The Smart Grid Landscape: What's on the Horizon?

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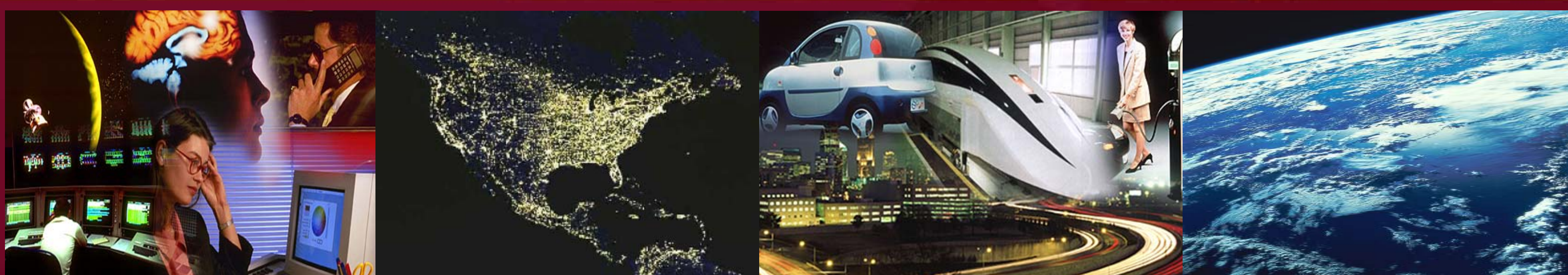

Keynote address at the Building a Smart Grid Coalition in Minnesota Workshop
University of Minnesota, St. Paul Student Center, Northstar Ballroom
November 18, 2009 8:10-9:00 a.m.

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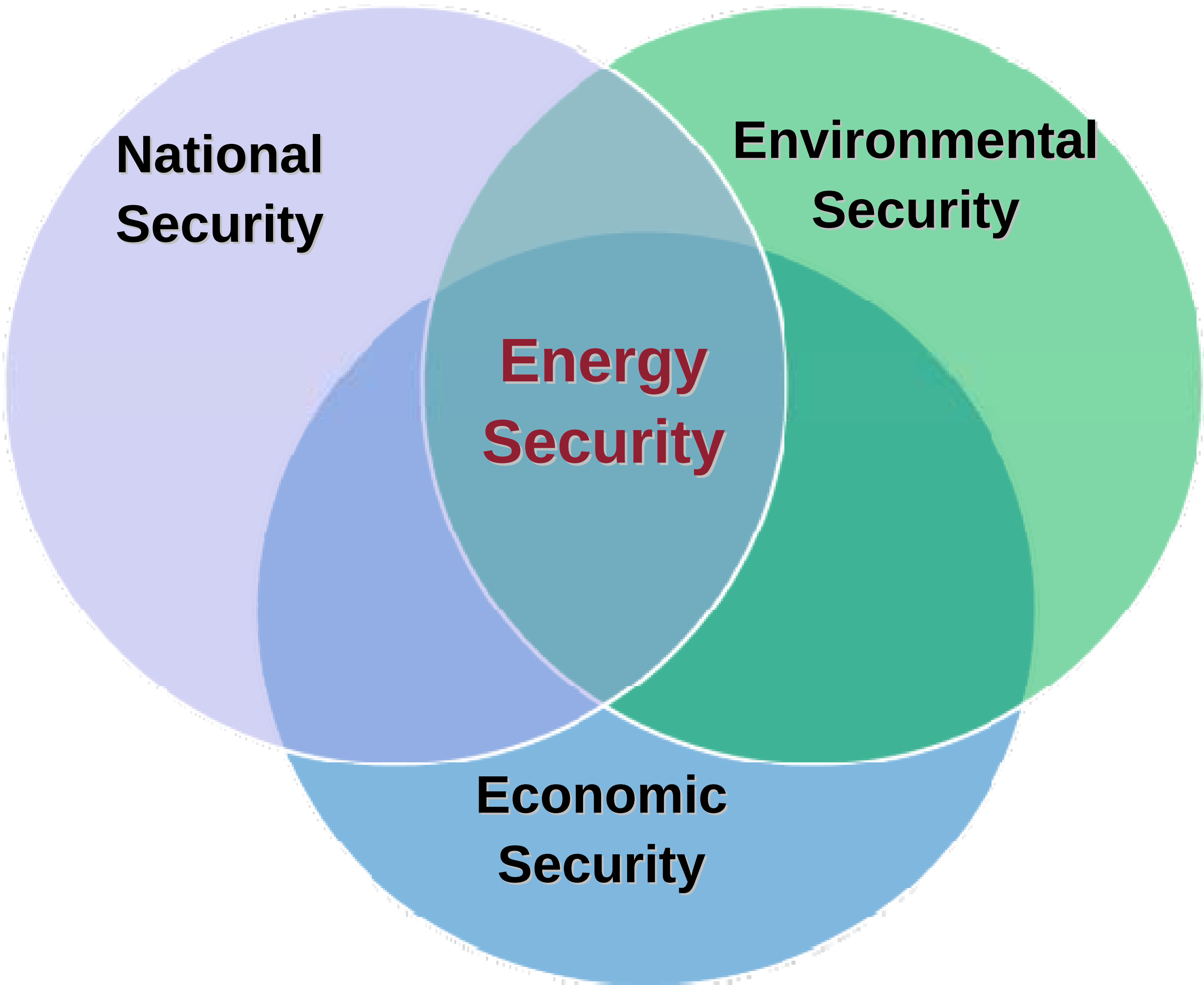
Material from the Electric Power Research Institute (EPRI), and support from EPRI, NSF, and ORNL for my graduate students' doctoral research is gratefully acknowledged

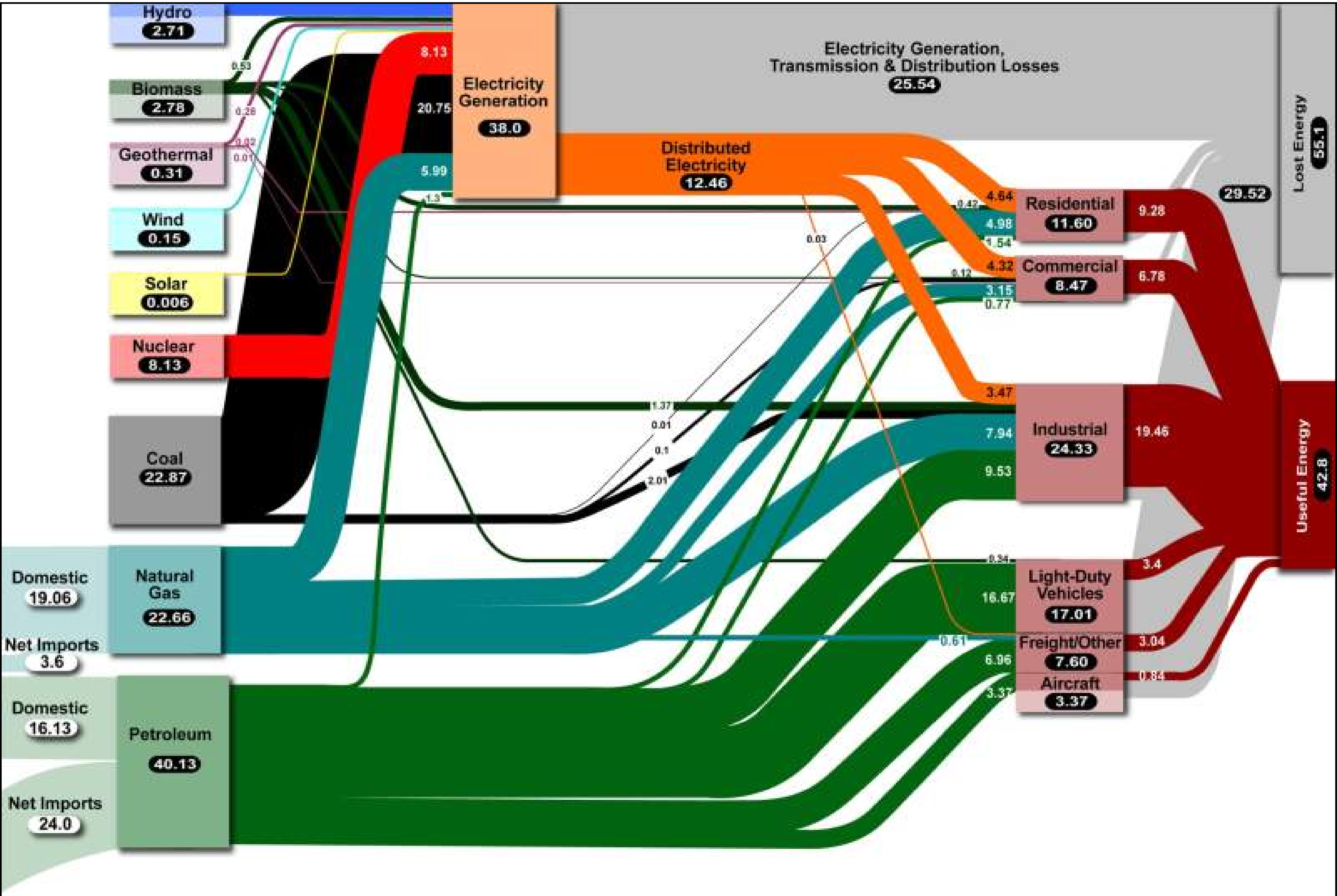
Foci

- Integration of Renewables
- Energy Efficiency
- Smart Grid Security
- Bottom Line → Economic Growth:
  - Building Minnesota's Competitive Advantage through Partnerships and Technology/Policy/Business Development

The Energy Nexus:
What we've learned from Energy Crises



Source: RAND



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

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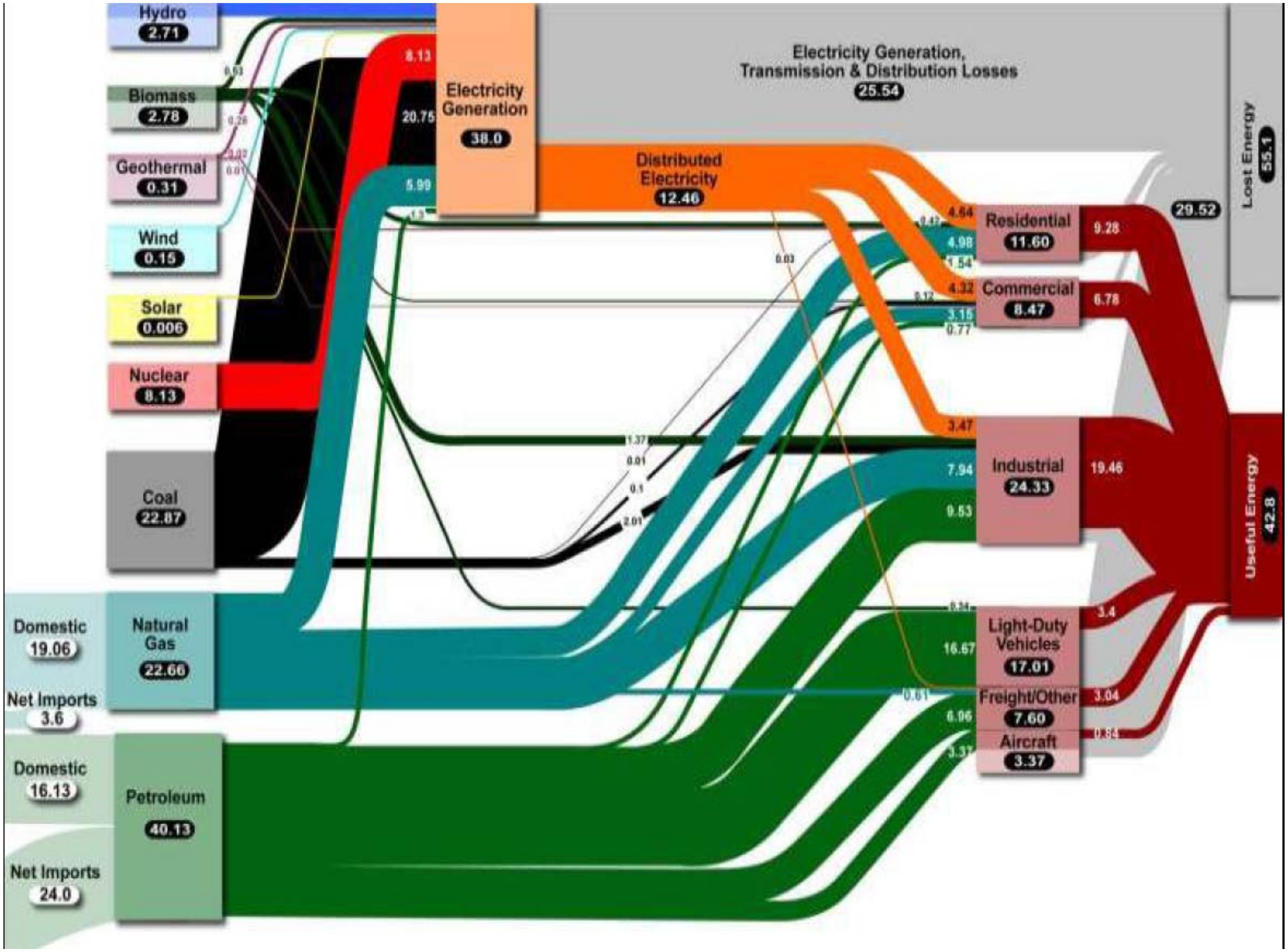
Energy Flow System in the U.S.



- Overall Energy losses in the U.S. are >55% and electricity energy losses of > 65% (due to transmission and distribution losses, there is potential to capture a lot systemic efficiencies).
- Smart Grid programs are targeted to capture 7% transmission and distribution T & D efficiencies.

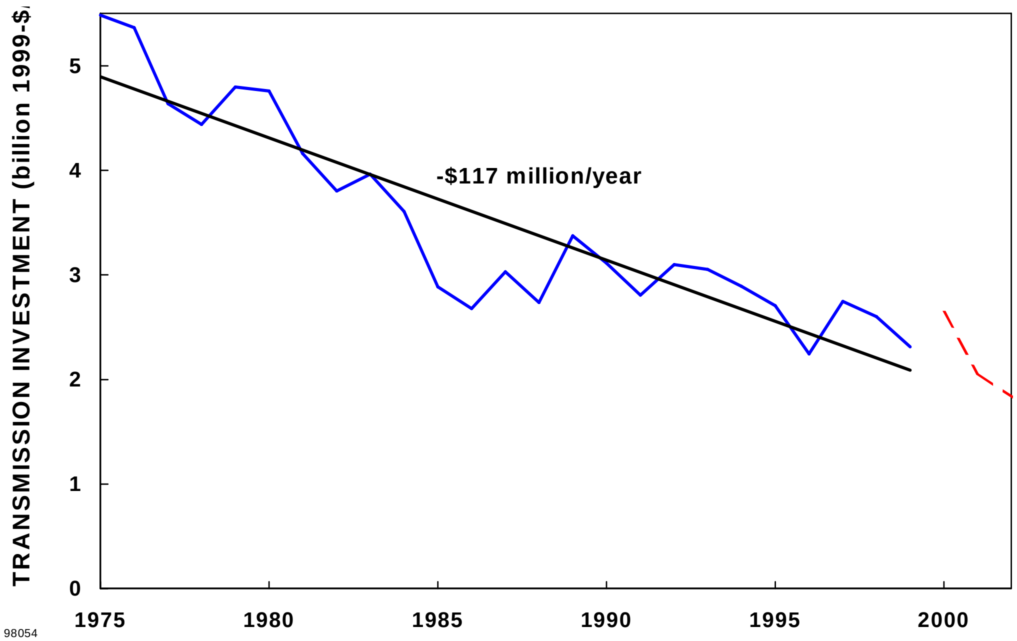
Energy map adapted from the U.S. DOE and LBNL

Goals and Recommendations

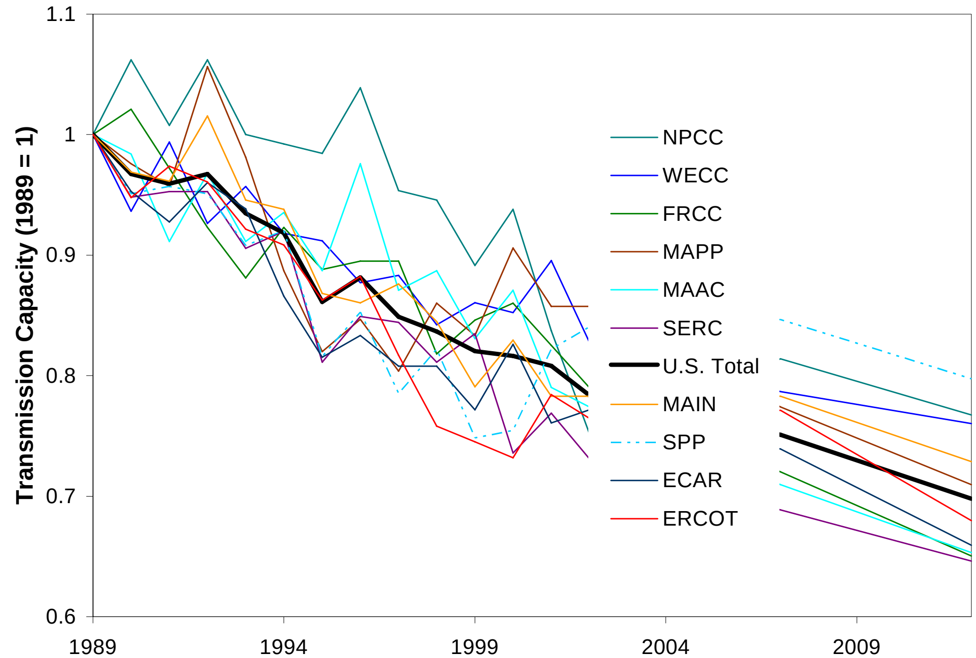
- **Building a stronger and smarter electrical energy infrastructure**
  - Transforming the Network into a Smart Grid
  - Developing an Expanded Transmission System
  - Developing Massive Electricity Storage Systems
- **Breaking our addiction to oil by transforming transportation**
  - Electrifying Transportation: 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: IEEE Energy Policy Committee, 2009, and M. Amin's briefing s at the Congressional R&D Caucus (March 26, 2009), and on Oct. 15, 2009

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.

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

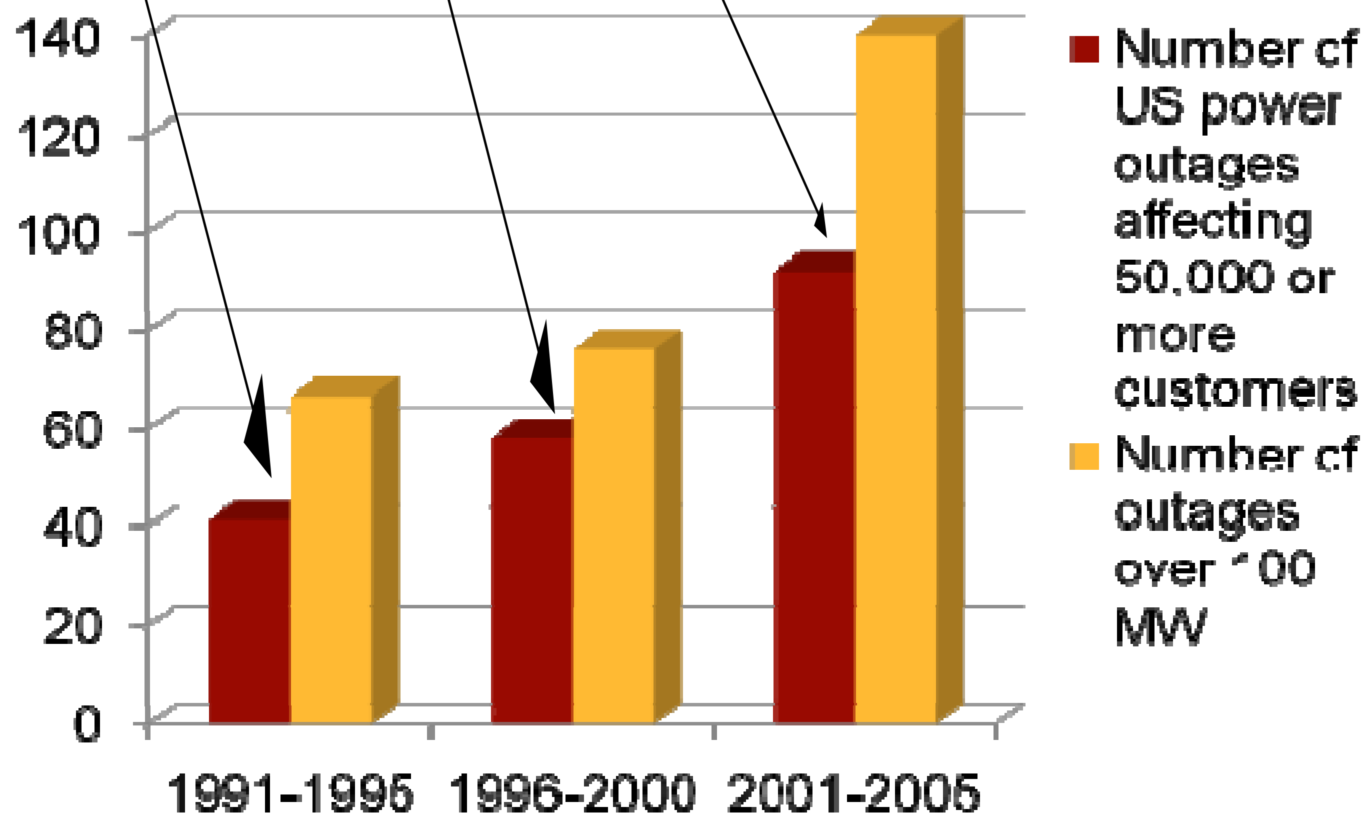
66 Occurrences over 100 MW
41 Occurrences over 50,000* Consumers

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.

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):

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)**

Underpinnings of Interdependent Critical National Infrastructures

Tools that enable secure, robust & reliable operation of interdependent infrastructures with distributed intelligence & self-healing

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

Response to 9/11 Tragedies

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

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

Self-healing Lifeline Infrastructure Systems

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

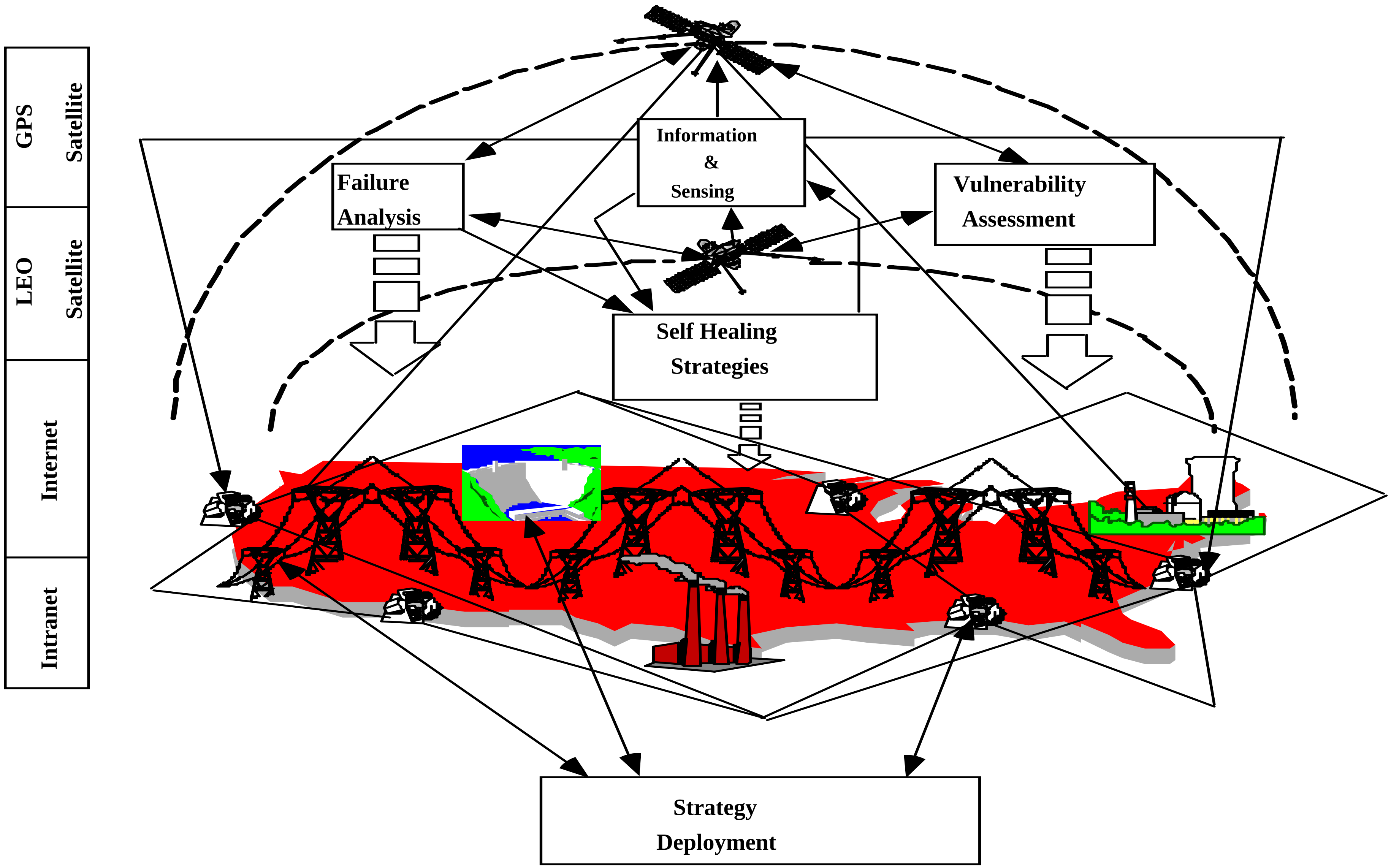
Complex interactive networks:

- **Energy infrastructure:** Electric power grids, water, oil and gas pipelines
- **Telecommunications:** Information, communications and satellite networks
- **Transportation and distribution networks**
- **Energy markets, banking and finance**

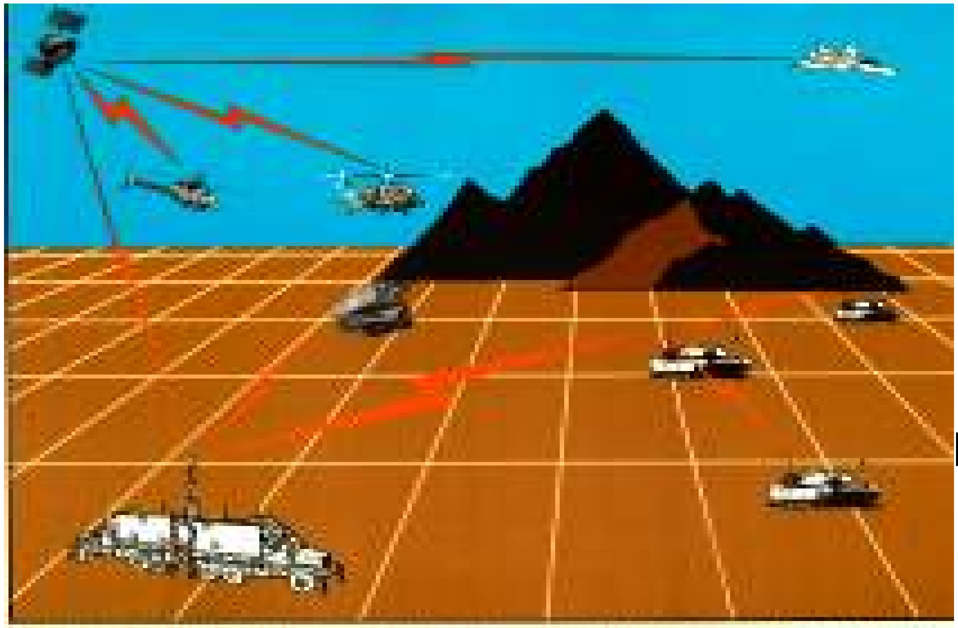
108 professors and over 240 graduate students in 28 U.S. universities were funded: Over 420 publications, and 24 technologies extracted, in the 3-year initiative

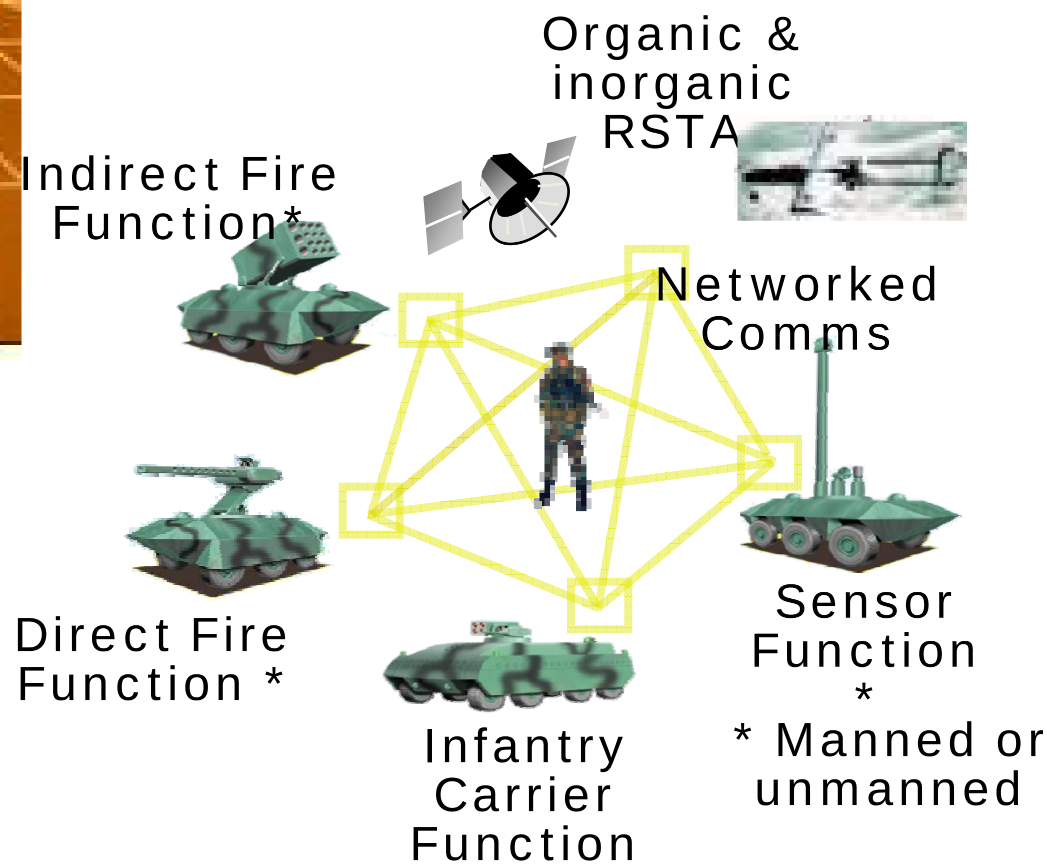
Goal: Develop tools that enable secure, robust and reliable operation of interdependent infrastructures with distributed intelligence and self-healing abilities

Complex Interactive Networks



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

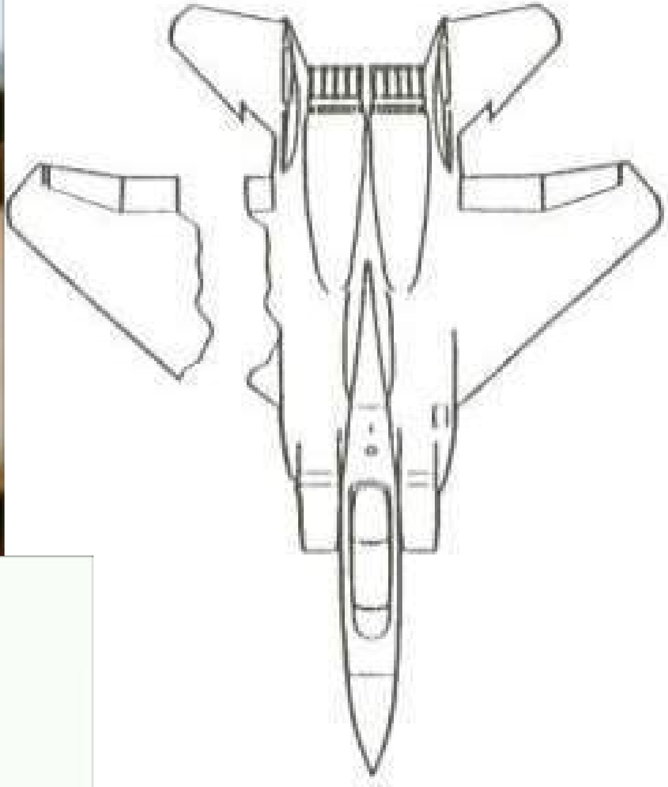
- U Washington, Arizona St., Iowa St., VPI
- Purdue, U Tennessee, Fisk U, TVA, ComEd/Exelon
- Harvard, UMass, Boston, MIT, Washington U.
- Cornell, UC-Berkeley, GWU, Illinois, Washington St., Wisconsin
- CMU, RPI, UTAM, Minnesota, Illinois
- Cal Tech, MIT, Illinois, UC-SB, UCLA, Stanford

- 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

Background:
The Self Healing Grid

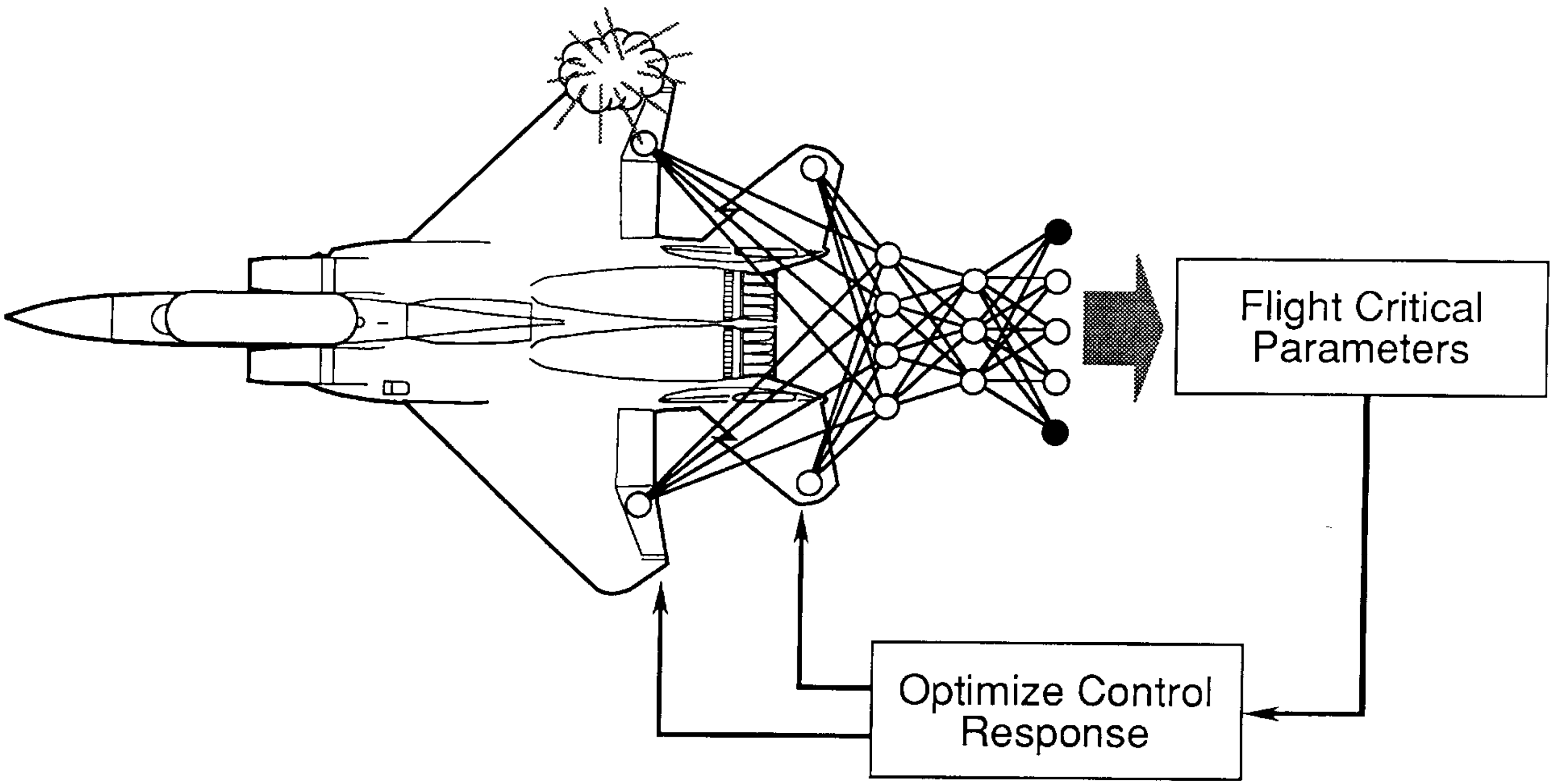
What is "self healing"?
A system that uses information, sensing, control and communication technologies to allow it to deal with unforeseen events and minimize their adverse impact

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



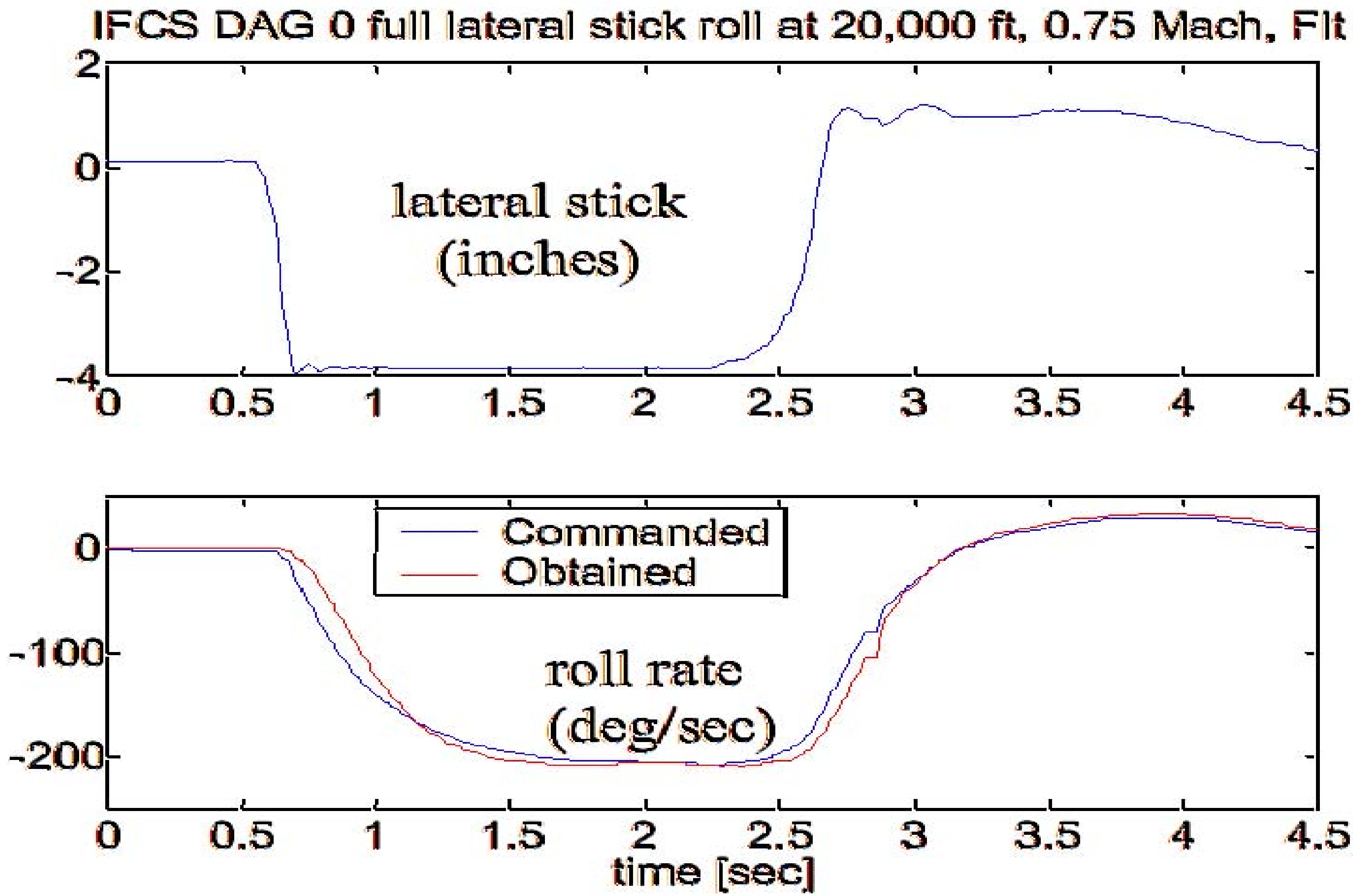
NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden, Boeing Phantom Works, and Washington University in St. Louis.

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



NASA/MDA/WU IFCS

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



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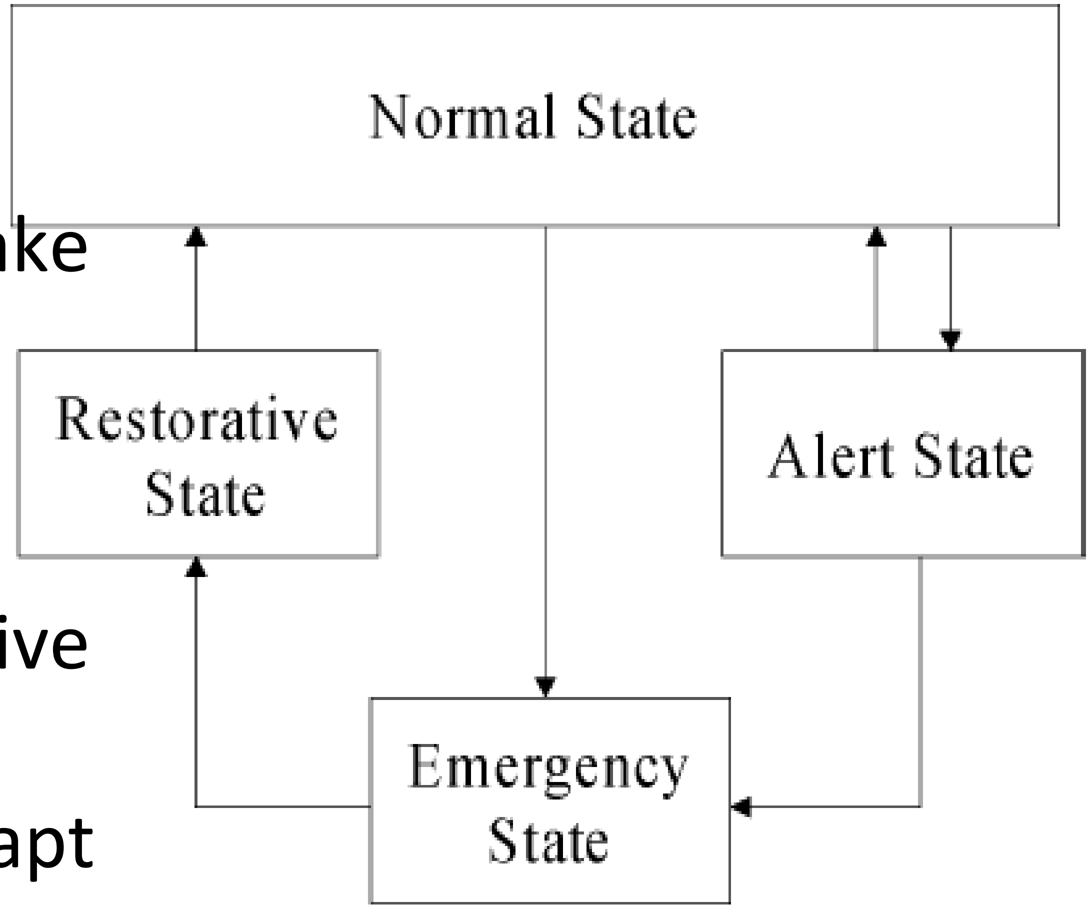
Accomplishments in the IFCS program

- 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.

