Toward Resilient, Smart and Self-healing Interdependent Infrastructures

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Director, Technological Leadership Institute
Honeywell/H.W. Sweatt Chair in Technological Leadership
Professor, Electrical & Computer Engineering
University Distinguished Teaching Professor

Awards Lunch at the TCLEE 2009: Earthquake Engineering in a Multi-Hazard Environment
June 30, 2009, Oakland, CA

Material from the Electric Power Research Institute (EPRI), and support from EPRI, NSF, and ORNL for my graduate students' doctoral research is gratefully acknowledged

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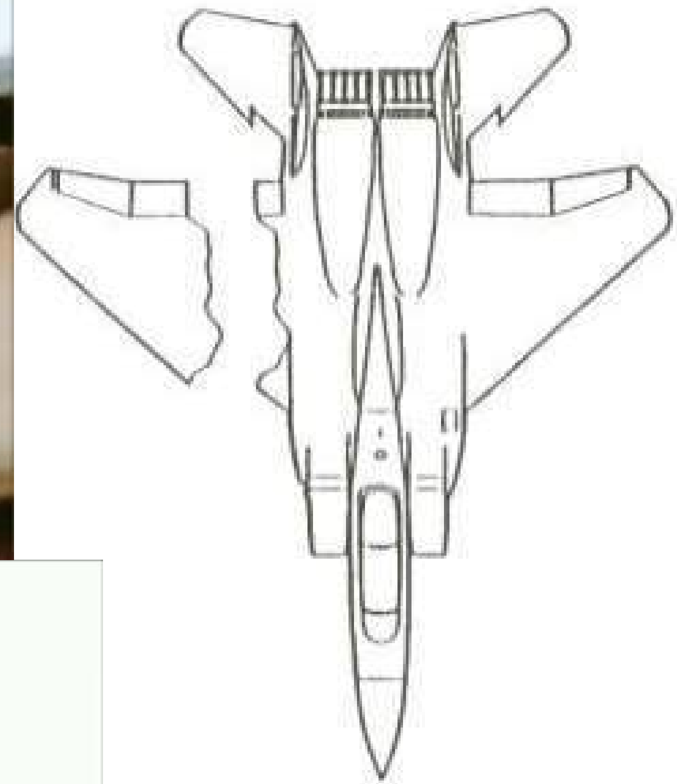
Saving systems from collapse in Multi-hazard environments: The Case of the Missing Wing (1983-97)



NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden, Boeing Phantom Works, and Washington University in St. Louis.

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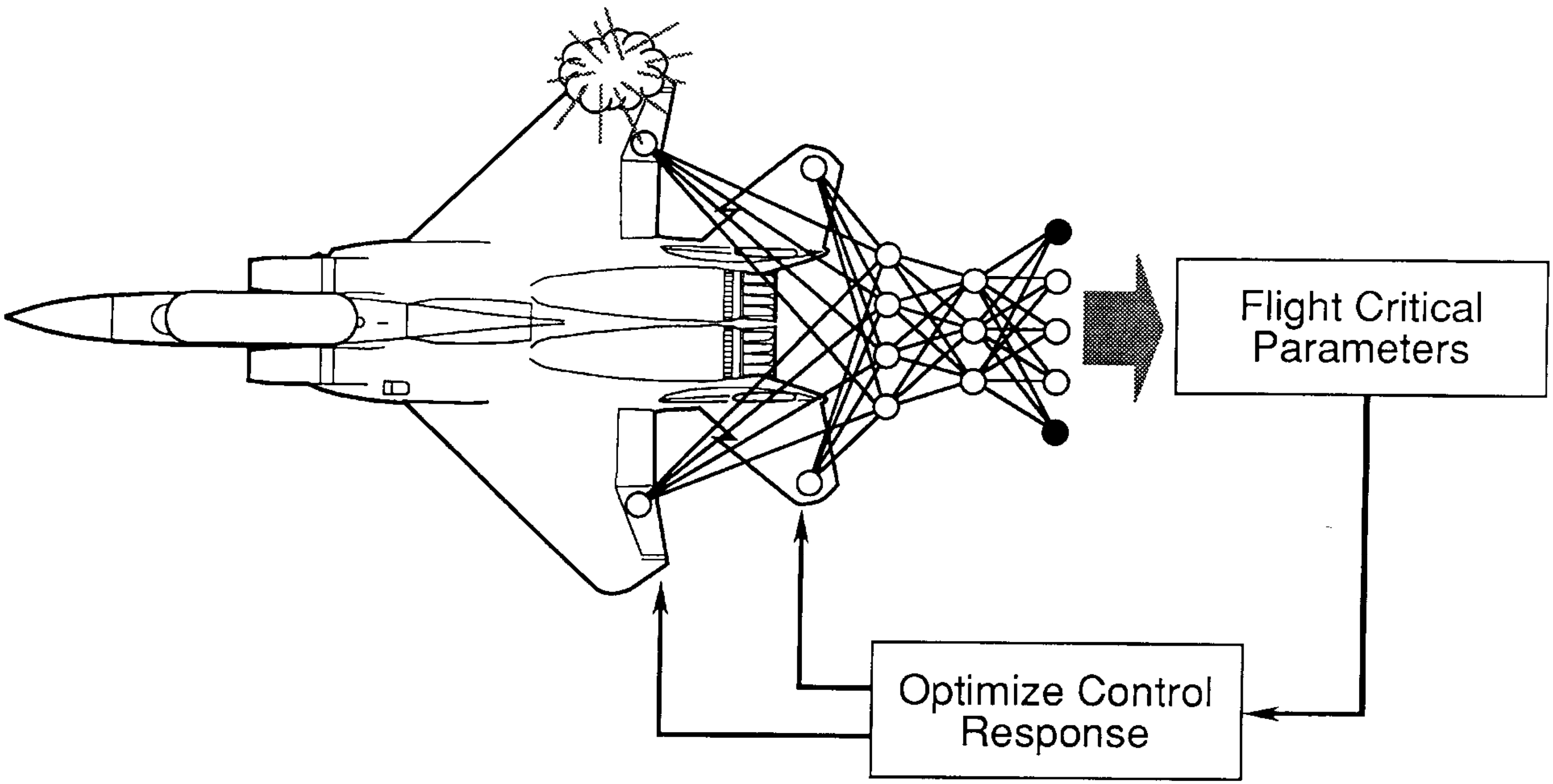
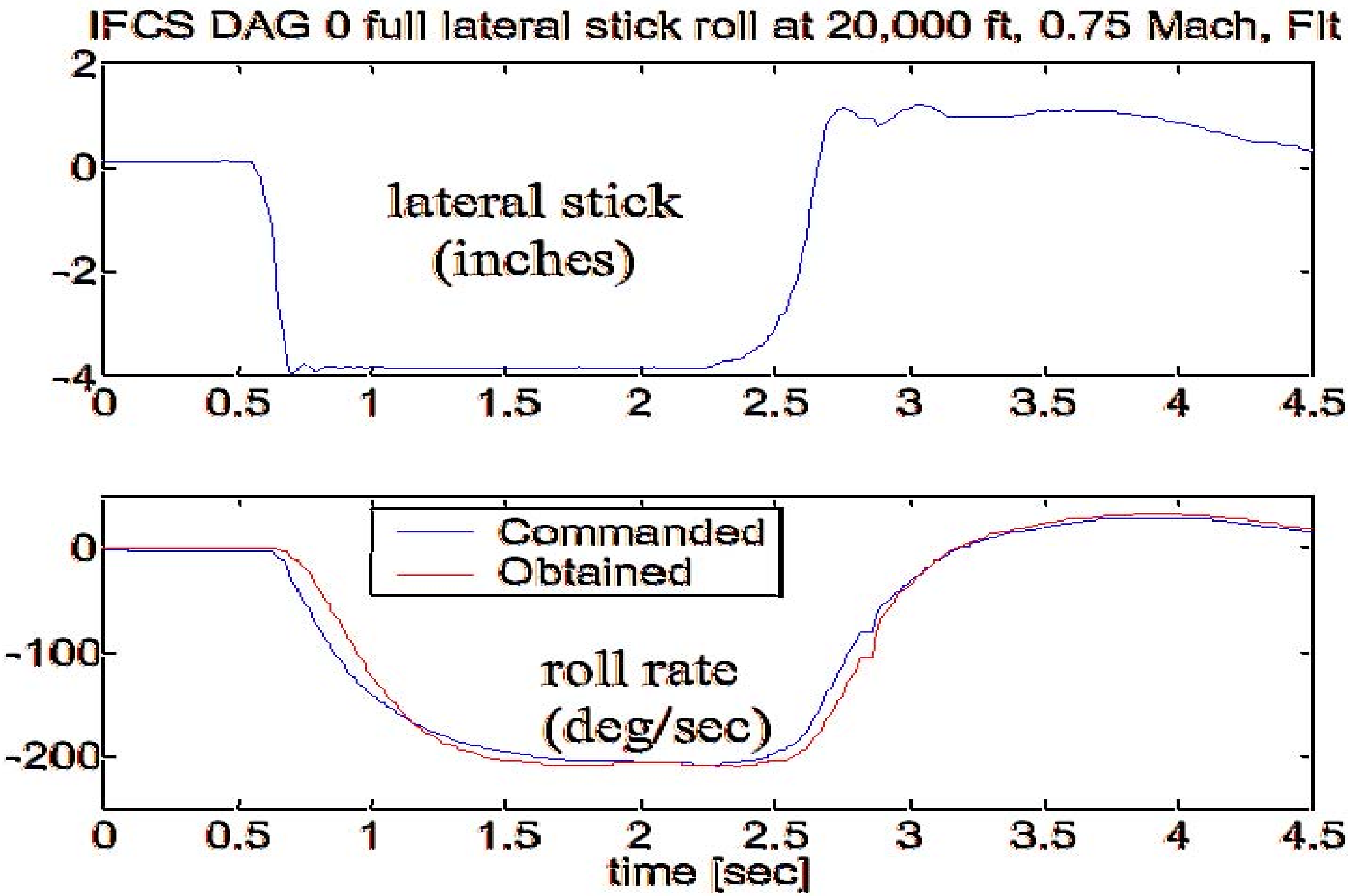
Goal: Optimize controls to compensate for damage or failure conditions of the aircraft



NASA/MDA/WU IFCS

Intelligent Flight Control System: Example – complete hydraulic failure (1997)

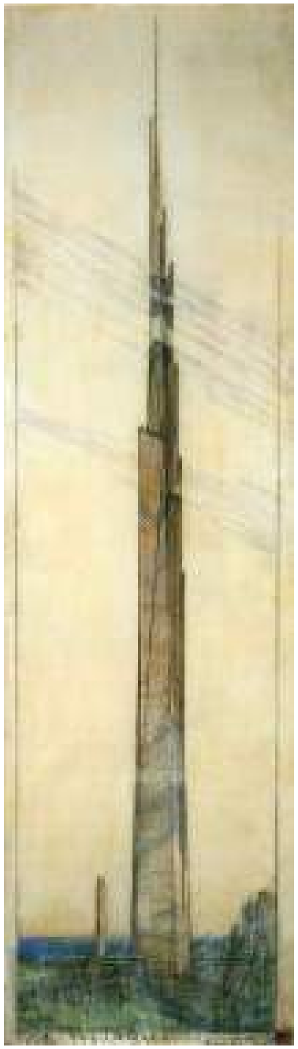


Background: Sensing, modeling, simulation and control of complex systems in multi-hazard environments

My areas of R&D: Aug. 1983- Dec. 1997

- Control of helicopters subject to disturbances and uncertainties (1983-1985)
- Flight & Fire Control System with Rockwell Int'l tested in Germany by Messerschmidt and adapted as the pilot's assistant for the Advanced Euro Fighter (1987-1990)
- Evasive maneuvering against multiple pursuers with countermeasures (1990-1993)
- Real-time system identification, disturbance rejection and optimal control (1992-1998):
  - Control of a damaged F-15 (with McDonnell Douglas and NASA; 1995-1996)
  - Parameter est. and control of antiskid braking system for an MD-90 (1997-98)
  - Improved models and controls for crystal growth (with MEMC, 1993-95)
- Modeling, simulation and optimization of DoD's large-scale air transport operations; Mobility Analysis Support System (USAF's Air Mobility Command and the US Transportation Command; 1992-1997)
- IVHS/ITS: Urban traffic monitoring, prediction, and management (with SEI, 1993-1998)

Self-healing "Smart" Grid (1998-present)



Building on the Foundation:

- Anticipation of disruptive events
- Look-ahead simulation capability
- Fast isolation and sectionalization
- Adaptive islanding
- Self-healing and restoration

Overview of my research areas (1998-2003):

Initiatives and Programs I developed and/or led at EPRI

1999-2001	Y2K2000-present	2002-present	2001-present
EPRI/DoD Complex Interactive Networks (CIN/SI)	**Enterprise Information Security (EIS)**	**Infrastructure Security Initiative (ISI)**	**Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)**

EPRI/DoD Complex Interactive Networks (CIN/SI)

- Underpinnings of Interdependent Critical National Infrastructures
- Tools that enable secure, robust & reliable operation of interdependent infrastructures with distributed intelligence & self-healing

Enterprise Information Security (EIS)

1. Information Sharing
2. Intrusion/Tamper Detection
3. Comm. Protocol Security
4. Risk Mgmt. Enhancement
5. High Speed Encryption

Infrastructure Security Initiative (ISI)

Response to 9/11 Tragedies

1. Strategic Spare Parts Inventory
2. Vulnerability Assessments
3. Red Teaming
4. Secure Communications

Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)

1. Self Healing Grid
2. IntelliGrid™
3. Integrated Electric Communications System Architecture
4. Fast Simulation and Modeling

Background: EPRI/DOD Complex Interactive Network/Systems Initiative (1998-2002)

Complex interactive networks:

- **Energy infrastructure:** Electric power grids, water, oil and gas pipelines
- **Telecommunications:** Information, communications and satellite networks; sensor and measurement systems and other continuous information flow systems
- **Transportation and distribution networks**
- **Energy markets, banking and finance**

Develop tools that enable secure, robust and reliable operation of interdependent infrastructures with distributed intelligence and self-healing abilities

Background: Sensing, modeling, simulation and control of complex systems in multi-hazard environments

EPRI: Jan. 1998 – February 2003

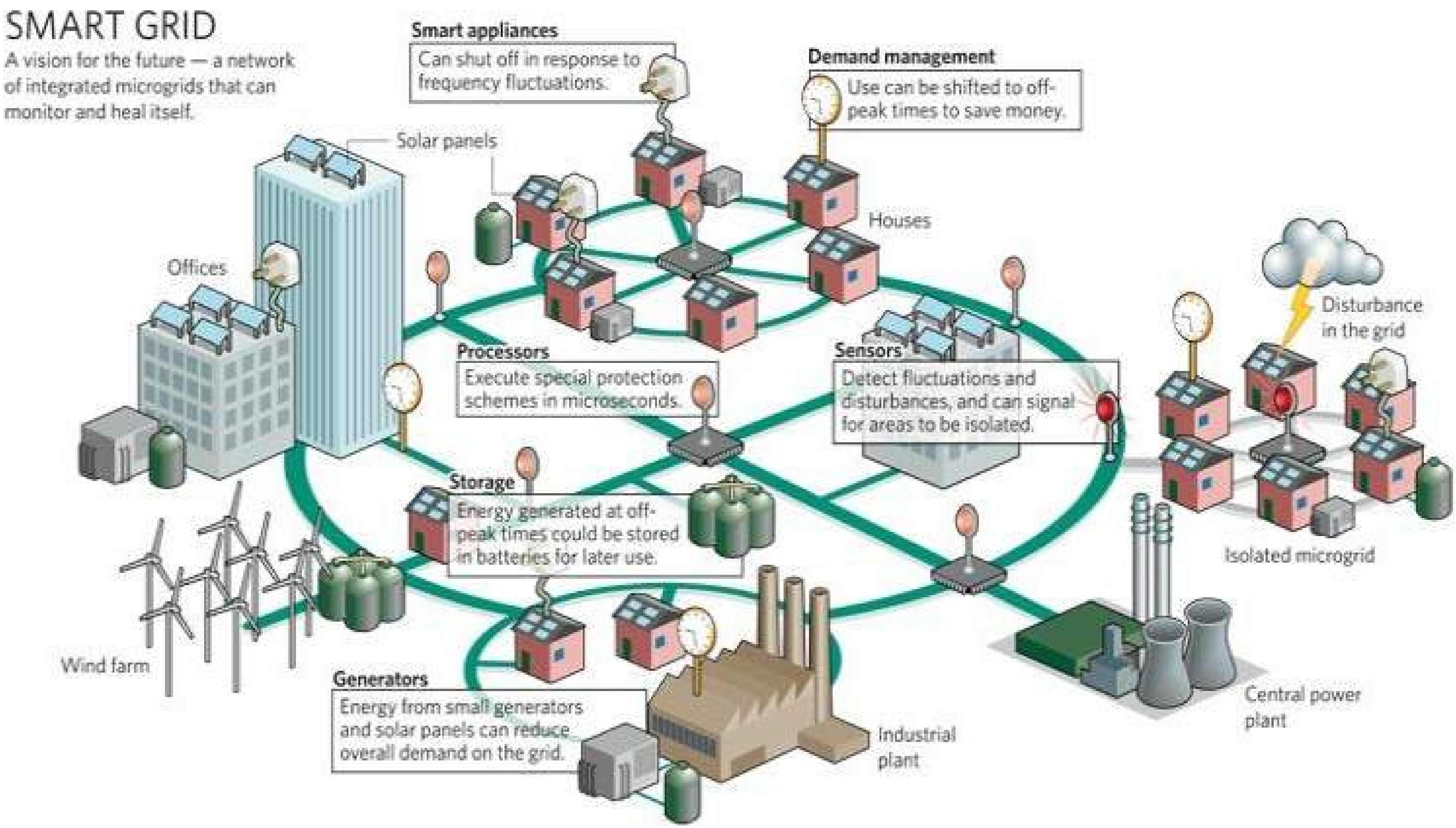
- EPRI/DoD Complex Interactive Networks Initiative: To address secure operations & management of our national critical infrastructures (1998-2001)
  - Initiated and led systems-based R&D toward the smart self-healing electric power grid and the development of more than 24 advanced technologies to enhance the security of our national critical infrastructures.
  - Led strategic research in modeling, simulation, optimization, and adaptive control of national infrastructures for energy, telecommunication, transportation, and finance.
- Directed R&D in Infrastructure Security, Grid Operations and Planning, Risk and Policy Assessment and Energy Markets (Oct 2001-Feb 2003)

UM: March 2003 – present

- Global Transition Dynamics to enhance resilience, security and efficiency of complex dynamic systems. These systems include national critical infrastructures for interdependent energy, computer networks, communications, transportation and economic systems.

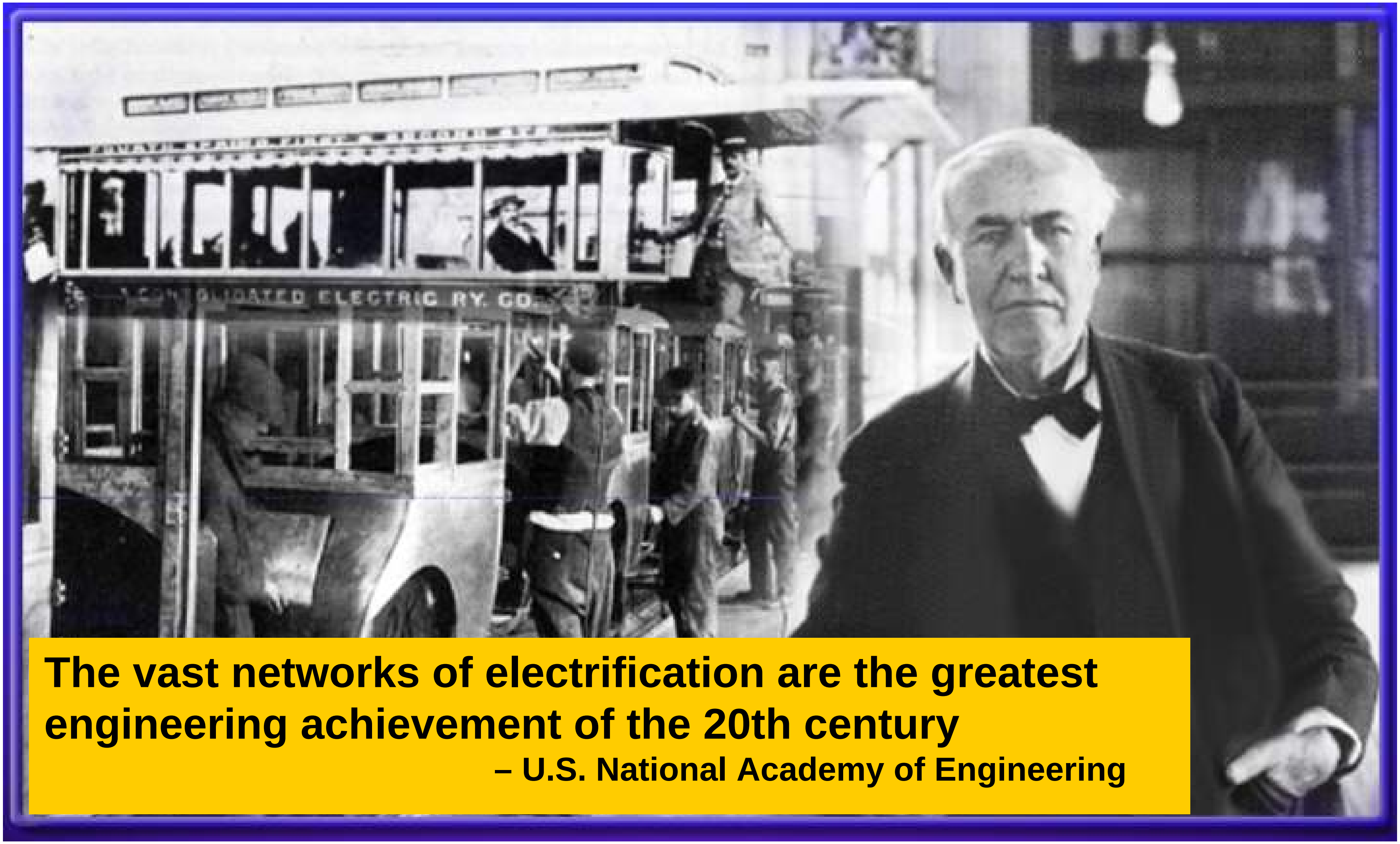
- Technology scanning, mapping, and valuation to identify new science and technology-based opportunities that meet the needs and aspirations of today's consumers, companies and the broader society. This thrust builds coherence between short- and longer-term R&D opportunities and their potential impact.

Our Goal: Enabling the Future



Source: Interview with Massoud Amin, "Upgrading the grid," *Nature*, vol. 454, pp. 570–573, 30 July 2008

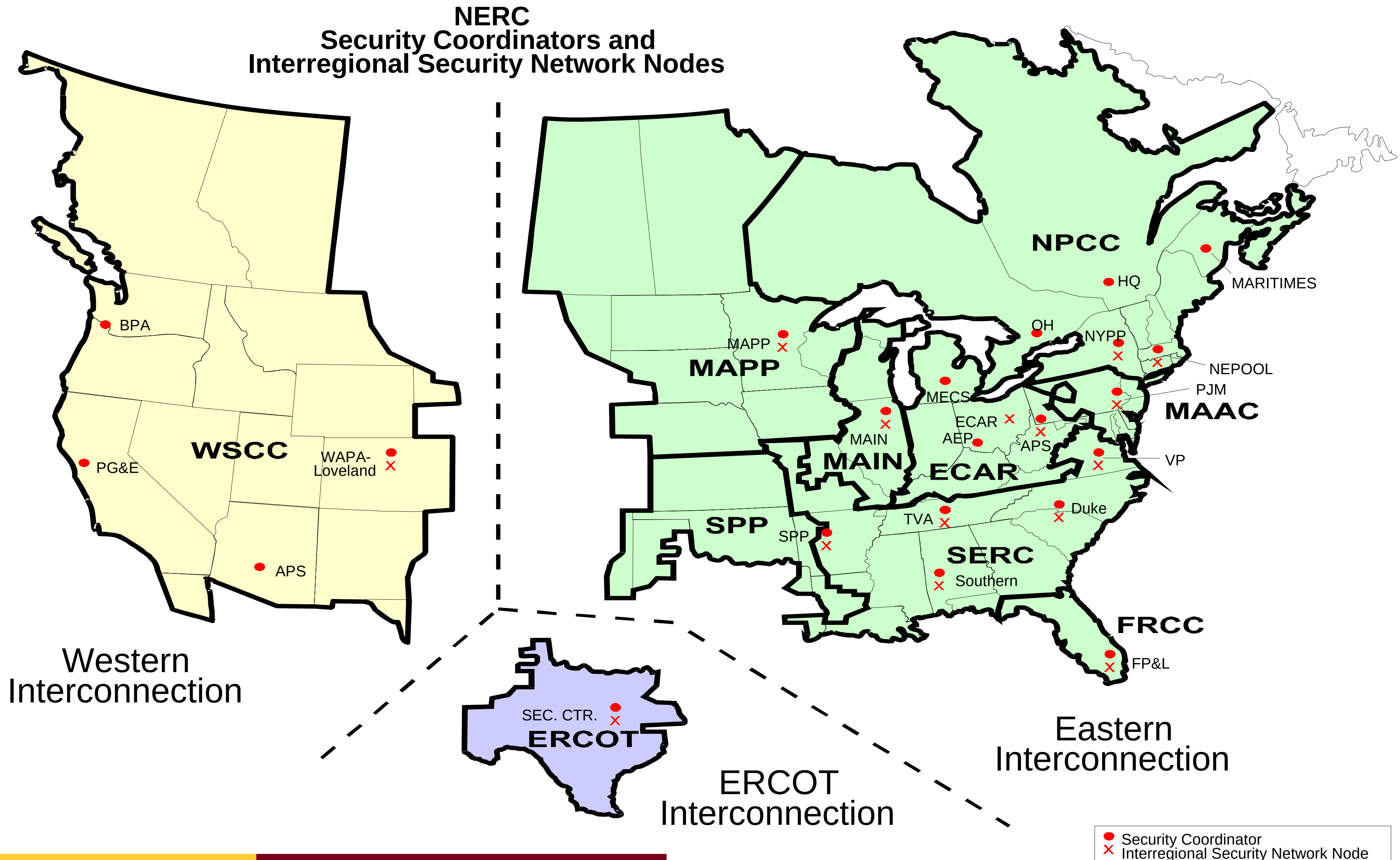
Context: Transforming Society



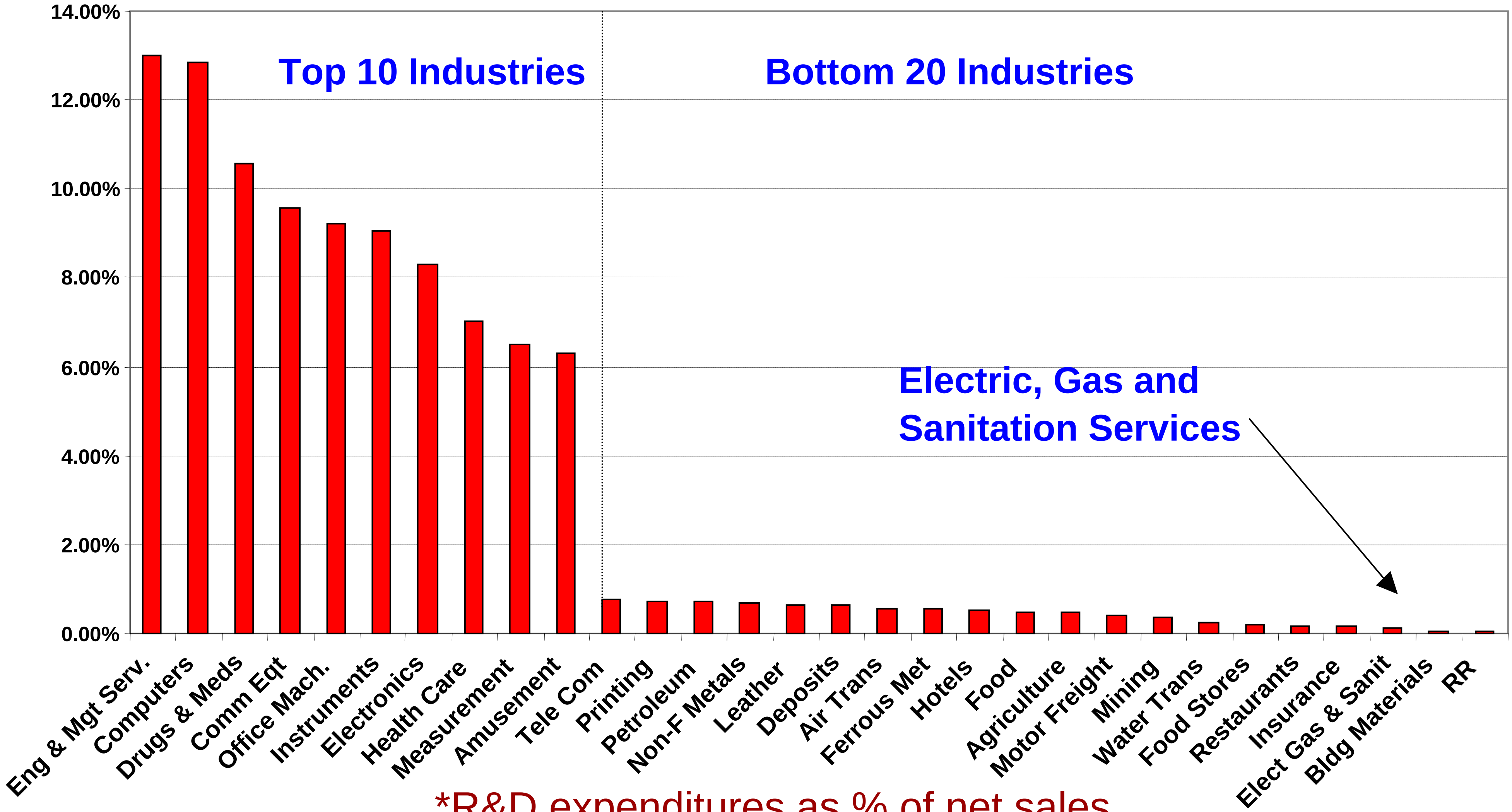
The vast networks of electrification are the greatest engineering achievement of the 20th century
– U.S. National Academy of Engineering

