Powering Progress

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

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

- Control of helicopters subject to disturbances and uncertainties (1983-1985)
- Flight & Fire Control System with Rockwell Int'l tested in Germany by Messerschmidt and adapted as the pilot's assistant for the Advanced Euro Fighter (1987-1990)
- Evasive maneuvering against multiple pursuers with countermeasures (1990-1993)
- Real-time system identification, disturbance rejection and optimal control (1992-1998):
  - **Control of a damaged F-15 (with McDonnell Douglas and NASA; 1995-1996)**
  - Parameter est. and control of antiskid braking system for an MD-90 (1997-98)
  - Improved models and controls for crystal growth (with MEMC, 1993-95)

- Modeling, simulation and optimization of DoD's large-scale air transport operations; Mobility Analysis Support System (USAF's Air Mobility Command (AMC) and the US Transportation Command; 1992-1997)

- **IVHS/ITS: Urban traffic monitoring, prediction, and management (with MODoT, SEI, … 1993-1998)** →

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

EPRI: Jan. 1998 – February 2003

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

UofM: March 2003 – present

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

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

A personal observation on electrification and societal transformation

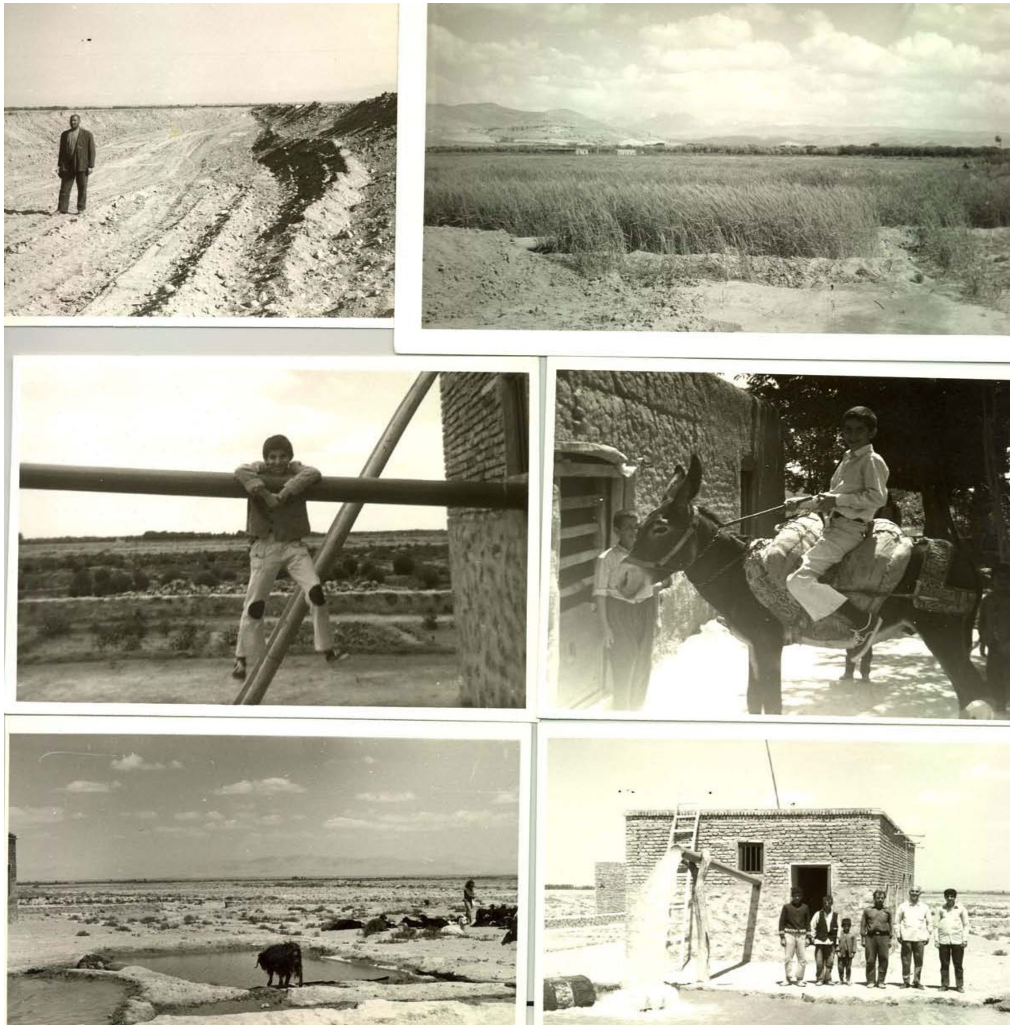
My father Dr. Mohammad Shafi Amin at the Mayo Clinic (pictured in Lake City, Minnesota on January 2, 1952)

My Mom Mrs. Nahid Loghman Adham (passport picture to go to Sorbonne, May 1946)

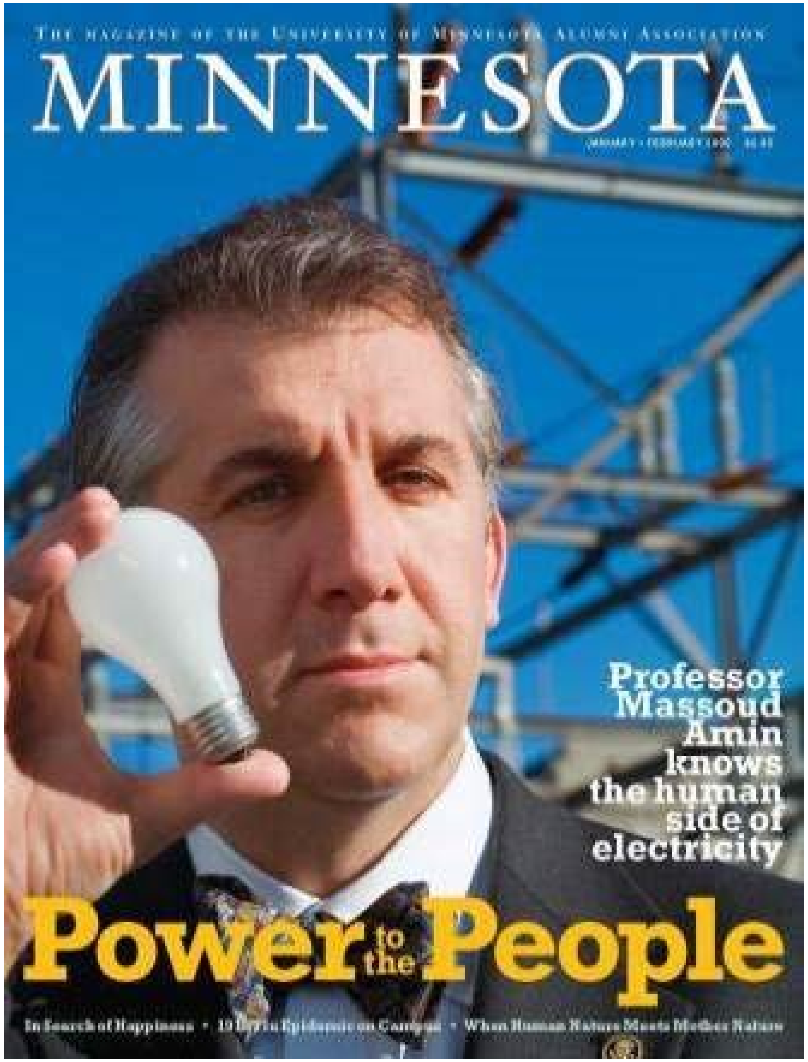
My Mom and me, Nov. 1961

Near Persepolis, Iran, age 8, March 1970

Rural electrification and societal development



Rural electrification outside of Tabriz, Iran
Massoud Amin at age 11, June 1973



Minnesota, January 2005
http://central.tli.umn.edu/amin/MN_Mag_Amin.pdf

Globally Interlocked Dynamics:
Understanding the Full Impacts of Decision Pathways

- To unfold the full potential of social progress requires an integrated understanding of the ma 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

Context: Mega Cities with 10 Million People (1998):

Increasing demands/stress on lifeline Infrastructures

- By 2020, more than 30 mega cities* in the now less-developed world
- By 2050, nearly 60 such cities
- World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity

Note: * Mega city 10 million population or greater

Update: There are over 47 Mega Cities already (2019) https://en.wikipedia.org/wiki/Megacity

Context and the Global Macro-Environment: Cities with 10 million people

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

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

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

Note: * Mega city 10 million population or greater

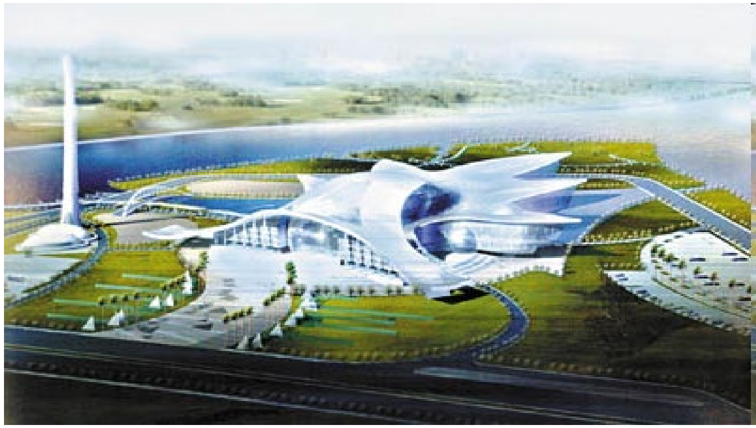
GDP Density

Satellite picture of the earth at night

Global Technology Diffusion

June 2006

Guangdong
Science Center --
China
Opened 2008



Macroeconomic Rationale

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

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

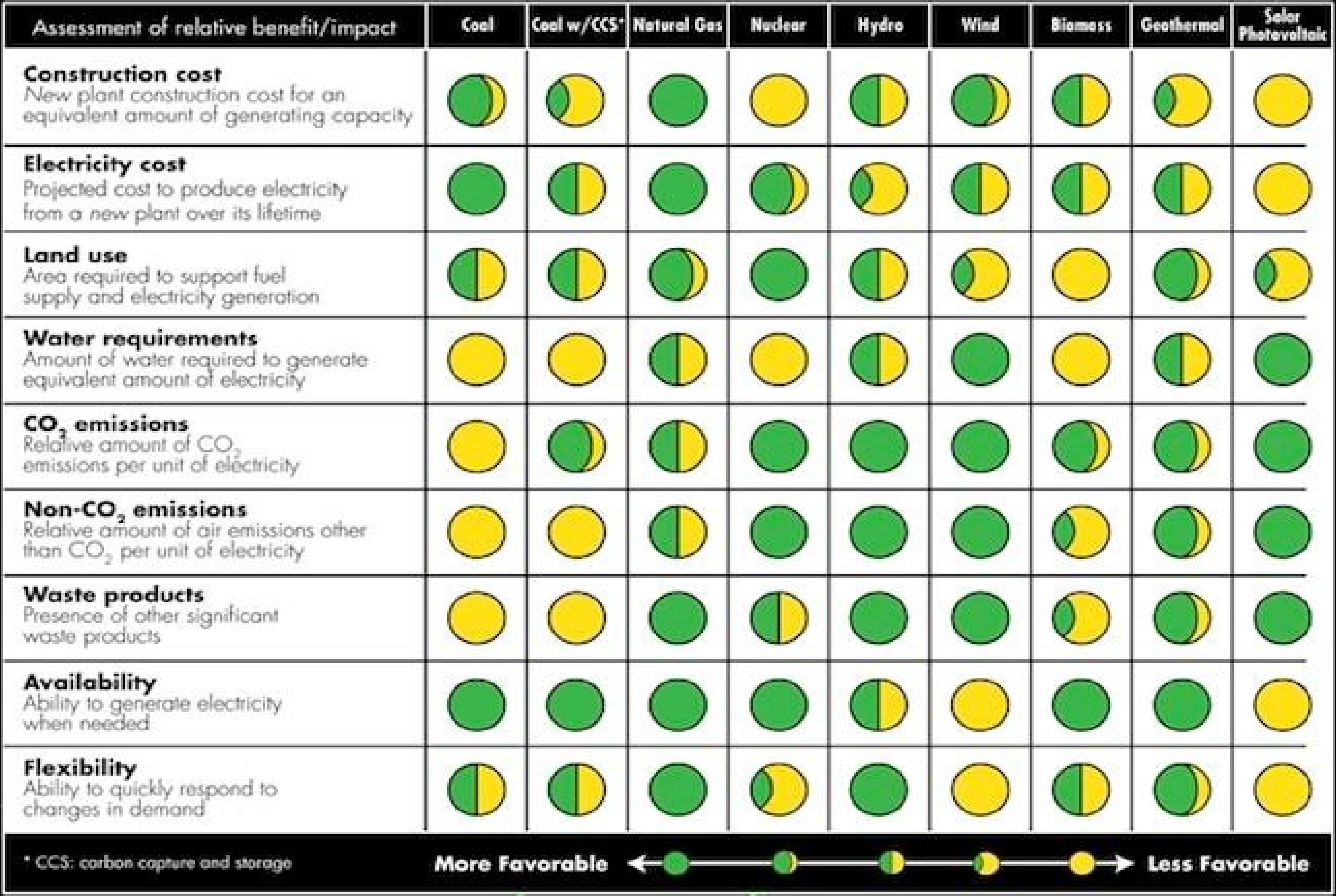
   Y = GDP

   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



Assessment of relative benefit/impact	Coal	Coal w/CCS*	Natural Gas	Nuclear	Hydro	Wind	Biomass	Geothermal	Solar Photovoltaic
Construction cost New plant construction cost for an equivalent amount of generating capacity	◕	◔	●	○	◑	◕	◑	◔	○
Electricity cost Projected cost to produce electricity from a new plant over its lifetime	●	◑	●	◕	◔	◑	◑	◑	○
Land use Area required to support fuel supply and electricity generation	◑	◑	◕	●	◑	◔	○	◕	◔
Water requirements Amount of water required to generate equivalent amount of electricity	○	○	◑	○	◑	●	○	◑	●
CO_2 emissions Relative amount of CO_2 emissions per unit of electricity	○	◕	◑	●	●	●	◕	◕	●
Non-CO_2 emissions Relative amount of air emissions other than CO_2 per unit of electricity	○	○	◑	●	●	●	◔	◕	●
Waste products Presence of other significant waste products	○	○	●	◑	●	●	◔	◕	●
Availability Ability to generate electricity when needed	●	●	●	●	◑	○	●	●	○
Flexibility Ability to quickly respond to changes in demand	◑	◑	●	◔	●	○	◑	◕	○