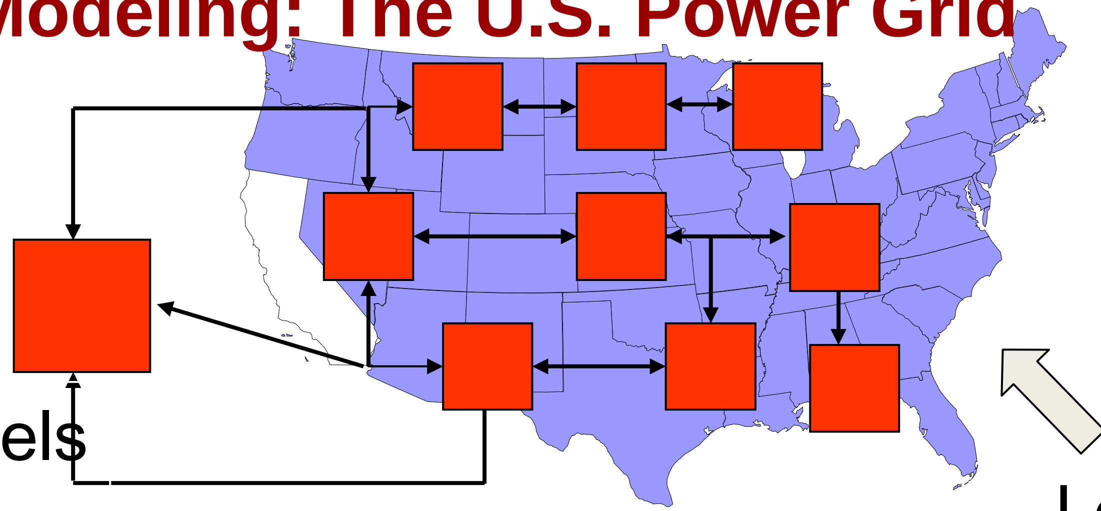
Complex Dynamical Systems

Systems have multiple "modes" during which specific operational and control actions/reactions take place

Enable complex systems to become smarter and adaptive to stressors ... detect precursors, predict, and adapt to disturbances



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



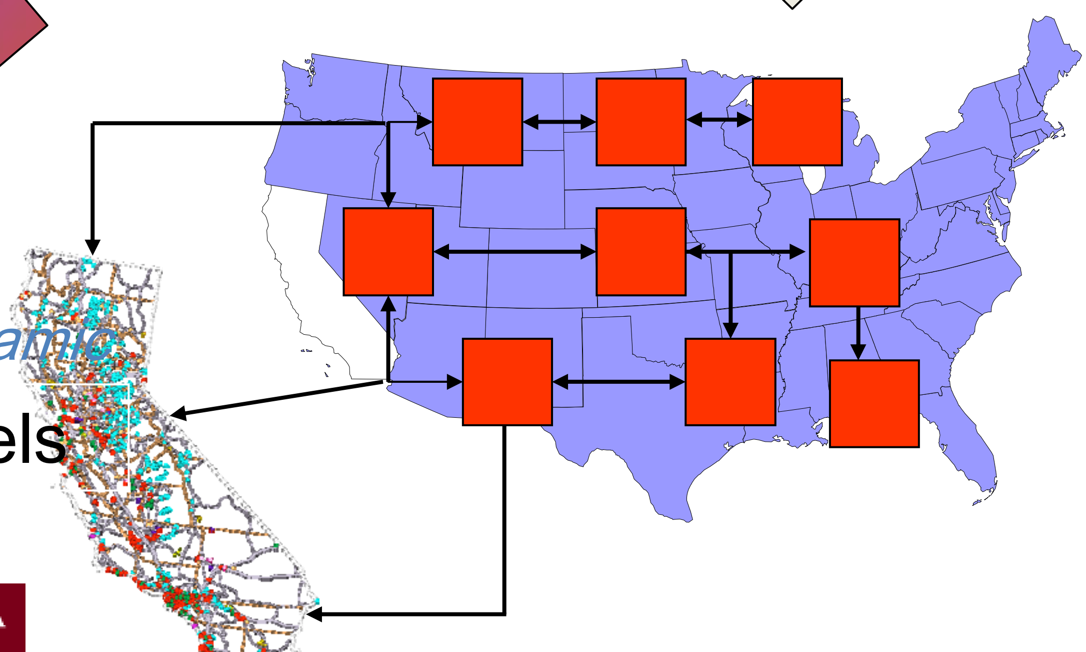
Simplified models

Low-resolution model

MODEL REDUCTION

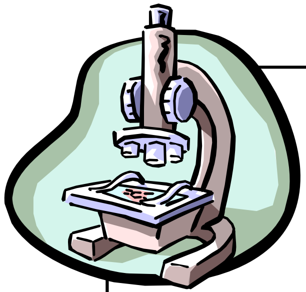
MODEL REFINEMENT

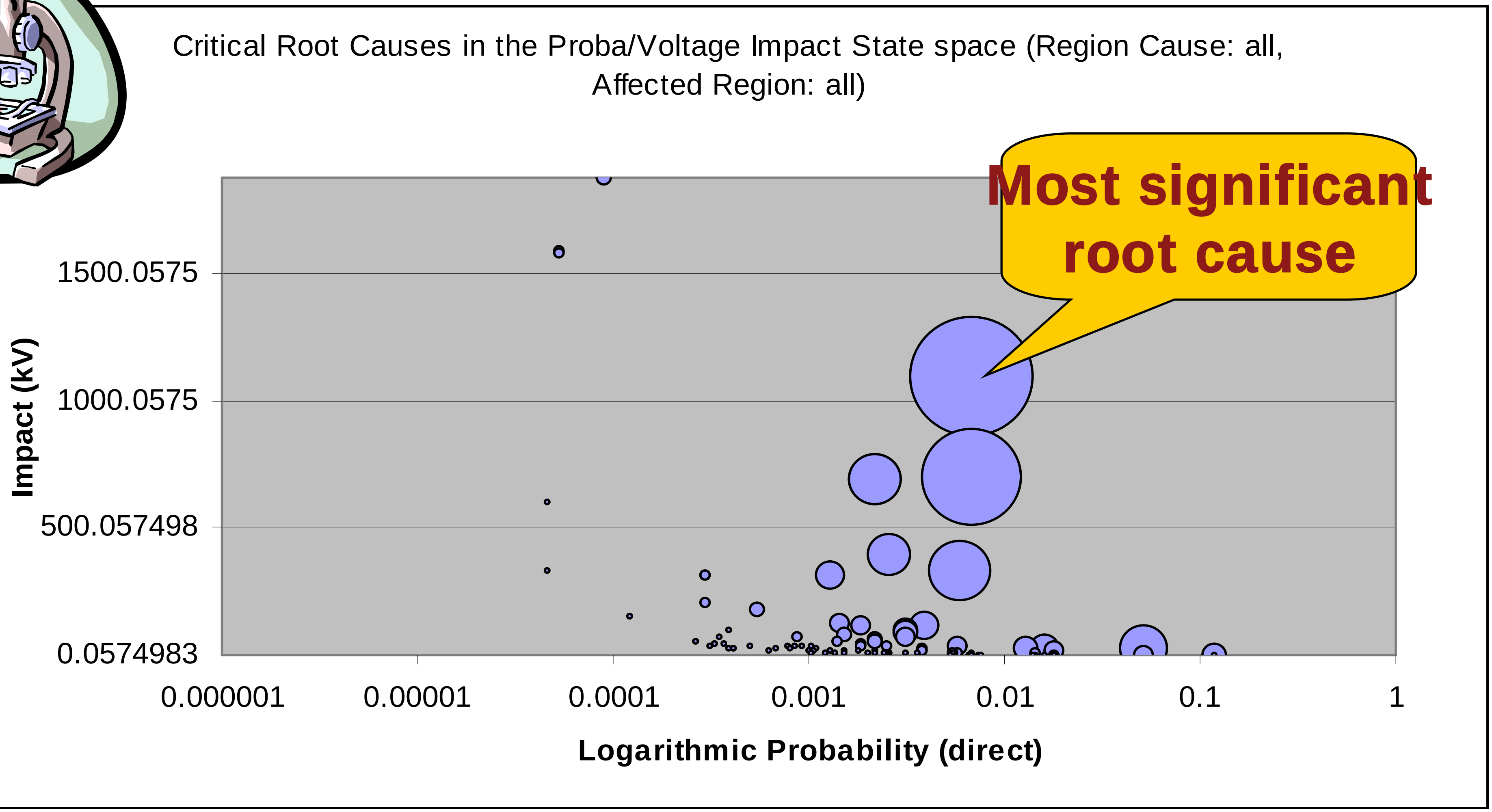
- Variable levels of details
- Lines, loads, generators are *dynamic*



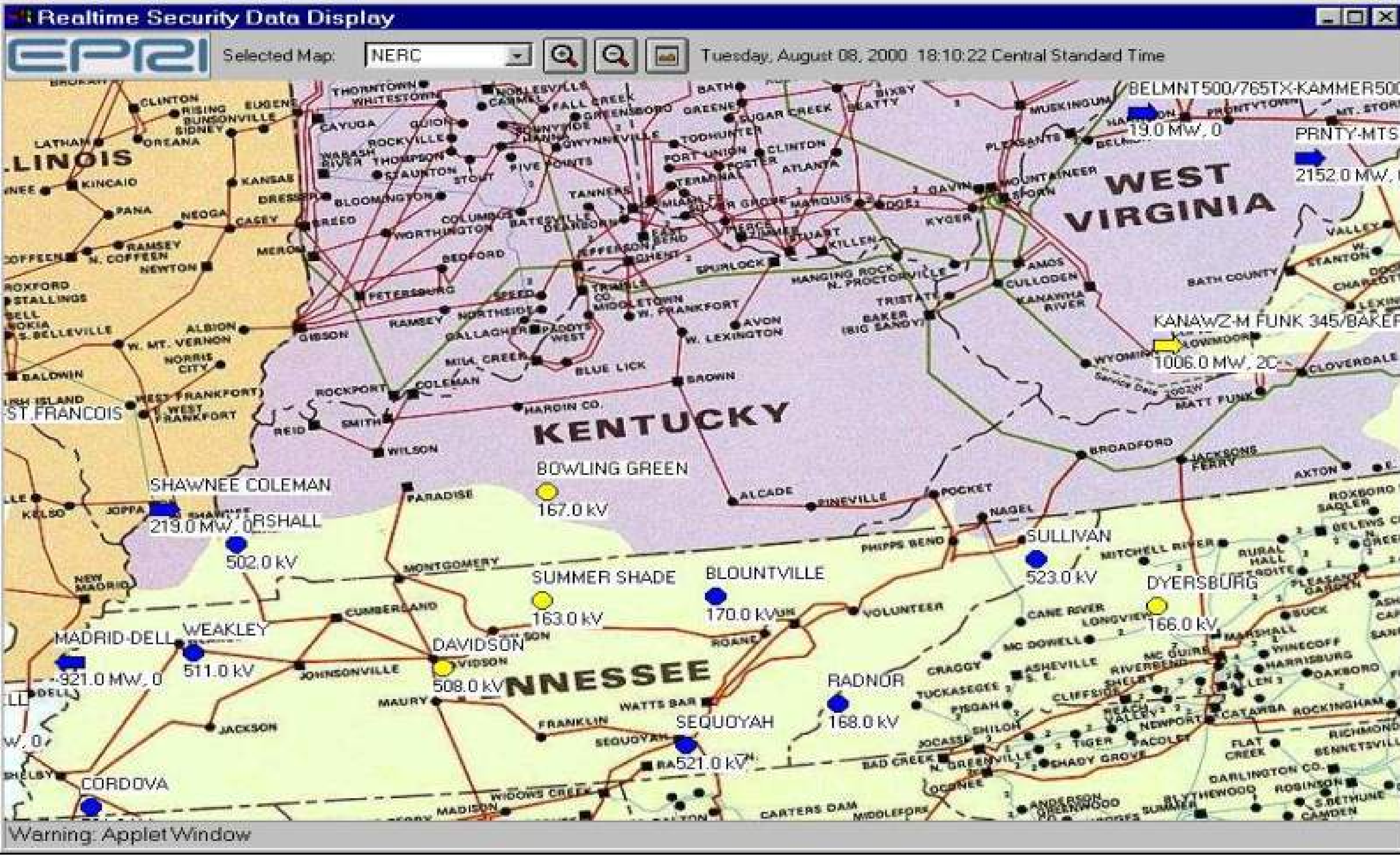
Detailed models

Example of In Depth Analysis: Critical Contingency Situations





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



Overview of Consortia Research Results:

A Canvas of R&D for Reliable and Robust Operation vs. Solution Components:

108 professors and over 240 graduate students in 28 U.S. universities funded (lead universities shown)

Challenges	**Efficient Operation**	Harvard Purdue U. Washington	Caltech Cornell Harvard Purdue	Carn. Mellon Harvard Purdue U. Washington	Caltech Carn. Mellon Cornell Harvard U. Washington	Carn. Mellon Harvard Purdue U. Washington
	Security and Robustness	Harvard Purdue U. Washington	Caltech Carn. Mellon Cornell Harvard Purdue	Caltech Carn. Mellon Harvard Purdue Washington	Caltech Carn. Mellon Cornell Harvard U. Washington	Carn. Mellon Harvard Purdue U. Washington
	Cascading Failure - single infrastructure	Harvard Purdue U. Washington	Caltech Carn. Mellon Cornell Harvard Purdue U. Washington	Caltech Carn. Mellon Cornell Harvard Purdue U. Washington	Caltech Carn. Mellon Cornell Harvard U. Washington	Carn. Mellon Cornell Purdue U. Washington
	Cascading Failure - multiple infrastructures	Harvard	Caltech Cornell	Caltech Cornell Harvard U. Washington	Cornell Harvard U. Washington	Cornell U. Washington
		Measurement & Sensing (including visualization)	**Modeling & Theory**	**Simulation**	**Control System Design**	**Operation & Management**
Solution Components						

State of Understanding about Complex Interactive Networks and Systems:

The CIN/SI represents the first systems approach to complex interactive networks, based on advancing the mathematical and theoretical foundations:

Understanding of Complex Networks in Key Challenge and Solution Component Areas before and after CIN/SI

Challenges	Solution Components: Measurement & Sensing (including visualization)		Modeling & Theory		Simulation		Control System Design		Operation & Management	
	before	after	before	after	before	after	before	after	before	after
Efficient Operation	3	4	3	4	3	3.5	3	3.5	3	3.5
Security and Robustness	2	3.5	3	4	3	4	2	4	2	3.5
Cascading Failure - single infrastructure	1	3.5	2	3	2	4	1	4	2	3.5
Cascading Failure - multiple infrastructures	1	3.5	1	3	1	4	1	4	2	3.5

Key:
1—minimal understanding
2—some understanding but insufficient for practical applications
3—partial understanding with some useful practical applications
4—solid understanding with many practical applications
5—complete (or near-complete) understanding and applicability
Shading indicates the degree that understanding advanced by CINSI research.

"Complex Interactive Networks/Systems Initiative: Final Summary Report", (Amin), 155 pp., Overview and Summary Final Report for Joint EPRI and U.S. DOD University Research Initiative, EPRI, 2003

"Development and Leadership of Research Consortia: Lessons learned and possible road ahead for continued innovation", (Amin), Proceedings of the IEEE PES Summer Conf., panel on Organizing Research Consortia, Vancouver, BC, Jul. 18, 2001

Complex Interactive Networks/Systems Initiative: Final Summary Report

Overview and Summary Final Report for Joint EPRI and U.S. Department of Defense University Research Initiative

Product ID #

Final Report, March 2003

Cosponsor
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Development and Leadership of R&D Consortia: Lessons learned and possible road ahead for continued innovation[1]

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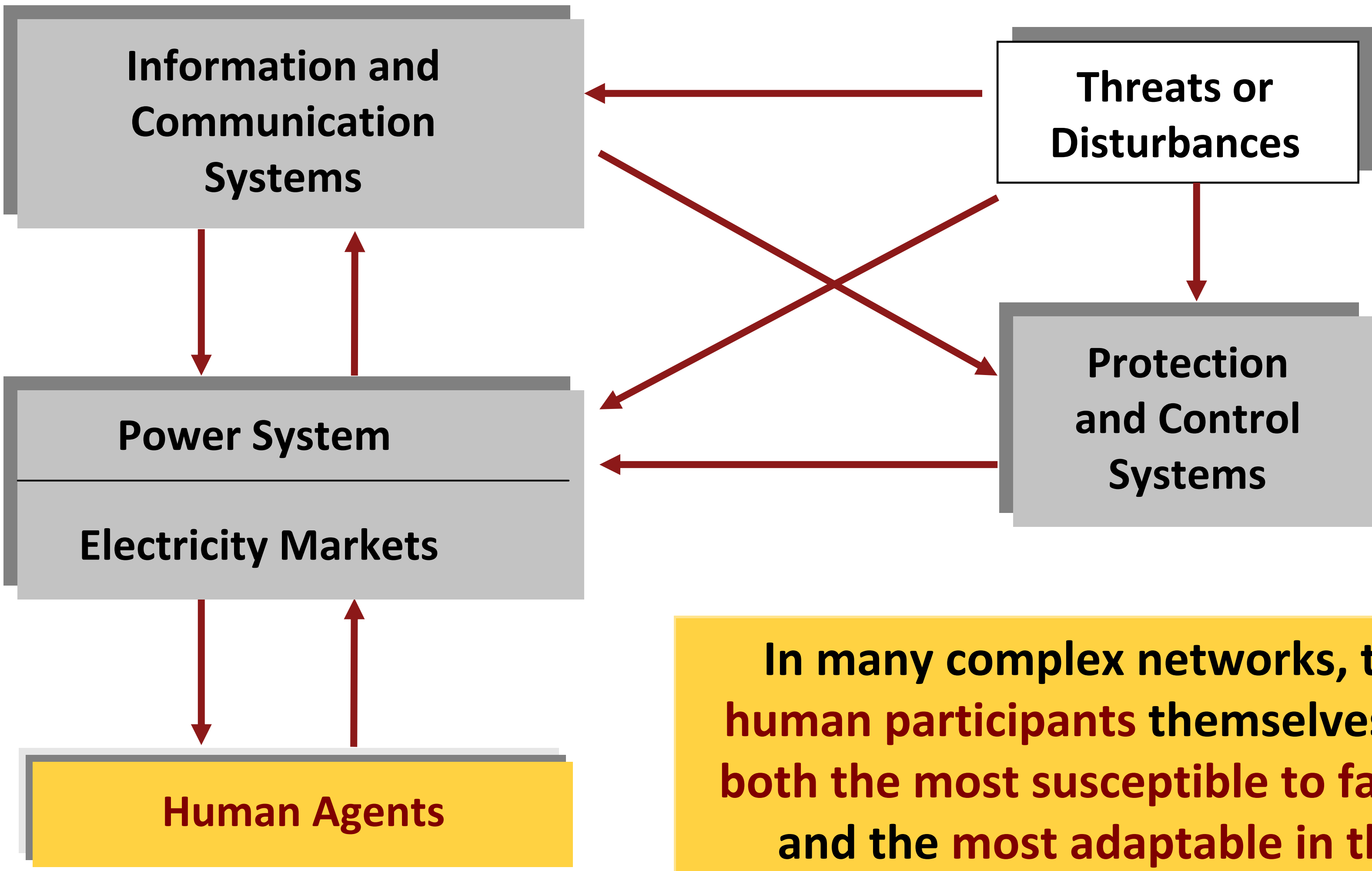
The objective of this presentation is to discuss issues involved in the formation, and successful operation of research consortia. As an example, the Complex Interactive Network and Systems Initiative, CINSI, is a program that aims to develop tools and techniques that will enable national infrastructures to self-heal. EPRI and DOD are jointly funding the project for about $30 million over five years. From the very start, the funding partners appreciated that the research challenges were beyond the scope of any single contractor or university department; thus CINSI was organized on a consortia basis. The kick-off for the program was held in May 1999. There are six consortia, each comprising about three to six universities and, in a few of the consortia, an industrial partner. I shall provide an analysis of the funded consortia and discuss issues involved based on models of (i) creativity and innovation and (ii) successful knowledge management projects. Pertinent issues and some thoughts on successful team formation and continued innovation include:

- Why form consortia? Is collaboration and teaming worthwhile? Does it lead to elitist "us vs. them" attitudes instead of open communication leading to creative work? How to identify and prevent such tendencies? Identify potentially divisive issues including allocation of resources among consortia members.
- Setting the theme very early on and up front, before the actual work begins, in a clear examination of assumptions, re-visiting groups' vision and re-examining their responsibilities after their selection and at an on-going basis.
- Communication: How would the consortia participants share their progress reports inter-/ intra-consortium? How would the consortia participants share their progress reports with funders? How often, in what form? Also... satisfying the associated milestones and time-lines.
- Develop an ecology of networked collaboration: Avoid "micro managing"; encourage researchers' own feeling of excitement for their innovative work and of their control over their activities and contributions. A good opportunity to enhance this, for example, by asking each team to develop its own methods of effectively communicating between the various members of the team. Culture and chief researchers' attitudes could play a key role in success or failure of graduate student interactions both within a university and between them. Charging the members to develop their own communication processes, make it their responsibility/goal to be successful rather than "micro-

[1] Keynote on "Leadership of R&D Consortia and Social Implications of Science and Technology," NSF/EPRI/IEEE PES, August 2000. A summary report was published for the panel session on "Organizing Research Consortia," *Proceedings of the IEEE Summer Power Conf.*, July 2001

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.

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 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

Smart Grid: Background and Next Steps

- Self-Healing Grid (May 1998- Dec. 2002)
  - 1998-2002: EPRI/DOD Complex Interactive Networks/Systems Initiative (CIN/SI):
  - 108 professors and over 240 graduate students in 28 U.S. universities funded, including Carnegie Mellon, Minnesota, Illinois, Arizona St., Iowa St., Purdue, Harvard, MIT, Cornell, UC-Berkeley, Wisconsin, RPI, UTAM, Cal Tech, UCLA, and Stanford.
  - 52 utilities and ISO (including TVA, ComEd/Exelon, CA-ISO, ISO-NE, etc.) provided feedback; 24 resultant technologies extracted.
- Intelligrid (2001-present): EPRI trademarked
- Smart Grid: Final name adopted at EPRI and DOE

Smart Grid definitions

New enabling smart grid technologies are fuelling the modernization and development of a smart distribution grid

- Distribution Grid of the future will:

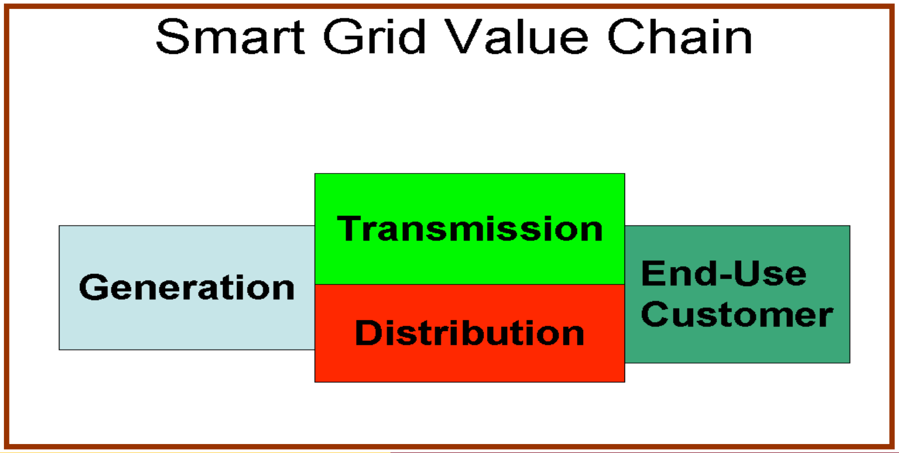
– **Allow 2-way power and information flows**

– **Enable clean and renewable energy and help decarbonize power system**

– **Enable effective demand management, customer choice and efficient operation of the grid**

Information systems that facilitate renewable energy, demand response, new technologies and other things to be prescribed later.

Ontario Electricity Act, amended section 2(1) and new subsection (1.3)



An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level."

The Smart Grid: An Introduction – U.S. Department of Energy

Source: various presentations from the Canadian Smart Grid Summit, Oct 2009

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

- **What is a smart grid?**

  The term "smart grid" refers to the use of computer, communication, sensing and control technology which operates in parallel with an electric power grid for the purpose of enhancing the reliability of electric power delivery, minimizing the cost of electric energy to consumers, improving security, quality, resilience, robustness, and facilitating the interconnection of new generating sources to the grid.

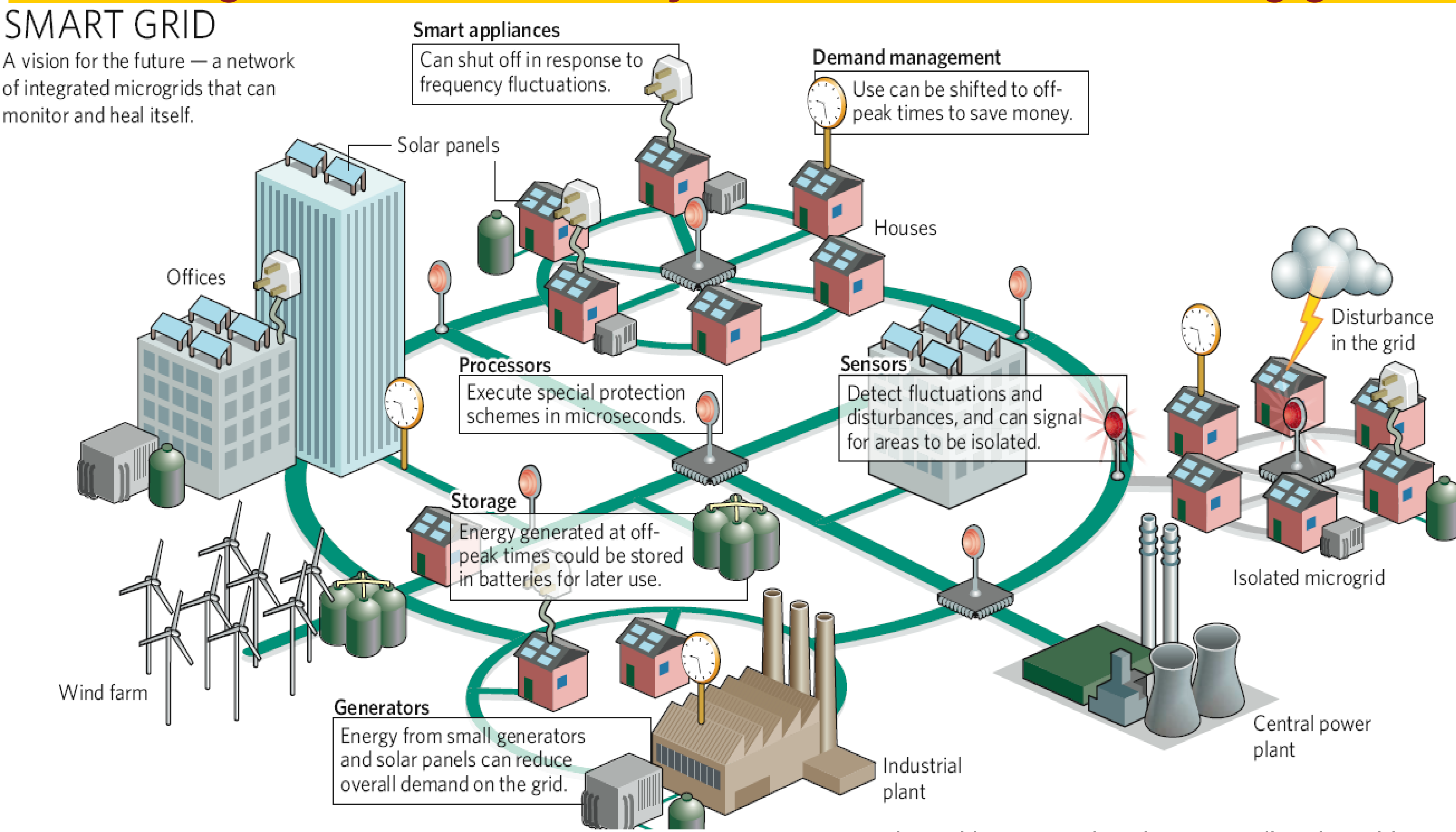
- **What are the power grid's emerging issues?** They include

  1) integration and management of DER, renewable resources, and "microgrids";
  2) use and management of the integrated infrastructure with an overlaid sensor network, secure communications and intelligent software agents;
  3) active-control of high-voltage devices;
  4) developing new business strategies for a deregulated energy market; and
  5) ensuring system stability, reliability, robustness, security and efficiency in a competitive marketplace and carbon constrained world.

Smart Grid

Our Goal: Enabling the Future

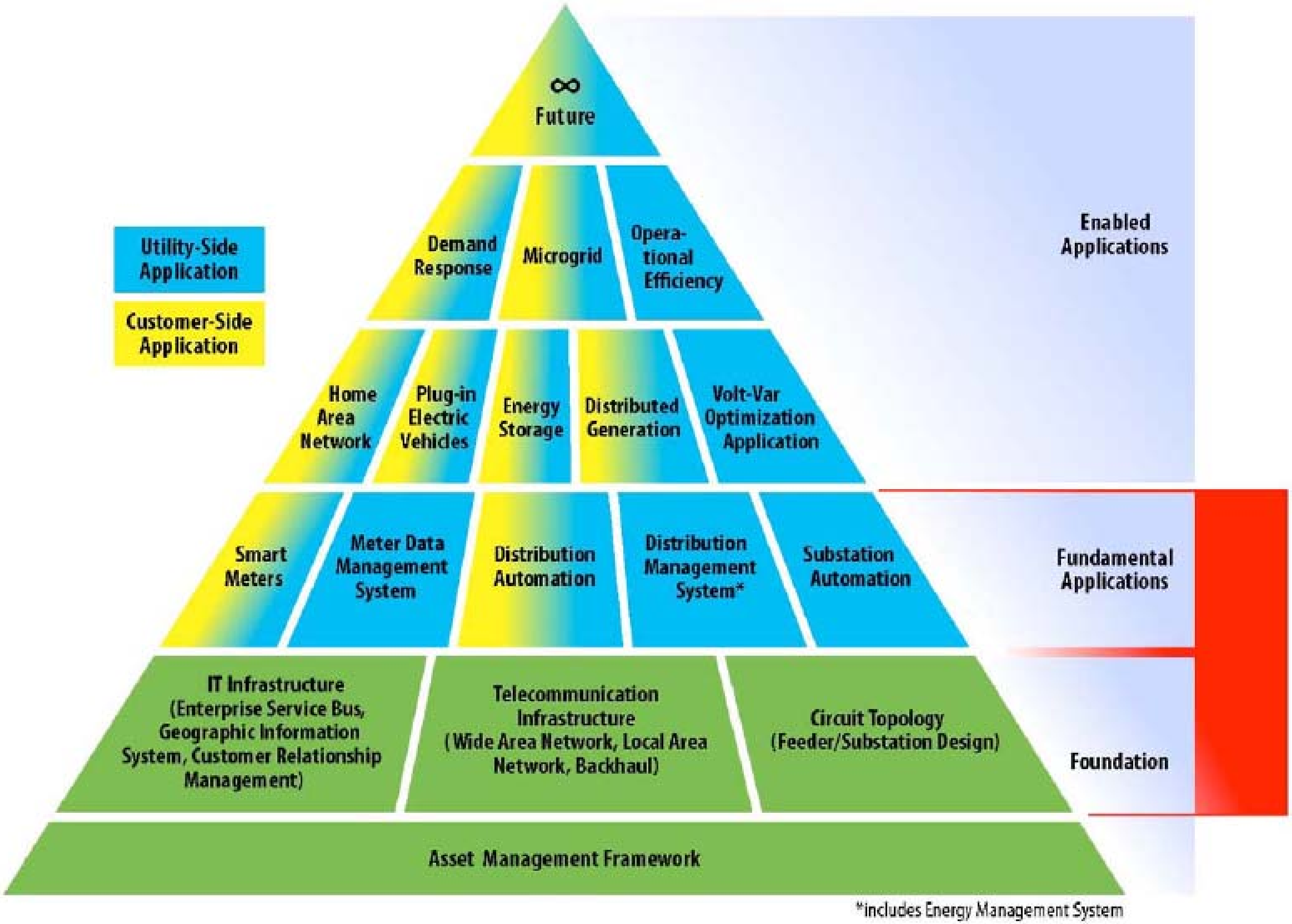
Infrastructure integration of microgrids, diverse generation and storage resources into a system of a smart self-healing grid



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

The Smart Grid in diagrams

Smart Grid framework



Source: BC Hyrdo, Canadian Smart Grid Summit, Oct. 2009

Power & Energy

Smart Grids Components & Devices

Currently it is still very difficult for consumers to see how much electricity they are using, but smart grid devices are quickly being developed. It is hoped that by being able to monitor how much electricity they are using, consumers will use less of it, subsequently cutting energy bills and, moreover, pinpointing off-peak hours to run their energy-intensive machines.

Optimises assets and operates efficiently

A Smart Grid will be able to generate more power through the existing systems by optimising them, allowing the reduction of power-flow waste and maximising the distribution of lowest-costgeneration sources. The harmonisation of local distribution with interregional energy flows will improve thecurrent use of grid assets, reducing grid congestion and potentially outages / disruptions.

Variety of Generation Options

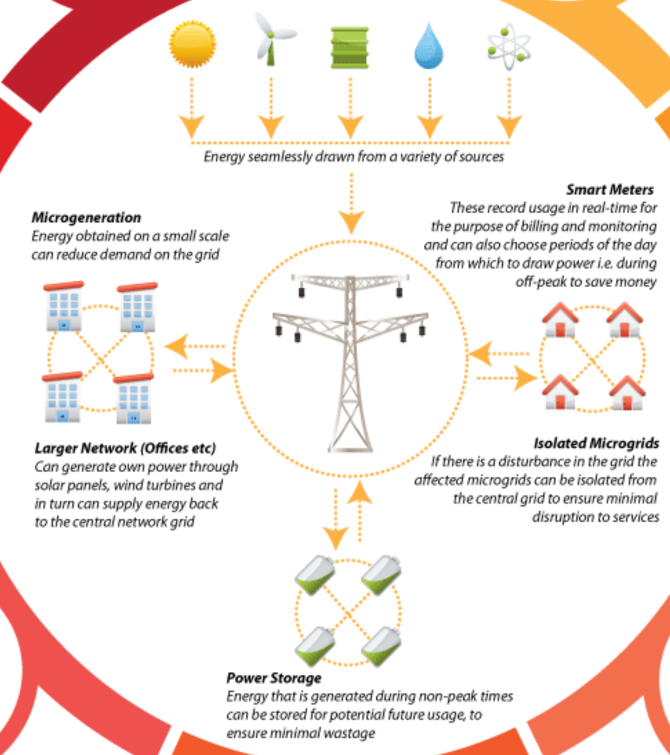
With CO2 emissions on the increase and primary sources of energy running out it is imperative that new sources are found and integrated into the grid system. The current electricity grid cannot facilitate energy being drawn seamlessly from a variety of energy sources via a number of distributed technologies, but this is the aim of the Smart Grid.

Accommodates all generation and storage options

All sources will be interconnected allowing consumers to access a general and renewable generated sourceof energy. Energy storage will also be available ensuring none is wasted, and that energy can be tapped at a late date should the need arise.

Demand Response

Consumers are changing what they need from a power supplier and are moving towards flexible energy, cheaper alternatives and the option for microgeneration, all of which are not currently facilitated by the electricity grid. The development of the Smart Grid and associated "smart" technologies and devices will allow users to have a more direct control over the energy they use on a day-to-day basis.



Self-healing

Automatically detects and responds to grid problems, ensuring quick recovery after disturbances. The incorporation of micrograids also means that affected areas can be isolated from the main network as to cause minimal disruption to services

Power for 21st Century Needs

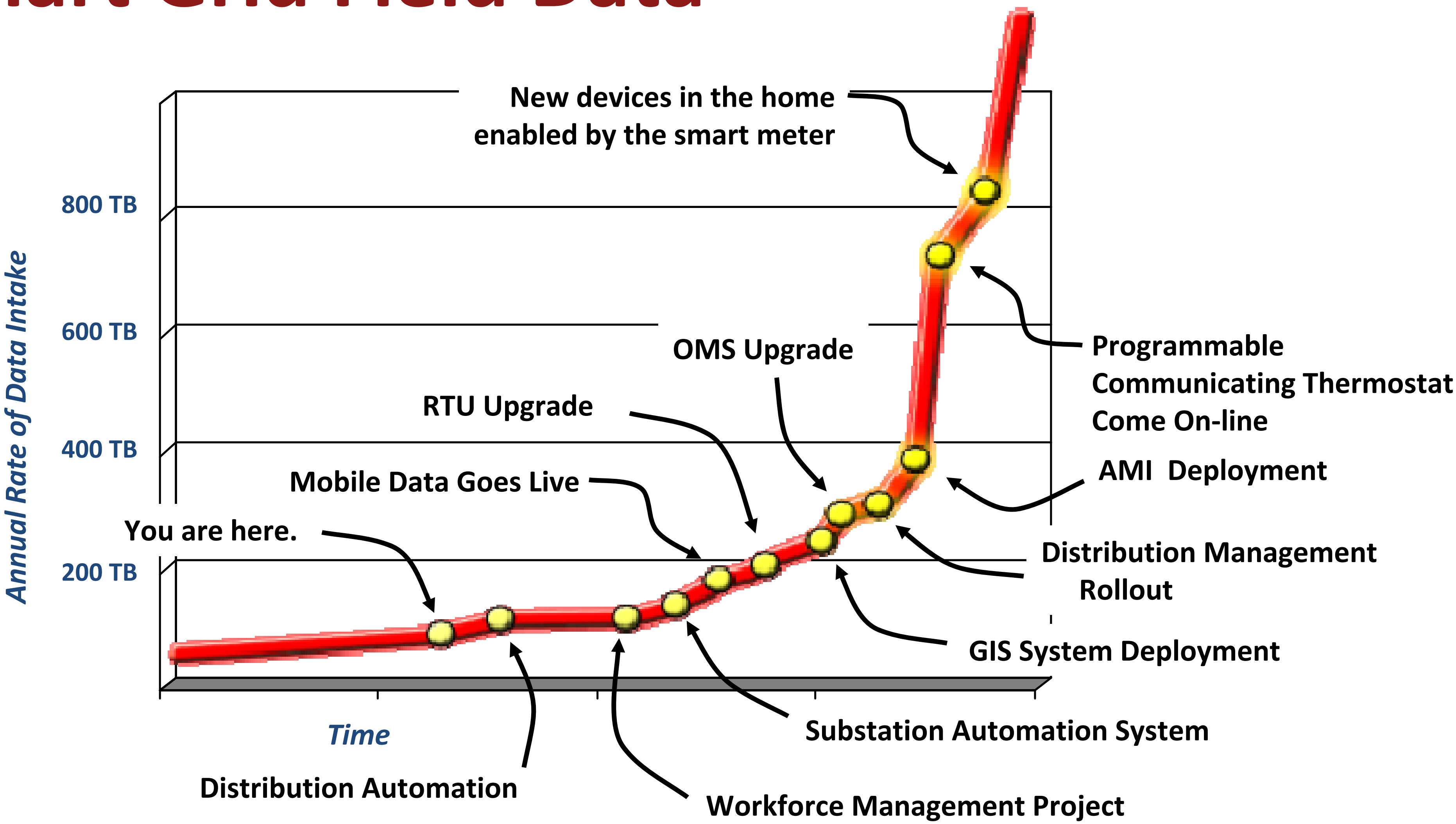
Power outages and quality issues cost businesses billions every year. A Smart Grid will reduce downtimes issues ensuring everyone can obtain power when they need it with solutions at both a system and consumer level

Electricity Market

Creating an open market where alternative energy sources can be sold to customers regardless of location. Microgeneration of electricity will also be a viable source of energy and will potentially contribute a good source of income to local economies.

Sources: Office of Electricity and Energy Reliability and European SmartGrids Technology Platform

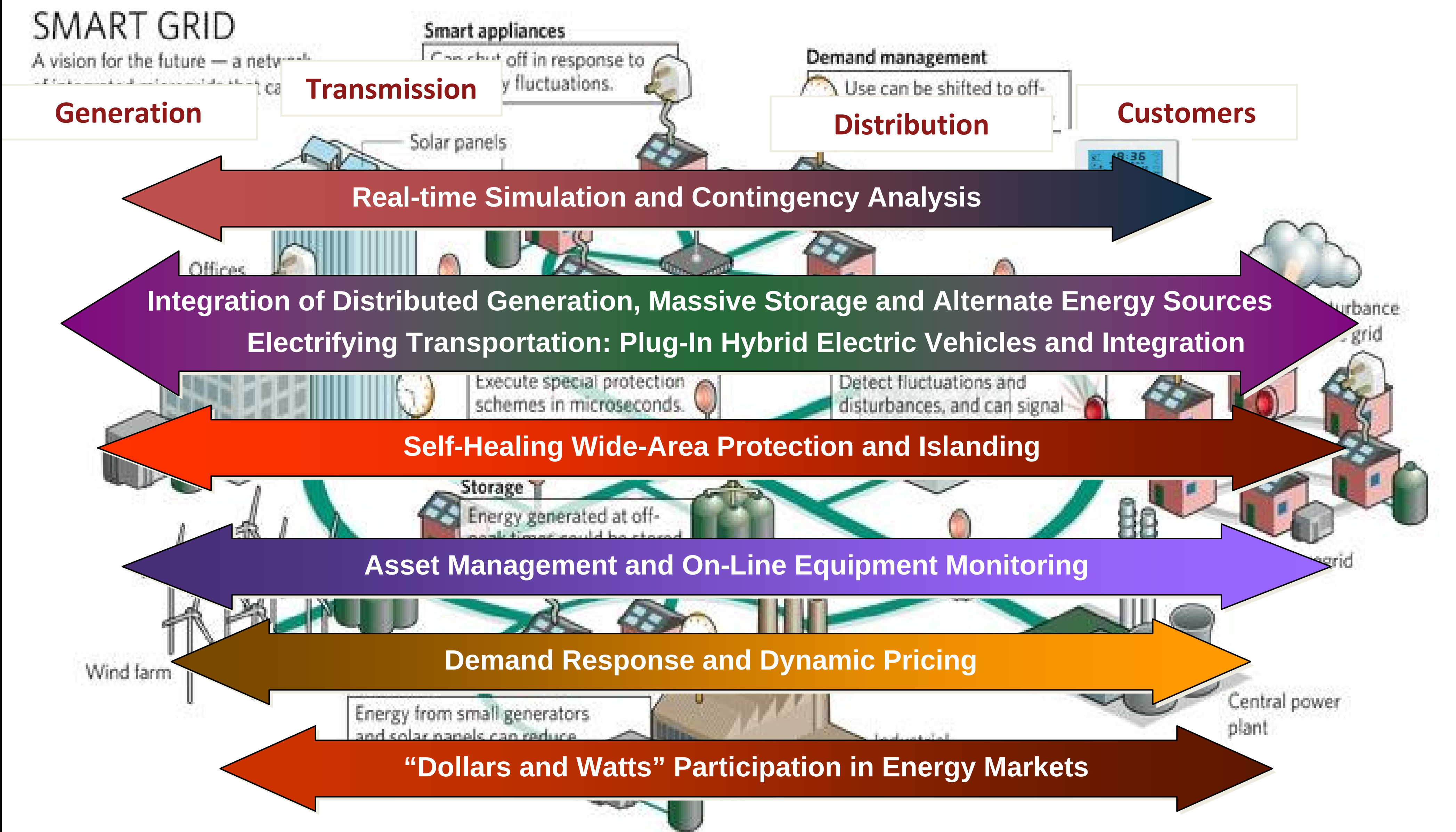
Smart Grid Field Data



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

Source: EPRI

Enabling a Stronger and Smarter Grid

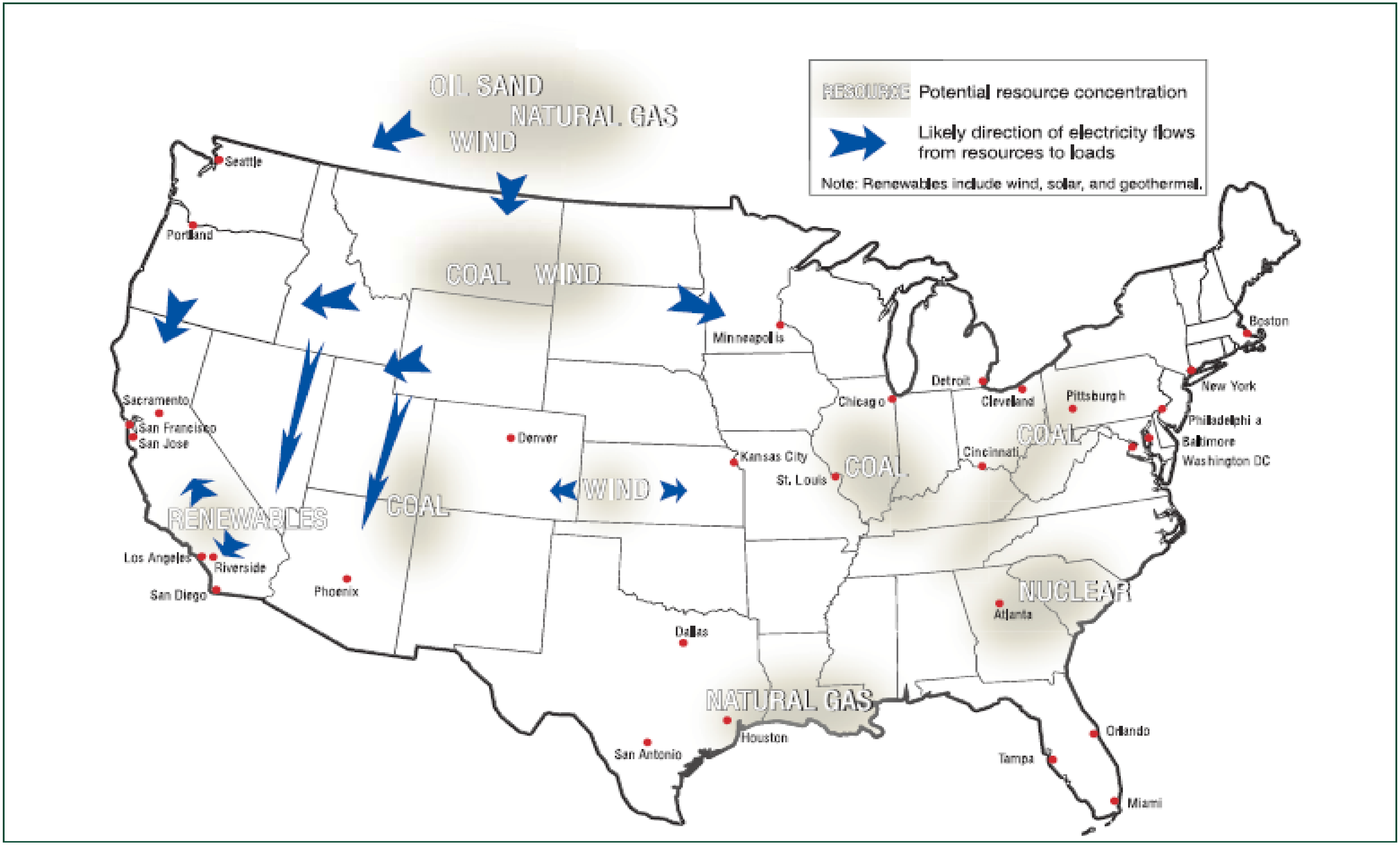


Enabling a Stronger and Smarter Grid

- **Smart Grid Challenges/Opportunities:**
  - Infrastructure for Generation/Transmission/Distribution Systems
  - Infrastructure for Smart Customer Interface
  - Distribution Automation
  - Smart metering improves load models and profiles
  - Distributed Sensing and Control
  - Device monitoring and self-healing diagnostics
  - Communication infrastructure provides opportunities for monitoring and diagnostics
  - Fault detection, sensor networks, etc. for smart grid
  - Alternative Smart Grid Architectures
  - Infrastructure Security: Controls, Communications and Cyber Security
  - Markets and Policy
  - Distributed generation and storage adds complexity

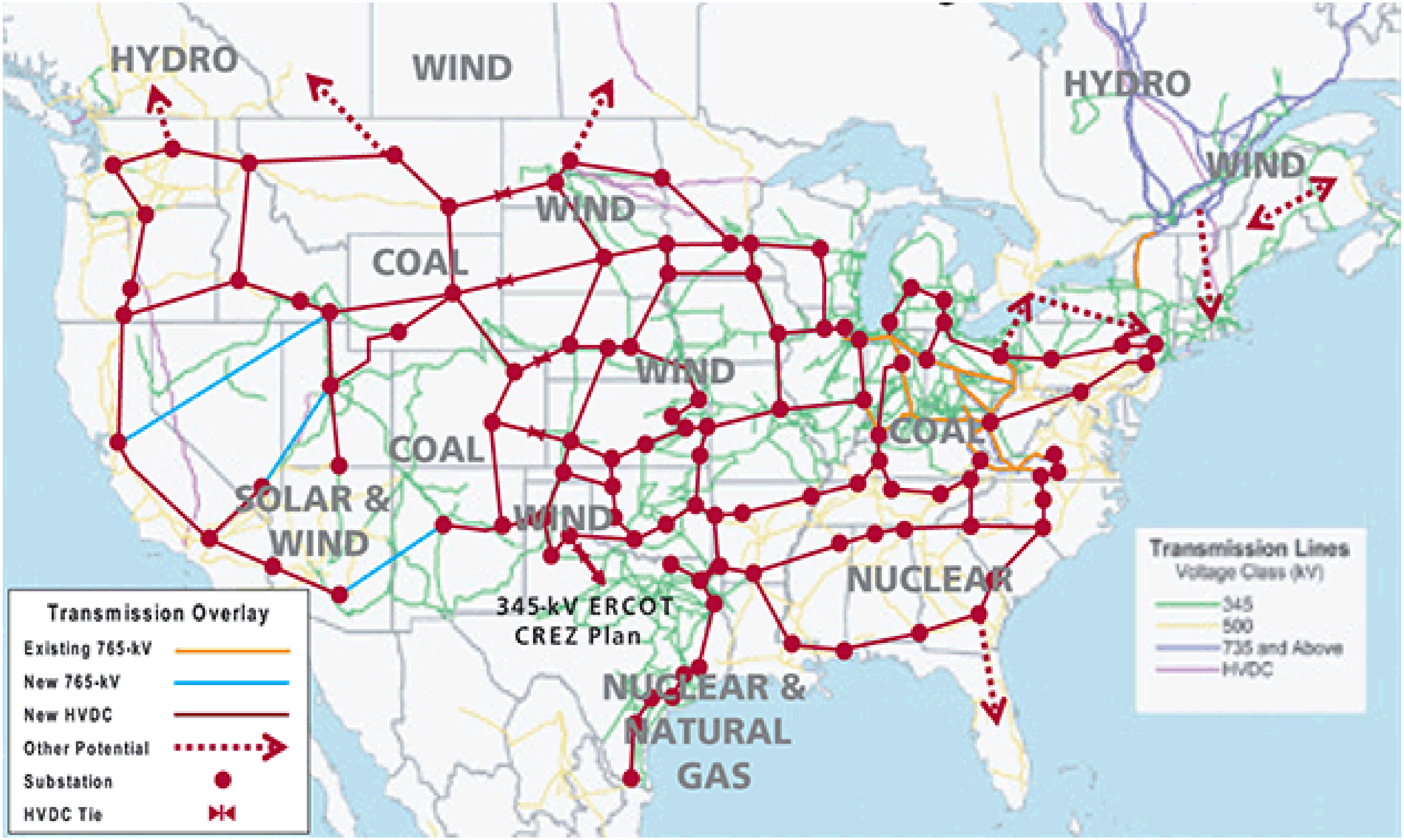
Integration of Renewables

Context: New patterns in power delivery



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

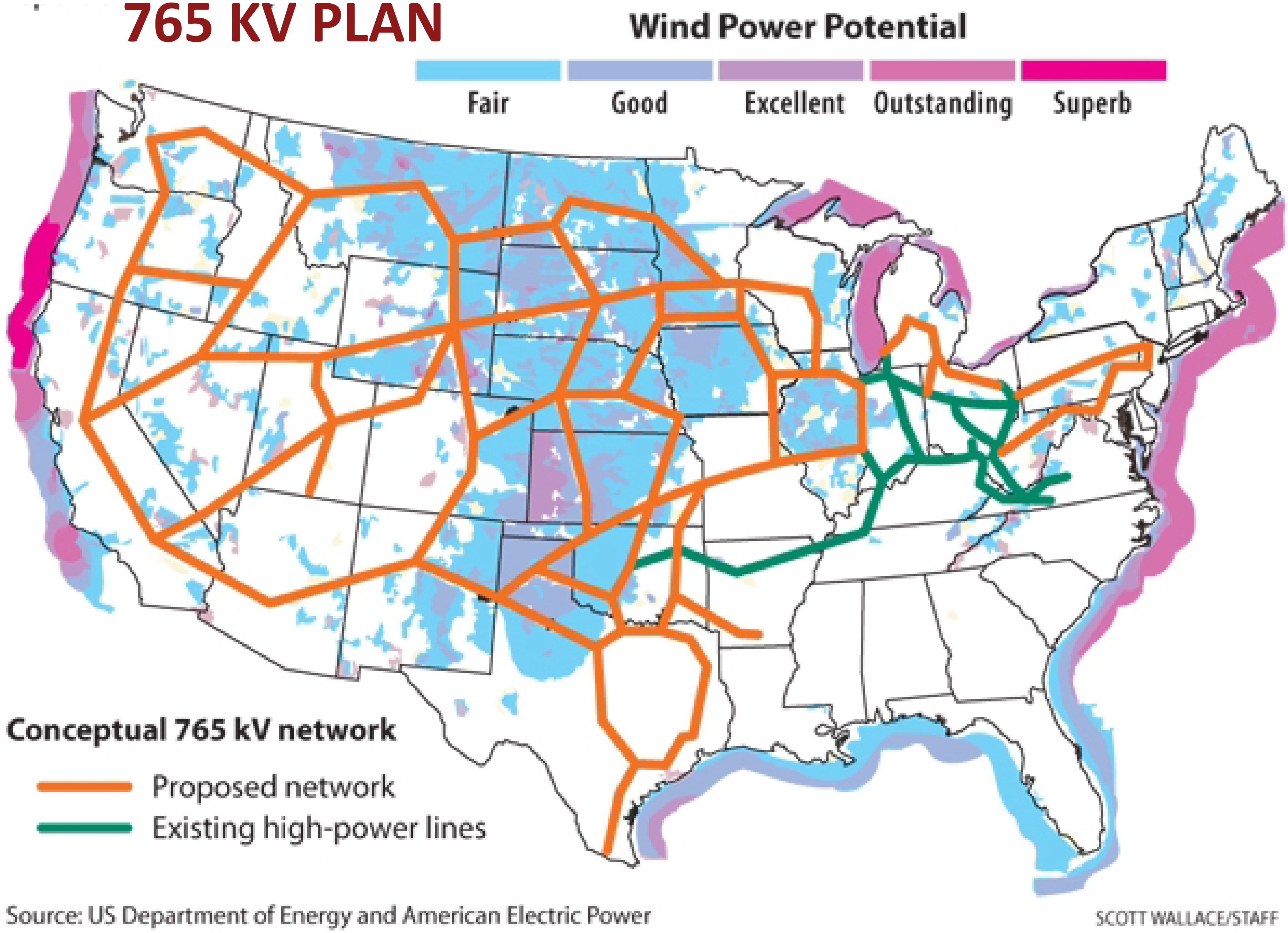
Enabling a Stronger Grid



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

Example: American Electric Power (AEP) Corp.

