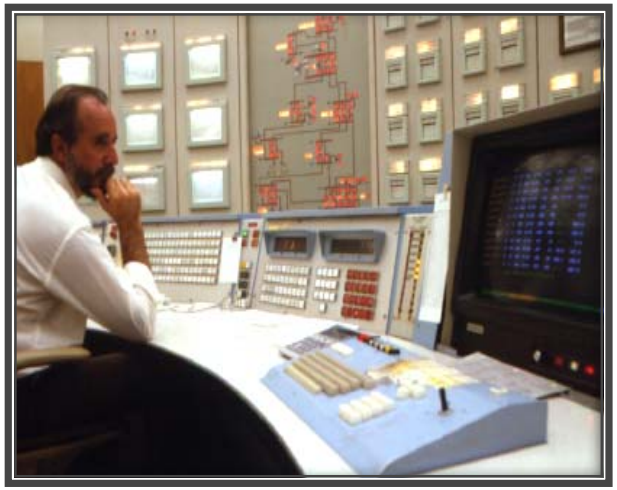


Network Events in Electric Transmission Grids

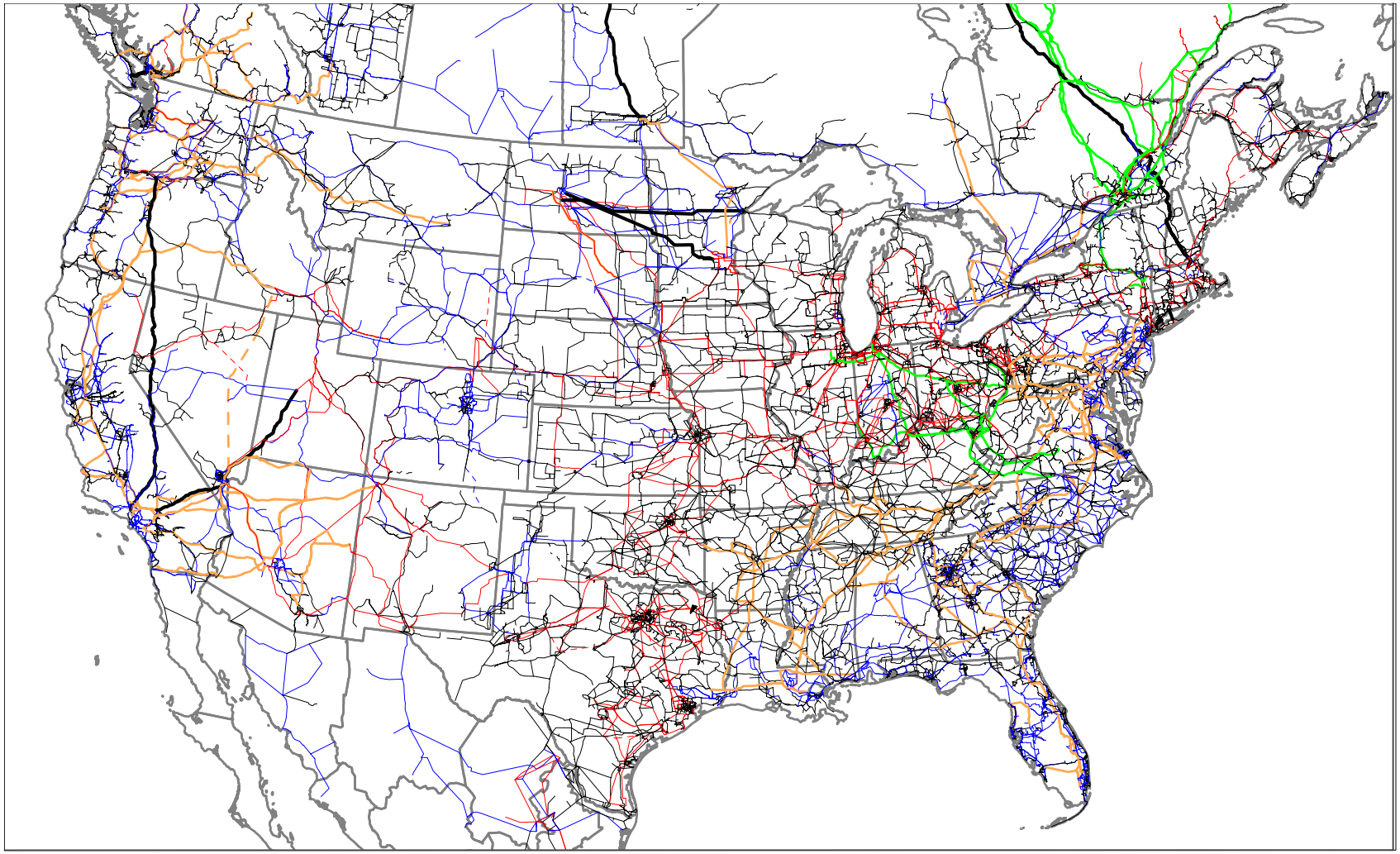
Dejan J. Sobajic

EPRI

December 8, 2003

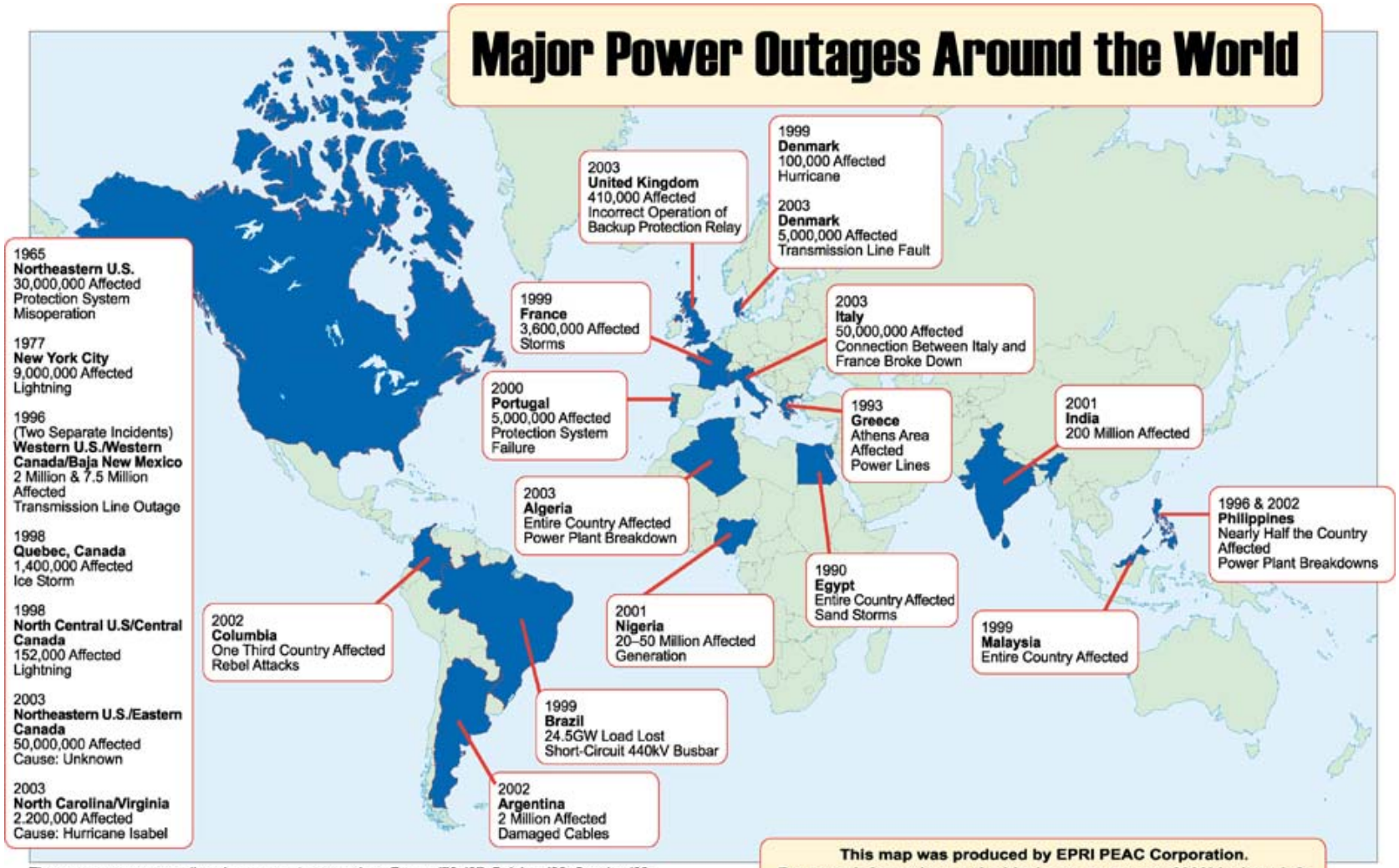
North American Electric Grid

Largest Machine Ever Built!



EPRI

Vulnerabilities of Electricity Grid: Examples



There are numerous small-scale power outages such as France '78, '87; Belgium '82; Sweden '83; Italy '89, '93, '94; Netherlands '97; and Chicago '99 that are not shown on the map.

Vulnerabilities of Electricity Grid:
Industry Response

- **DOD/EPRI Complex Interactive Networks/Systems Initiative (1998 – 2001)**
- **EPRI Reliability Initiative (1999 – 2002)**
- **EPRI Infrastructure Security Initiative (started in 2001, Phase Zero completed)**
- **DHS/EPRI/NERC North American Electricity Infrastructure Security Monitoring System (started in 2003)**

How Networks Fall Apart?

- Cascading Events (CE)
  - Unnoticed early on
    - Progressive weakening of the Grid
    - Sequential Phase
  - Then things speed up
    - Grid is out of balance
    - Transition Phase