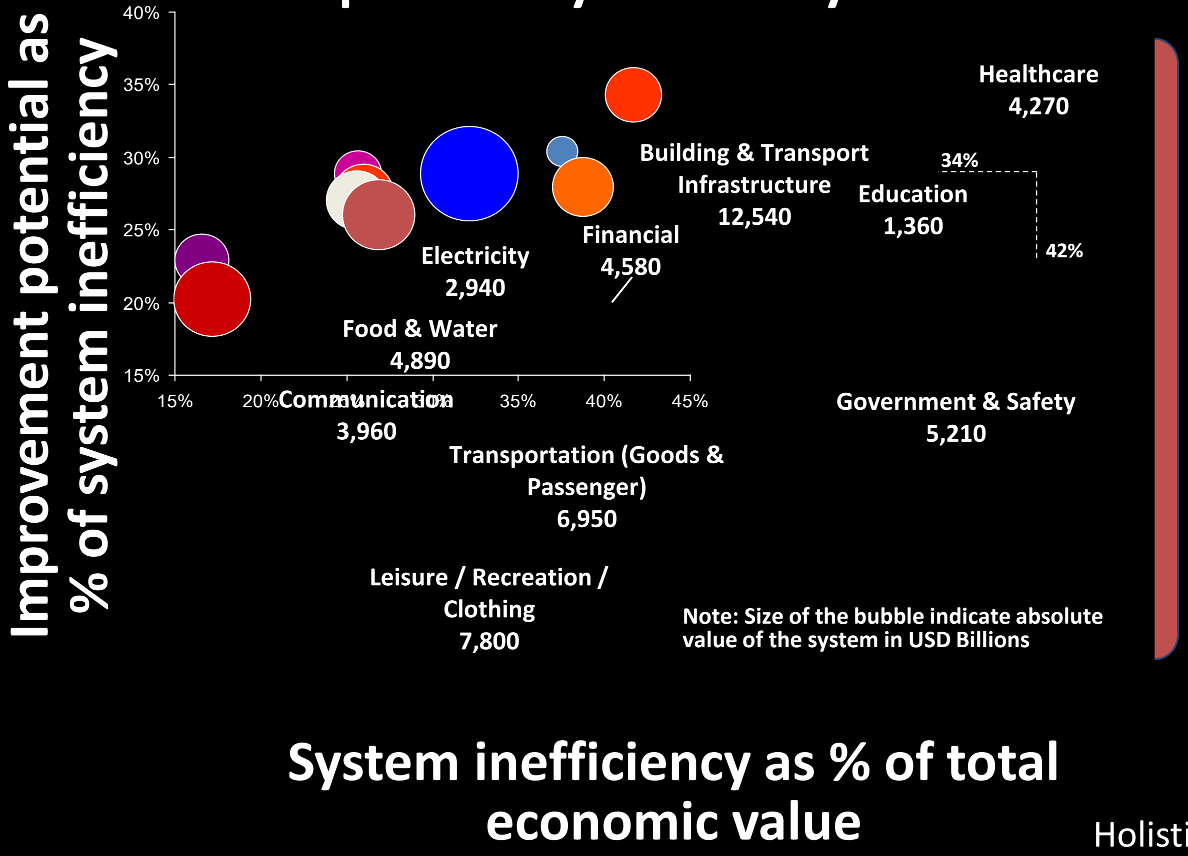
* CCS: carbon capture and storage

More Favorable ← ● — ◕ — ◑ — ◔ — ○ → **Less Favorable**

http://sites.epri.com/refcard/comparison.html

Economists estimate, that all systems carry inefficiencies of up to $15 Tn, of which $4 Tn could be eliminated

Analysis of inefficiencies in the planet‘s system-of-systems



Note: Size of the bubble indicate absolute value of the system in USD Billions

Global economic value of

System-of-systems	**$54 Trillion** 100% of WW 2008 GDP
Inefficiencies	**$15 Trillion** 28% of WW 2008 GDP
Improvement potential	**$4 Trillion** 7% of WW 2008 GDP

How to read the chart:

For example, the Healthcare system‘s value is $4,270B. It carries an estimated inefficiency of 42%. From that level of 42% inefficiency, economists estimate that ~34% can be eliminated (= 34% x 42%).

Holistic Modeling: Korsten & Seider 2010
This chart shows ‘systems‘ (not ‘industries‘)
Source: IBM economists survey 2009; n= 480

Conflict and Leadership:

"Effective leaders are also highly skilled negotiators… Human interaction creates conflict, adding strong minded, intelligent people to business and technology amplifies this conflict. The key is how to use it as an opportunity for leadership, which begins from within and fundamentally depends on values like courage, decency, honesty, empathy, care. Those values are independent of the course we choose in life. They apply to whatever position we hold and in whatever situations we may be. Conflict can provide stimuli for positive change. It is a point of bifurcation with potential options and new opportunities. If you aspire to leadership, know the road ahead, park your ego at the door, and cultivate a quiet mind. Humility is fundamental."

-- Massoud Amin, "Conflict Friendly Waters," Technological Leadership Magazine, pp. 9-10, Spring/Summer 2007, http://www.cdtl.umn.edu/publications/121233.pdf

Resilience:

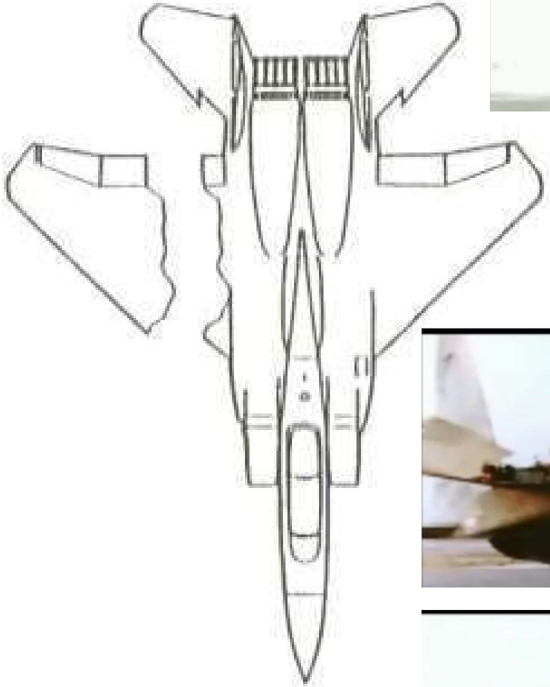
Precursor Detection for Situational Awareness and Proactive Actionable Intelligence

Fast modeling, and high-confidence look-ahead simulation, and validation of Complex Dynamical Systems

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

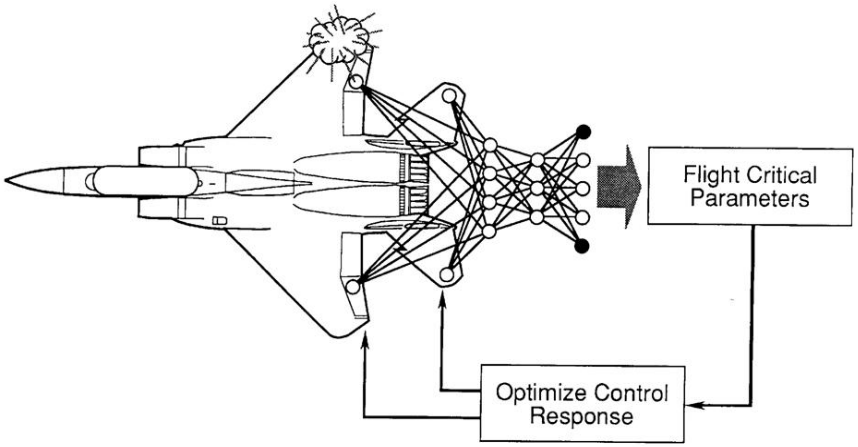
Believe it or not, this one made it back! This F-15, with half its wing missing, is a good example of what is currently considered an "unflyable" aircraft. However, the pilot's success in bringing it home helped to inspire a new program at Aeronautical Systems Division's Flight Dynamics Laboratory aimed at enabling future fighter pilots to fly aircraft with severely damaged control surfaces. The pilot of this F-15 configured in unusual ways the control surfaces that were still working to compensate for the damaged wing. The FDL program will make this "survivors" reaction automatic to the aircraft. Therefore, flying a damaged aircraft will be much easier on the pilot. Through a self-repairing flight control system nearing development, a computerized "brain" will automatically reconfigure such surfaces as rudders, flaperons, and ailerons to compensate for grave damage to essential flying surfaces, according to FDL.

Only smart work by the pilot and the unique combination of interworking control surfaces on the F-15 brought this one back alive. With old-fashioned conventional ailerons and horizontal stabilizer, it couldn't have happened.



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



Flight Critical Parameters

Optimize Control Response

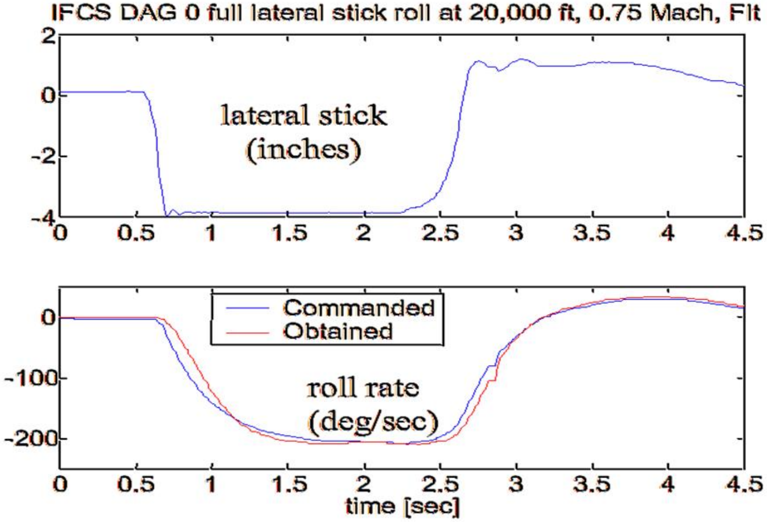
NASA/MDA/WU IFCS

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.

NASA/MDA/WU IFCS

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



Self-healing Grid (1998-present)

Building on the Foundation:

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

Critical System Dynamics and Resilience 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.

Smart Grids… Decades in the Making

- 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

Definition: Smart Self-Healing Grid

Source: Massoud Amin, "Toward a Secure and Smart Self-Healing Grid," presentation to the Strategic Science & Technology EPRI Research Advisory Committee (RAC), Tuesday, January 27, 1998 page 5 at http://massoud-amin.umn.edu/presentations/CINSI_01-27-1998_RAC.pdf

- What is a Smart Self-healing 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, 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.

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

Self-healing Grid and Network-centric Objective Force

Complex interactive networks:

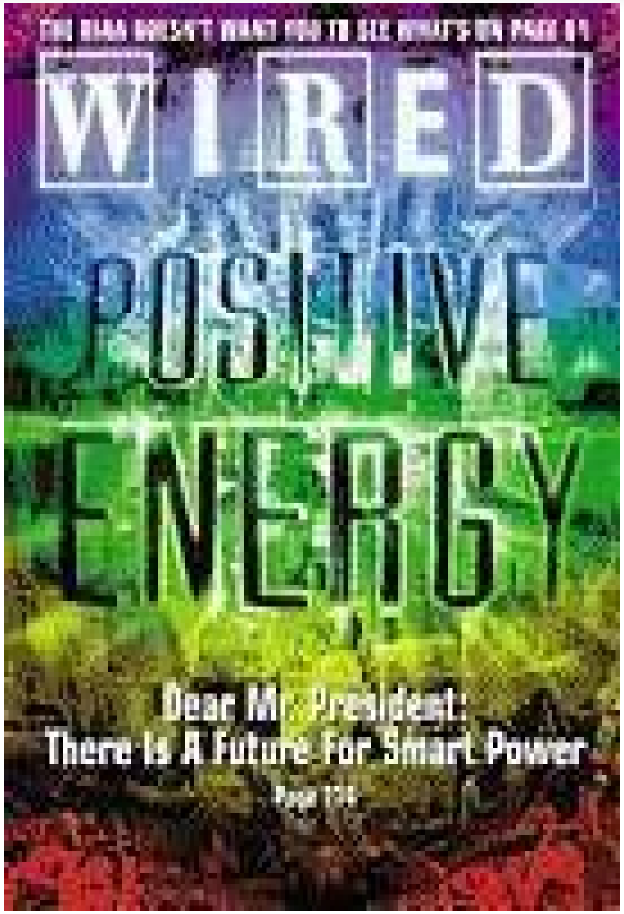
- **Energy infrastructure:** Electric power grids, water, oil and gas pipelines
- **Telecommunications:** Information, communications and satellite networks
- **Transportation and distribution networks**
- **Energy markets, banking and finance**

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

Smart Grids: Two Decades in the Making

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



Smart Grid… "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."

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

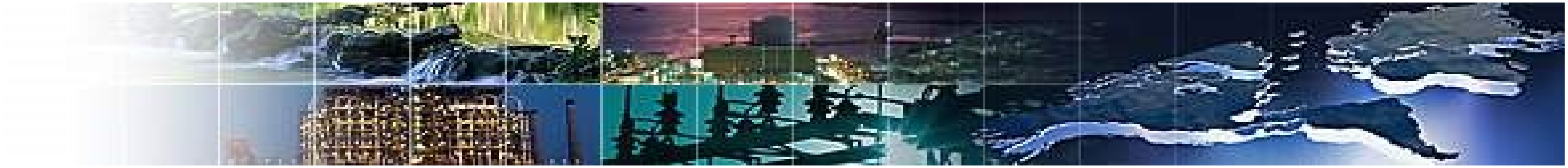
Energy Independence and Security Act

- Passed by U.S. Congress in 2007.

- “It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system … that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid:
    - **Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.**
    - **Dynamic optimization of grid operations and resources, with full cyber-security…”**

Power of Smart Resilient Networks: The Integrated Grid

- The Electricity Industry is in the midst of profound change.
- The Dynamic, Secure, Electronic grid systems are needed for precise control and 2-way power flow.
- Grid Performance Criteria requires a fully integrated grid with full substation microgrids.



The Infrastructure Challenge

Will today’s national and local infrastructure systems be left behind as a relic of the 20th century, or become the critical infrastructure supporting the digital society, a self-healing infrastructure?

