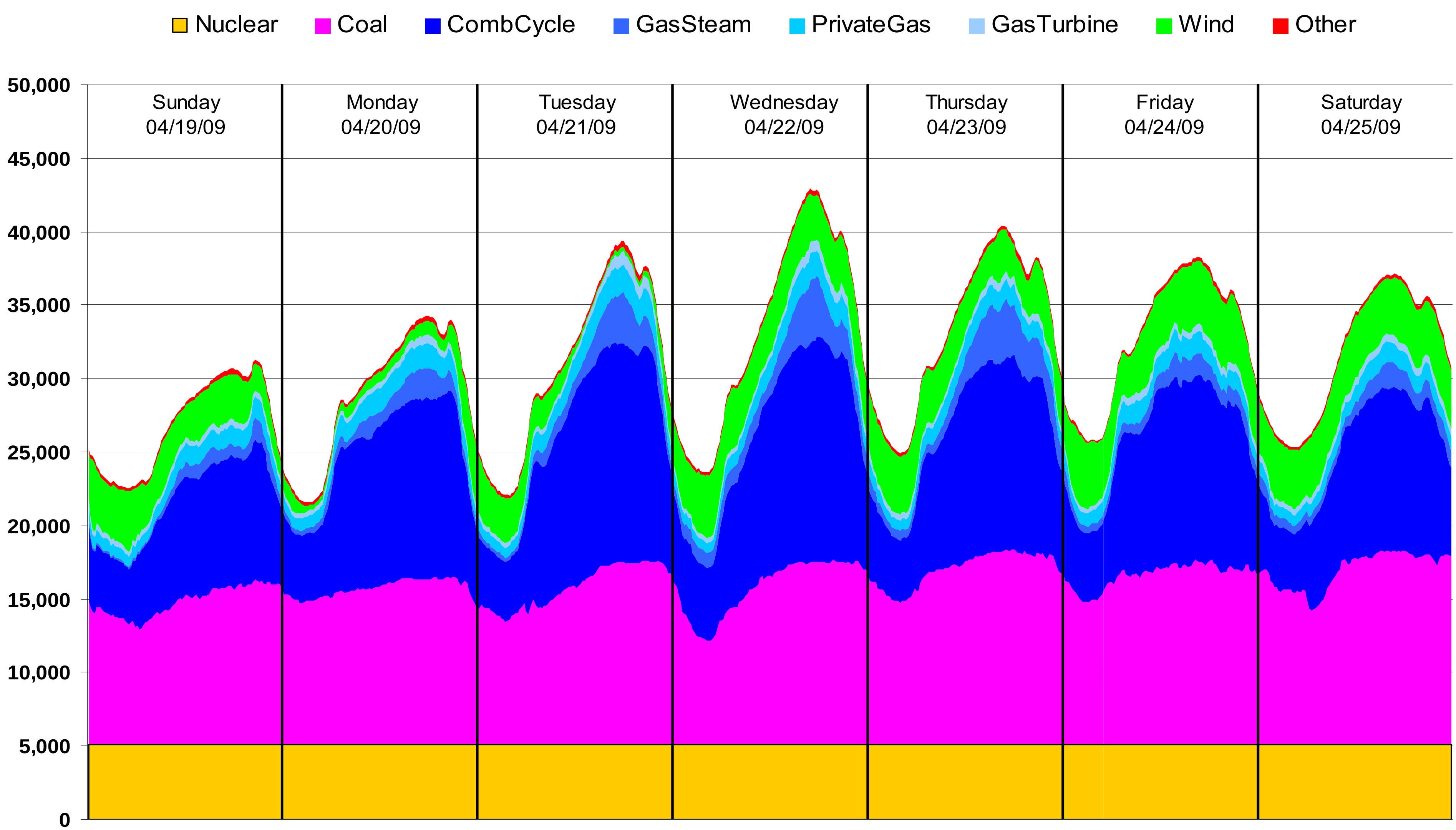
Load, Wind Output, Solar Output