  - When obvious it's too late for human actions
    - Loss of supply
    - Parallel & Terminal Phase

Transmission Networks are:

- Large
- Nonlinear
- Uncertain
- Time-dependent. and
- Not Fully Understood

On Cascading Events

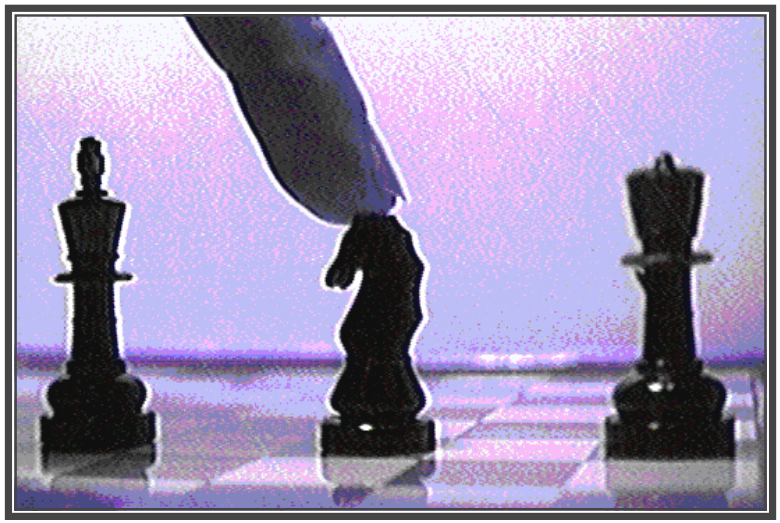
- Early CE Warning Systems badly needed
- Avoid CE by design?
  - Market efficiency vs. failure resistance
- Avoid CE through Control & Mitigation?
  - Italians tried but it didn't work

Monitoring Interconnected Transmission Networks requires:

- Real-time hardware/software
- Communications
- Accurate measurements
- Well trained people

Preventing cascades
Today's Technology

- Transaction Scheduling
  - "contract path"
- Near Real-Time System Operations
- Protection Relaying
  - Automatic & fast
  - Pre-programmed
  - Market-insensitive

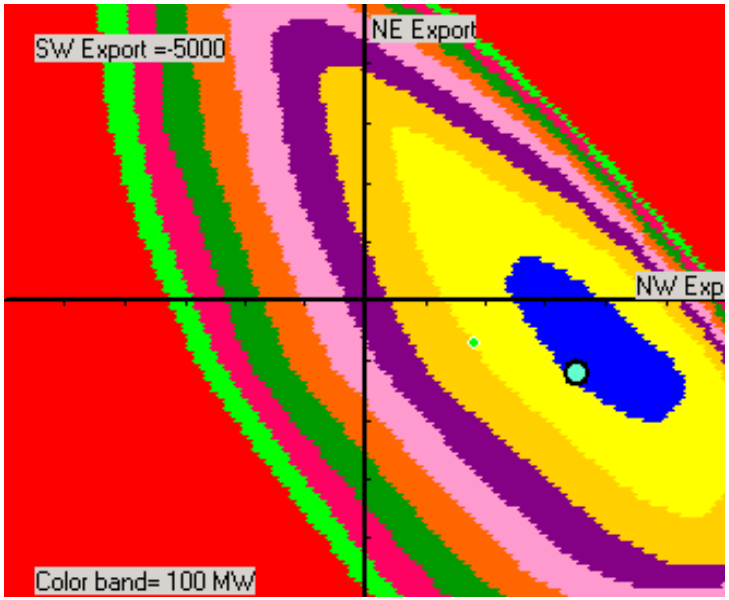


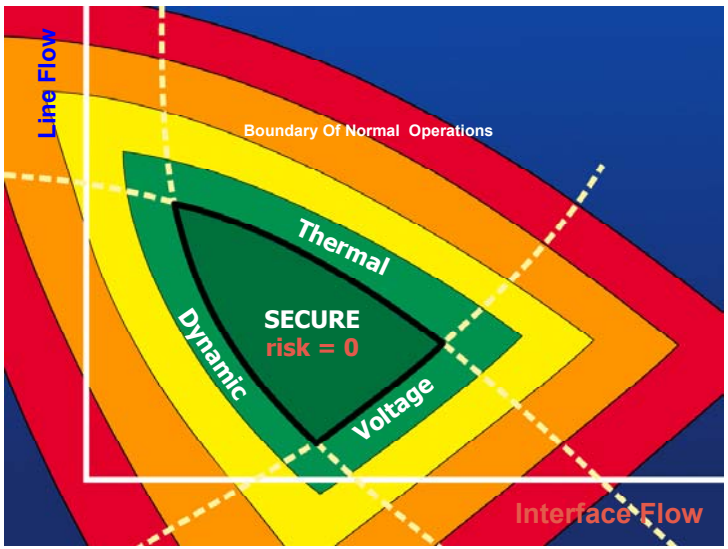
On Interconnectedness:

- US ITN was built to provide reserve not enable commerce
- How would TN look like were it built for commerce?
- Is US TN going to become a limiting factor for growing economy? How soon?