Electricity Supply Chain

North American Interconnections



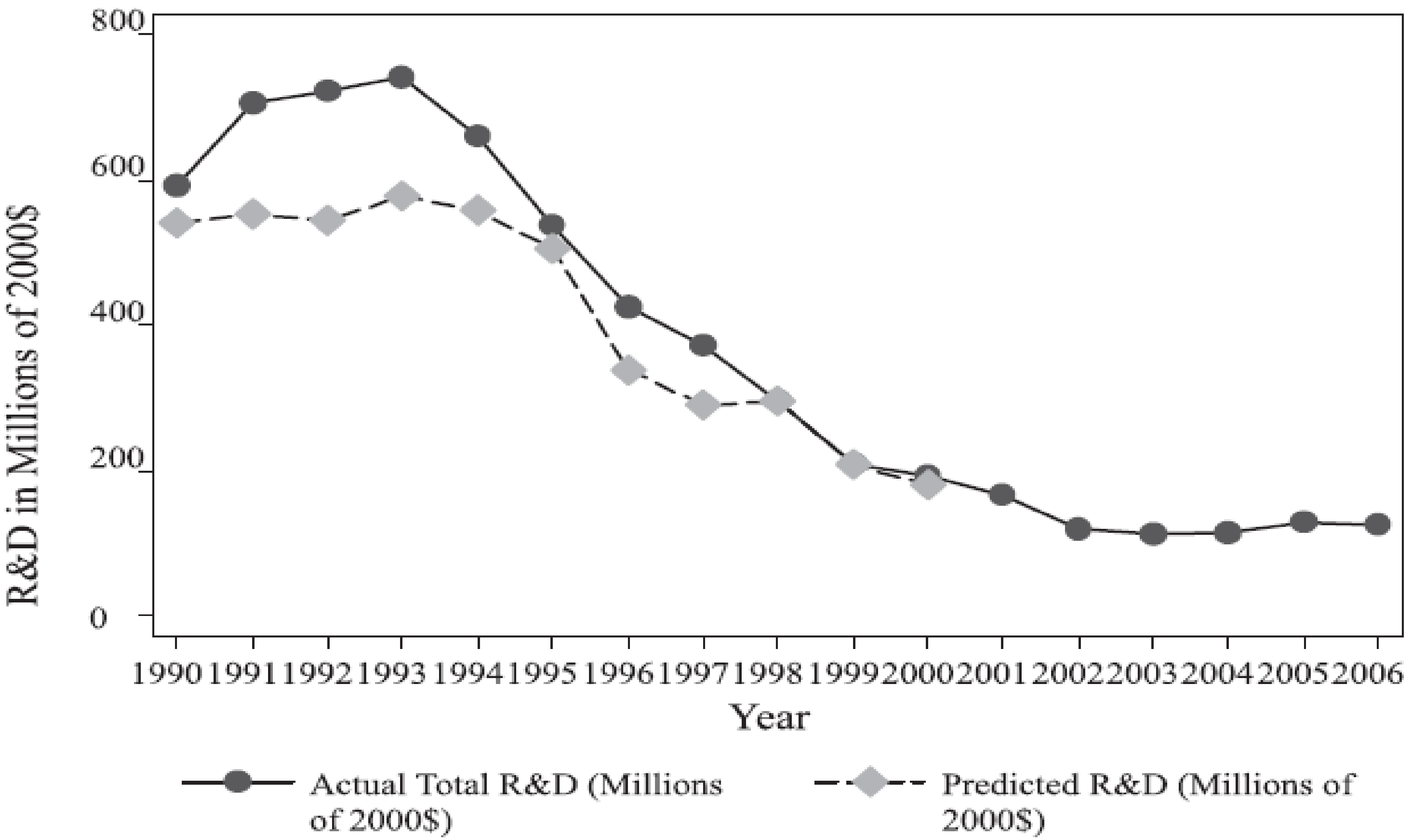
Context: R&D Expenditures*



*R&D expenditures as % of net sales

U.S. Electric Utilities R&D: 1990-2006

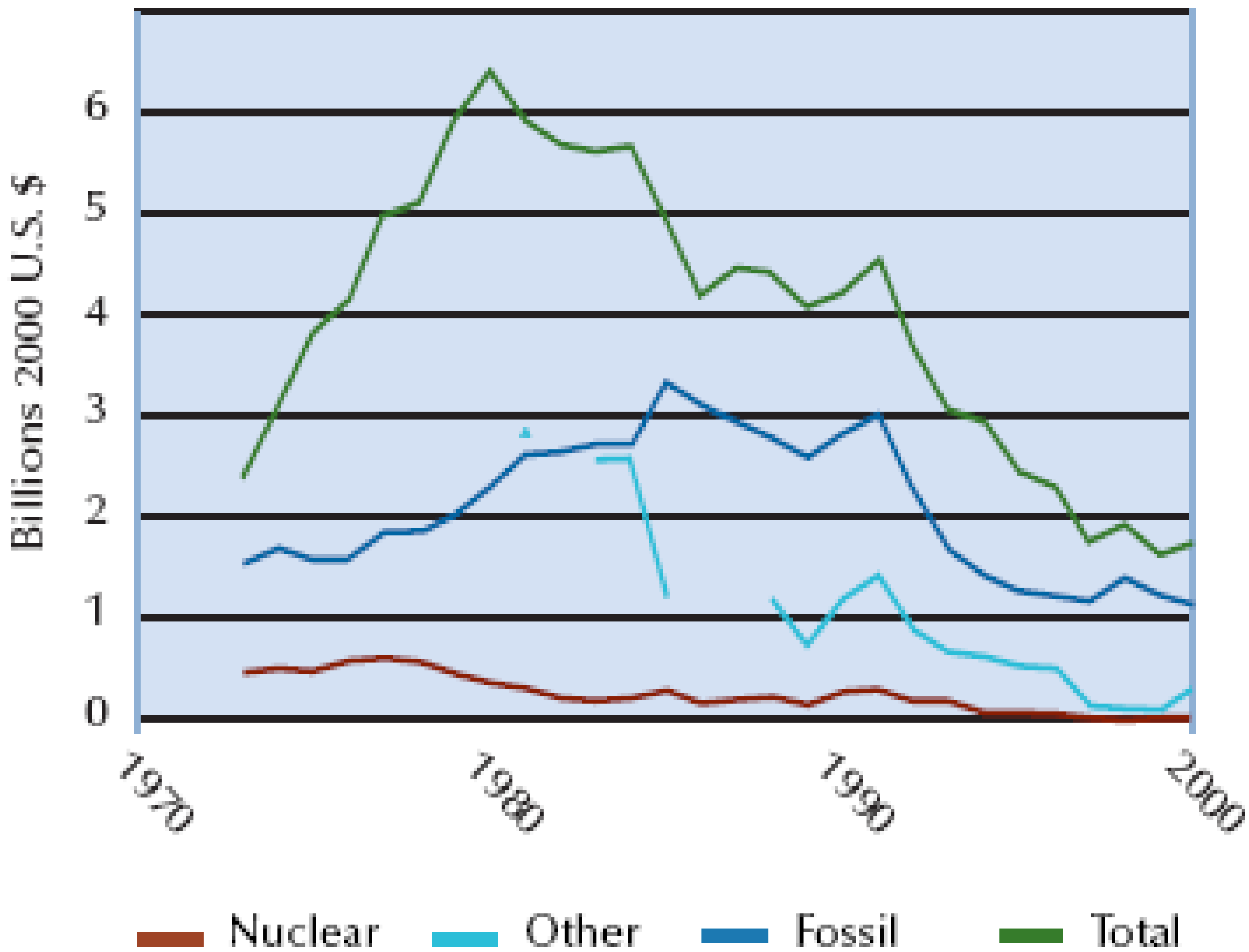
Annual R&D in the lowest rates of any major industrial sector with the exception of the pulp and paper



Source: "Powering Progress: Restructuring, Competition, and R&D in the U.S. Electric Utility Industry," by *Paroma Sanyal and Linda Cohen, The Energy Journal*, Vol. 30, No. 2, 2009

Private Sector Energy RD&D

An analysis of less complete private-sector data indicates a drop by about a factor of three in the private sector funding for the indicated purposes during the same period.

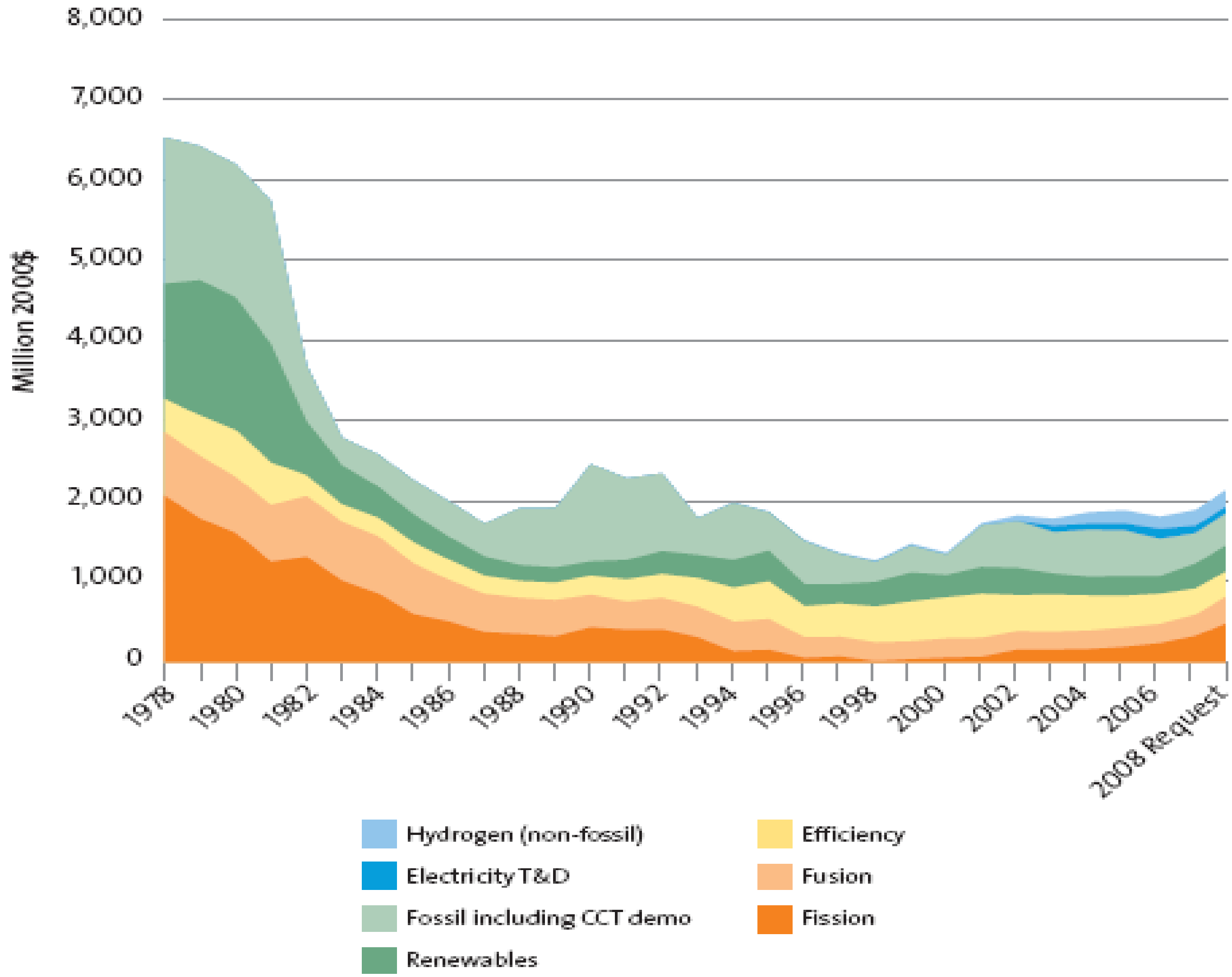


Dooley and Runci, 2004

U.S. DOE ENERGY RD&D: Real Spending FY 1978–FY2008

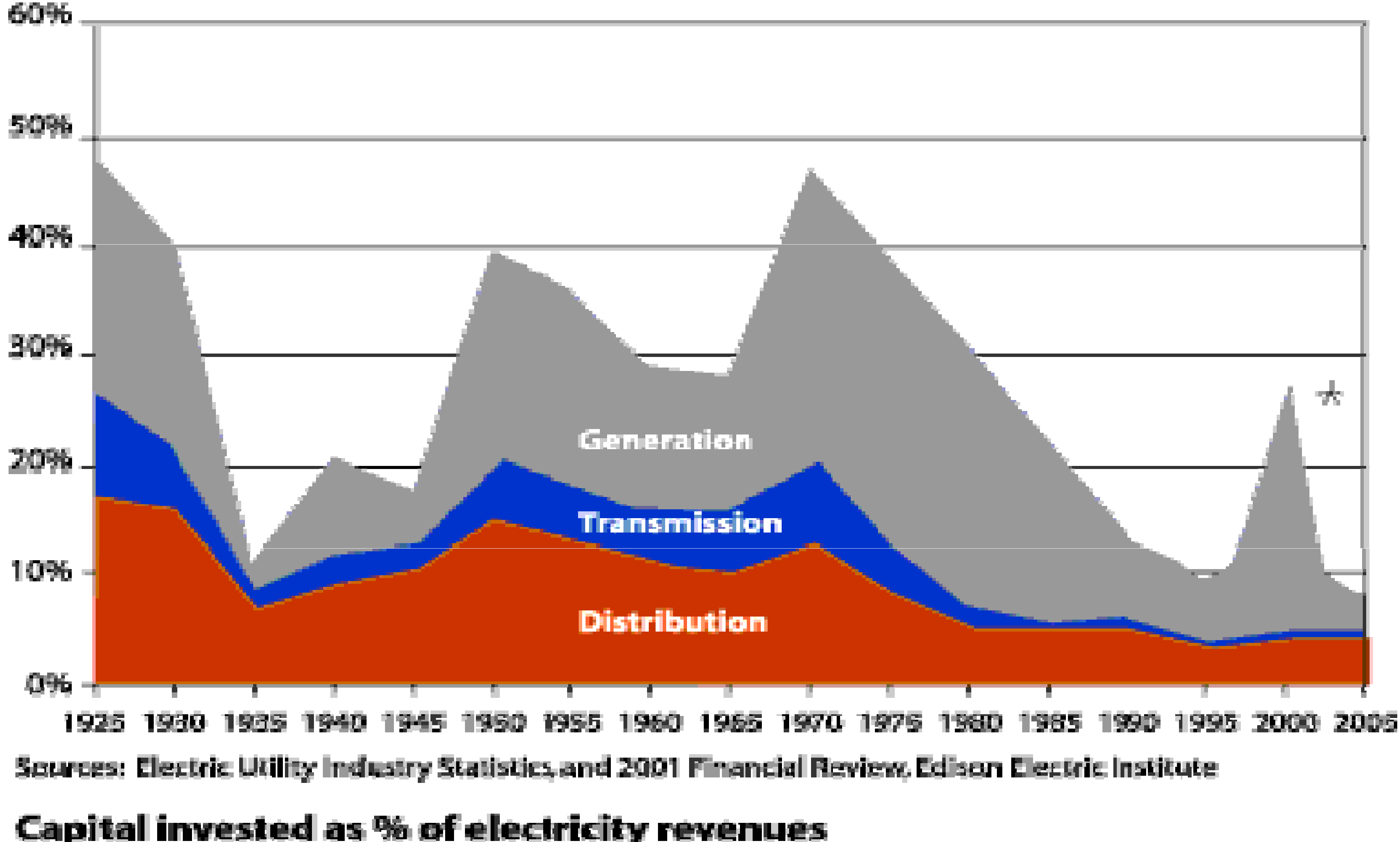
•Analyses of DOE data shows that over the 25 years from FY 1978 to FY 2004, US government appropriations for ERD&D fell from 6.4B to $2.75B in constant year-2000 dollars, a nearly 60% reduction.

•The part of these appropriations devoted to applied energy-technology RD&D fell from $6.08 B to $1.80B.



Source: Gallagher, K.S., A. Sagar,D. Segal, P. de Sa, and J.P. Holdren. 2007. DOE Budget Authority for Energy Research, Development and Demonstration Database. Energy Technology Innovation Project. John F. Kennedy School of Government, Harvard University.

Capital Invested as % of electricity revenue



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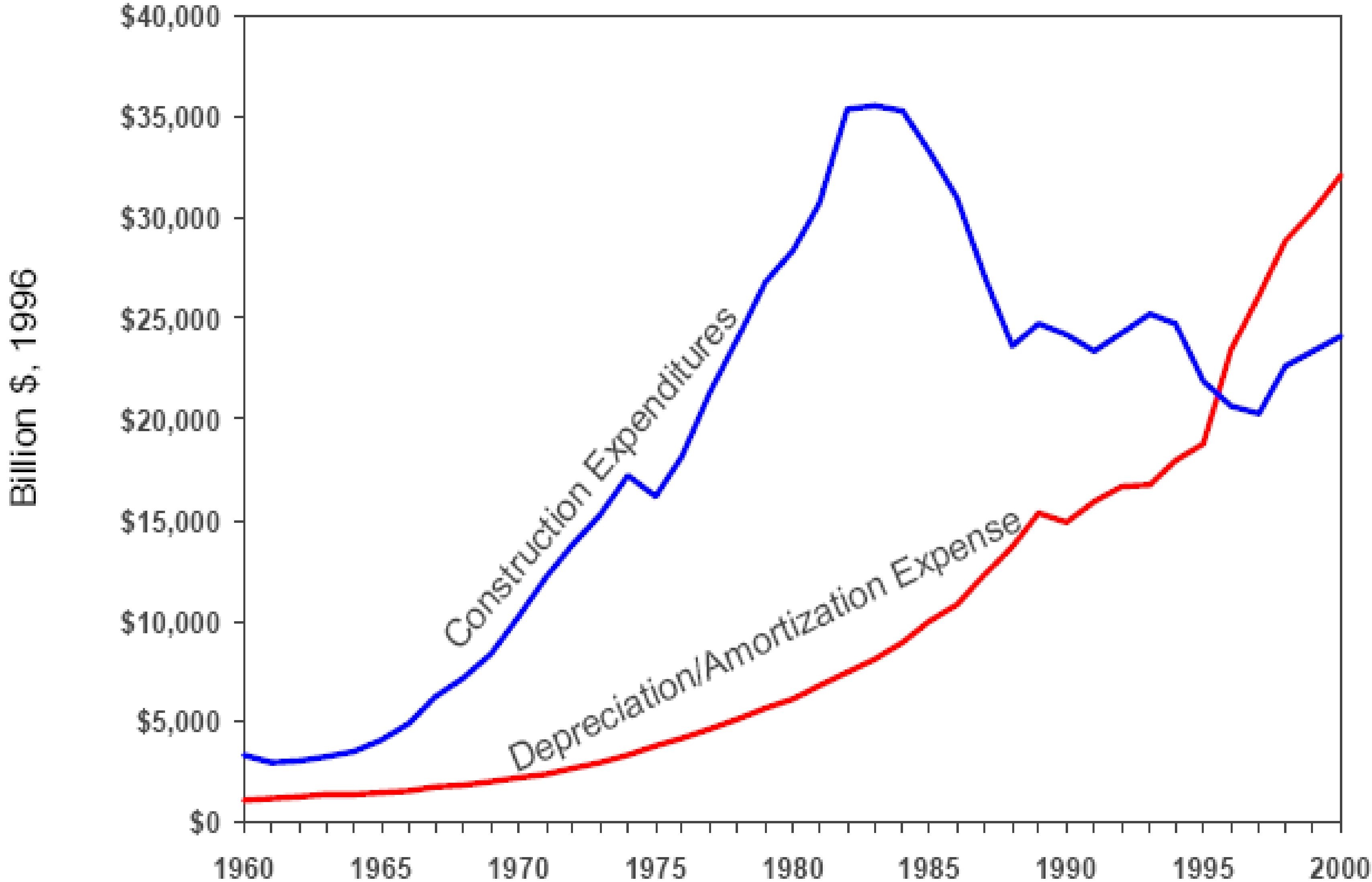
Utility construction expenditures



Source: "Historical Statistics of the Electric Utility Industry" and "EEI Statistical Yearbook" - EEI

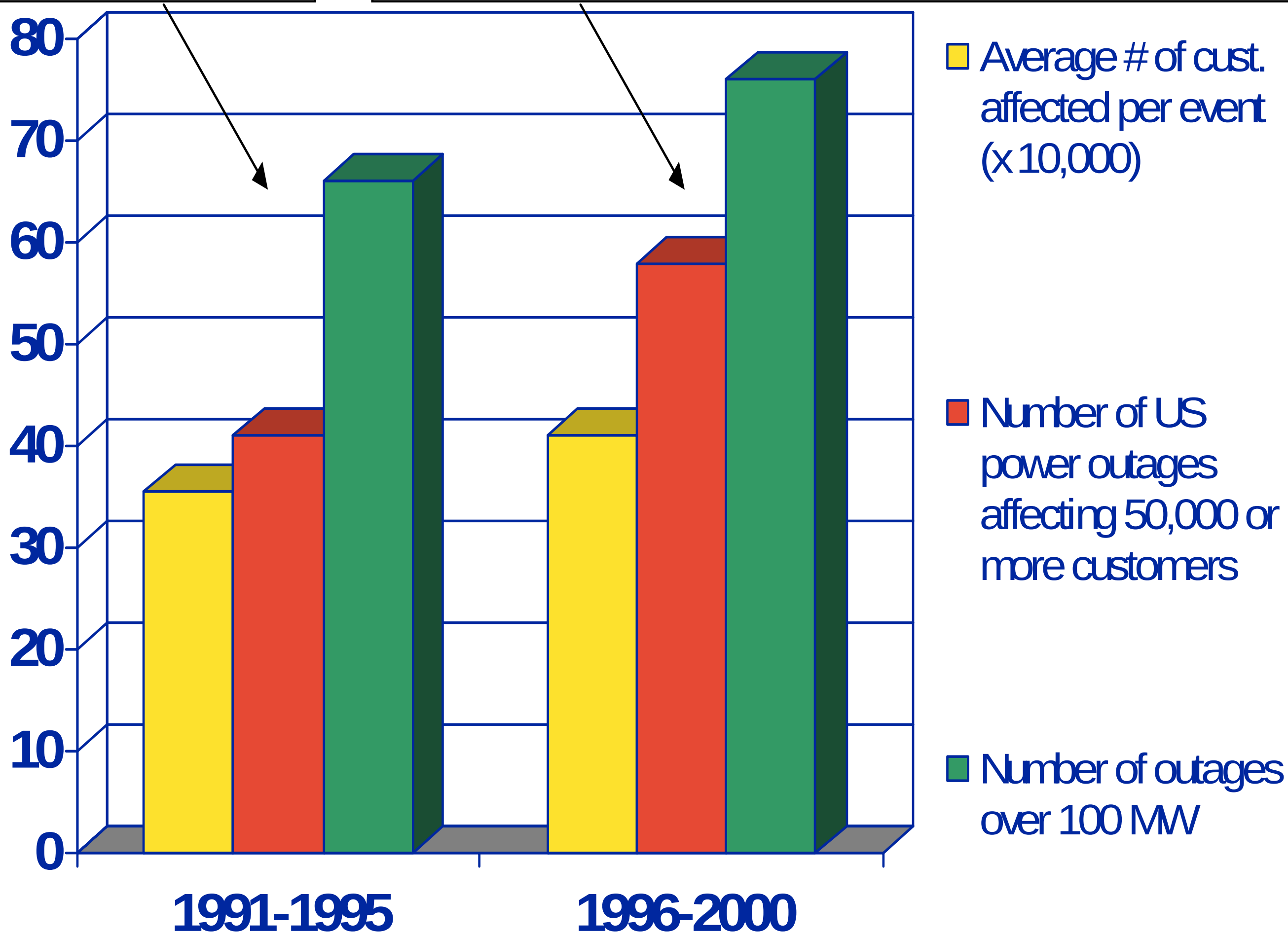
Historical Analysis of U.S. outages (1991-2000)

66 Occurrences over 100 MW
798 Average MW Lost
41 Occurrences over 50,000 Consumers
355,204* Average Consumers Dropped

76 Occurrences over 100 MW
1,067 Average MW Lost
58 Occurrences over 50,000 Consumers
409,854* Average Consumers Dropped

Increasing frequency and size of US power outages 100 MW or more (1991-1995 versus 1996-2000), affecting 50,000 or more consumers per event.

Data courtesy of NERC's Disturbance Analysis Working Group database



*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

Historical Analysis of U.S. outages (1991-2005)

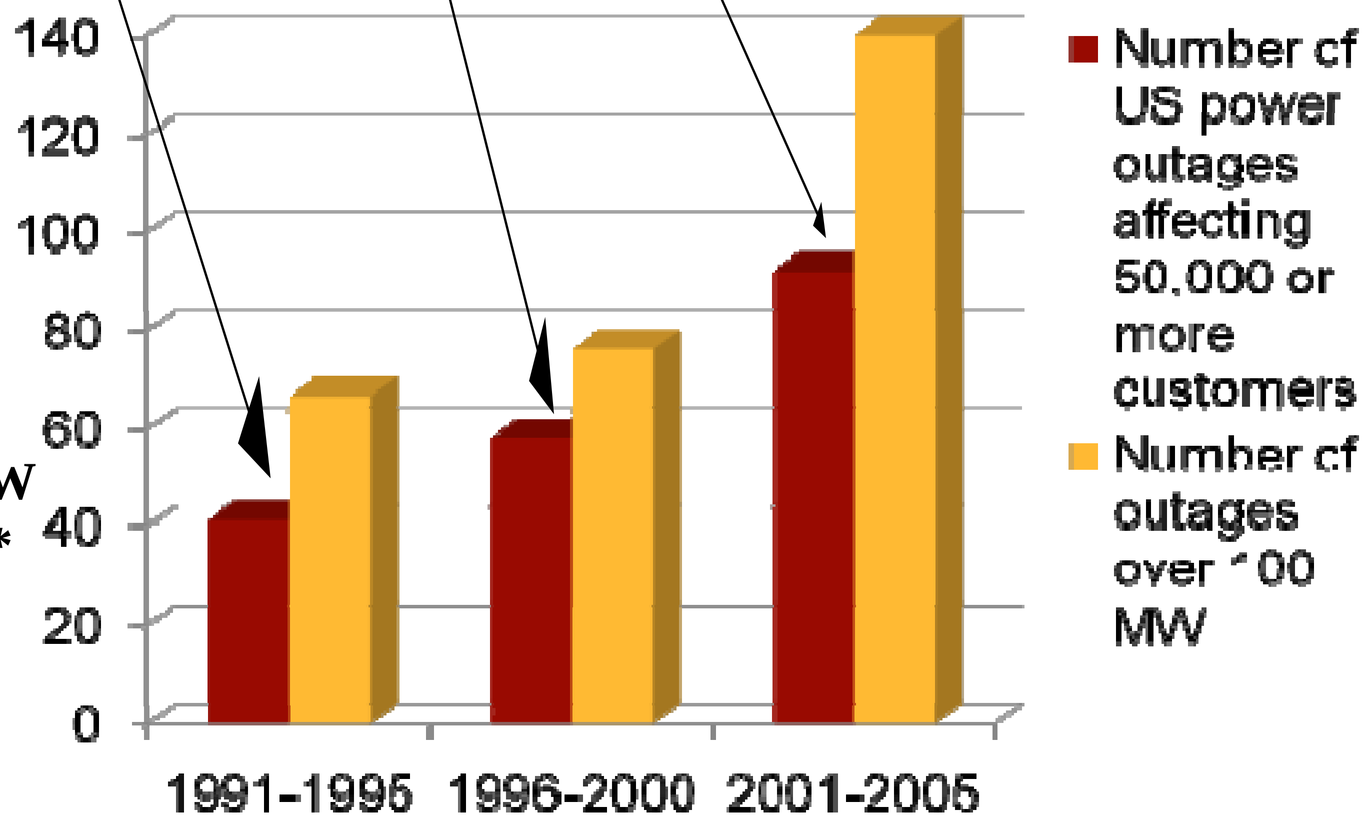
66 Occurrences over 100 MW
41 Occurrences over 50,000* Consumers

76 Occurrences over 100 MW
58 Occurrences over 50,000* Consumers

140 Occurrences over 100 MW
92 Occurrences over 50,000* Consumers

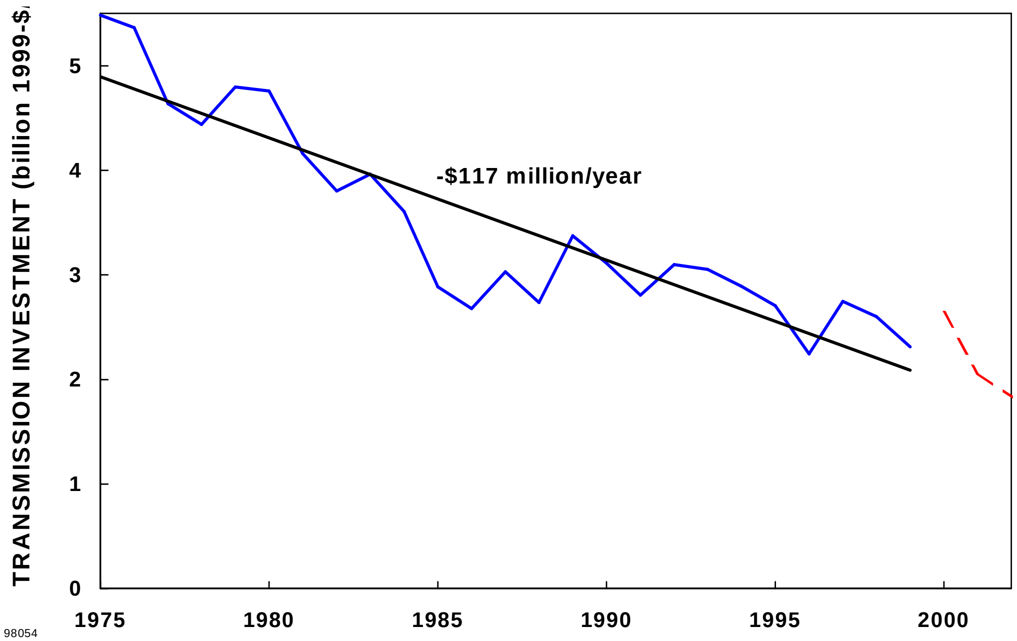
Result: Large blackouts are growing in number and severity.