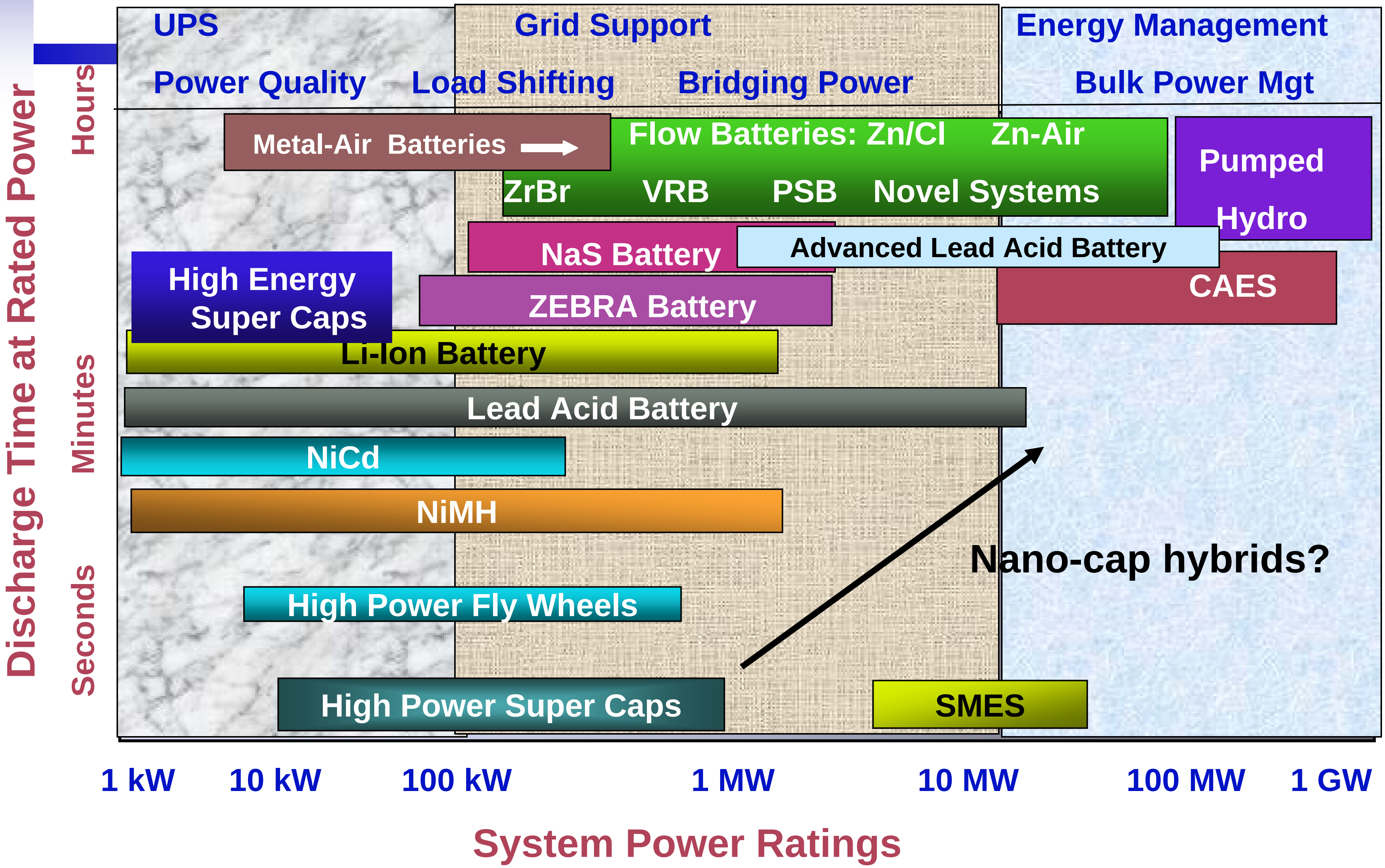
Net Load



Typical Spring Week Generation by Fuel Type [ACTUAL]