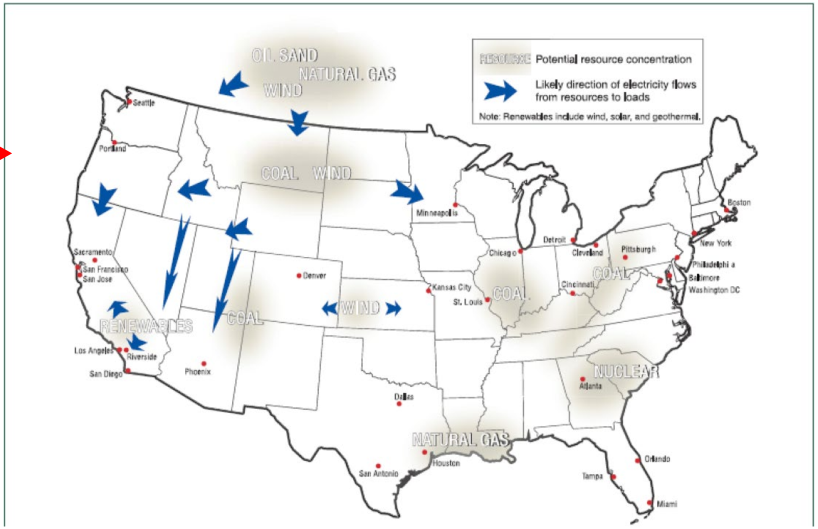
Smart Grid: Integrate Dispersed Energy Sources into a Modern Grid to Provide Energy to Centers of Demand

Recommendations for moving to energy systems to meet demand of tomorrow

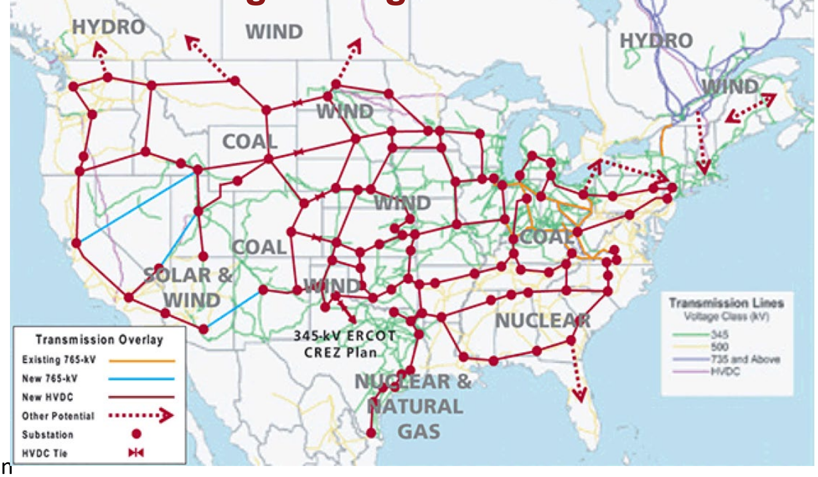
- **Build a stronger and smarter electrical energy infrastructure**
  - – Transform the Network into a Smart Grid
  - – Develop an Expanded Transmission System
  - – Develop Massive Electricity Storage Systems
- **Break our addiction to oil by transforming transportation**
  - – Electrify Transportation: Plug-In Hybrid Electric Vehicles
  - – Develop and Use Alternative Transportation Fuels
- **Green the electric power supply**
  - – Expand the Use of Renewable Electric Generation
  - – Expand Nuclear Power Generation
  - – Capture Carbon Emissions from Fossil Power Plants
- **Increase energy efficiency**

Source: Massoud Amin's Congressional briefings on March 26 and Oct. 15, 2009

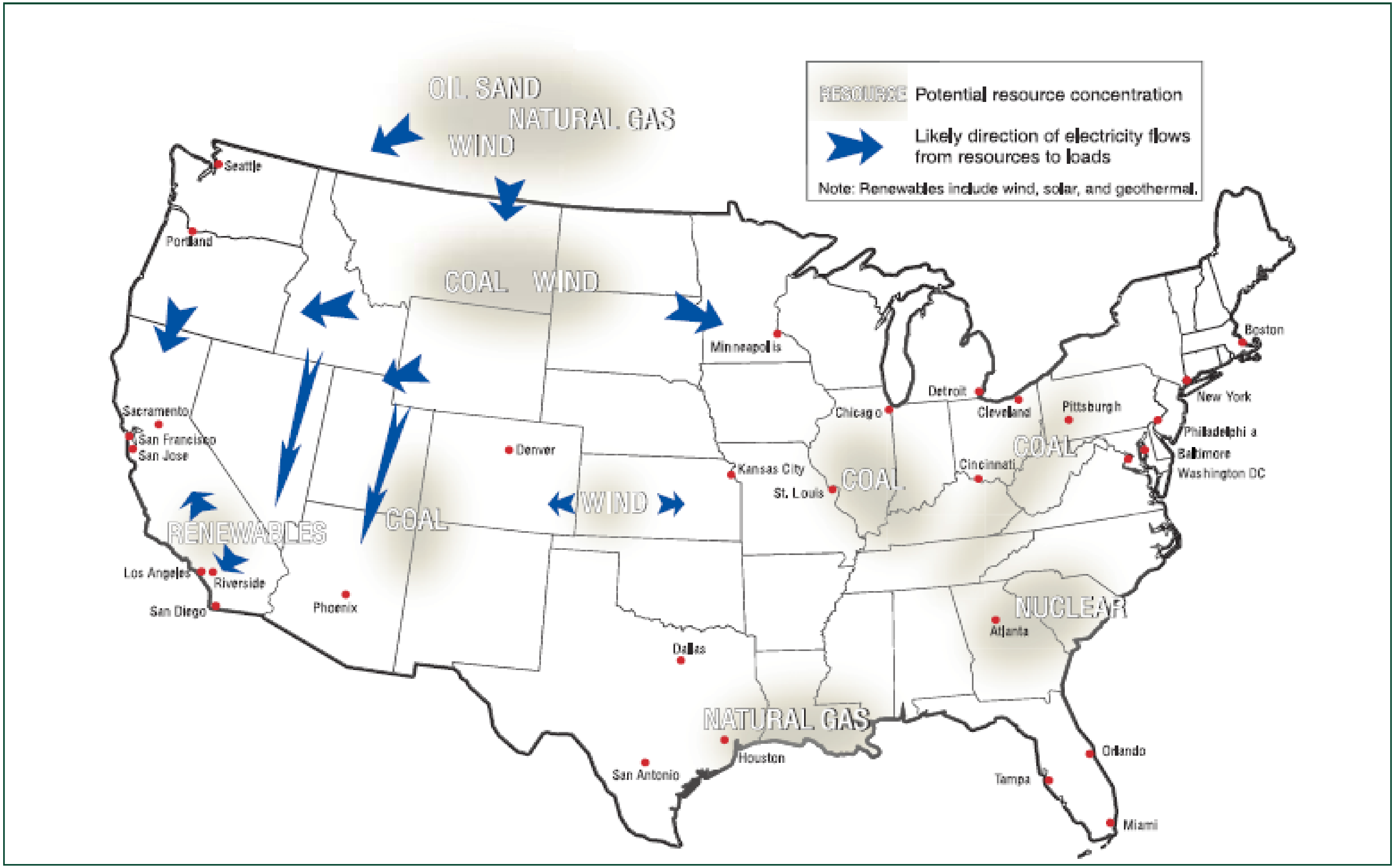
Emerging Supply and Demand Patterns



A Multi-layer Grid System in need of Strengthening and Protection

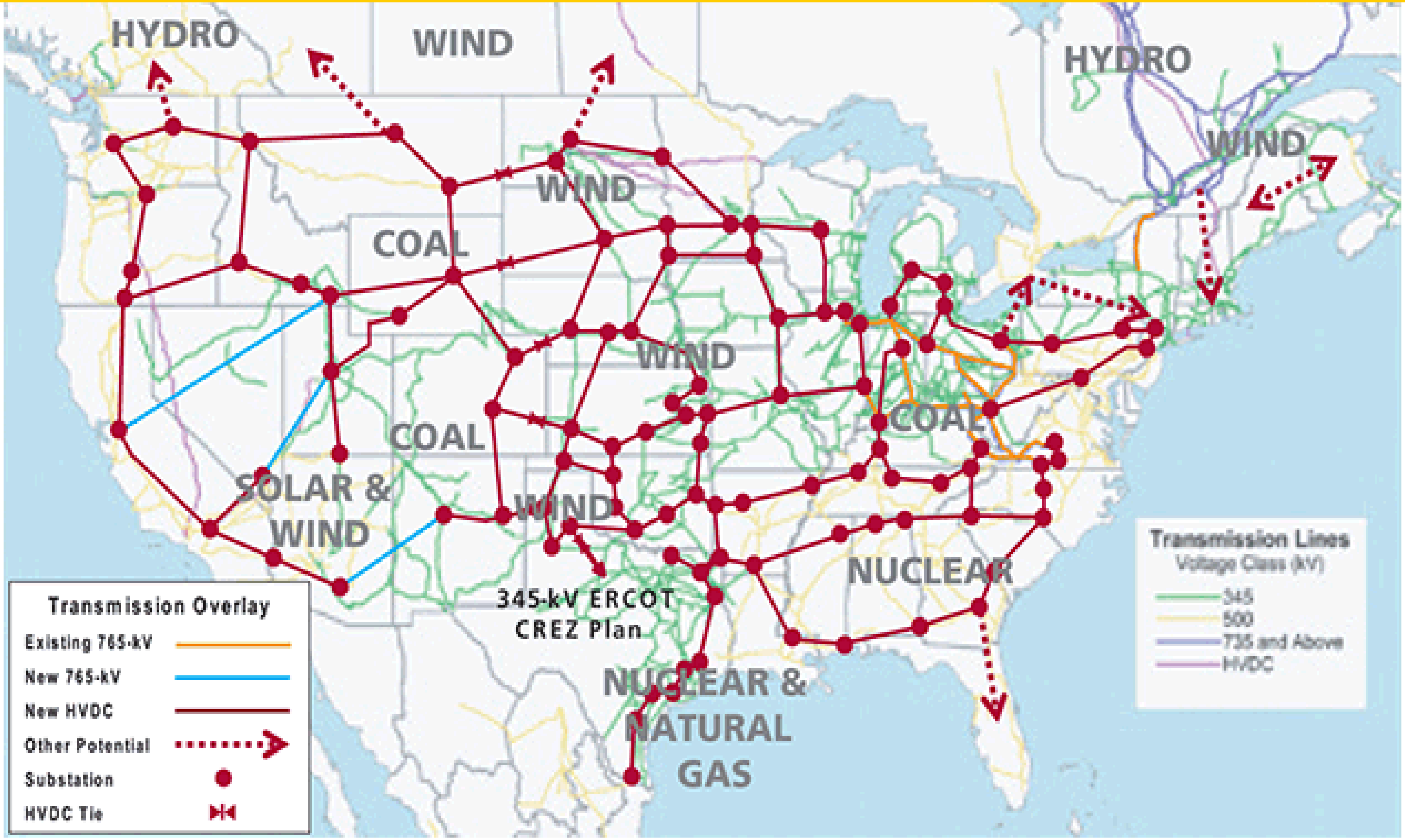


Emerging Supply and Demand Patterns



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

A Multi-layer Grid System in need of Strengthening and Protection



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

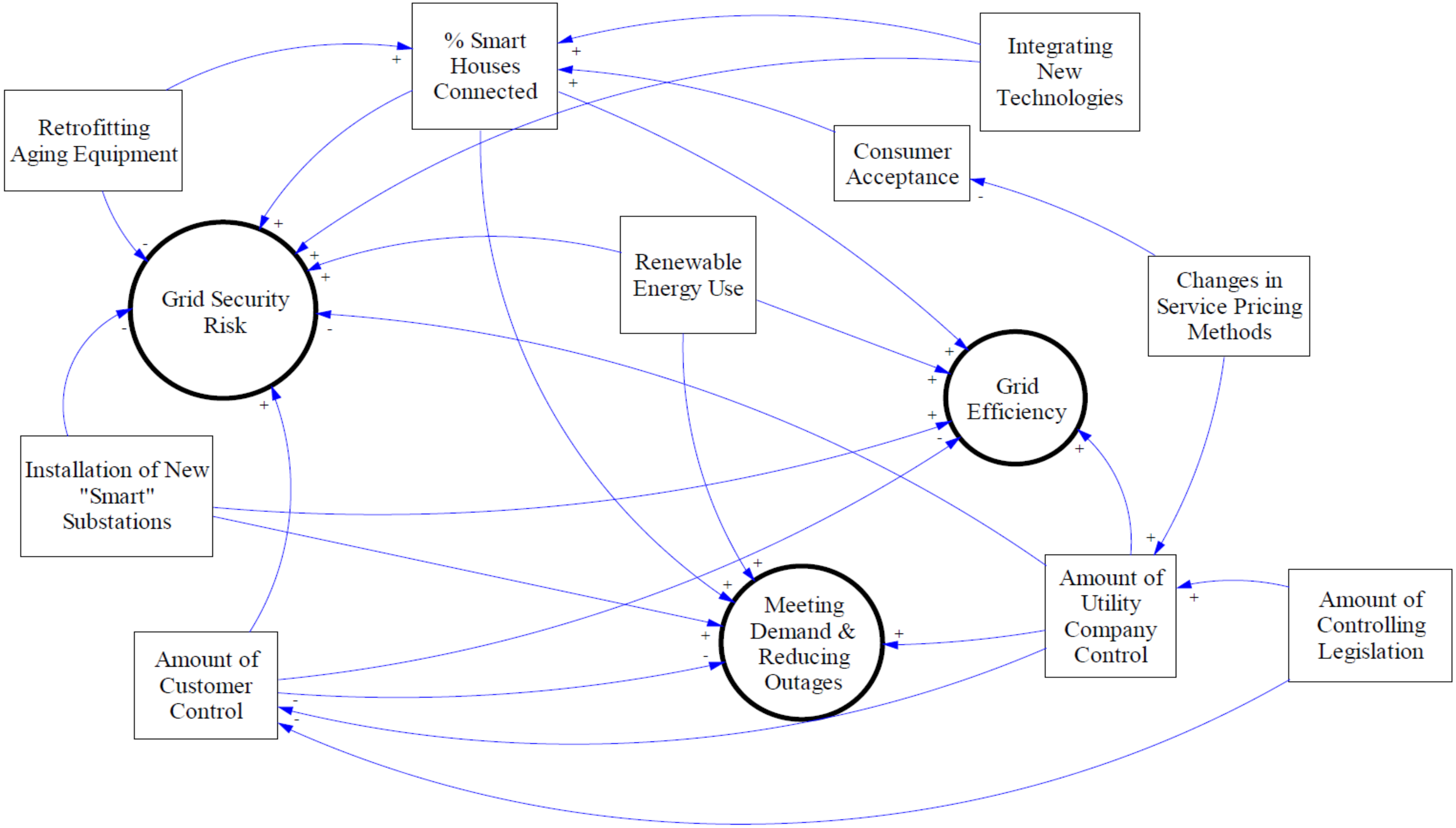
Smart Grids: What are we working on at the University of Minnesota?

- Integration and optimization of storage devices and PHEVs with the electric power grid
- Grid agents as distributed computer
- Fast power grid simulation and risk assessment
- Security of cyber-physical infrastructure: A Resilient Real-Time System for a Secure & Reconfigurable Grid
- Security Analyses of Autonomous Microgrids: Analysis, Modeling, and Simulation of Failure Scenarios, and Development of Attack-Resistant Architectures

University of Minnesota Center for Smart Grid Technologies (2003-present)
Faculty: Professors Massoud Amin and Bruce Wollenberg (retired)
PhD Candidates/RA and Postdocs: Sara Mullen (Phd'09), Anthony Giacomoni (PhD'11), Jesse Gantz (MS'12), Laurie Miller (PhD'13), Vamsi Parachuri (part-time PhD candidate, full-time at Siemens), Trung Ha (Cummins Power Gen.)
PI: Massoud Amin, Support from EPRI, NSF, ORNL, Honeywell and SNL

Smart Grid Interdependencies

Security, Efficiency, and Resilience



Smart Grid U™

- Goal: transform the University of Minnesota's Twin Cities' and the Morris campuses into *SmartGridU.*
  - Develop system models, algorithms and tools for successfully integrating the components (generation, storage and loads) within a microgrid on the University of Minnesota campus.
  - Conduct "wind-tunnel" data-driven simulation testing of smart grid designs, alternative architectures, and technology assessments, utilizing the University as a living laboratory.
  - Roadmap to achieve a "net zero smart grid" at the large-scale community level – i.e., a self contained, intelligent electricity infrastructure able to match renewable energy supply to the electricity demand.