***Analyzing 2006 outages:**
24 Occurrences over 100 MW
34 Occurrences over 50,000* or more Consumers
Data courtesy of NERC's Disturbance Analysis Working Group database

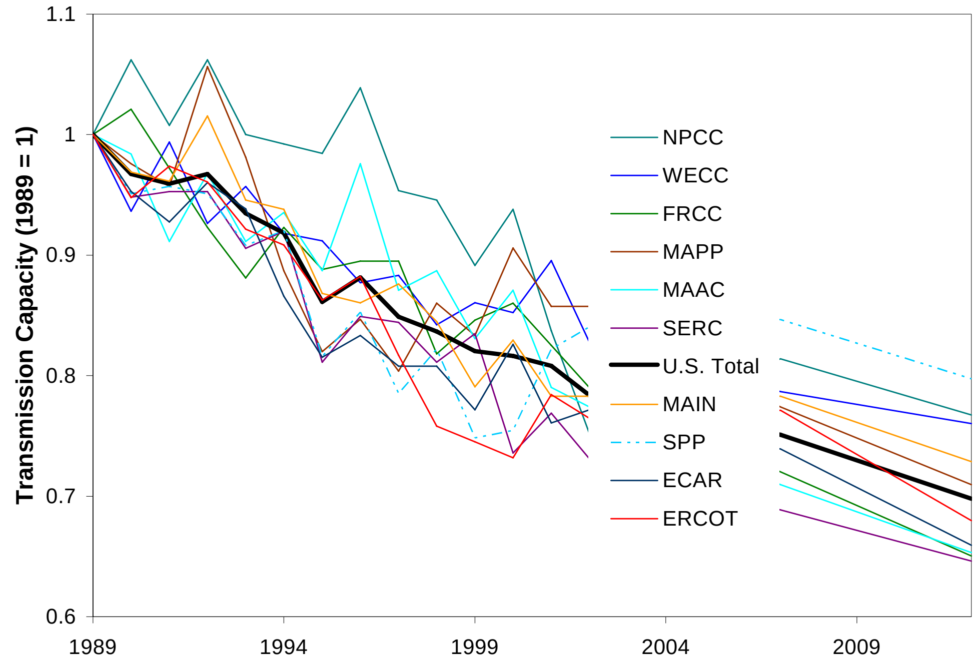


*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

Increasing Outage Events: Transmission Investment



Transmission *investment* ($) since 1975



Transmission *capacity margin* in every NERC region since 1982

Transmission investment lags load growth and will remain very difficult in the future due to environmental, political, and cost issues.

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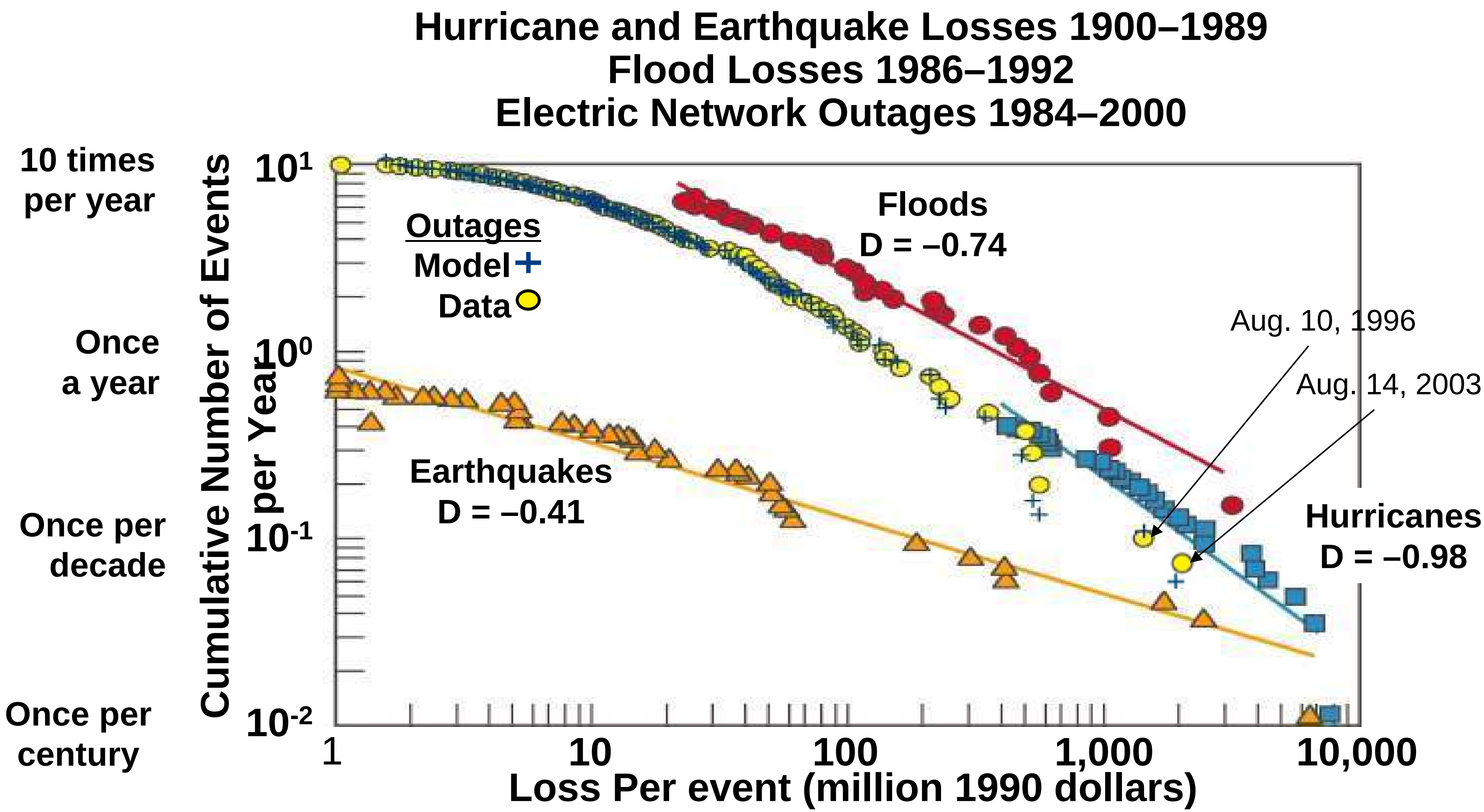
Context: Transmission investment in the United States and in international competitive markets

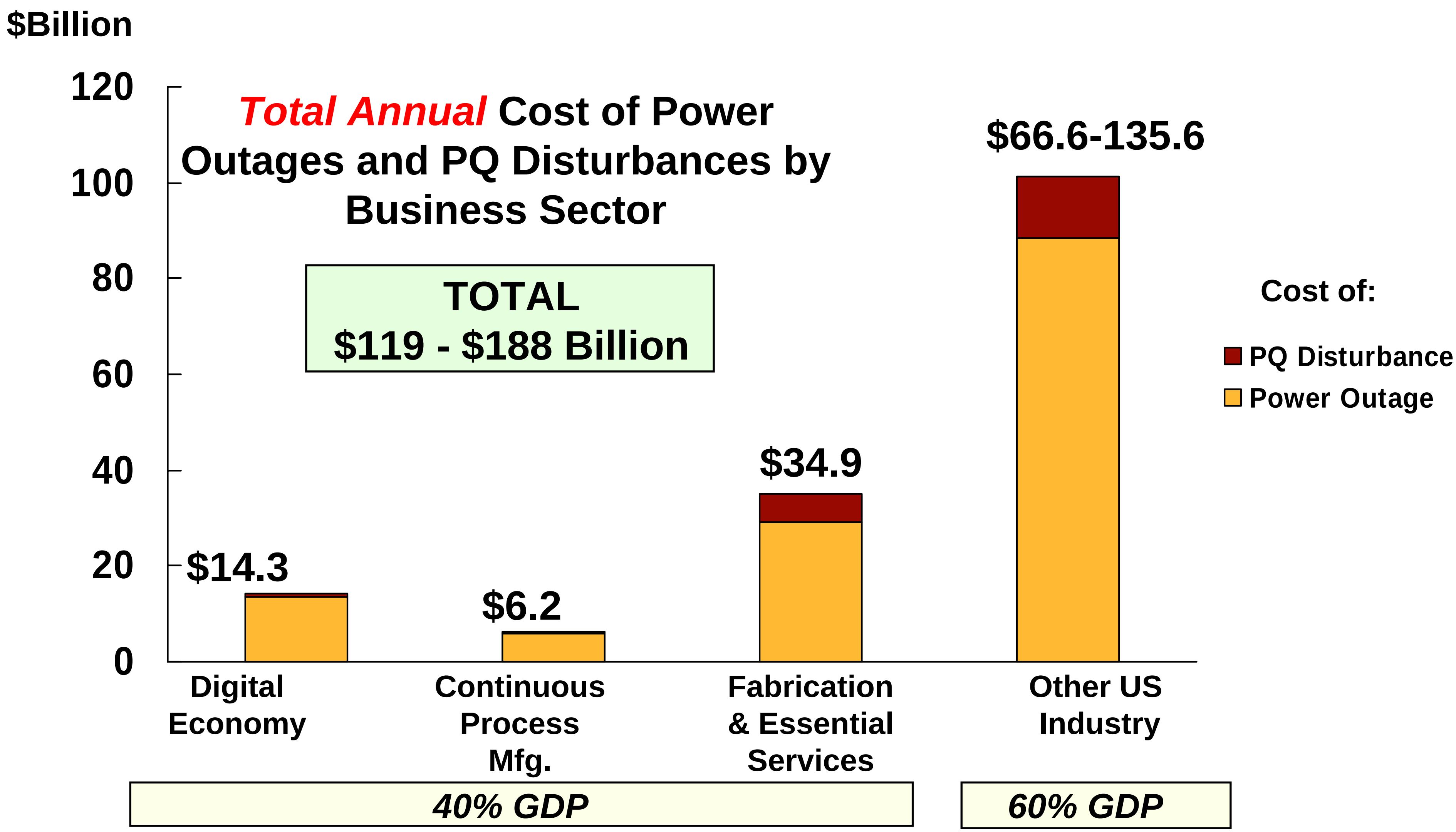
Country	Investment in High Voltage Transmission (>230 kV) Normalized by Load for 2004–2008 (in US$M/GW/year)	Number of Transmission-Owning Entities
New Zealand	22.0	1
England & Wales (NGT)	16.5	1
Denmark	12.5	2
Spain	12.3	1
The Netherlands	12.0	1
Norway	9.2	1
Poland	8.6	1
Finland	7.2	1
United States	4.6 (based on representative data from EEI)	450 (69 in EEI)

Source: IEEE PES, 2006

Power Law Distributions: Frequency & impacts of major disasters



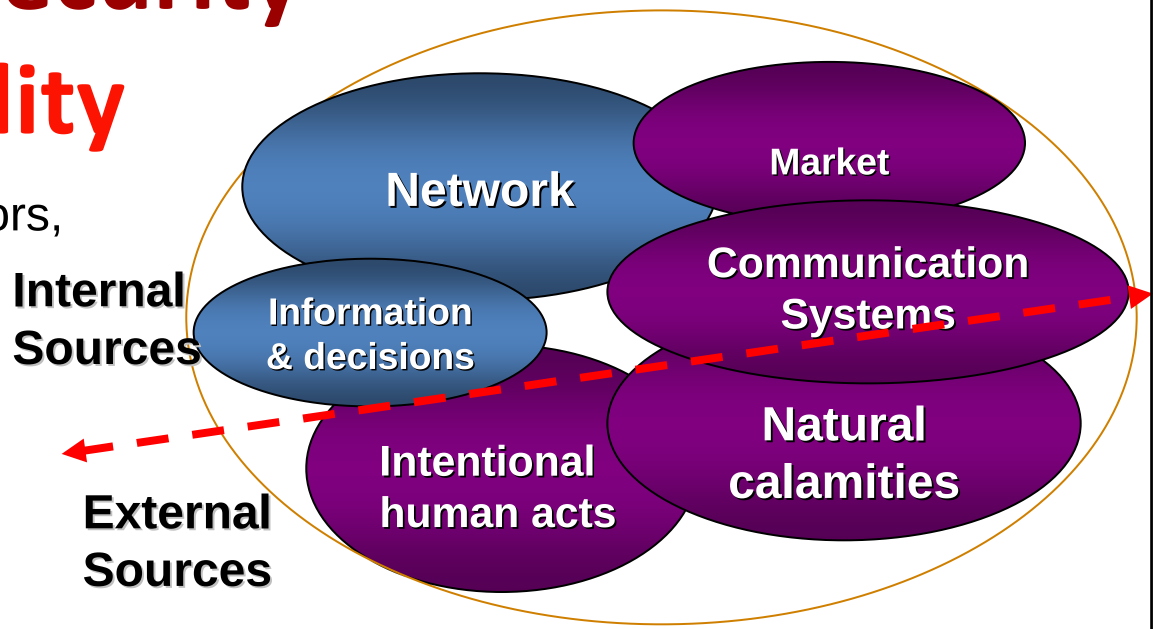
A Toll Felt Throughout the U.S. Economy: Over $100B per year



Source: Primen Study: The Cost of Power Disturbances to Industrial & Digital Economy Companies

Context: Threats to Security

Sources of Vulnerability



- Transformer, line reactors, series capacitors, transmission lines...
- Protection of ALL the widely diverse and dispersed assets is impractical

-- 202,835 miles of HV lines (230 kV and above

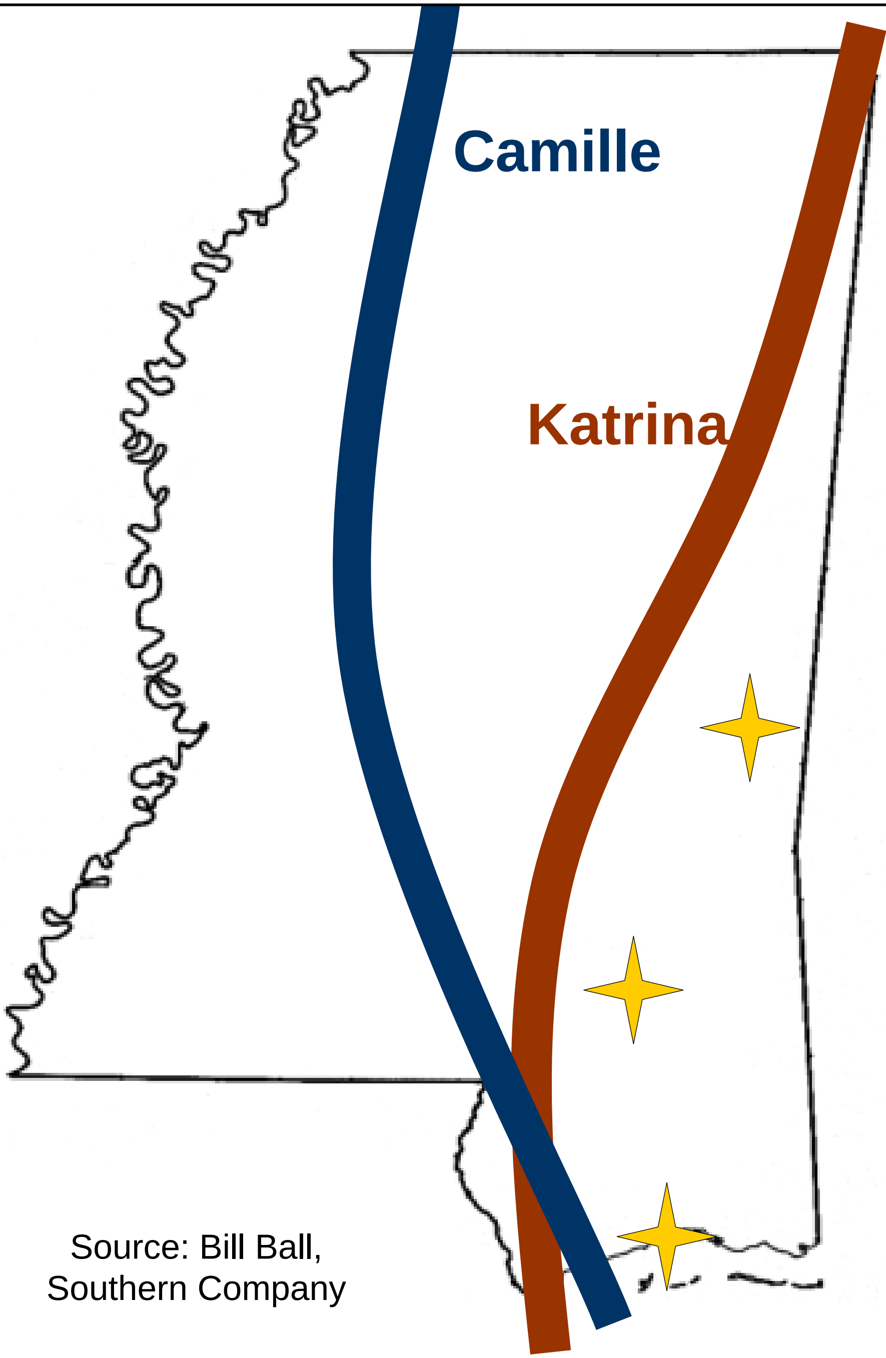
-- 6,644 transformers in Eastern Intercon.

- Control Centers
- Interdependence: Gas pipelines, compressor stations, etc.; Dams; Rail lines; Telecom – monitoring & control of system
- Combinations of the above and more using a variety of weapons:
- Truck bombs; Small airplanes; Gun shots – line insulators, transformers; more sophisticated modes of attack…

- Hijacking of control
- Biological contamination (real or threat)
- Over-reaction to isolated incidents
- Internet Attacks
- Over 80,000 hits/day at an ISO
- Storms, Earthquakes, Forest fires & grass land fires… Loss of major equipment – especially transformers…

"… for want of a horseshoe nail … "

Peak Wind Speed Comparison (MPH)



Source: Bill Ball, Southern Company

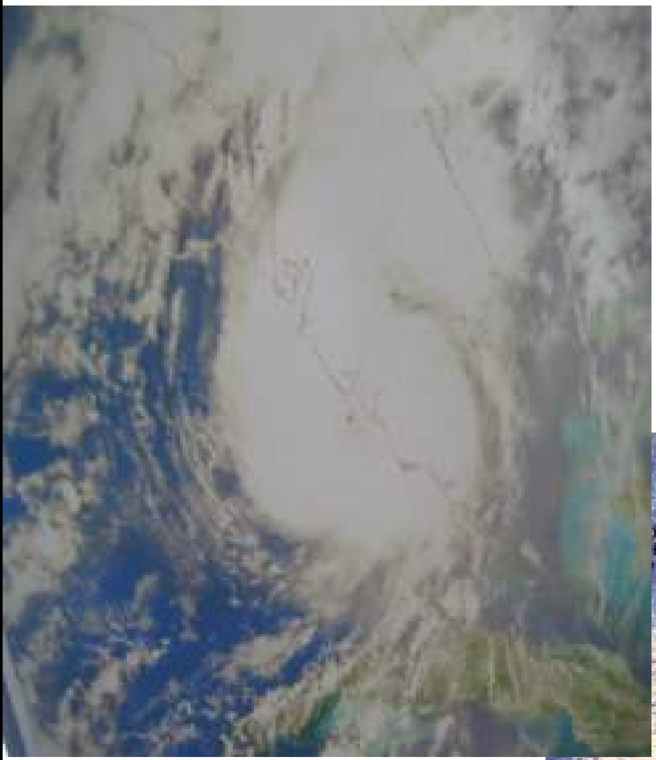
	Katrina 08.29.05	Camille 08.17.69
Meridian	90	55
Hattiesburg	110	
Gulfport	140	190

	CAMILLE	IVAN	KATRINA
Landfall Date	08.17.69	09.16.04	08.29.05
Landfall	Waveland/BSL, MS	Eastern Mobile Bay	MS/LA State Line
Category at Landfall	Category 5	Category 3	Category 4
Wind Speed/Gusts	190 / 220 mph	115 / 135 mph	140 / 180 mph
Tidal Surge (Maximum)	20-28'	10-15'	35-40'
Hurricane Winds (Size of Storm)	60 miles	35-40 miles	125 miles
Forward Motion	NNW at 15 MPH Sustaining at Landfall	NNE at 12 MPH Weakening at Landfall	NNE at 15 MPH Strengthening & Expanding at Landfall
System Outages	104,000*	1.7 million	971,000
System Companies Most Affected	MPC - 77% Loss	Gulf - 90% Loss APC - 65% Loss	MPC - 100% Loss APC - 49% Loss
Others Impacted	APC	MPC, GPC	APC, Gulf, GPC
Service Restoration	15 days	2 weeks	2 weeks

Hurricane Charley

- Duration Aug. 9 - 14, 2004
- Highest winds 150 mph (240 km/h) sustained
- Areas affected Jamaica, Cayman Islands, Cuba, Florida, South Carolina
- Damages $15-17 billion
- Fatalities 15 direct, 20 indirect

Hurricane Charley– August 13, 2004



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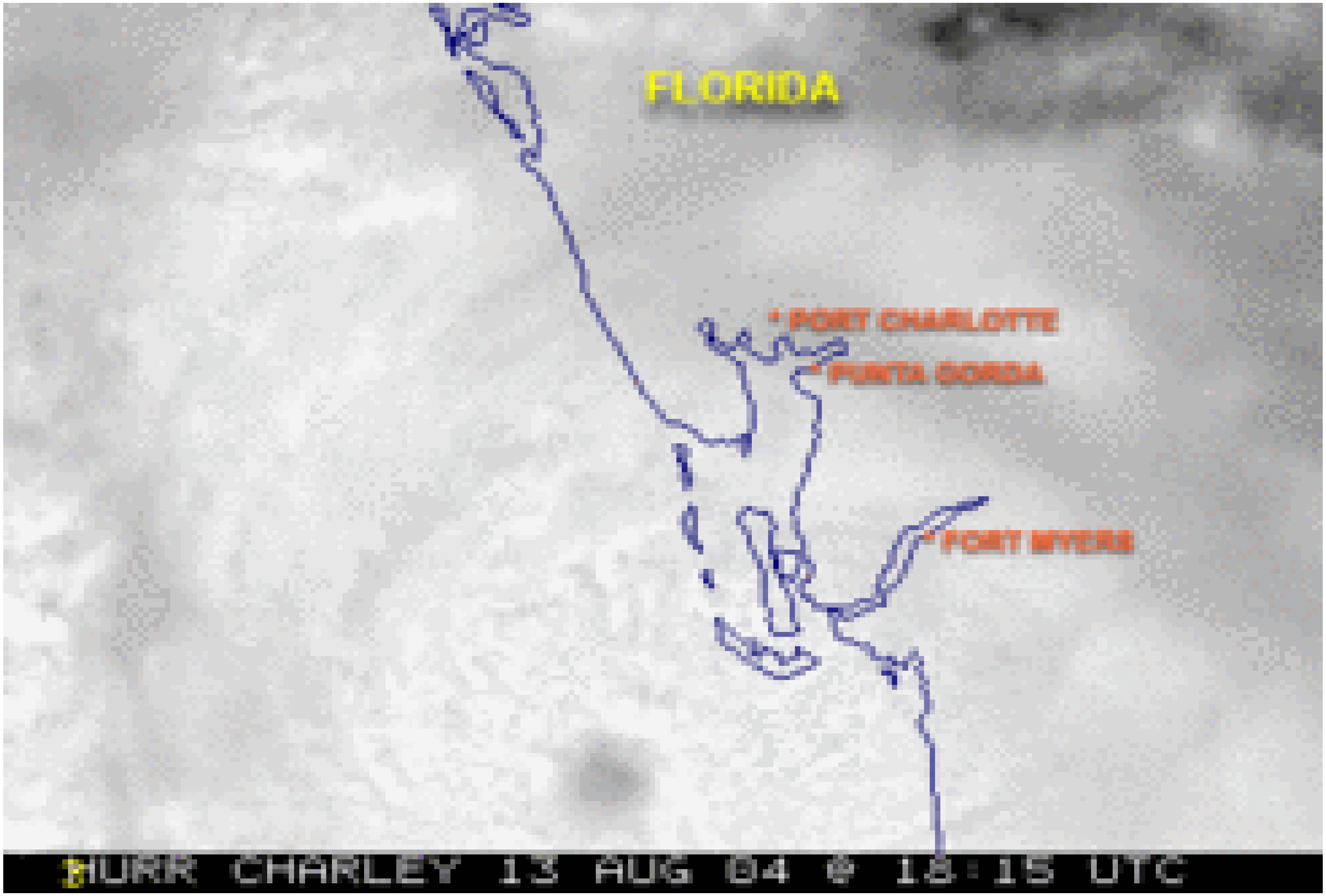
Hurricane Charley (…went over our home in Bokeelia, Fl in Pine Island with winds >145 m/hr gusting to over 150 mi/hr)




PIKE

Example: Threats to the Transmission Grid

September 2002 fires

Biscuit Fire - Cascade Fire (Oregon)

Iron Mountain fire

Hickok fire - 776 acres

Freeway Fire - no threat to SCE facilities

Curve Fire: San Gabriel Canyon Road. 30-Miles N/O Azusa, 10,000 acres

Curb Fire: 19,500 acres

Leona Fire: Midway-Vincent area

Whitmore fire: Kilarc-Deschultes 60kV lost

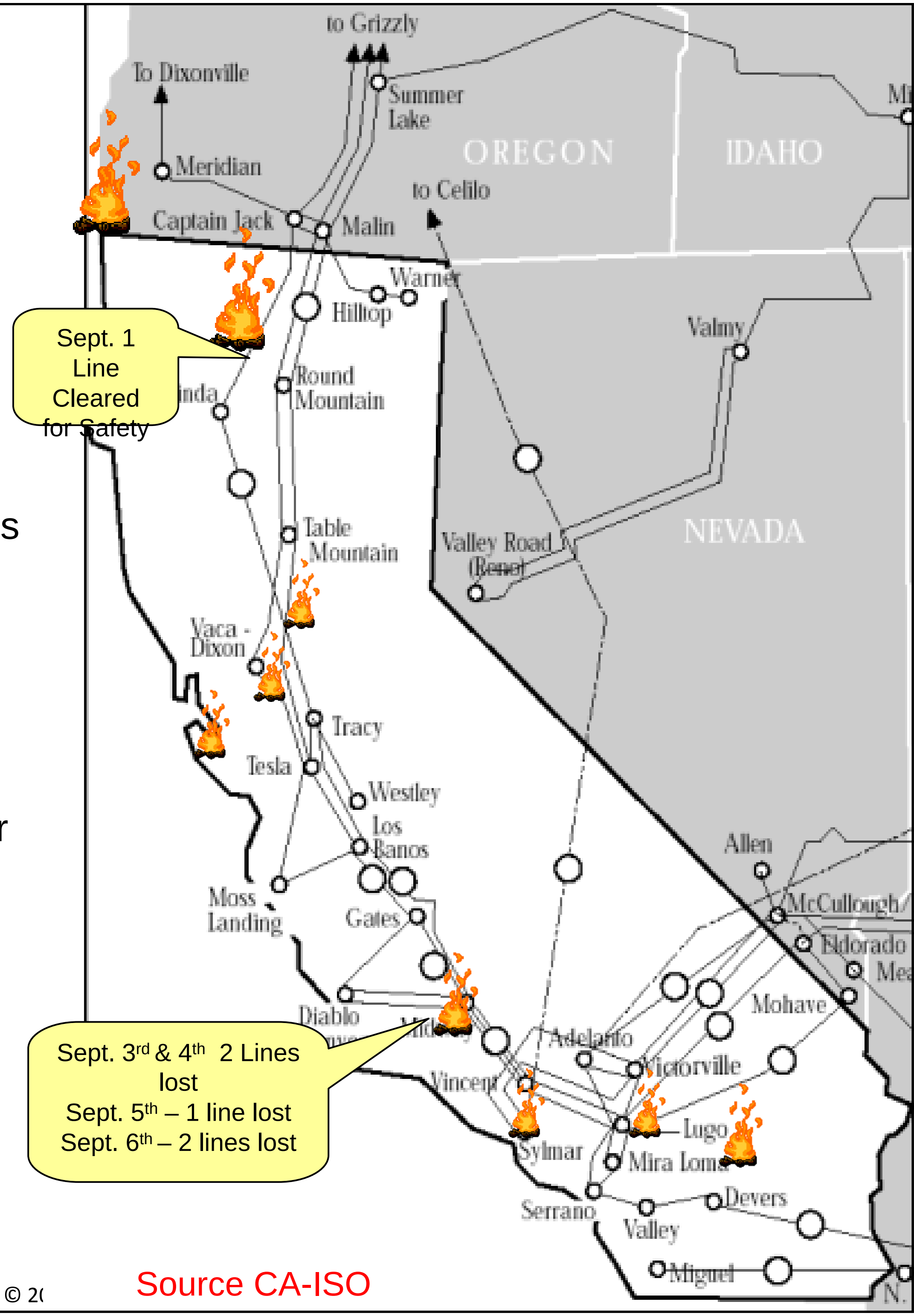
Glendale - Eagle Rock fire: Near Gould-Sylmar 220kV line

Olita Fire: El Dorado County –Gold Hill SS

Mountain Fire: Rutledge - Hardie area

Croy Fire: Morgan Hill area -Metcalf-Green Valley 115kV line impacted

Williams Fire: 35,000 acres



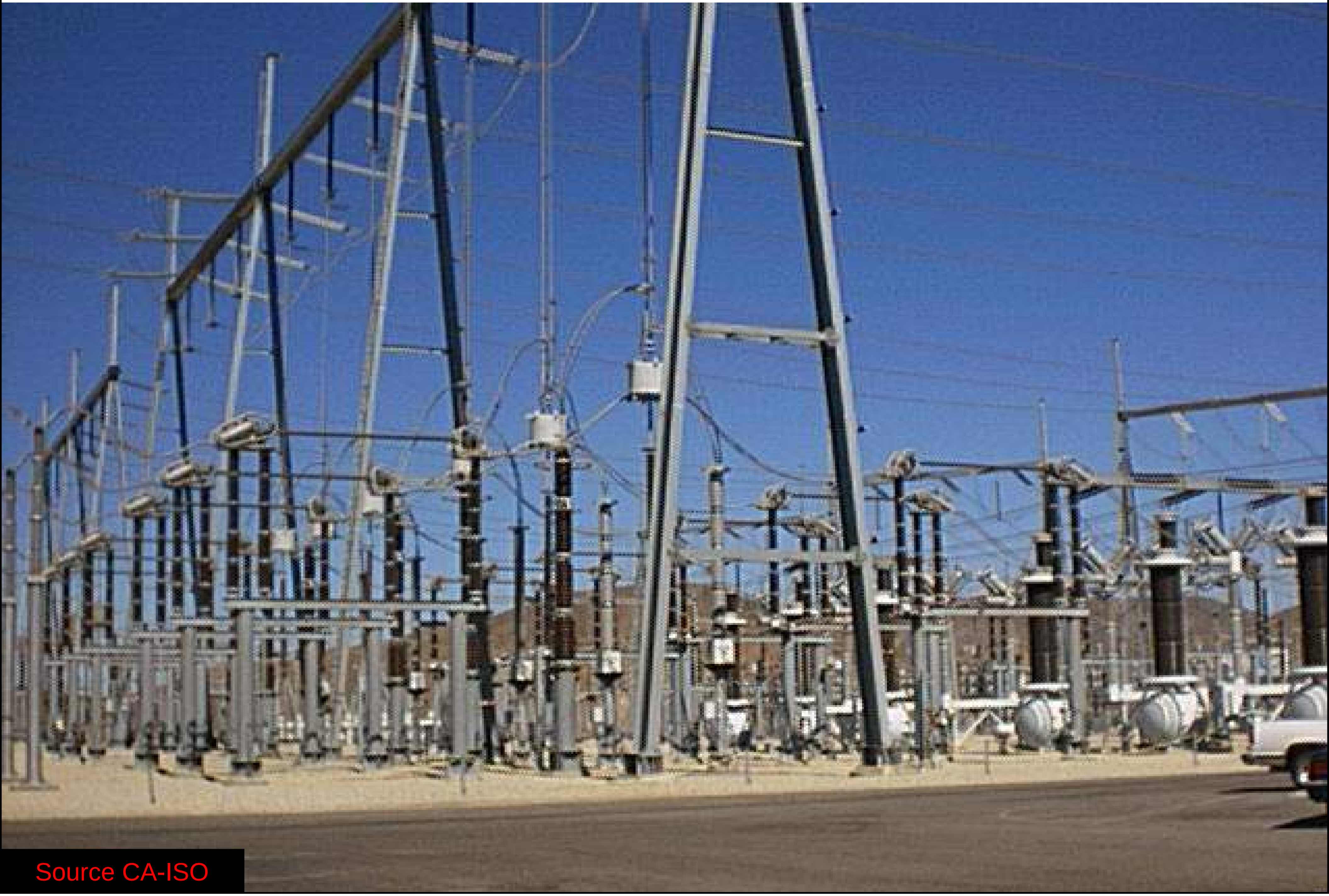
Source CA-ISO

Example Fire under the 500 kV Lines – Sept 2002 **:**

Example: Midway – Vincent 500 kV line tower damage

Midway – Vincent 500 kV line damage

Vincent Substation before Transformer Explosion & Fire



Source CA-ISO

500 / 230 kV Transformer Explosion & Fire, March 21, 2003, Vincent Substation

Lessons learned, e.g.: Redundancy Lowers Impact of Threats

- Two Separate Control Rooms – 500 miles apart
- Dual EMS systems at each location + Training/testing EMS
- Diversified communications networks

The Infrastructure Challenge

Will today's electricity supply system be left behind as an industrial relic of the 20th century, or become the critical infrastructure supporting the digital society, a smart self-healing grid?