Positioning of Energy Storage Options



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Compressed Air Energy Storage

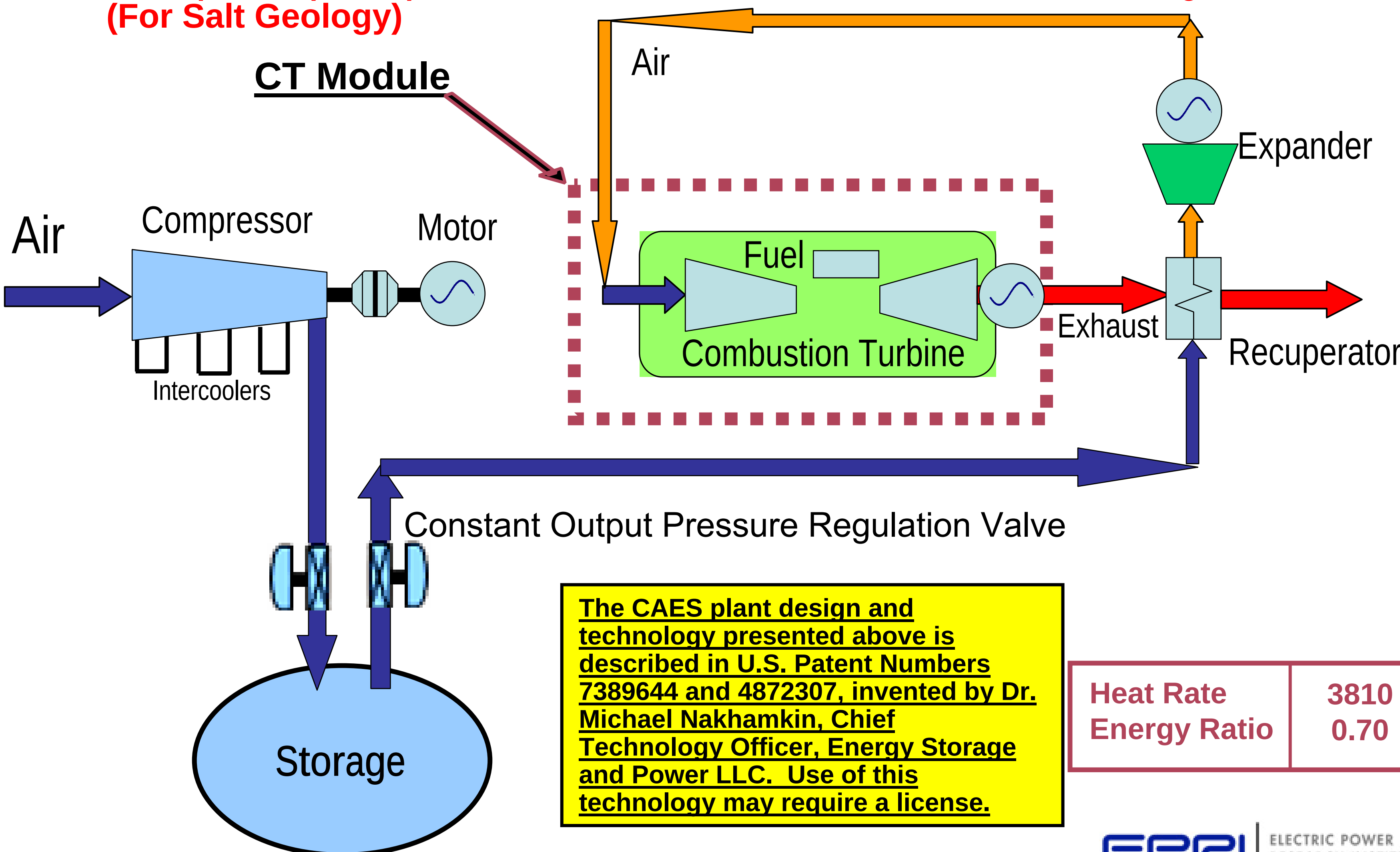
AEC CAES Plant (McIntosh, Alabama):
- - Arial View - -