Preventing cascades
Tomorrow's Technology

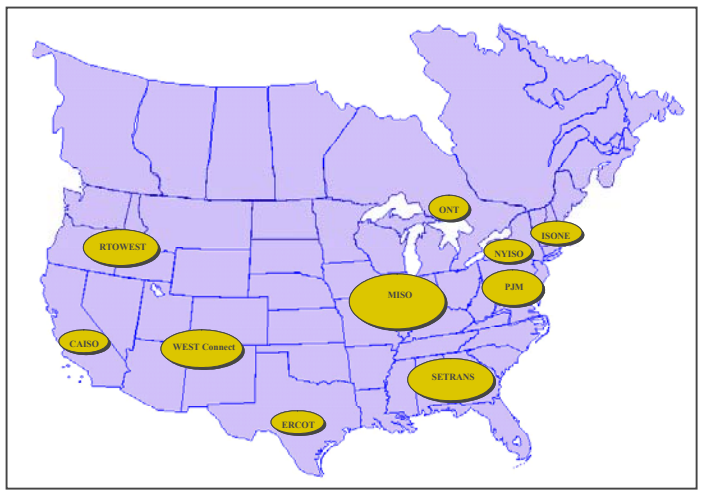
- Transaction Scheduling
  - "flow-based"
- TRUE Real-Time System Operations
- Protection Relaying
  - Automatic & fast
  - Adaptive Islanding
    - What happens with interconnectivity?
    - Adaptive Interconnectivity
  - Self-Healing





Policy Issues

- Investments in US Transmission Network are insufficient
  - As a corollary, reliability R&D dollars are unacceptably low
- Business practices need to take into account physical realities of the Grid
- Generation & Transmission extension planning has to be integrated
- Incomplete markets don't work
  - Demand response must be deployed beyond an emergency measure



Conclusion

- Cascading events may be triggered in many different ways.
- Deeper understanding of CE is a necessity
- Keeping the lights on !
  - Is an enormous undertaking
- Requiring a collaborative workshop including
  - Industry
  - Government
  - Academia
  - International “point–of –view”

Infrastructure Security Initiative:
Phase 1 -- Major Project Activities

- **Recovery Transformer**
  - Build and Test Prototype Hardware at Manufacturer Sites
- **Vulnerability Assessment**
  - Develop Methodology & Software to Evaluate Gas and Electric Grid Interactions/Vulnerabilities
- **Secure Communications**
  - Develop & Demonstrate Cyber Tools to Secure Communication Networks
- **Red Team Attacks**
  - Document Lessons-Learned from Cyber Attacks on Host Utility Systems
- **Immediate Countermeasures**

  (Response to 8/14/03 NE Blackout)
  - Document Lessons-Learned from International & Domestic Utility Attacks

Crude Propagation Model

"Domino Effect"

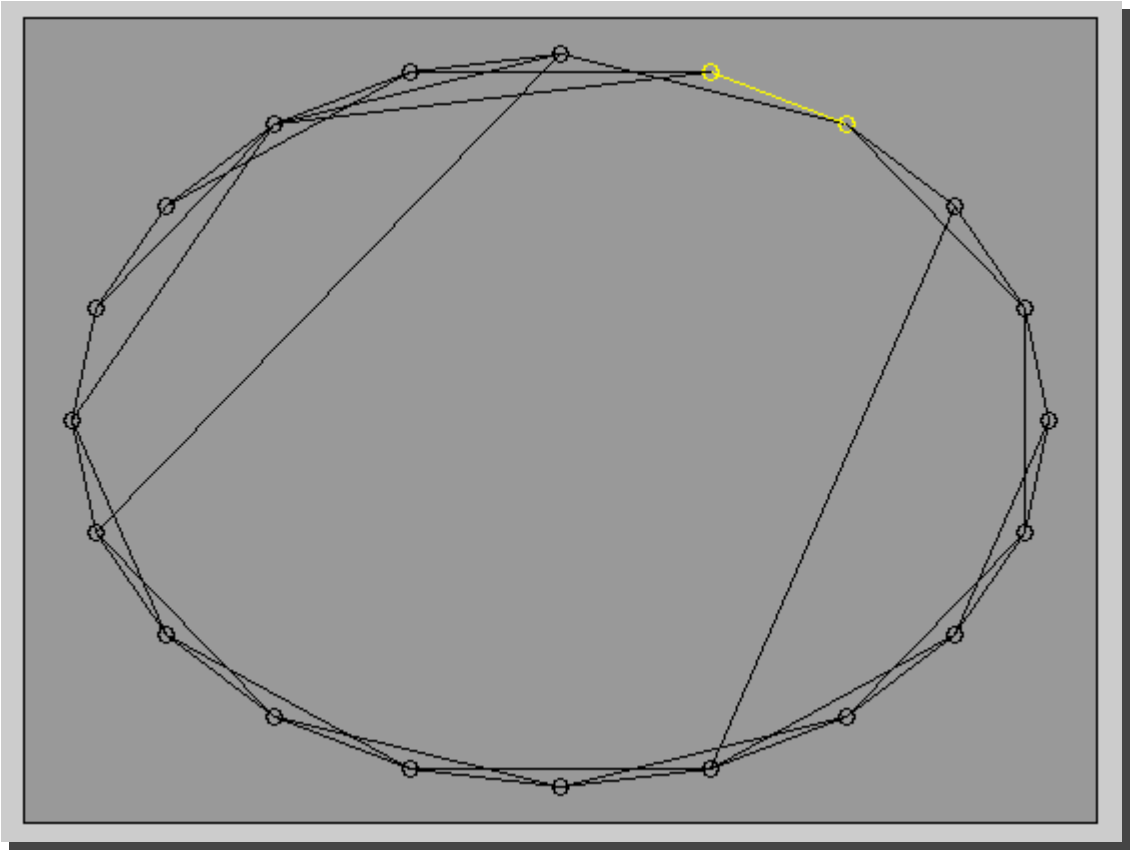
Circuit Breaker Action
$\Leftrightarrow$ virus spreading

1) Lightening strikes a line.