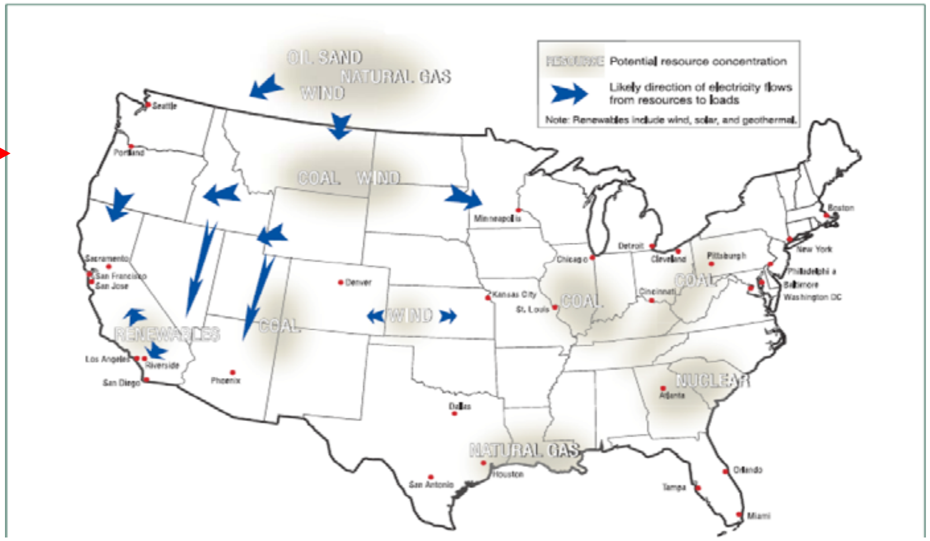
765 KV PLAN

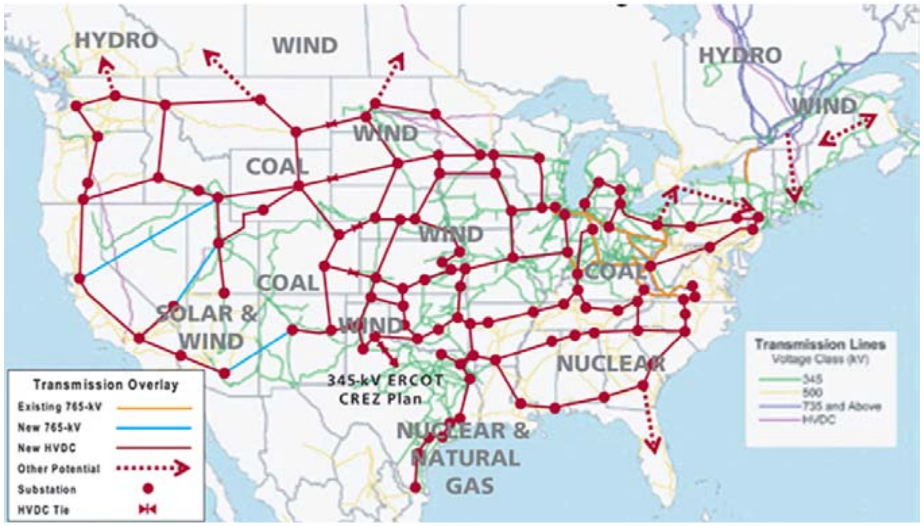


Smart Grid: Integrating dispersed renewables into a modern transmission grid to provide energy to centers of demand

Recommendations for moving to energy system's to meet demand of tomorrow

- **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: Adapted from presentation by S. Massoud Amin, University of Minnesota

Foresight

Renewables/infrastructure integration,
Electrification of transportation

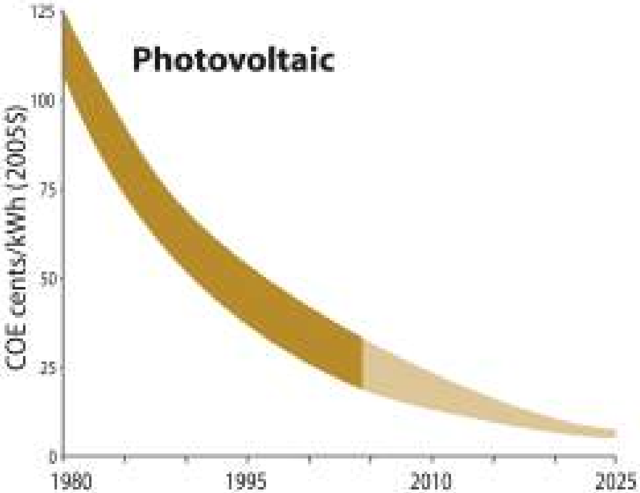
- "***Wind power could blow electric grid:*** Utilities and developers are poised to more than quadruple the amount of wind power in the Northwest, but a study shows the electric grid might not be able to handle it all, *The Oregonian* reported. The federal Bonneville Power Administration said in its assessment it has space on the grid to add only one-third of the planned 4,716 megawatts without additional power lines, the newspaper reported. A total of 6,000 megawatts of wind would supply about 8% of the Northwest's electricity needs, according to the BPA report. "A resource isn't very valuable unless you can deliver it," Elliot Mainzer, a transmission manager with the power agency, told *The Oregonian*. Bringing lines from the current grid to new wind farms costs up to $3 million a mile…"

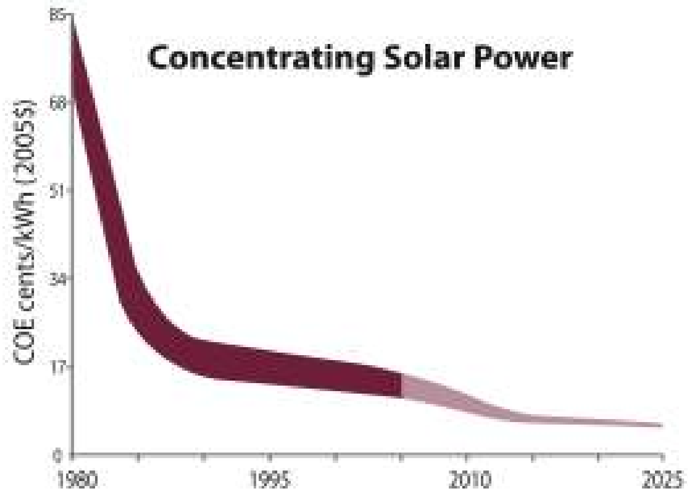
(July 22, 2008)

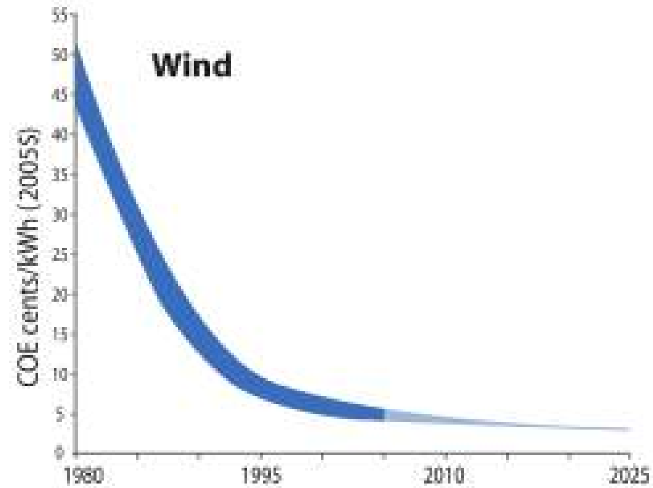
- "***GM, utilities team up on electric cars:*** Partnership aims to tackle issues that will crop up when electric vehicles are rolled out… General Motors Corp. has joined with more than 30 utility companies across the U.S. to help work out electricity issues that will crop up when it rolls out new electric vehicles in a little more than two years."

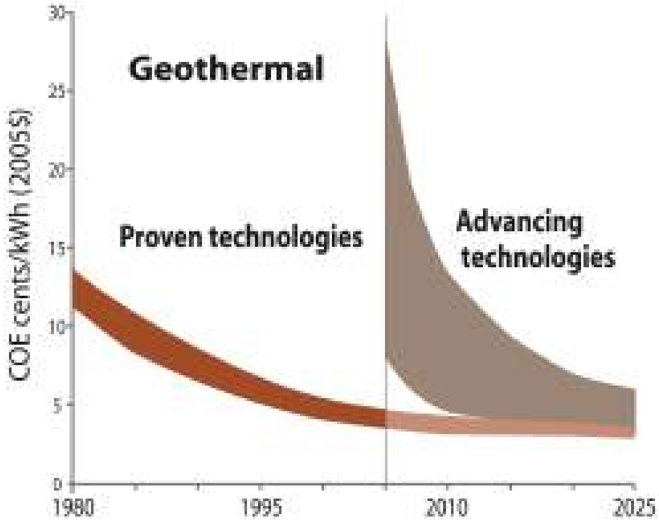
Renewable Energy Cost Trends

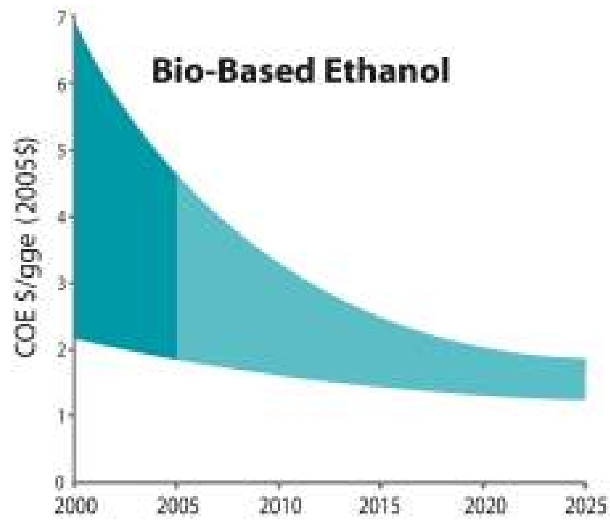
Levelized cost of energy in constant 2005$[1]







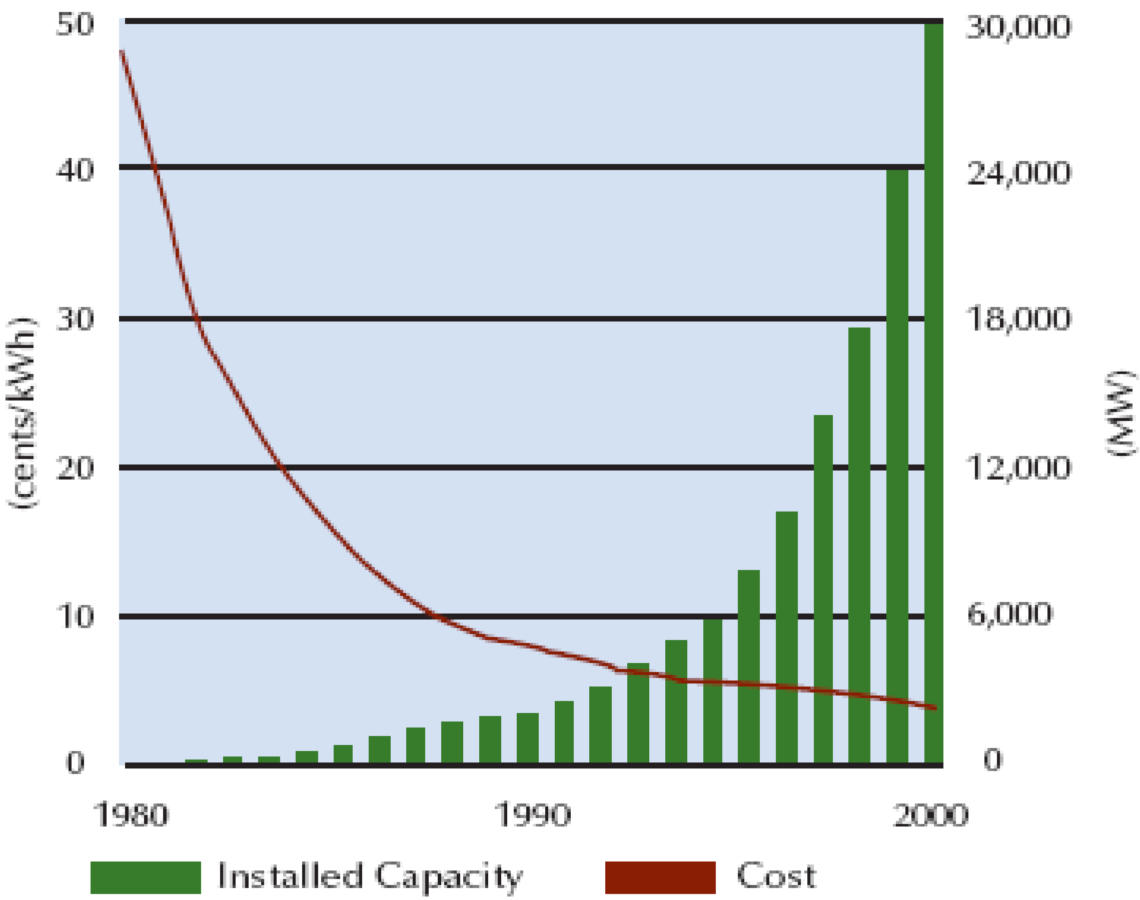




Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)
[1]These graphs are reflections of historical cost trends NOT precise annual historical data.

Declining Cost of Wind Power

As experience grows and technology improves with more wind turbine installations, the costs of wind power have dramatically decreased over the past two decades.



The Energy Foundation, 2004

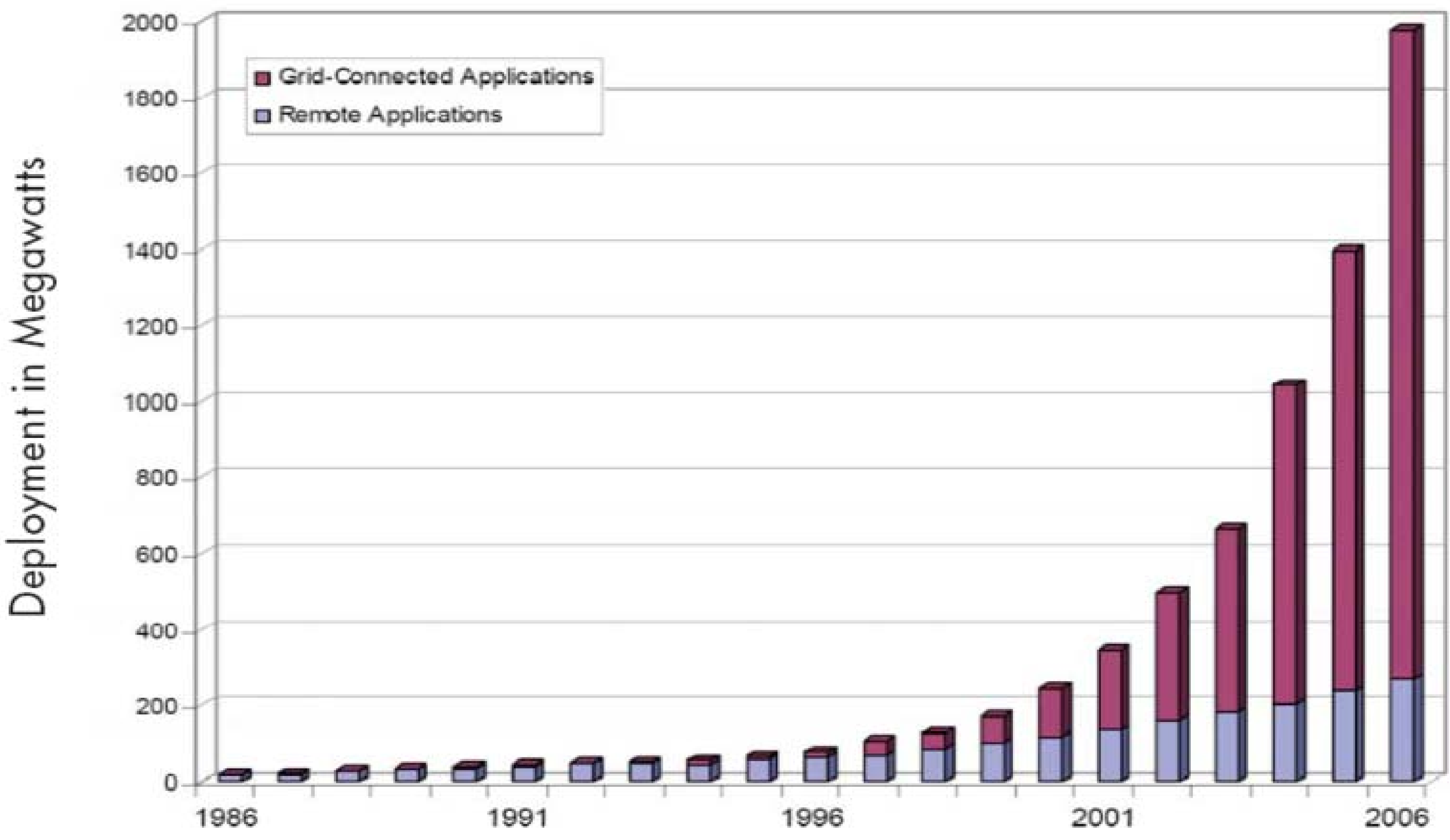


Figure 9
Proportion of Grid-Connected vs. Off-Grid PV Applications Worldwide, 1986-2006 (Source: Navigant Consulting PV Service Practice)

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

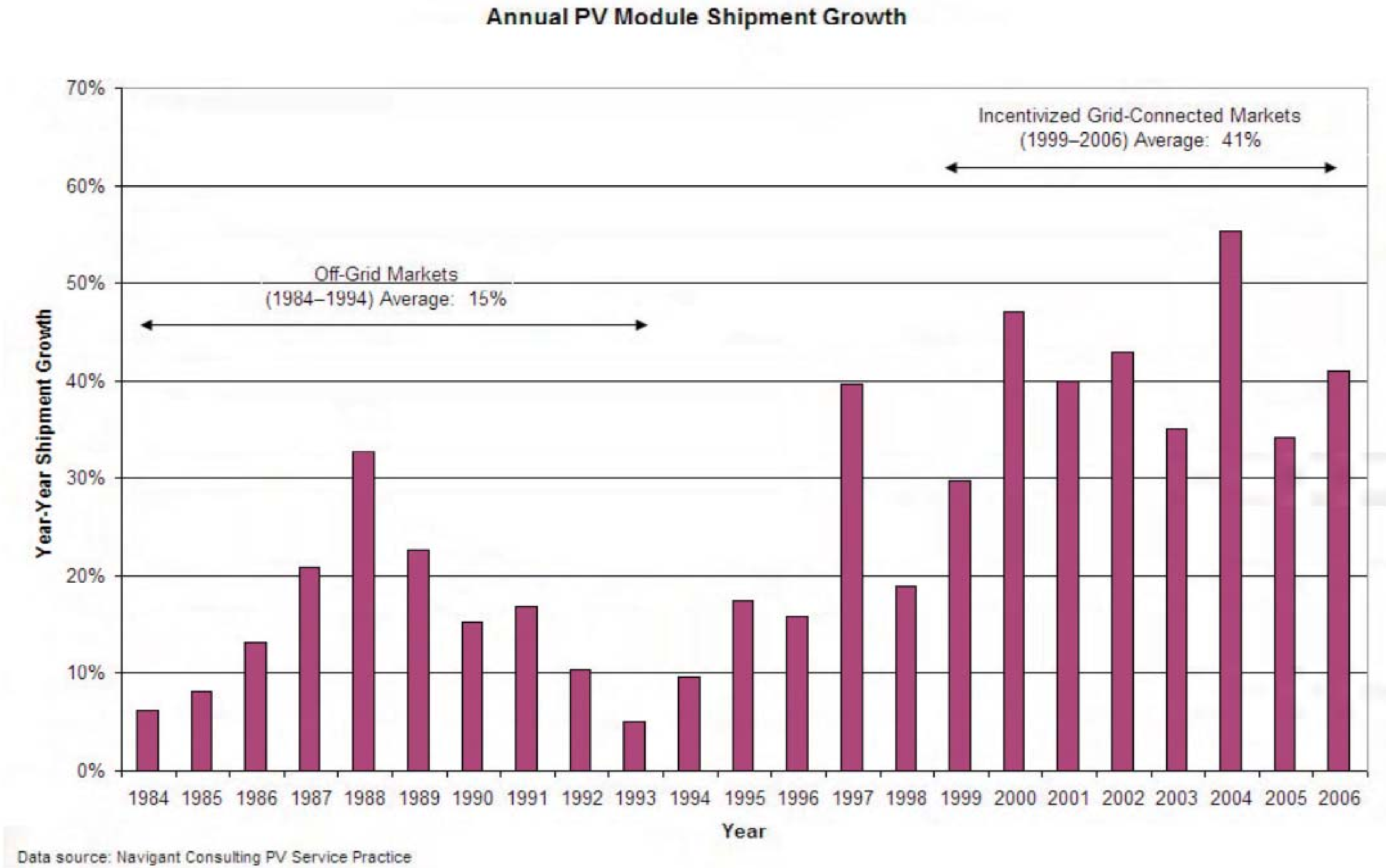


Figure 10
Before incentives for grid-tied systems in Japan, Germany, and California took effect, annual PV module shipments grew at 15% on average, mainly in off-grid applications. Subsidies boosted average annual growth to 41% overall. (Data source: Navigant Consulting PV Service Practice)

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Distributed PV: Japan

Distributed PV in Sapporo (Credit: IEA-PVPS)

Japanese policies have emphasized distributed rather than centralized solar power production, as illustrated by residential developments in Sapporo, a designated "Solar City."

Sapporo established a goal of reducing per capita carbon dioxide emissions in 2012 by 10% compared to 1990 levels. The city has active programs to increase public awareness, stimulate citizen initiatives, provide incentives, and host city-sponsored activities. Local schools are hosting five 10-kW solar power demonstration projects, and a suburban residential complex with 500 homes will be equipped with 1,500 kW of rooftop PV (3 kW per house) when completed in 2008. In addition to encouraging solar power, Sapporo has installed several large cogeneration projects that utilize waste heat from steam turbines, thereby increasing the overall efficiency of energy production.

Many other "Solar Cities" have instituted similar goals and programs, including Copenhagen, Denmark; Barcelona, Spain; Qingdao, China; Adelaide, Australia; Freiburg, Germany; and Portland, Oregon.

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Utility-Scale PV: Germany

Central-Station PV: 6.3-MW Solarpark Mühlhausen (Credit: SunPower)

Due to the structure of its incentive policies, Germany is a world leader in centralized PV deployment, with several megawatt-scale plants in operation or development.

The 10-MW Bavaria Solarpark, dedicated in June 2005, includes ground-mounted PV systems at three sites: the 6.3-MW Solarpark Mühlhausen, the 1.9-MW Solarpark Günching, and the 1.9-MW Solarpark Minihof. All together, the three projects comprise 57,600 solar panels over 62 acres of land. Cumulatively, they make up the largest PV plant in the world.

The Bürstadt Plant in Bürstadt is a 5-MW system incorporating building-integrated and roof-mounted systems. It was completed in February 2005. Solarpark Leipziger in Espenhain is a 5-MW system built in August 2004. The facility has both stand-alone and grid-connected PV elements. The Solarpark Geiseltalsee/Merseburg employs 25,000 mono- and polycrystalline modules from BP Solar to generate 4 MW of electricity. At the time of its completion in September 2004, it was the fifth largest PV plant in the world.

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pd

Central-Station PV: 4-MW Solarpark Geiseltalsee (Credit: BP plc)

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Building-Integrated PV: New York City

Building-Integrated PV in New York City (Credit: Schott AG)

Reconstruction of New York's Stillwell Avenue subway station provided an opportunity to integrate amorphous silicon thin-film PV into a semi-opaque roof canopy that, upon its completion in 2005, was one of the largest building-integrated PV (BIPV) structures in the world.

The station's canopy roof was constructed with ASI solar modules from Schott Solar to provide the station with electricity as well as shade. Some 2,800 thin-film modules covering 76,000 square feet (7,060 m^2) generate approximately 210 kW while permitting 20% to 25% of daylight to pass through. During summer, the system provides approximately two-thirds of the station's power needs (not related to powering the trains). Its annual output is about 250,000 kWh.

Planning and design took more than four years, and the station's design process was done in conjunction with an educational component that included a large-scale industry workshop involving several major companies in the photovoltaics industry. The station was designed so its architecture would invoke the historic architecture of nearby Coney Island and provide passengers with a grand sense of arrival, elegance, and civic pride.

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Tracking PV: Portugal

Central-Station Tracking PV in Portugal (Credit: SunPower)

In March 2007, GE Energy Services, PowerLight, and Catavento commissioned an 11-MW solar power plant in Serpa, Portugal. The station's 52,000 modules from SunPower, Sanyo, Sharp and Suntech cover 150 acres (60 hectares) and employ the SunPower® single-axis tracking system to keep the PV panels pointing toward the sun, increasing their daily electricity output by up to 35%. The project cost approximately $150 million.

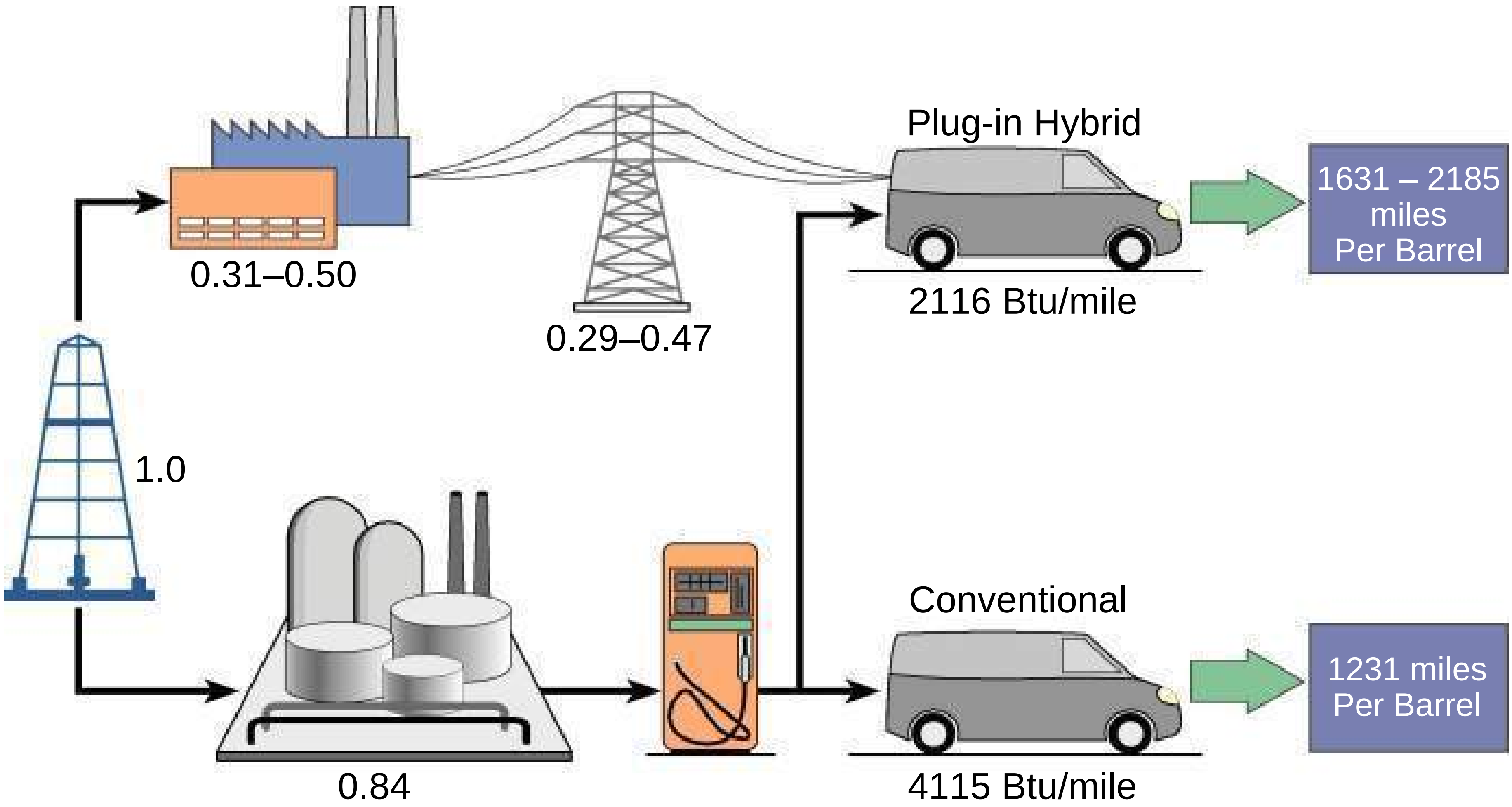
Portugal relies heavily on imported fossil fuels and has implemented aggressive incentives for renewable energy installations. A key component of Portugal's "Energy Efficiency and Endogenous Energies" (E4) program is a $0.317/kWh to $0.444/kWh feed-in tariff for both ground-mounted and rooftop solar power systems with a 15-year power purchase guarantee. Adopted in 2001, the E4 program is expected to provide 4,400 MW of renewable energy by 2010, 150 MW of it in the form of PV.

Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Figure 9. Parabolic trough CSP plants (such as the one in California, pictured here) utilize a mature technology; 419 MW of capacity are currently operating in the U.S., while several 50-MW plants are under construction in Spain. Source: Alan Radecki.

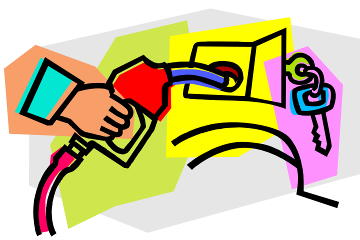
Source: courtesy of Dr. Terry Peterson, EPRI white paper 1016279, Dec. 2007: http://mydocs.epri.com/docs/SEIG/1016279_Photovoltaic_White_Paper_1207.pdf

Full Fuel Cycle Efficiency Comparison

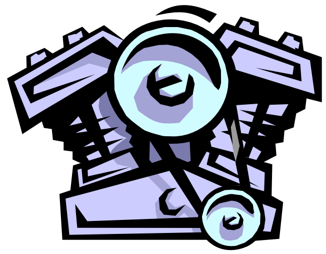


Hybrid Vehicle Efficiency

Gas tank

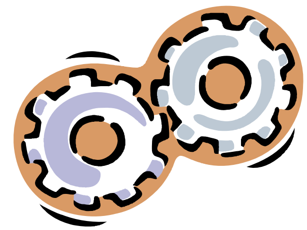


Engine



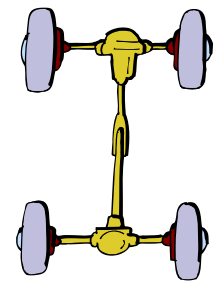
15-20%

Transmission



90-
95%

Driveline



95%

Battery

85-90%

Motor

85-95%

Gasoline: 13-18% Efficient

Electric: 62-77% Efficient

Foresight: Integration Technologies

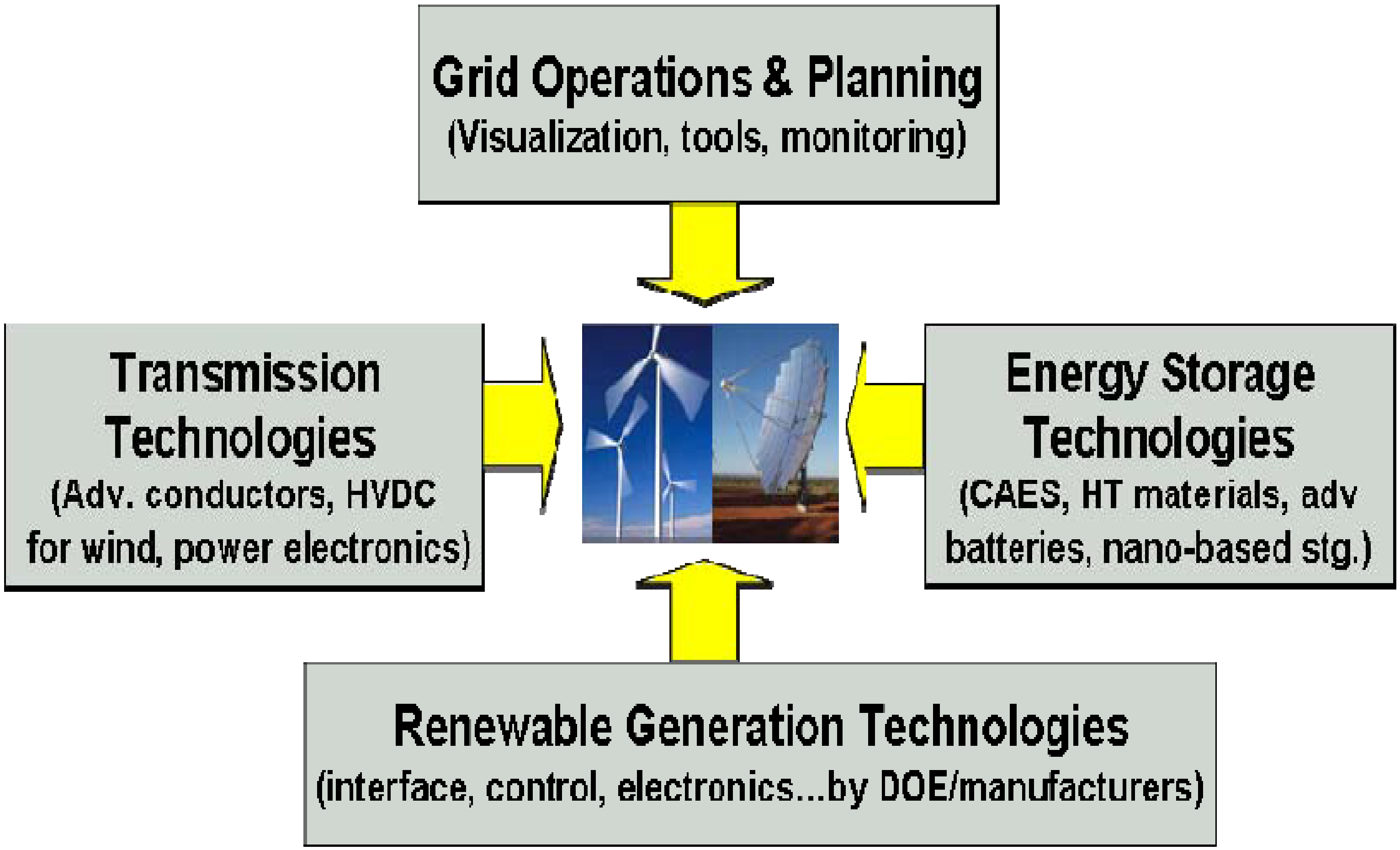
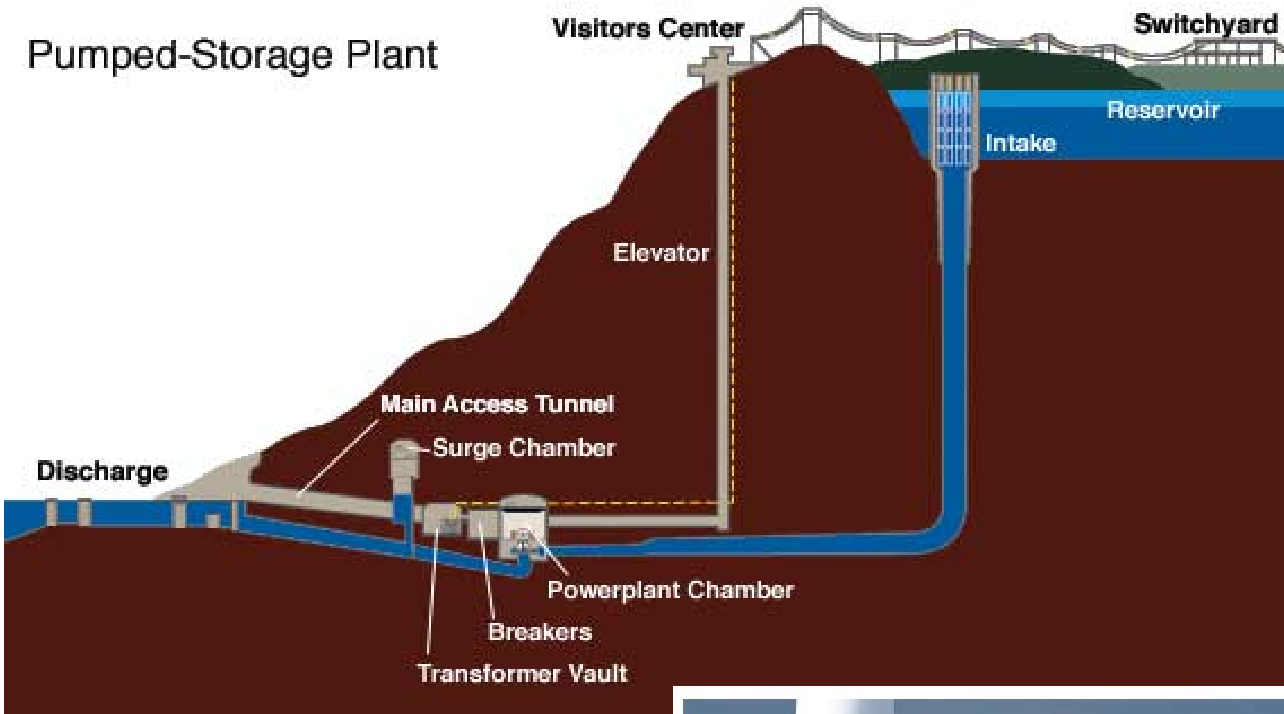


Figure 4-10
Several Different Integration Technologies Will Combine to Ease Integration of Renewable Energy Resources

Renewable Energy Technical Assessment: EdF Annual Update 2008: Solar Photovoltaics, Solar Thermal, and Grid Integration Technologies and Greenhouse Gas Emissions Control. EPRI, Palo Alto, CA: 2009. 1018492.

Foresight: Integration Technologies: Energy Storage



- These technologies and many others hold great potential
- Each is at a different stage of development
- Each has different time, cost and scale limitations

Flywheels

Pumped Hydro

Compressed Air

EPRI STORAGE TABLE (1 of 2)

Table 10-6
Advantages and Disadvantages of Candidate Energy Storage Technologies to Support Wind Power Energy Intermittency and Output Fluctuations

	Technology	Advantages	Disadvantages	Manufacturers
Independent Operating Electric Storage Technology	Vented Lead-Acid (PbA Default)	Mature and well-known Low initial cost Long life	Coup de fouet Relatively intolerant of temperature extremes	Enersys GNB (Exide)
	Valve-Regulated Lead-Acid	Low maintenance Low initial cost	Coup de fouet Intolerant of temperature extremes, Short life	C&D Technologies Hawker Energy (Enersys)
	Vented Nickel-Cadmium (Ni-Ca)	Mature and well-known Long life, Relatively tolerant to temperature extremes	Low cell voltage Float effect makes, capacity testing difficult	Saft Alcad
	Lithium ion batteries	High energy density Long life	Relatively untested, High initial cost (at present), Requires balancing and charge control electronics	Valence Johnson Controls (formerly Varta)
	Lithium metal polymer batteries	High energy density Tolerant to temperature extremes	Relatively untested, High initial cost (at present), Requires balancing and charge control electronics, one source	Avestor
	Nickel-Metal Hydride (Ni-MH)	High energy density, possible cycle life advantage over PbA	Low cell voltage Intolerant of temperature extremes, Float effect makes capacity testing difficult	Johnson Controls (formerly Varta) Electro Energy
	Vanadium Redox (VRB)	Relatively high energy for large system Power and energy rating is independent	Single manufacture and limited sources for Vanadium, Not yet proven for cycle life or maintenance costs	VRB Power Systems
	Compressed Air (CAES)	Mature technology, long life, Low cost for large scale Power and energy independent	Requires suitable site geology, may have ramp rate limit Large scale requires large capital investment and collaborations	For main Turbo-expander, Alstom, Dresser-Rand, Sulzer

Renewable Energy Technical Assessment Guide—TAG-RE: 2005. EPRI, Palo Alto, CA: 2005. 1010407.