- First US CAES Plant: Alabama Electric Cooperative McIntosh Plant (110MW – 26 Hr)
- Started commercial operation: midnight May 31, 1991
- Due to excellent part load efficiency, regulation ramping, and/or spinning reserve duty are often used

AEC McIntosh Site: CAES Plant On Right and Two Combustion Turbines On Left

Advanced CAES Plant: Schematic
- - - Second Generation "Chiller" Design- - -

Estimated Cap. Cost (2008 $) ~ $600/kW to $750/kW + Substation, Permits & Contingencies (For Salt Geology)

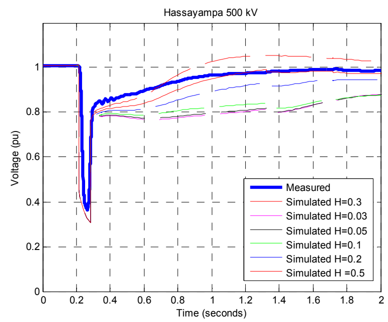


The CAES plant design and technology presented above is described in U.S. Patent Numbers 7389644 and 4872307, invented by Dr. Michael Nakhamkin, Chief Technology Officer, Energy Storage and Power LLC. Use of this technology may require a license.

Heat Rate	3810
Energy Ratio	0.70

PMU Applications

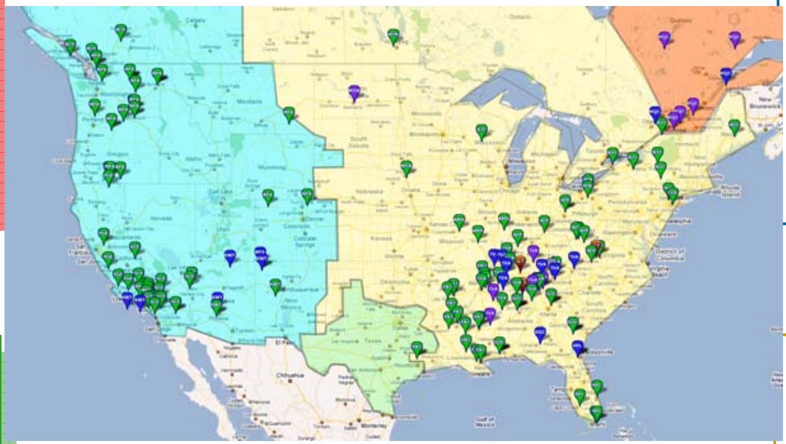
Model Validation & Adjustment



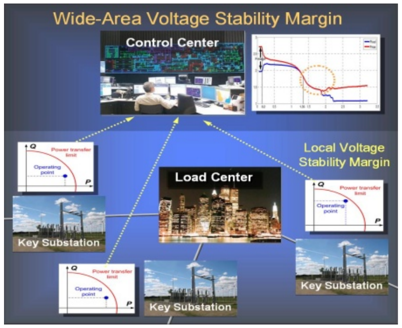
Development