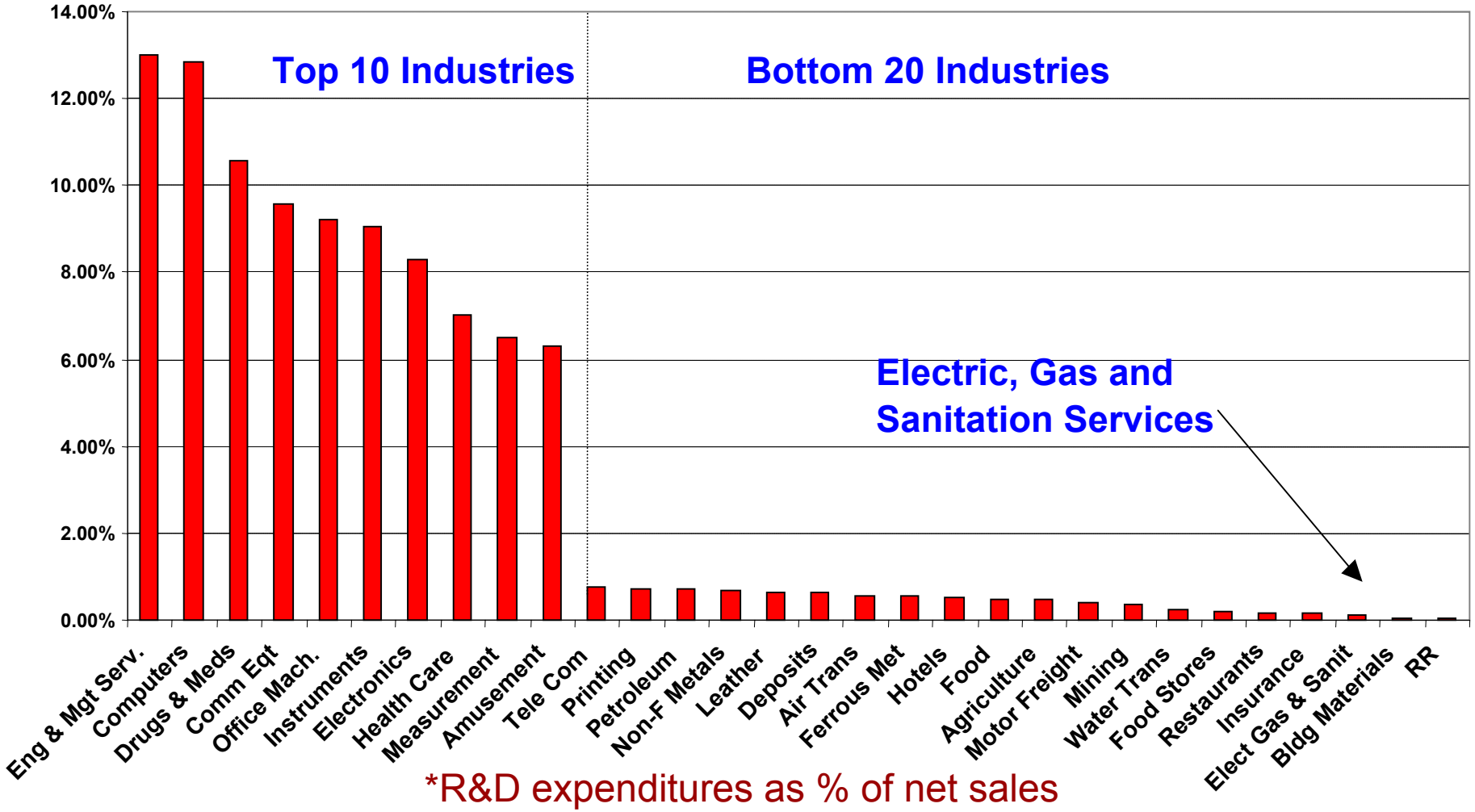
2) Induced transient trips breakers at neighboring busses with probability $0 \leq q \leq 1$.

3) Continue until cascade stops.

4) Blackout size $\propto$ number of busses affected.