EPRI STORAGE TABLE (2 of 2)

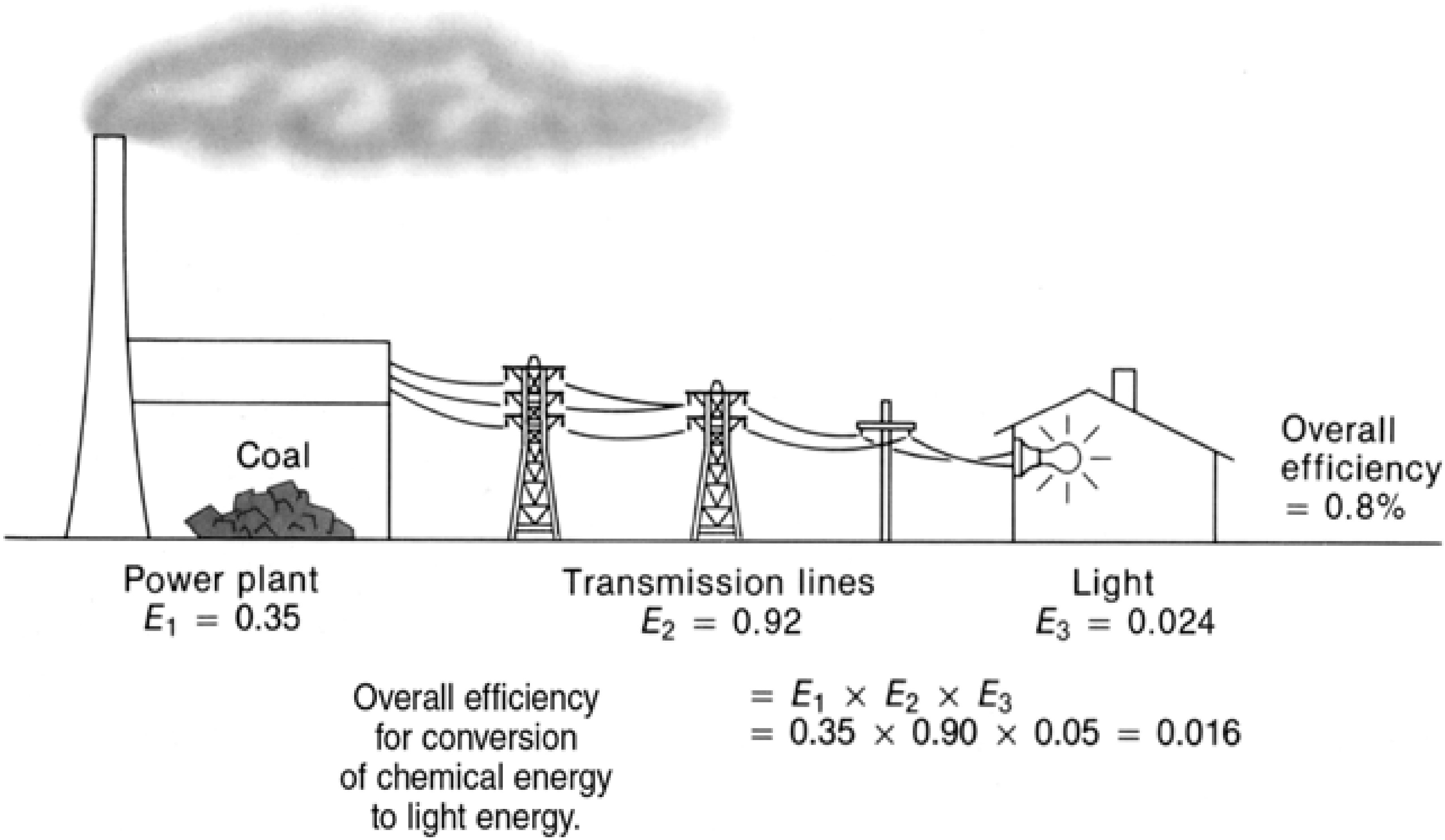
Table 10-6 (Continued)
Advantages and Disadvantages of Candidate Energy Storage Technologies to Support Wind Power Energy Intermittency and Output Fluctuations

	Technology	Advantages	Disadvantages	Manufacturers
	Pumped Hydro	Mature technology, long life, Low cost for large scale Power and energy independent	Requires suitable site geology, difficult environmental, large scale requires large capital investment and collaborations	For systems, Gugler GmbH, Sulzer, North Am. Hydro, Water Alchemy, Harris
	Sodium sulfur batteries (NAS)	High energy density	Relatively new and untested, High initial cost (at present), Single manufacture	NGK Insulator
Hybrid Pairs	Zinc-bromine batteries, (needs Power partner)	High energy density Flat voltage profile	Relatively unknown and untested, Mechanical parts require maintenance May require occasional stripping cycles, Single manufacture	ZBB Energy
	Regenerative zinc-air, (needs power partner)	High energy density	Relatively unknown and untested, Voltage drop at start of discharge, Limited shelf and cycle life, Single manufacture	Metallic Power
Short Term Stabilizer	Ultracapacitors	High current density, for short-term power, high cycle life	High initial cost (at present), Relatively low energy density, stacking limitation TBD	Maxwell, NESS Capacitor, EPCOS, ESMA, NEC, etc
	Flywheels	High current density, for short-term power, High cycle life	Relatively high initial cost per kWH, Low energy density	Active Power, Beacon, Hitec, Piller, Pentadyne, Teledyne, Urenco

Renewable Energy Technical Assessment Guide—TAG-RE: 2005. EPRI, Palo Alto, CA: 2005. 1010407.

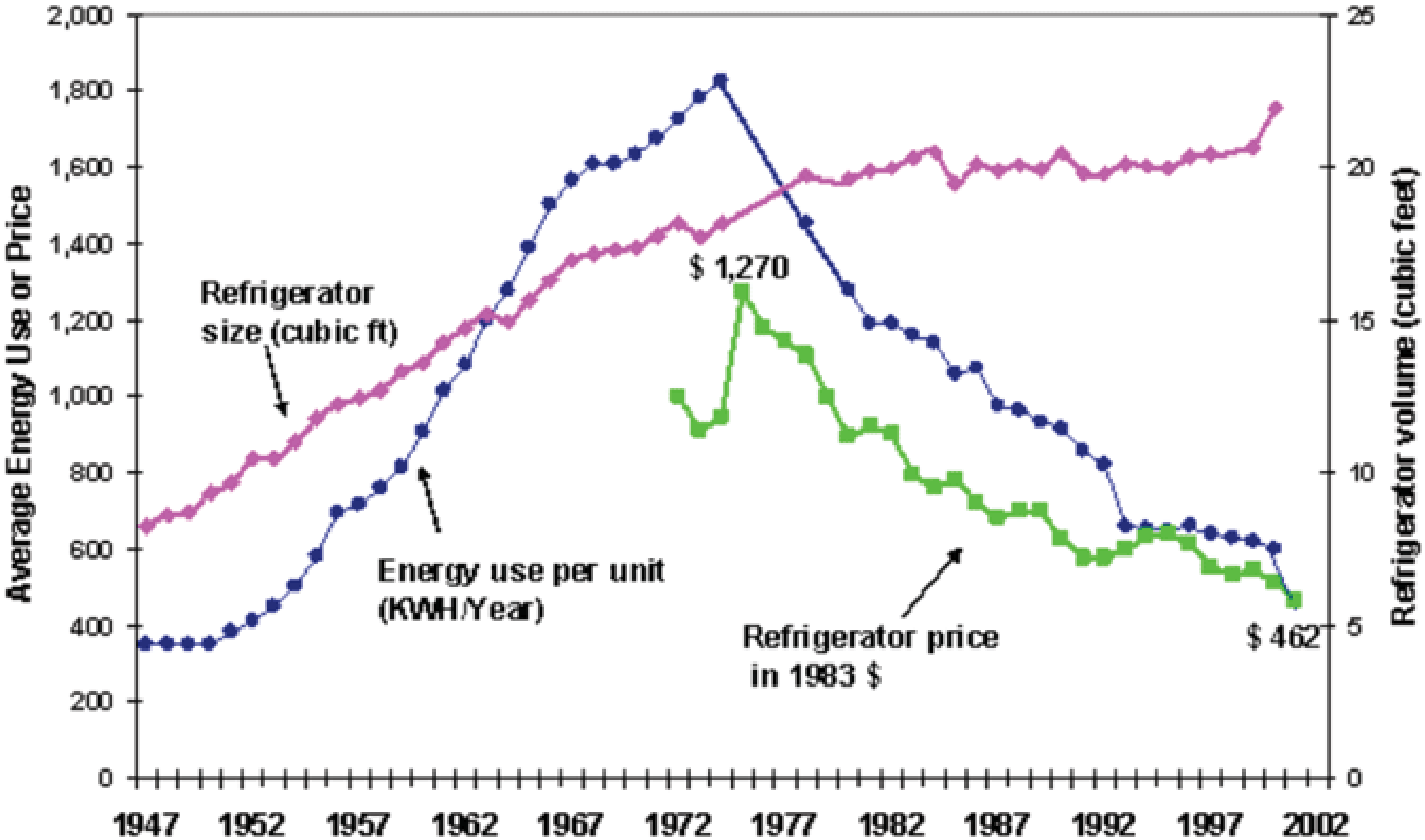
Energy Efficiency

End-to-End Energy Efficiency: Lighting efficiency



Source: NRC, 2009

Example: Energy Efficiency of refrigerator



Source: NRC, 2009

Technological Leadership Institute

University of Minnesota
Driven to Discover℠

Example: Energy Use in Buildings

• 81 million single-family houses, 25 million multifamily residences, and 7 million mobile homes, together with 75 billion square feet of commercial floor space account for 73% of electricity use and 40% of total energy use in the U.S.

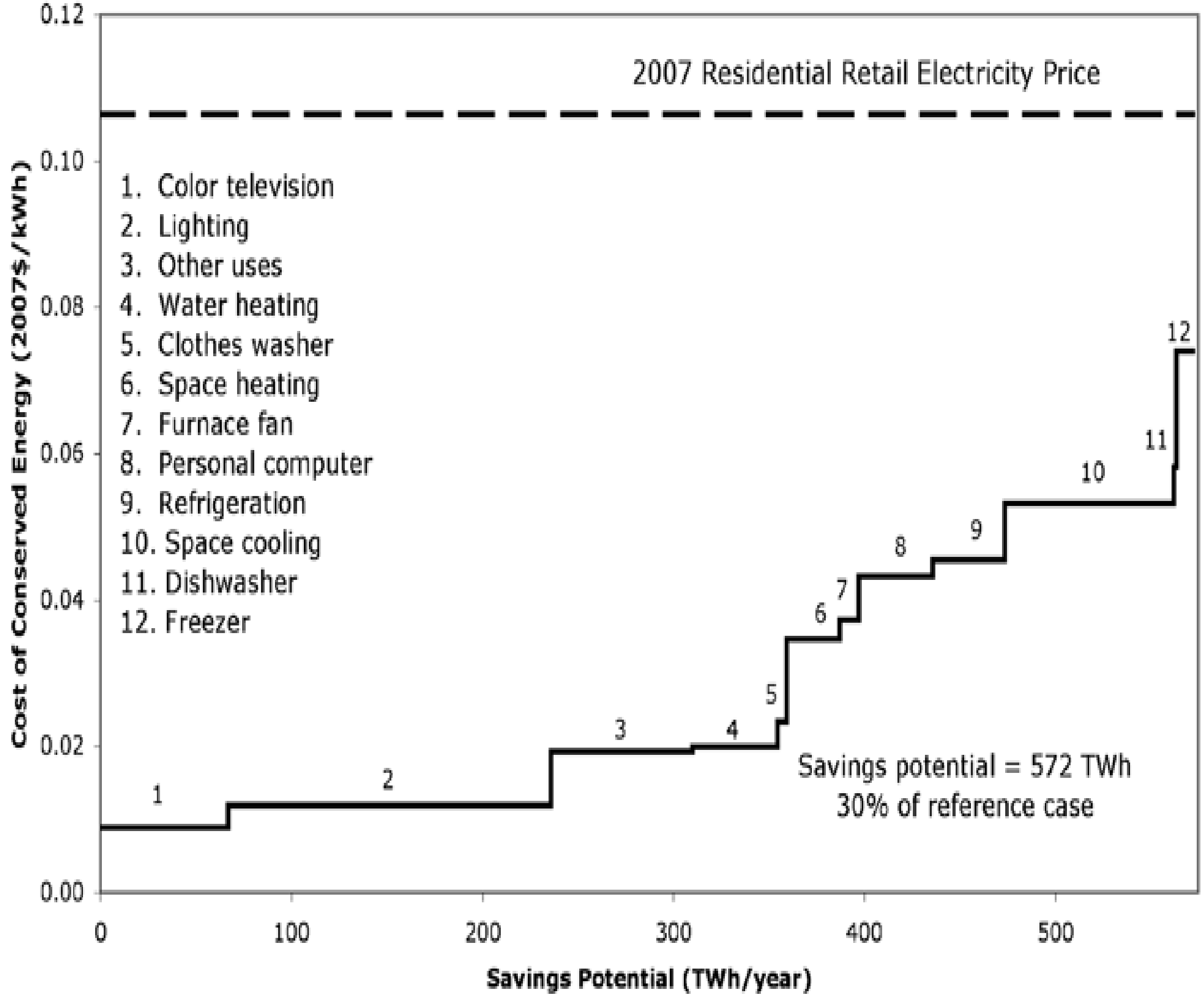
• From 1975 to 2005, despite increased energy efficiencies, an increase in the number of residences and the amount of commercial space led to substantial increases in total energy use—15% in residential buildings and 50% in commercial buildings.

• The efficiency gains, made in refrigerators and lighting, in air conditioners, building envelopes, and many appliances, were promoted by Energy Star labeling of appliances and even of buildings.

• The number of new residences that attained Energy Star status increased from 57,000 in 2001 to 189,000 in 2006. For buildings, the median cost-effective and achievable potential (taking barriers to implementation into account) are 24% for electricity and 9% for natural gas (sensitive to price, especially for natural gas).

Example: Potential electricity savings for residential products-- how much electricity can be saved for all U.S. residences with various expenditures, beginning with the most cost-effective changes

- E.g., if energy-efficient color televisions are selected, they would save a total of 70 TWh of electricity per year at a cost of 1 cent per kWh, a 90% reduction in operating cost.
- Energy-efficient lighting, such as CFLs, could save an additional 160 TWh at a cost of just over 1 cent per kWh.
- In total, choosing the 12 appliances listed rather than their less efficient models could save more than 600 TWh per year (about 15% of total electricity use) at a cost of 8 cents per kWh or less, leading to substantial dollar savings as well as substantial energy savings.



Source: NRC, 2009

Example: Energy Use in U.S. Industry

TABLE 2 Potential for Energy-Efficiency Improvements in Industry by 2020: Sector-wide and for Selected Subsectors and Technologies (in Quads)

	CEF Study[a] Scaled to AEO 2008[b]	McKinsey and Company (2008)	Other U.S. Studies	Global Estimates from IEA (2007)
Petroleum refining	N/A	0.3	0.07–1.46 to 1.68–3.94	13–16%
Pulp and paper	0.14	0.6	0.53–0.85	15–18%
Iron and steel	0.21	0.3	0.76	9–18%
Cement	0.08	0.1	0.04 to 0.65	28–33%
Chemical manufacturing	N/A	0.3	N/A	13–16%
Combined heat and power	2.0	0.7		
Total Industrial Sector	7.7	4.9		18–26%
	(22.4%)	(14.3%)		

Source: Based on NRC, 2009.

[a] For CEF study, see Intergovernmental Working Group, 2000.

[b] AEO 2008, see EIA, 2008a.

Source: NRC, 2009

Example: Energy Use in U.S. Industry

TABLE 3 Summary of Potential Savings in Industry (estimated energy savings due to energy-efficiency improvements in industry)[a] (in Quads)

	Energy Use in Industry			Savings over Business as Usual (BAU) in 2020[a,b]	
	BAU Projection (DOE/EIA Reference Case)				
Industry	2007	2020	2030	Savings in 2020[a,b]	
Petroleum refining	4.09	6.07	7.27	0.77–2.81	
Iron and steel	1.38	1.36	1.29	0.21–0.76	
Cement	0.44	0.43	0.41	0.04–0.39	
Bulk chemicals	6.85	6.08	5.60	0.30	
Pulp and paper	2.15	2.31	2.49	0.53–0.85	
Total savings for all industries (including those not shown)					4.9–7.7[c] 14%–22%

Source: NRC, 2009.

[a] Based on review of studies for specific major energy-using industries, for industrial combined heat and power (CHP), and for industry as a whole.

[b] Savings shown are for cost-effective technologies, defined as those providing an internal rate-of-return of at least 10 percent.

[c] Includes 0.7–2.0 quads from CHP systems.

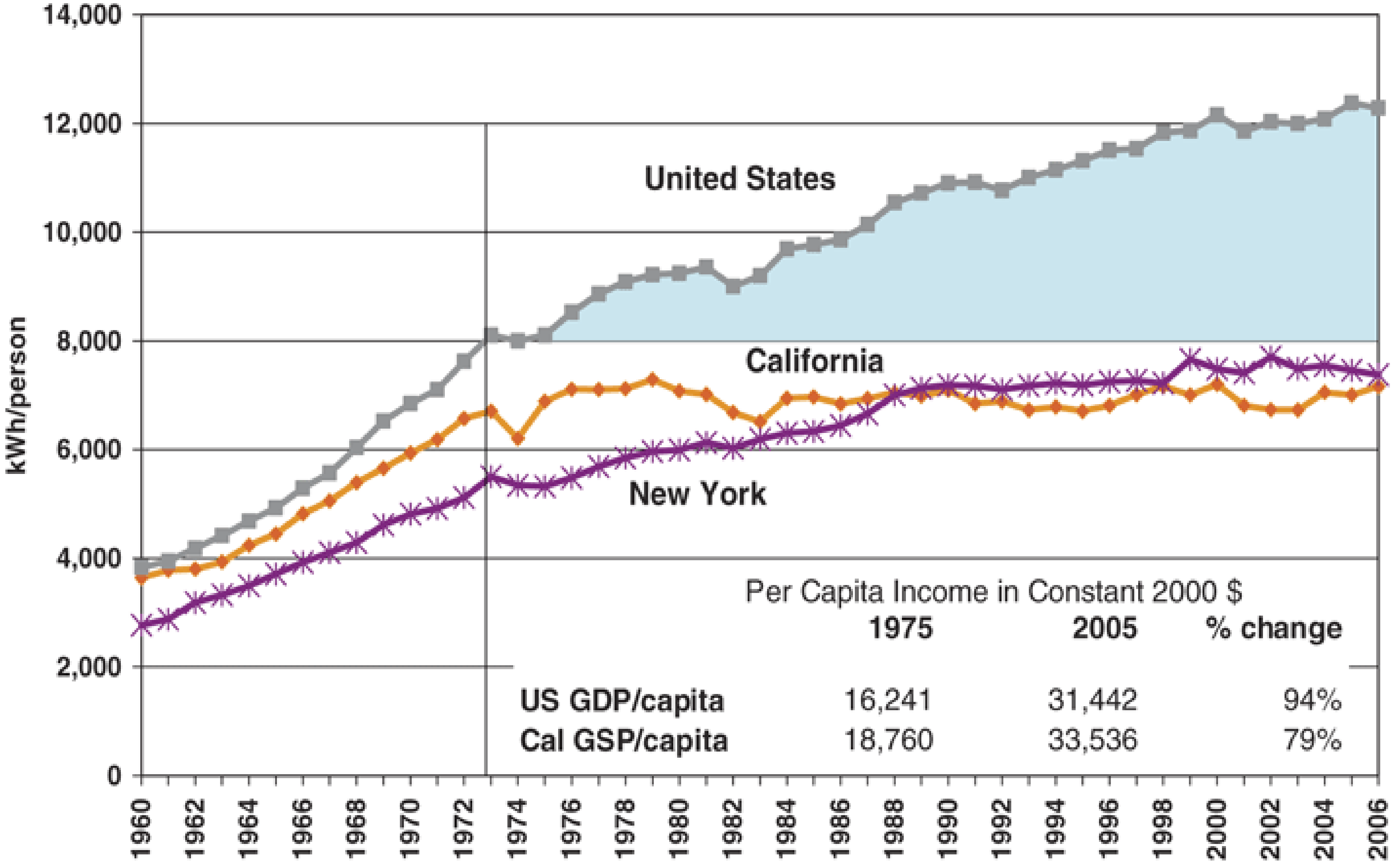
Source: NRC, 2009

Example: Energy Use in U.S. Industry

- Cross-cutting technologies, such as combined heat and power, better separation processes, advanced materials that resist corrosion and can withstand high temperatures, better steam and process heating technologies, new fabrication processes, and better sensors could lower energy use in many industries.

- Table 3: by 2020, improvements in energy efficiency could reduce energy use by 14 to 22 %, compared to the usual projection, with rates of return of at least 10%. However, major barriers would have to be overcome to achieve these levels of improvement:
  - Because each industrial plant is unique, new technologies pose technical risks and may interrupt production or lower the quality of a product, even if they have been proven effective in other plants.
  - Industry is looking for a much higher rate of return than 10% in allocating investment funds among competing projects.
  - Plant managers are unlikely to have the discretion to invest in energy efficiency or reductions in emissions unless they are required to do so by regulation or ordered to do so by company management.
  - Efficiency innovations often require specialized knowledge that many current plant managers do not have.

Potential electricity savings for residential products



Source: Lester Lave, The Potential of Energy Efficiency, NRC 2009

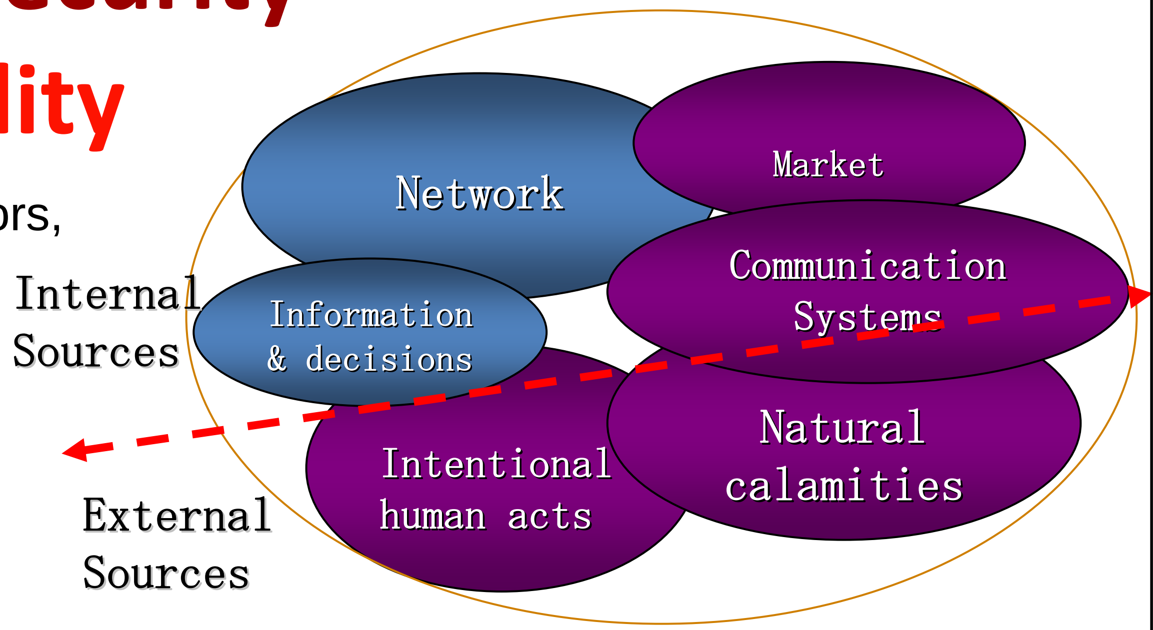
Security

The difficulty lies not with the new ideas, but in escaping the old ones. . . .

John Maynard Keynes

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.

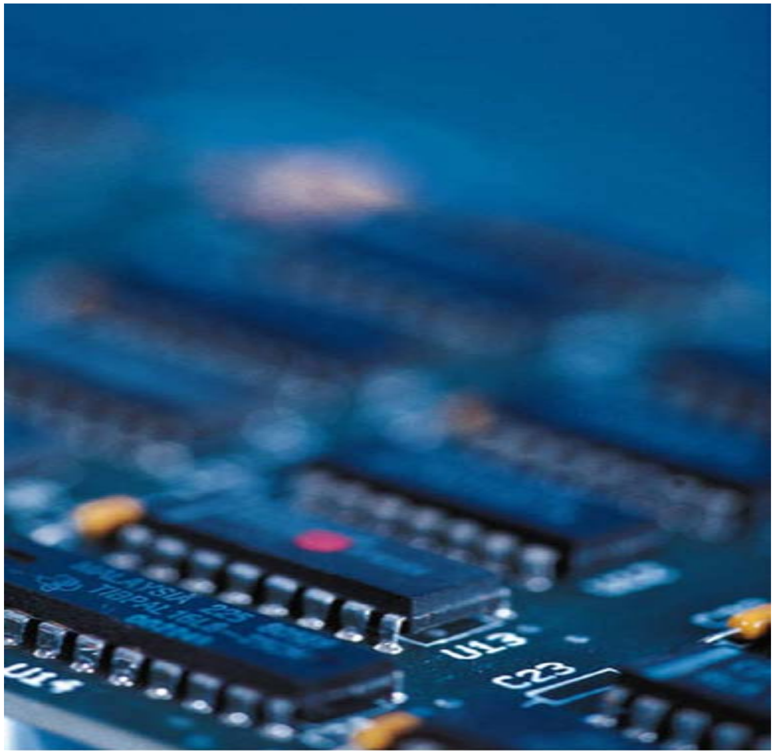
- Control Centers
- Interdependence: Gas pipelines, compressor stations, etc.; Dams; Rail lines; Telecom – monitoring & control of system
- Combinations of the above and more using a variety of weapons:
- Truck bombs; Small airplanes; Gun shots – line insulators, transformers; more sophisticated modes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

Unconventional Threats to Security

Connectivity



Complexity

Context: IT interdependencies and impact

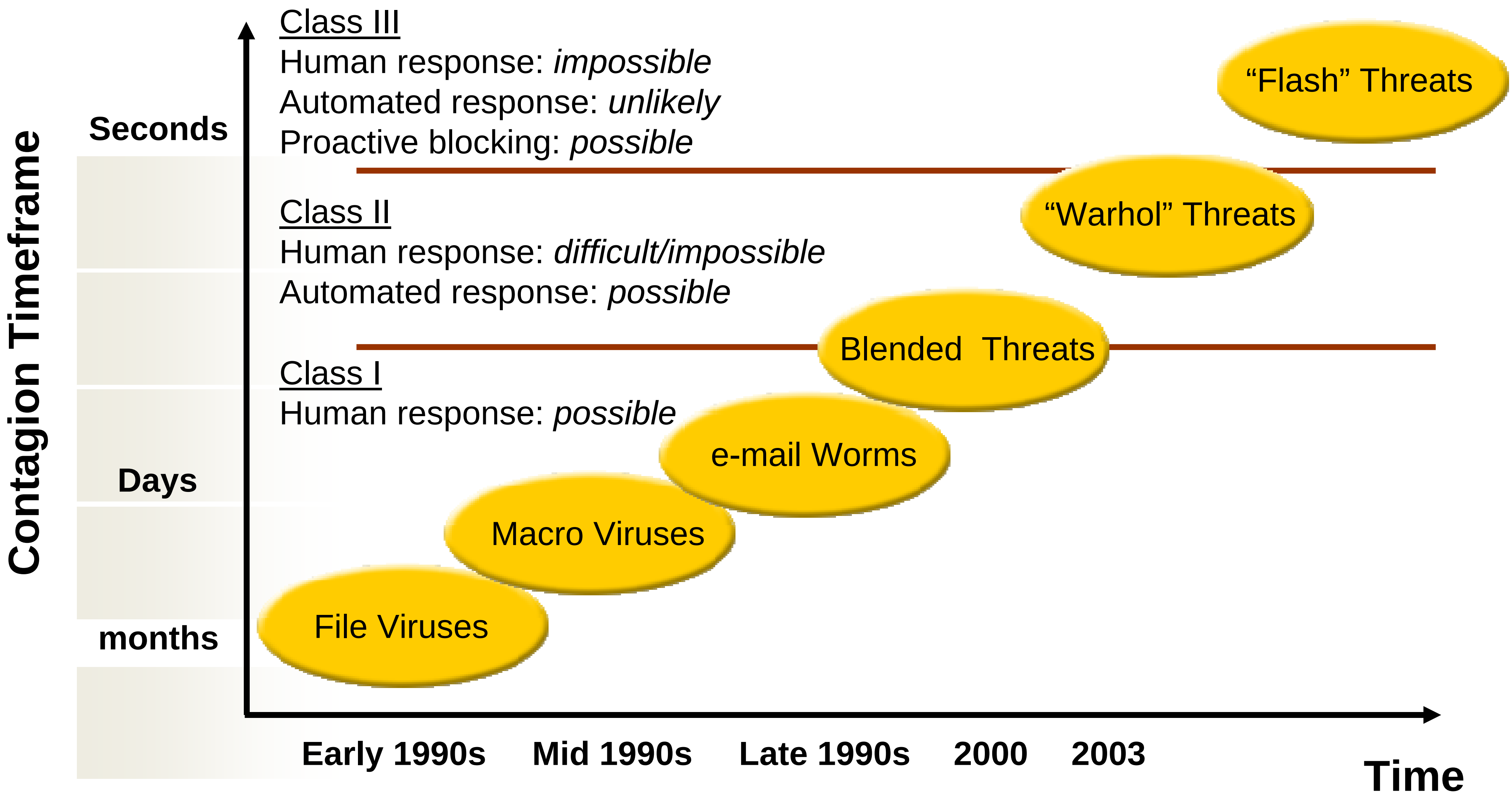
Dependence on IT: **Today's systems require a tightly knit information and communications capability. Because of the vulnerability of Internet communications, protecting the system will require new technology to enhance security of power system command, control, and communications.**

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.**

Threat Evolution: Malicious Code



The Threat Situation

Continuing serious cyber attacks on information systems, large and small; targeting key federal, state, local, and private sector operations and assets…

- Attacks are organized, disciplined, aggressive, and well resourced; many are extremely sophisticated.
- Adversaries are nation states, terrorist groups, criminals, hackers, and individuals or groups with intentions of compromising federal information systems.
- Effective deployment of malicious software causing significant exfiltration of sensitive information (including intellectual property) and potential for disruption of critical information systems/services.

-- Dr. Ron Ross
NIST, *Computer Security Division*
Information Technology Laboratory

What is at Risk?

- Federal information systems supporting agencies within the federal government; state and local information systems.
- Private sector information systems supporting U.S. industry and businesses (intellectual capital).
- Information systems supporting critical infrastructures within the United States (public and private sector) including:
  - Energy (electrical, nuclear, gas and oil, dams)
  - Transportation (air, road, rail, port, waterways)
  - Public Health Systems / Emergency Services
  - Information and Telecommunications
  - Defense Industry
  - Banking and Finance
  - Postal and Shipping
  - Agriculture / Food / Water / Chemical

Context: The North American Economy is Dependent on Electronic Communications

- **North America uses:**
  - **42% of world's computing power**
  - **60% of world's Internet assets**
  - **90% of large & 75% of small companies have Local Area Networks**

- **Number* of documented computer attacks increasing-- from about 2,100 in 1997, 3,700 (1998), 9,800 (1999), 21,750 (2000), to 52,600 in 2001**
  - **Costs* of Worldwide economic impact (in billions of dollars):**
    - 1999: Explorer ($1B), Melissa ($1.1B)
    - 2000: Love Bug ($8.8B)
    - 2001: Nimda ($0.6B), SirCam ($1.2B), Code Red($2.6B)

*sources: Computer Emergency Response Team, Computer Economics, and USA Today

September 11, 2001 Tragedies

Electric industry may lead pack in disaster safeguards

By David Wagman
dwagman@ftenergy.com

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.

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.

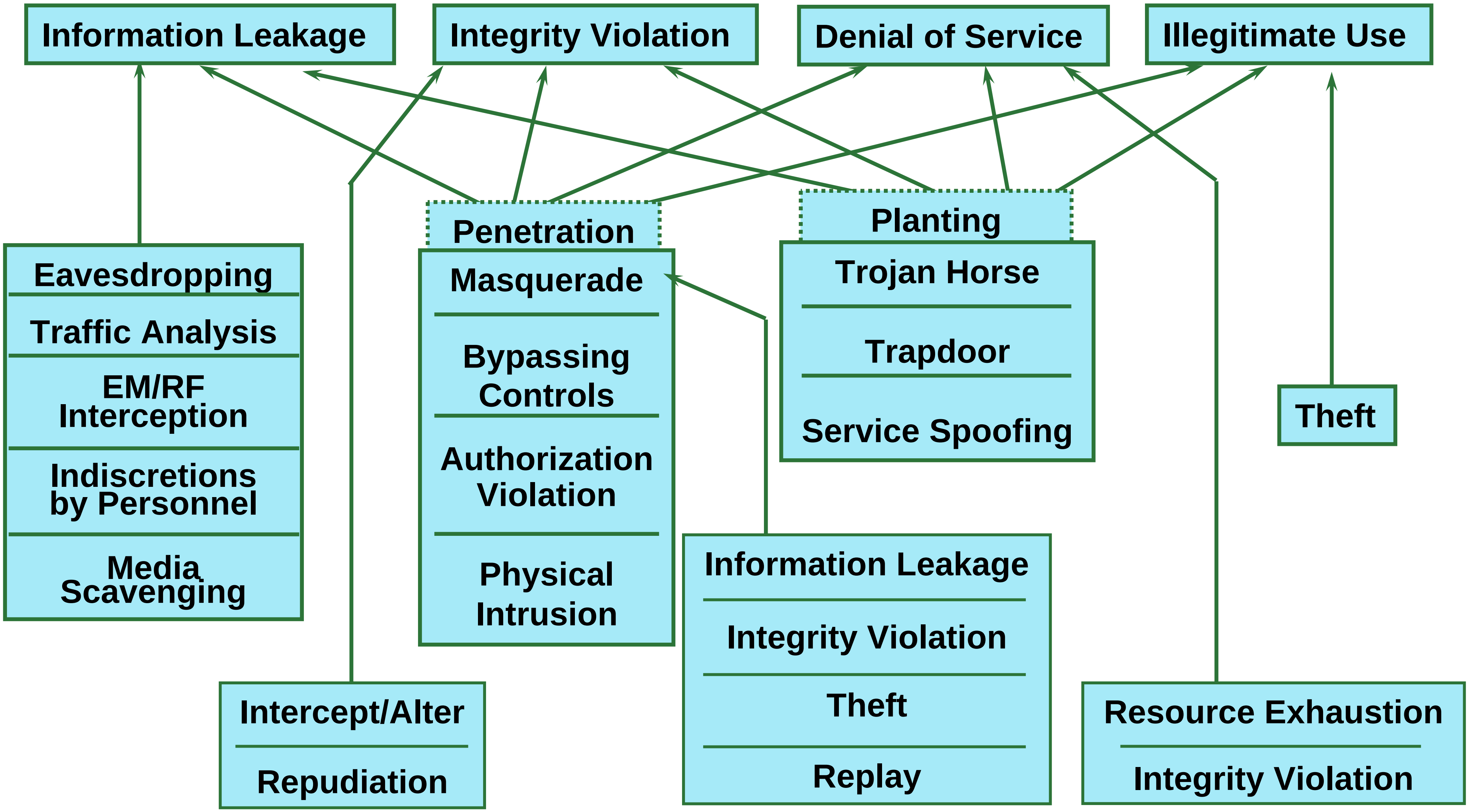
"It was indeed ironic that we were engaged at the very moment of the attack in a conference attempting to find realistic technical ways to mitigate disaster," said Amin.

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.

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

OCTOBER 1, 2001 PAGE 1

What Can They Do and How Can They Do It?

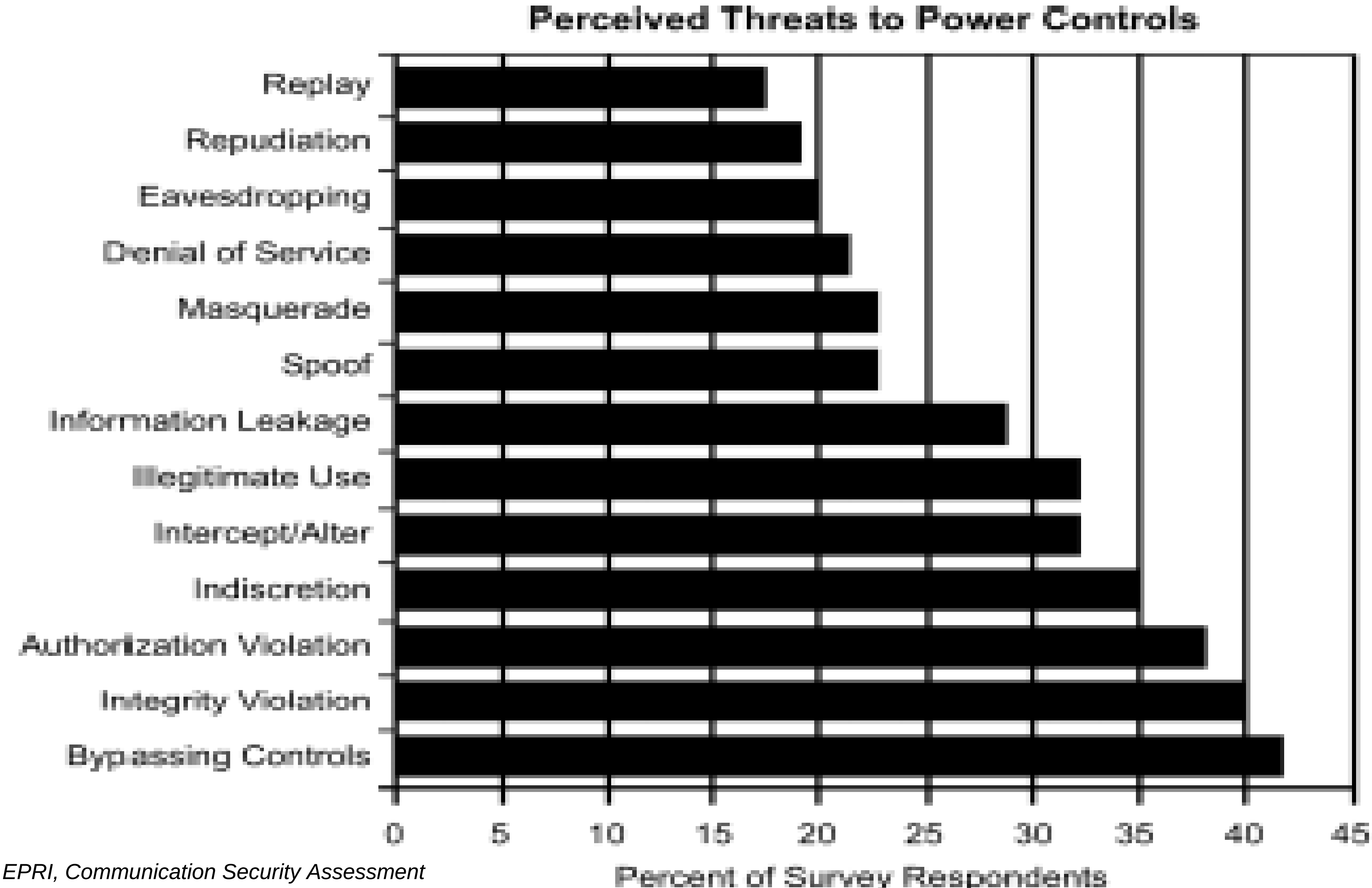


Electric Company Vulnerability Assessment

- 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

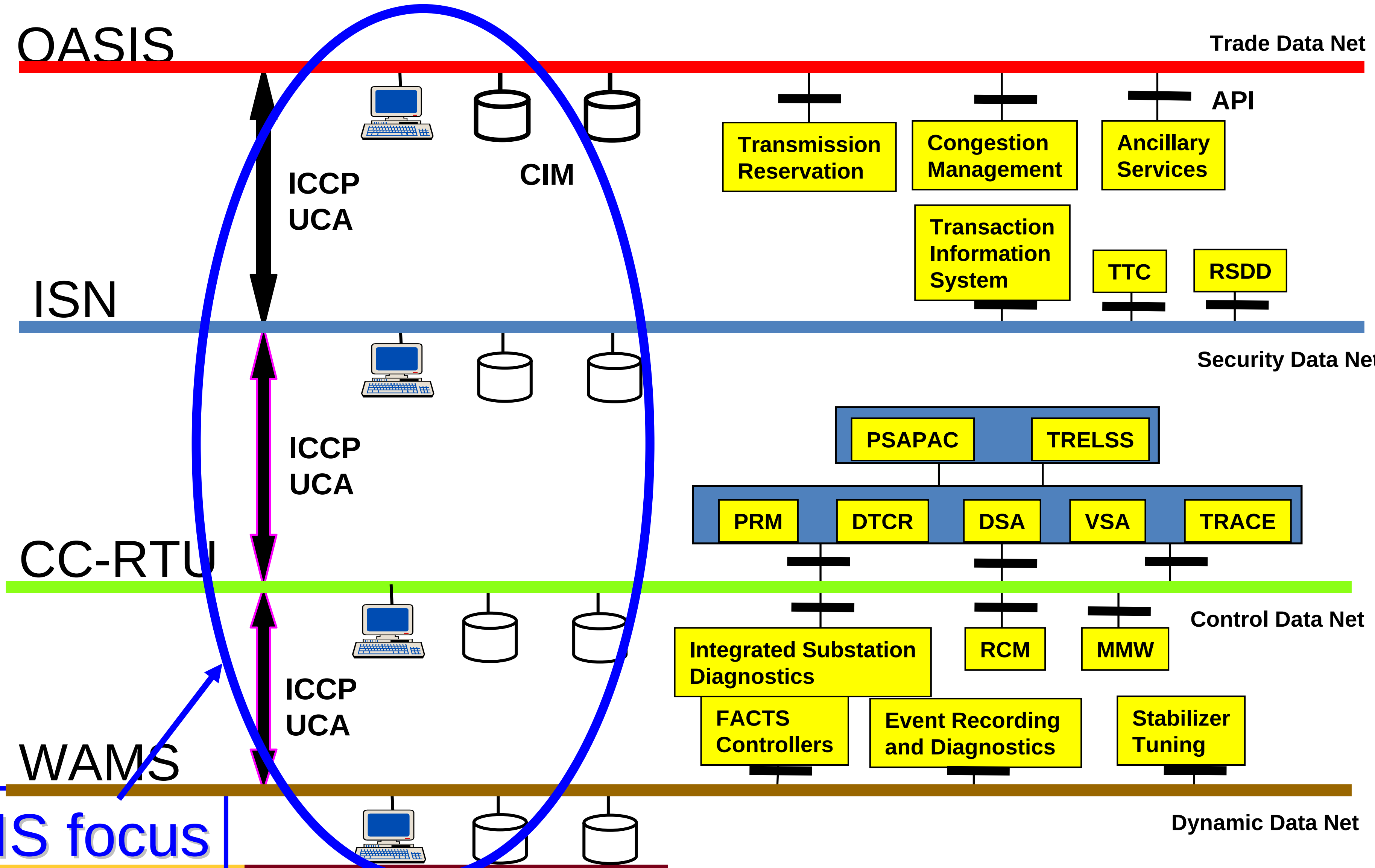


Source: *EPRI, Communication Security Assessment for the United States Electric Utility Infrastructure,* EPRI, Palo Alto, CA: 2000. 1001174.