Improve situational awareness

Increase transfer capabilities

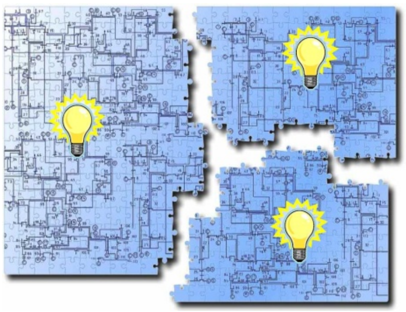


Online Stability Monitoring & Analysis



Demonstration

Controlled Separation & Restoration



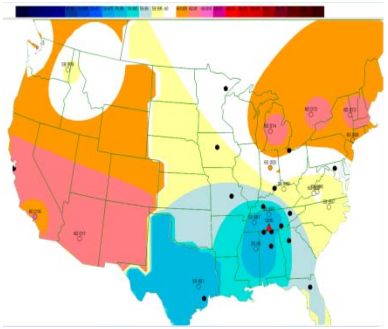
Research

Prevent cascading failures & reduce wide-area blackouts

Reduce system restoration time and outage durations

Improve accuracy of models

Wide Area Visualization



Application

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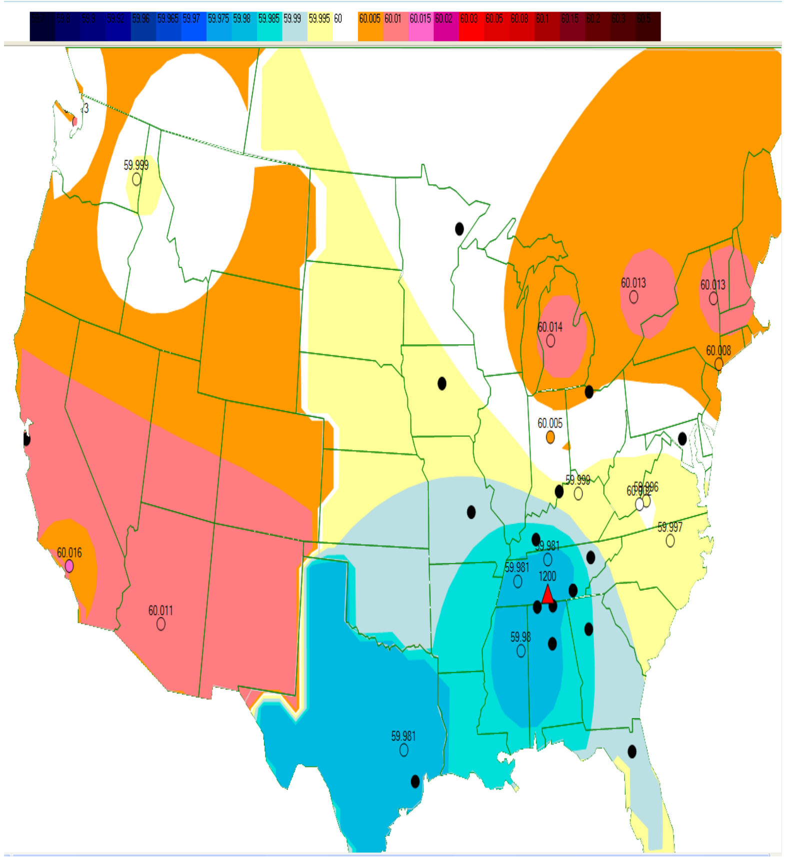
Wide Area Visualization using PMU and EMS Data

- **Industry Issues**
  - How to use PMUs to improve system operators situational awareness?
  - How to handle large volume of PMU data?
- **EPRI Solutions: Developed wide area visualization tool using PMU and EMS data**
  - Developed event-replay function to assist post-event analysis
  - Developed real-time security monitoring function
  - Developed disturbance location determination function