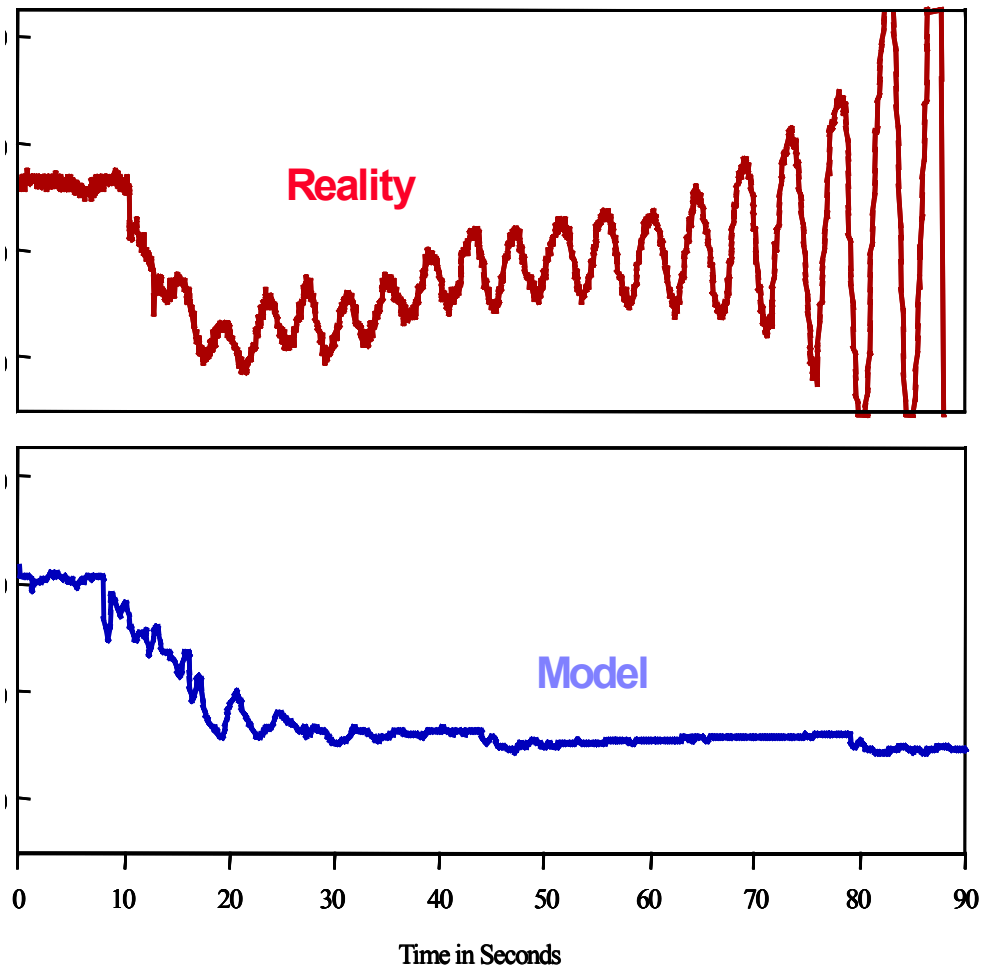


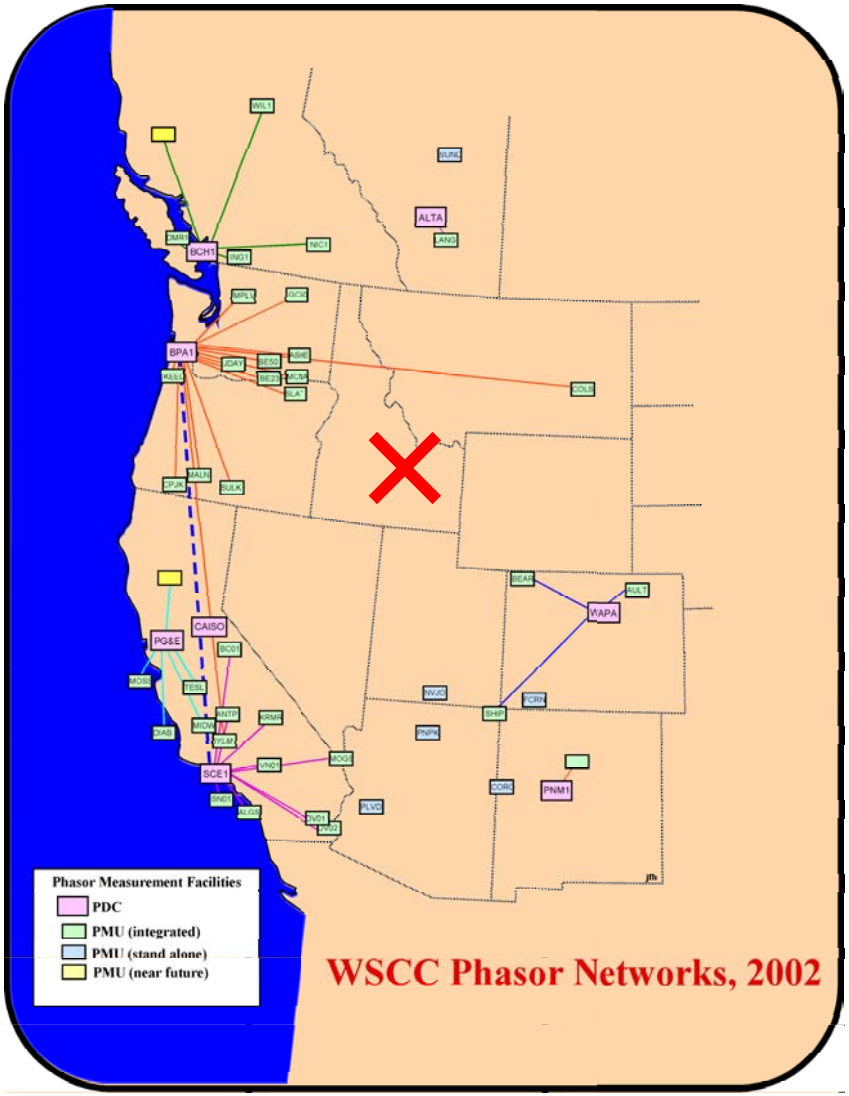
R&D Expenditures*



*R&D expenditures as % of net sales

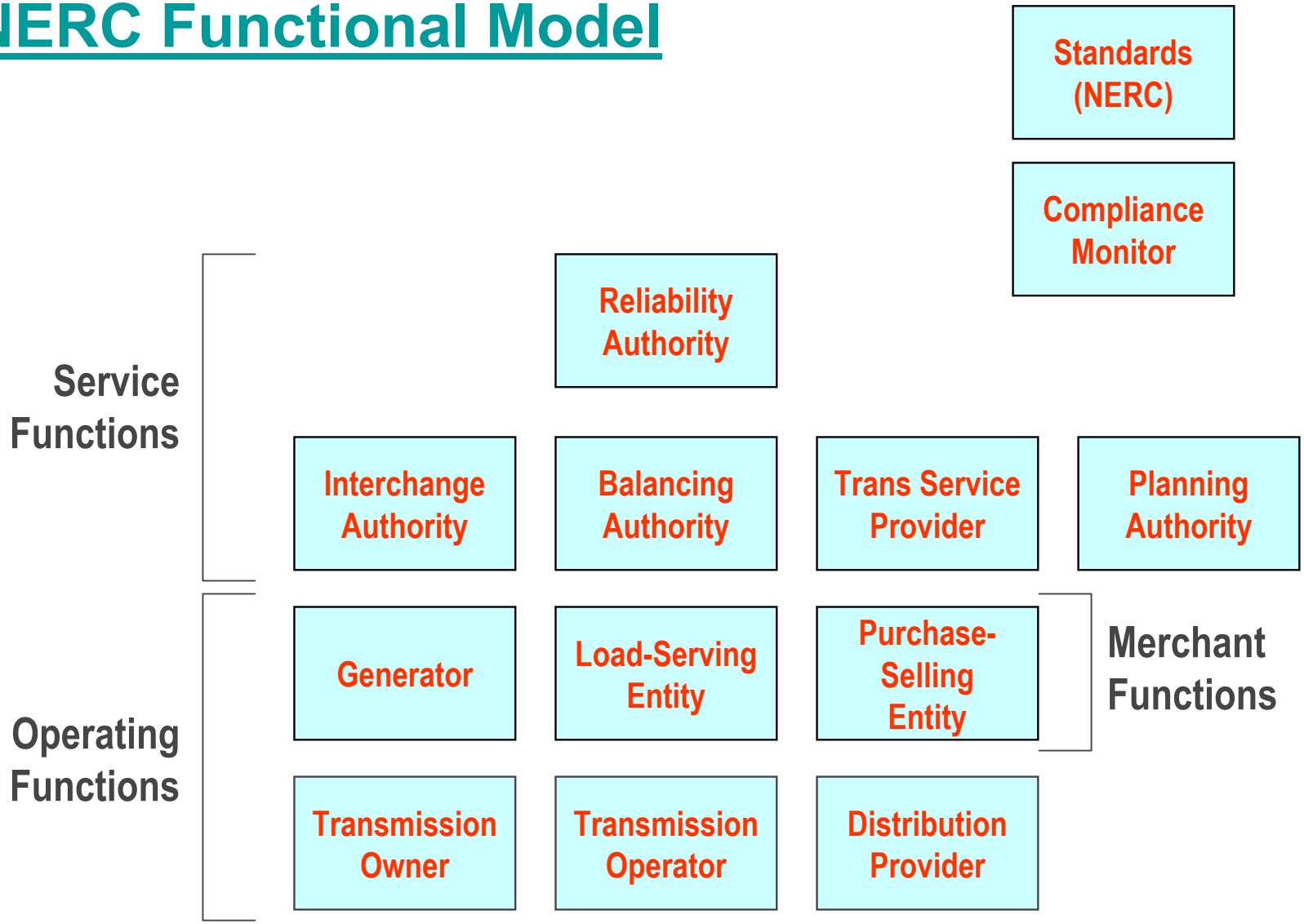
Modeling Failures May Spell Future Troubles!