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

Information Networks for On-Line Trade, Security and Control



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)

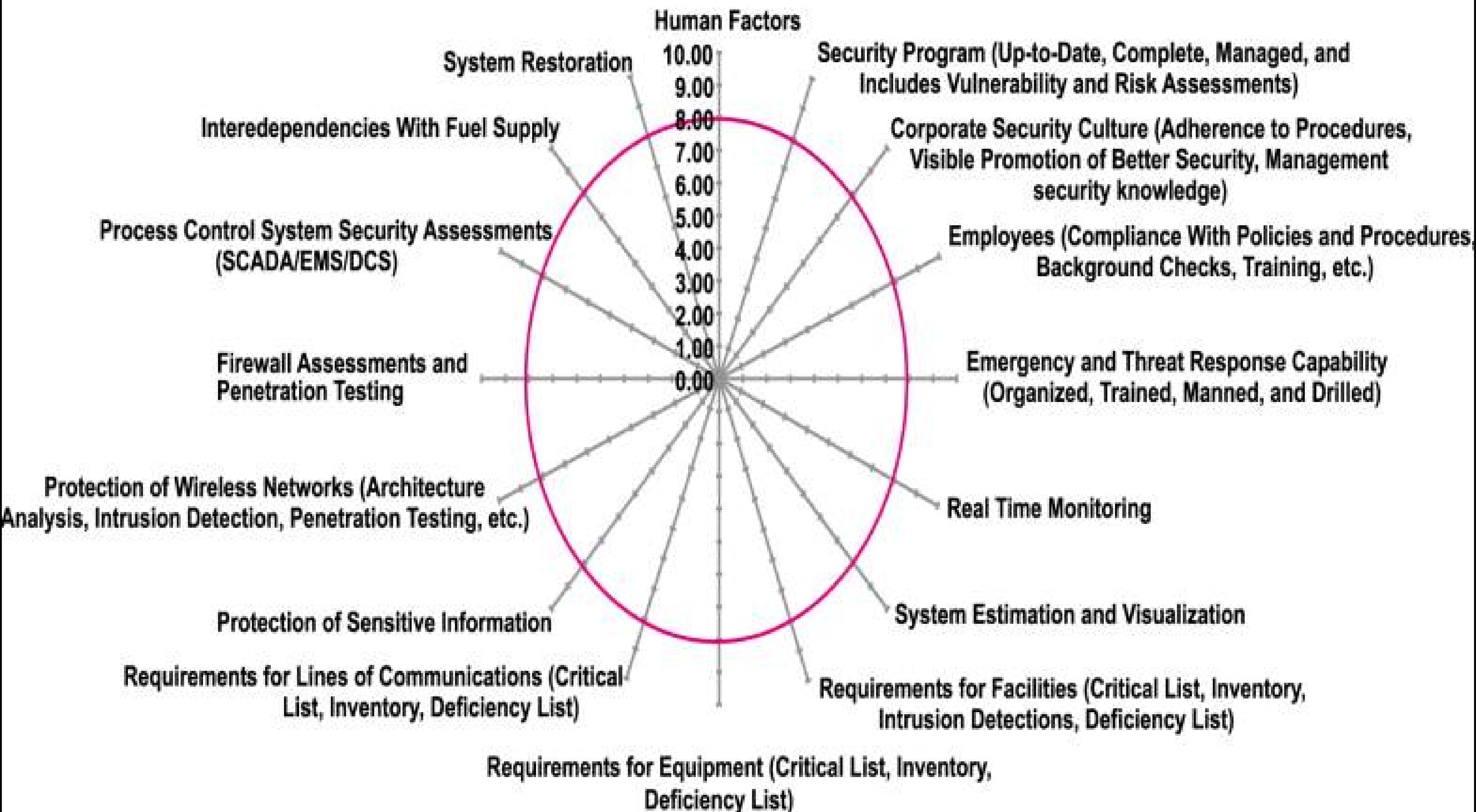
Physical

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



Technological Leadership Institute

University of Minnesota
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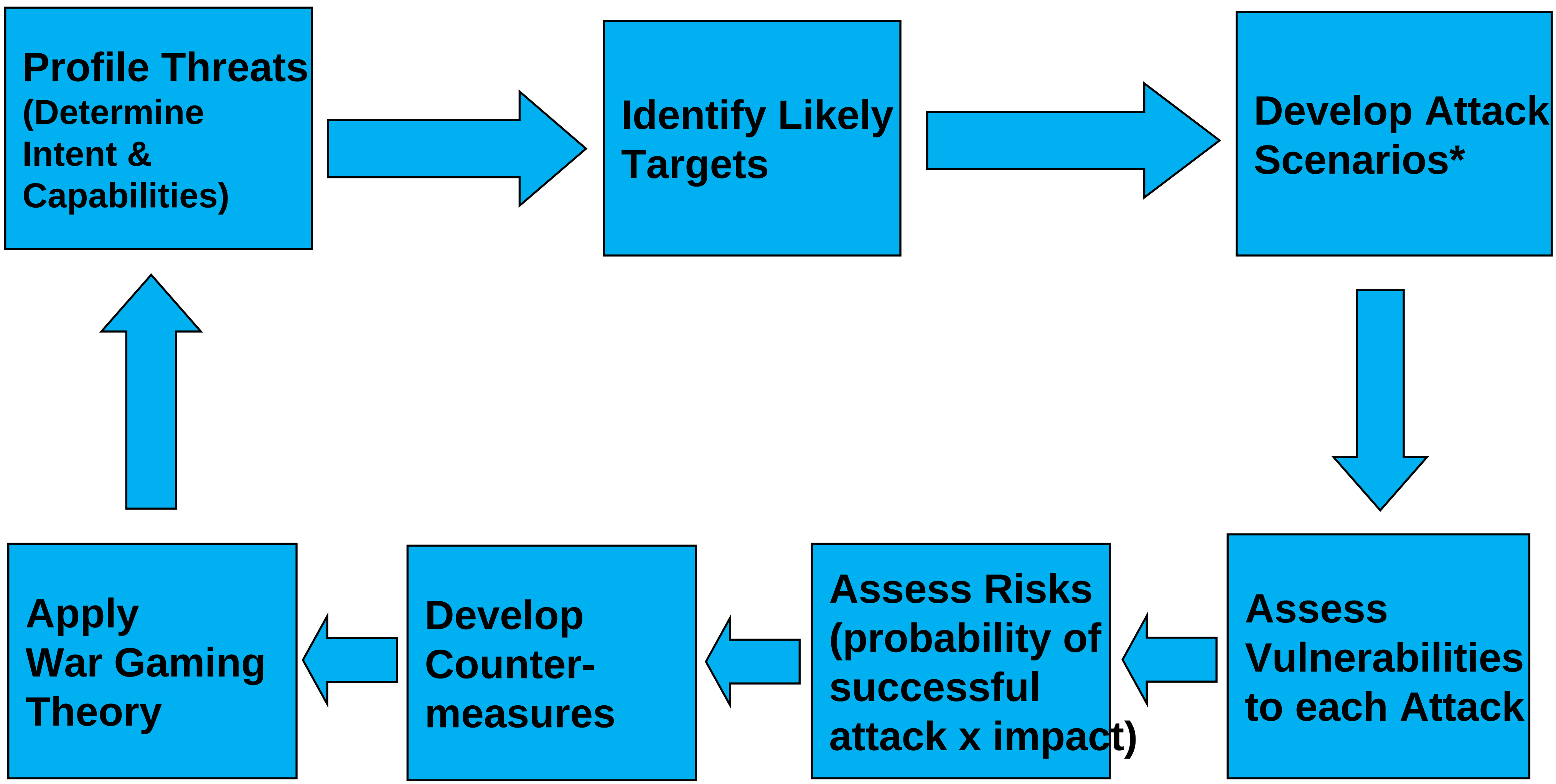
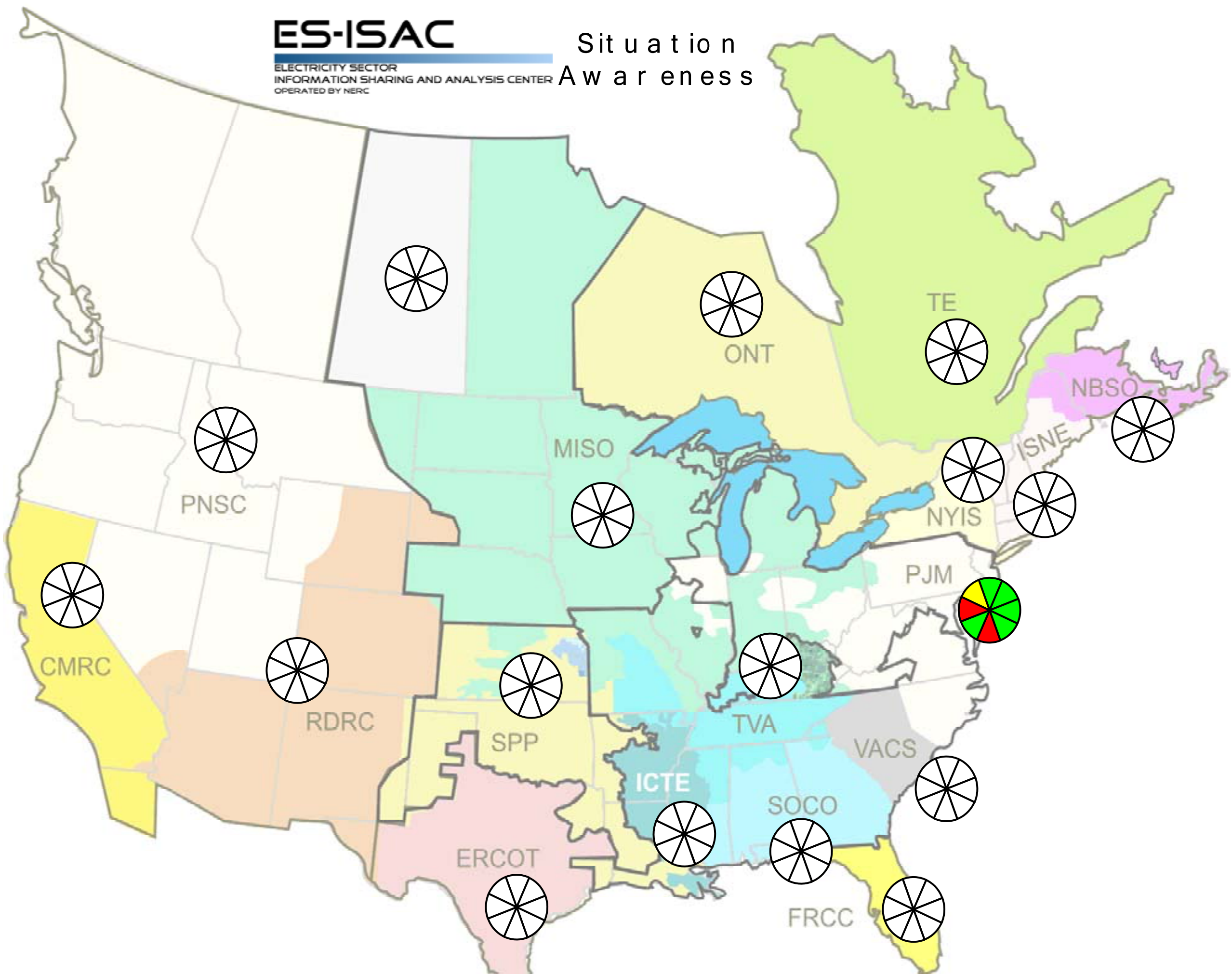
What can be Done?

Vulnerability Assessment and Layered Defense in Depth



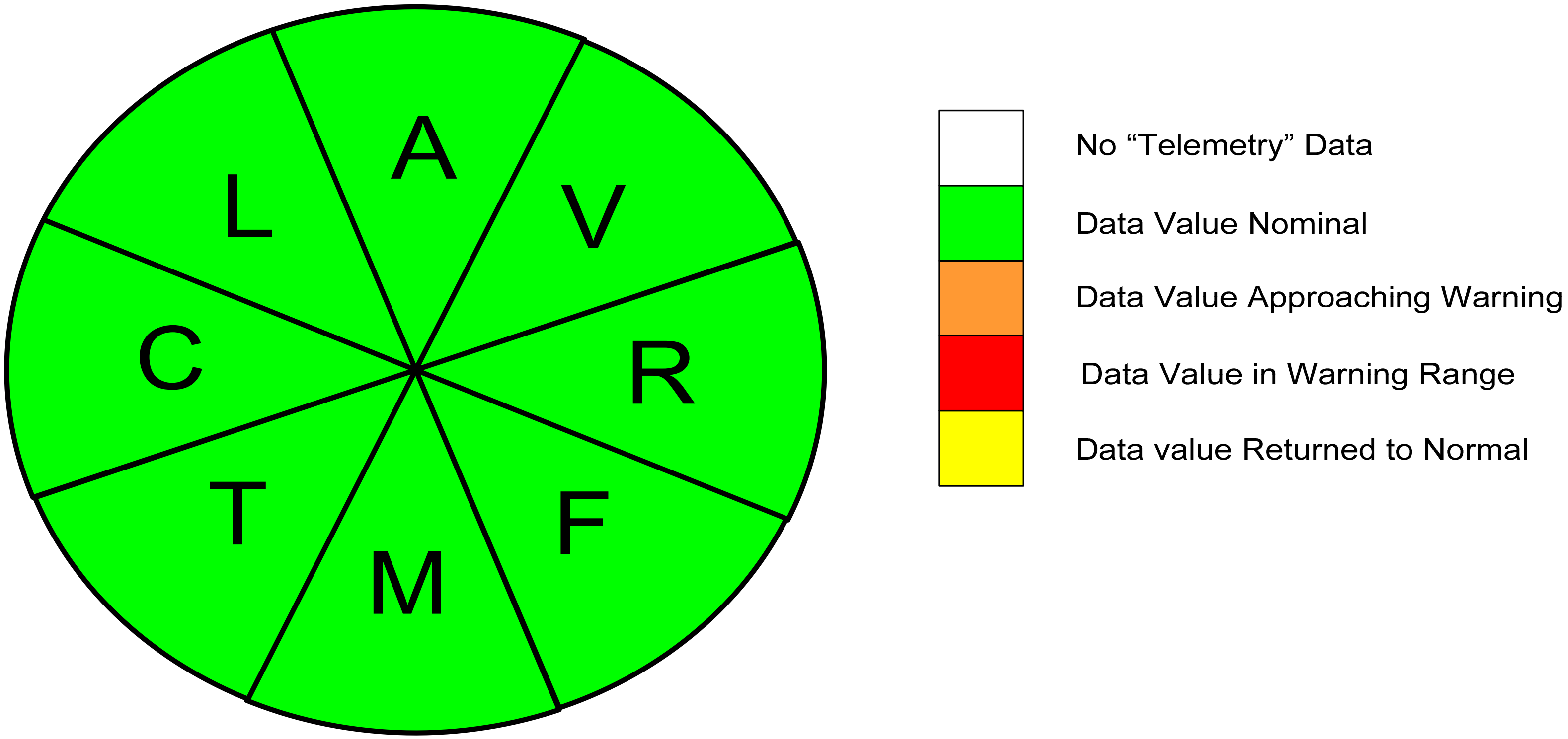
*Evolving spectra of targets and modes of attack

Situation Awareness Tool (SAT)



Source: NERC

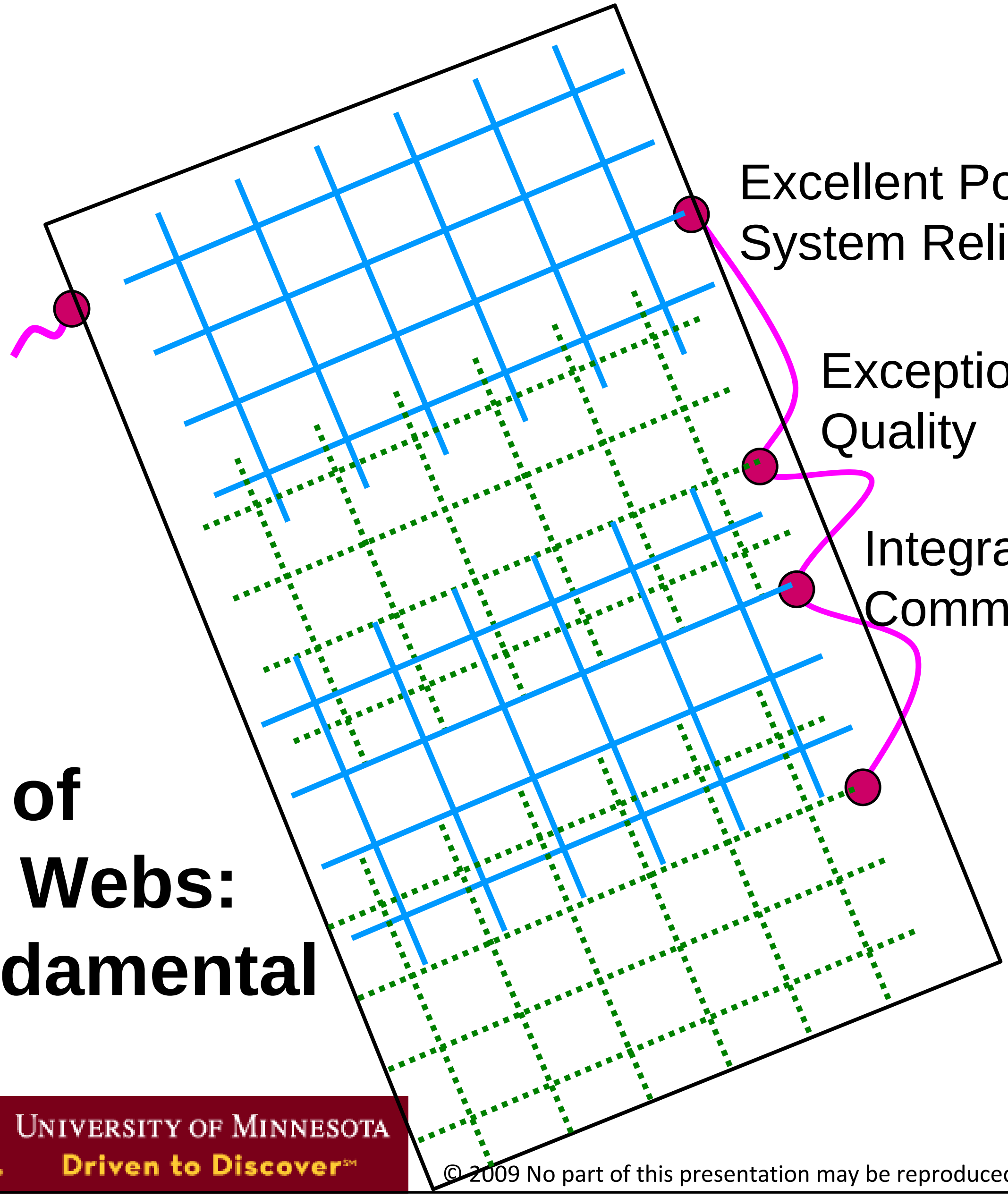
Situation Awareness Tool (SAT)



A – ACE
L – Deviation from Forecasted Load
C – Reserve Real-power Capacity
V – Voltage Deviation from Normal
R – Reserve Reactive-power Capacity
M – Text Message
T – Transmission Constraint
F – Frequency

Source: NERC

The Smart Infrastructure for a Digital Society



A Complex Set of Interconnected Webs: Security is Fundamental

An Example: Smarter 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 (at less than 0.5% of total cost).**

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

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

Source: Massoud Amin, Congressional briefings, March 26 and October 15, 2009

An Engine for Economic Growth

GDP Density

Satellite picture of the earth at night

Macroeconomic Rationale

1. Endogenous growth models - theoretical support for domestic technology creation

2. Y = f(R, K, H), where:

   Y = GDP

   R = R&D

   K = physical capital

   H = human capital

3. GDP growth: a) Velocity and proportion of R, K, H, and b) available and affordable energy: determinants of success

Economic Growth:

Building Minnesota's Competitive Advantage through Partnerships and Technology/Policy/Business Development

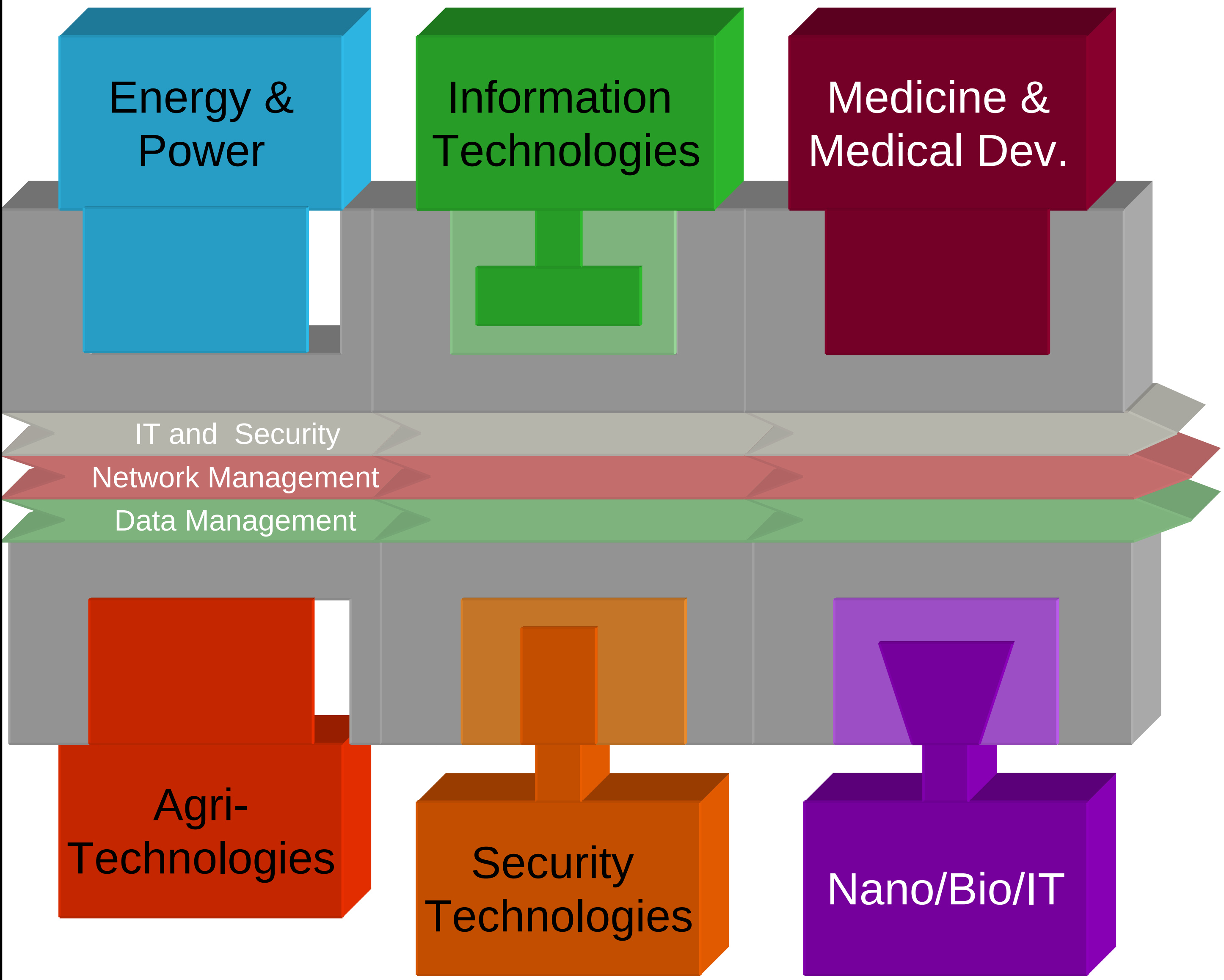
Globally Interlocked Dynamics:
Understanding the Full Impacts of Decision Pathways

•To unfold the full potential of social progress requires an integrated understanding of the many dimensions of social development, their underpinnings, and the role of science and technology.

•Goal: To target our constrained development resources to maximize benefit and minimize unintended consequences

Minnesota's Technological Leadership Role:

Enabling Economic Growth→ First Build the Right Foundation



Build The Right Foundation

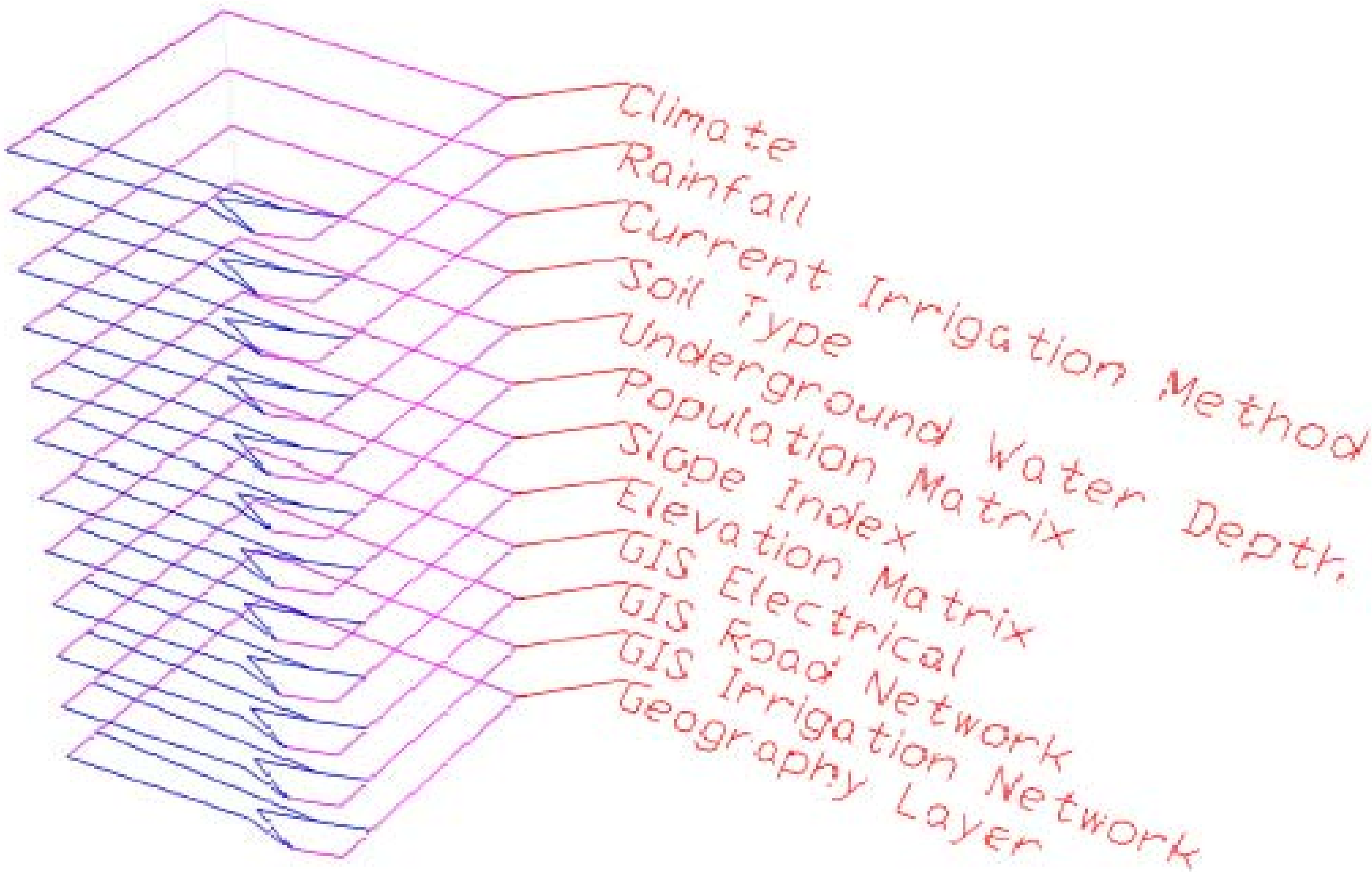
Security

Network Management

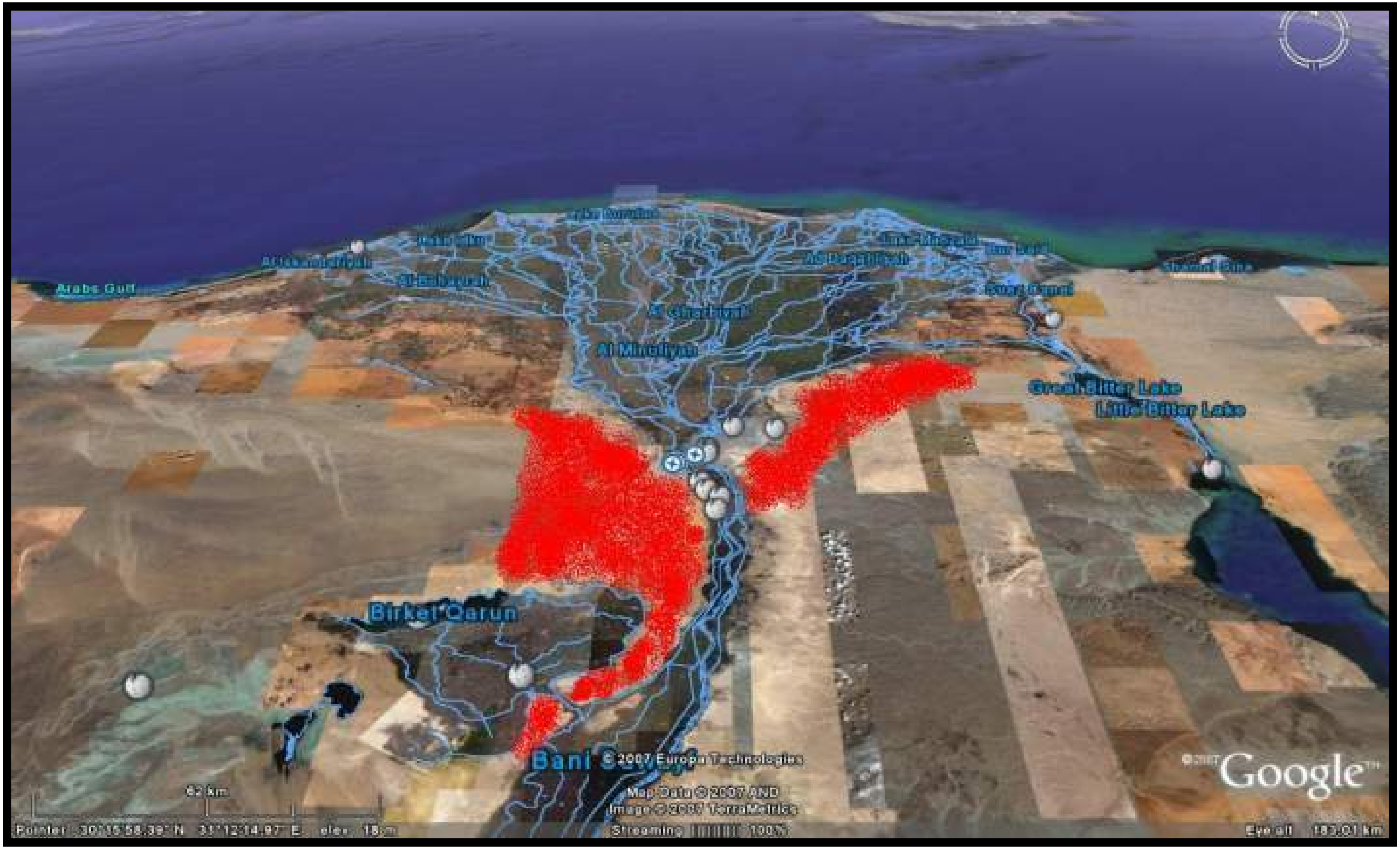
Data Management

Interoperability

Example: EGYPT
Analysis-- Factors Affecting Agriculture



Decision Real Life Picture



An 'About FACE' is Required

- Focus
- Alignment
- Collaboration
- Execution

Begin with a 360 ***Systems' Approach*** *and the End Goal in Mind:*

Focus on a few big 'problems that matter' to our nation and the world in the next half century

Smart Power and Energy · ***Security S&T*** · ***Sustainable Water*** · ***Sustainable Agriculture*** · ***Public Health*** · ***Environment*** · ***Smart Planet*** · ***etc.***

Exploit Core Competencies to Address Strategic Areas:

Focus on the intersection of 3-5 problems that matter AND our core competencies (build and leverage expertise, Government/Industry/University relationships, to power economic growth).

Source: Collab. With Kirk Froggatt, TLI, University of Minnesota

We have a bright future if we challenge the best minds and marshal their talents…

- Albert Einstein once said that "compounded interest is the most powerful force in the universe":
  - "250 year reserves of coal" will shrink very quickly even at 2-3% growth rate per year.
- Advanced Nuclear and renewable resources:
  - Solar - Wind -Geothermal
  - Ocean/Wave energy -- Waste to energy
  - Agricultural, incl. soy/corn, sugar (e.g., Brazil)
    - Biodiesel, cellulosic, ethanol, methanol, biomass
  - Hydrogen from renewables (longer term)
    - will it require more energy to produce?
- Broad range of R&D including end-use and system efficiency, electrification of transportation, stronger and smarter grid, and with security built-in.

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 self-healing infrastructure interdependency R&D, resilience, and security
- Revitalize the national public/private electric power and energy infrastructure partnership needed to fund the “Smart Grid” deployments

Source: Massoud Amin, Congressional briefings, March 26 and October 15, 2009

Policy

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.

Smart Grid Initiatives

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

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.

Smart Grid

- **PEAK DEMAND** reduction through the application of smart devices and how they might affect consumer behavior and enable renewable and distributed energy resources
- **ASSET UTILIZATION** assets better utilized through improved demand-side management and infrastructure investment deferrals
- **RELIABILITY** improved through the application of smarter sensing, communication and control devices
- **REDUCED EMISSIONS** of environmental pollutants, e.g., carbon dioxide, and reliance on foreign-supplied fuels

U.S. DOE smart grid announcements

- Smart Grid Investment Grant Program
  - Refers to Section 1306 of Energy Independence and Security Act of 2007 (EISA), later modified by the American Recovery and Reinvestment Act of 2009 (ARRA)
  - "… federal assistance to cover up to fifty percent of investments by electric utilities and other entities for projects that promote the goal of deployment, including development of component technologies."
  - Minimum 50% cost share
- Smart Grid Demonstrations
  - Three areas covered: Smart Grid, Synchrophasors, and Energy Storage
  - Minimum 50% cost share

Smart Grid Investment Grant program

- Eligible applicants
  - Investor-owned and municipality-owned utilities
  - Rural electric cooperatives
  - Load serving/distribution companies
  - Retail distributors or marketers of electricity
  - System operators
  - "Manufacturers of appliances and equipment to enable smart grid functionalities"

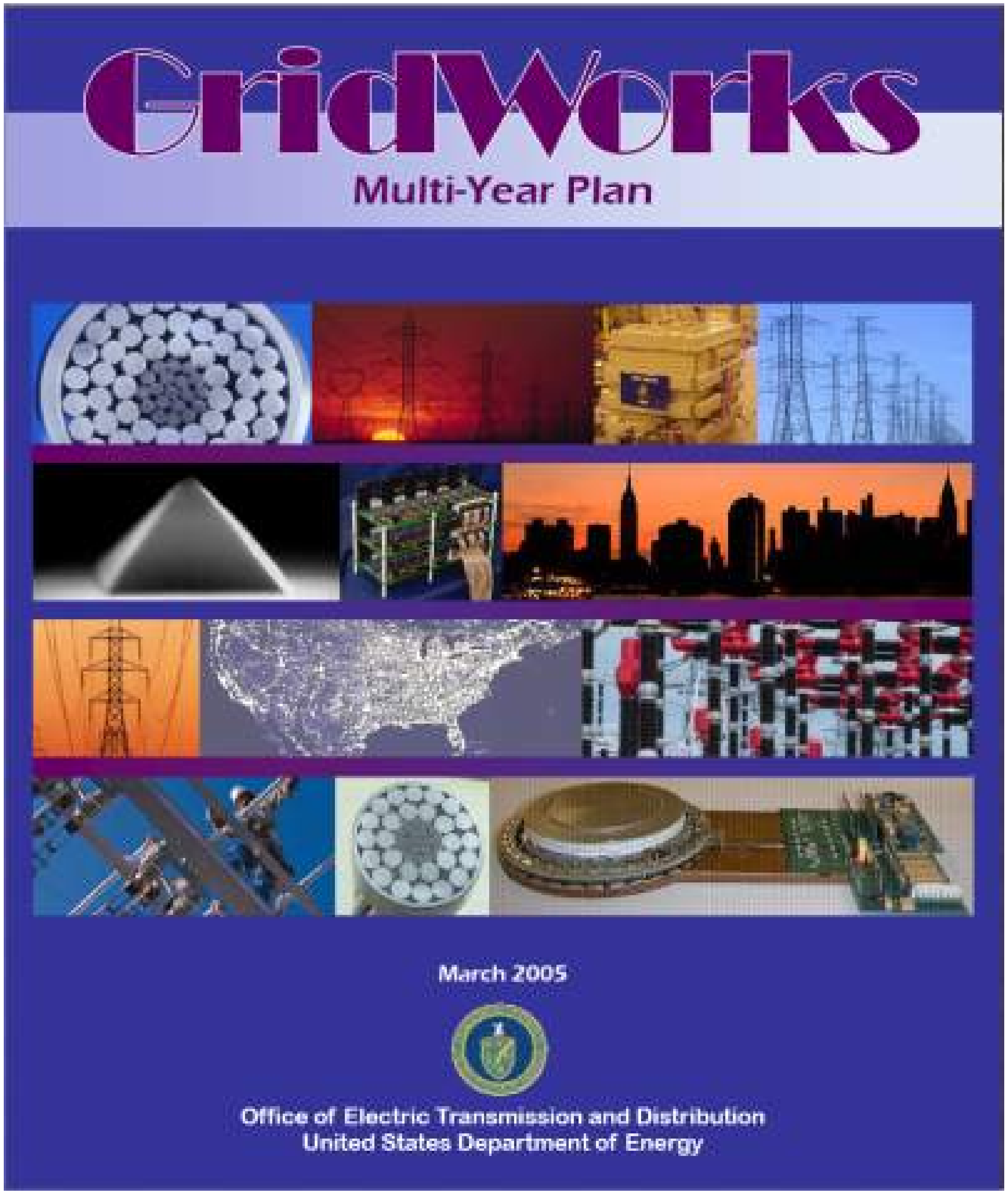
Smart Grid Investment Grant program

- Projects should support or advance one or more smart grid functions for example:
  - Develop, store, send, and receive digital information concerning
    - Electricity use, costs, prices, time of use, nature of use
    - Storage or other relevant information
  - Measure or monitor electricity use as a function of
    - Time of day, power quality characteristics
    - Source or type of generation
    - Store, synthesize or report that information
  - Address system security, especially cyber security, concerns
  - Automatic (or manually preprogrammed) response of appliances and machines

Electric Power Research Institute

IntelliGrid℠

www.epri-intelligrid.com/intelligrid/home.jsp



US Department of Energy

GRIDWISE

www.gridwise.org

Standards: NIST

As part of the Energy Independence and Security Act (EISA) of 2007, the National Institute of Standards and Technology (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…"

[EISA Title XIII, Section 1305]

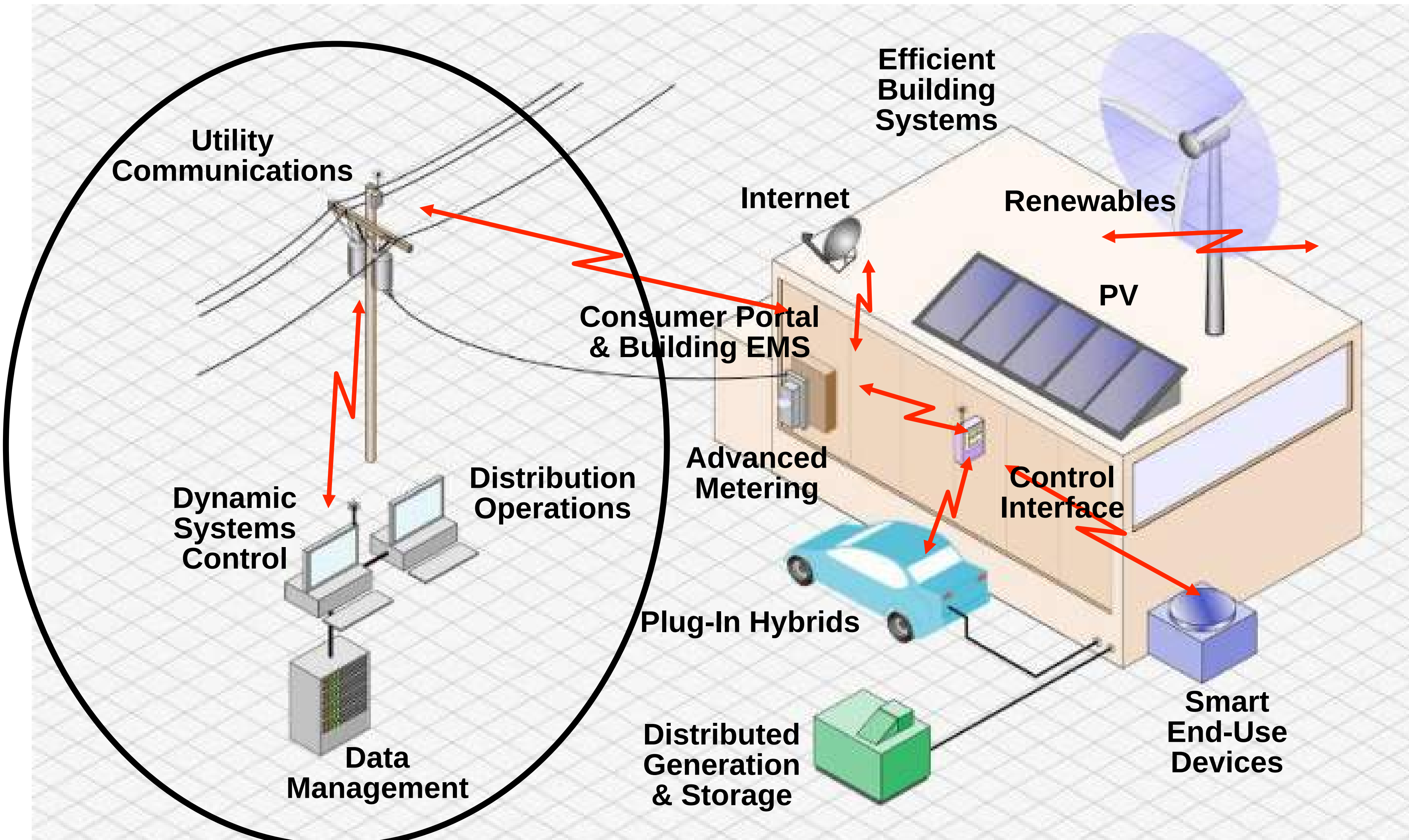
NIST Solar Energy Research, from NIST Photographic Collection

Near-Term Actions for NIST to advance the Interoperability Framework

- Developing a common semantic model
- Developing a common pricing model
- Developing a common semantic model for advanced metering, demand response, and electric transportation
- Conducting an analysis to select Internet Protocol Suite profiles for smart grid applications
- Investigating Communications Interference in Unlicensed Radio Spectrums
- Developing common time synchronization and management
- Coordinating efforts across Standards Development Organizations

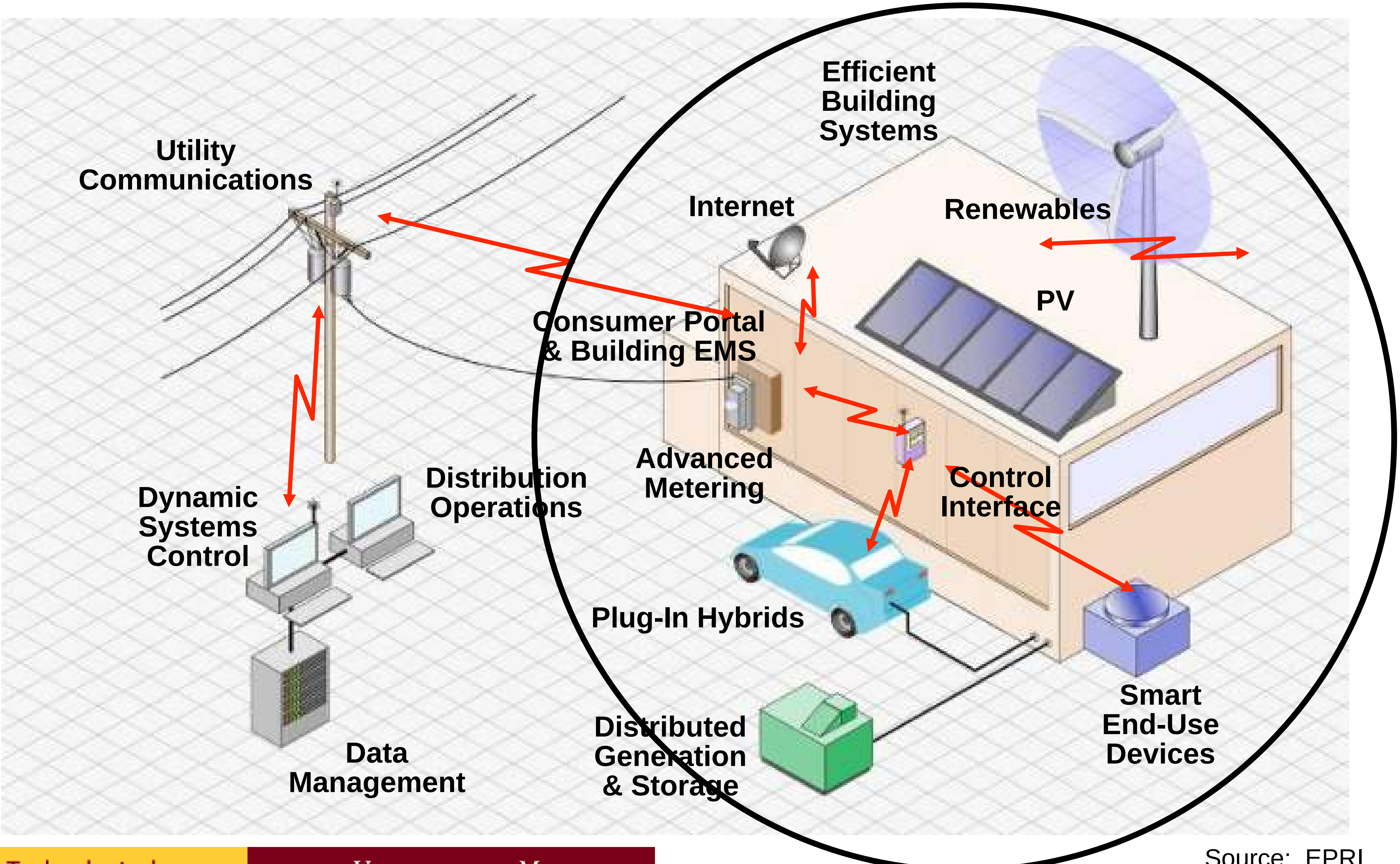
Source: **"Report to NIST on the Smart Grid Interoperability Roadmap," prepared by EPRI, released June 17th, 2009.**

Smart Grids and Local Energy Networks



Source: EPRI

Smart Grids and Local Energy Networks

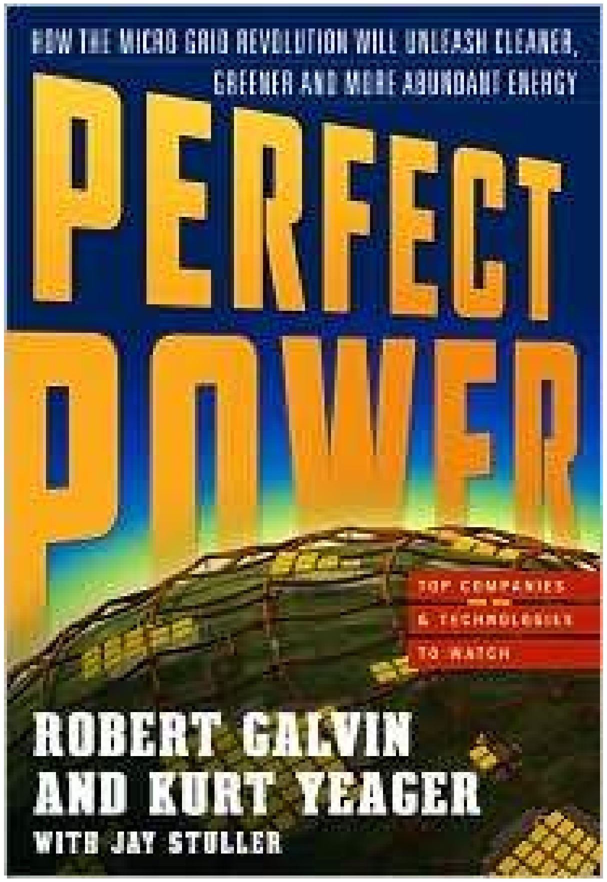


Source: EPRI

Galvin Electricity Initiative

Working to transform the power grid into a "perfect power system" that cannot fail, through the use of smart microgrids.

http://www.galvinpower.org/



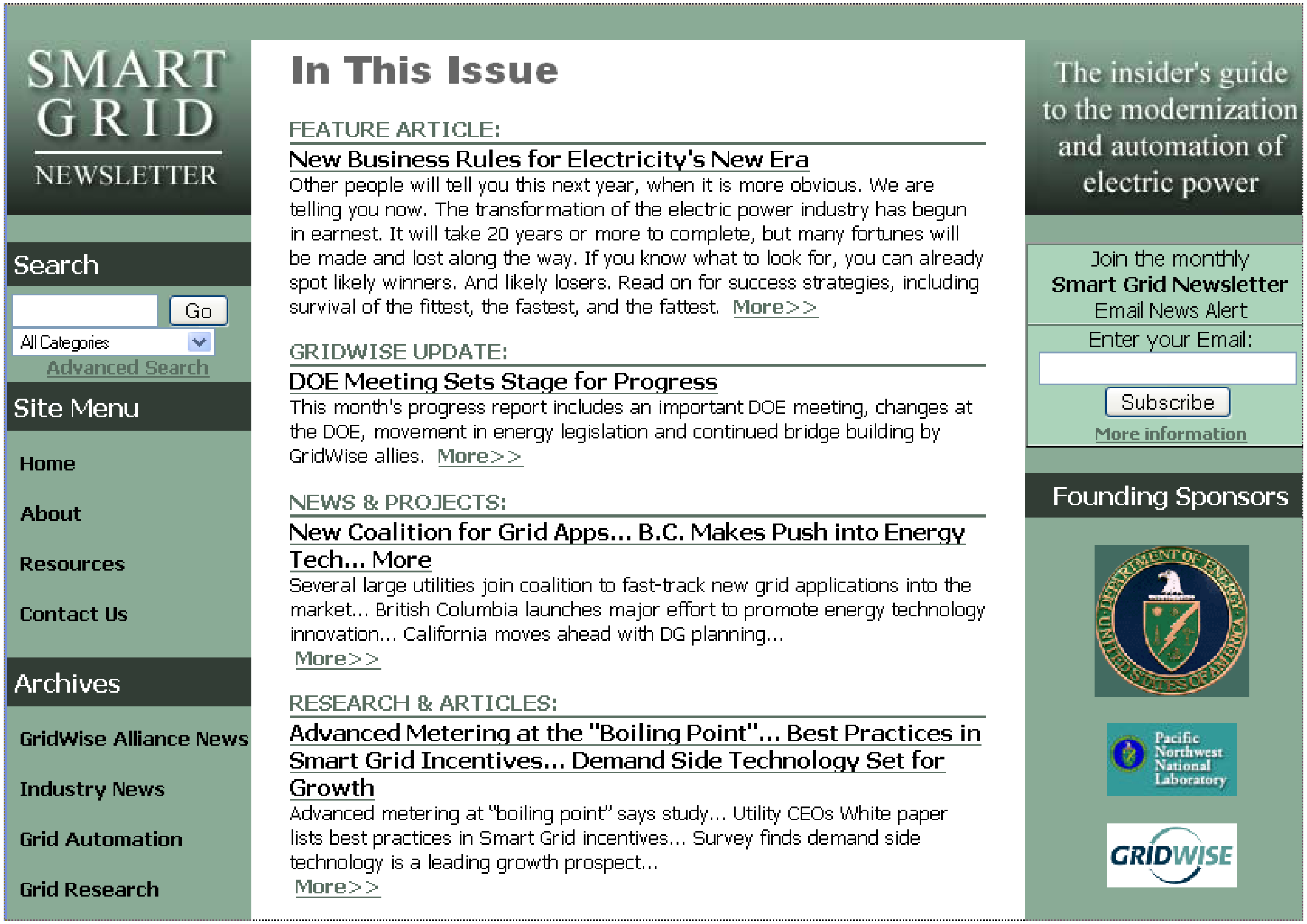
Demand Response *and* Smart Grid *Coalition*

"…is the trade association for companies that provide products and services in the areas of demand response, smart meters, and smart grid technologies."

http://www.drsgcoalition.org/index.html

Source: http://www.echelon.com/company/press/2009/images/smarthome_lg.jpg

SMART GRID NEWSLETTER



SMART GRID NEWSLETTER

The insider's guide to the modernization and automation of electric power

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Go

All Categories

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- GridWise Alliance News
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- Grid Automation
- Grid Research

In This Issue

FEATURE ARTICLE:

New Business Rules for Electricity's New Era

Other people will tell you this next year, when it is more obvious. We are telling you now. The transformation of the electric power industry has begun in earnest. It will take 20 years or more to complete, but many fortunes will be made and lost along the way. If you know what to look for, you can already spot likely winners. And likely losers. Read on for success strategies, including survival of the fittest, the fastest, and the fattest. More>>

GRIDWISE UPDATE:

DOE Meeting Sets Stage for Progress

This month's progress report includes an important DOE meeting, changes at the DOE, movement in energy legislation and continued bridge building by GridWise allies. More>>

NEWS & PROJECTS:

New Coalition for Grid Apps... B.C. Makes Push into Energy Tech... More

Several large utilities join coalition to fast-track new grid applications into the market... British Columbia launches major effort to promote energy technology innovation... California moves ahead with DG planning... More>>

RESEARCH & ARTICLES:

Advanced Metering at the "Boiling Point"... Best Practices in Smart Grid Incentives... Demand Side Technology Set for Growth

Advanced metering at "boiling point" says study... Utility CEOs White paper lists best practices in Smart Grid incentives... Survey finds demand side technology is a leading growth prospect... More>>

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Baltimore Gas & Electric

BG&E Rolls Out 2 Million Meter Initiative; Seeks $200 Million from Feds (July 15, 2009)

Smart Grid Demonstrations

- Smart Grid Regional Demonstrations
- Synchrophasor Demonstrations
- Utility-Scale Energy Storage Demonstrations

Key Points

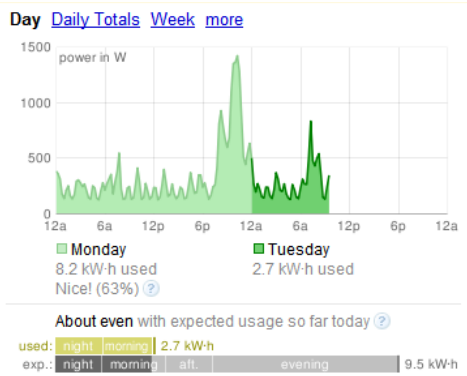
- Integration of Renewables
- Energy Efficiency
- Smart Grid Security
- Bottom Line → Economic Growth:
  - Building Minnesota's Competitive Advantage through Partnerships and Technology/Policy/Business Development

Transformative Innovations in Power & Energy

- Digital Control of the Energy Infrastructure (Reliability, Robustness, Resilience & Security)
- Integrated energy, information and communications for the user.
- Transformation of the meter into a secure two-way energy/information portal.
- Integration of distributed energy resource into the network.
- Robust advanced power generation portfolio.