Smart Grid U™

- Lessons learned and key messages:
  - Consider all parts together (Holistic Systems approach)
  - Focus on Benefits to Cost Payback
  - Remove deficiencies in foundations
  - The University as a Living laboratory
  - Education and Research → Implement new solutions

- Consumer engagement critical to successful policy implementation to enable end-to-end system modernization

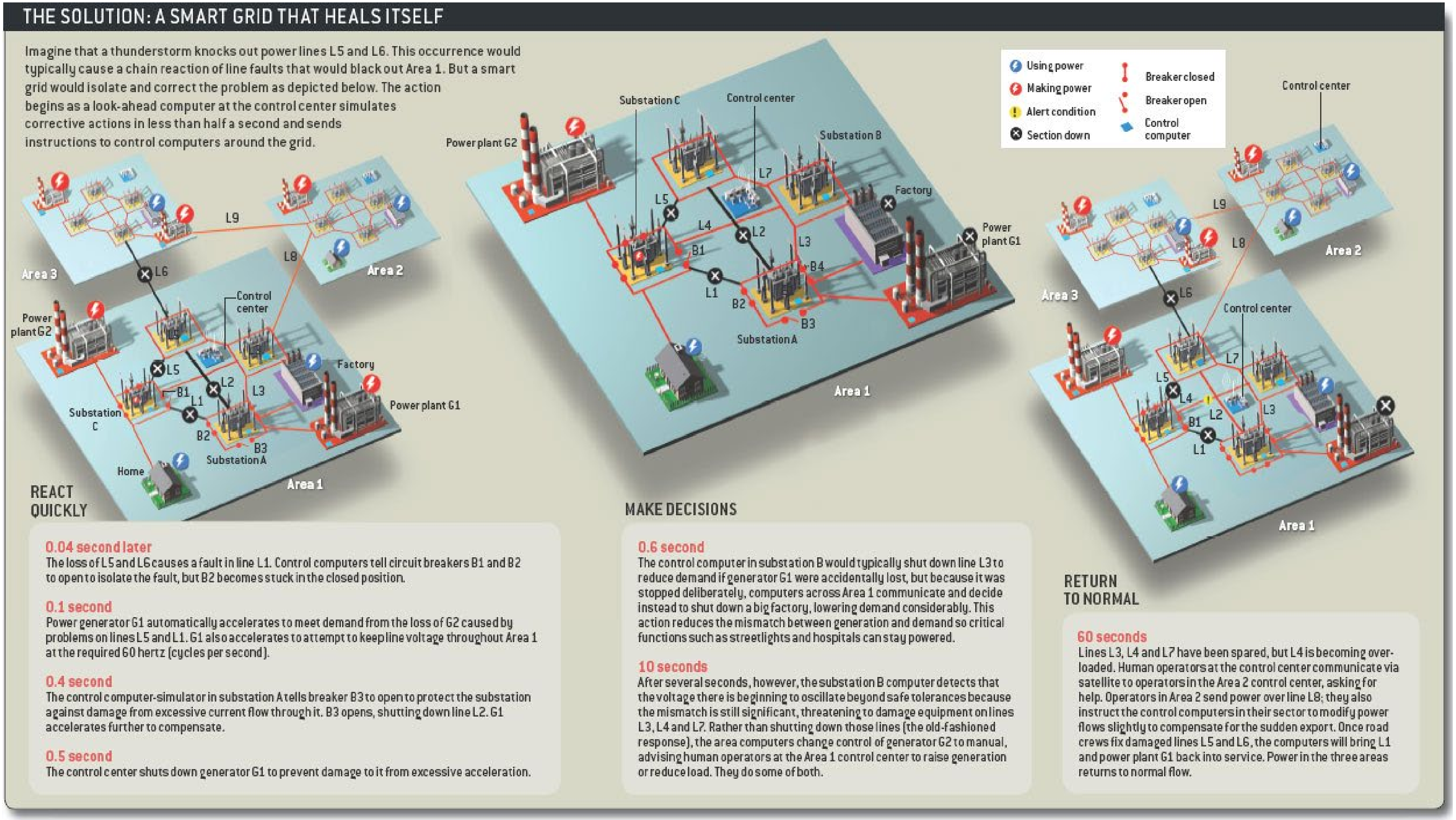
- If the transformation to smart grid is to produce real strategic value for our nation and all its citizens, our goals must include:
  - Enable **every building and every node to become an efficient and smart energy node**.

Examples: Pivotal and Emerging Technologies

1. Energy storage
2. Microgrids
3. Cyber-Physical Security
4. Advanced Controls with Secure Communications
    - Operating Platform – Advanced EMS/DMS
    - Sensors, Monitoring, and Diagnostics
    - Smart Breakers
5. From Smart Cities to Smart Buildings…. And In-home Technologies
    - Smart homes and Demand Response

The next phase of power grid evolution is managing demand through consumers as part of a well-managed, secure, and smarter grid

Smart Self-Healing Grid



THE SOLUTION: A SMART GRID THAT HEALS ITSELF

Imagine that a thunderstorm knocks out power lines L5 and L6. This occurrence would typically cause a chain reaction of line faults that would black out Area 1. But a smart grid would isolate and correct the problem as depicted below. The action begins as a look-ahead computer at the control center simulates corrective actions in less than half a second and sends instructions to control computers around the grid.

REACT QUICKLY

0.04 second later
The loss of L5 and L6 causes a fault in line L1. Control computers tell circuit breakers B1 and B2 to open to isolate the fault, but B2 becomes stuck in the closed position.

0.1 second
Power generator G1 automatically accelerates to meet demand from the loss of G2 caused by problems on lines L5 and L1. G1 also accelerates to attempt to keep line voltage throughout Area 1 at the required 60 hertz (cycles per second).

0.4 second
The control computer-simulator in substation A tells breaker B3 to open to protect the substation against damage from excessive current flow through it. B3 opens, shutting down line L2. G1 accelerates further to compensate.

0.5 second
The control center shuts down generator G1 to prevent damage to it from excessive acceleration.

MAKE DECISIONS

0.6 second
The control computer in substation B would typically shut down line L3 to reduce demand if generator G1 were accidentally lost, but because it was stopped deliberately, computers across Area 1 communicate and decide instead to shut down a big factory, lowering demand considerably. This action reduces the mismatch between generation and demand so critical functions such as streetlights and hospitals can stay powered.

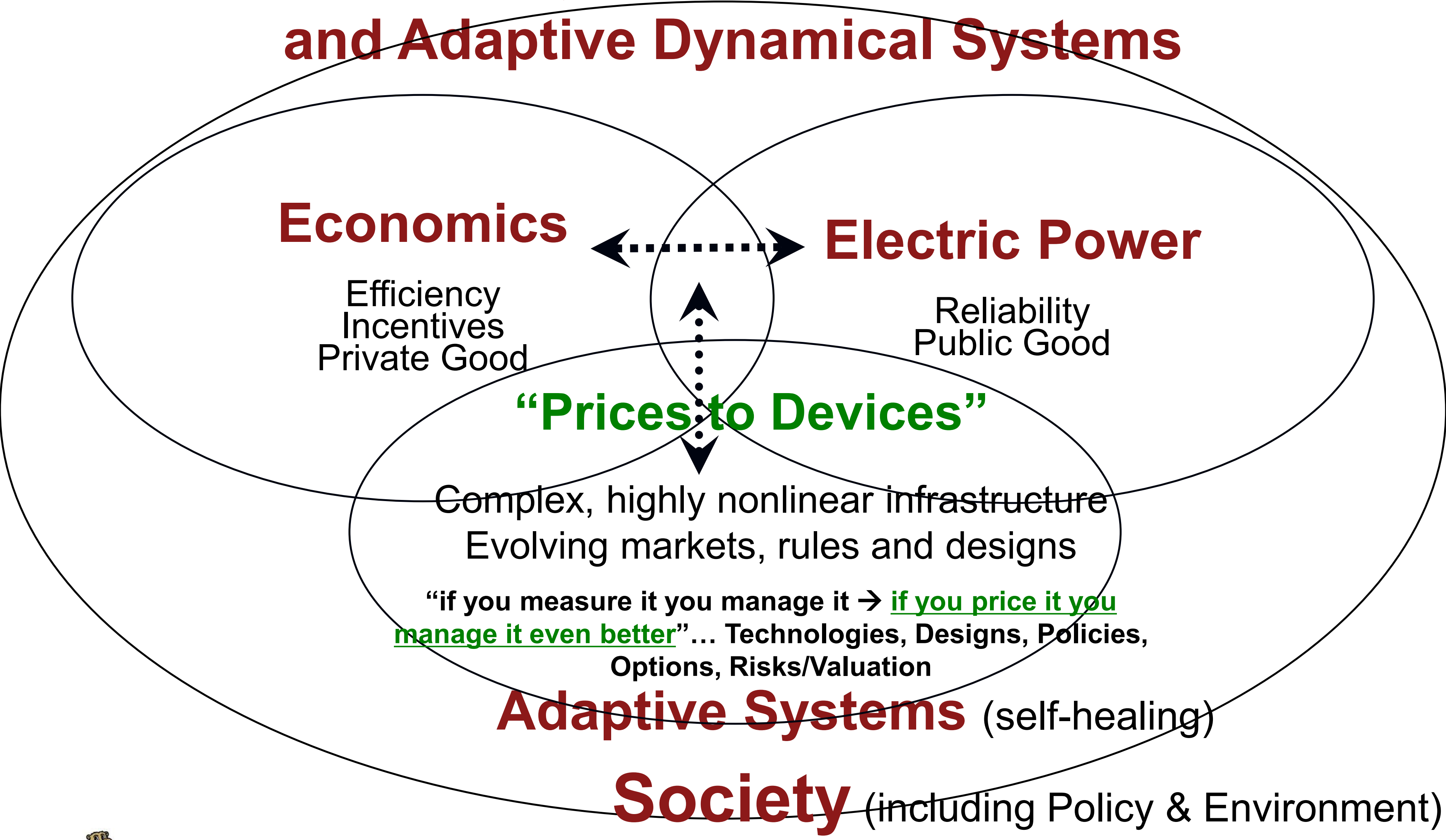
10 seconds
After several seconds, however, the substation B computer detects that the voltage there is beginning to oscillate beyond safe tolerances because the mismatch is still significant, threatening to damage equipment on lines L3, L4 and L7. Rather than shutting down those lines (the old-fashioned response), the area computers change control of generator G2 to manual, advising human operators at the Area 1 control center to raise generation or reduce load. They do some of both.

RETURN TO NORMAL

60 seconds
Lines L3, L4 and L7 have been spared, but L4 is becoming overloaded. Human operators at the control center communicate via satellite to operators in the Area 2 control center, asking for help. Operators in Area 2 send power over line L8; they also instruct the control computers in their sector to modify power flows slightly to compensate for the sudden export. Once road crews fix damaged lines L5 and L6, the computers will bring L1 and power plant G1 back into service. Power in the three areas returns to normal flow.

"Preventing Blackouts," Amin & Schewe, Scientific American, May 2007

Energy Infrastructure, Economics, Efficiency, Environment, Secure Communications and Adaptive Dynamical Systems



Economics

Efficiency
Incentives
Private Good

Electric Power

Reliability
Public Good

"Prices to Devices"

Complex, highly nonlinear infrastructure
Evolving markets, rules and designs

"if you measure it you manage it → <u>if you price it you manage it even better</u>"… Technologies, Designs, Policies, Options, Risks/Valuation

Adaptive Systems (self-healing)

Society (including Policy & Environment)