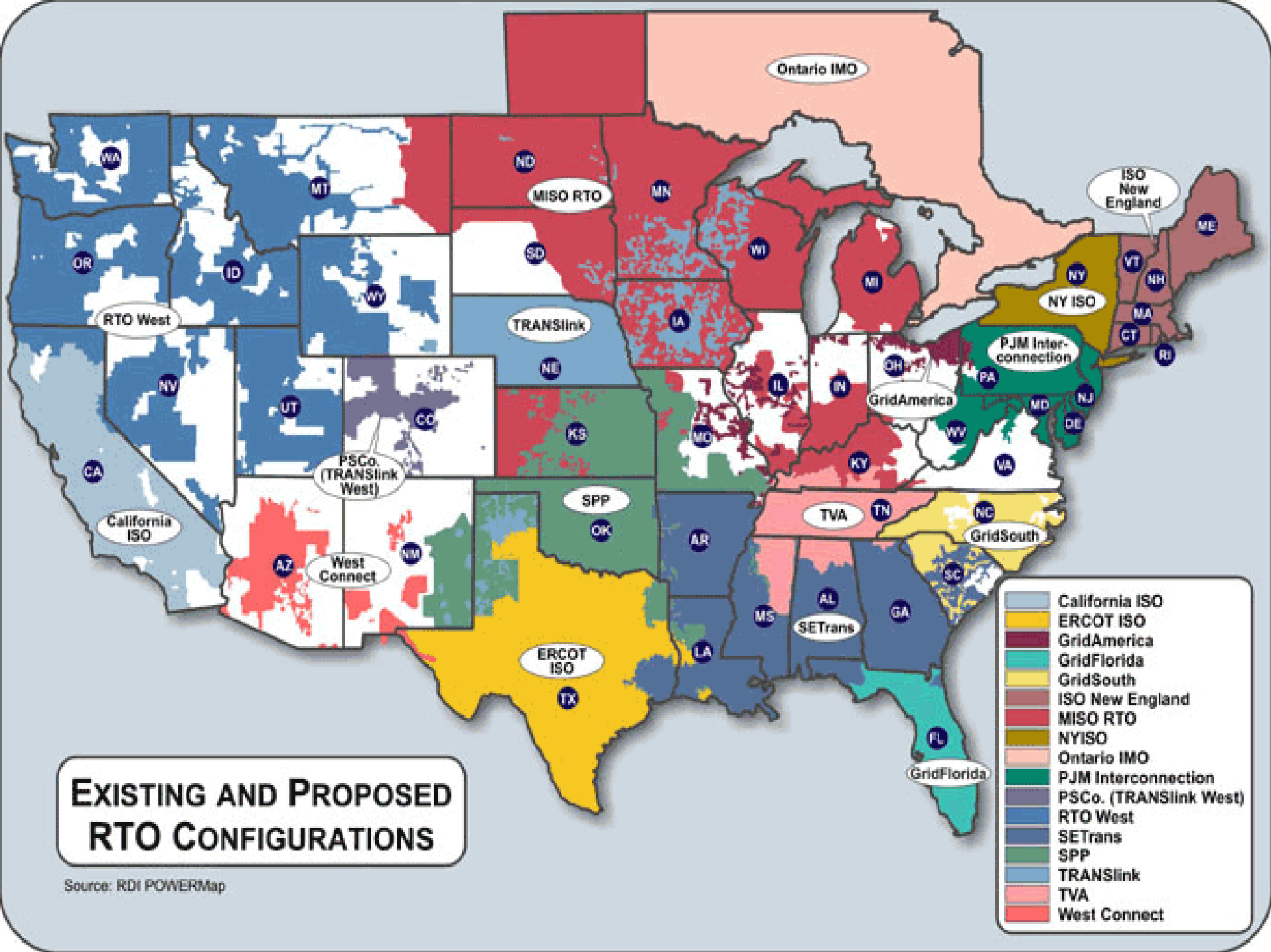


Provided by Dr. John Hauer, PNNL

NERC Functional Model



return



Existing and Proposed RTO Configurations

Source: RDI POWERMap

RTO Characteristics & Minimal Functions

Characteristics

- Independence
- Scope and Regional Configuration
- Operational Authority
- Short Term Reliability

Minimal Functions

- Tariff Administration
- Congestion Management
- Parallel Path Flow
- Ancillary Services
- OASIS and TTC/ATC
- Market Monitoring
- Planning and Expansion
- Interregional Coordination

Approved RTOs

- **PJM (RT01-2-000)**
- **MISO (RT01-87-000)**

Independent System Operators

Key Objectives

- Enhance interregional reliability through coordinated operations and planning.
- Facilitate broader competitive markets.
- Improve flow of information to market participants and the public.

Existing ISOs	**- CAISO**	**- PJM**
	- ISONE	**- MISO**
	- NYISO	**- ERCOT**
	- IMO (Canada)	

The August 14 Blackout

from the US-Canada Interim Report

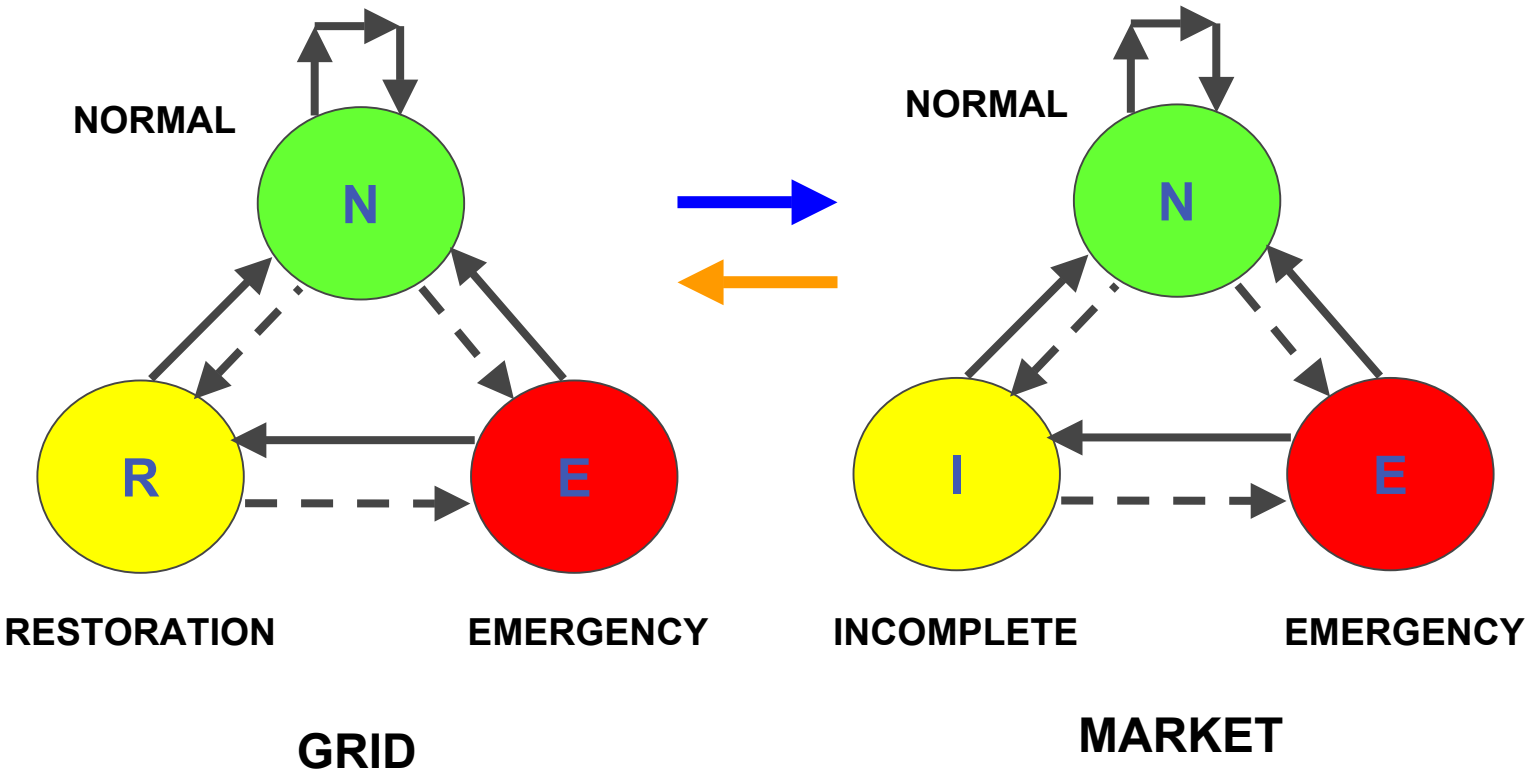
Causes or contributing factors

- Inadequate vegetation management
- Failure to ensure operation within secure limits
- Failure to identify emergency conditions and communicate that status to neighboring systems
- Inadequate operator training
- Inadequate regional-scale visibility over the power system.