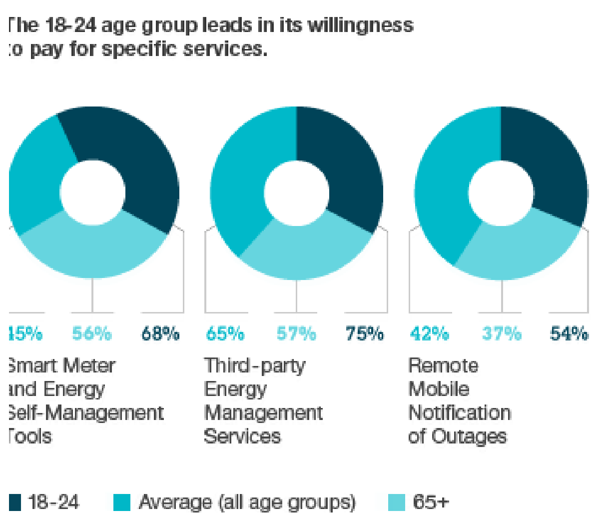
"Smart Grid" Components & Devices

Smart power strip (bridge) by Hyuk Jae Chang



Google Power Meter

Smart Meters



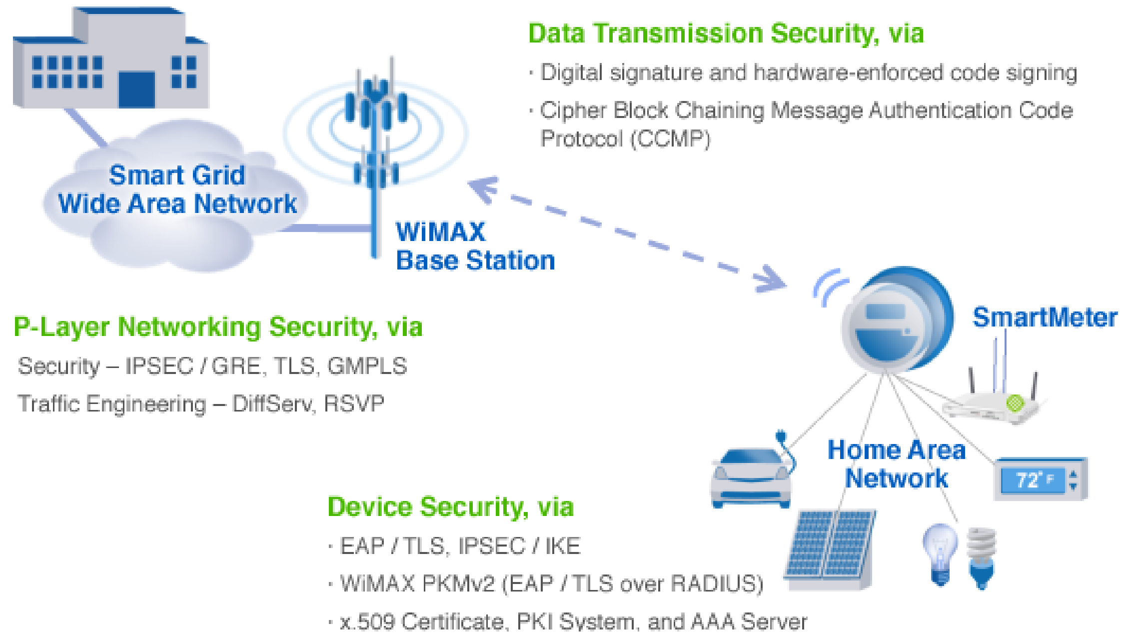
Source: IBM Smart Grid

Fast Company

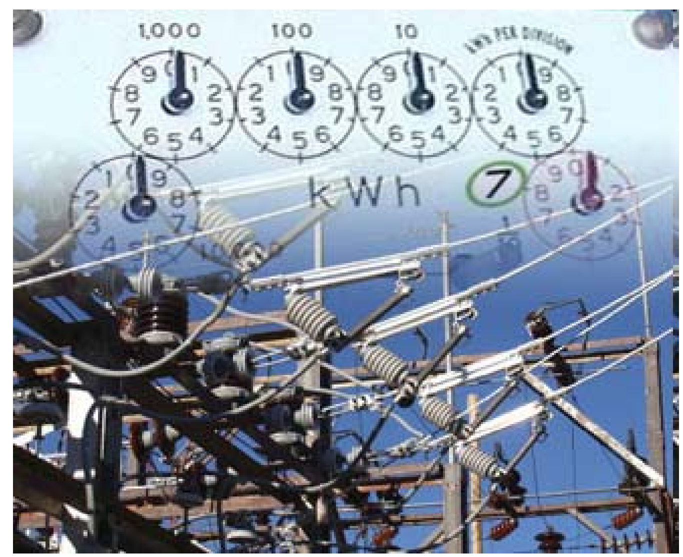
"Smart Grid" Components & Devices

Control4's EMS-100

Source: GE



Secure Smart Grids are architected with standards (source: Gridnet)

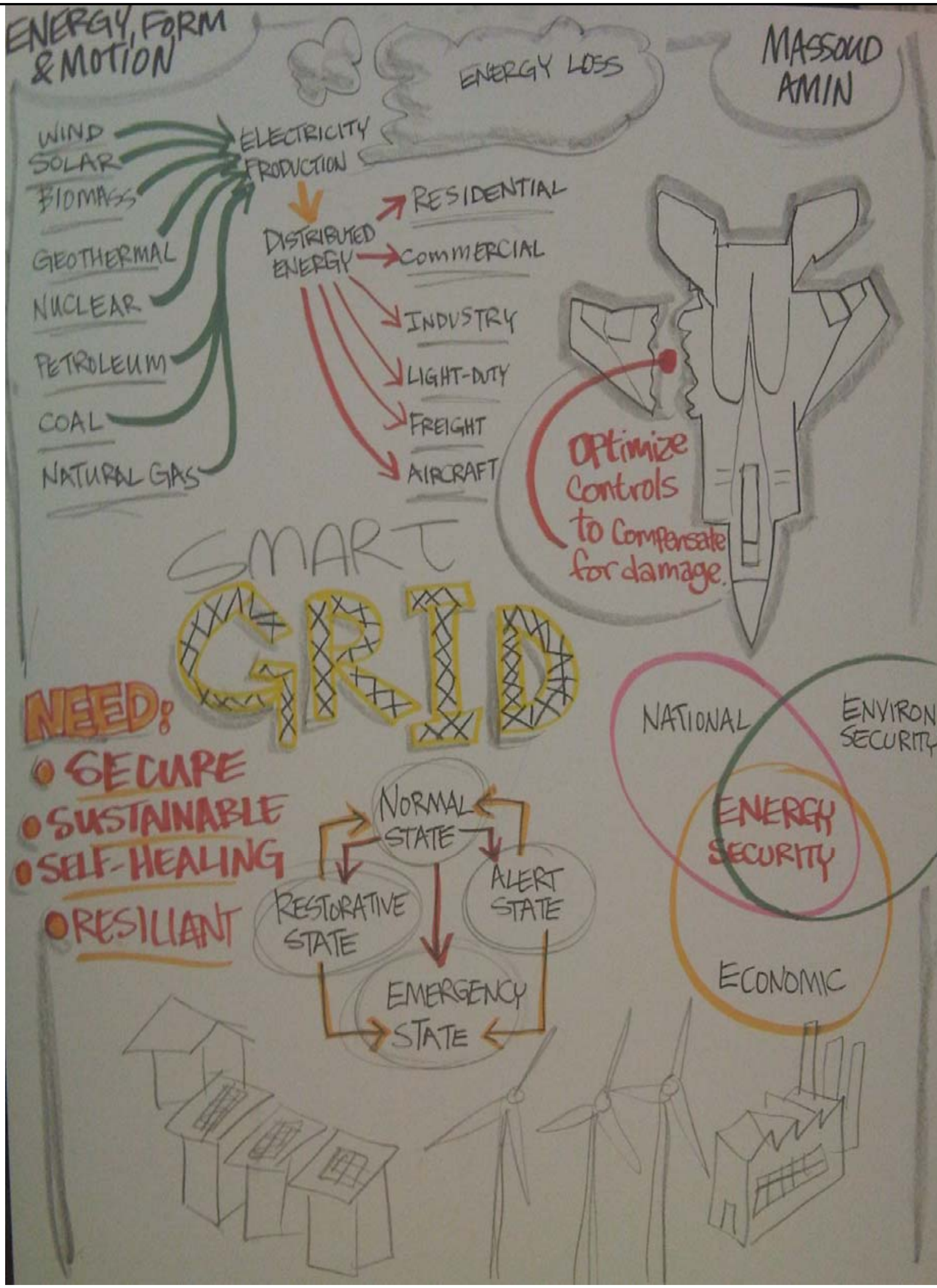


The Emerging Smart Grid or Energy Web:
A Complex Adaptive Infrastructure System

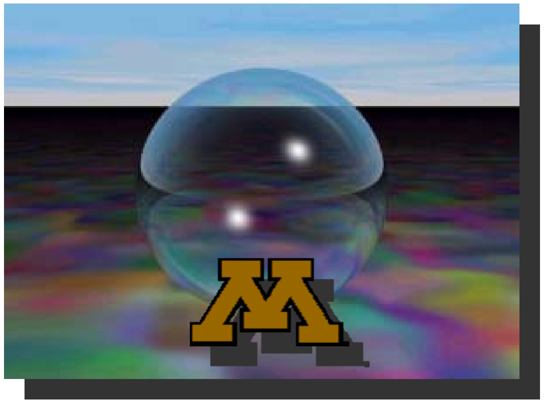
"… not to sell light bulbs, but to create a network of technologies and services that provide illumination…"

"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



The CoLAB Model

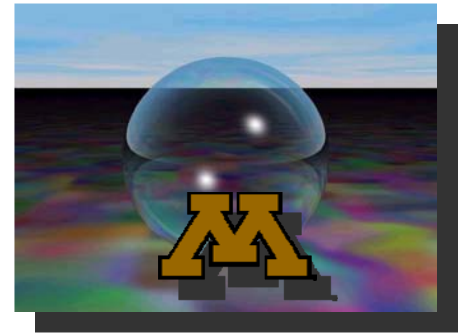


Each collaboratory is a nimble, for-profit skunkworks, that enables the University's 'best and brightest' students and faculty to collaborate with multiple corporate partners to rapidly co-create innovative IP, products, or service. Each new venture:

- Is a 'persistent innovation platform' that shares rights and royalties from co-invented IP among its collaborators and investors
- Has a defined project mission, clear ROI focus and time-to-market urgency
- Targets a high-growth niche which leverage collaborator core competencies

Gary Smaby, Director
Collaborative Innovation
OVPR, U of M

What's the University's Role?



- The University of Minnesota designed its Collaboratory model as an **innovation framework** to facilitate the rapid creation and **commercialization of new IP in multi-party collaborations**.
- The University funded a three-year, $500,000 pilot initiative called **Innovation by Design** which successful tested the concepts underlying the model
- The University maintains a **indirect vested interest** in each collaboratory through a 'surrogate' venture fund professionally managed by the University of Minnesota Foundation Investment Advisors (UMFIA).

Foci

- Integration of Renewables
- Energy Efficiency
- Smart Grid Security
- Bottom Line → Economic Growth:
  - Building Minnesota's Competitive Advantage through Partnerships and Technology/Policy/Business Development

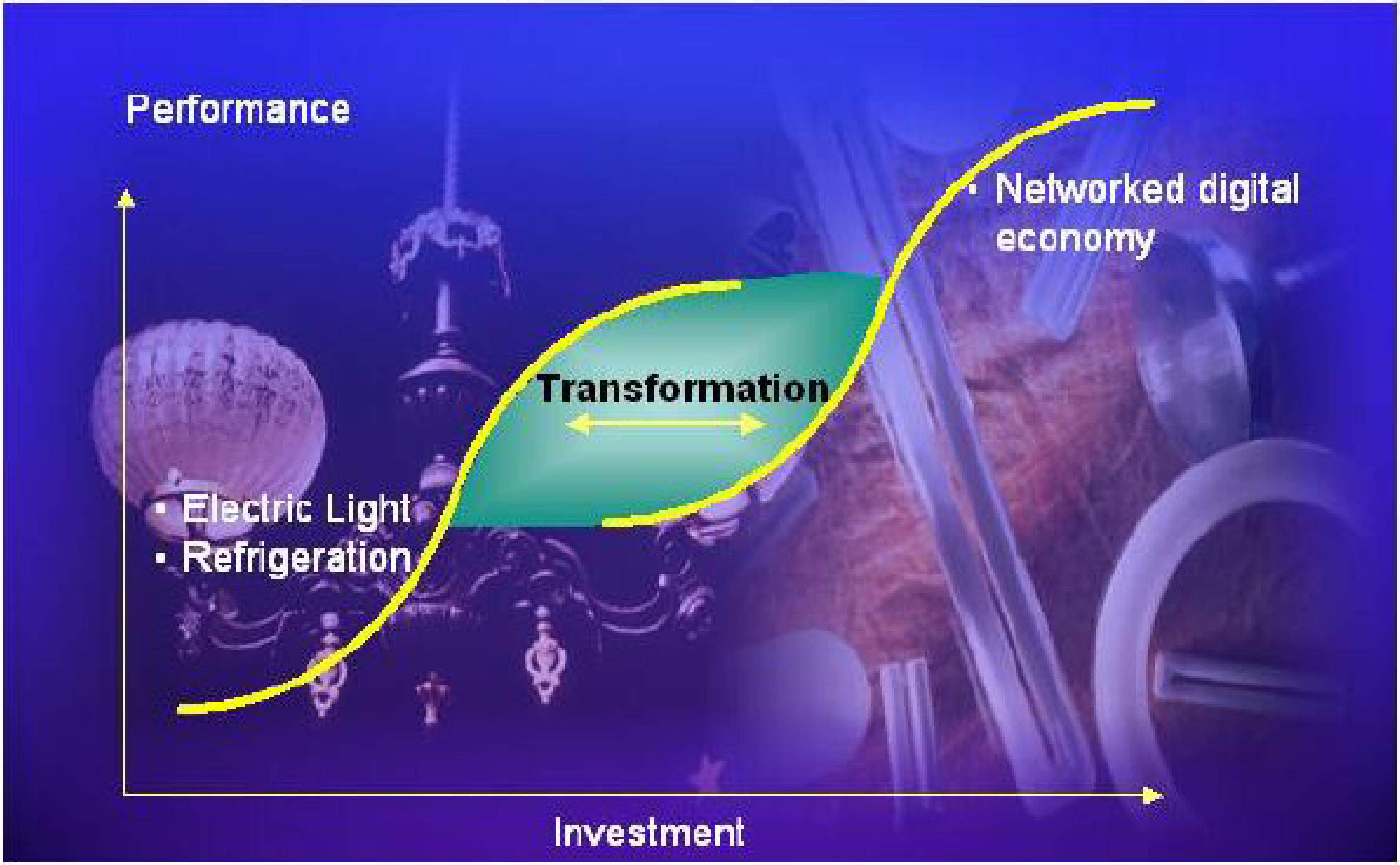

LEADERSHIP

Bottom Line:

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

-- Peter Drucker

Breaking the Limits on Electricity Value



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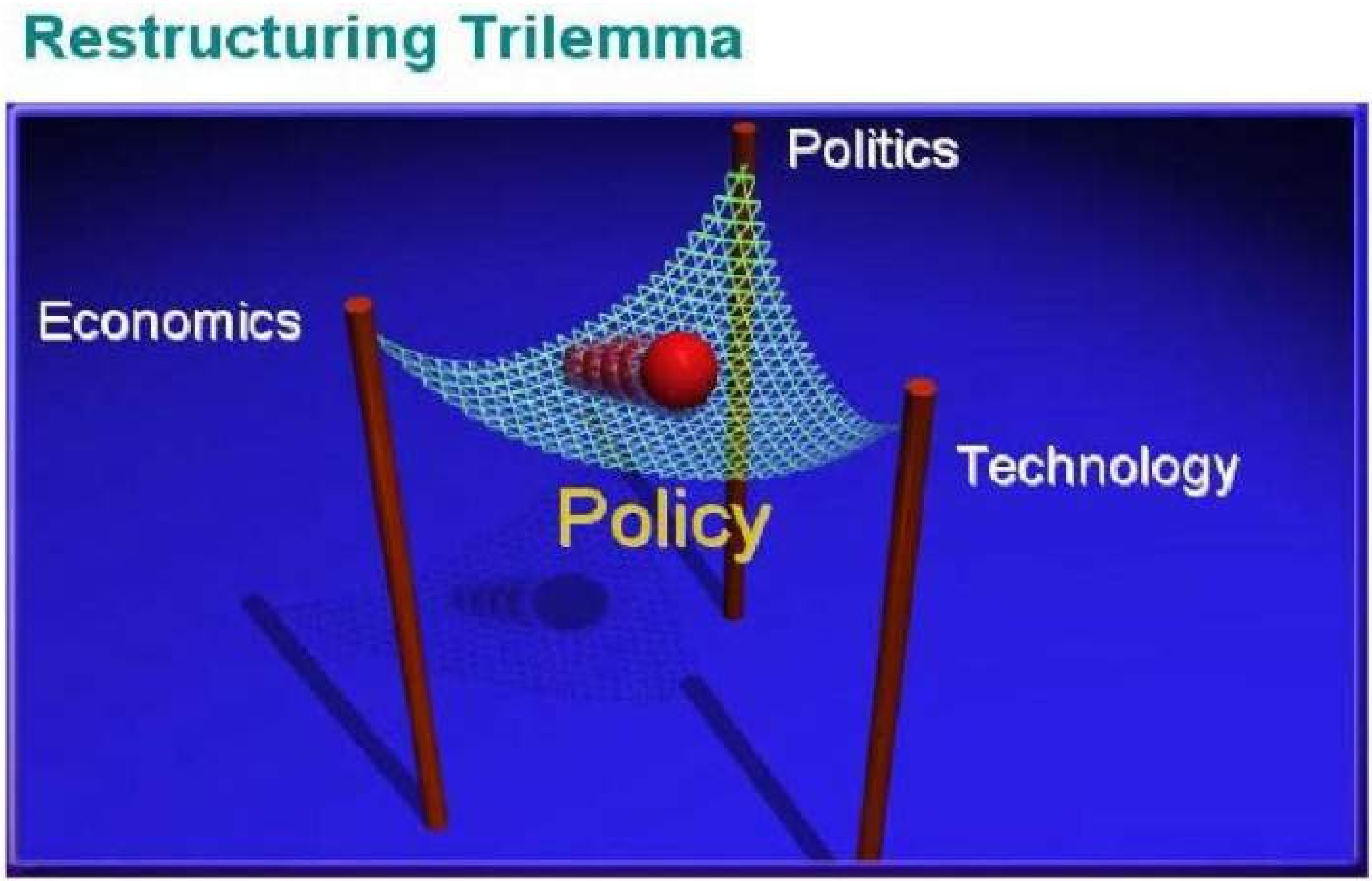
Unresolved Issues Cloud Planning for the Future



Discussion and the Road Ahead:

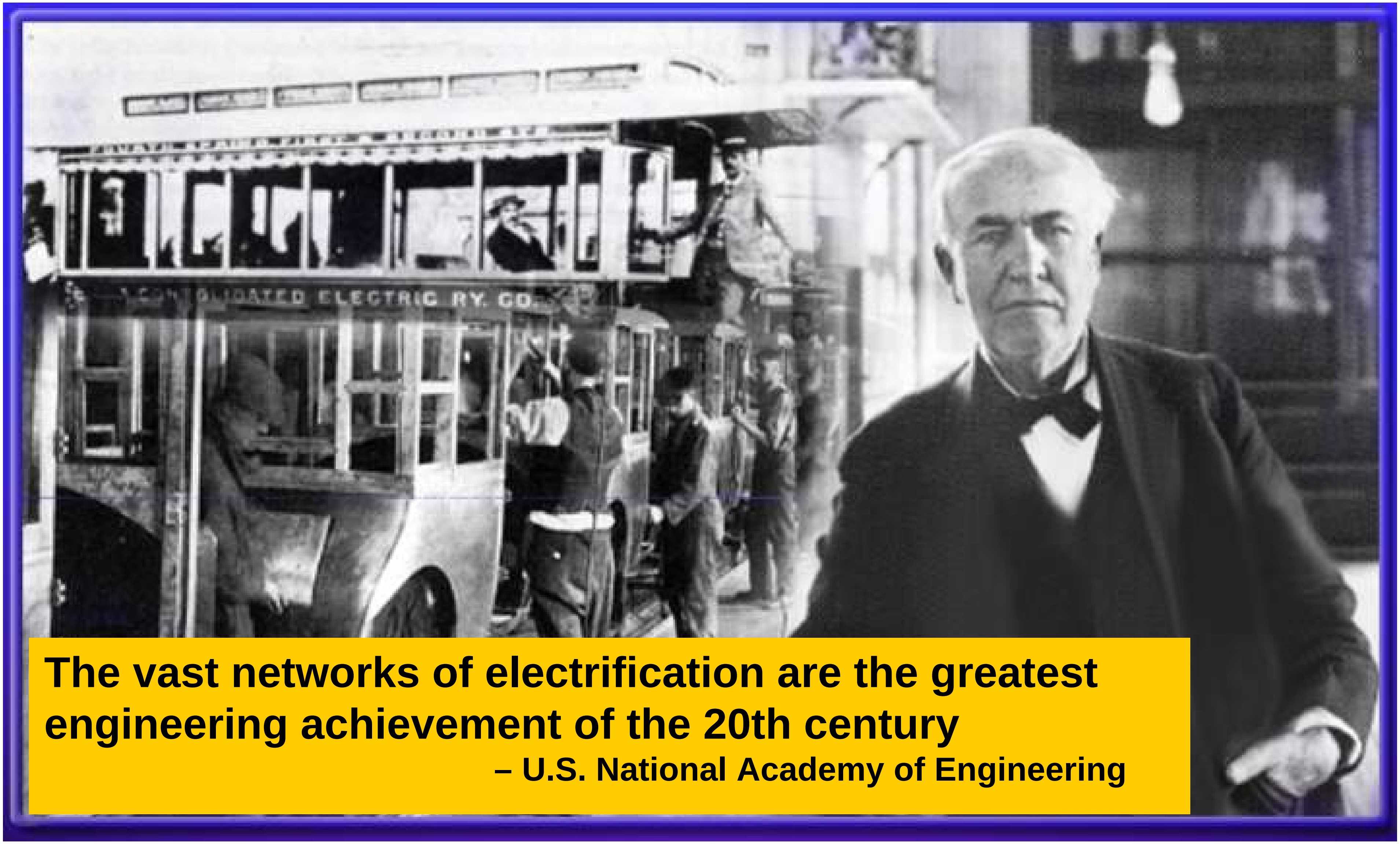
- What are the key SG security issues and opportunities for MN enterprises? In which areas can we lead?
- What is your vision for the future– what will it like or how will it perform in 2010-2020?
  - **Pinch points:** What are the difficult challenges to overcome to achieve your vision?
  - **Pathways:** What enabling technologies and policies are needed to address these?
  - **Foresight:** What critical issues should we consider in beginning plans for 2010 and beyond?

…The Future is Bright…

Courtesy FPL Energy

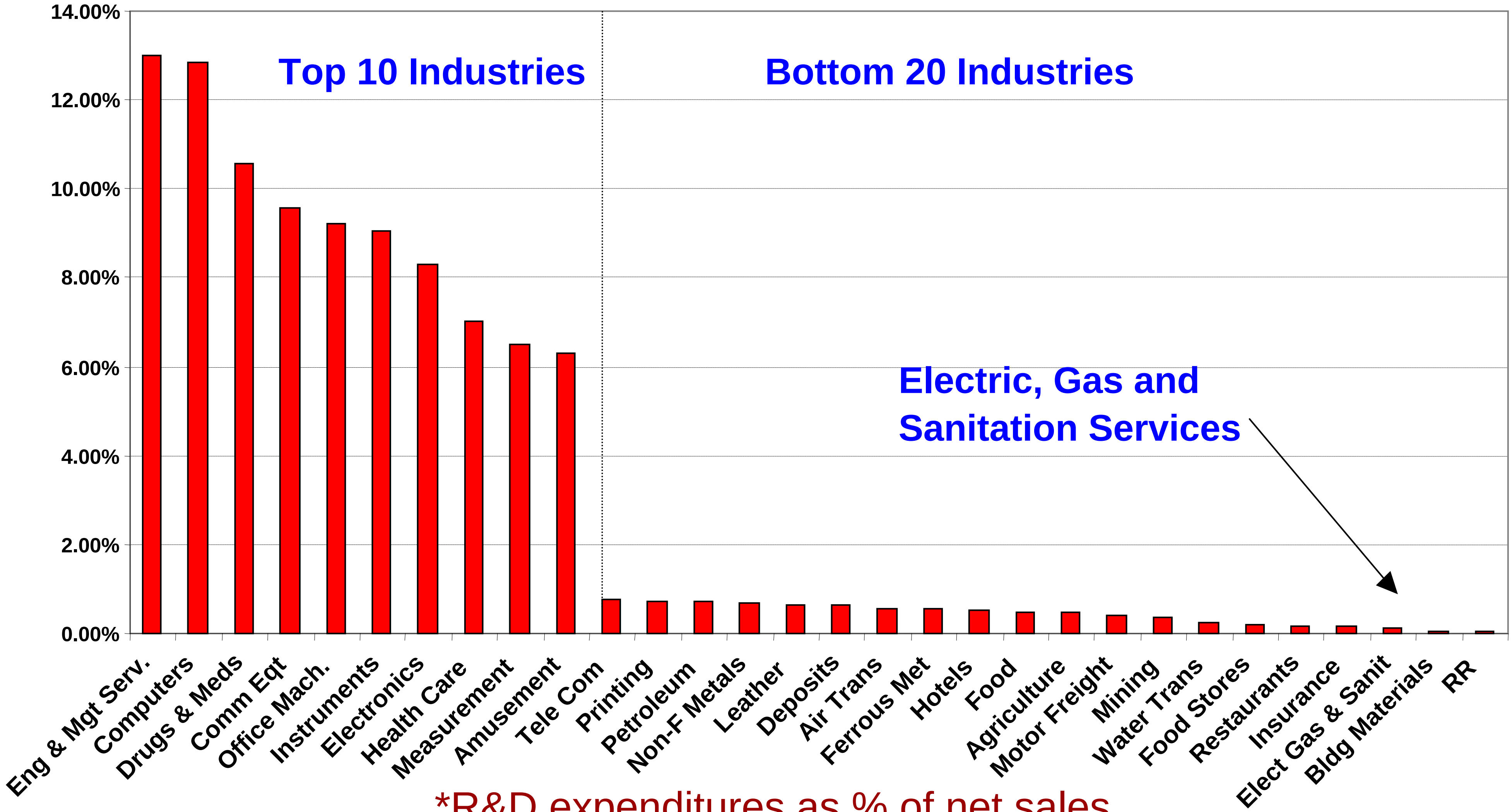
Appendix

Context: Transforming Society



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

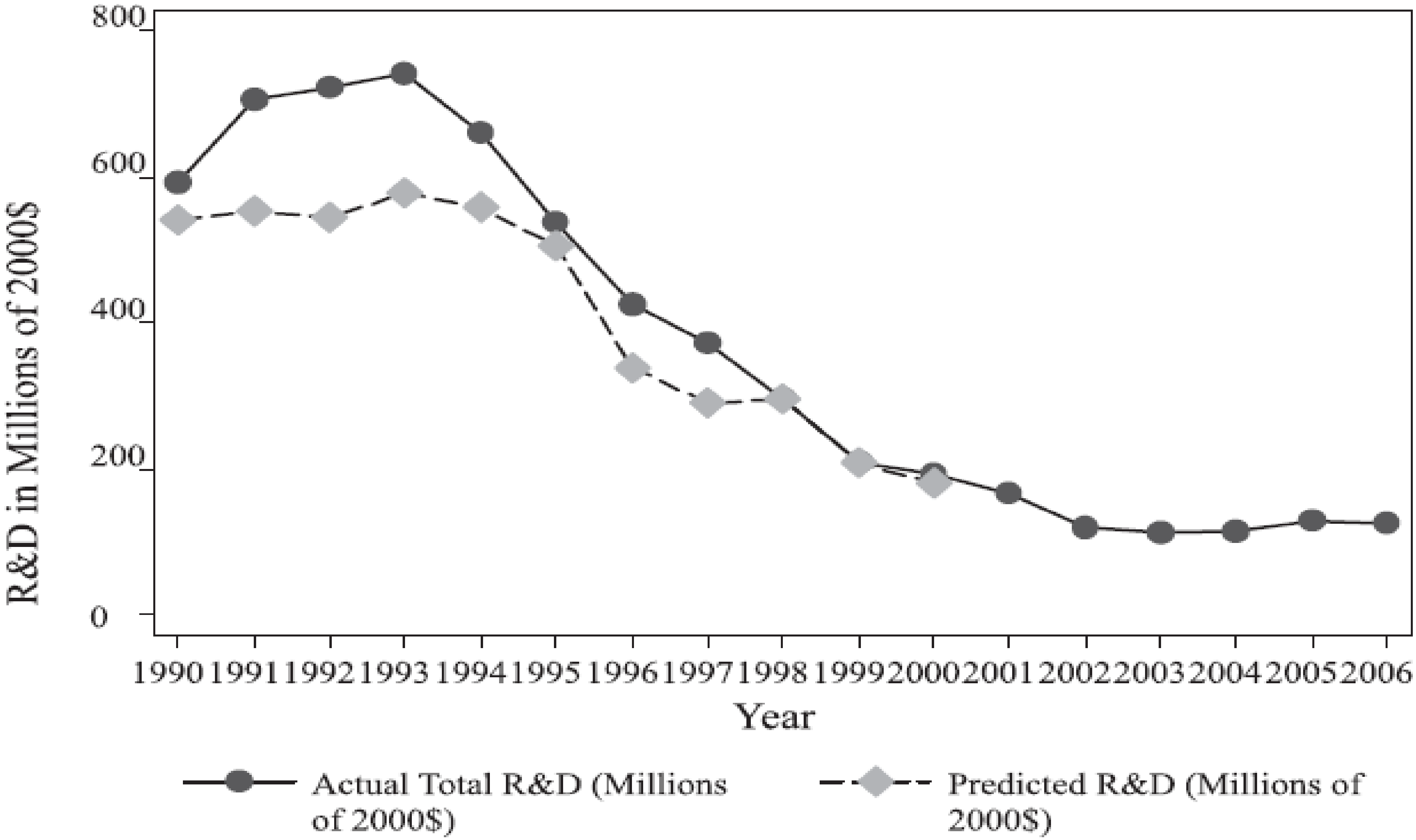
Context: R&D Expenditures*



*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

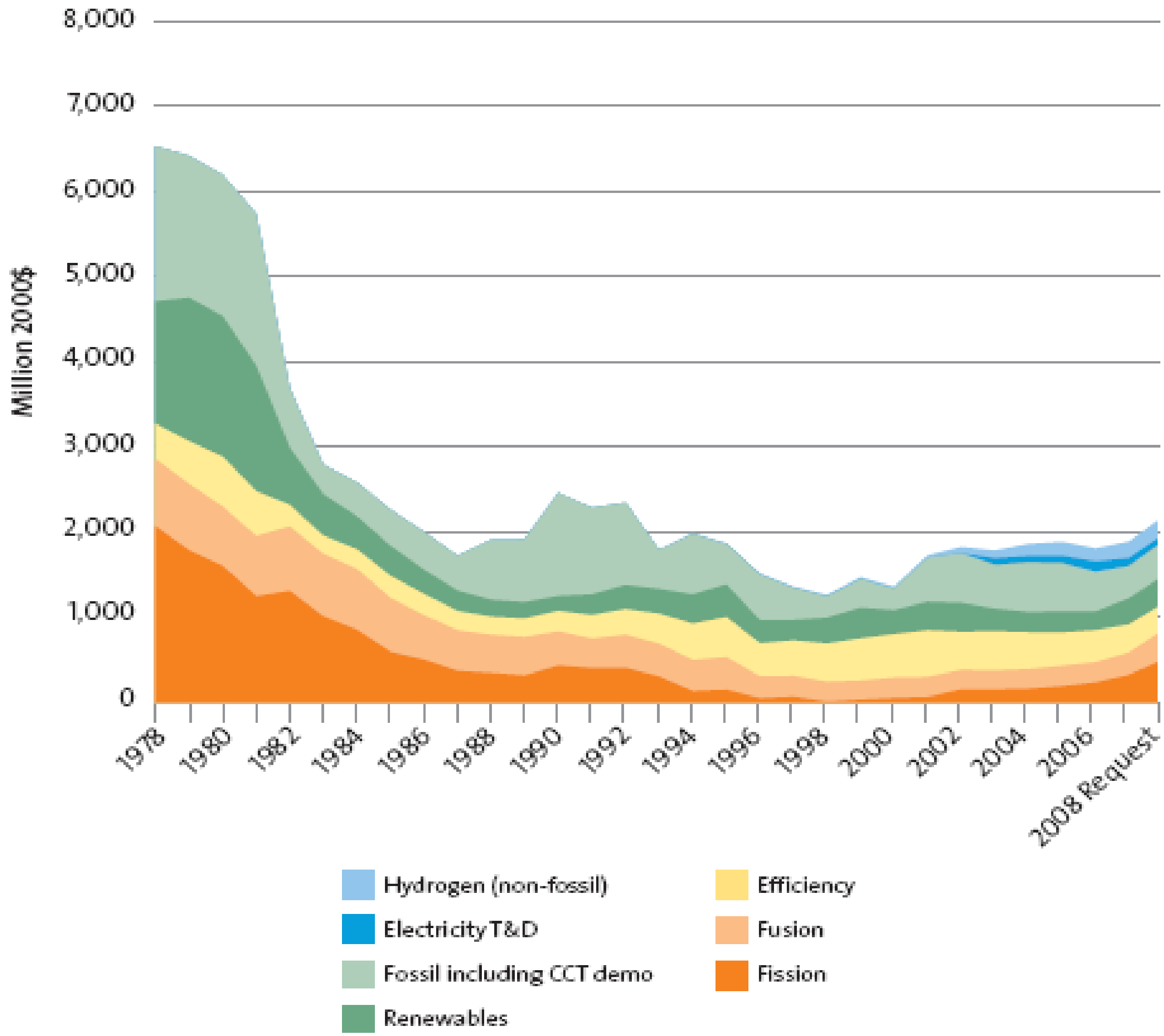


Source: "Powering Progress: Restructuring, Competition, and R&D in the U.S. Electric Utility Industry," by *Paroma Sanyal and Linda Cohen, The Energy Journal*, Vol. 30, No. 2, 2009

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

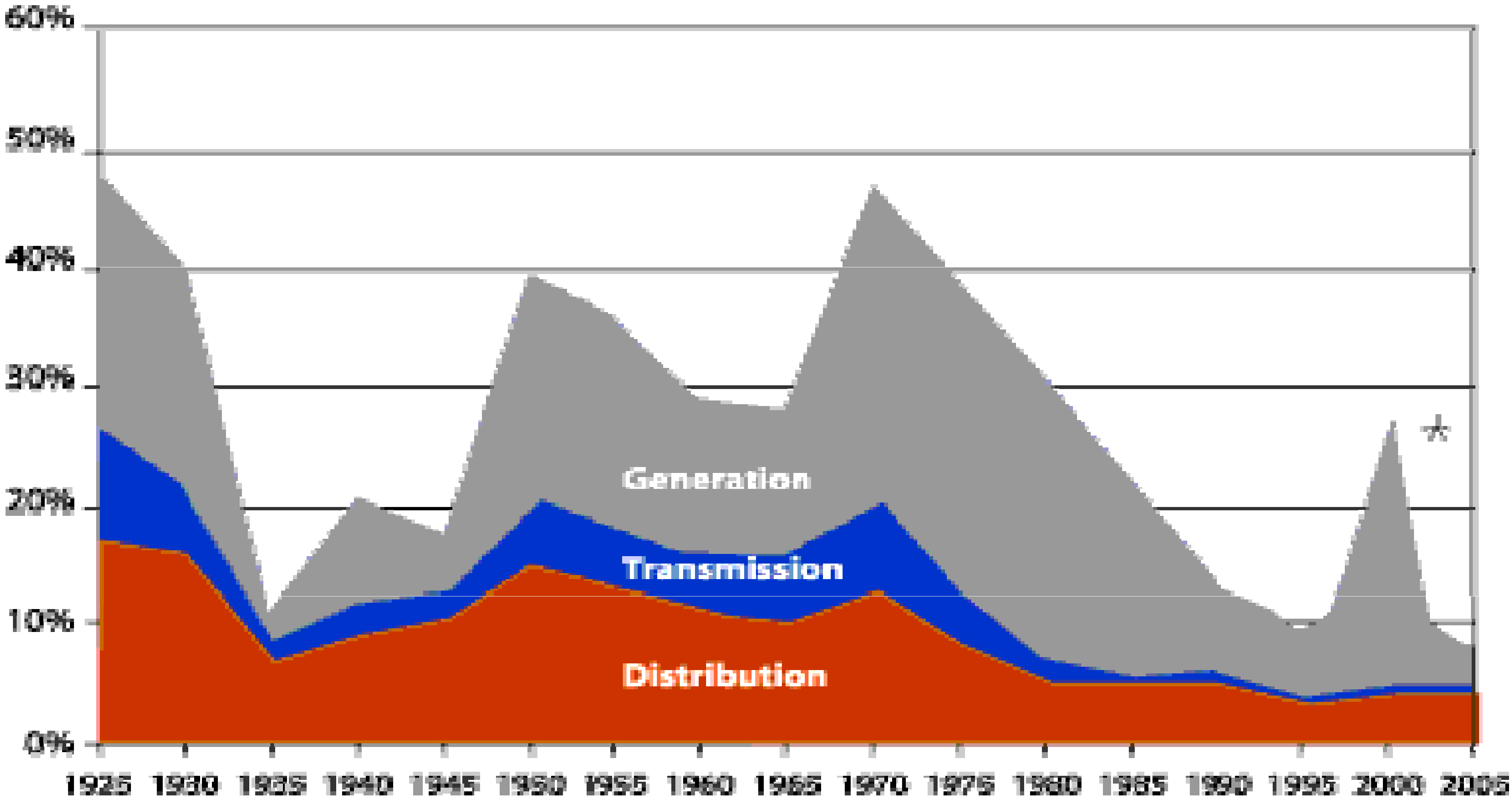
•Analyses of DOE data shows that over the 25 years from FY 1978 to FY 2004, US government appropriations for ERD&D fell from 6.4B to $2.75B in constant year-2000 dollars, a nearly 60% reduction.

•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.