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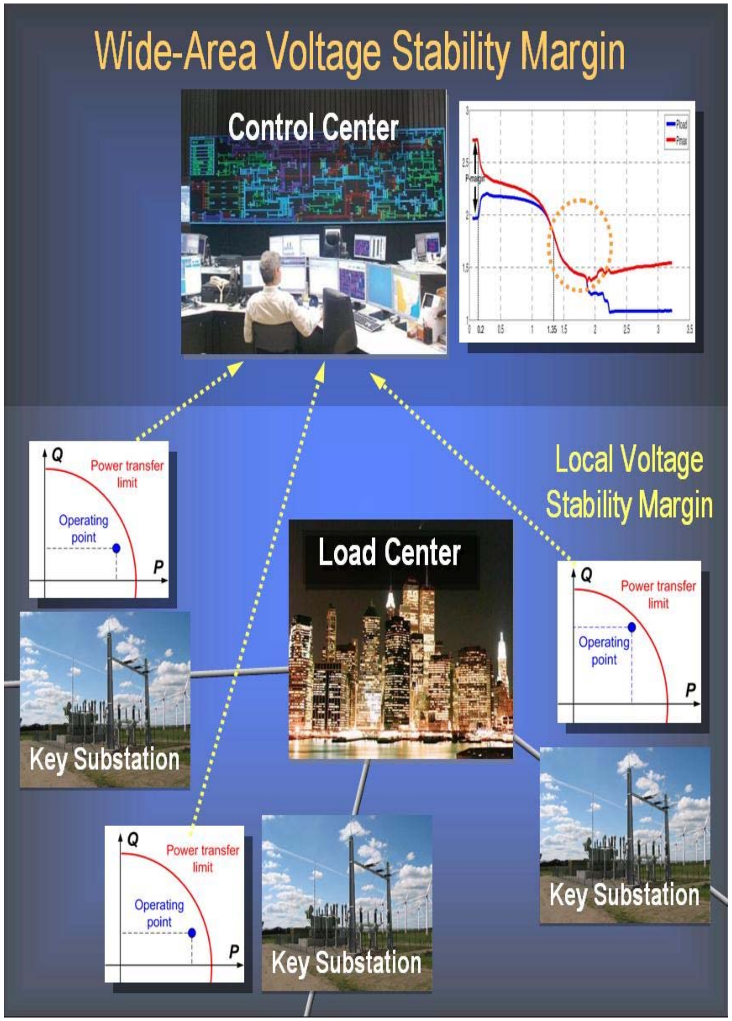
Measurement-based Voltage Stability Analysis

- **Industry Issues**
  – Need online voltage stability monitoring and analysis capabilities
  – Simulation-based voltage stability analysis approach has limitations.
- **EPRI Solutions: Developed three-level voltage stability monitoring and analysis framework**
  – Developed Voltage Instability Load Shedding to calculate voltage stability margin at substation level
  – Developed Measurement-based Voltage Stability Monitoring and Control algorithm to calculate voltage stability margin at Voltage Control Area level
  – Developing visualization tool to help system operators monitor system-wide voltage stability condition