Cybersecurity

Changing Risks

Cyberspace

Cyber Activism

Cyber Insurance

Cyber War

Cyberattack

Cyber-Alert

Cyber Bullying

Cyber-ethics

Cyber crime

Cyber FININT

Cyberpower

Cybersecurity

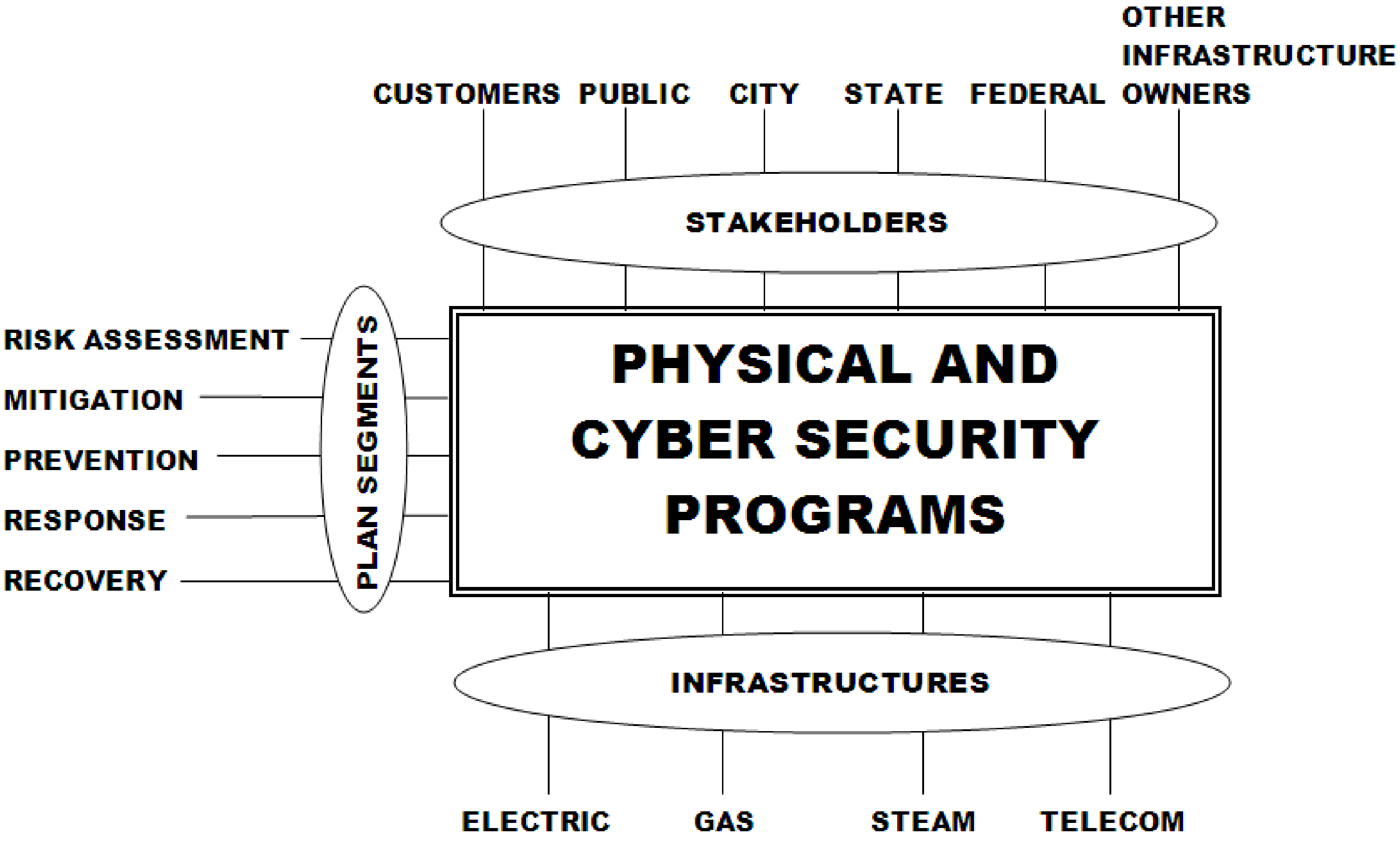
Cyber-Commerce

Cyber Espionage

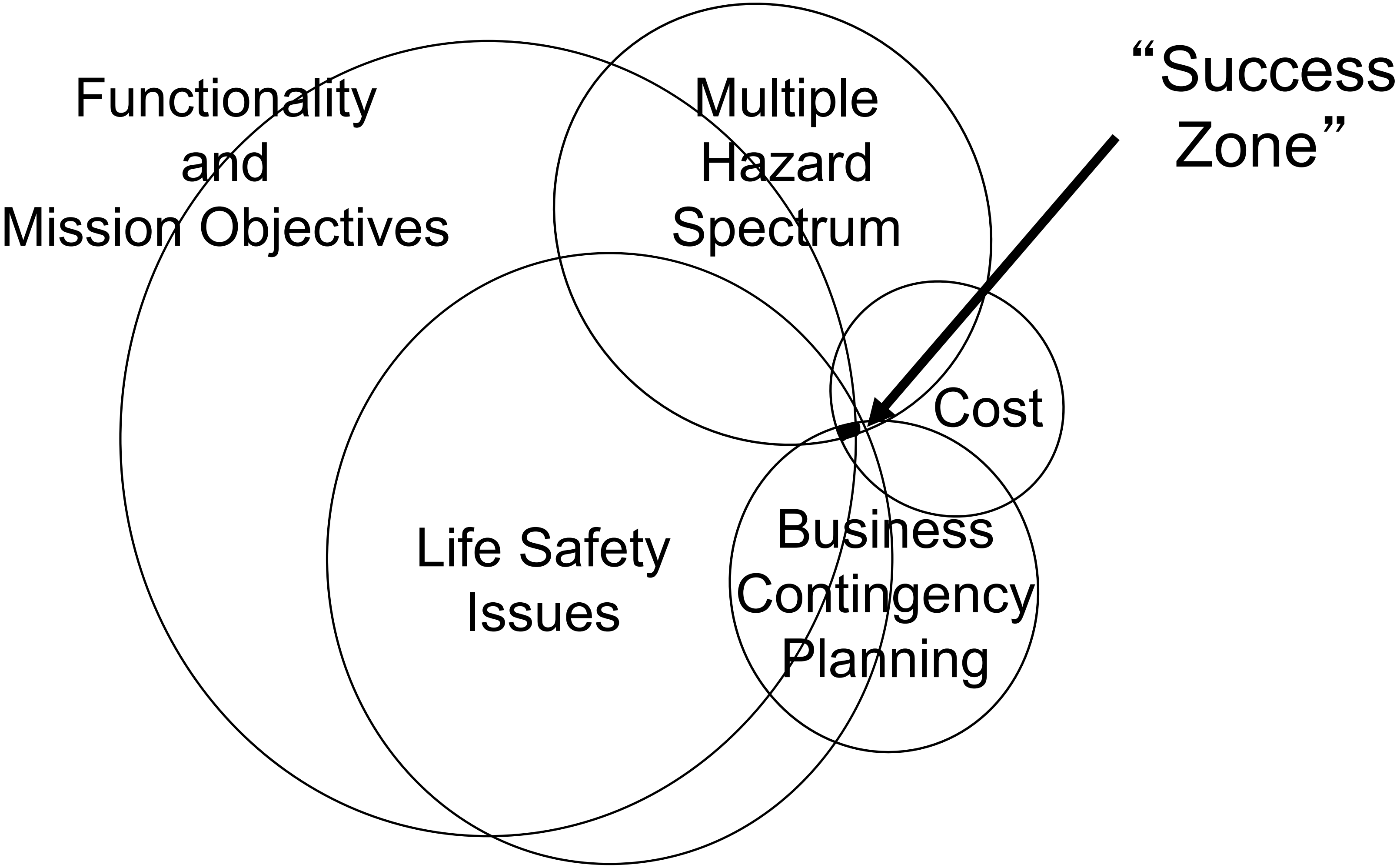
Cyber Law

Cyber Communication

CIP programs in the industry



Real world solutions may be elusive



Functionality
and
Mission Objectives

Multiple
Hazard
Spectrum

“Success
Zone”

Cost

Life Safety
Issues

Business
Contingency
Planning

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.

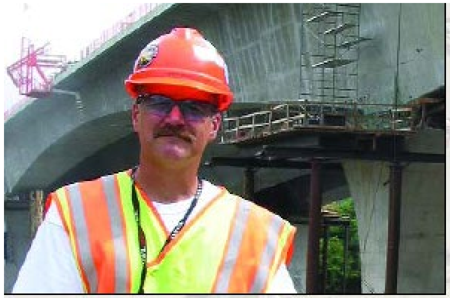
"As an individual, it was shocking and very painful to witness it from our offices here in Minneapolis," says Amin, director of the Center for the Development of Technological Leadership (CDTL) and the H.W. Sweatt Chair in Technological Leadership. Amin also viewed the tragedy from a broader perspective 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.

To improve the future and avoid a repetition of the past:

Sensors built in to the I-35W bridge at less than 0.5% total cost by TLI alumni

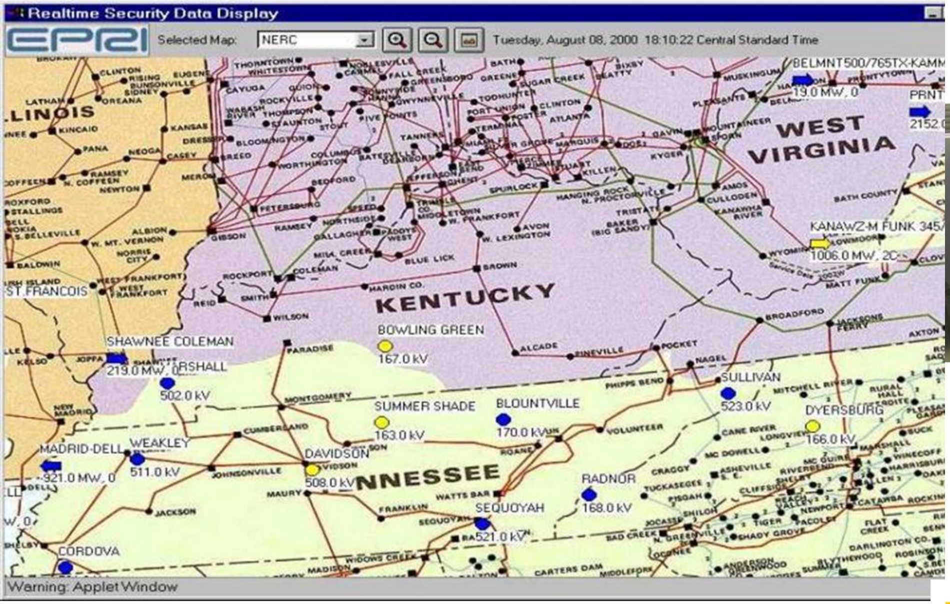

Terry Ward


Heidi Hamilton


Val Svensson


Joe Nietfeld

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



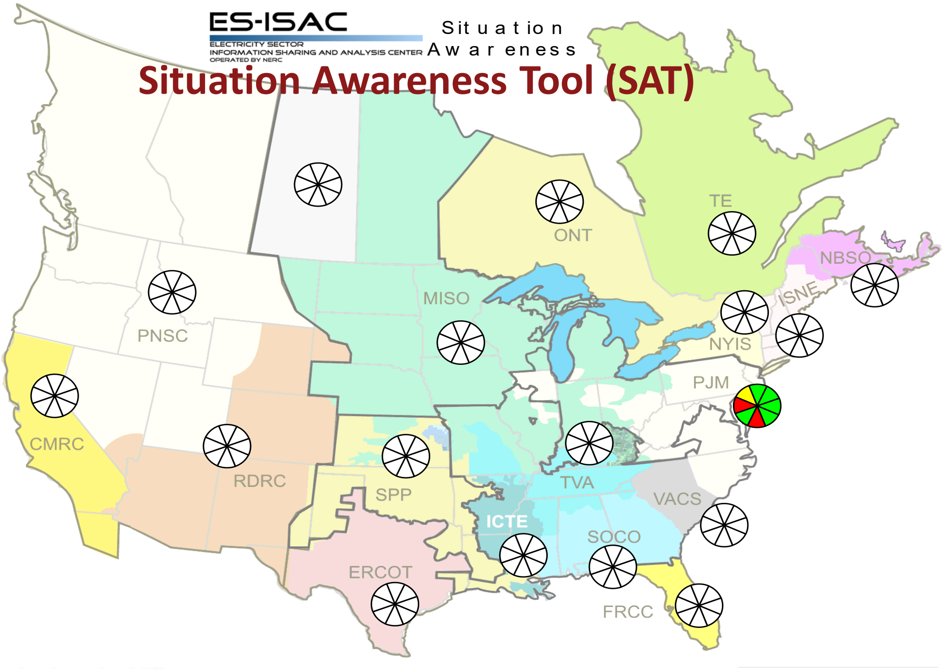
Fast Power Systems Risk Assessment

Doctoral Dissertation: Laurie Miller (June 2005-present)

ORNL contract, the U of MN start-up fund (2005-2008), and NSF grant (2008-2009), PI: Massoud Amin

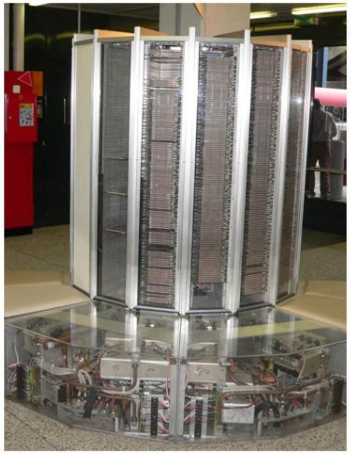
Connection Machine 2: $5 million in 1987, only a few dozen made

NVIDIA Tesla C870: $1300 in 2009, over 5 million sold



Situation Awareness Tool (SAT)

Fast Power Grid Simulation

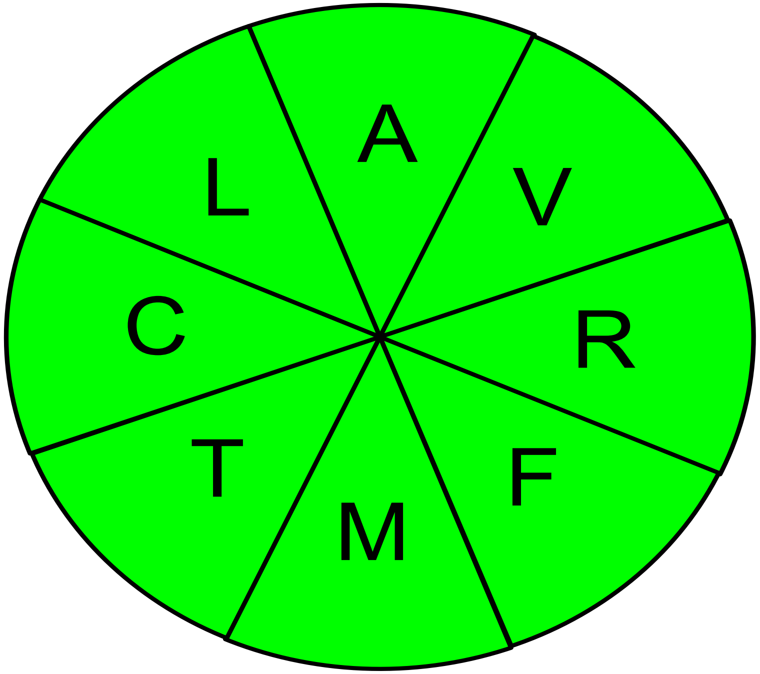


CRAY Supercomputer

Nvidia GeForce GPU card for PC

- Use Nvidia GeForce GPU card to gain 15 times faster power flow calculation on PC (Laurie Miller)

Situation Awareness Tool (SAT)

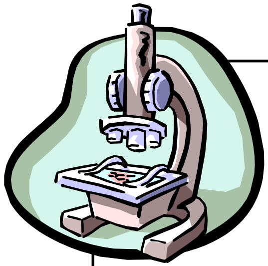


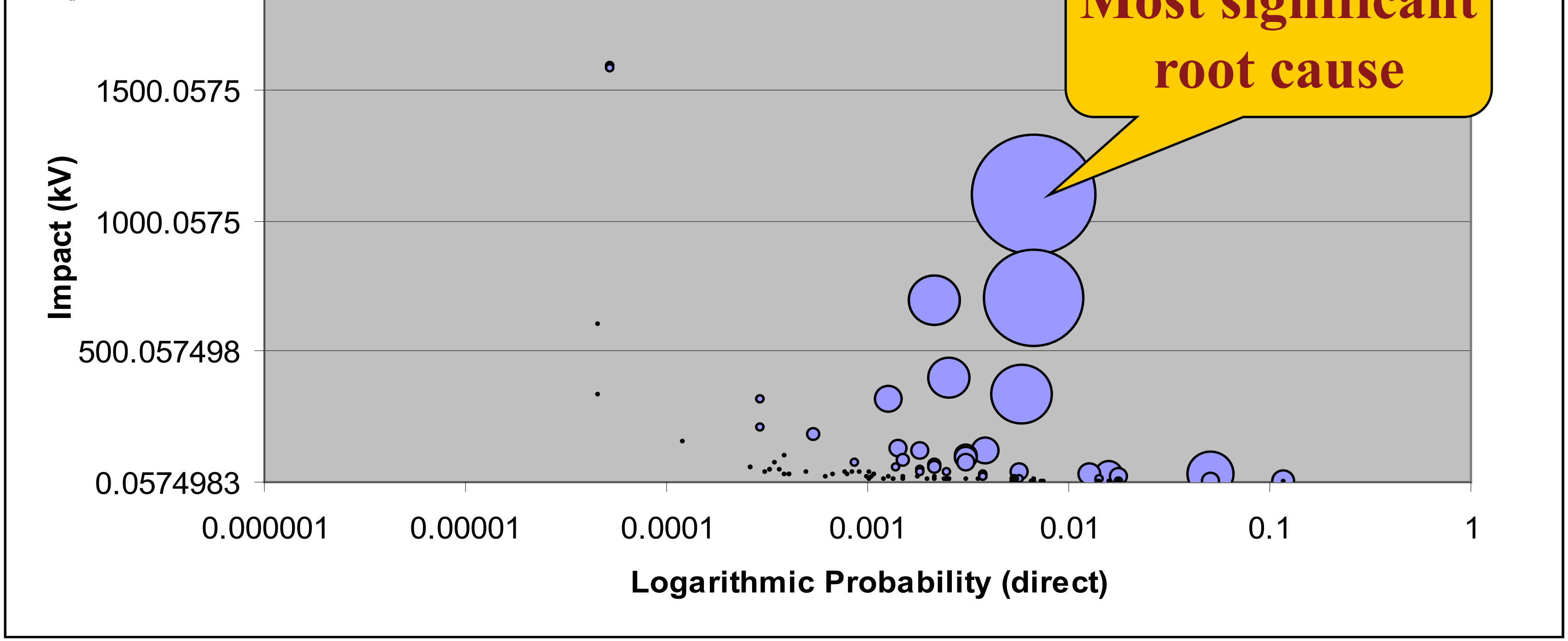
⬜ No “Telemetry” Data
🟩 Data Value Nominal
🟧 Data Value Approaching Warning
🟥 Data Value in Warning Range
🟨 Data value Returned to Normal