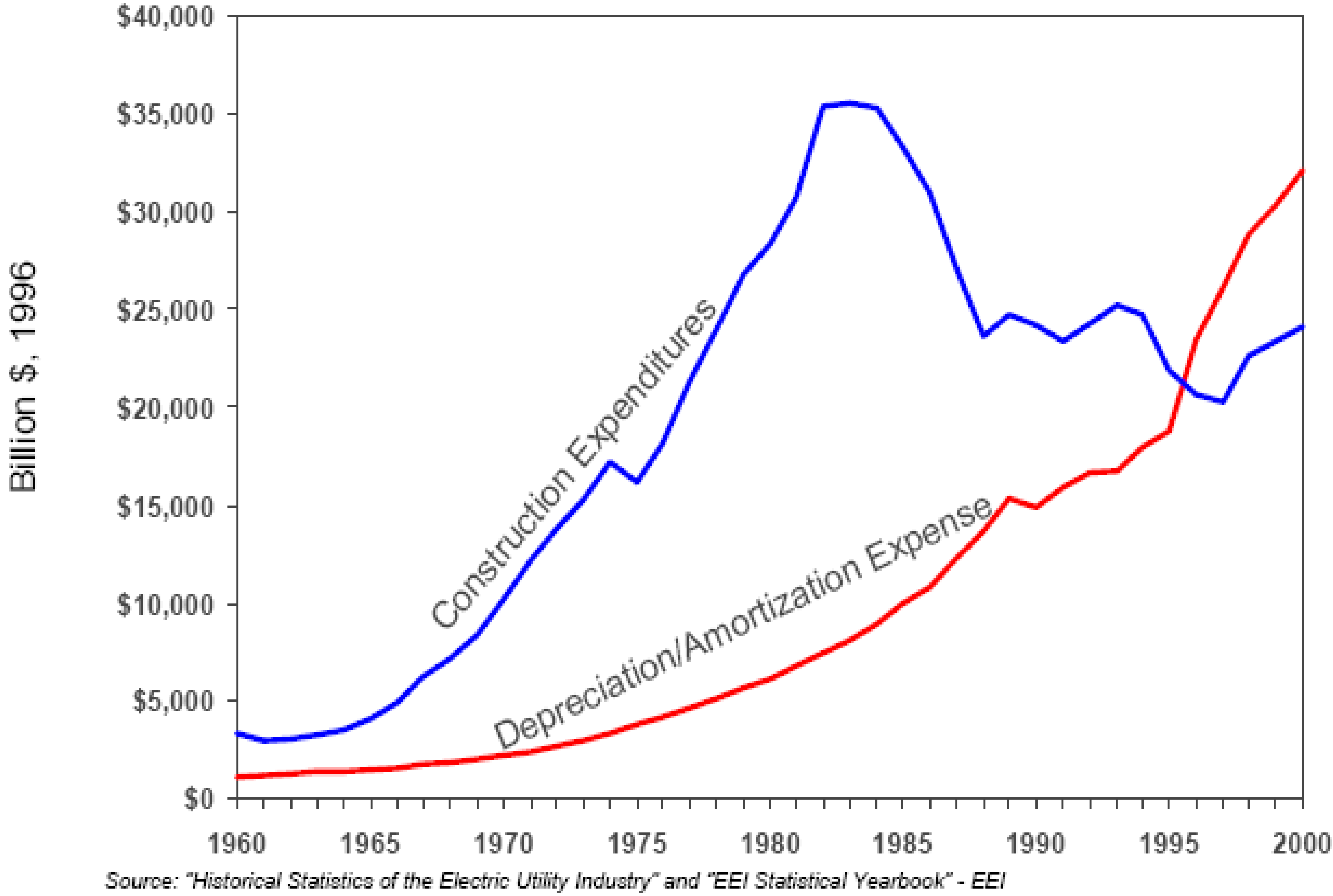
Capital Invested as % of electricity revenue



Sources: Electric Utility Industry Statistics, and 2001 Financial Review, Edison Electric Institute

Capital invested as % of electricity revenues

Utility construction expenditures



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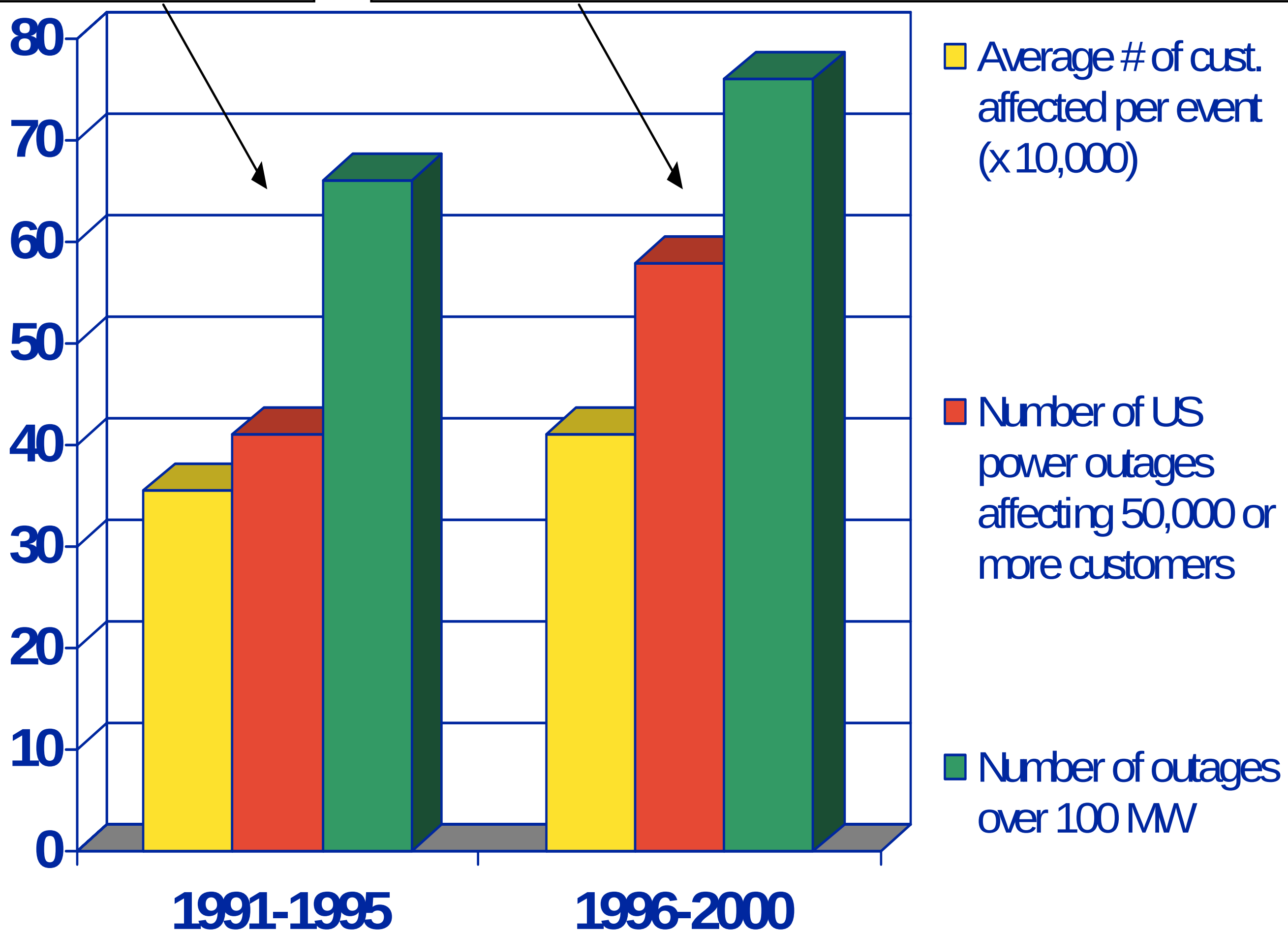
Historical Analysis of U.S. outages (1991-2000)

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.

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

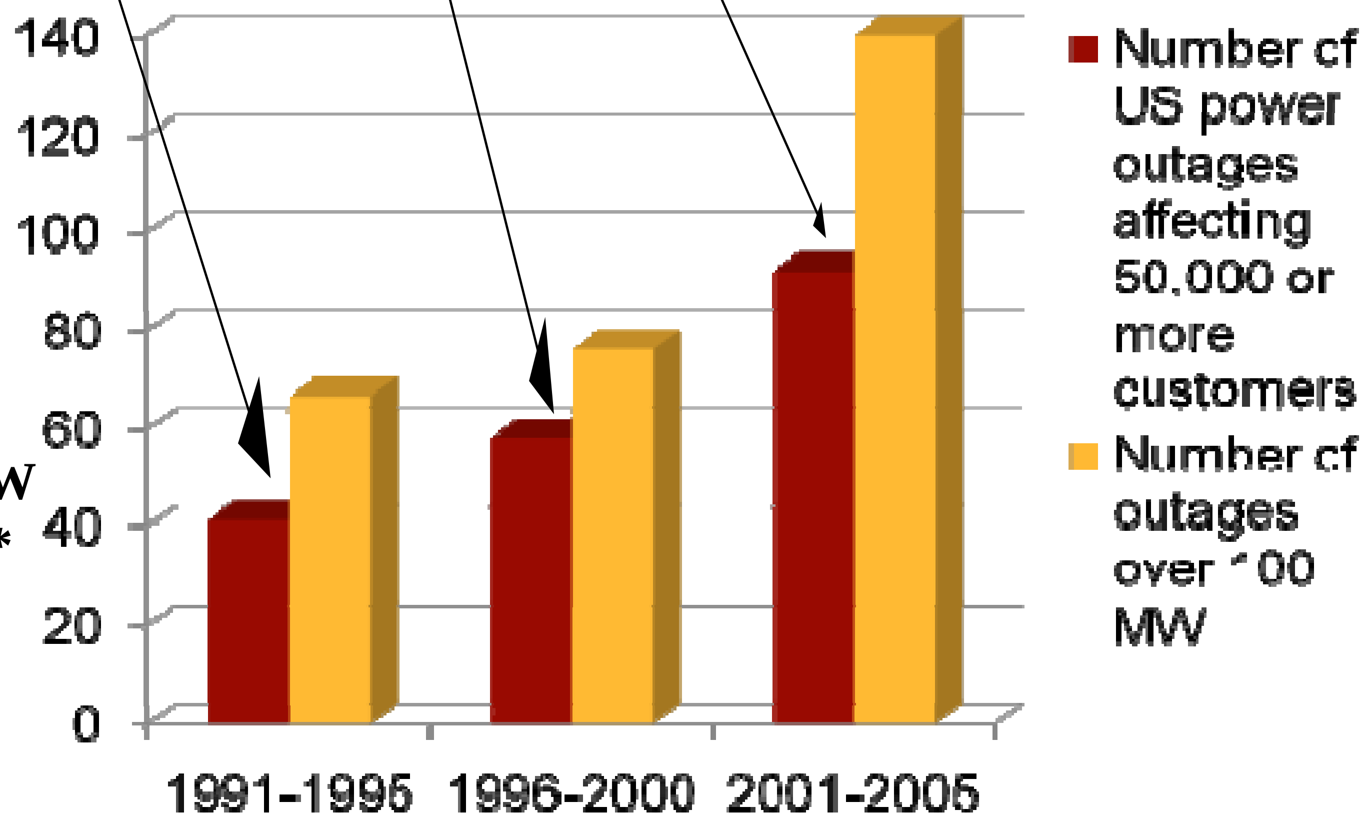
66 Occurrences over 100 MW
41 Occurrences over 50,000* Consumers

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

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

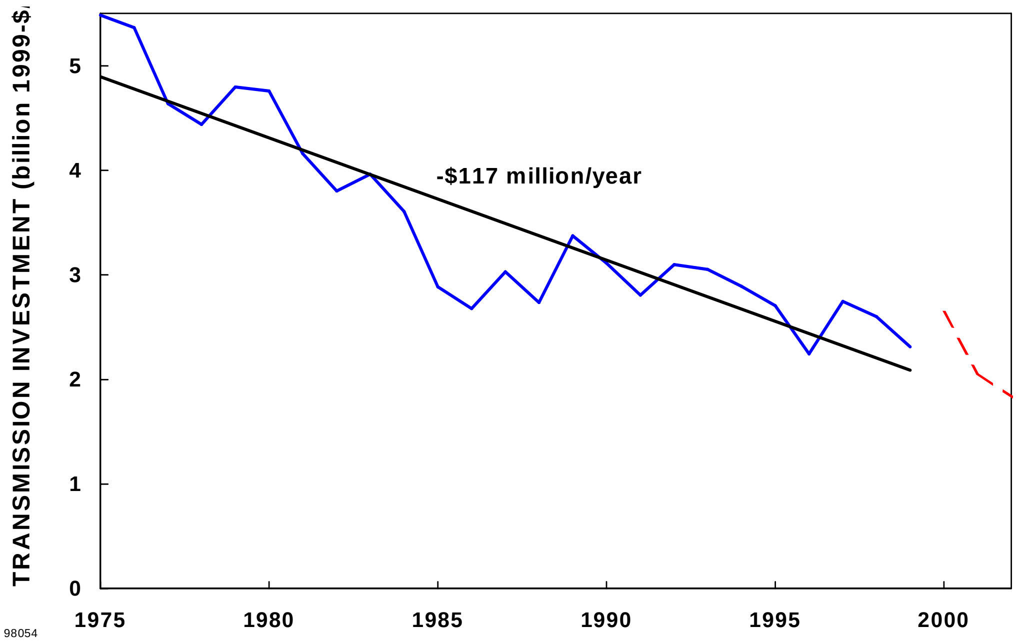
Result: Large blackouts are growing in number and severity.

***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

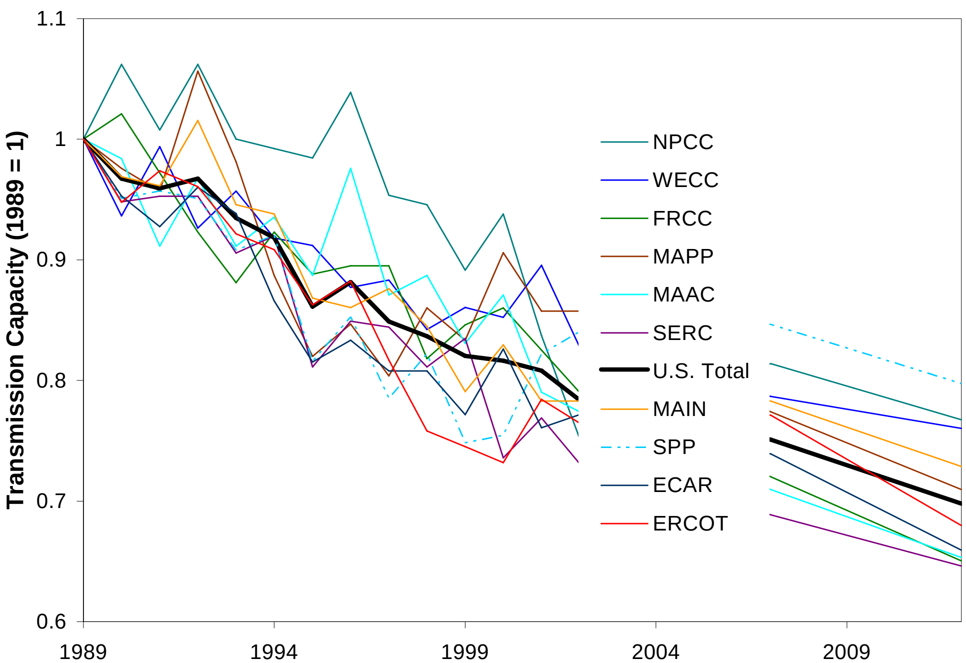


*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

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.

Infrastructure and R&D Investments

- **Industry: U.S. Electric Utilities R&D (1990- 2008):**
  - **Annual R&D in the lowest rates of any major industrial sector with the exception of the pulp and paper**
- **Government: 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
- **Systematic underinvestment in R&D for the electric power systems**
  - Various attempts in regulatory proceedings to encourage or establish higher levels of R&D investments
  - The results from such efforts have been mixed. Some funds used for economic development activities or local demonstrations of already commercially available technology, which do little to evolve the innovations in science and technology that are needed
  - Collaborative programs have had more success in this regard; however, states have difficulty in funding any research outside of their state
  - Motivation among state regulators to encourage higher levels of R&D for the utilities is tempered by the difficulty of providing strong business cases for R&D—which by its nature is inherently uncertain. These investments also require patience for longer-term paybacks.
- **U.S. outages (1984-2008) with increasing frequency, severity, and costs of over $80B/year.**

Source: Massoud Amin, Congressional Staffer briefing, convened by ASME, Discover Magazine, IEEE, and the National Science Foundation, Washington D.C., October 15, 2009

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

Challenges

- Power produced in one place and used hundreds of miles away. This creates new opportunities, especially in terms of encouraging the construction of new power generation, possibly transmission, and in making full use of the power produced, rights of way and assts, but it also creates challenges:

- *1) Regulatory Challenges*: More than ever power transmission is an inter-state transaction. This has led to numerous conflicts between federal statutes applying to energy and rules set up by public utility commissions in the various states. Generally the federal goal is to maximize competition, even if this means that traditional utility companies should divest themselves of their own generators. Since the 1990s, the process of unbundling utility services has brought about a major change in the way that energy companies operate. On the other side, generally the goal of state regulators has been to provide reliable service and the lowest possible prices for customers in state.

- *2) Investment Challenge*: Long-distance interstate routing, or "wheeling," of power, much encouraged by the federal government, has put the existing transmission network, largely built in the 1970 and 1980s in a time of sovereign utilities, under great stress. Money spent by power companies on research is much lower than in past decades. Reserve power capacity, the amount of power-making to be used in emergencies, 25-30% 25 years ago, are now at levels of 10-15%.

Challenges (Cont.)

- ***3) Security, Reliability, and Innovation Challenges:*** The August 2003 northeast blackout, when operators did not know of the perilous state of their grid and when a local power shutdown could propagate for hundreds of miles, leaving tens of millions in the dark, demonstrated the need for mandatory reliability rules governing the daily operation of the grid. Such rules are now coming into place.

- ***4) Marketplace Challenges:*** Some parts of the power business operate now without regulations. Other parts, such as the distribution of power to customers might still be regulated in many states, but the current trend is toward removing rules. The hope here is that rival energy companies, competing for customers, will offer more services and keep their prices as low as possible. Unfortunately, in some markets, this has the risk of manipulating the market to create energy shortages, even requiring rolling blackouts, in an effort to push prices higher.

- These are recognized by the power companies and stakeholders in a rapidly changing marketplace. The public, usually at times of dramatic blackouts, and the business community, which suffers losses of over $80 billion per year, have taken notice. Even Congress, which must negotiate the political fallout of power problems and establish laws governing the industry, takes up the problems of power transmission and distribution on a recurring basis, although usually in the context of the larger debate over energy policy. In the meantime, the US power grid has to be administered and electricity has be to delivered to millions of customers. Fortunately, many new remedies, software and hardware, are at hand.

Policy

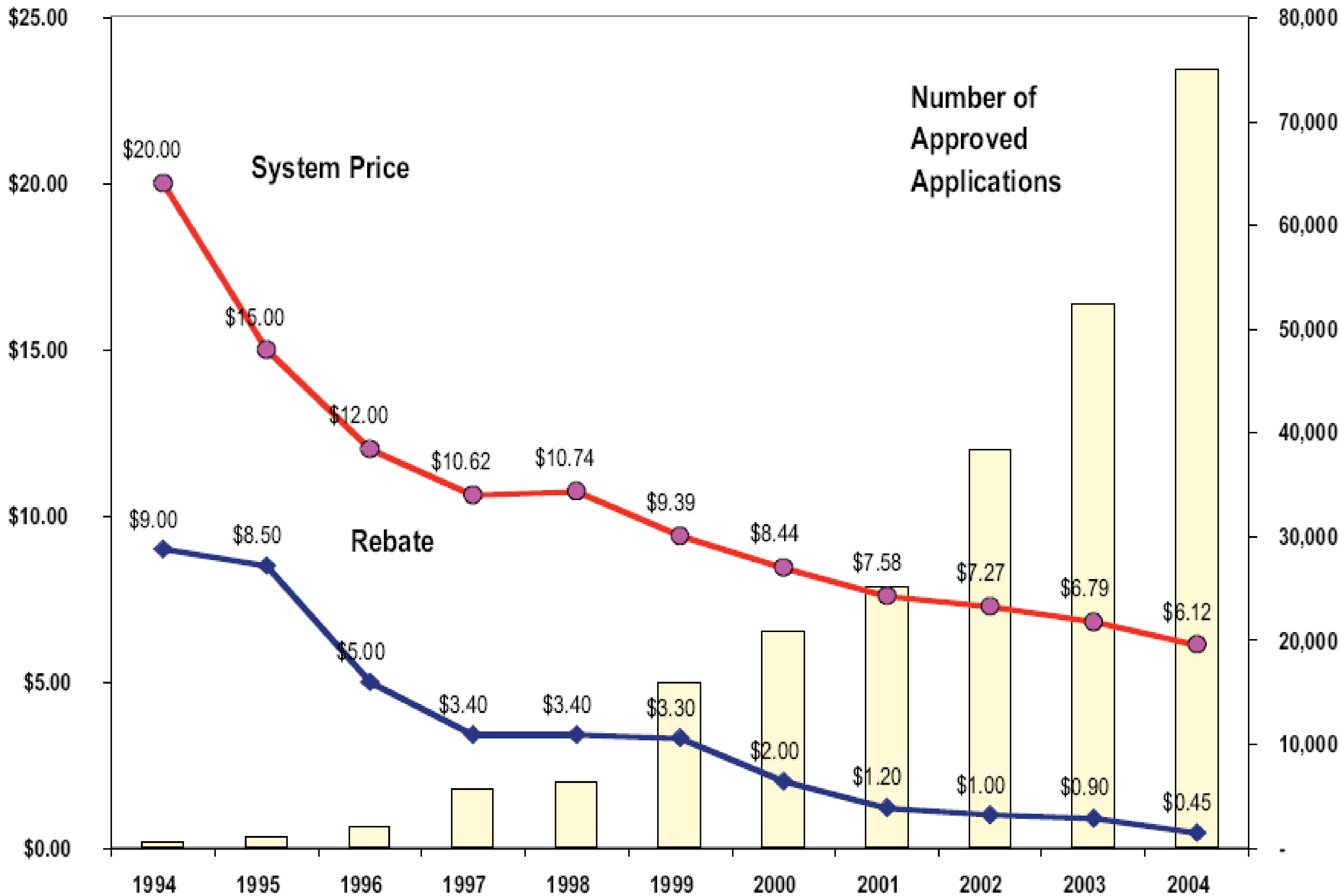
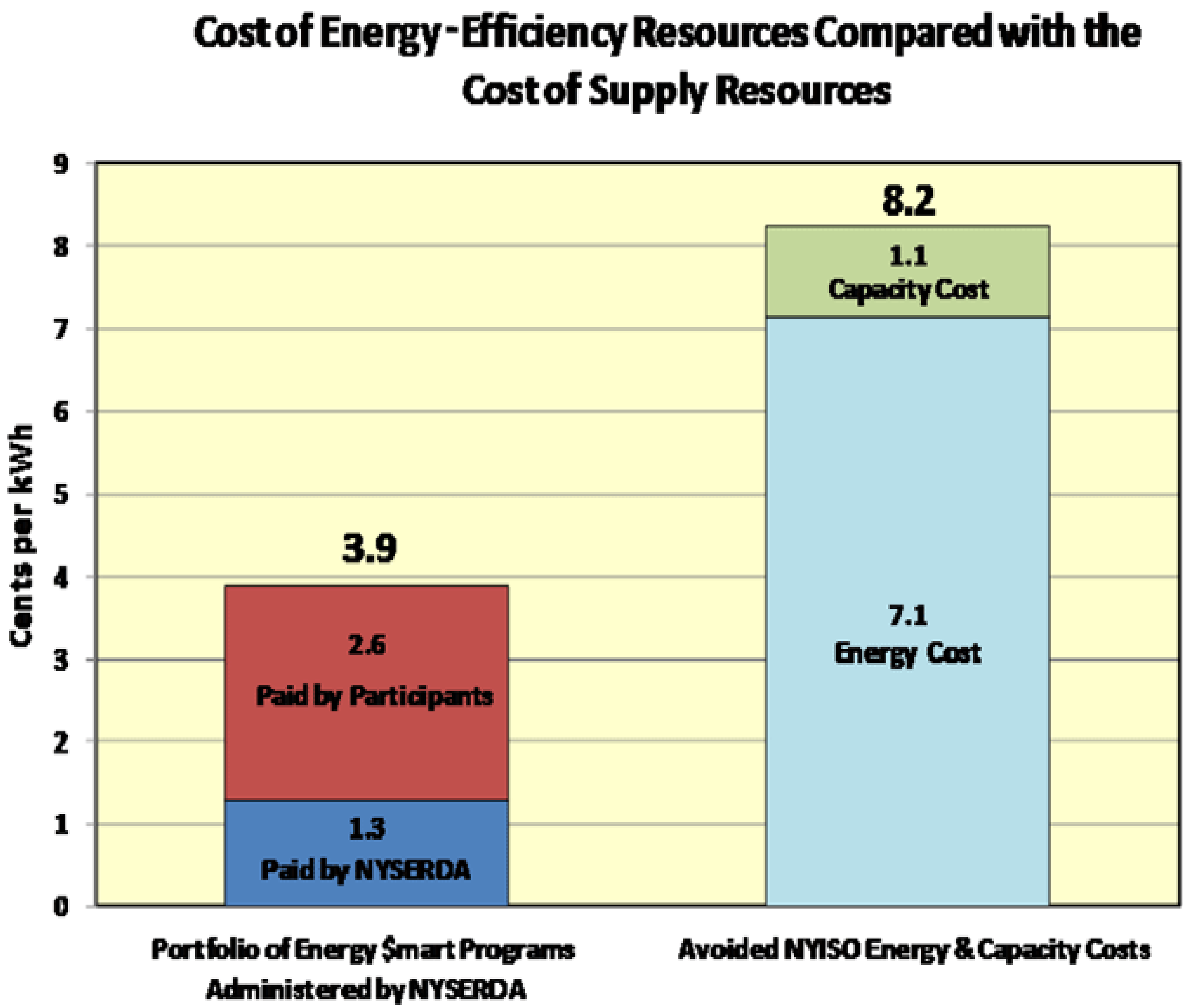


Figure 11
Japanese PV Program Rebates and Participation, 1994-2004 (Source: California Energy Commission)

Energy-efficiency costs vs. generation



Source: NYSERDA and Paul DeCotis: Coming of Age in New York: The Maturation of Energy Efficiency as a Resource, The Bridge, Vol. 39, N. 2 - Summer 2009, NRC

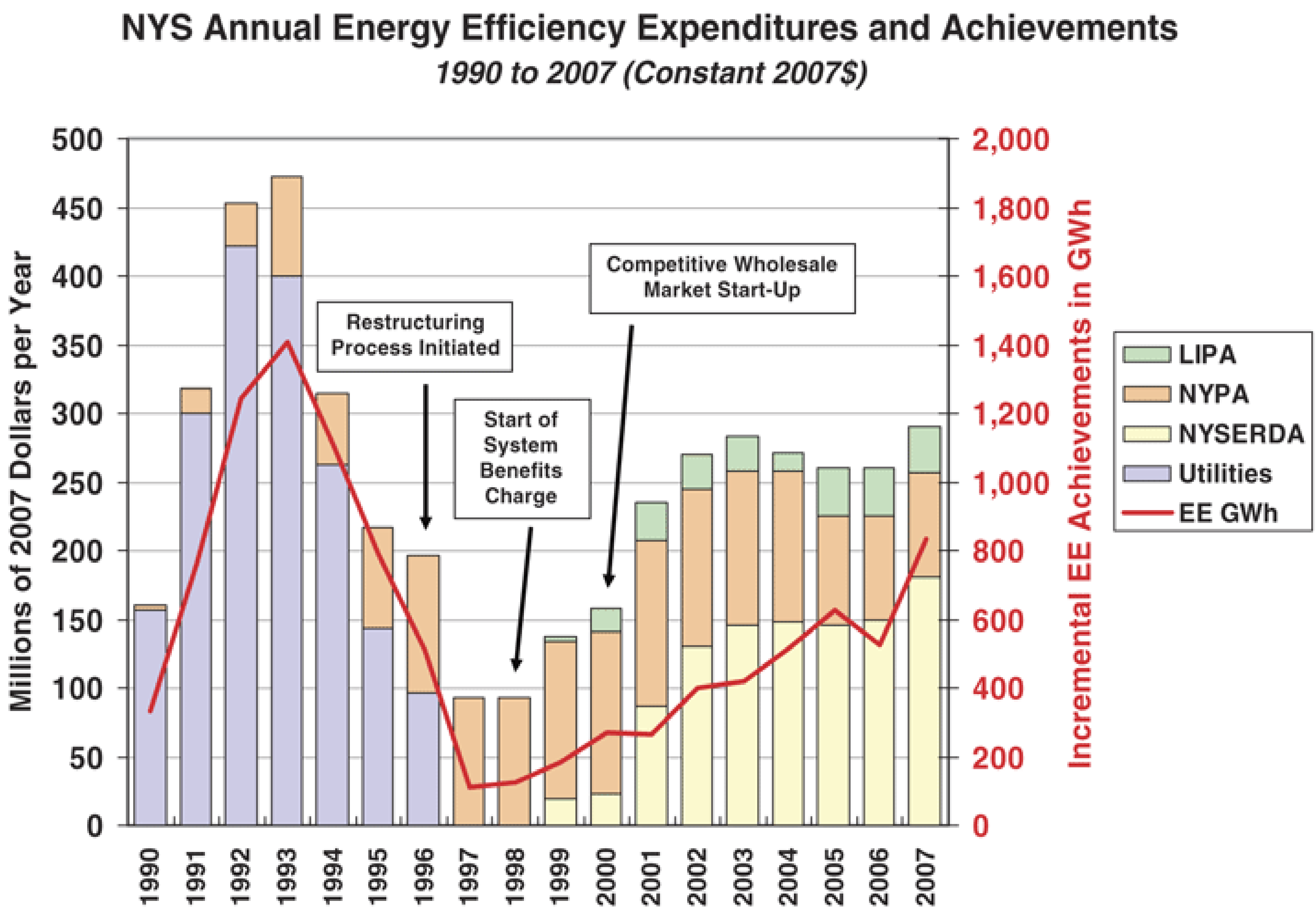
Energy-efficiency costs vs. generation

TABLE 1 Electricity Use by Sector

	Comparison of United States and New York per Capita Electricity Use in 2006			
	United States (kWh per person)	New York (kWh per person)	Difference (kWh per person)	Percentage of Difference
Residential	4,514	2,508	2,006	41
Commercial	4,341	3,938	403	8
Industrial	3,378	776	2,602	53
Transportation	25	145	-121	-2
Total	12,258	7,367	4,890	100

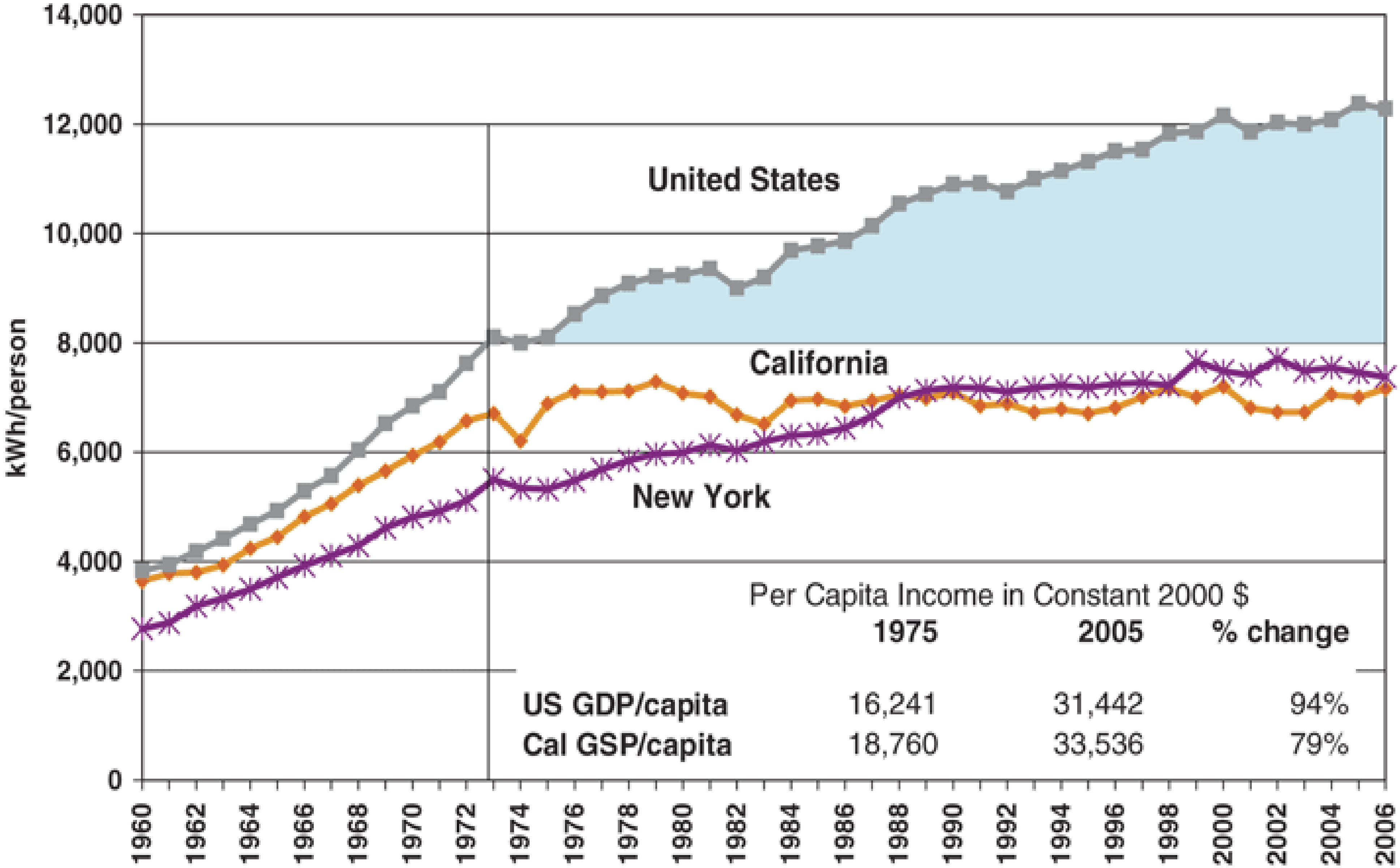
Source: NYSERDA.

Energy-efficiency investments and achievements



Source: NYSERDA

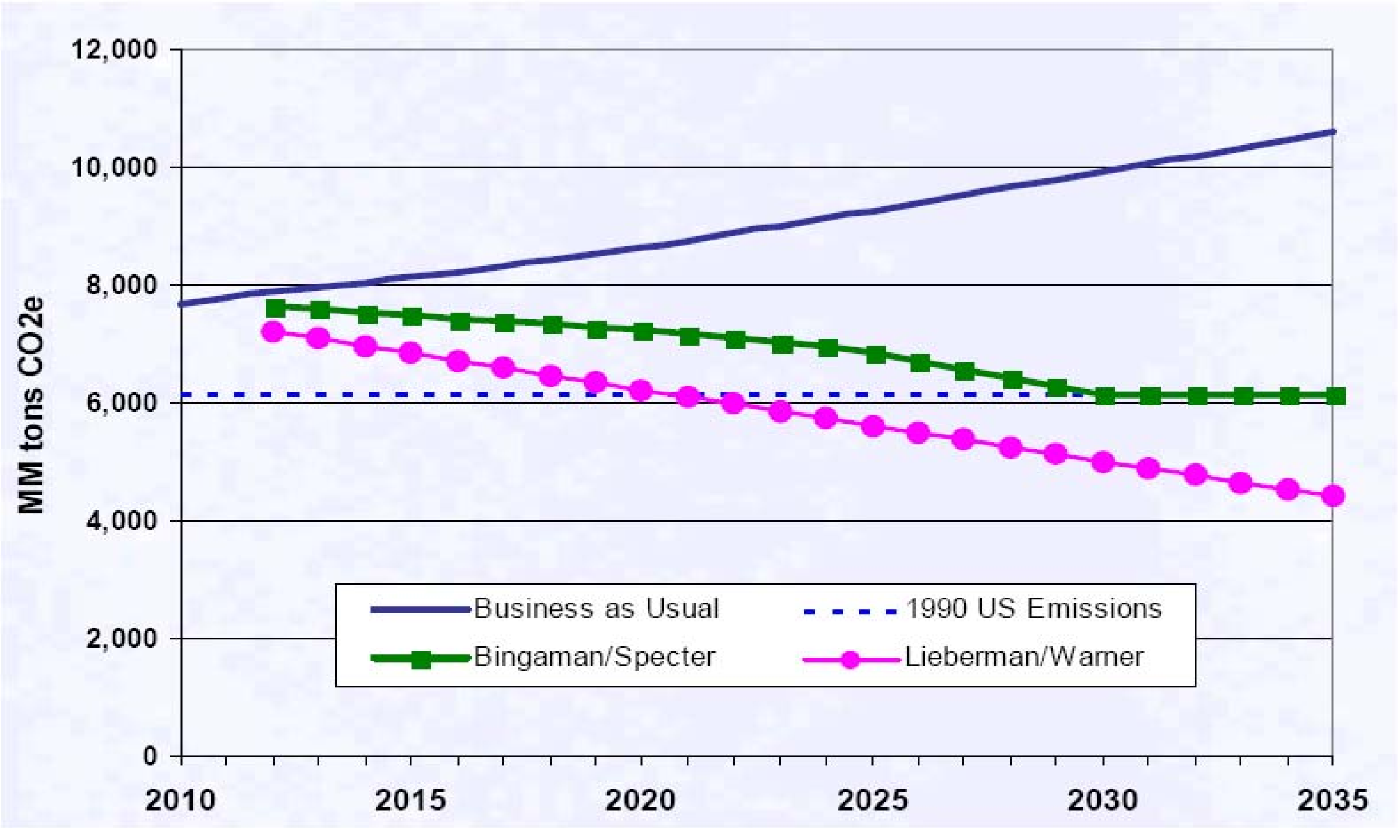
Potential electricity savings for residential products



Source: Lester Lave, The Potential of Energy Efficiency, NRC 2009

...coupled with emerging environmental programs

US GHG Emissions and Proposed Cap-and-Trade Programs



Business as usual emissions based on US Energy Information Administration projections

Meeting either objective will require improvements in supply-side emissions and reduction in consumption.

U.S. energy use per dollar of GDP, 1850–2006

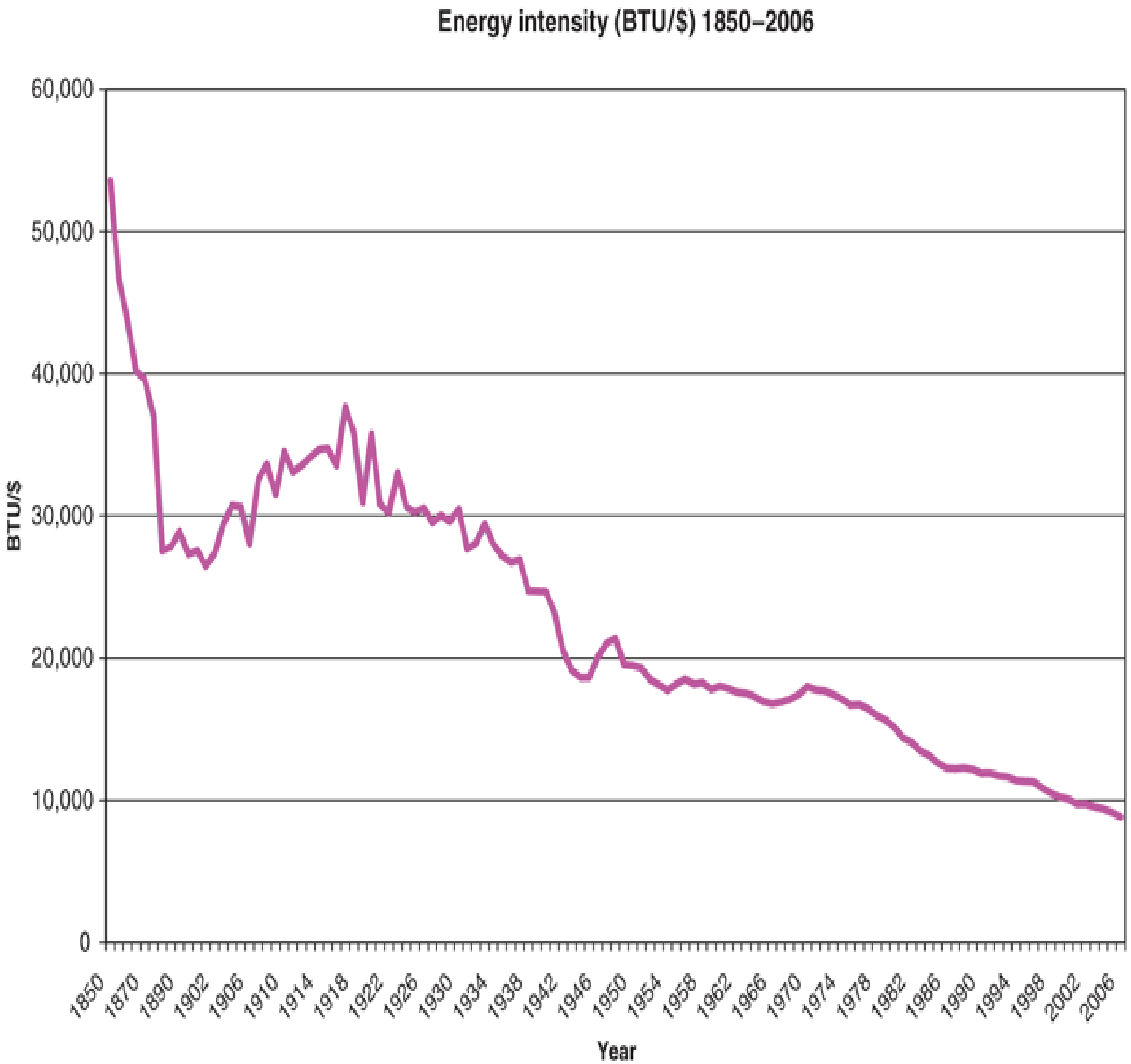
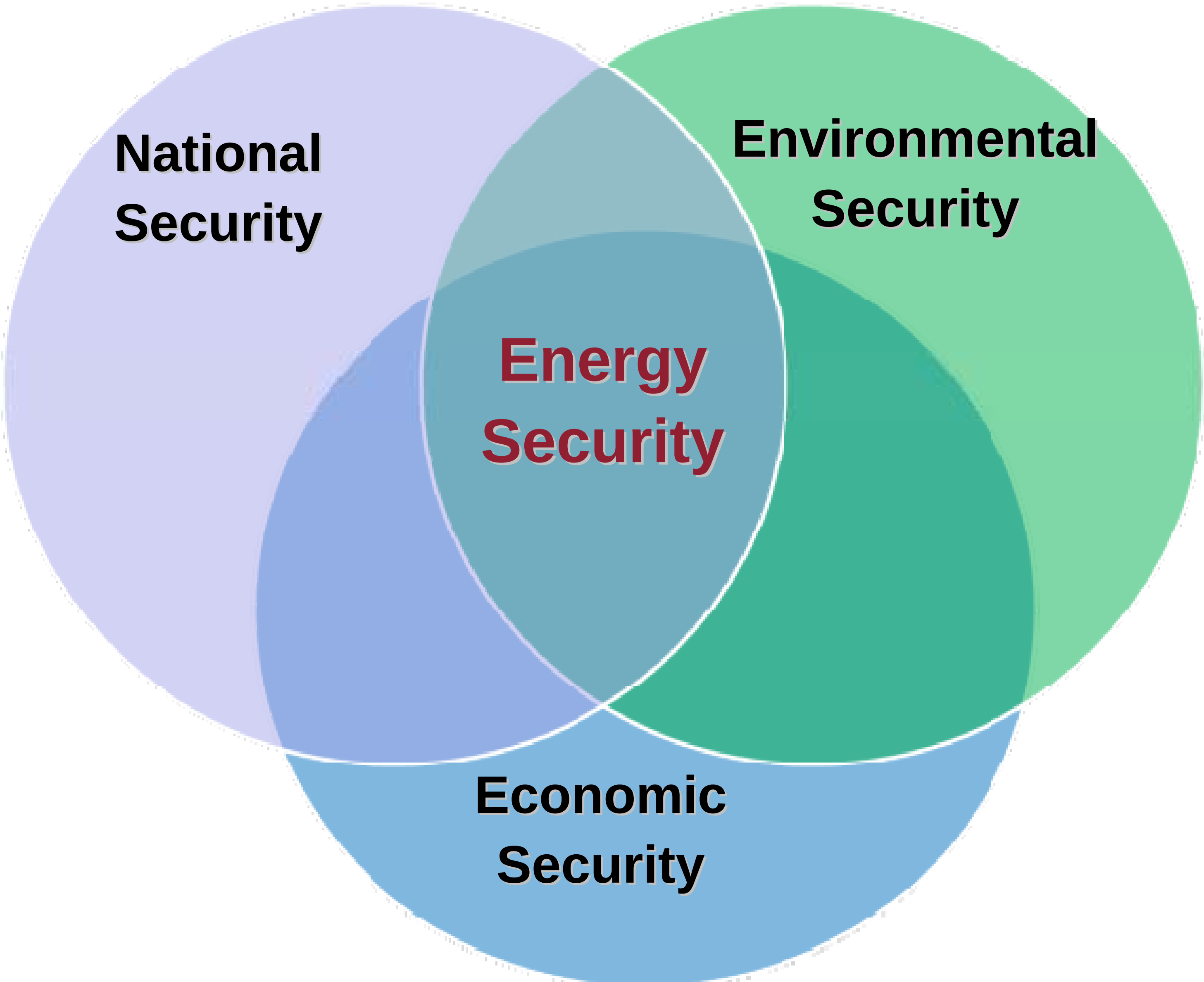


TABLE 1 Energy Use in 2005—Per Capita and Per Dollar of GDP

	BTU per person (million BTUs)	BTU per dollar of GDP
United States	340	9,113
Japan	177	4,519
Denmark	153	4,845
France	182	7,994
Germany	176	7,396

Source: EIA, 2009b,c.

The Energy Nexus:
What we've learned from Energy Crises



Source: RAND

Energy & Global Dimensions:

Minnesota's Leadership Role

Context: Cities with 10 million people

- By 2020, more than 30 mega-cities in the now less-developed world. By 2050, nearly 60 such cities.

- Increased population creates need for more resources. World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity.

Context: Global energy growth in developing countries

Note: * Mega city 10 million population or greater

- **World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity.**

By 2020, more than 30 mega cities* in the now less-developed world. By 2050, nearly 60 such cities.