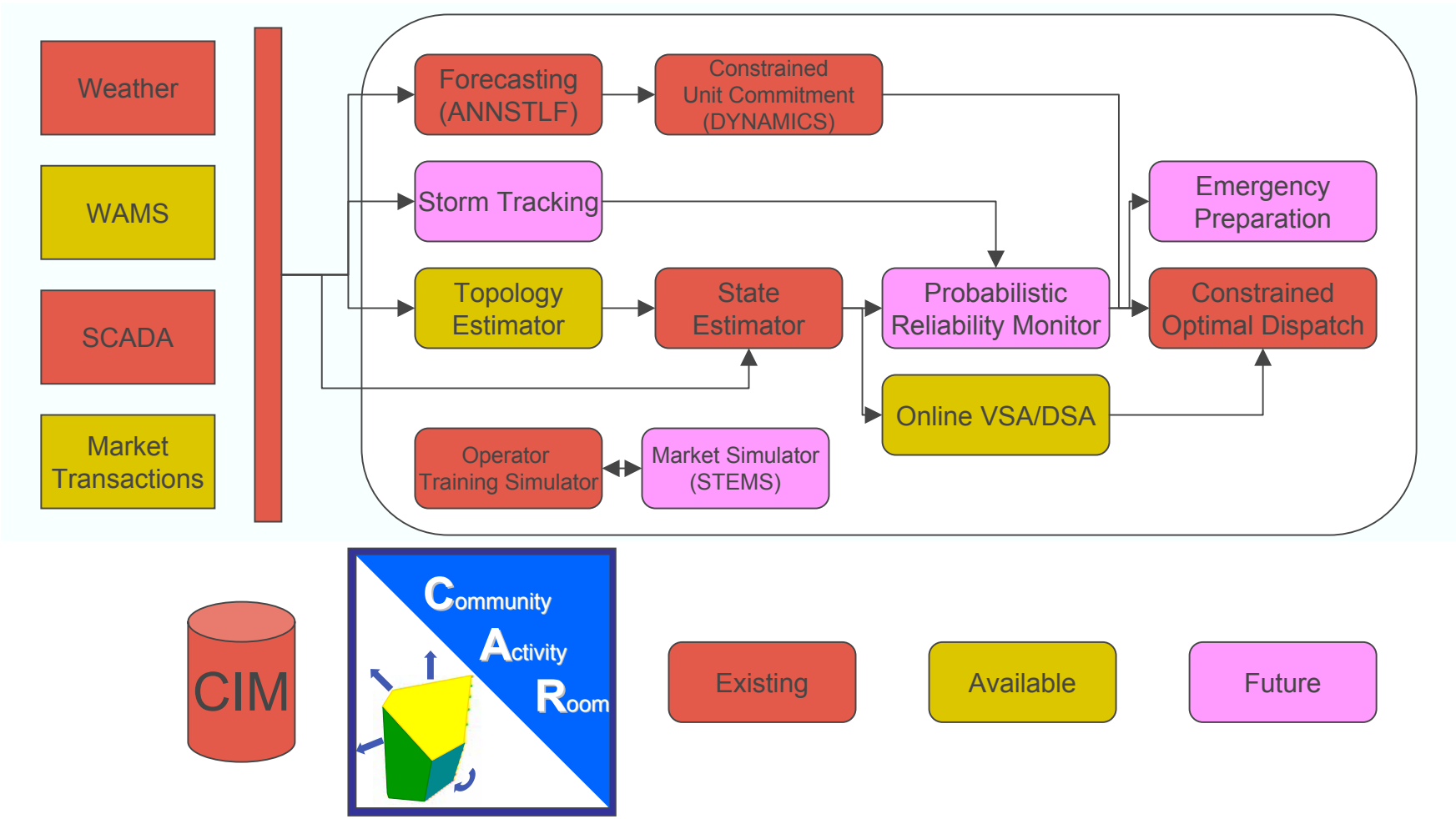
New causal features of the August 14 blackout

- Inadequate interregional visibility over the power system
- Dysfunction of a control area's SCADA/EMS system and
- Lack of adequate backup capability to that system.

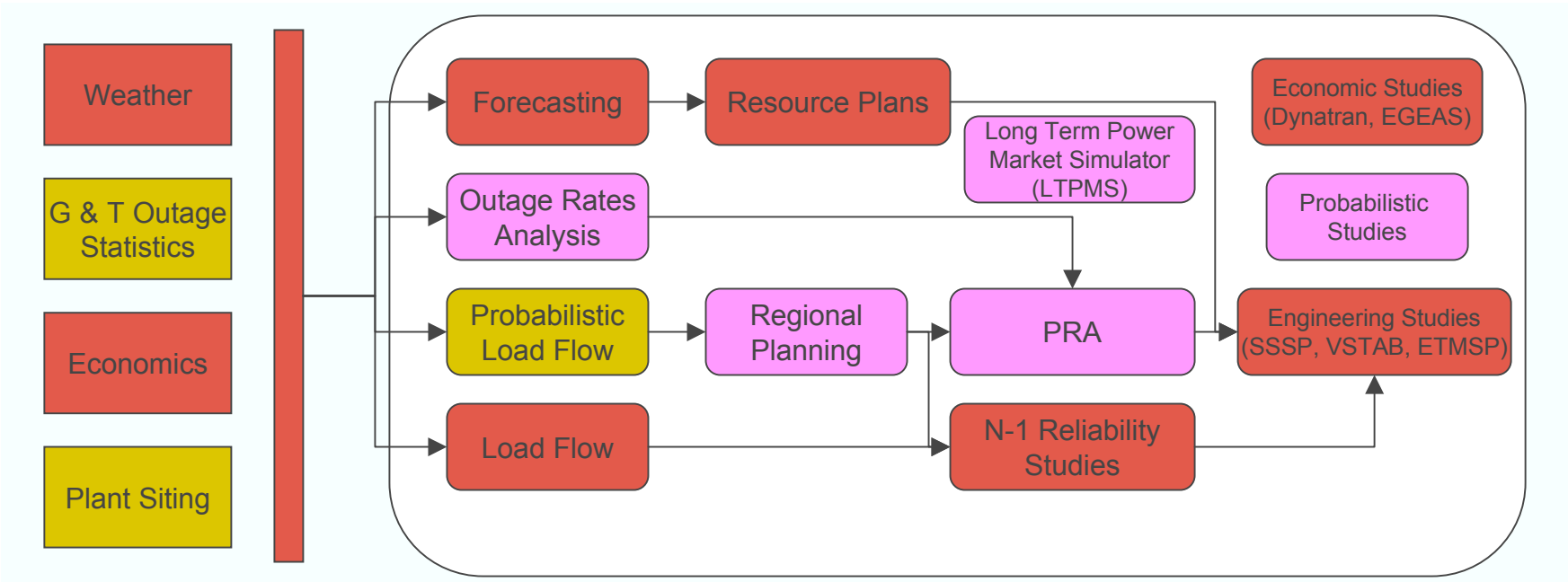
Framework for Market/Grid Operations & Analysis