What are we doing about it?

Overview of my research areas (1998-2003):

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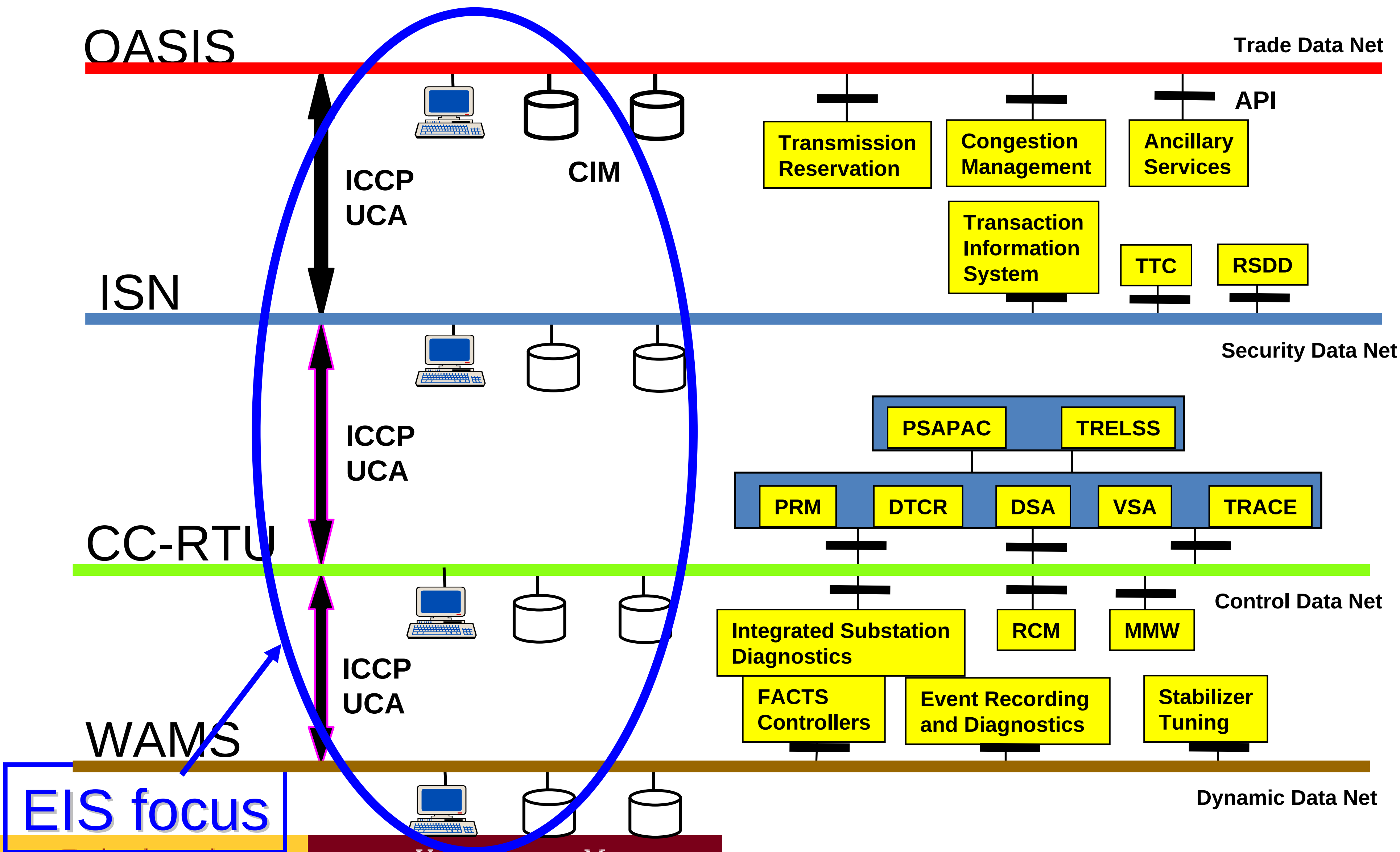
Information Networks for On-Line Trade, Security and Control



Context: IT interdependencies and impact

Dependence on IT: Today's systems require a tightly knit information and communications capability. Because of the vulnerability of Internet communications, protecting the system will require new technology to enhance security of power system command, control, and communications.

Increasing Complexity: System integration, increased complexity: call for new approaches to simplify the operation of complex infrastructure and make them more robust to attacks and interruptions.

Centralization and Decentralization of Control: The vulnerabilities of centralized control seem to demand smaller, local system configurations. Resilience rely upon the ability to bridge top--down and bottom-up decision making in real time.

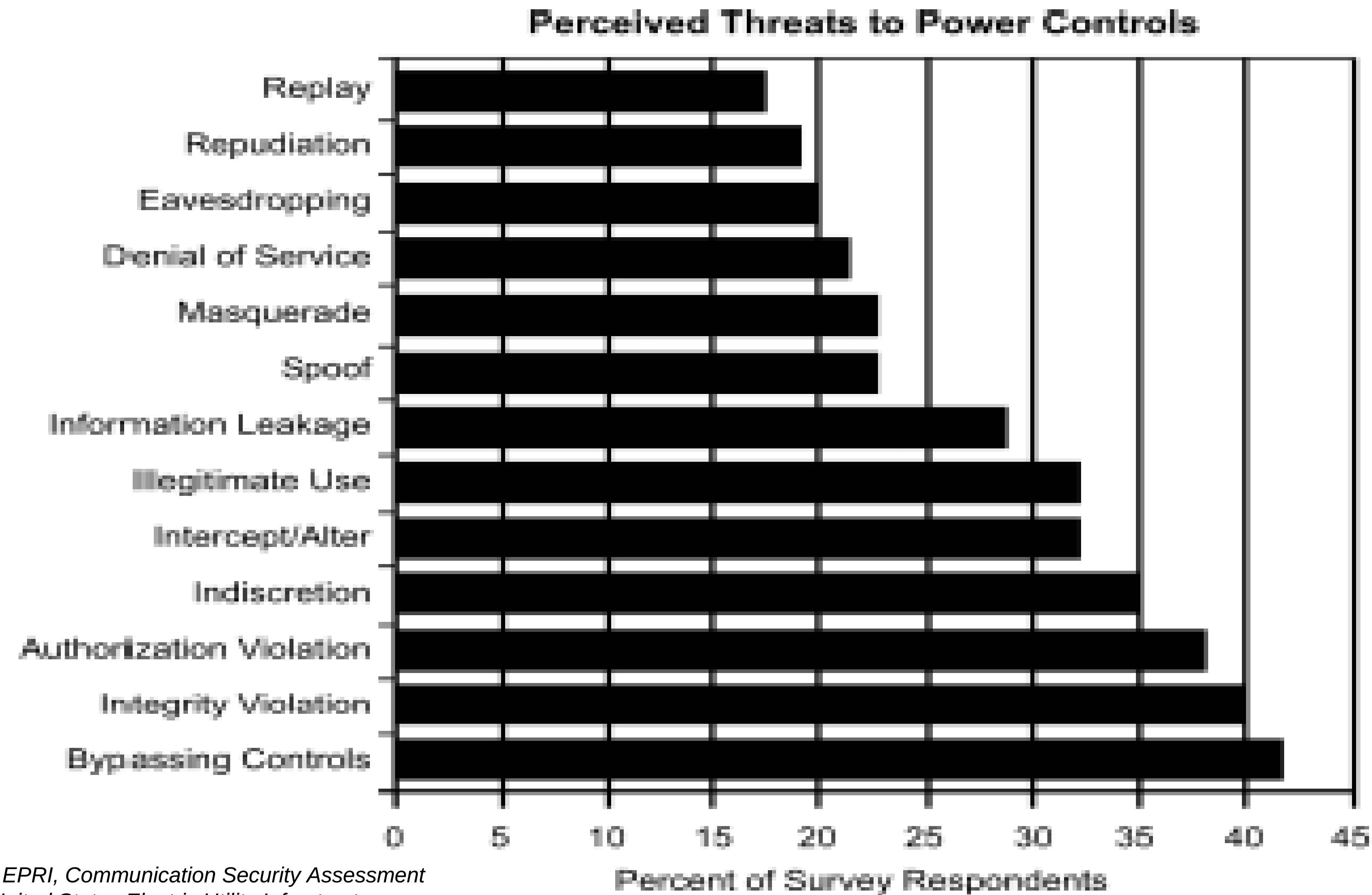
Assessing the Most Effective Security Investments: Probabilistic assessments can offer strategic guidance on where and how to deploy security resources to greatest advantage.

Electric Company Vulnerability Assessment

- Conducted by 4 National Labs and consultant
- Able to assemble detailed map of perimeter
- Demonstrated internal and end-to-end vulnerabilities
- Intrusion detection systems did not consistently detect intrusions
- X-Windows used in unsecured manner
- Unknown to IT, critical systems connected to internet
- Modem access obtained using simple passwords

Much of the above determined from over 1200 miles away.

Cyber Threats to Controls



Source: *EPRI, Communication Security Assessment for the United States Electric Utility Infrastructure,* EPRI, Palo Alto, CA: 2000. 1001174.

Prioritization: Security Index

General

1. Corporate culture (adherence to procedures, visible promotion of better security, management security knowledge)
2. Security program (up-to-date, complete, managed, and includes vulnerability and risk assessments)
3. Employees (compliance with policies and procedures, background checks, training)
4. Emergency and threat-response capability (organized, trained, manned, drilled)

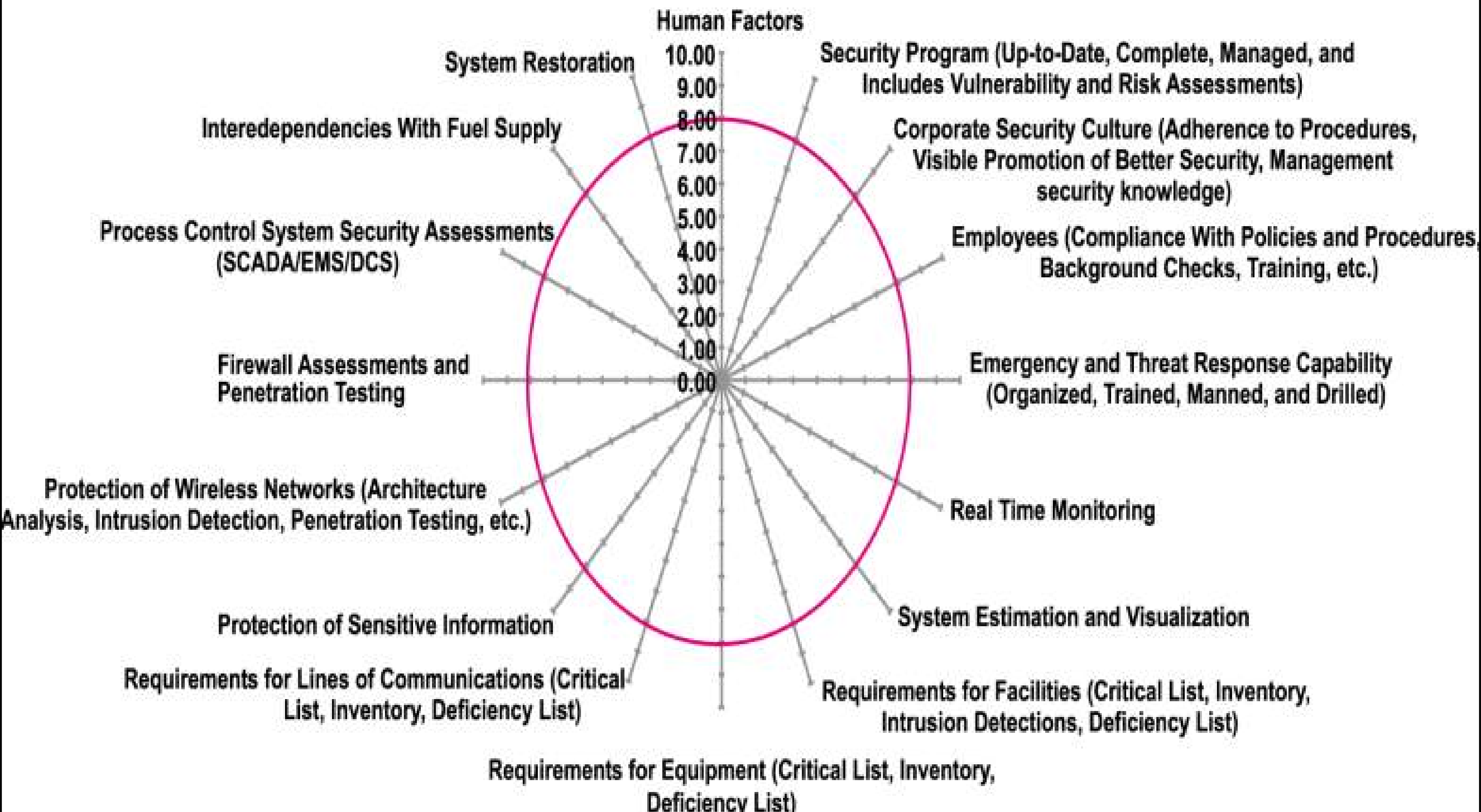
Physical

1. Requirements for facilities (critical list, inventory, intrusion detections, deficiency list)
2. Requirements for equipment (critical list, inventory, deficiency list)
3. Requirements for lines of communications (critical list, inventory, deficiency list)
4. Protection of sensitive information

Cyber and IT

1. Protection of wired networks (architecture analysis, intrusion detection)
2. Protection of wireless networks (architecture analysis, intrusion detection, penetration testing)
3. Firewall assessments
4. Process control system security assessments (SCADA, EMS, DCS)

Assessment & Prioritization: A Composite Spider Diagram to Display Security Indices



Recent Directions: EPRI/DOD Complex Interactive Network/Systems Initiative (1998-2002)

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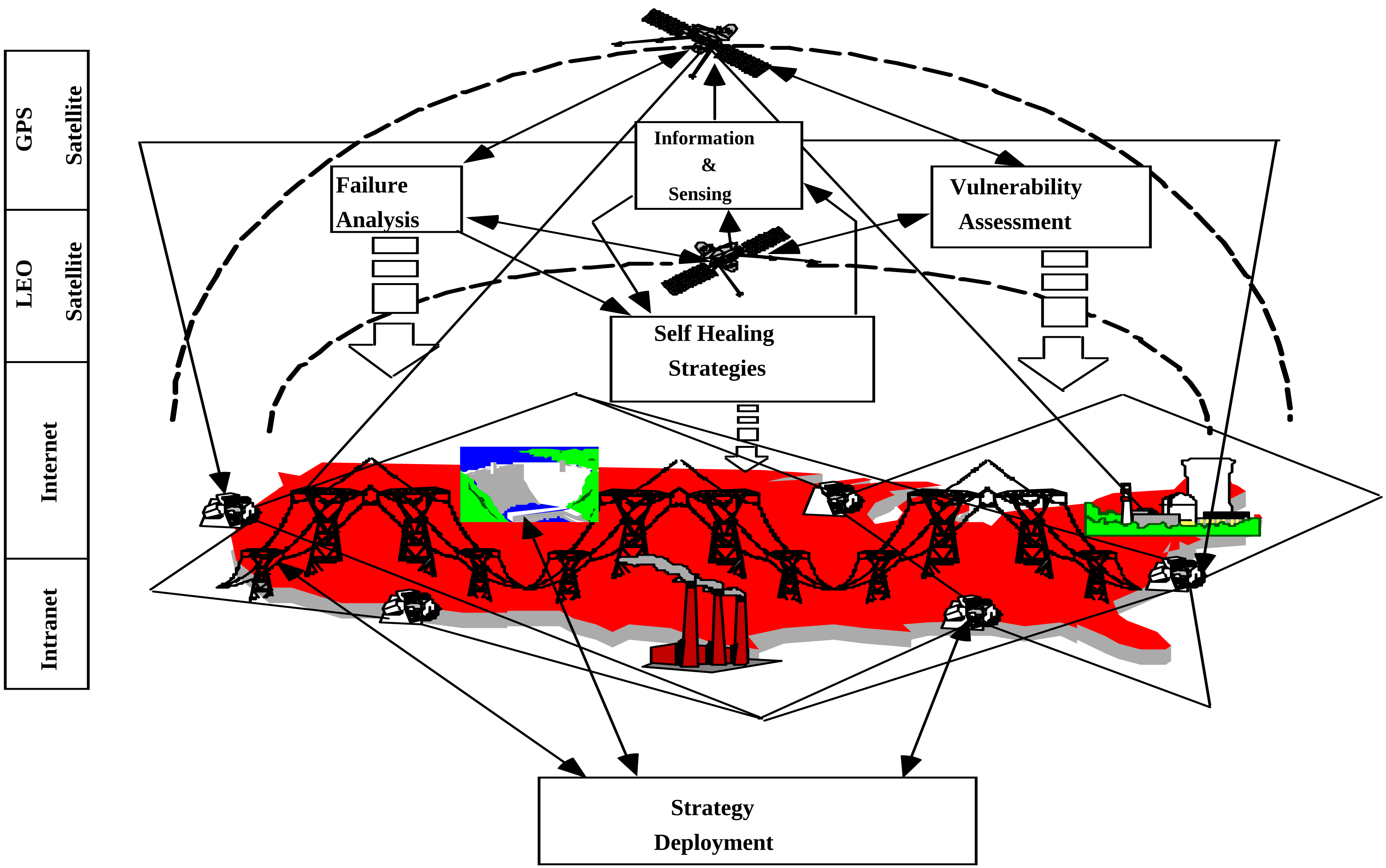
Complex Interactive Networks



EPRI/DOD Complex Interactive Network/Systems (CIN/S) Initiative

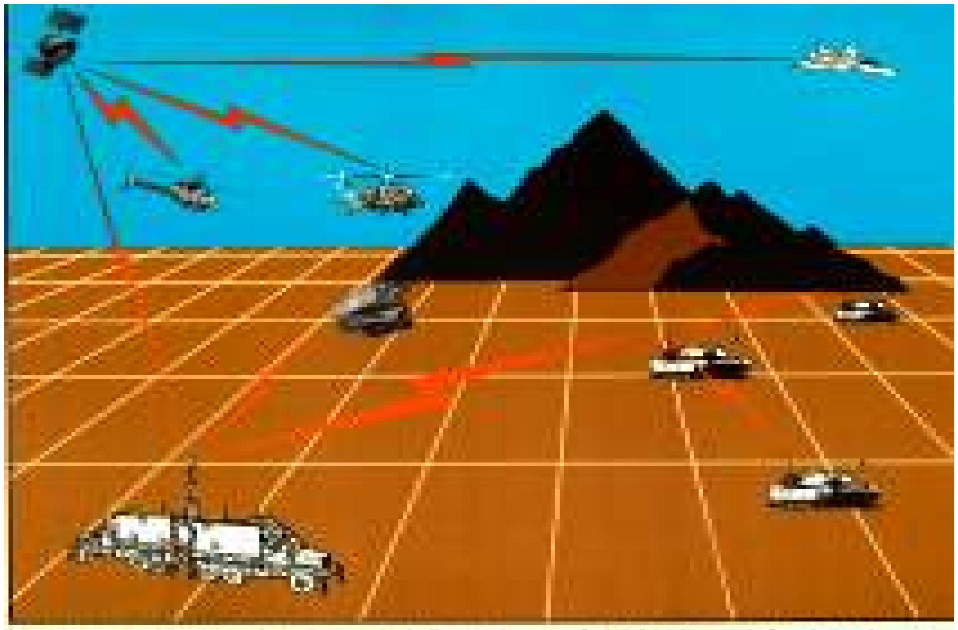
The Reason for this Initiative: "Those who do not remember the past are condemned to repeat it."
George Santayana

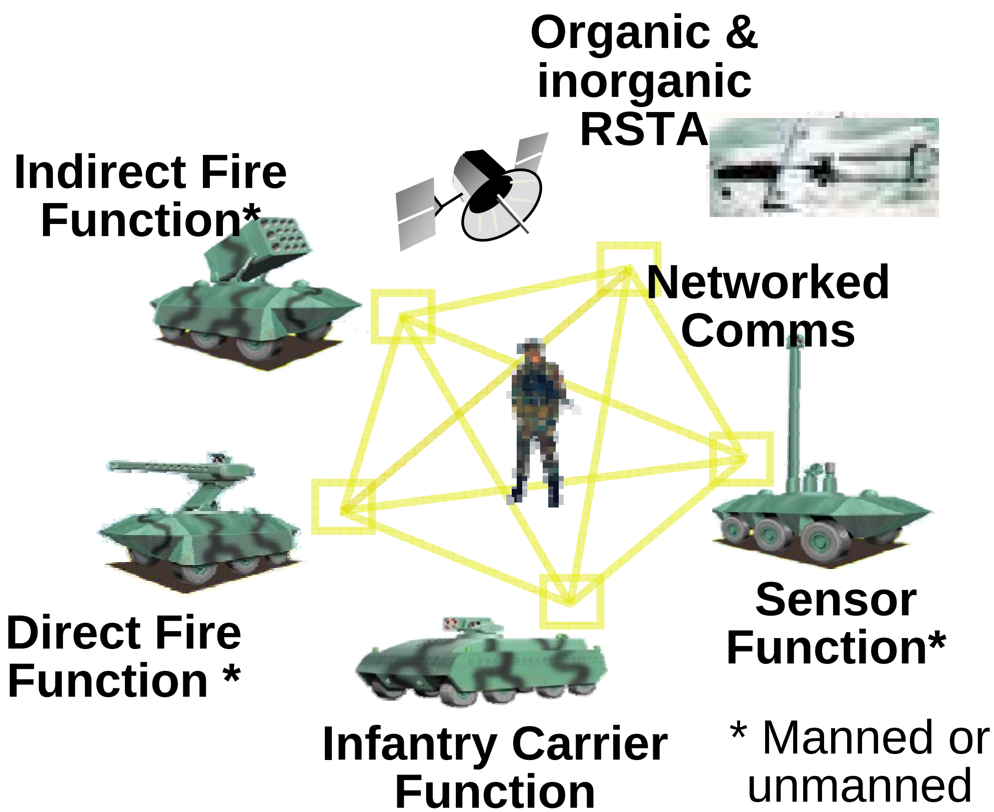
- Two faults in Oregon (500 kV & 230 kV) led to…
  - …tripping of generators at McNary dam
  - …500 MW oscillations
  - …separation of the Pacific Intertie at the California-Oregon border
  - …blackouts in 13 states/provinces
- **Some studies show with proper "intelligent controls," all would have been prevented by shedding 0.4% of load for 30 minutes!**

August 10, 1996

Everyone wants to operate the power system closer to the edge. A good idea! but *where is the edge* and *how close are we to it*.

Network Centric Objective Force





CIN/SI Funded Consortia

108 professors and over 240 graduate students in 28 U.S. universities were funded: Over 420 publications, and 24 technologies extracted, in the 3-year initiative

- U Washington, Arizona St., Iowa St., VPI
- Purdue, U Tennessee, Fisk U, TVA, ComEd/Exelon
- Harvard, UMass, Boston, MIT, Washington U.
- Cornell, UC-Berkeley, GWU, Illinois, Washington St., Wisconsin
- CMU, RPI, UTAM, Minnesota, Illinois
- Cal Tech, MIT, Illinois, UC-SB, UCLA, Stanford

- Defense Against Catastrophic Failures, Vulnerability Assessment
- Intelligent Management of the Power Grid
- Modeling and Diagnosis Methods
- Minimizing Failures While Maintaining Efficiency / Stochastic Analysis of Network Performance
- Context Dependent Network Agents
- Mathematical Foundations: Efficiency & Robustness of Distributed Systems

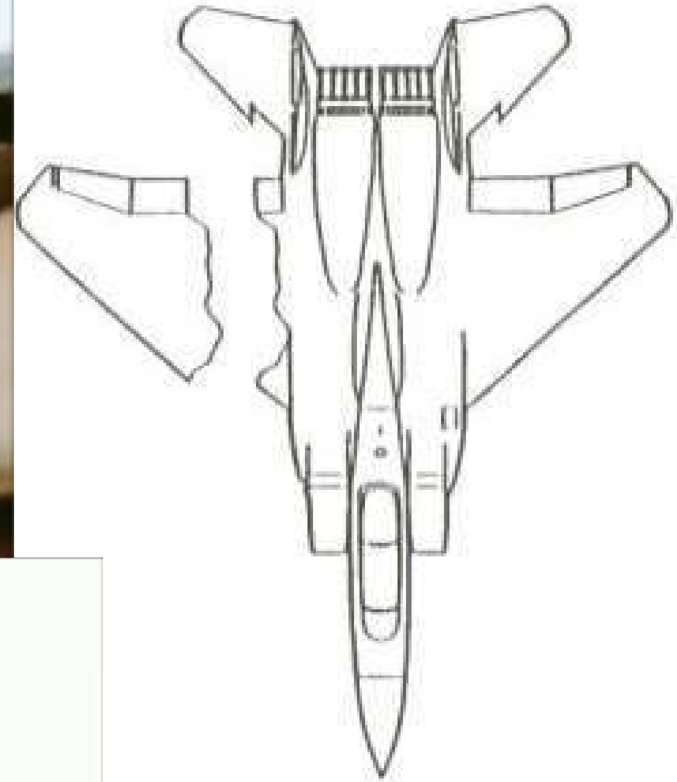
Definition: Self-Healing ("Smart") Grid (1998-present)

- **What is "self healing"?**
  - A system that uses information, sensing, control and communication technologies to allow it to deal with unforeseen events and minimize their adverse impact

- **Why is self healing concept important to the Electric Power Grid and Energy Infrastructure?**
  - A secure "architected" sensing, communications, automation (control), and energy overlaid infrastructure as an integrated, reconfigurable, and electronically controlled system that will offer unprecedented flexibility and functionality, and improve system availability, security, quality, resilience and robustness.

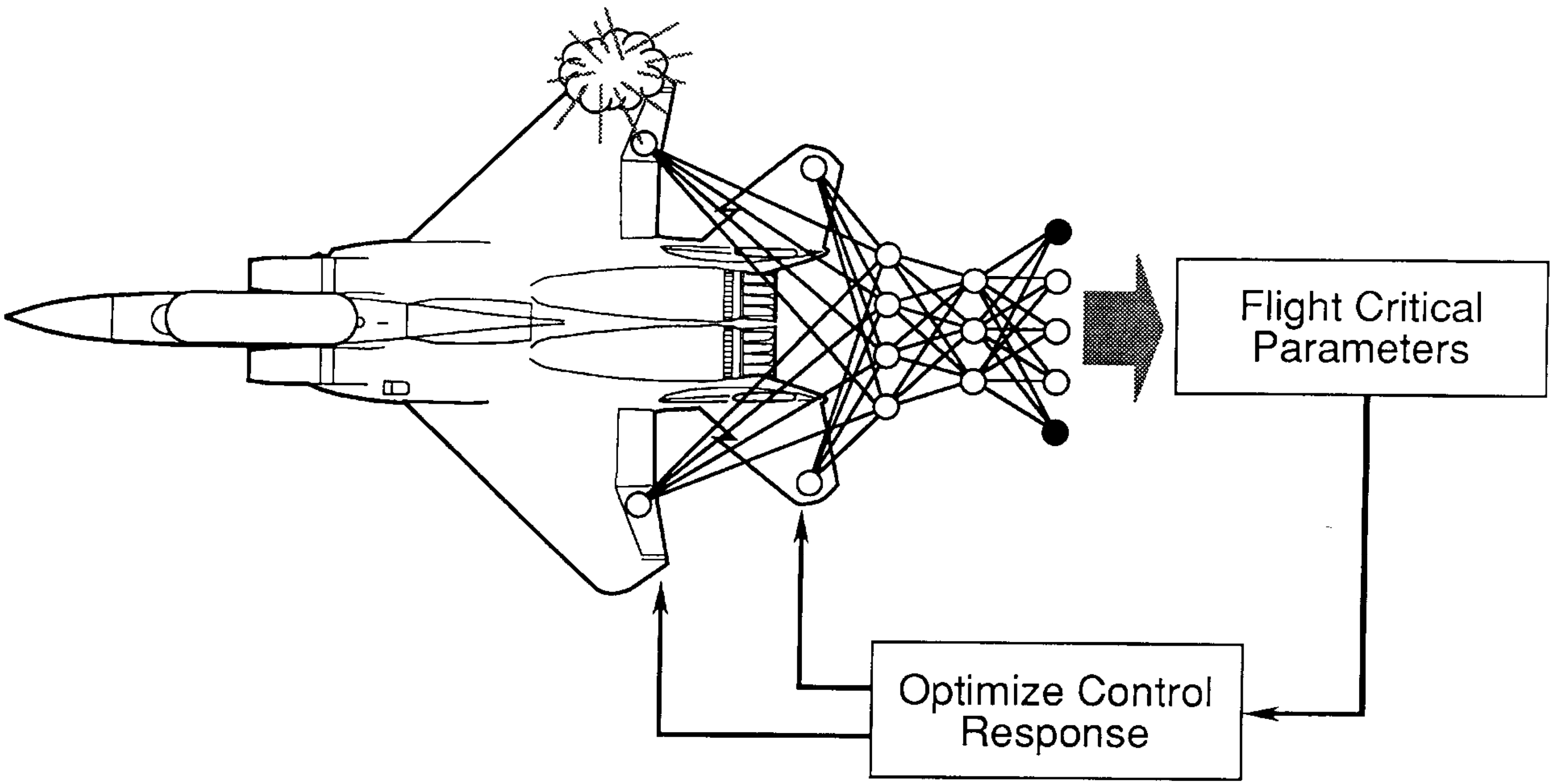
Background:
The Self Healing Grid

Saving systems from collapse: The Case of the Missing Wing (1983-1997)



NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden, Boeing Phantom Works, and Washington University in St. Louis.