Source: Drawn from presentation by S. Massoud Amin

The Energy Gap

- Half the world's population subsists on agrarian or lower levels of energy access, and
- Their population density generally exceeds the carrying capacity of their environment

Social Conditions and Access to Electricity

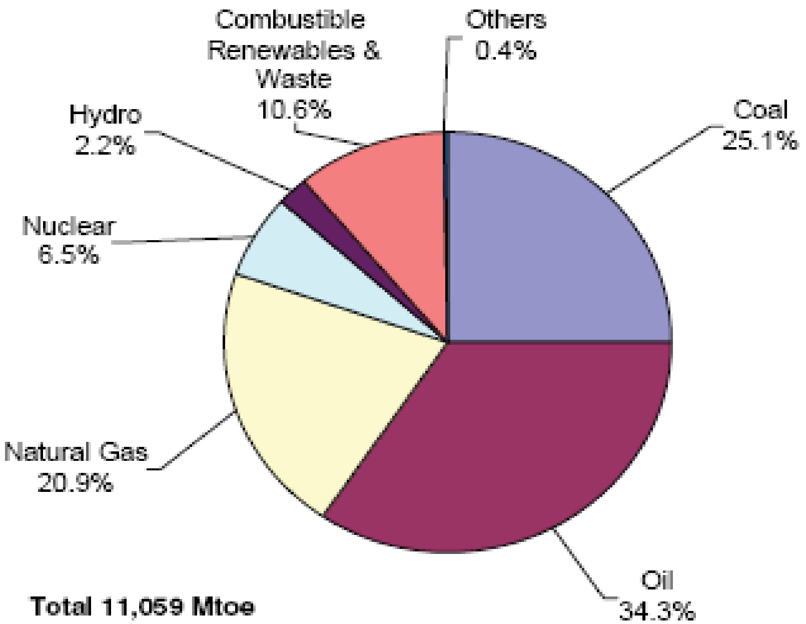
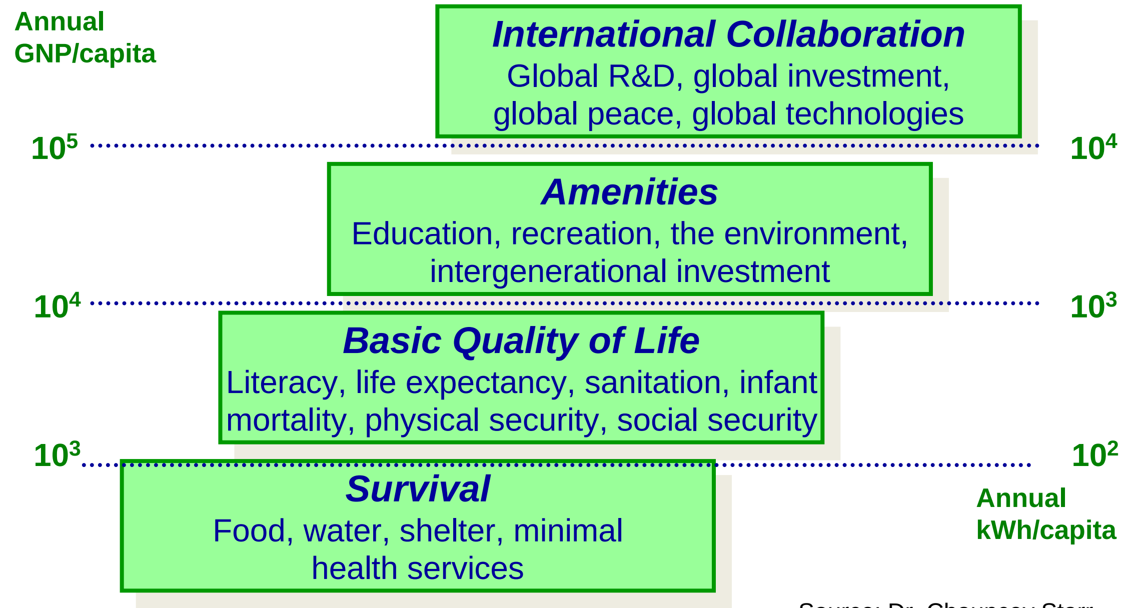


Figure 1. World total primary energy supply (2004) by source. *Note:* Mtoe is million tons of oil equivalent.[1]



Source: Dr. Chauncey Starr

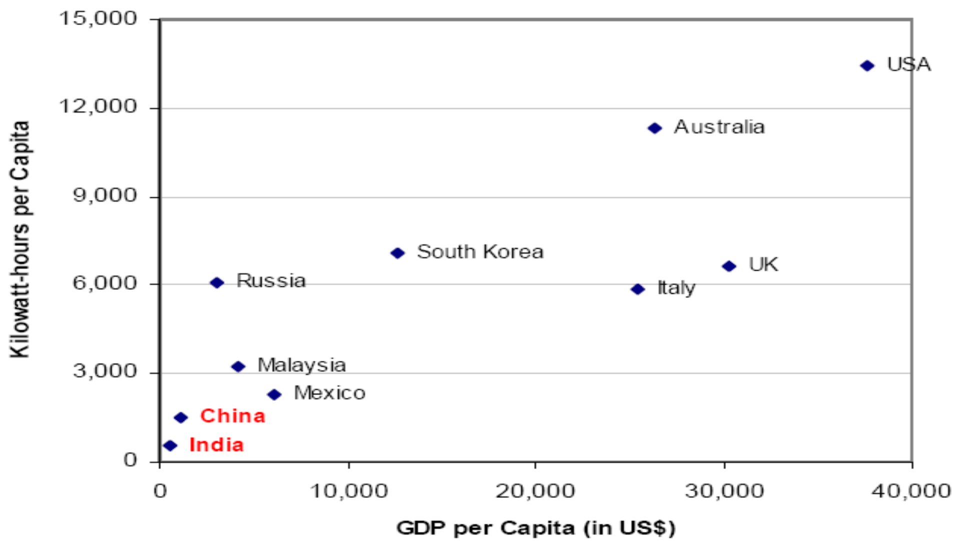


Figure 1: Electricity Usage Per Capita

Source: United Nations' *Human Development Report, 2005.*

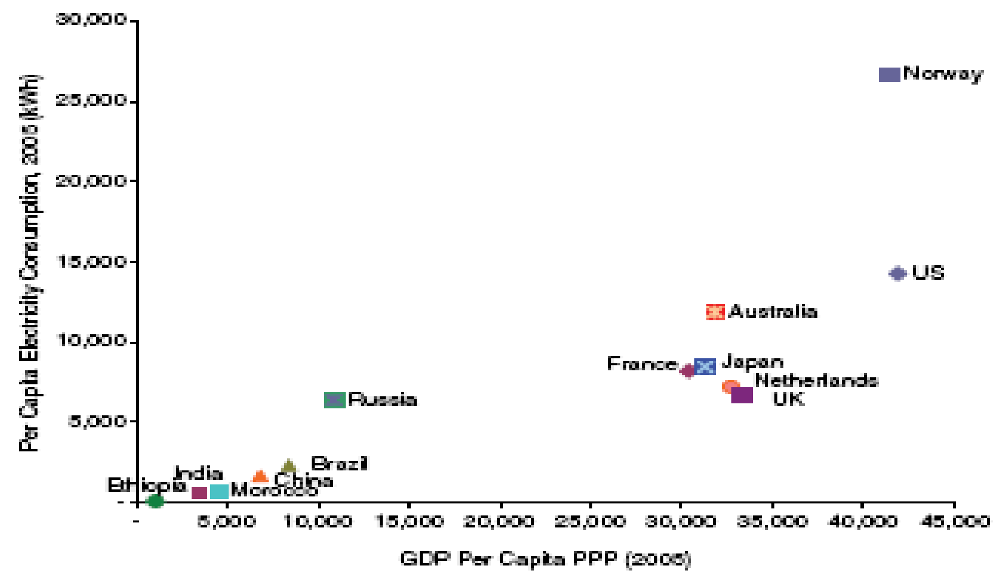
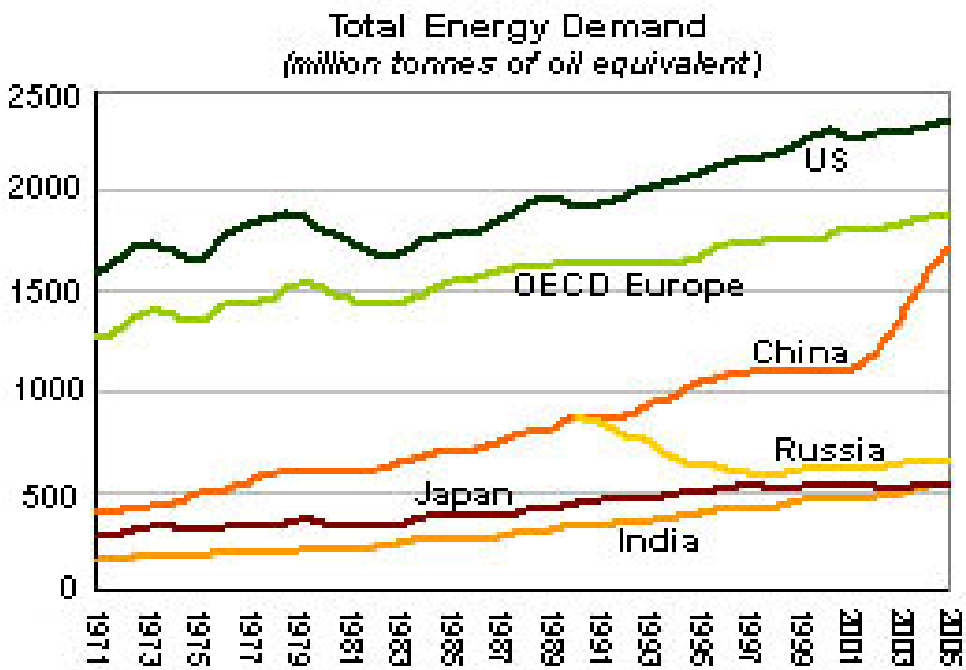
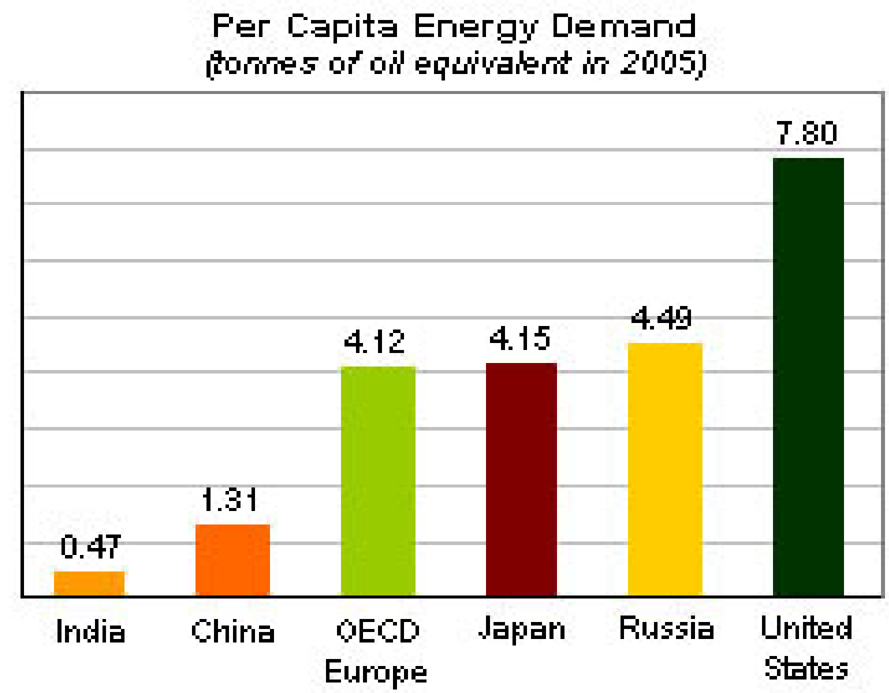


Figure 3. Per capita electricity consumption (kWh) versus GDP per capita purchasing power parity (PPP) of selected countries.[3]

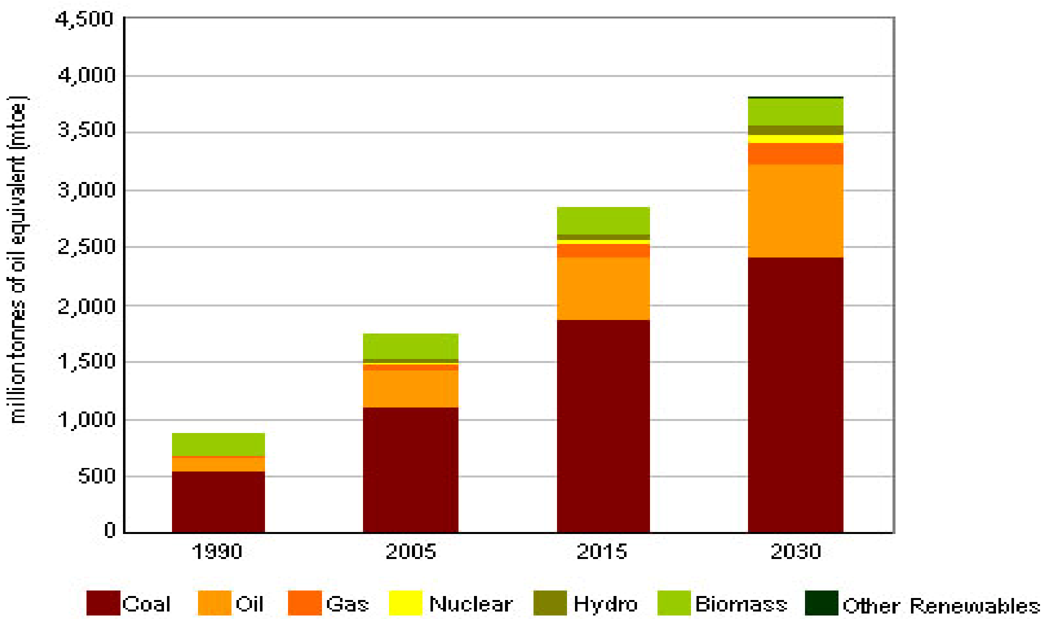
Energy Demand

Source: http://earthtrends.wri.org/updates/node/274





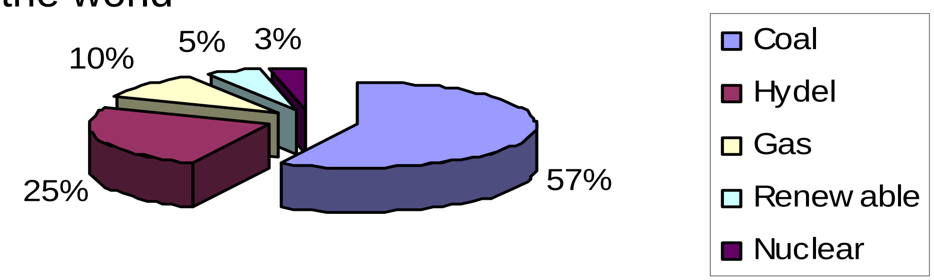
China's Energy Growth



India's installed Capacity

122 GW; 5th largest generation capacity in world

T & D network of 5.7 million circuit km – 3rd largest in the world

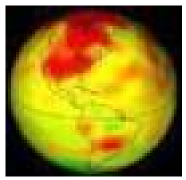


Low per capita consumption at 606 units -- less than half of China

What Lies Ahead?

The world faces enormous problems
– here is one person's list of the top 10

1. **ENERGY (carbon-free)**
2. WATER
3. FOOD
4. **ENVIRONMENT**
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

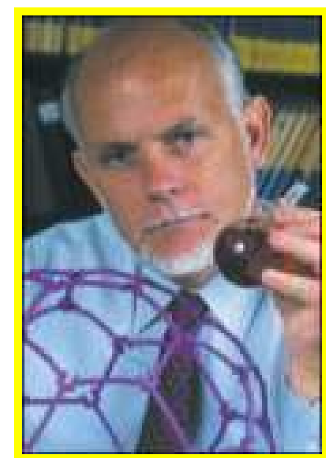


Rick Smalley, Rice U.

(1943-2005)

Nobel Prize 1996

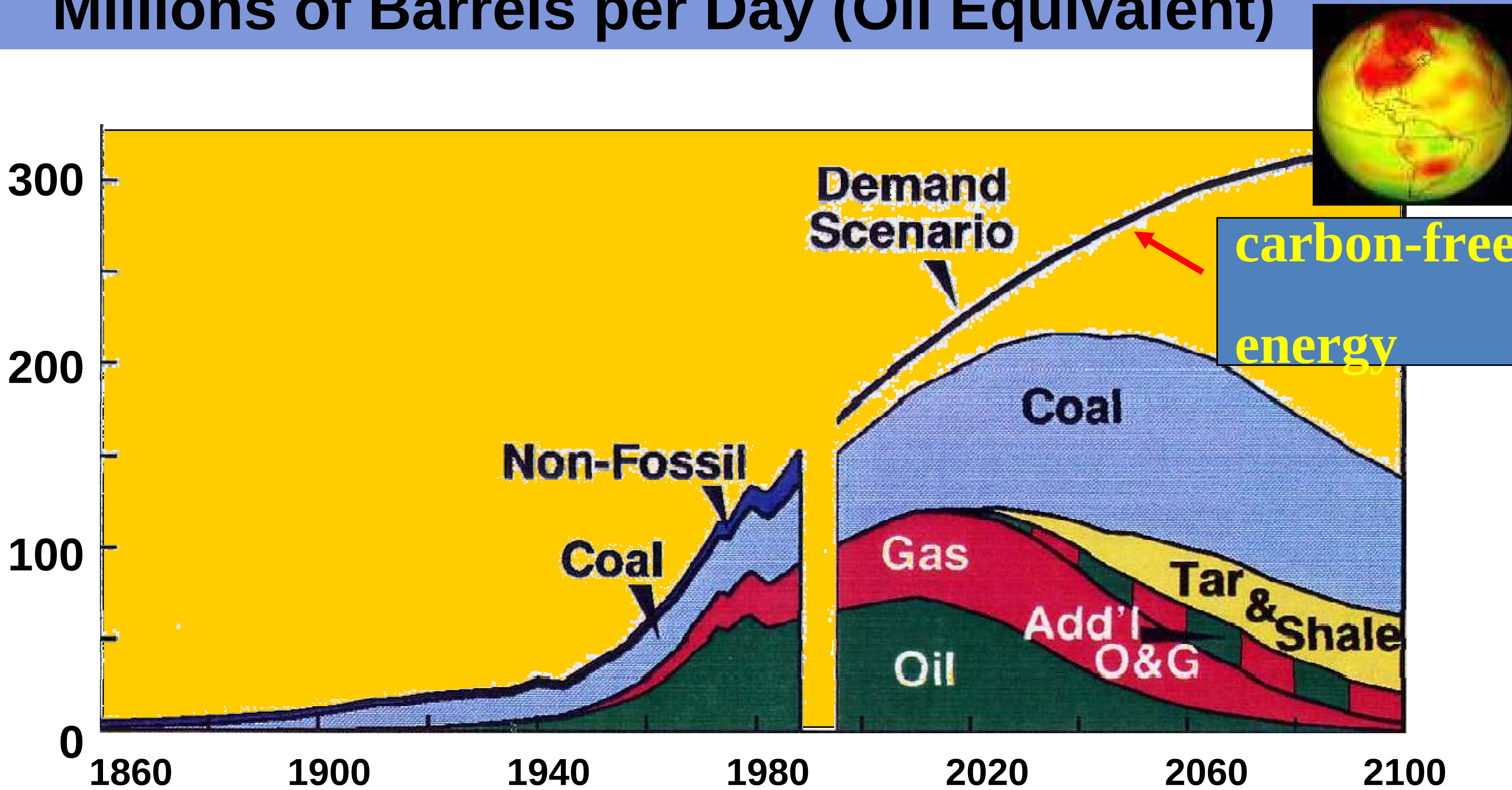
"CIVIC SCIENTIST"



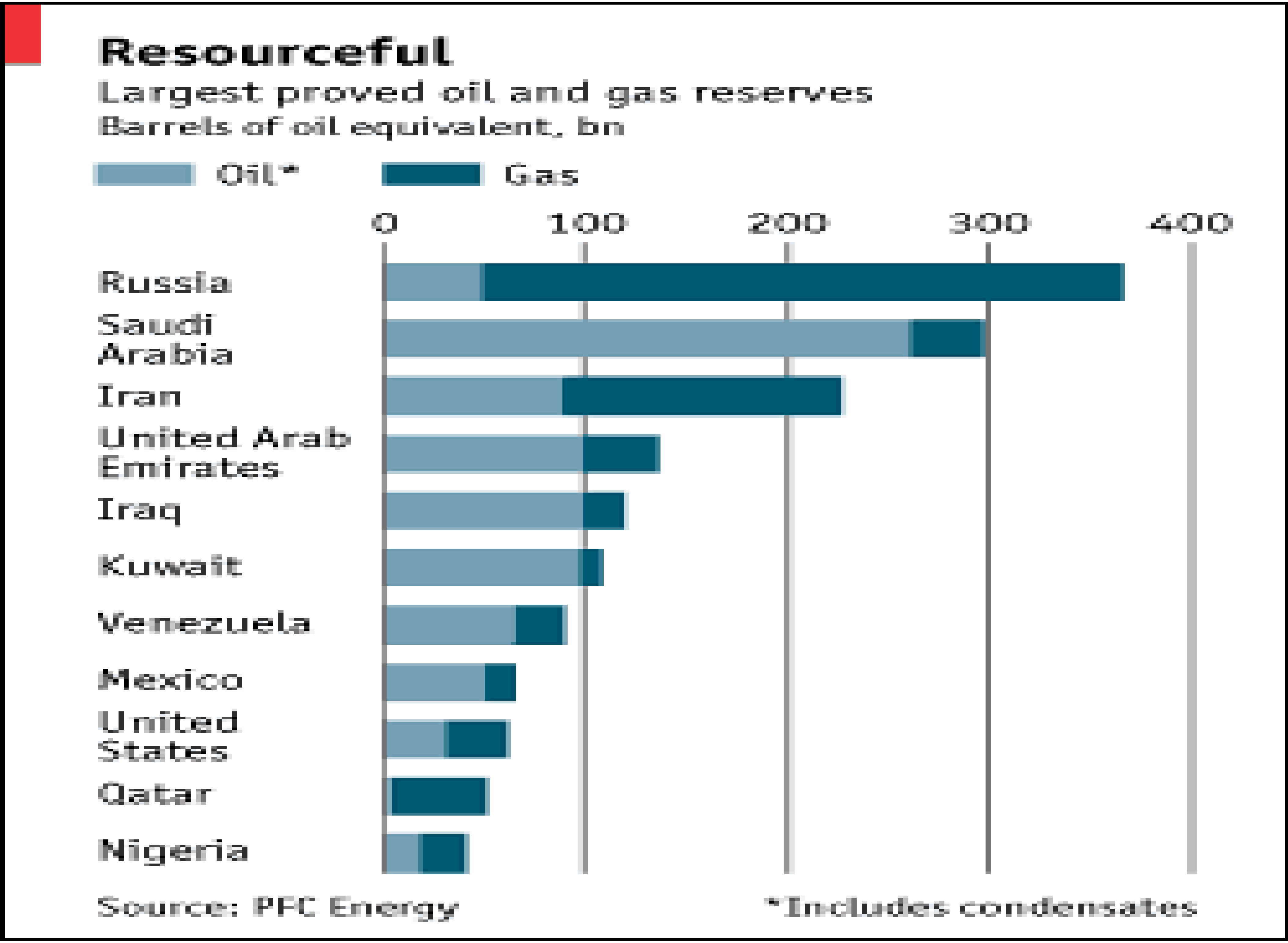
World Energy

Rick Smalley, Rice U.

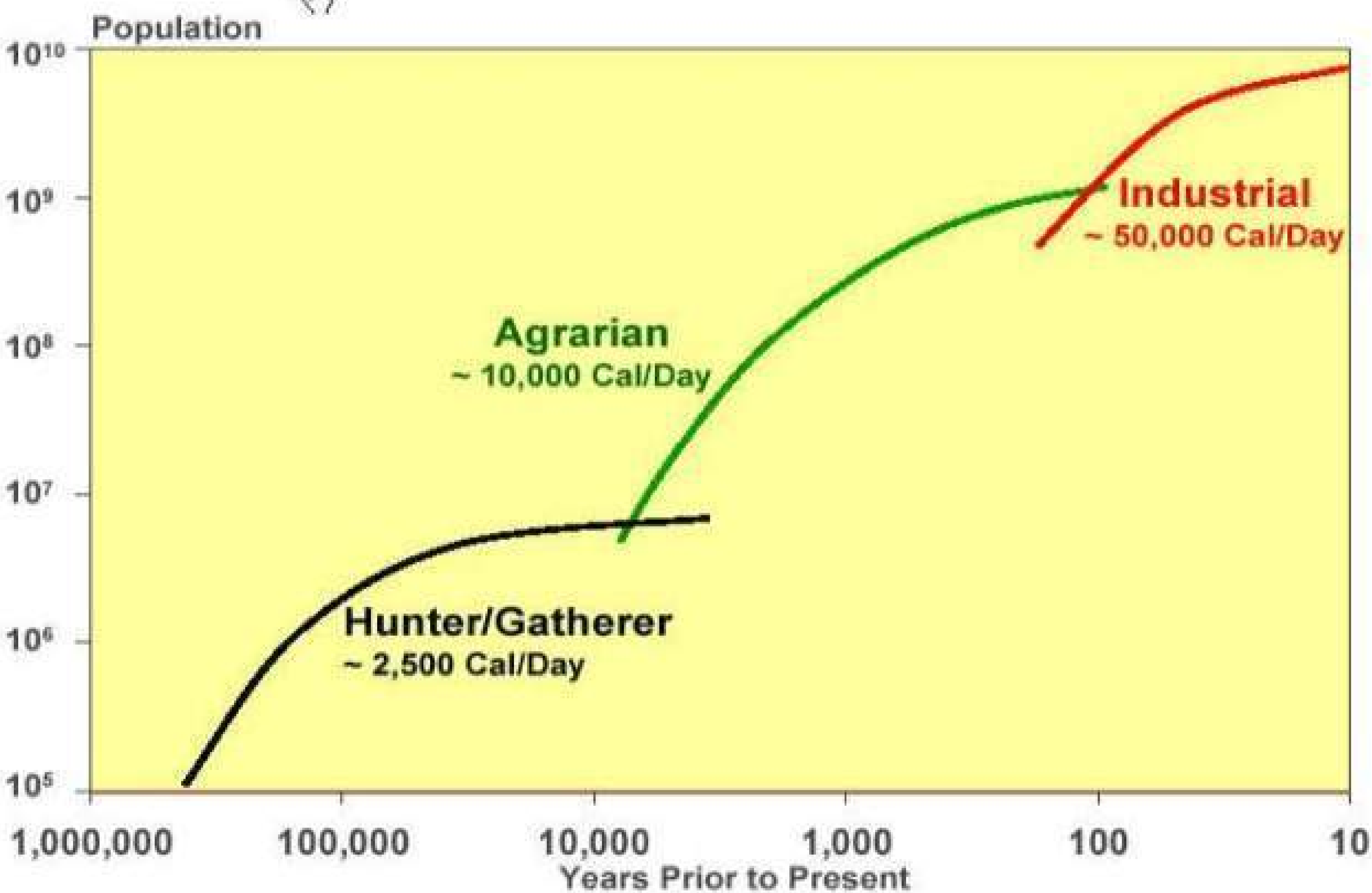
Millions of Barrels per Day (Oil Equivalent)



Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).


Resourceful
Largest proved oil and gas reserves
Barrels of oil equivalent, bn
Oil*
Gas
0
100
200
300
400
Russia
Saudi Arabia
Iran
United Arab Emirates
Iraq
Kuwait
Venezuela
Mexico
United States
Qatar
Nigeria
Source: PFC Energy
*Includes condensates

Energy Security and Cycles of Demographic Growth

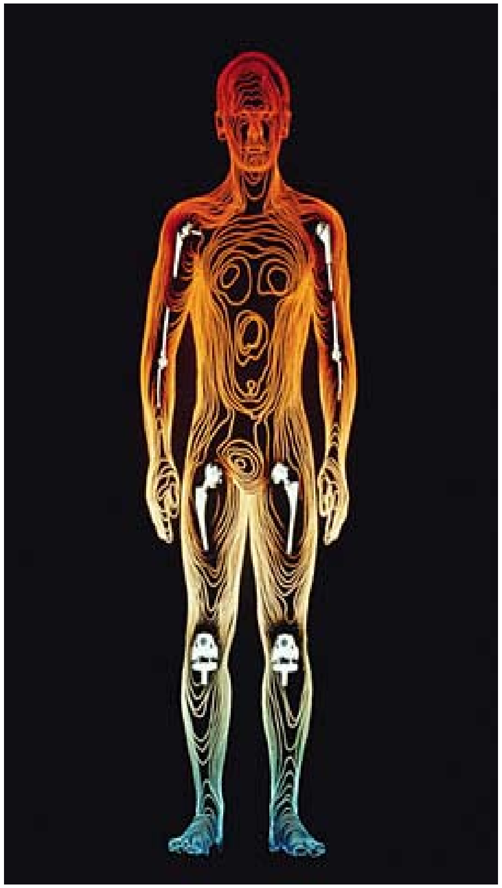


Technology and Policy to the rescue?

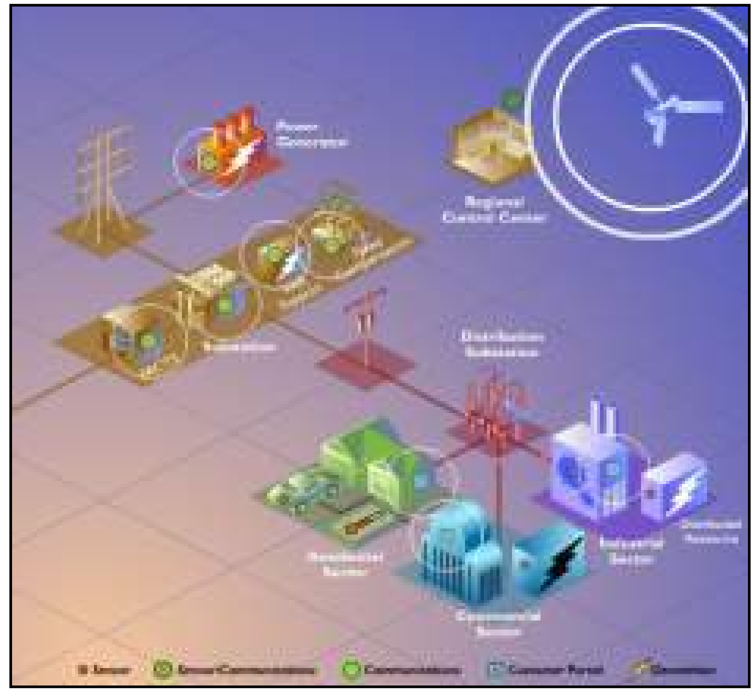
Context: Technology Megatrends

Revolutions in technology offer opportunities for better managing our resources and improving quality of life.

- Information revolution: the ability to disseminate knowledge instantaneously around the globe; information technology giving rise to virtual communities and an expanded international economy
- Materials advances: designer alloys, ceramics, polymers, nanotechnology, and biomimetics offering new capabilities (computer memory and speed, sensors, superconductivity, and superstrength)
- The new genetics: Human Genome Project providing the information foundation for medical advances; agricultural biotechnology offering the potential for feeding the world's population using less land

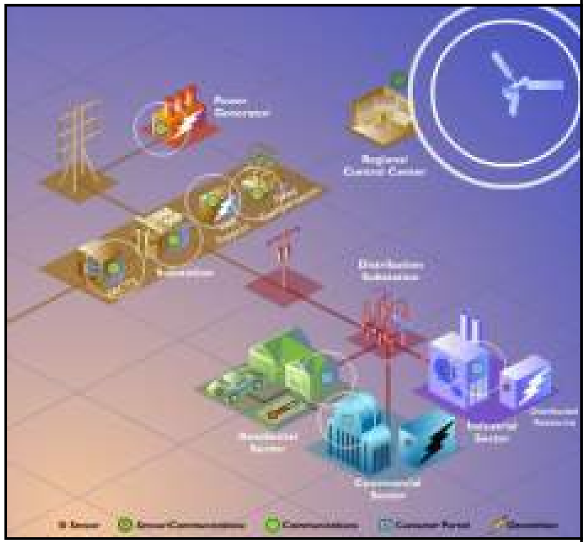


What are we doing about it? Enabling Technologies



- Monitoring: WAMS, OASIS, SCADA, EMS:
  - Wide-Area Measurement Systems (WAMS), integrate advanced sensors with satellite communication and time stamping using GPS to detect and report angle swings and other transmission system changes.
- Analysis: DSA/VSA, PSA, ATC, CIM, TRACE, OTS, ROPES, TRELSS, market/risk assessment…
  - Information systems and on-line data processing tools such as the Open Access Same-time Information System (OASIS); and Transfer Capability Evaluation (TRACE) software--determine the total transfer capability for each transmission path posted on the OASIS network, while taking into account the thermal, voltage, and interface limits.

What are we doing about it? Enabling Technologies (cont.)



- Control: FACTS; Fault Current Limiters (FCL)., …
  - Flexible AC Transmission System (FACTS): Up to 50% more power controlled through existing lines.
  - Fault Current Limiters (FCLs)-- large electrical “shock absorbers” for a few cycles
  - Intelligent Electronic Devices with security built in- combining sensors, computers, telecommunication units, and actuators-- "intelligent agent" functions
- Materials science: High-temperature superconducting cables, advanced silicon devices and wide-bandgap semiconductors for power electronics.
- Power Electronics to enable integration of intermittent sources, connection to smart grid, and increased controllability.
- Distributed resources such as small combustion turbines, solid oxide and other fuel cells, photovoltaics, superconducting magnetic energy storage (SMES), transportable battery energy storage systems (TBESS), etc.

Enabling Technologies (cont.)

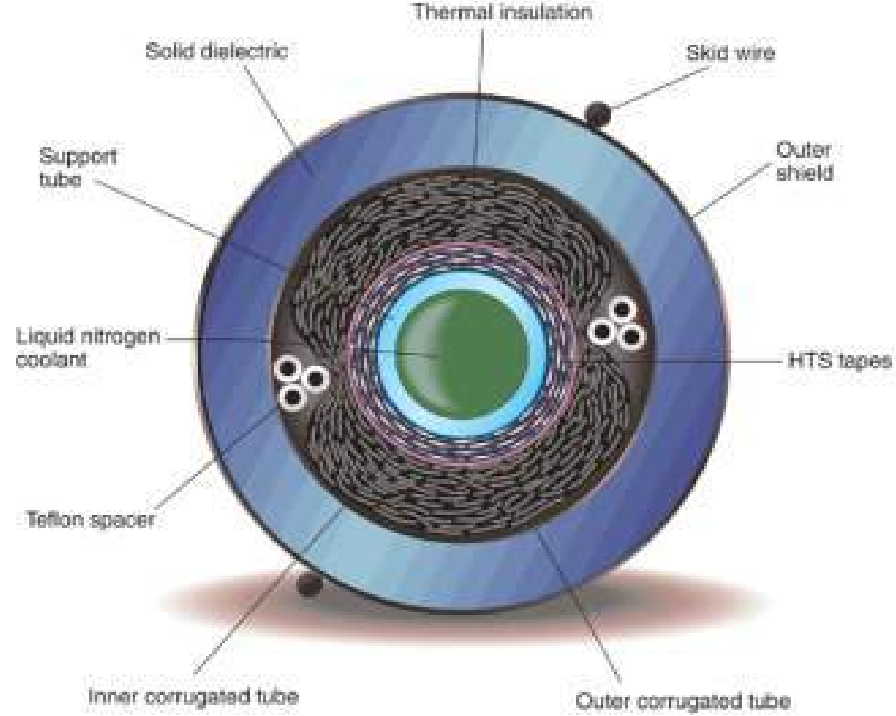
An example of a static VAR compensation installation.

A gas insulated transmission line tunnel in Switzerland.

Technology Solutions: Maximize Utilization

Superconducting Cables

- 2 to 5 times the current
- Can be used to retrofit existing ducts and pipes
- Need to reduce cost, improve reliability of cryogenic system and gain more operating experience



The 13th International MOT Project: **March 23-April 6, 2008**

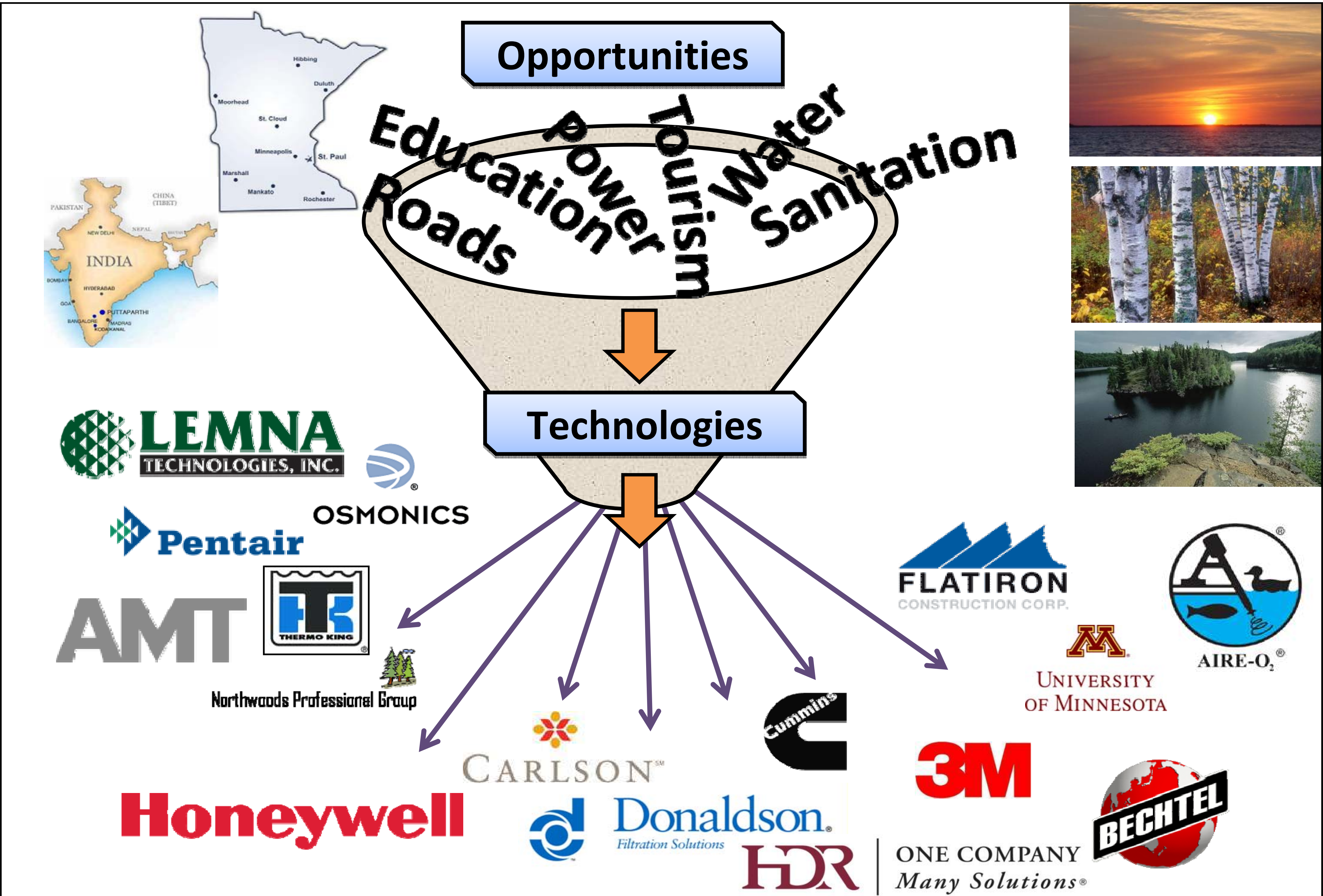
Academic Goals:

- Contrast between emerging & established (companies, countries, technology, foreign-owned vs. local, govt. vs. private sector, etc.);
- Management of Technology content;
- A "non-U.S. International" academic perspective on MOT;
- Ability to develop a coherent intellectual structure within this region/country (content, sequence, flow)

Successfully held in Delhi and Bangalore:

- Final project presentations/findings in India focused on:
  1. Energy,
  2. Information Technologies (IT),
  3. Medicine/Pharma/Biosciences,
  4. Infrastructure Development,
  5. R&D centers and Innovation.

We gratefully acknowledge:
•All of IIT-Delhi and Professors Sushil, Momaya, Yadav and colleagues
•All of IISc and Professors Bala Subrahmanya, Simha, and colleagues
•Professor Rishi at IIM Bangalore
•Outstanding presenters from Government, NGOs, and companies including Honeywell, 3M Innovation Center, SAP Labs, Hero Honda



Technological Leadership Institute

University of Minnesota
Driven to Discover℠

India's Energy: Executive Summary

- India has a significant amount of renewable projects. Focus is needed.
- Opportunities exist between the U.S. and India in the following renewable energy arenas:
  - Wind Power
  - Biomass (Biogas, Biofuels, …)
  - Hydro power
  - Water purification/filtering/recycling
  - Research
  - Manufacturing

Observations

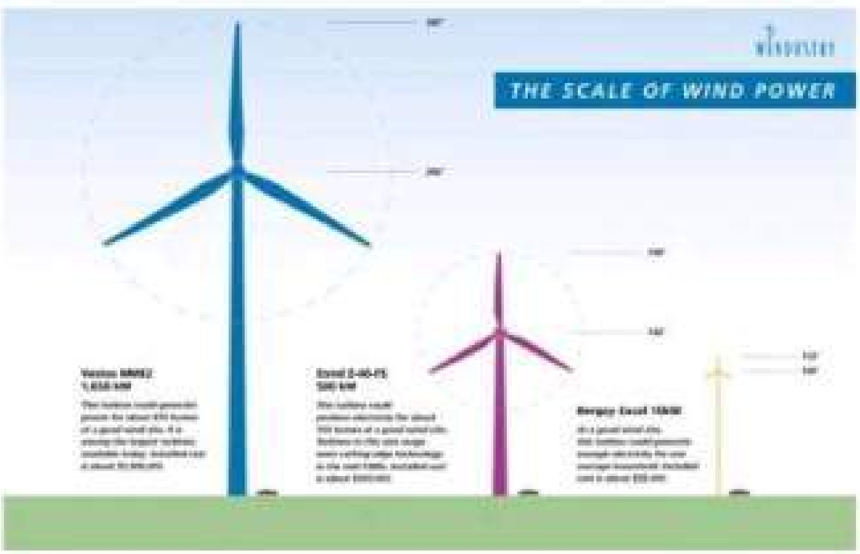
- Multiple technologies required (no one solution)
- Small, medium, and large scale initiatives underway
- Infrastructure challenges & dependency
- NGOs involved in monitoring progress
- FDI requires local partnership

Buffalo Ridge, Minnesota (USA)

Univ. of Minnesota, Morris (USA)

Minnesota Energy Sources

- Limited solar
- Good location for wind, hydro, and biomass renewable



Indian Players

Company	Purpose	Opportunity (with MN)
Suzlon	5th leading supplier for wind turbines	MN employer and leading wind turbine blade mfg
Tata BP Solar www.solarsv.com	Water heating Water Softening & Filtering	Partnership exists with **Pentair** (MN). Mfg in Goa.
OVN BIO Energy Private Ltd	Biomass Gasifier (Developed by IIS-Bangalore)	Bring technology to UofM And MN farms
Moser Baer Photo Voltaic Limited (MBPV)	PV cell manufacturer	Manufacturer of thin film PV ideal for rural applications both in MN and elsewhere
Orb Energy	Working to make solar power affordable and accessible to citizens of India	Distribution channels and service capabilities in place to test and market MN technologies in India
Delhi Transco Ltd. www.delhitransco.gov.in	State Transmission Utility -- Organizes solutions, suppliers, financing, rebates	Get on the list of approved mfgs and suppliers www.mnes.nic.in

Minnesota Players

Company	Purpose	Opportunity (with India)
Wind Turbine Industries (Prior Lake)	Jacobs Wind Turbine	India Mfg, Village electrification,
Next Gen Power Systems (Pipestone)	Small wind turbine	India Mfg, Village electrification,
Donaldson (Bloomington)	Filtration	Biomass / Water / Sewage filtration; Clean Coal
Aeration Systems (Chaska)	Water purification	Infrastructure / Local water purification
Energy Conservation Products and Services (Duluth)	Solar space and water heating	Mfg in India – cost arbitrage
Rural Renewable Development Alliance – RREAL (Backus)	Solar space heating	Grassroots education and opportunity analysis in India
Solar Skies (Starbuck)	Solar water heating	Mfg in India – cost arbitrage
IREE – Univ. of MN (St. Paul)	Promote statewide economic development	Joint research programs with II-Sc
Wells Fargo (Minneapolis)	Banking and Financing	Consumer financing; Capital financing

Short-term Moves

Recommendation	Who	What	How
Expand educational campaigns	NGOs, RREAL, Govt., Universities	Grass roots projects	Show and tell products, pilot projects
Local community action to build wind and solar generators	Solar clubs – India Windustry – MN	Build and integrate prototypes in rural communities infrastructure	Kits for education and demonstration
Research projects for renewable energy	IREE, IISc, Govt.	Strategic technology development, government incentives	Private R&D plus Govt. grants
Leverage multinationals that have integration / implementation capability	Honeywell / India Govt.	Joint research and implementation projects, memorandum of understanding between groups	Exchange programs, technology transfer
Technology transfer	US and Indian organizations	Energy Efficiency, Fuels, Renewable Electricity, Clean Coal, Biogas processing, MFG process	Consortiums Research Projects (Ex: Cellulolytic Enzymes, See MIT Tech Review – Apr 08)

Long-term Moves

Recommendation	Who	What	How
Develop renewable component manufacturing facilities in India	Private Industry, Govt.	Solar cells, biomass components,	Tax incentives, partnerships
Partner manufacturing opportunities with co-generation to promote both mfg and renewables	Govt., Industry	Promote partnerships and collaboration	Setup industry conferences, use government resources to seek partnerships
Consolidate and integrate renewable energy policies—focused vs. shotgun approach	India Govt.	Create a centralize department to assist investors	Create a one-stop shop for investors to get information for starting renewable businesses
Develop an attractive market for private enterprises to support / service projects	Govt.	Attract startups and small-medium size companies to invest, remove investment barriers; Maintenance and service providers	Raise awareness of India's opportunities, simplify INS/Visa requirements, setup free trade agreement
Measure the effectiveness of the renewable energy projects	NGOs	Continue monitoring of renewable projects	Publish results to inform and to show progress
Develop ways to reduce costs of SPV applications for households	Industry, Govt.	Promote university and private research	Use local materials, local talents, reduce tariffs
Create a joint infrastructure/renewable policy	Govt.	Government incentives	Carbon credits in exchange for funding

Next Step: What can we do?

"A lot of very smart people in Minnesota are working on pivotal Smart Grid technologies for our economic growth, Adam. You go on back to bed."

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

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Summary of presentation by Prof. Massoud Amin and related comments from

New Directions for Understanding Systemic Risk:
A report on a Conference Cosponsored by the Federal Reserve Bank of New York and the National Academy of Sciences

For the NAS book and complete FRBNY report please see:
Economic Policy Review, Federal reserve Bank of New York, Vol. 13, Number 2, Nov. 2007
New Directions for Understanding Systemic Risk, 108 pp. Nat'l Acad. Press, Washington DC, 2007

The stability of the financial system and the potential for systemic events to alter the functioning of that system have long been important topics for central banks and the related research community. Developments such as increasing industry consolidation, global networking, terrorist threats, and an increasing dependence on computer technologies underscore the importance of this area of research. Recent events, however, including the terrorist attacks of September 11th and the demise of Long Term Capital Management, suggest that existing models of systemic shocks in the financial system may no longer adequately capture the possible channels of propagation and feedback arising from major disturbances. Nor do existing models fully account for the increasing complexity of the financial system's structure, the complete range of financial and information flows, or the endogenous behavior of different agents in the system. Fresh thinking on systemic risk is, therefore, required.