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

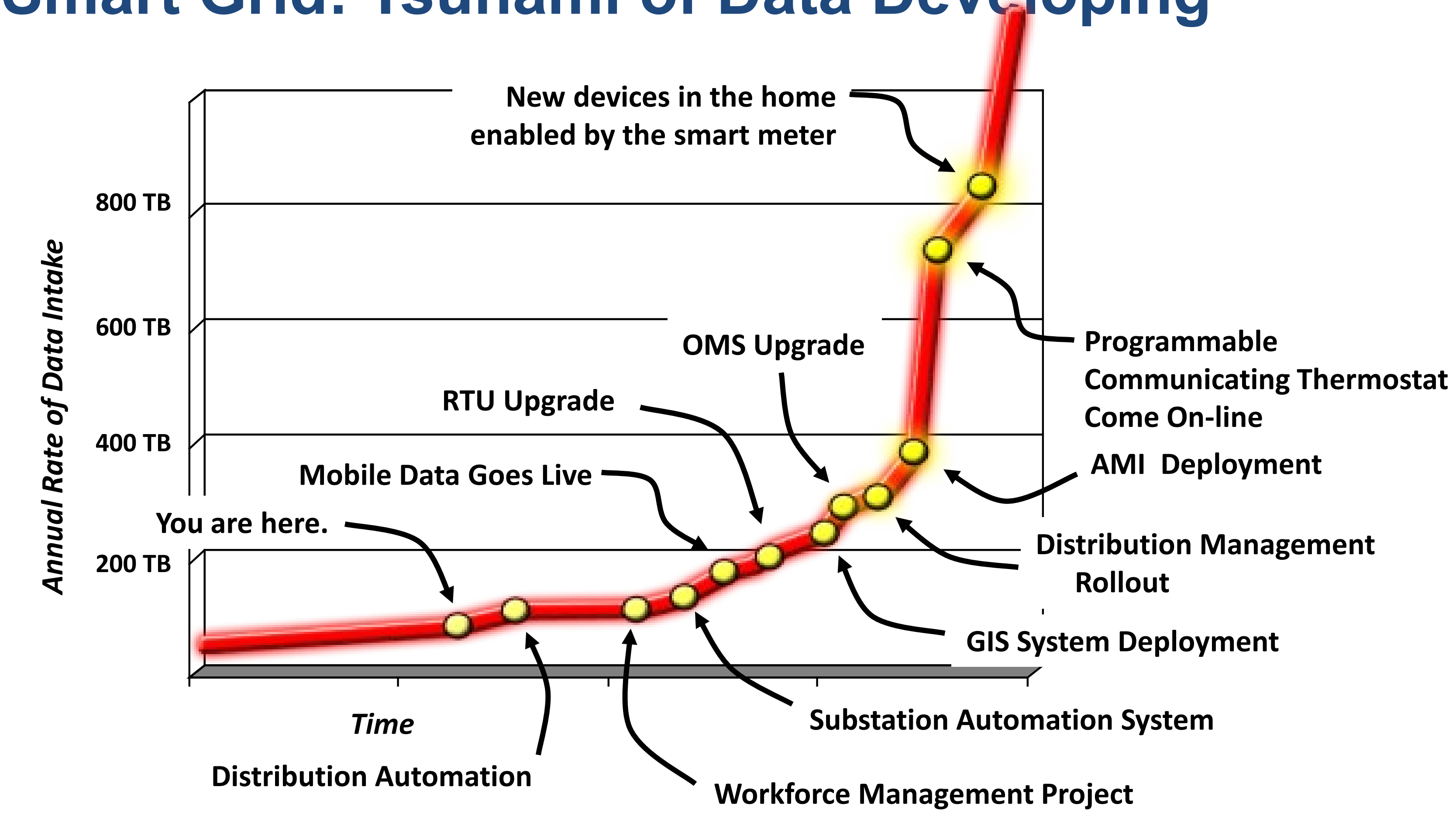
Example of In Depth Analysis: Critical Contingency Situations





Most significant root cause

Smart Grid: Tsunami of Data Developing



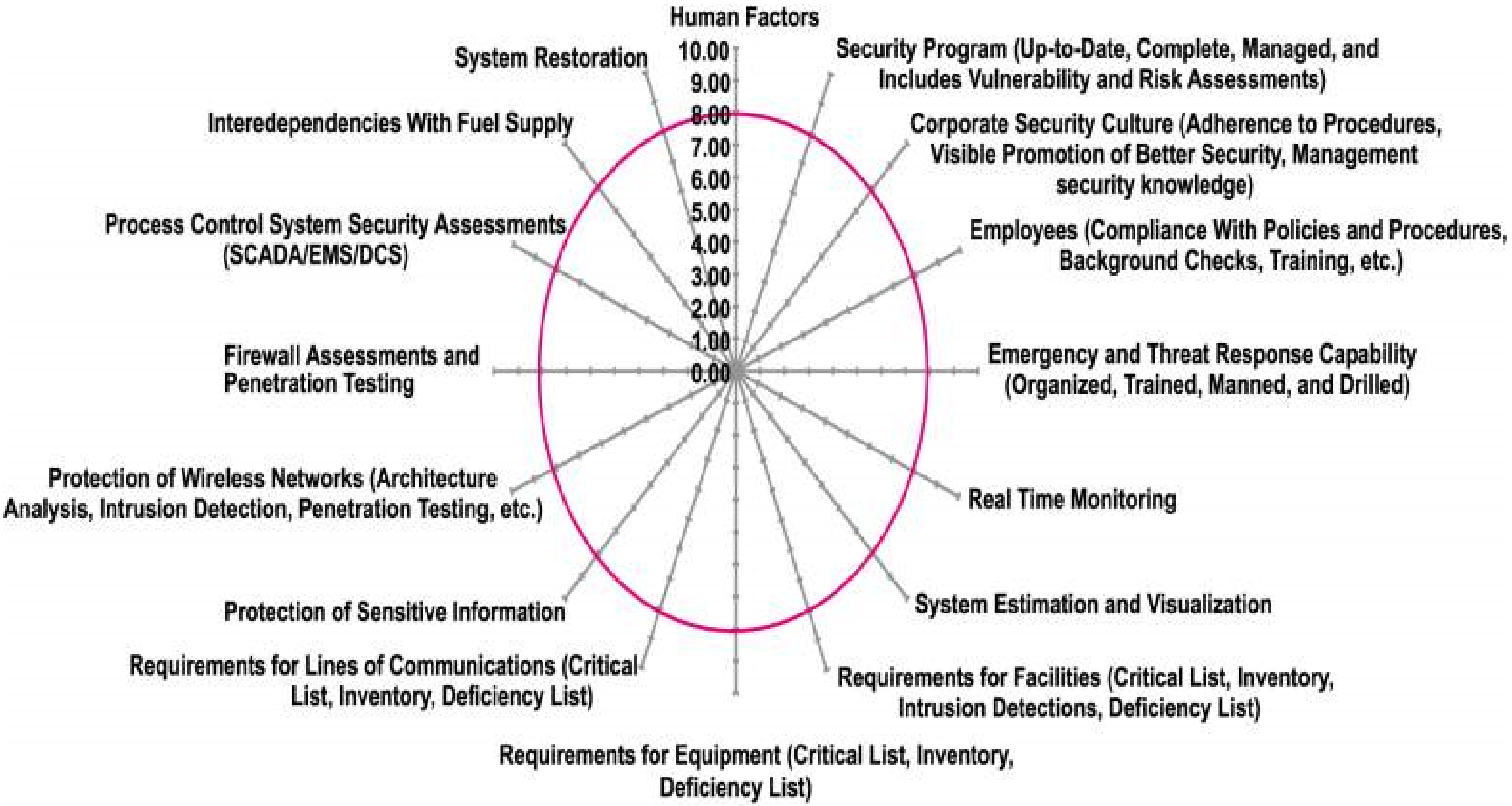
Tremendous amount of data coming from the field in the near future - paradigm shift for how utilities operate and maintain the grid

Prioritization: Security Index

General	Corporate culture
	Security Program
	Employees
	Emergency and threat response capability
Physical	Requirements for facilities, equipment and lines of communication
	Protection of sensitive information
Cyber and IT	Protection of wired and wireless networks
	Firewall assessments
	Process control system security assessments

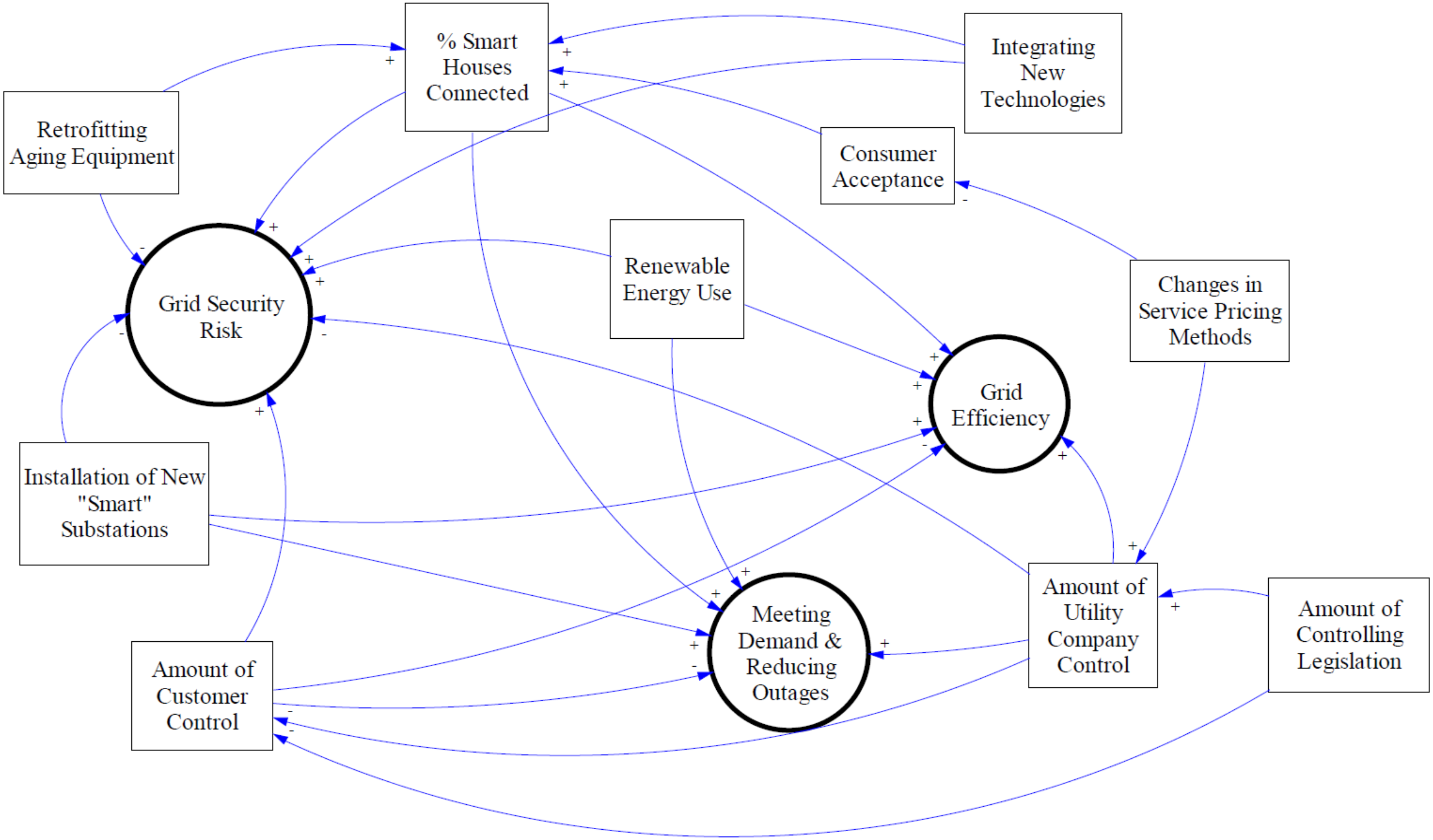
Assessment & Prioritization:

A Composite Spider Diagram to Display Security Indices



Smart Grid Interdependencies

Security, Efficiency, and Resilience



% Smart Houses Connected

Integrating New Technologies

Retrofitting Aging Equipment

Consumer Acceptance

Renewable Energy Use

Grid Security Risk

Changes in Service Pricing Methods

Grid Efficiency

Installation of New "Smart" Substations

Meeting Demand & Reducing Outages

Amount of Utility Company Control

Amount of Controlling Legislation

Amount of Customer Control

Fast Power Systems Risk Assessment

1987

Connection Machine 2

$5,000,000

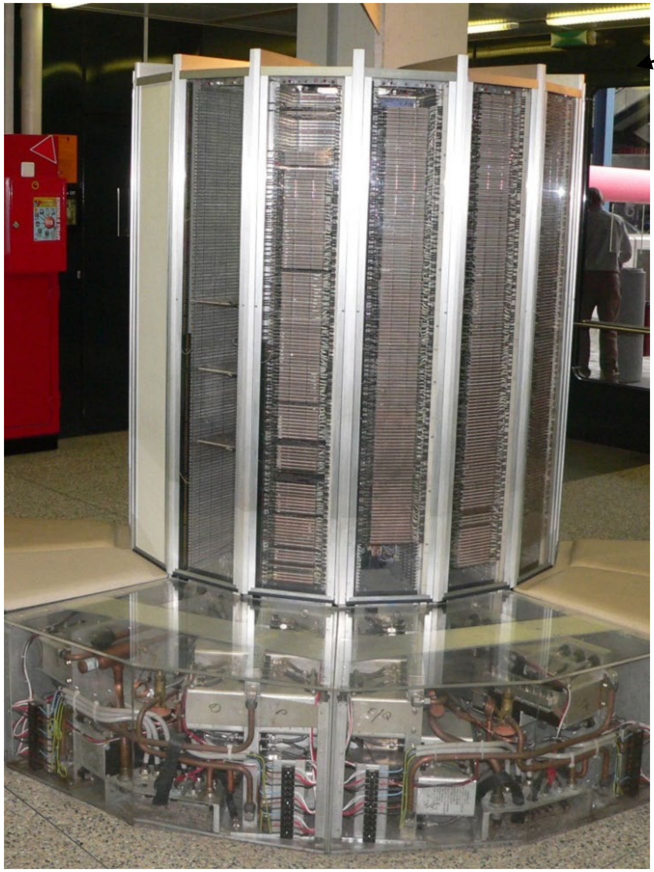
Only a dozen built

2010

$350

100 million sold

Fast Power Grid Simulation



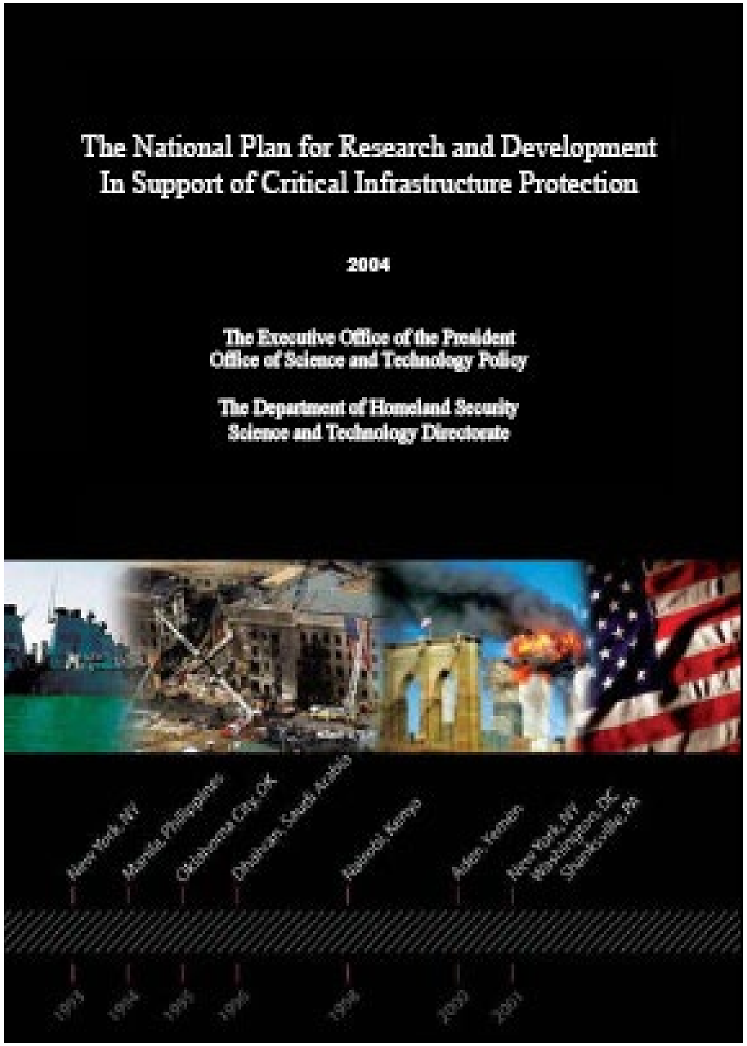
CRAY Supercomputer

Nvidia GeForce GPU card for PC

Use Nvidia GeForce GPU card to gain 15 times faster power flow calculation on PC

THE NATIONAL PLAN FOR RESEARCH AND DEVELOPMENT IN SUPPORT OF CIP

- The area of self-healing infrastructure has been recommended by the White House Office of Science and Technology Policy (OSTP) and the U.S. Department of Homeland Security (DHS) as one of three thrust areas for the National Plan for research and development in support of Critical Infrastructure Protection (CIP).