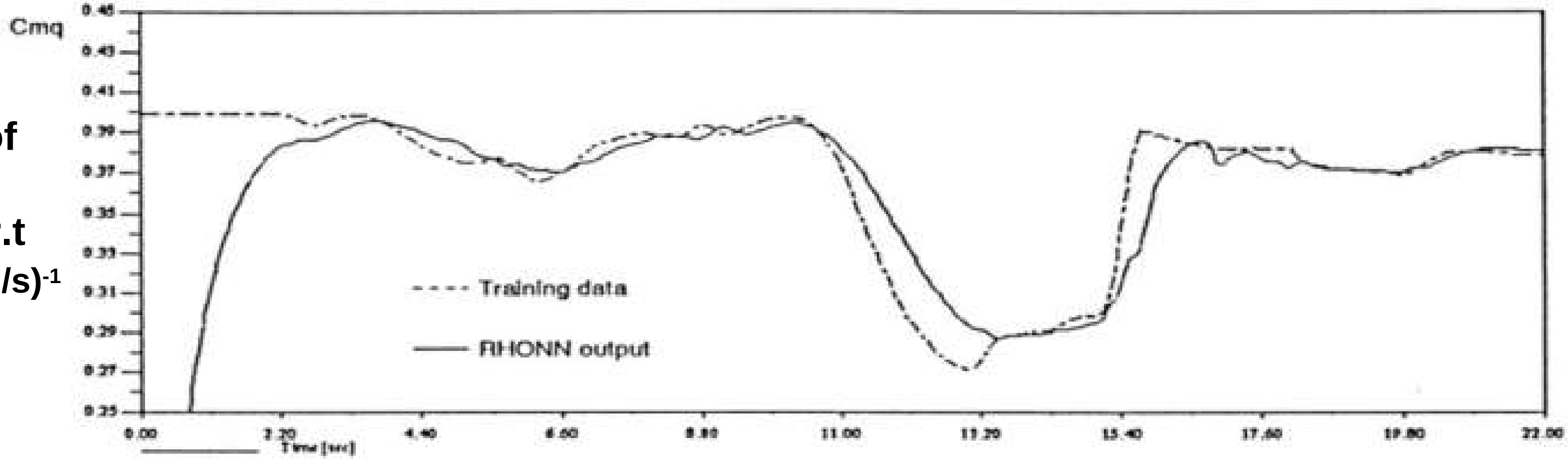
Goal: Optimize controls to compensate for damage or failure conditions of the aircraft



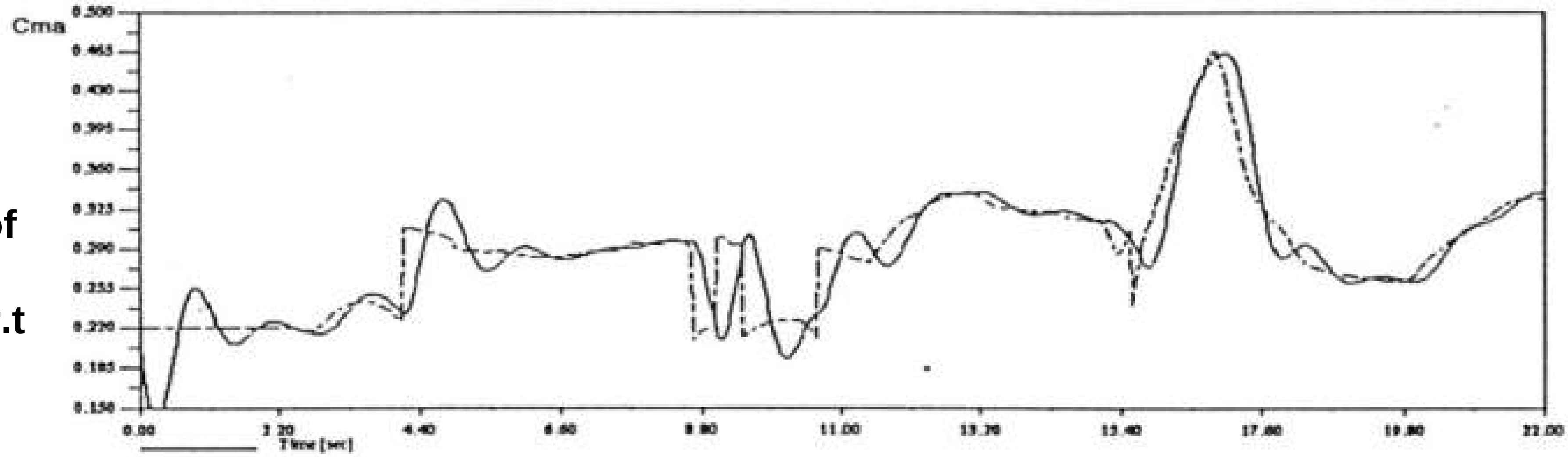
NASA/MDA/WU IFCS

On-Line Learning Without Baseline Network

Partial Derivative of Pitching moment w.r.t pitch rate (d/s)$^{-1}$

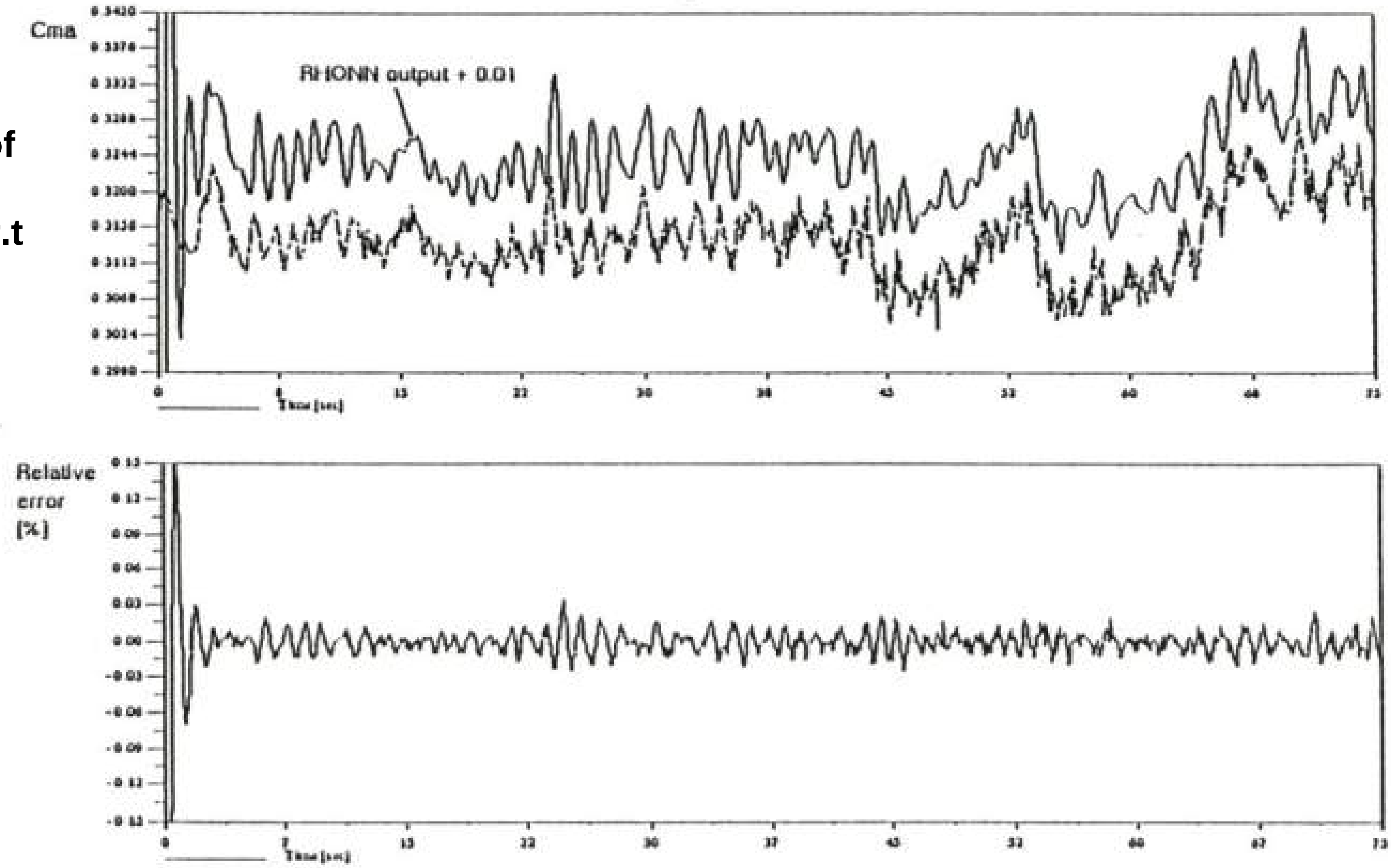


Partial Derivative of Pitching moment w.r.t AoA (d)$^{-1}$

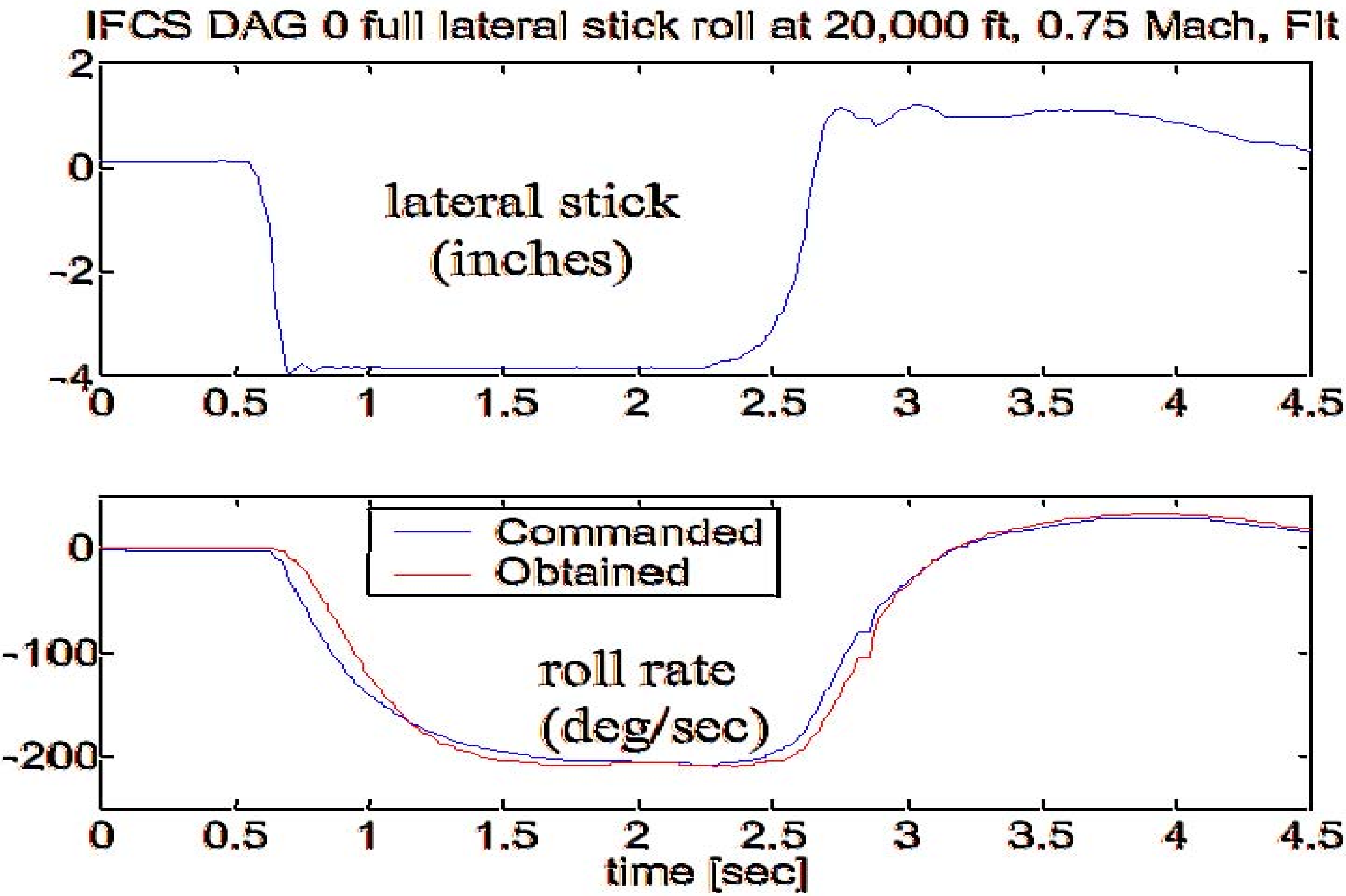


On-Line Learning Without Baseline Network

Partial Derivative of Pitching moment w.r.t AoA (d)$^{-1}$



Intelligent Flight Control System: Example – complete hydraulic failure (1997)



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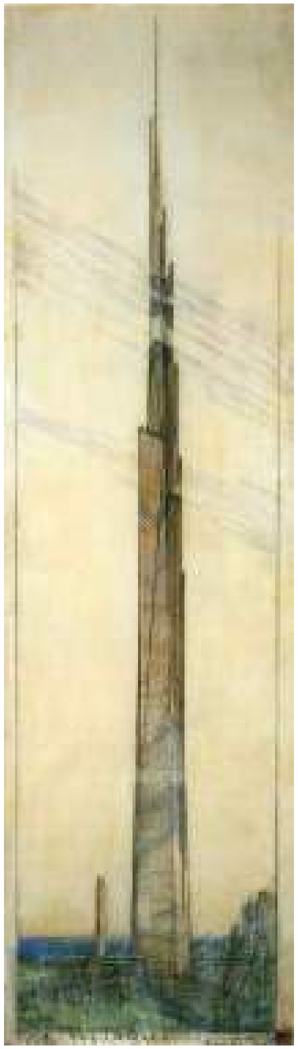
Accomplishments in the IFCS program

- The system was successfully test flown on a test F-15 at the NASA Dryden Flight Research Center:
  - Fifteen test flights were accomplished, including flight path control in a test flight envelope with supersonic flight conditions.
  - Maneuvers included 4g turns, split S, tracking, formation flight, and maximum afterburner acceleration to supersonic flight.
- Stochastic Optimal Feedforward and Feedback Technique (SOFFT) continuously optimizes controls to compensate for damage or failure conditions of the aircraft.
- Flight controller uses an on-line solution of the Riccati equation containing the neural network stability derivative data to continuously optimize feedback gains.
- Development team: NASA Ames Research Center, NASA Dryden Flight Research Center, Boeing Phantom Works, and Washington University.

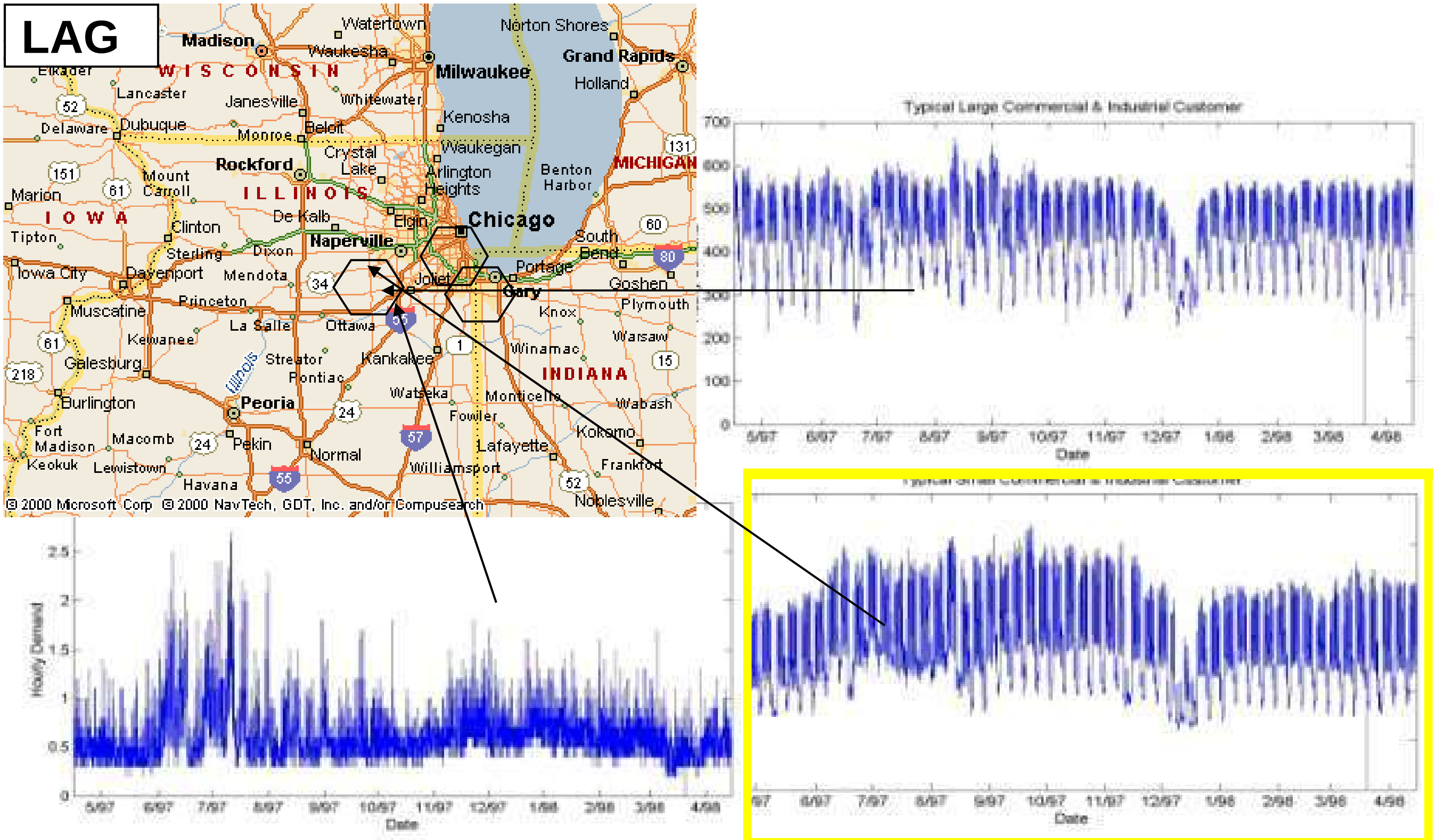
Self-healing Grid (1998-present)



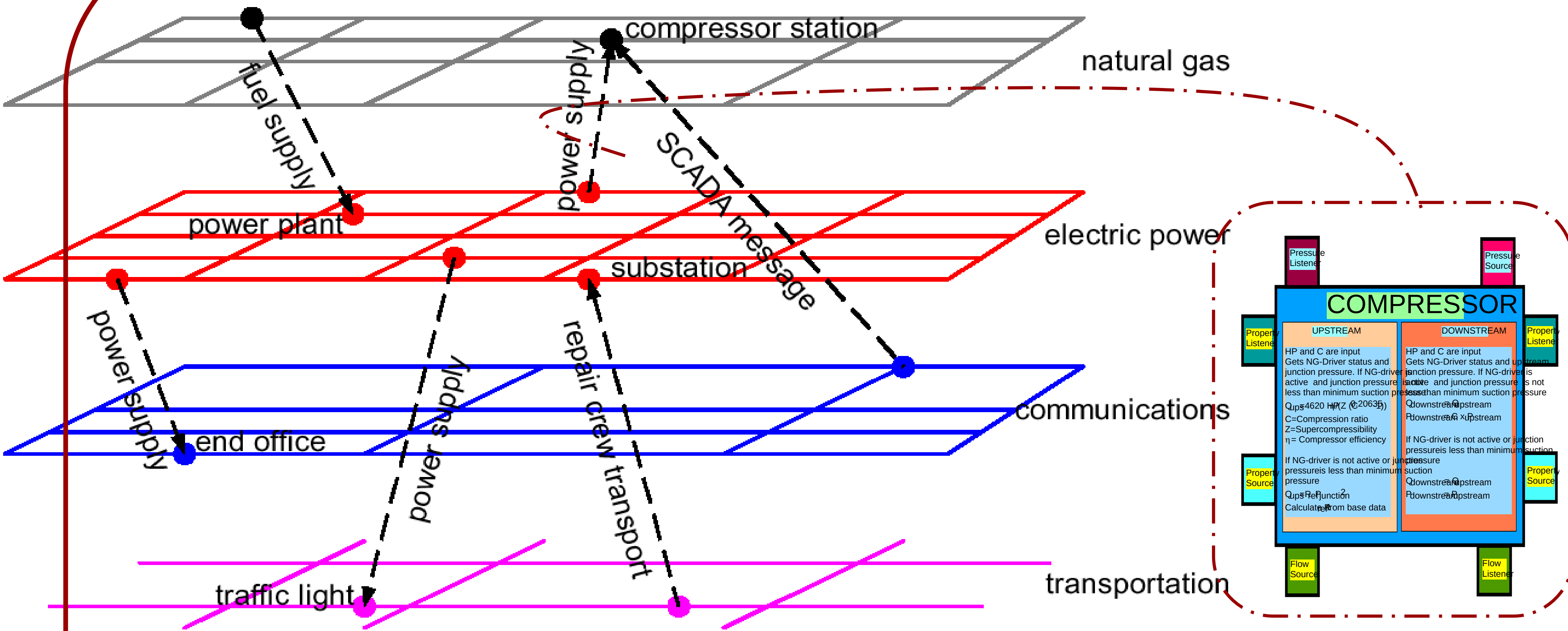
Building on the Foundation:

- Anticipation of disruptive events
- Look-ahead simulation capability
- Fast isolation and sectionalization
- Adaptive islanding
- Self-healing and restoration

Local area grids (LAG)



Infrastructure Interdependencies

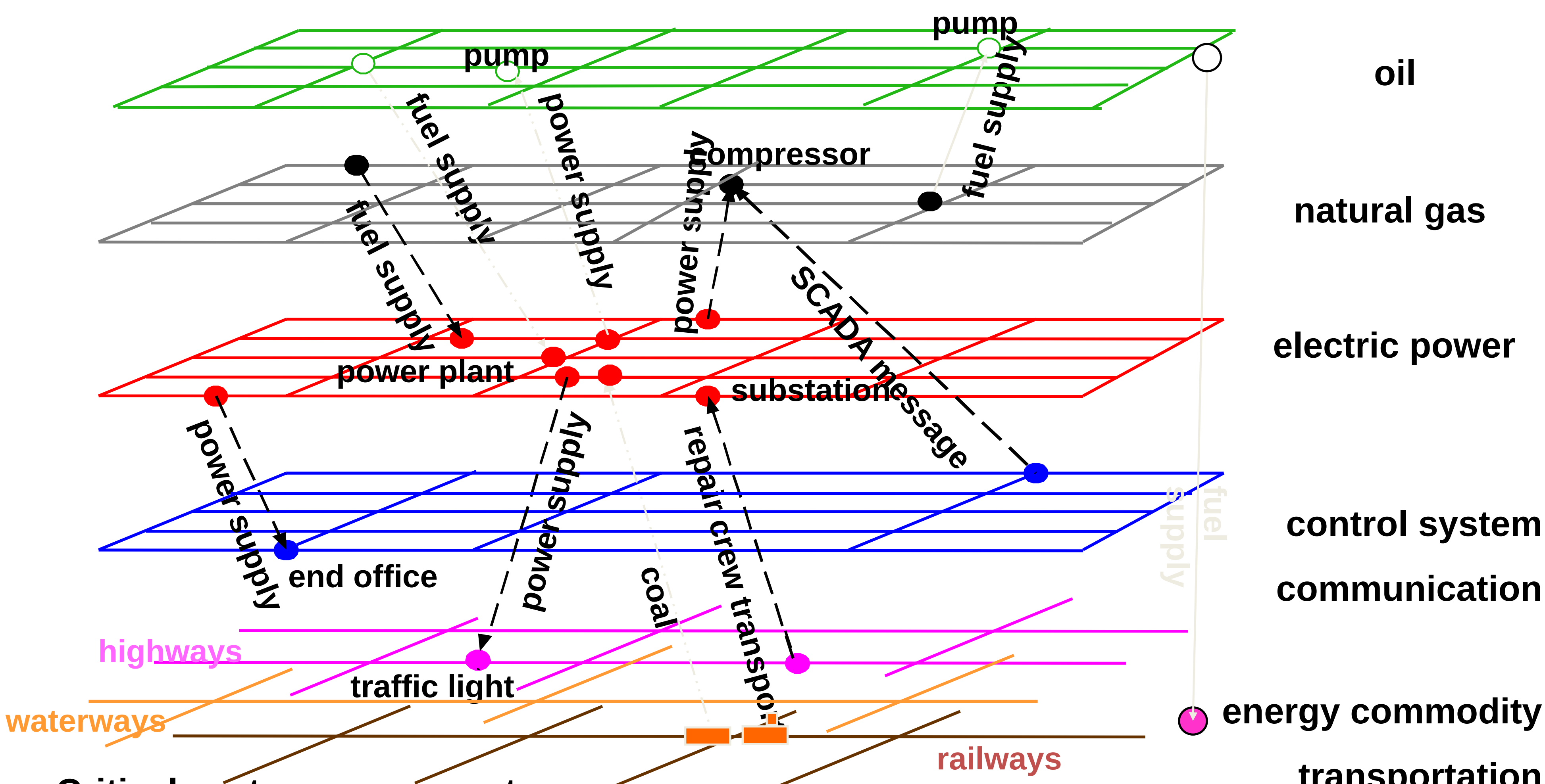


$$HP = \frac{3.0325}{10^6} Q_s \frac{P_b T_s Z}{\eta T_b} \left(\frac{k}{k-1}\right)\left(C^{(k-1)/k} - 1\right)$$

Detailed component models

ANL

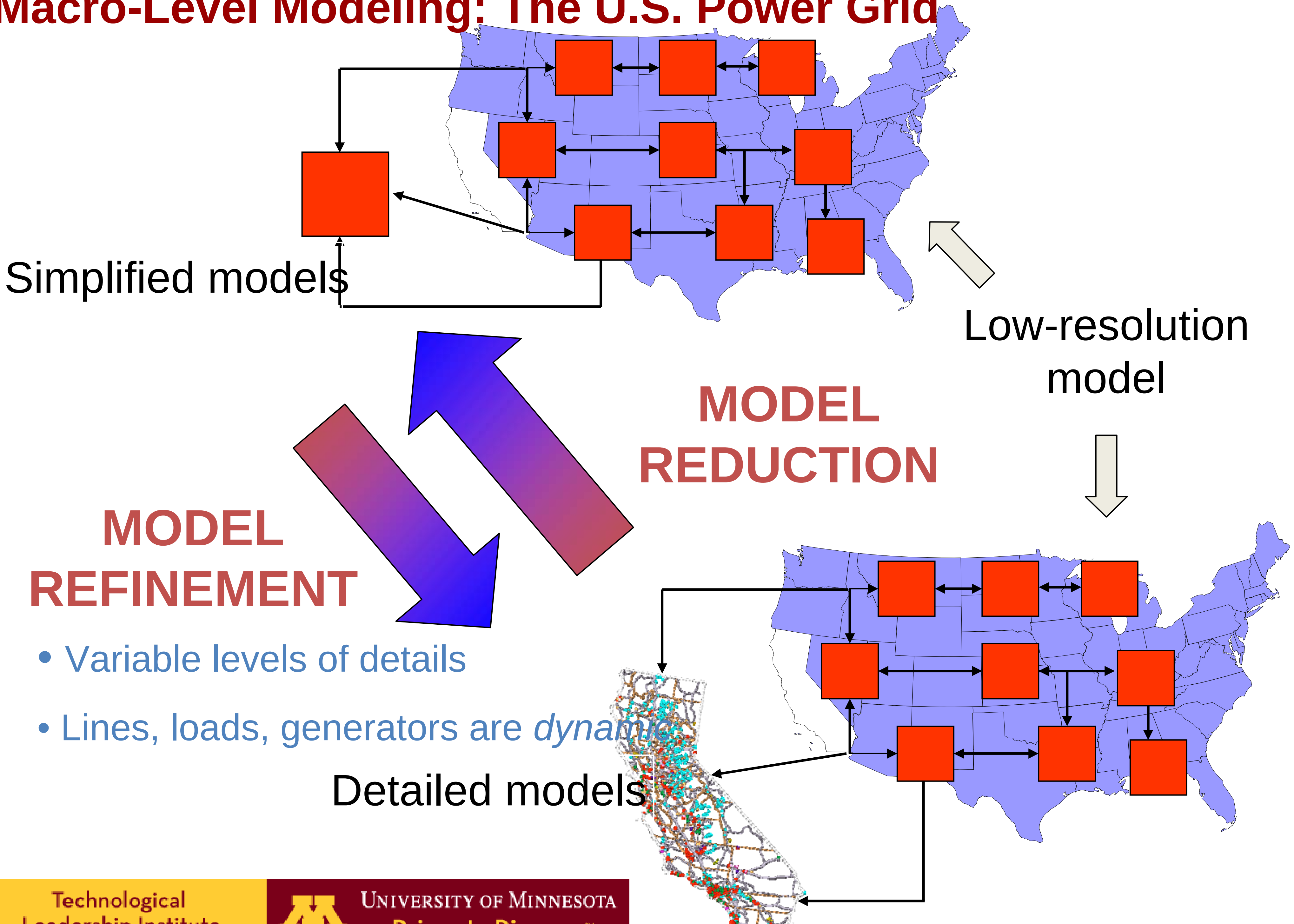
Infrastructure Interdependencies



- Critical system components
- Interdependent propagation pathways and degrees of coupling
- Benefits of mitigation plans