Architecture of Future Operation



Architecture of Future Planning



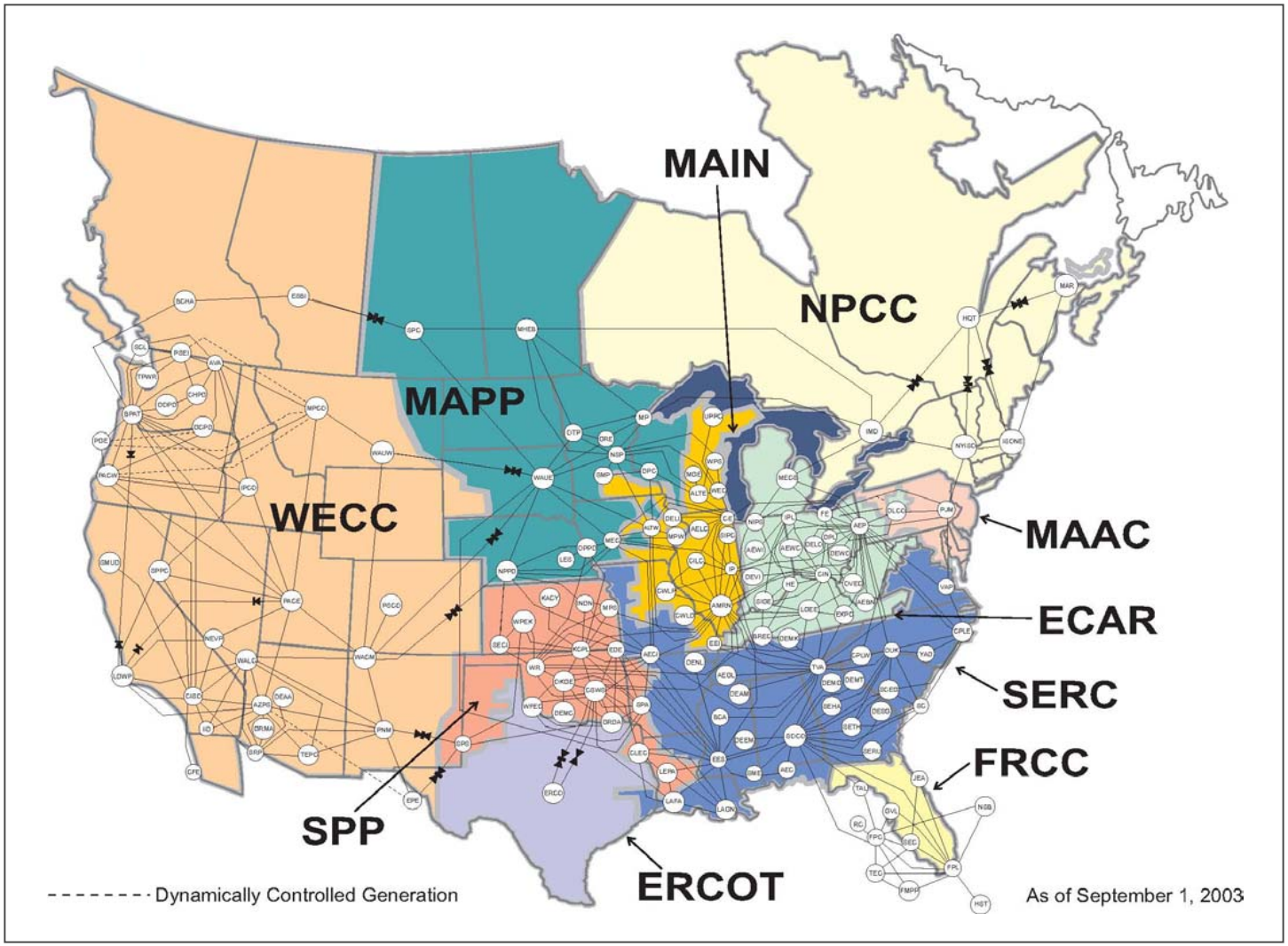
Existing

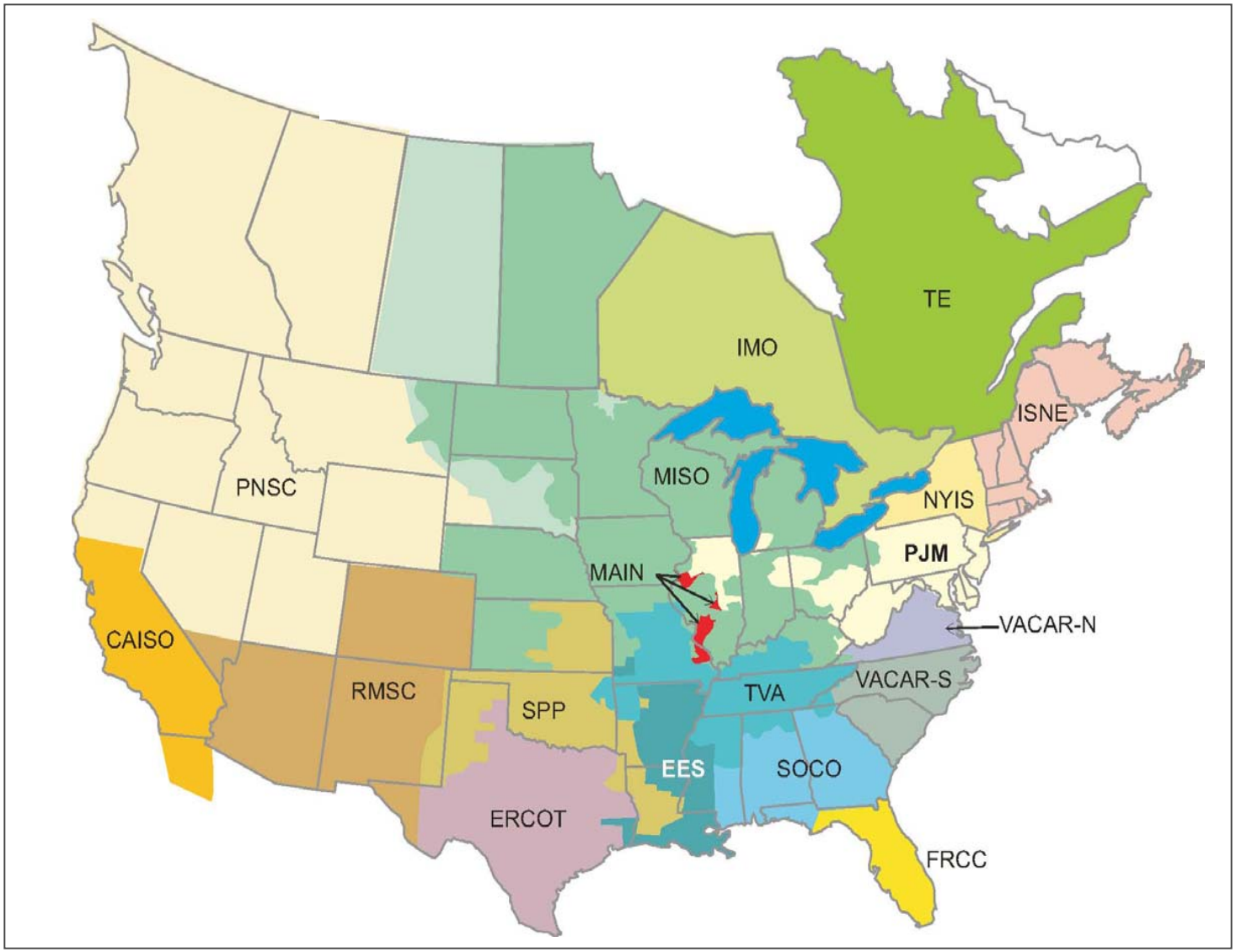
Available

Future

Who are our clients?

NERC Control Areas



Who are our clients?

Reliability Coordinators & ISOs