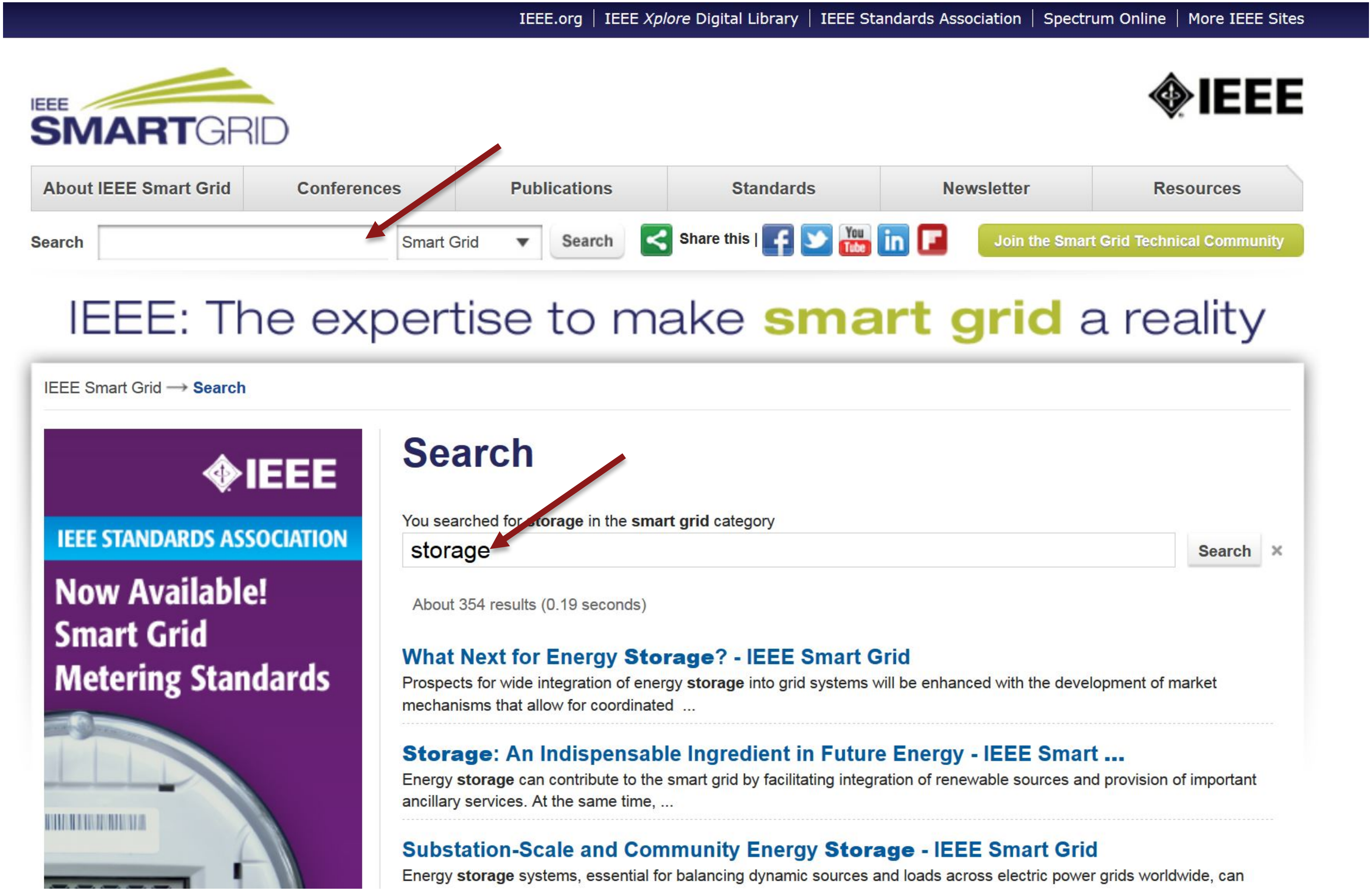


The National Plan for Research and Development
In Support of Critical Infrastructure Protection

2004

The Executive Office of the President
Office of Science and Technology Policy

The Department of Homeland Security
Science and Technology Directorate



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storage

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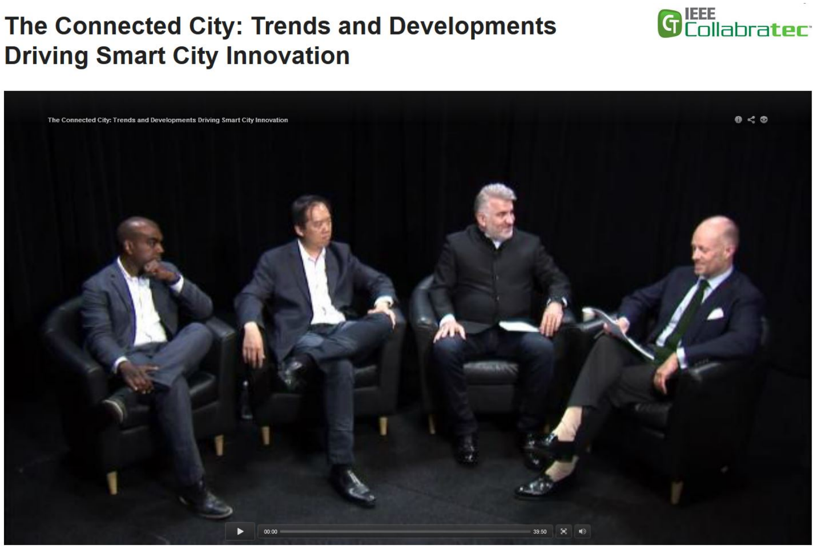
Energy **storage** systems, essential for balancing dynamic sources and loads across electric power grids worldwide, can

The Connected City: Trends and Developments Driving Smart City Innovation

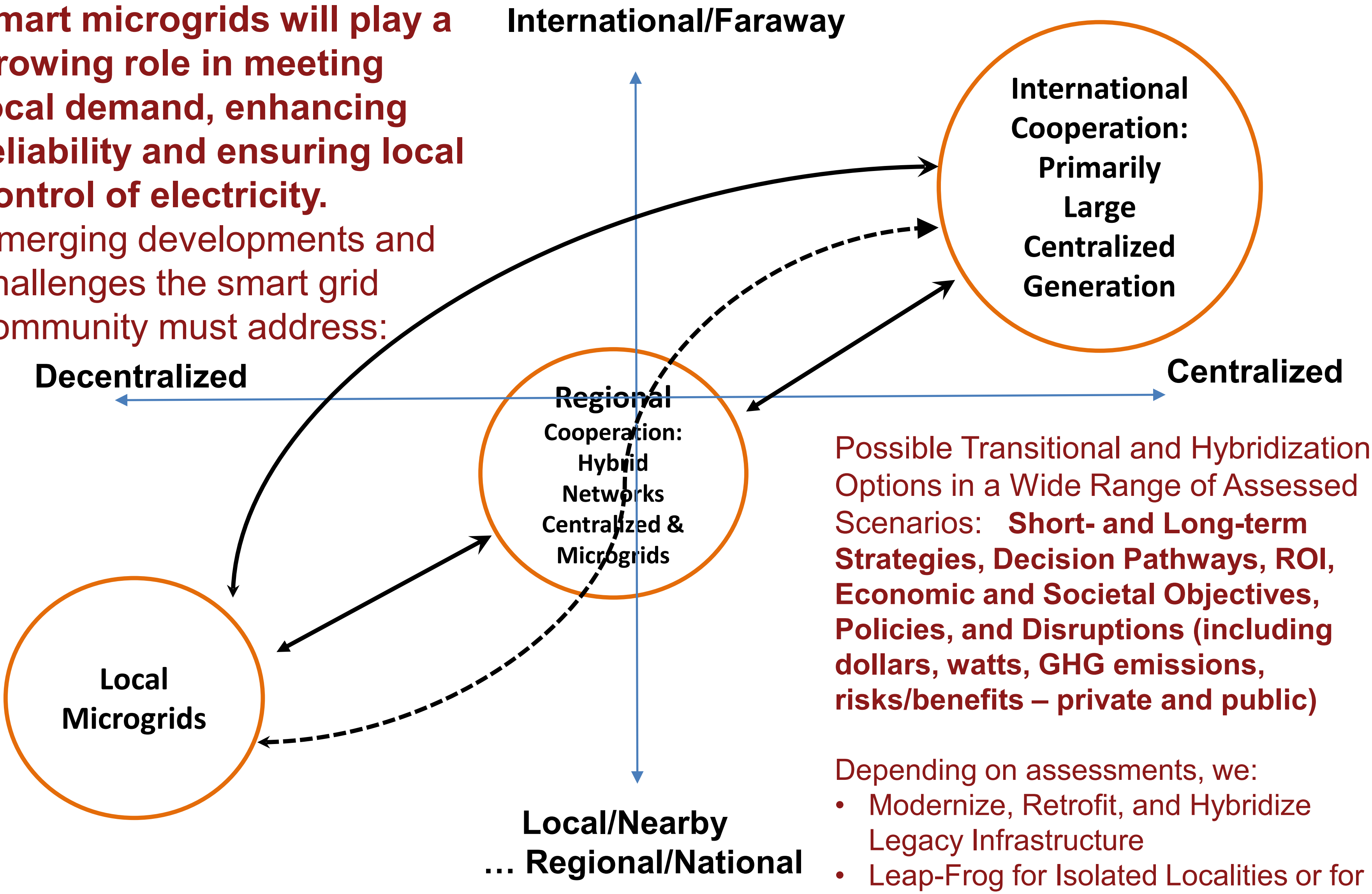
- A "Smart City" is more than just high-tech infrastructure - it's about advancing our society.

- Improving human condition and advancing the civilization that we often take for granted … As engineers, we enable better quality of life for people
- The whole idea of a smart city is not just about power or buildings. It's about the whole ecosystem--how you educate people, how you empower people, the economic growth it can bring and what opportunities it can bring.


The Connected City: Trends and Developments Driving Smart City Innovation

"The Connected City: Trends and Developments Driving Smart City Innovation," produced by MIT Technology Review and IEEE Collabratec…. vision, efficient use of technology, an environment that attracts a talented workforce, and an enabling infrastructure. Everything we do is geared towards that vision.

Over the next five years, **smart microgrids will play a growing role in meeting local demand, enhancing reliability and ensuring local control of electricity.** Emerging developments and challenges the smart grid community must address:



International/Faraway

Decentralized

Centralized

Local/Nearby
… Regional/National

International Cooperation: Primarily Large Centralized Generation

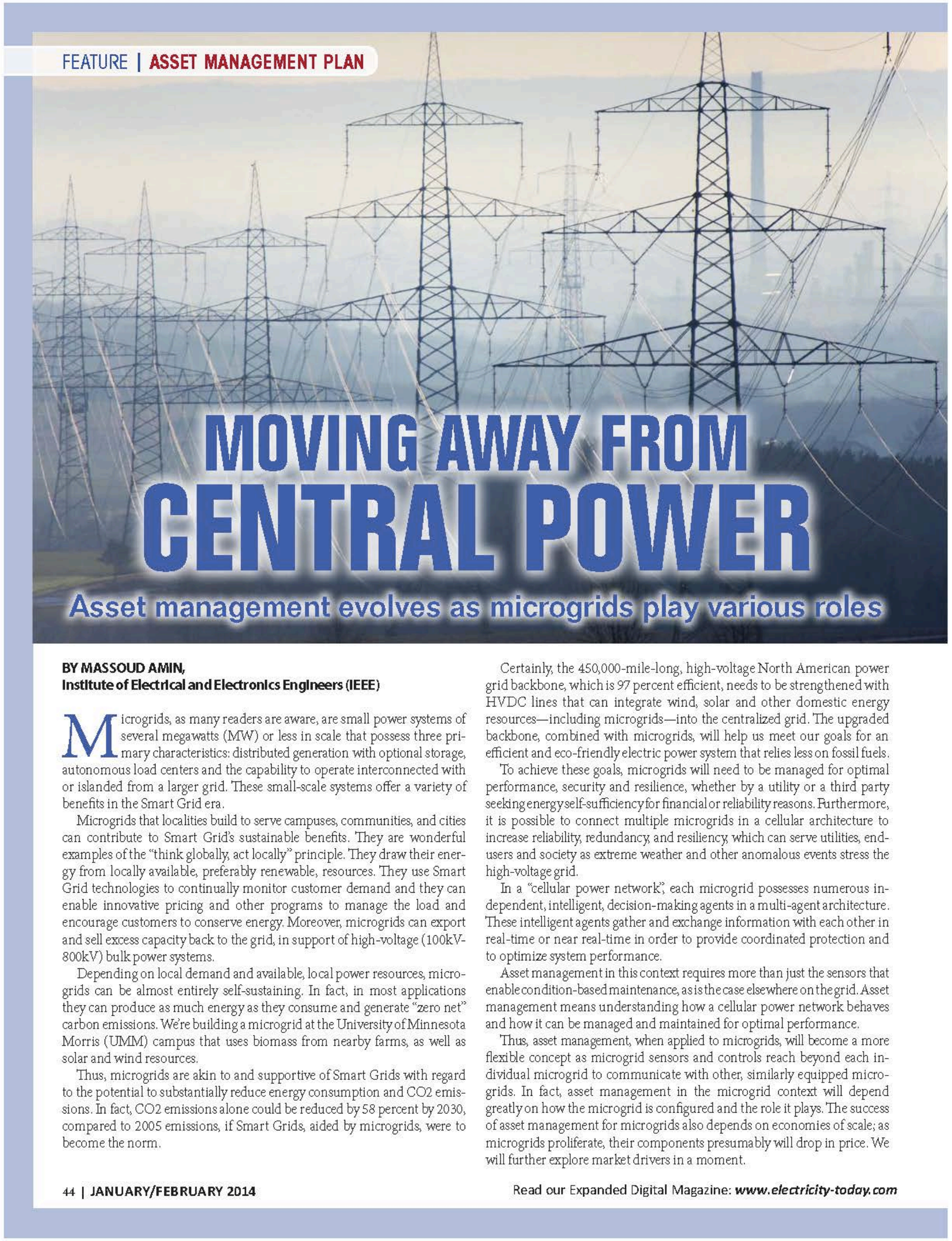
Regional Cooperation: Hybrid Networks Centralized & Microgrids

Local Microgrids

Possible Transitional and Hybridization Options in a Wide Range of Assessed Scenarios: **Short- and Long-term Strategies, Decision Pathways, ROI, Economic and Societal Objectives, Policies, and Disruptions (including dollars, watts, GHG emissions, risks/benefits – private and public)**

Depending on assessments, we:

- Modernize, Retrofit, and Hybridize Legacy Infrastructure
- Leap-Frog for Isolated Localities or for Clean Slate Designs



FEATURE | ASSET MANAGEMENT PLAN

MOVING AWAY FROM CENTRAL POWER

Asset management evolves as microgrids play various roles

BY MASSOUD AMIN,
Institute of Electrical and Electronics Engineers (IEEE)

Microgrids, as many readers are aware, are small power systems of several megawatts (MW) or less in scale that possess three primary characteristics: distributed generation with optional storage, autonomous load centers and the capability to operate interconnected with or islanded from a larger grid. These small-scale systems offer a variety of benefits in the Smart Grid era.