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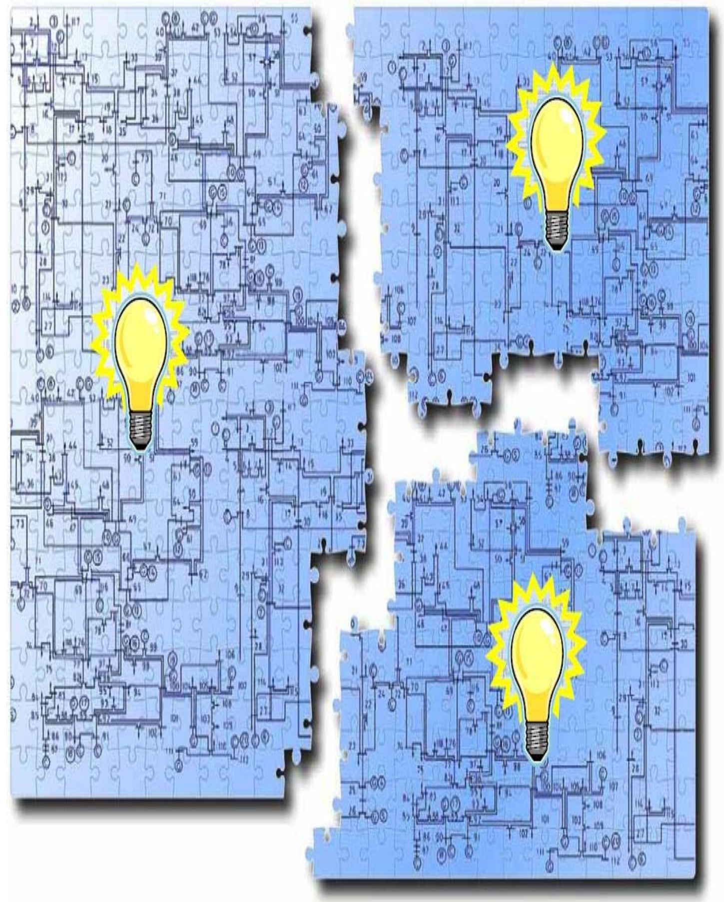
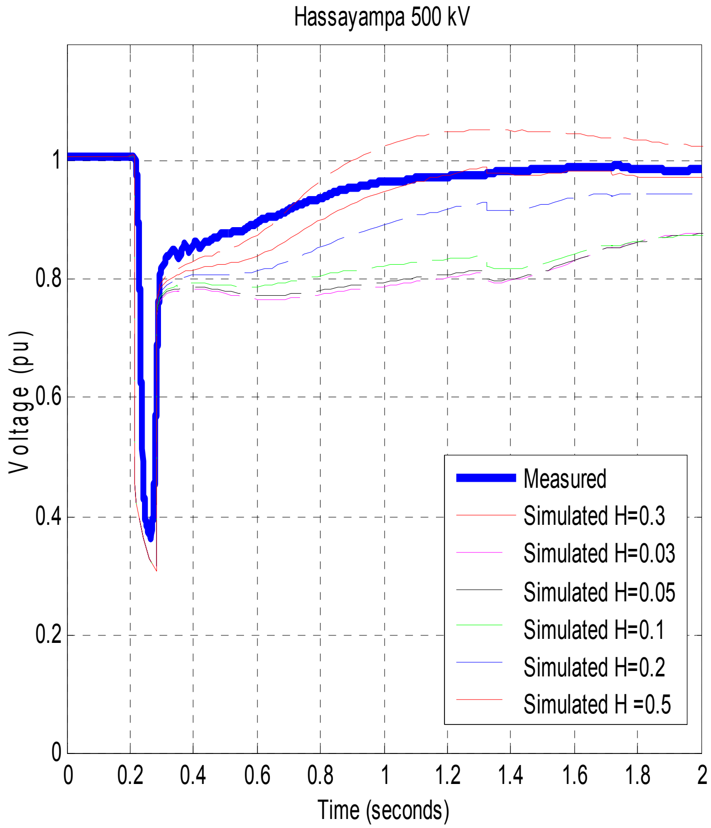
PMU-based Controlled Separation Scheme

- **Industry Issues**
  - Where to separate?
  - When to separate?
  - How to separate?
- **EPRI Solutions:** Developed PMU-based Controlled Separation Framework
  - Study cascading scenarios offline and determine potential separation interfaces
  - Use PMU to monitor oscillation and developed algorithm to quickly identify the dominate oscillation mode.
  - Developed PMU-based Out-of-Step Relay scheme to determine the separation timing



Application of Synchrophasor Measurements for Validating System Planning Models

- **Industry Issues**
  - Having accurate models is important for system planning studies
  - Validation of models is challenging
- **EPRI Solutions:**
  - Developed measurement-based load modeling methods and tools that can use measured disturbance data to validate load models.
  - Developed methods and tools that can use measured disturbance data to validate generator dyanmic models



Conclusions

- Need to Make the Bulk Power System Smarter
- Interest in Smart Grid could modernize the Electric Power System
- Key Messages:
  - Focus on Benefits to Cost Payback
  - Consider all parts together (Holistic approach)
  - Remove deficiencies in foundations
  - Implement new solutions

THANK YOU!

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