ANL

Macro-Level Modeling: The U.S. Power Grid



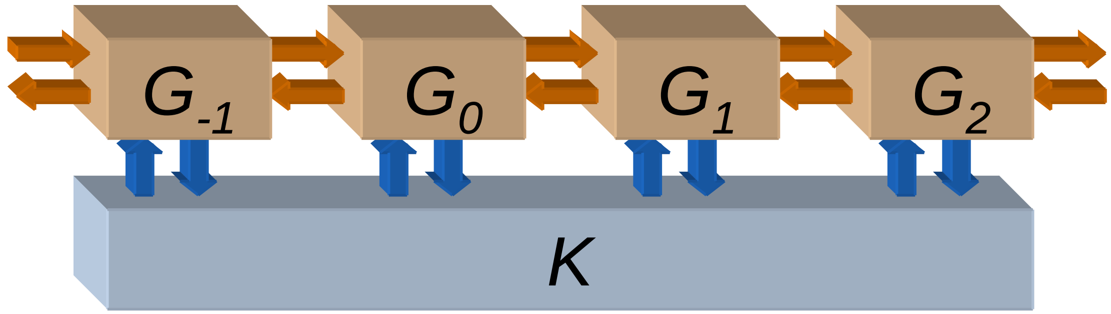
- Variable levels of details
- Lines, loads, generators are *dynamic*

Look-Ahead Simulation Applied to Multi-Resolution Models

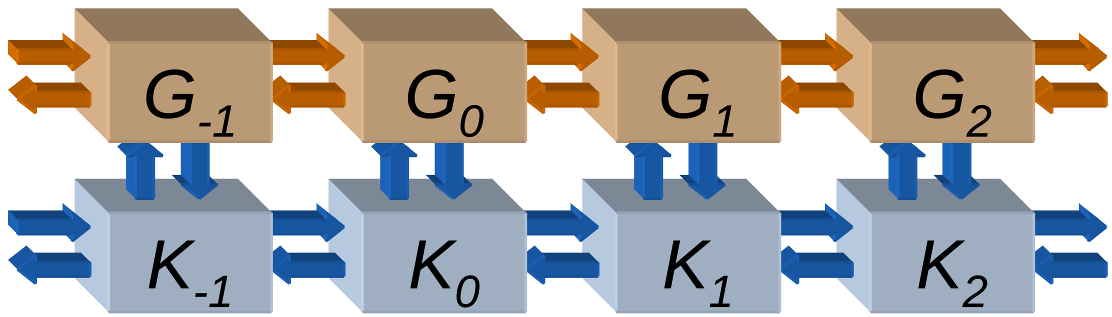
- Provides faster-than-real-time simulation
  - By drawing on approximate rules for system behavior, such as power law distribution
  - By using simplified models of a particular system
- Allows system operators to change the resolution of modeling at will
  - Macro-level (regional power systems)
  - Meso-level (individual utility)
  - Micro-level (distribution feeders/substations)

Sensing and Control Strategies

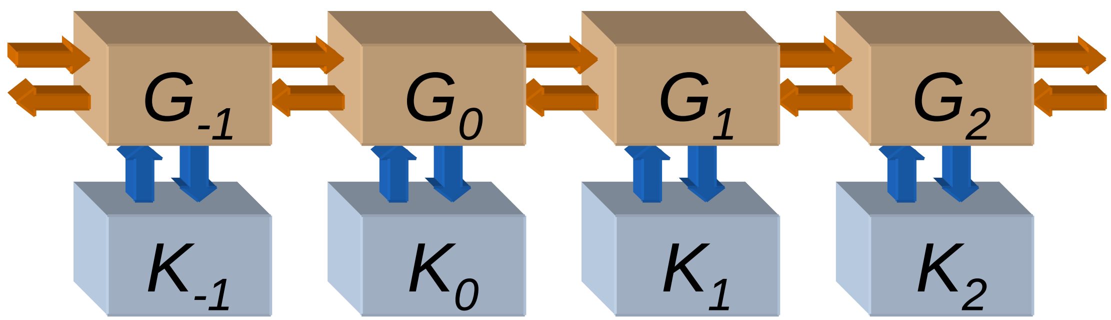
- Centralized



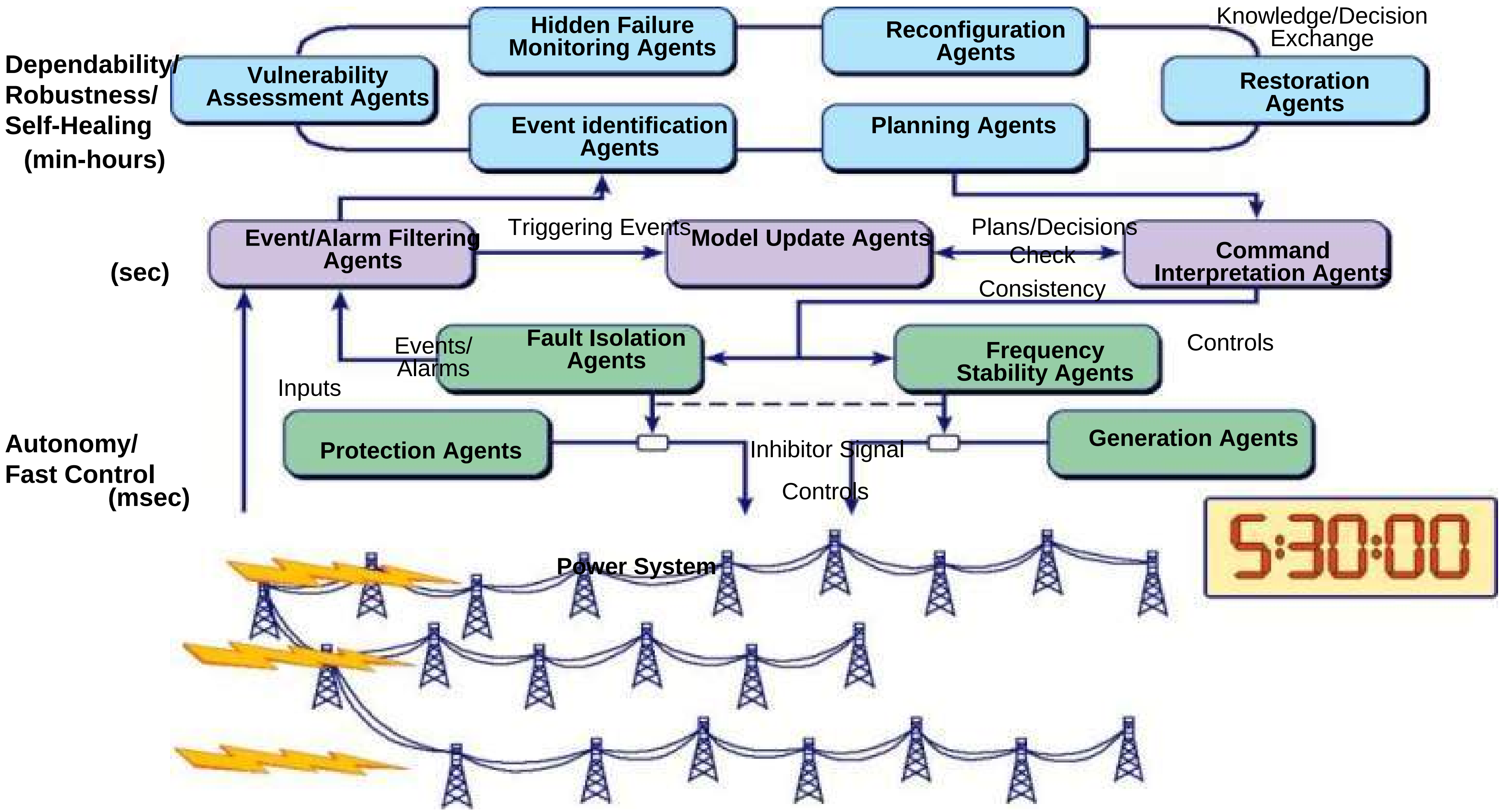
- Distributed



- Perfectly decentralized

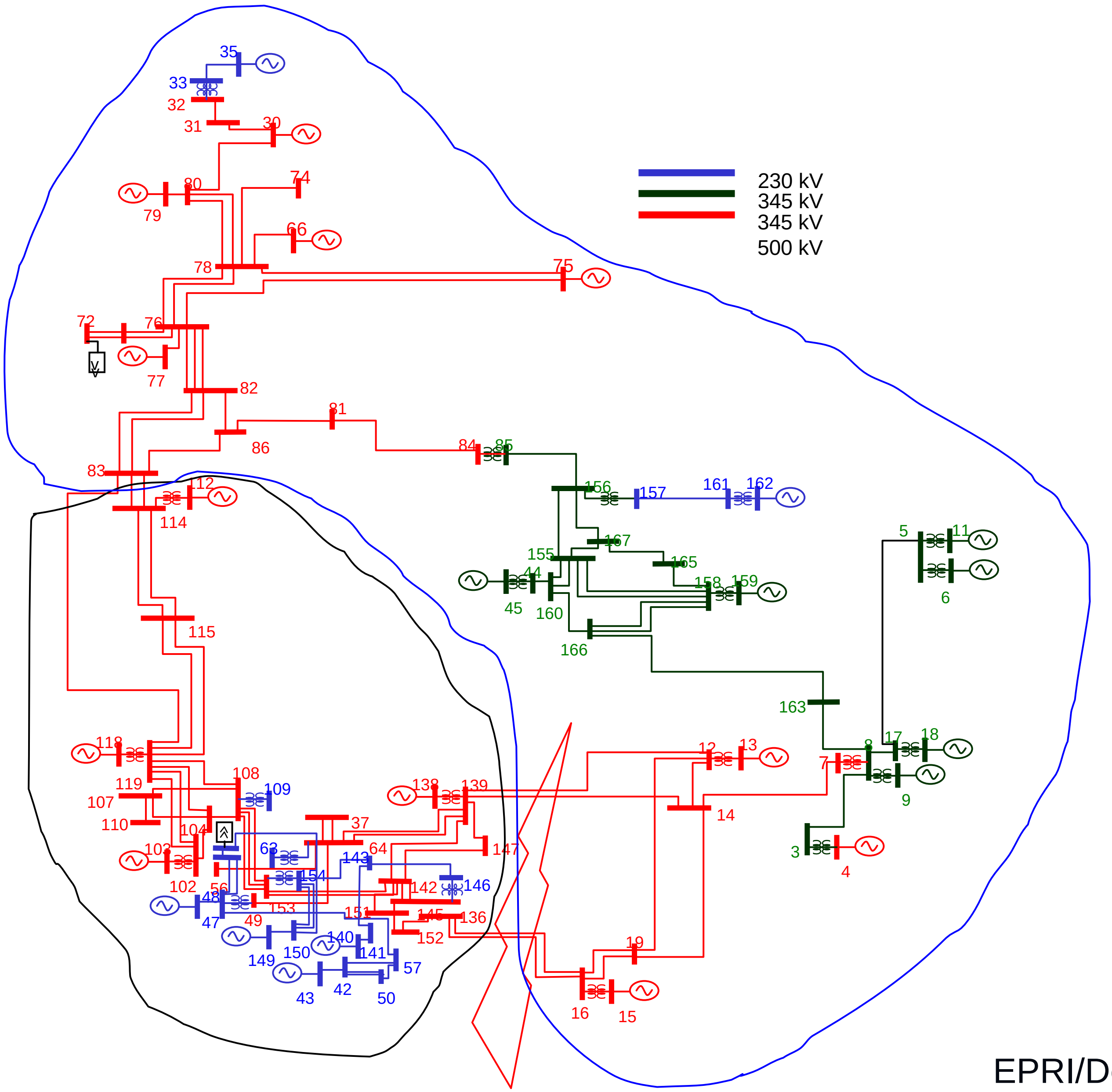


Background: The Self-Healing Grid



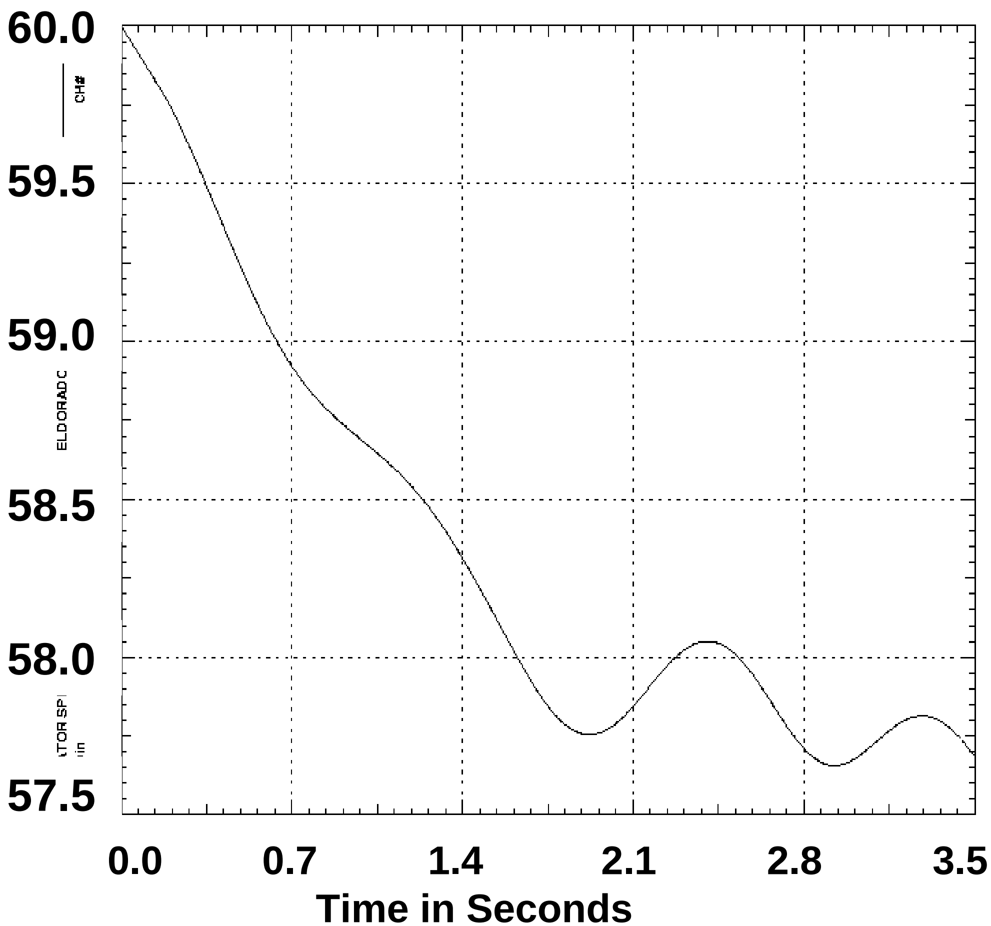
EPRI/DoD CIN/S Initiative

Background: The Self-Healing Grid
Intelligent Adaptive Islanding

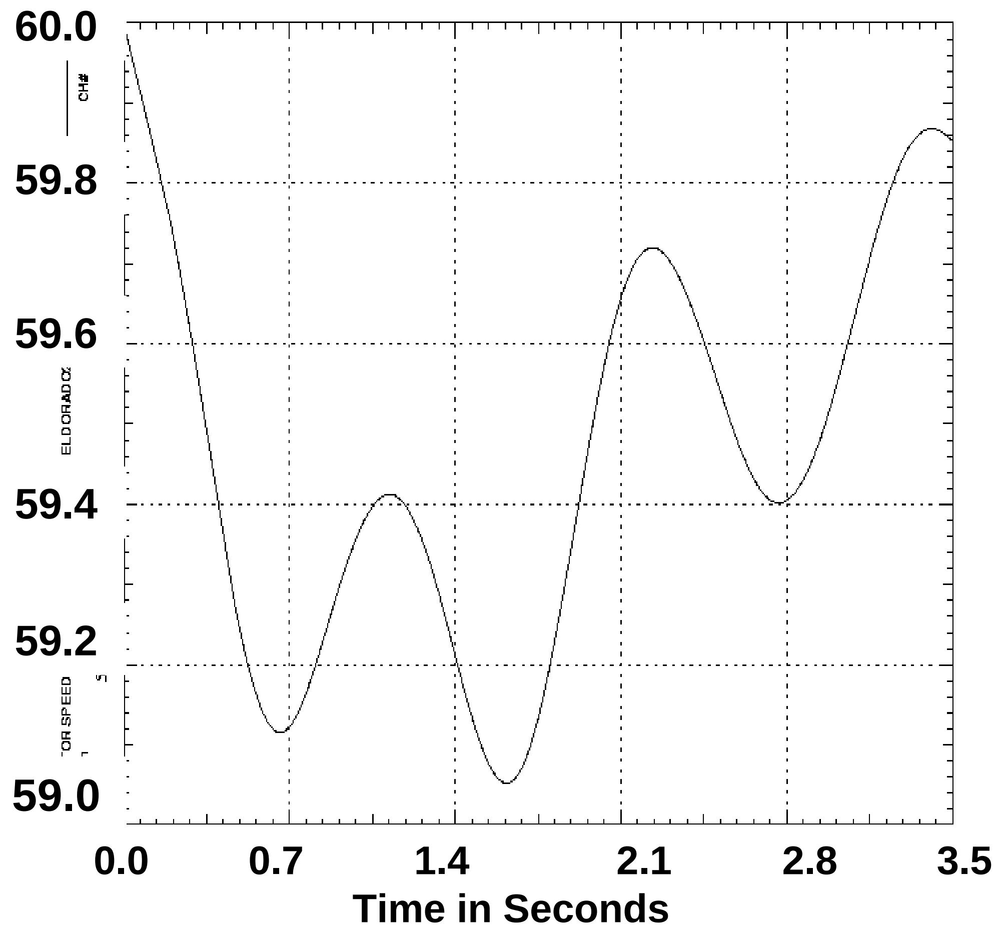


EPRI/DoD CIN/S Initiative

Background: Simulation Result

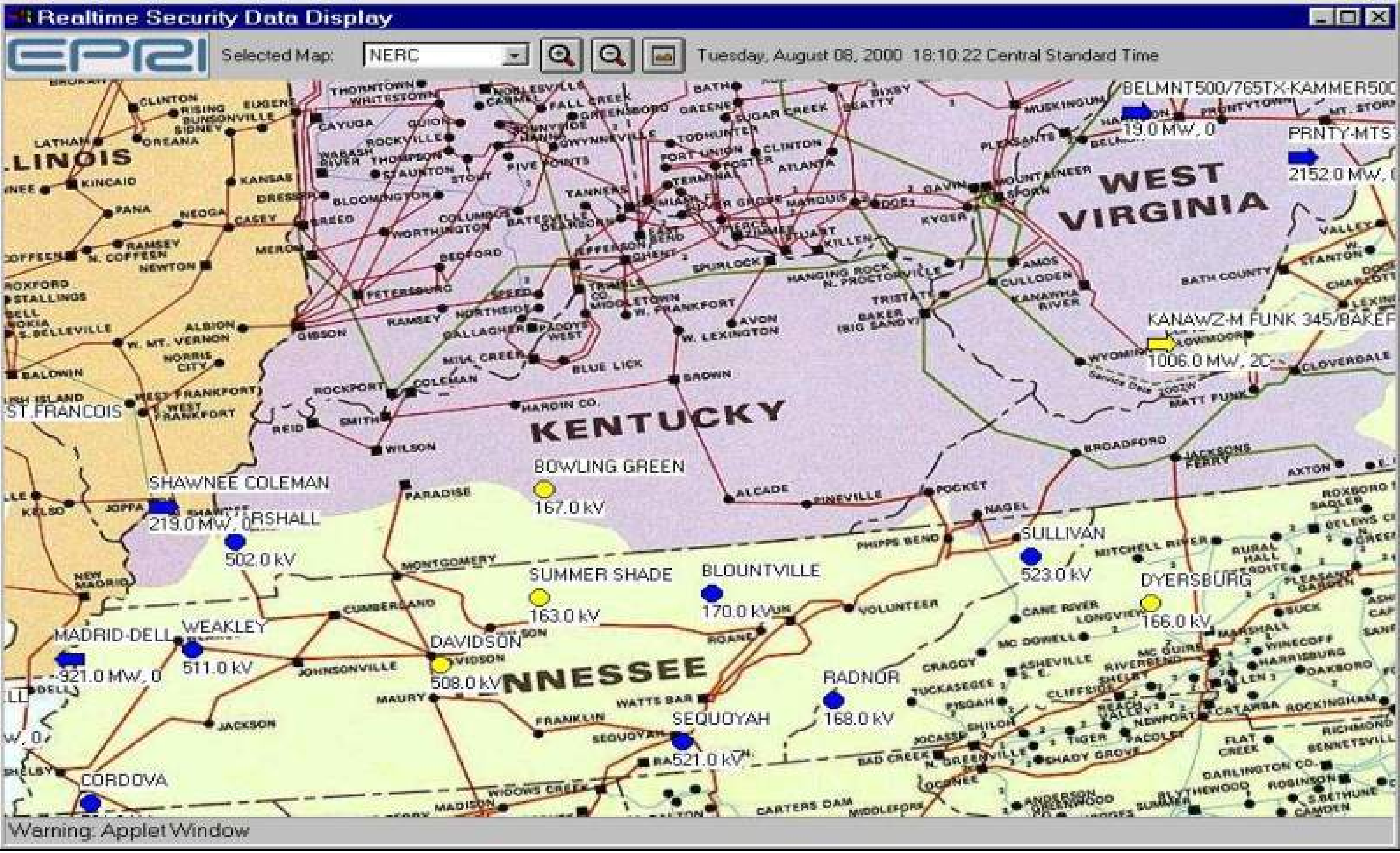


Past Scheme

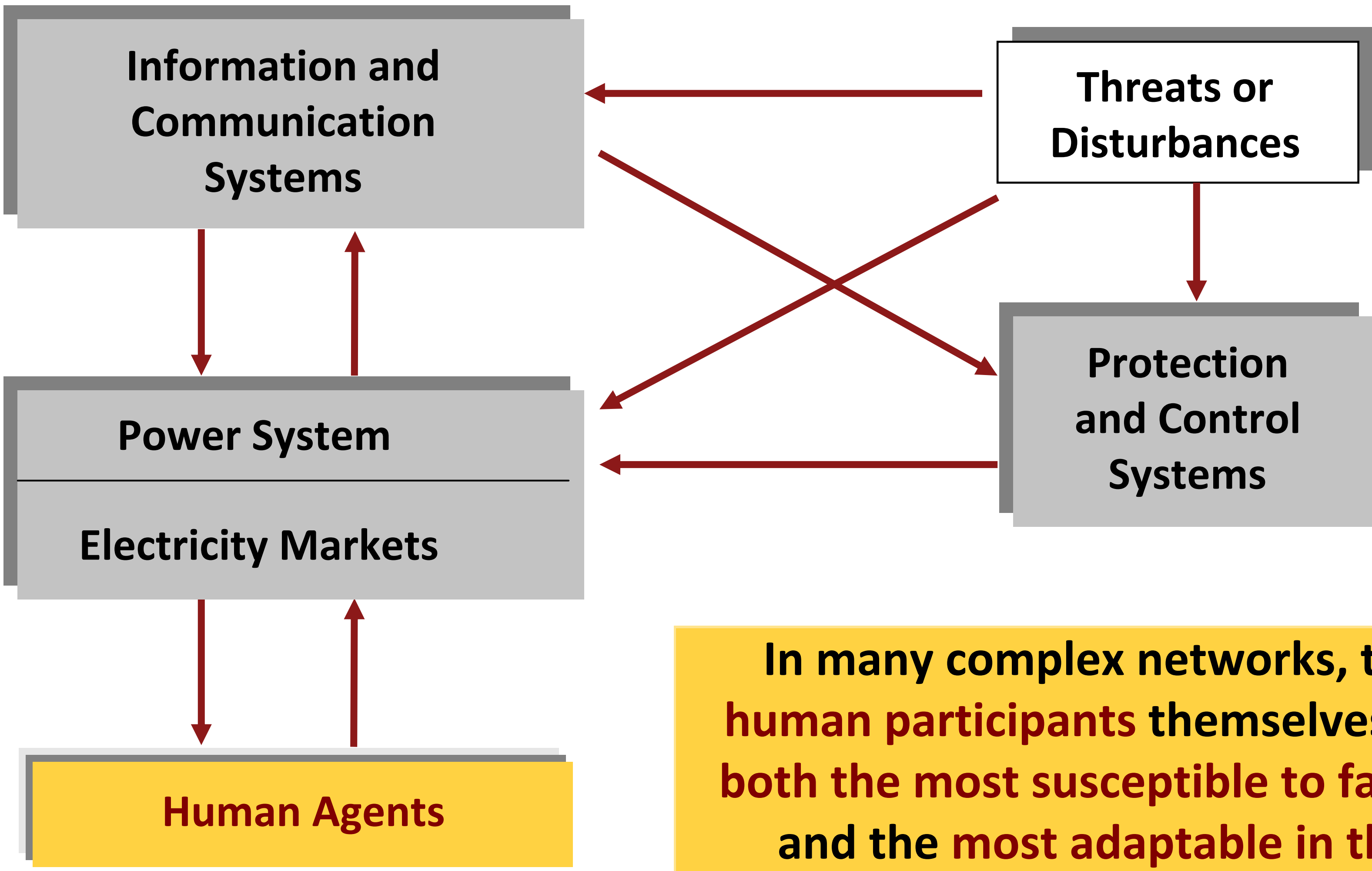


New Scheme

EPRI's Reliability Initiative-- Sample Screen of Real-time Security Data Display (RSDD)



Integrated Sensing, Protection and Control



In many complex networks, the human participants themselves are both the most susceptible to failure and the most adaptable in the management of recovery.

The Emerging Smart Grid or Energy Web:
A Complex Adaptive Infrastructure System

"… not to sell light bulbs, but to create a network of technologies and services that provide illumination…"

"The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming and interconnected with everything else."

-- Wired Magazine, July 2001
http://www.wired.com/wired/archive/9.07/juice.html

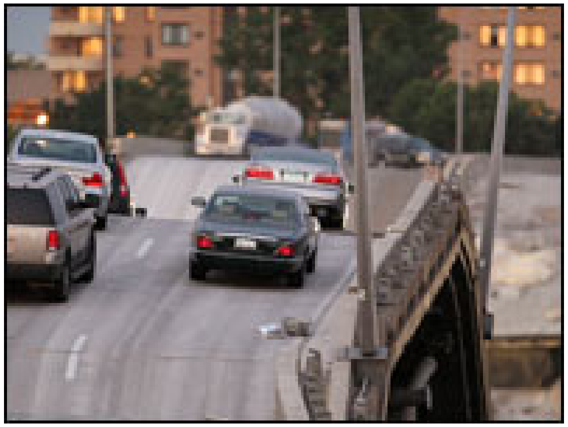
I-35W bridge

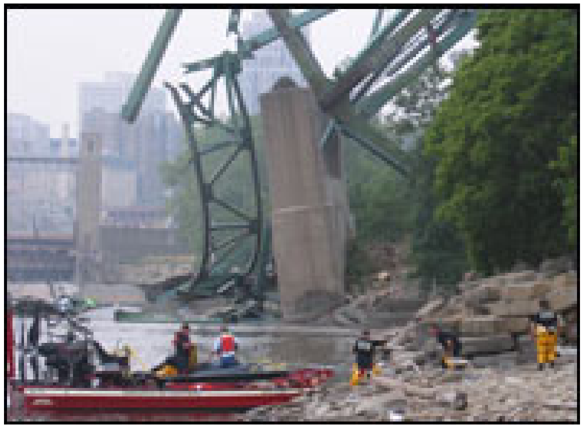
Just after 6:00 p.m. on Aug. 1, Prof. Massoud Amin was at work in his office on the University of Minnesota's West Bank, where he heard and watched the unthinkable happen—the collapse of the I-35W bridge about 100 yards away.

"As an individual, it was shocking and very painful to witness it from our offices here in Minneapolis," says Amin, director of the Center for the Development of Technological Leadership (CDTL) and the H.W. Sweatt Chair in Technological Leadership. Amin also viewed the tragedy from a broader perspective as a result of his ongoing work to advance the security and health of the nation's infrastructure.

In the days and weeks that followed, he responded to media inquiries from the BBC, Reuthers, and the CBC, keeping his comments focused on the critical nature of the infrastructure. He referred reporters with questions about bridge design, conditions, and inspections to several professional colleagues, including Professors Roberto Ballarini, Ted Galambos, Vaughan Voller, and John Gulliver in the Department of Civil Engineering and the National Academy of Engineering Board on Infrastructure and Constructed Environment.

For Amin, Voller, and many others, the bridge collapse puts into focus the importance of two key issues—the tremendous value of infrastructure and infrastructure systems that help make possible indispensable activities such as transportation, waste disposal, water, telecommunications, and electricity and power, among many others, and the search for positive and innovative ways to strengthen the infrastructure.





I-35W bridge

- In less than a year, a city of sorts with an ever-changing landscape has taken shape, complete with a host of heavy-duty equipment, temporary on-site areas for casting and other tasks, and crews constantly at work.

- The days and months that followed required extraordinary efforts from many, including our alumni of the Master of Science in Infrastructure Systems Engineering (ISE) program.

→ Sensors built into the bridge.

Contributors

The construction of the new I-35W bridge involves many professionals, including the following list of CDTL alumni who have lent their expertise to the project:

B. J. Bonin, ISE '05

Charles Cadenhead, ISE '04

Jon Carlson, MOT '99

Brian Connolly, ISE '06

Petra DeWall, ISE '02

Pete Jenkins, ISE '08

Heidi Hamilton, ISE '04

Brian Kamnikar, ISE '03

Joe Nietfeld, ISE '07

Chris Roy, ISE '02

Michael Schadegg, ISE '03

Val Svensson, ISE '06

Terry Ward, ISE '05

Terry Ward

Heidi Hamilton

Val Svensson

Joe Nietfeld

Critical Infrastructure Security & Protection

September 11, 2001 Tragedies

Electric industry may lead pack in disaster safeguards

By David Wagman
dwagman@ftenergy.com

Massoud Amin, a mathematician with EPRI, was attending a disaster risk management workshop outside Washington, D.C., Sept. 11 when pagers and cell phones began going off in the room.

The workshop, whose attendees included White House and Department of Defense (DOD) officials, quickly ended with word of the World Trade Center and Pentagon attacks.

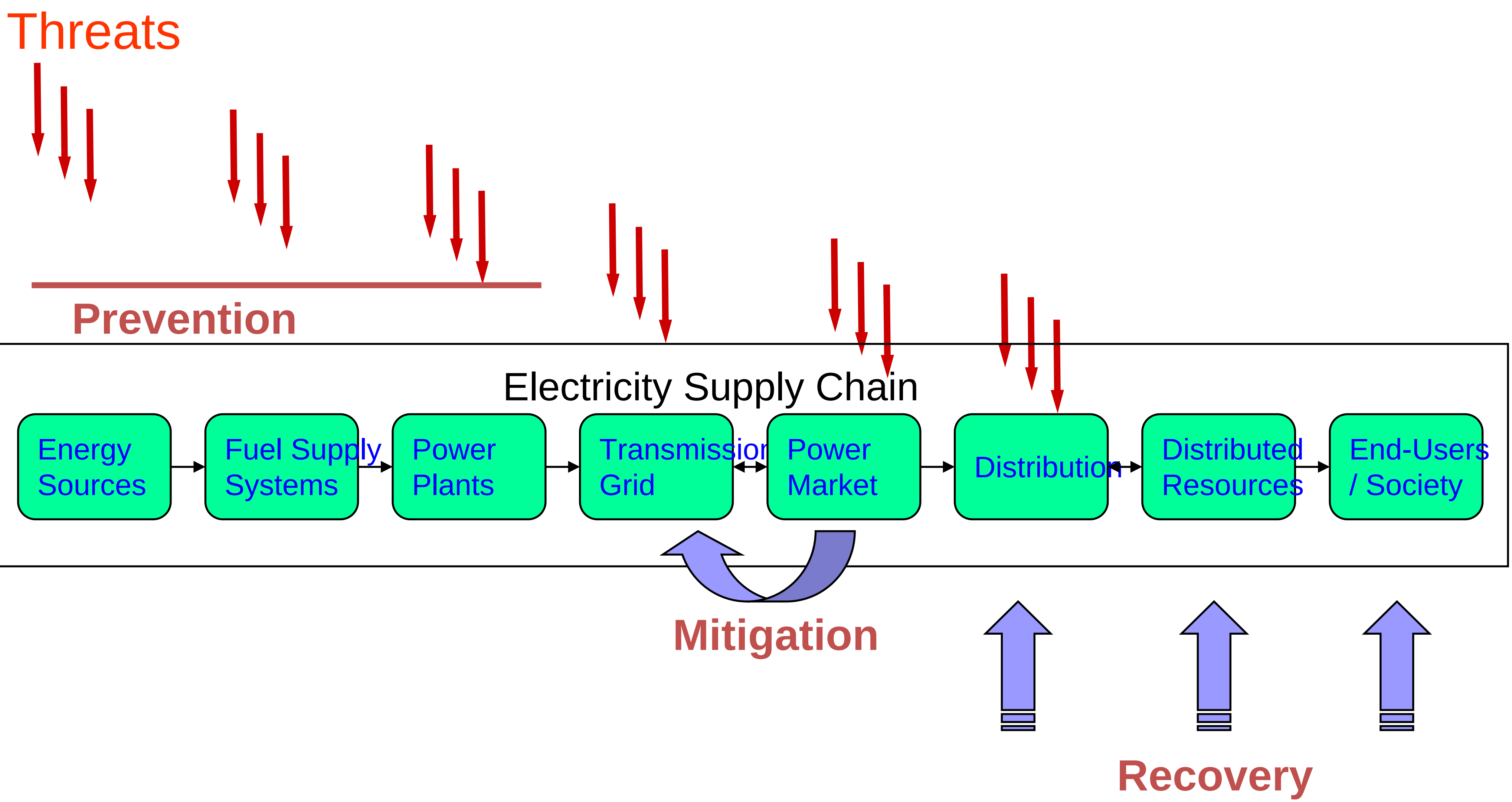
"It was indeed ironic that we were engaged at the very moment of the attack in a conference attempting to find realistic technical ways to mitigate disaster," said Amin.

What is even more ironic is that the DOD late last year opted to stop funding its share of the $30 million, five-year project Amin is leading on behalf of EPRI to design a "self-healing" electric transmission network. The DOD money ran out Friday, at the end of the current federal fiscal year.

After all, the electric infrastructure is quite vulnerable to disruption. Hurricanes, tornadoes, ice storms, fires, blizzards and even solar flares periodically disrupt electric service. Given these natural disasters, the events of Sept. 11 make it possible to imagine the effects of a disruption that is both purposeful and malicious.

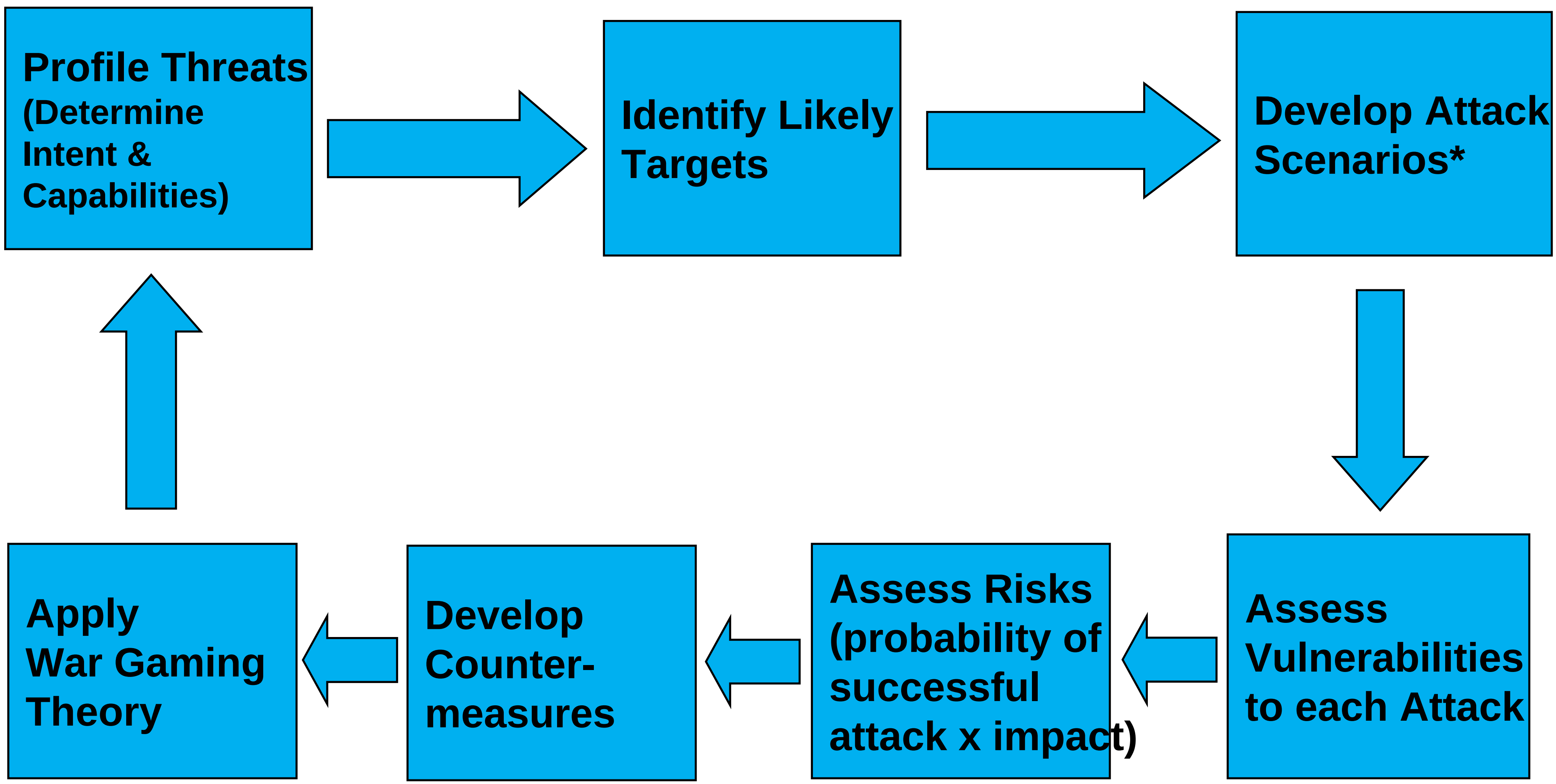
A self-healing transmission system would keep substations running even if a portion of the system was damaged.

End-to-End PVA Model



What can be Done?

Vulnerability Assessment and Layered Defense in Depth



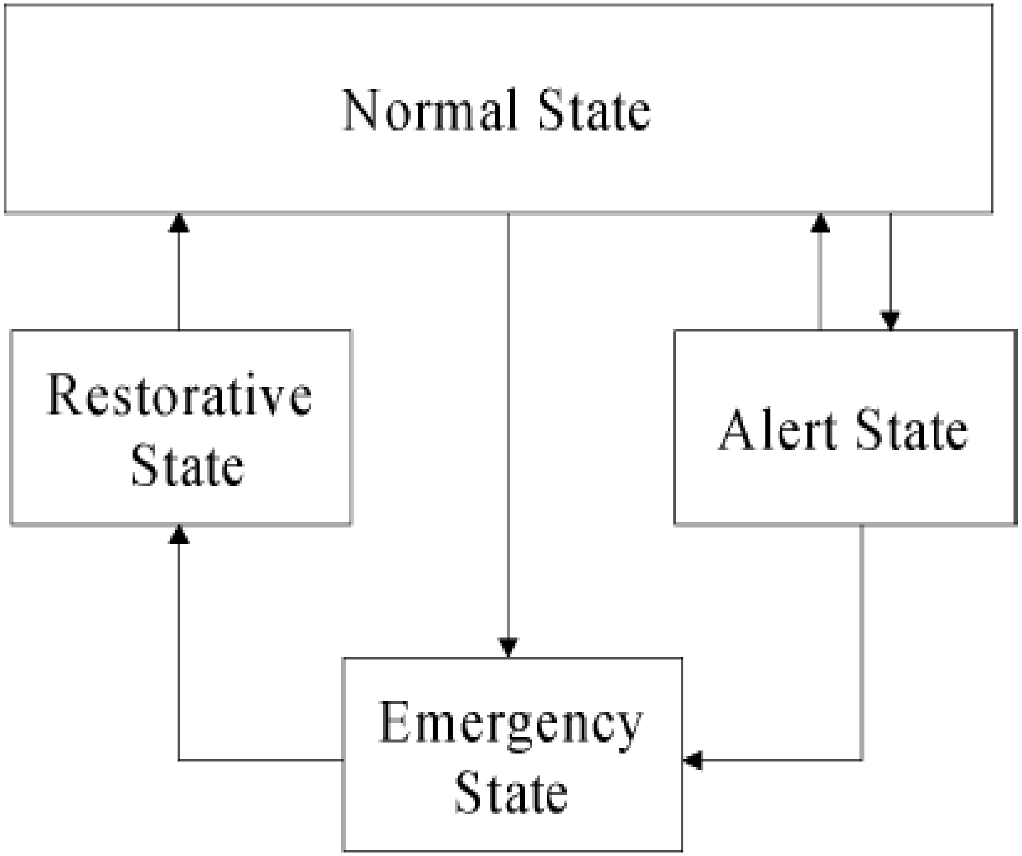
*Evolving spectra of targets and modes of attack

Understanding Complex Dynamical Systems

… Systems' operations, mathematical foundations, and guidance on how to measure and adapt to disturbances:

System is characterized as having multiple states, or "modes," during which specific operational and control actions/reactions are taking place:

- ***Normal mode:*** economic dispatch, load frequency control, maintenance, forecasting, etc.;
- ***Alert mode:*** red flags, precursor detection, reconfiguration and response;
- ***Emergency/Disturbance mode:*** stability, viability, and integrity -- instability, load shedding, etc.;
- ***Restorative mode:*** rescheduling, resynchronization, load restoration, etc.



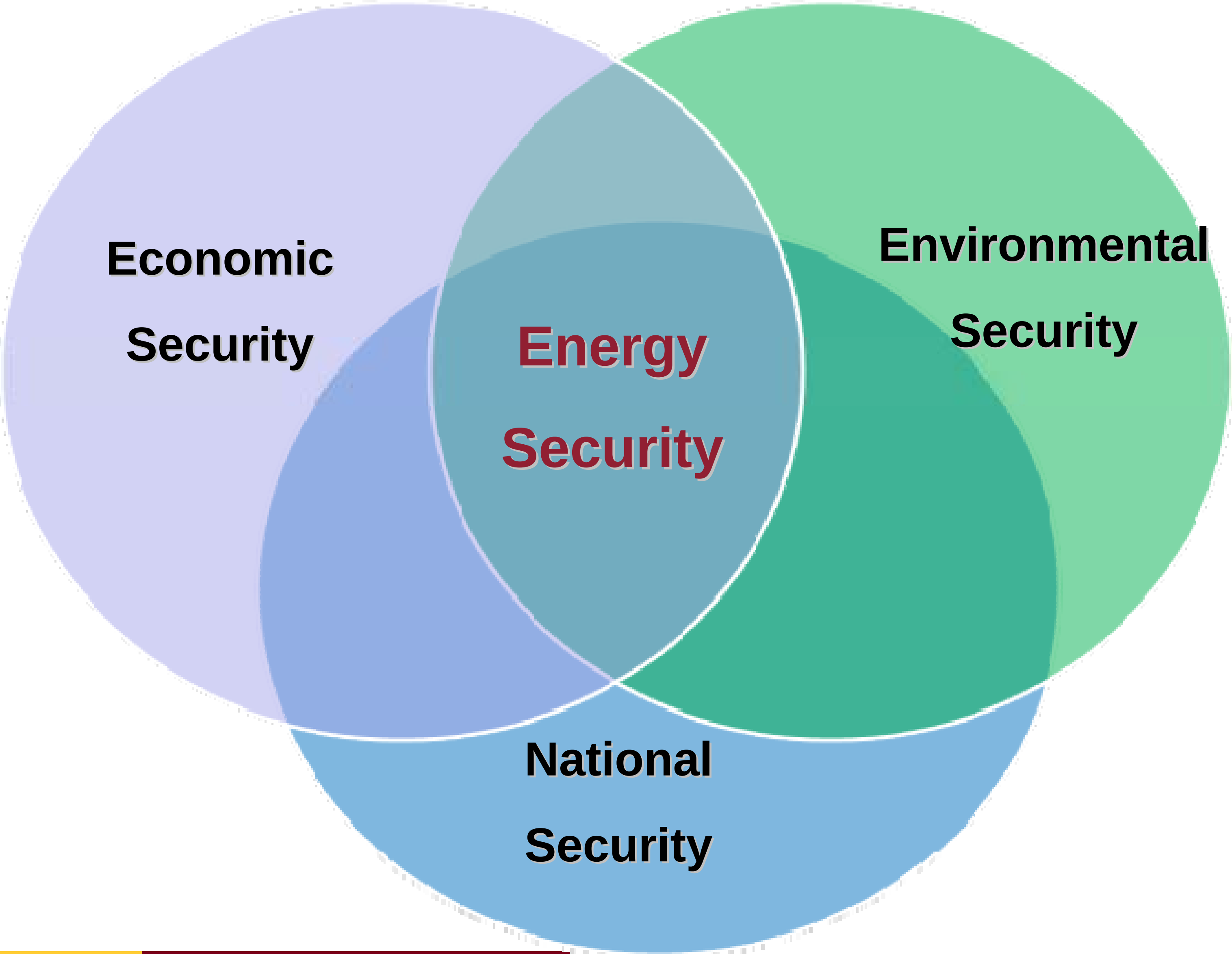
Critical System Dynamics and Capabilities

- **Anticipation of disruptive events**
- **Look-ahead simulation capability**
- **Fast isolation and sectionalization**
- **Adaptive islanding**
- **Self-healing and restoration**

re·sil·ience, *noun,* 1824:
The capability of a strained body to recover its size and shape after deformation caused especially by compressive stress;
An ability to recover from or adjust easily to misfortune or change

Resilience enables "Robustness": A system, organism or design may be said to be "robust" if it is capable of coping well with variations (internal or external and sometimes unpredictable) in its operating environment with minimal damage, alteration or loss of functionality.

The Energy Nexus
What we've learned from Energy Crises



Source: RAND

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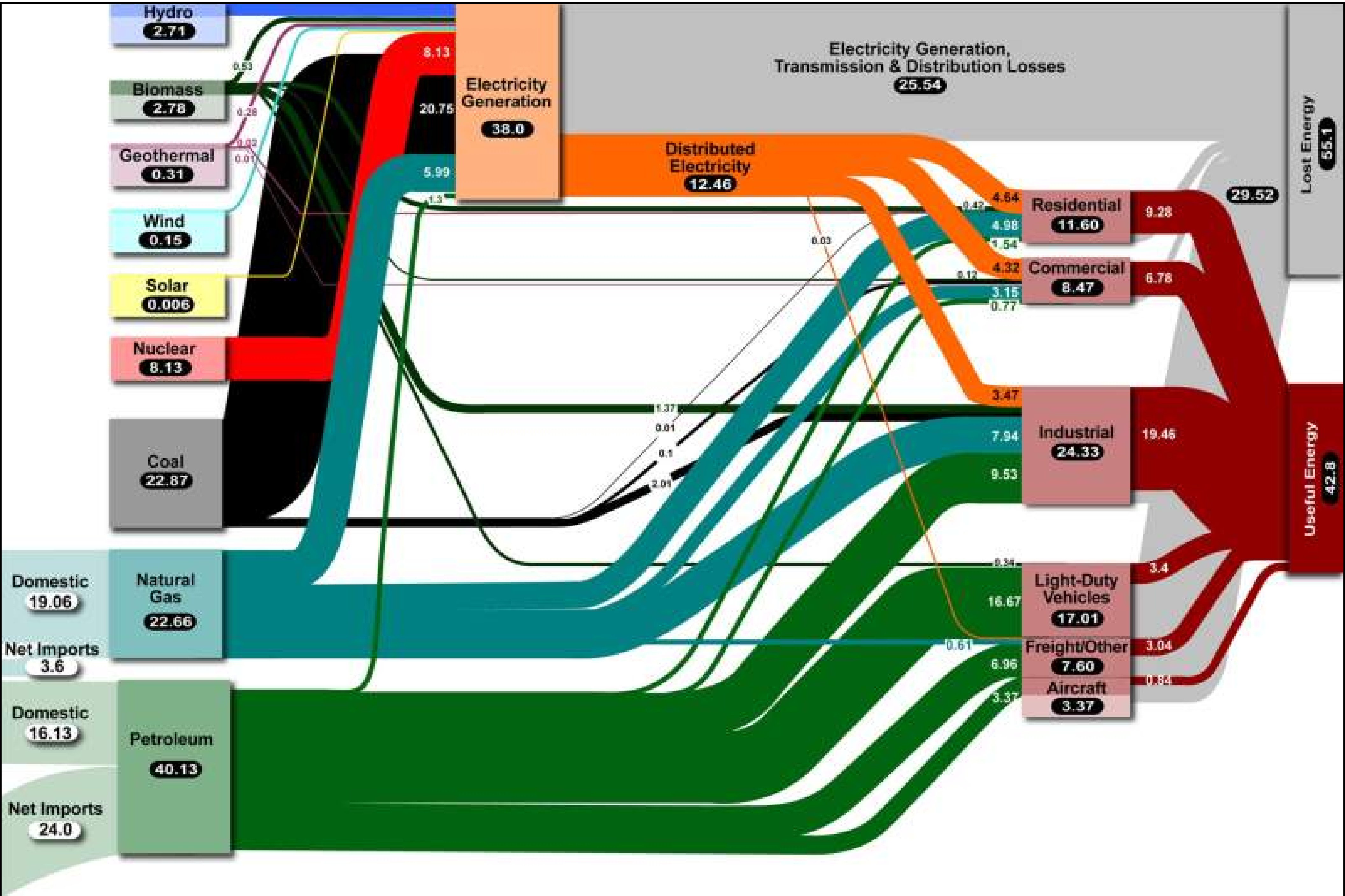

Energy map adapted from the U.S. DOE and LBNL

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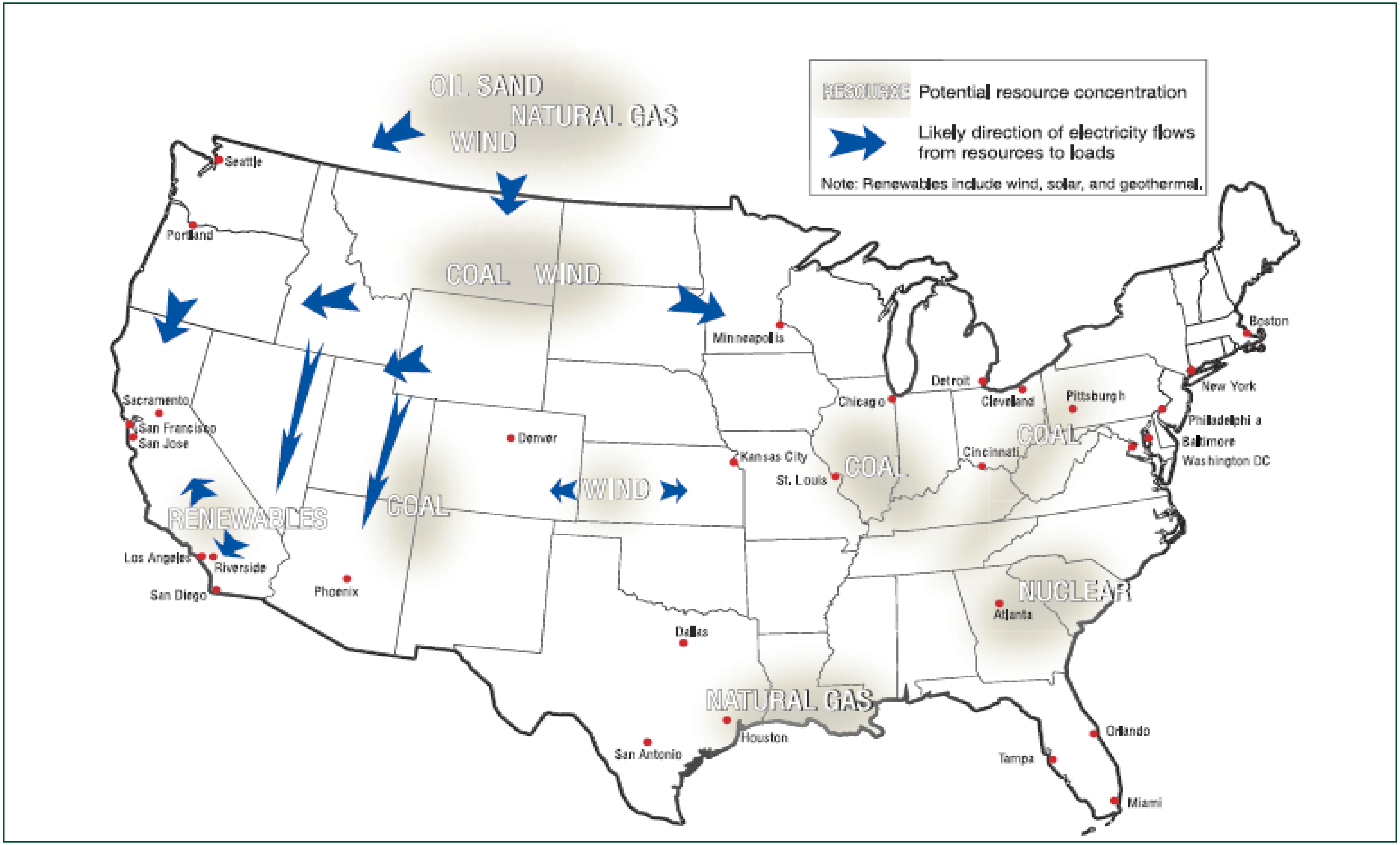
Goals and Recommendations

- **Building a stronger and smarter electrical energy infrastructure**
  - Transforming the Network into a Smart Grid
  - Developing an Expanded Transmission System
  - Developing Massive Electricity Storage Systems
- **Breaking our addiction to oil by transforming transportation**
  - Electrifying Transportation: Plug-In Hybrid Electric Vehicles
  - Developing and Using Alternative Transportation Fuels
- **Greening the electric power supply**
  - Expanding the Use of Renewable Electric Generation
  - Expanding Nuclear Power Generation
  - Capturing Carbon Emissions from Fossil Power Plants
- **Increasing energy efficiency**

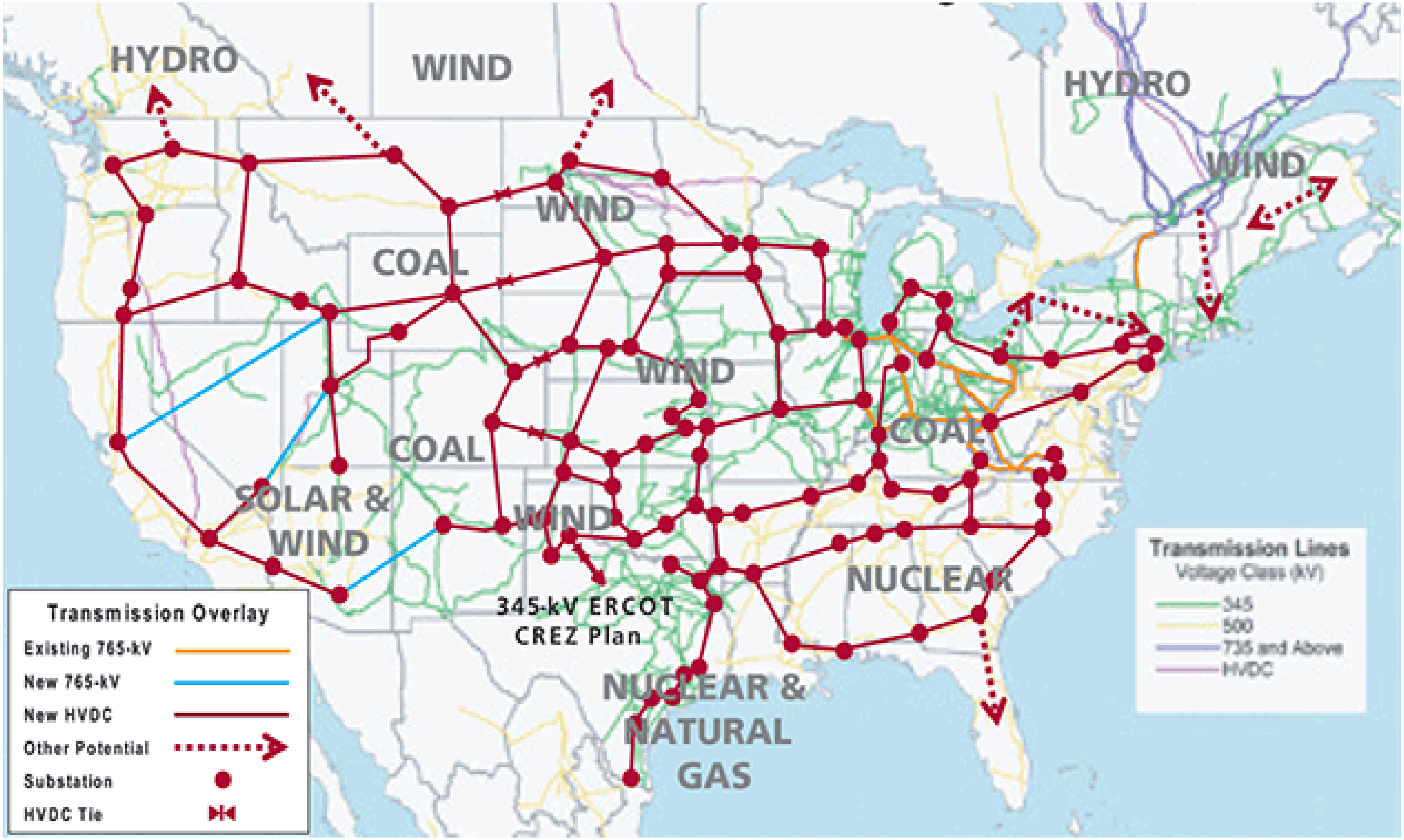
Source: M. Amin's briefing at the Congressional R&D Caucus, March 26, 2009, and IEEE Energy Policy Committee, 2009

Context: New patterns in power delivery



Map adapted from the U.S. DOE National Electric Transmission Congestion Study

Enabling a Stronger Grid



Map adapted from the U.S. DOE National Electric Transmission Congestion Study

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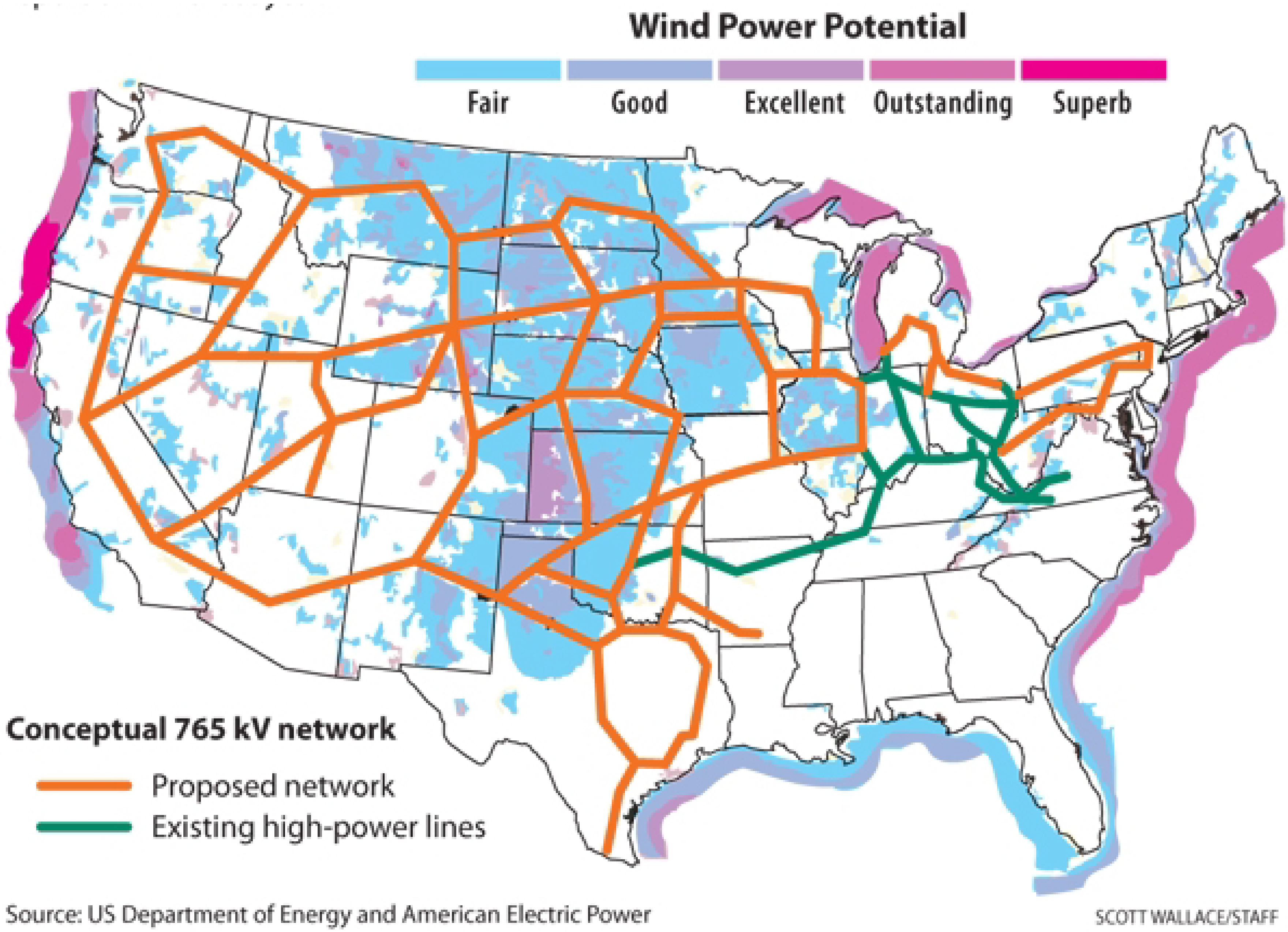
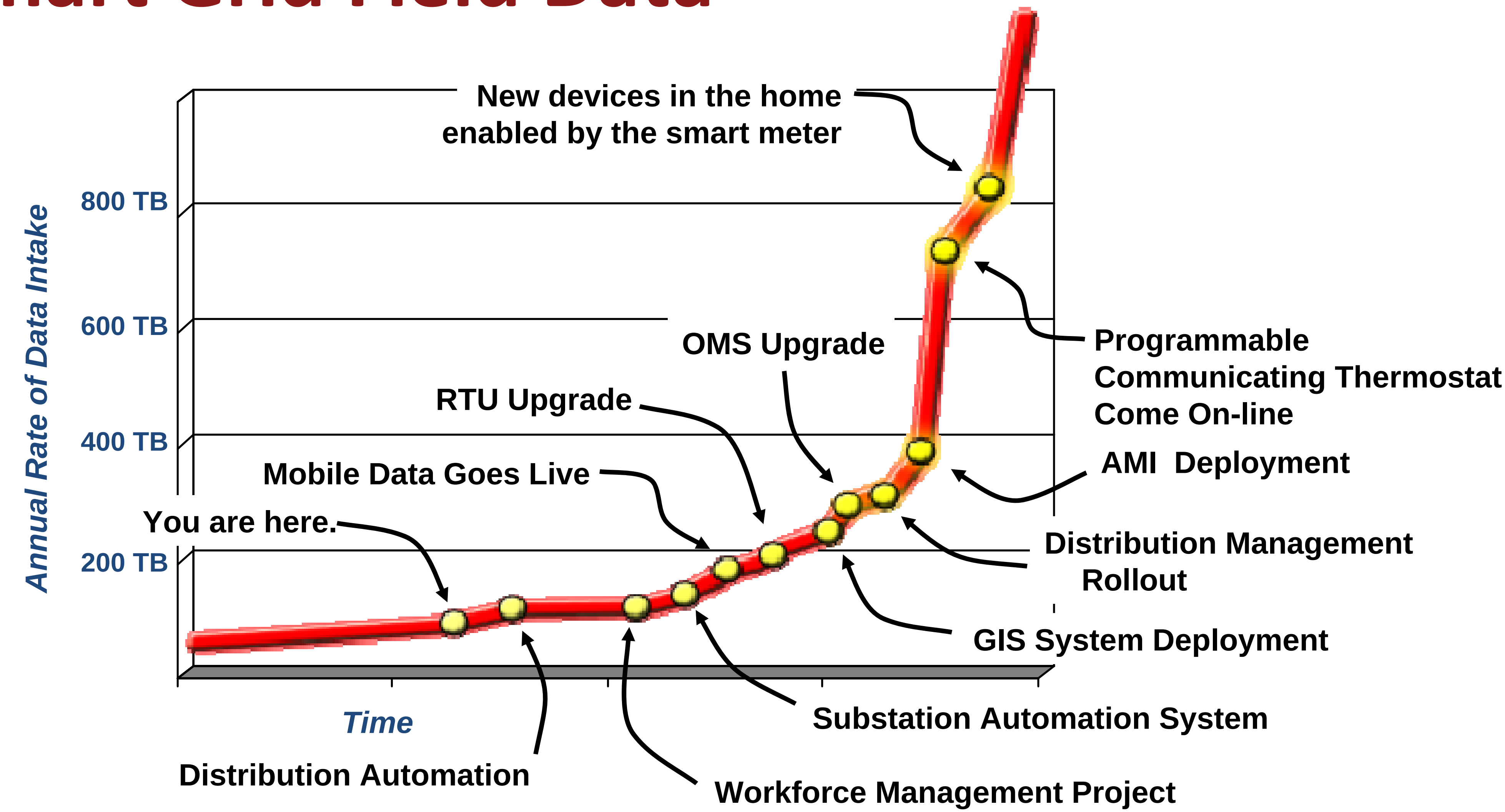
AEP 765 KV PLAN



Smart Grid

Smart Grid Field Data

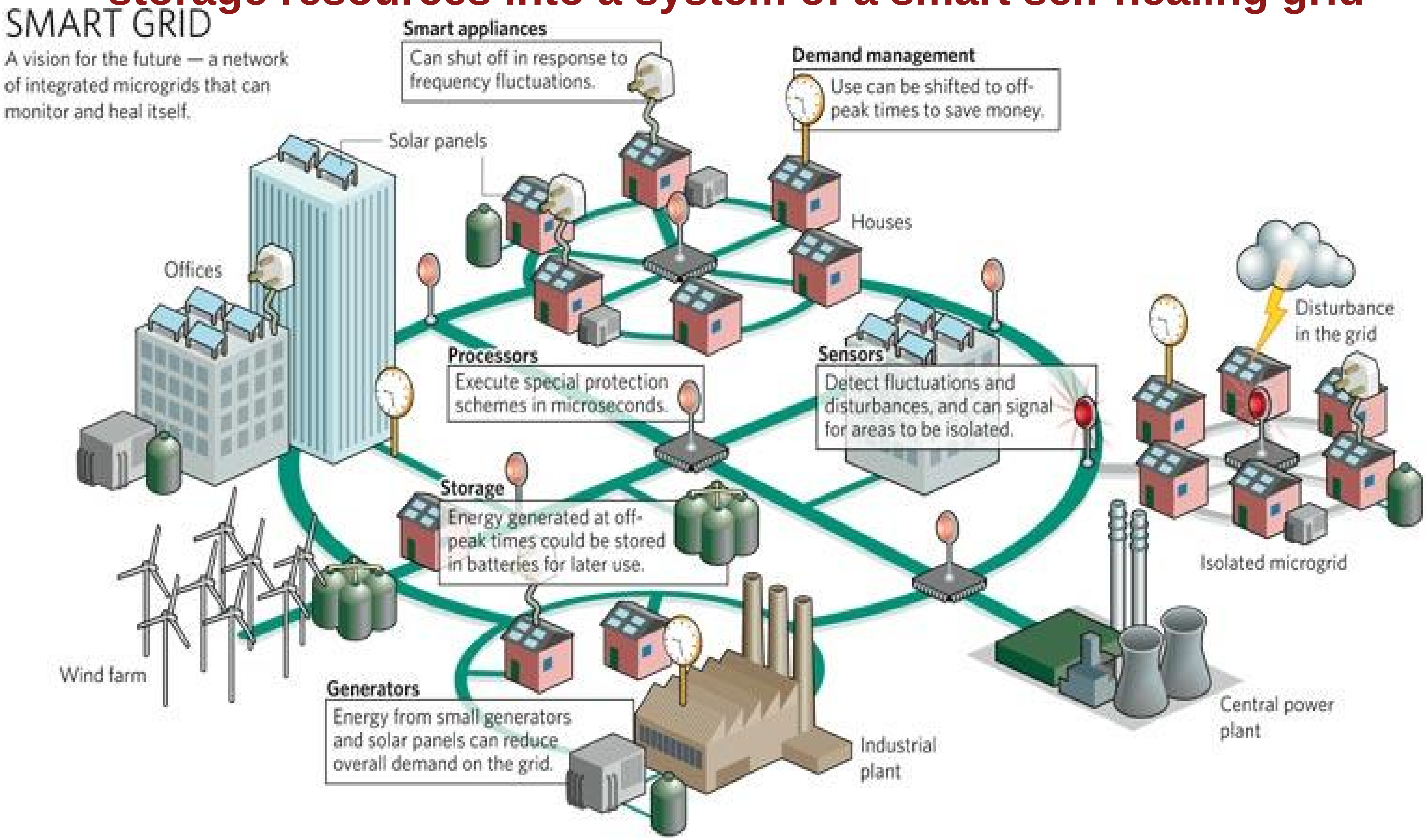


Tremendous amount of data coming from the field in the near future - paradigm shift for how utilities operate and maintain the grid

Source: EPRI

Our Goal: Enabling the Future

Infrastructure integration of microgrids and diverse generation and storage resources into a system of a smart self-healing grid



Source: Interview with Massoud Amin, "Upgrading the grid," *Nature,* vol. 454, pp. 570–573, 30 July 2008

Summary of numbers: Direct Spending

- **Total Direct Spending for Renewable Energy and Energy Efficiency:** The bill provides $16.8 billion in direct spending for renewable energy and energy efficiency programs over the next ten years.
- **Grid Development:** The bill provides $4.5 billion to modernize the nation's electricity grid with smart grid technology. The bill increases federal matching grants for the Smart Grid Investment Program from 20% to 50%.
- **R&D, Demonstration Projects:** The bill provides $2.5 billion for renewable energy and energy efficiency R&D, demonstration and deployment activities.
- **Federal Power Marketing Administrations:** The bill provides $6.5 million for capital investments by certain federal power marketing administrations in electric power transmission systems.
- **Advanced Battery Grants:** The bill provides $2 billion for grants for the manufacturing of advanced batteries and components. This includes the manufacturing of advanced lithium ion batteries, hybrid electrical systems, component manufacturers, and soft-ware designers.
- **Defense Energy and Efficiency Programs:** The bill provides $300 million to the DOD for the purpose of research, testing and evaluation of projects to energy generation, transmission and efficiency. The bill provides an additional $100 million for Navy and Marine Corps facilities to fund energy efficiency and alternative energy projects.
- **Study of Electric Transmission Congestion:** The bill requires the Secretary of Energy to include a study of the transmission issues facing renewable energy in the pending study of electric transmission congestion that is due to be issued in August 2009.

Summary of numbers: Tax Incentives

Three-Year Extension of PTC: The bill provides a three-year extension of the Production Tax Credit (PTC) for electricity derived from wind facilities through December 31, 2012, as well as for geothermal, biomass, hydropower, landfill gas, waste-to-energy and marine facilities through December 31 2013.

Investment Tax Credit (ITC) Accessible to All Renewable Energy: The bill provides project developers of wind, geothermal, biomass and other technologies eligible for the PTC, the option of instead utilizing the 30% ITC that previously only applied to solar and other clean technology projects.

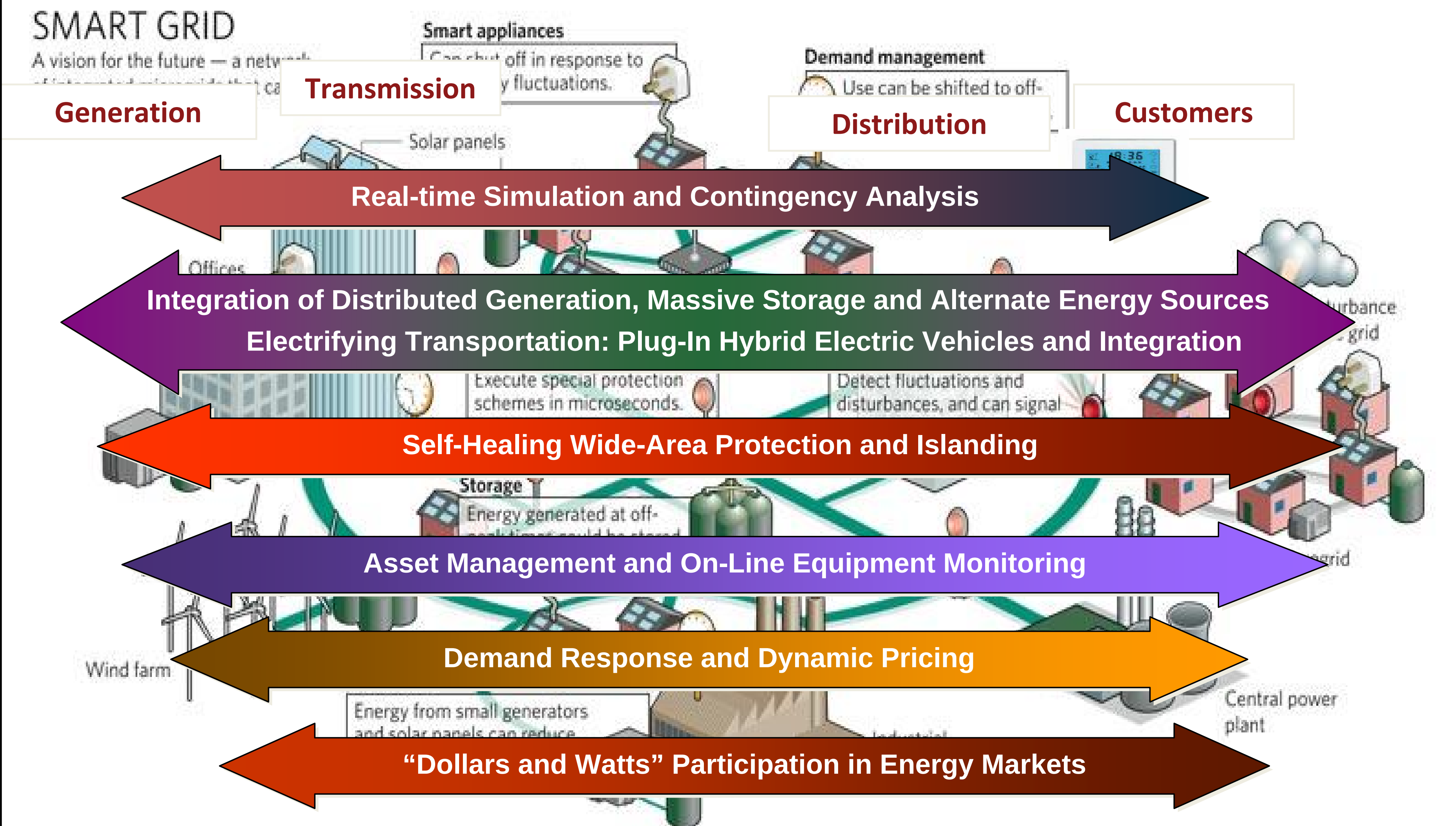
Advanced Energy Manufacturing Credits: The bill provides $2 billion worth of energy related manufacturing investment credits at a 30% rate. These credits apply to projects creating or retooling manufacturing facilities to make components used to generate renewable energy, storage systems for use in electric or hybrid-electric cars, power grid components supporting addition of renewable sources, and equipment for carbon capture and storage (CCS).

Plug-in Electric Drive Vehicle Credit: The bill increases the tax credit for qualified plug-in electric drive vehicles for the first 200,000 placed in service. The base amount of the credit is $2500. Batteries with at least 5 kilowatt hours of capacity have a credit of $2917. The credit is further increased by $417 for every kilowatt hour in excess of 5 kilowatt hours, but cannot exceed $5000.The credit is allowed to be taken against the alternative minimum tax.

Related on-going R&D include

- EPRI: UCA, CIN/SI, Intelligrid, Fast Simulation and Modeling
- Initiatives at several utilities, including Xcel, AEP, Austin Energy, SCE, PG&E, ISOs, and also in companies including GE, Honeywell, IBM, Siemens, etc.
  - Austin Energy journey as an example:
    - Delivering SG1.0 (power plant - transmission, distribution - meter - customer info/bill and back) by August 2009 for 1 million consumers, 43,000 businesses, 440 square miles, 500,000 devices, and 100 terabytes.
    - Planning SG 2.0 (SG 1.0 integration to Smart Appliances, Distributed Generation, Storage, and Plug-in Hybrid EVs - EVs) via the Pecan Street Project - www.pecanstreetproject.org
- Energy Bill passed in December 2007: Title XIII Smart Grid, Sections 1301 -1309
  - Establishes a statement of policy supporting modernization of the grid; authorizes a biennial status report and survey of barriers to modernization
- US Department of Energy: Gridwise and Modern Grid Initiatives
- University of Minnesota Center for Smart Grid Technologies

Enabling a Stronger and Smarter Grid



Observations

- Critical importance of **consumer empowerment** and end-to-end system modernization

- If the transformation to smart grid is to produce real strategic value for our nation and all its citizens, our goals must include:
  - To seamlessly integrate and optimize electricity supply and demand, and
  - To enable every building and every node to become an efficient and smart energy node.

- Considerable effort is focused on interstate transmission, on incremental improvements and maintaining the regulated monopoly service status-quo to avoid stepping on states' rights.
  - This will inevitably undermine most of the real smart grid value by continuing the business as usual of the past, rather than for enhancing the reliability, efficiency, security and quality of consumer services.

Policy, Science and Technology Must Support This Transformation: Recommendations

- Establish the "Smart Grid" and "self-healing" interdependent infrastructure security & protection as national priorities
- Authorize increased funding for R&D and demonstrations of the "Smart Grid", and interdependency R&D, resilience/security
- Revitalize the national public/private electricity infrastructure partnership needed to fund the "Smart Grid" deployment

M. Amin's briefing at the U.S. Congressional R&D Caucus (www.researchcaucus.org) on March 26, 2009

Enabling a Stronger and Smarter Grid:

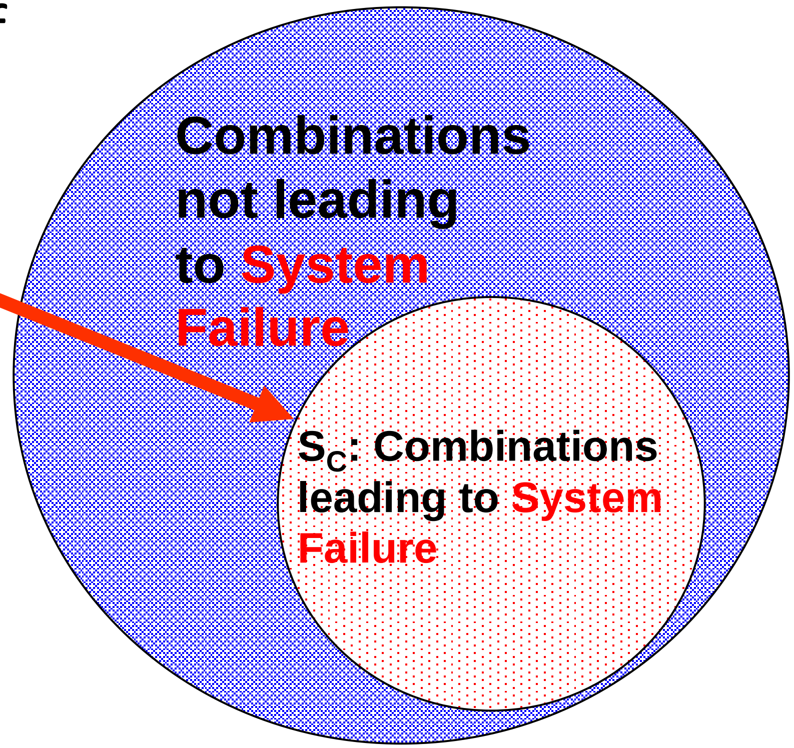
- Broad range of R&D including end-use and system efficiency, electrification of transportation, stronger and smarter grid with massive storage
- Sensing, Communications, Controls, Security, Energy Efficiency and Demand Response *if architected correctly* could assist the development of a smart grid
- Smart Grid Challenge/Opportunity areas include:
  - Distributed Control
  - Grid Architectures
  - Cyber Security

M. Amin's briefing at the U.S. Congressional R&D Caucus (www.researchcaucus.org) on March 26, 2009

Another Persisting Challenge

(Massoud Amin)

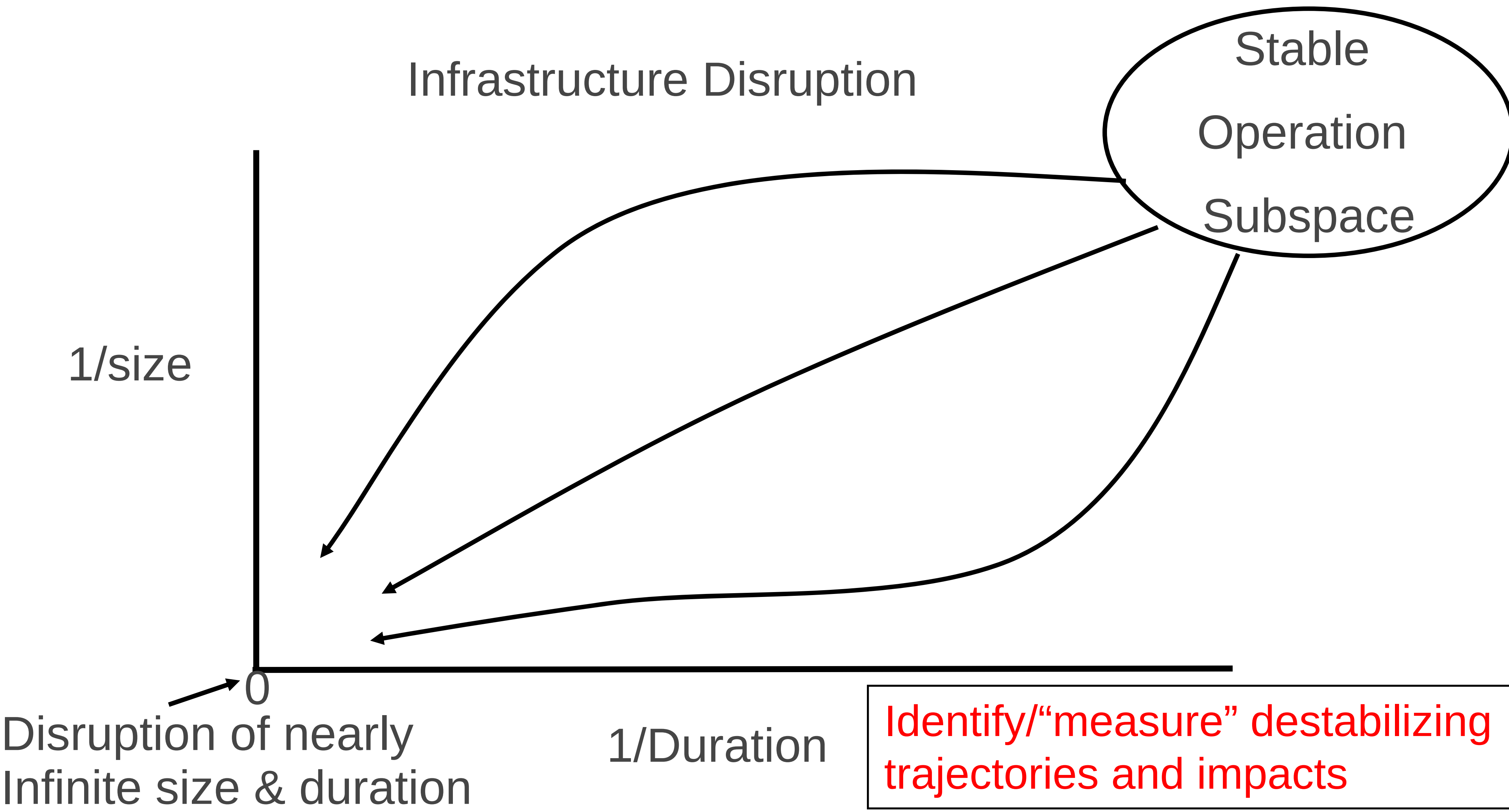
- Enhancing Reliability and Security of Network Operation via quantification of the system state and its "direction/ speed/momentum" toward a major failure
- Making Network Availability (quick restoration) a key requirement
- Introducing Quality of Service as an additional constraint
- Ultimately, enabling operators to act more efficiently and with greater confidence in difficult (sometimes unclear, unexpected or even conflicting) circumstances



Which trajectories lead to catastrophic failures?

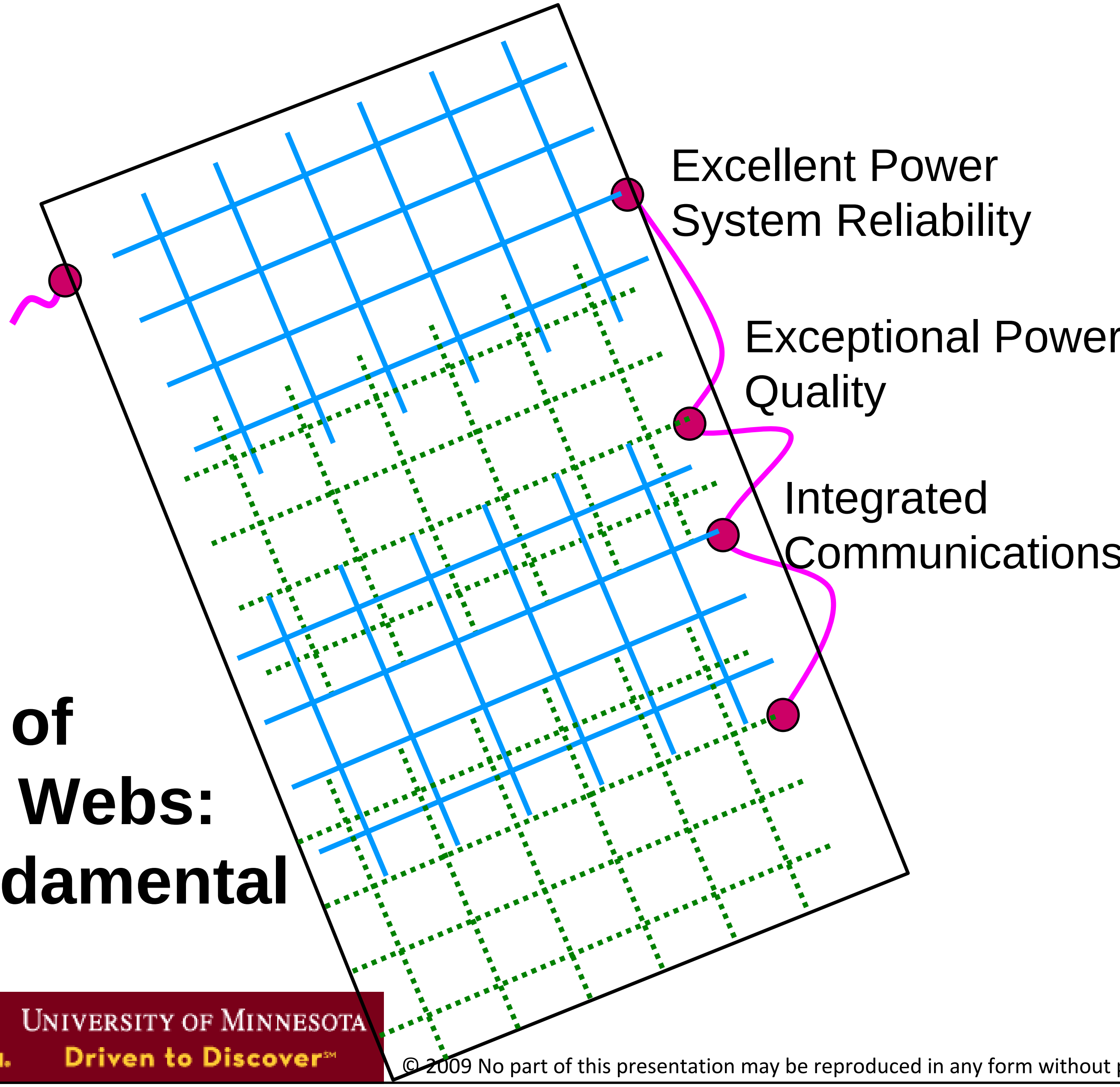
An Assessment Methodology

(Massoud Amin)



Identify/“measure” destabilizing trajectories and impacts

The Infrastructure for a Digital Society



A Complex Set of Interconnected Webs: Security is Fundamental


LEADERSHIP

Bottom Line:

"Only three things happen naturally in organizations:
friction, confusion and underperformance.
Everything else requires leadership."

-- Peter Drucker

Discussion and the Road Ahead:

- What are the key energy and security issues facing the world, our nation, regions, and cities?
  - **What is your vision for the future–what will it like or how will it perform in 2010-2020?**
  - **What are the difficult challenges to overcome to achieve your vision?**
  - **What enabling technologies and policies are needed to address these?**
  - **What critical issues should we consider in beginning plans for 2010 and beyond?**

Selected References

Downloadable at: http://umn.edu/~amin

"For the Good of the Grid: Toward Increased Efficiencies and Integration of Renewable Resources for Future Electric Power Networks," IEEE Power & Energy, Vol. 6, Number 6, pp. 48-59, Nov/Dec 2008

"The Electric Power Grid: Today and Tomorrow," MRS Bull., Vol. 33, No. 4, pp. 399-407, April 2008

"Preventing Blackouts," Scientific American, pp. 60-67, May 2007

"Powering the 21st Century: We can -and must- modernize the grid," IEEE Power and Energy Magazine, pp. 93-95, March/April 2005

"North American Electricity Infrastructure: Are We Ready for More Perfect Storms? ," IEEE Security and Privacy, Vol. 1, no. 5, pp. 19-25, Sept./Oct. 2003


May others benefit
from your lead.
Thank you