Microgrids that localities build to serve campuses, communities, and cities can contribute to Smart Grid's sustainable benefits. They are wonderful examples of the "think globally, act locally" principle. They draw their energy from locally available, preferably renewable, resources. They use Smart Grid technologies to continually monitor customer demand and they can enable innovative pricing and other programs to manage the load and encourage customers to conserve energy. Moreover, microgrids can export and sell excess capacity back to the grid, in support of high-voltage (100kV-800kV) bulk power systems.

Depending on local demand and available, local power resources, microgrids can be almost entirely self-sustaining. In fact, in most applications they can produce as much energy as they consume and generate "zero net" carbon emissions. We're building a microgrid at the University of Minnesota Morris (UMM) campus that uses biomass from nearby farms, as well as solar and wind resources.

Thus, microgrids are akin to and supportive of Smart Grids with regard to the potential to substantially reduce energy consumption and CO2 emissions. In fact, CO2 emissions alone could be reduced by 58 percent by 2030, compared to 2005 emissions, if Smart Grids, aided by microgrids, were to become the norm.

Certainly, the 450,000-mile-long, high-voltage North American power grid backbone, which is 97 percent efficient, needs to be strengthened with HVDC lines that can integrate wind, solar and other domestic energy resources—including microgrids—into the centralized grid. The upgraded backbone, combined with microgrids, will help us meet our goals for an efficient and eco-friendly electric power system that relies less on fossil fuels.

To achieve these goals, microgrids will need to be managed for optimal performance, security and resilience, whether by a utility or a third party seeking energy self-sufficiency for financial or reliability reasons. Furthermore, it is possible to connect multiple microgrids in a cellular architecture to increase reliability, redundancy, and resiliency, which can serve utilities, end-users and society as extreme weather and other anomalous events stress the high-voltage grid.

In a "cellular power network", each microgrid possesses numerous independent, intelligent, decision-making agents in a multi-agent architecture. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

Asset management in this context requires more than just the sensors that enable condition-based maintenance, as is the case elsewhere on the grid. Asset management means understanding how a cellular power network behaves and how it can be managed and maintained for optimal performance.

Thus, asset management, when applied to microgrids, will become a more flexible concept as microgrid sensors and controls reach beyond each individual microgrid to communicate with other, similarly equipped microgrids. In fact, asset management in the microgrid context will depend greatly on how the microgrid is configured and the role it plays. The success of asset management for microgrids also depends on economies of scale; as microgrids proliferate, their components presumably will drop in price. We will further explore market drivers in a moment.

"locality" for an autonomous microgrid implies that it operates with maximum independence from other microgrids and minimal interdependencies. To place this notion of autonomy in context: a cellular power network is a large-scale dynamic-topology power network composed of autonomous microgrids that each exhibit self-similar properties to enable scale-up, but which can default to locality to continue functioning if and when other microgrids in the network fail.

The architecture for the autonomous microgrids and microgrid assemblies being modeled in my research is based on a multi-agent architecture for operating cellular power networks. In the architecture, each autonomous microgrid, and resulting cellular power network, is composed of numerous independent, intelligent, decision-making agents. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

We have tested microgrids that incorporate a dynamical systems perspective of threat and uncertainty to investigate the performance of the multi-agent architecture for autonomous microgrids and microgrid assemblies as part of cellular power networks. As opposed to the computer science perspective that focuses on securing information, the focus of this work is on analyzing the actions or dynamics of network components and their overall management. The goal of such assessments is to determine the expected performance of such systems, including the effects of failure, repair, contention for resources, attacks and other uncertainties. Again, asset management in this fluid, network environment must remain a flexible concept.

Simulation models capture detailed system behavior, but they require a great deal of time to run. Analytical models, in contrast, create an abstraction of the system, but once set up, they make it easier and faster to carry out trade-off studies, perform sensitivity analyses, and compare design alternatives.

CURRENT RESEARCH

Research that serves the Smart Grid will also benefit microgrids. During the past two decades, my research efforts have focused on a better understanding of the true dynamics of complex and interdependent energy and communications networks and their economics in order to enable stronger, greener, more secure and smarter power grids—whether they're large and centralized or small and local in nature, such as microgrids.

Our on-going R&D projects include work on distribution system automation, security and resilience, smart power delivery and utilization systems and cyber-physical security. Of particular relevance to microgrids, we also have a project focused on security analyses of autonomous microgrids which includes analysis, modeling, and simulation of failure scenarios and development of attack-resistant architectures.

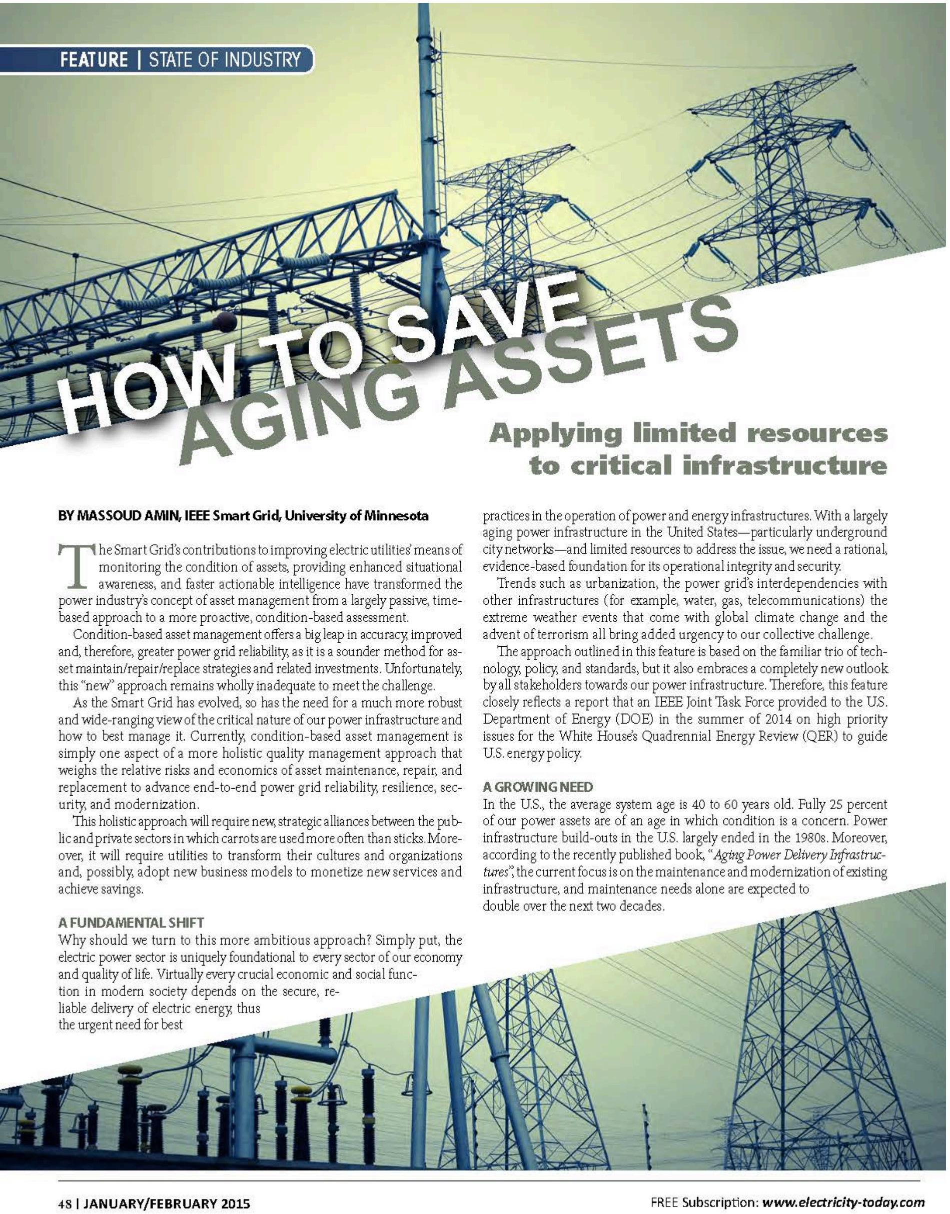
The objective of this cluster of projects is to model, design, and develop reconfigurable and distributed smart energy systems supported by secure sensing/wireless communication network overlay and fault-resilient, real-time controls. The results will aid in the development of Smart Grids and microgrids.

In fact, university microgrid projects offer very practical environments for testing Smart Grid systems. Our Smart Grid Assessments for communities at the UMM campus and UMore Park is a case in point. Building and managing our own microgrid provides direct experience on microgrid management and it serves as a test bed for consumer- and community-scale Smart Grid-related innovations. These projects engage faculty, postdoctoral students, researchers, undergraduates, and consumers from across the local community, as well as utilities from a wider Smart Grid coalition in Minnesota.

FAMOUS LAST WORDS

Recent disruptions of high-voltage grids and traditional distribution systems—Hurricane Sandy's first anniversary just passed—illustrates that if electricity supplies were not so dependent purely on centralized power plants and assets, and on the one-way flow of electrons and information, then customers would experience greater electrical reliability. That, in a nutshell, is the promise of microgrids. ET

Dr. Massoud Amin directs the Technological Leadership Institute (TLI) at the University of Minnesota. At TLI, Dr. Amin leads university staff and faculty, in conjunction with industry executives and government officials, to develop local and global leaders for over 400 technology enterprises.



FEATURE | STATE OF INDUSTRY

HOW TO SAVE AGING ASSETS

Applying limited resources to critical infrastructure

BY MASSOUD AMIN, IEEE Smart Grid, University of Minnesota

The Smart Grid's contributions to improving electric utilities' means of monitoring the condition of assets, providing enhanced situational awareness, and faster actionable intelligence have transformed the power industry's concept of asset management from a largely passive, time-based approach to a more proactive, condition-based assessment.

Condition-based asset management offers a big leap in accuracy, improved and, therefore, greater power grid reliability, as it is a sounder method for asset maintain/repair/replace strategies and related investments. Unfortunately, this "new" approach remains wholly inadequate to meet the challenge.

As the Smart Grid has evolved, so has the need for a much more robust and wide-ranging view of the critical nature of our power infrastructure and how to best manage it. Currently, condition-based asset management is simply one aspect of a more holistic quality management approach that weighs the relative risks and economics of asset maintenance, repair, and replacement to advance end-to-end power grid reliability, resilience, security, and modernization.

This holistic approach will require new, strategic alliances between the public and private sectors in which carrots are used more often than sticks. Moreover, it will require utilities to transform their cultures and organizations and, possibly, adopt new business models to monetize new services and achieve savings.

A FUNDAMENTAL SHIFT

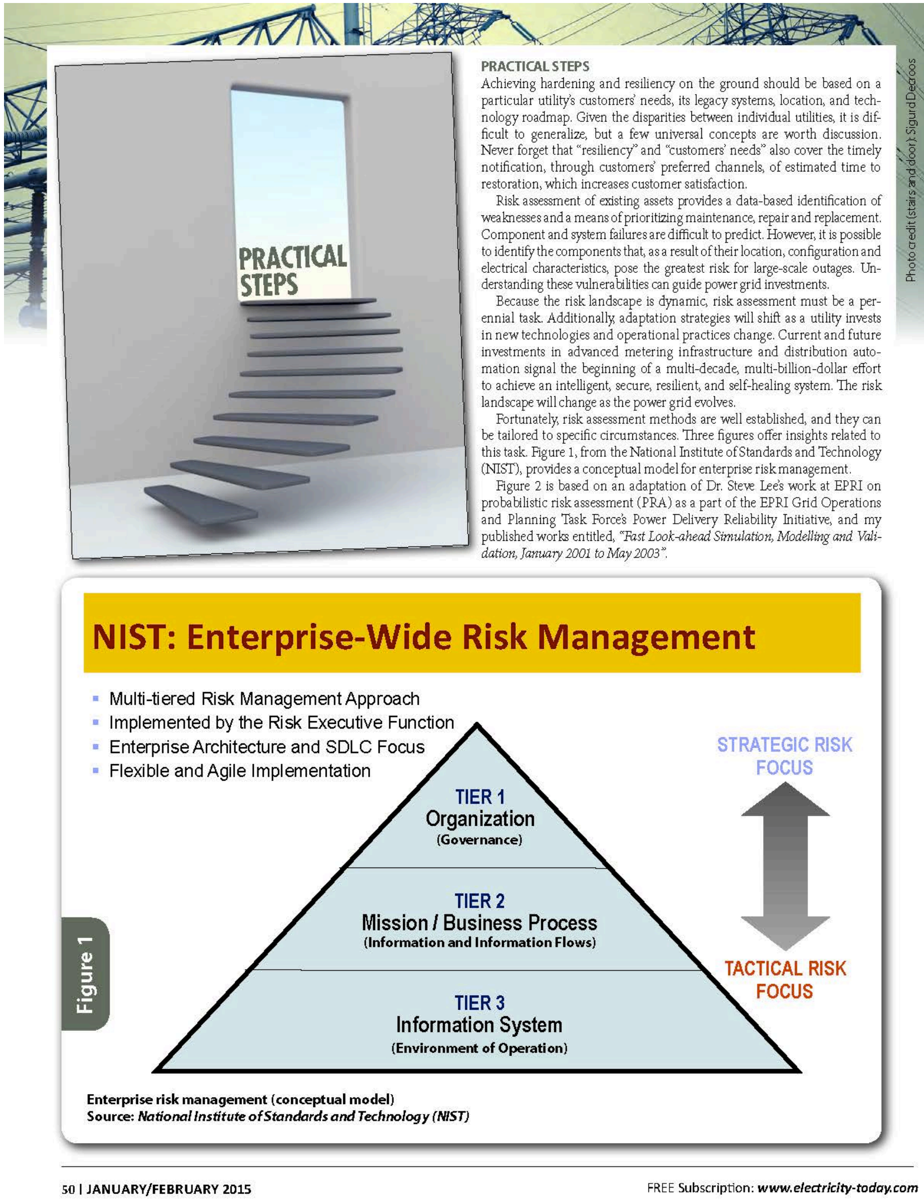
Why should we turn to this more ambitious approach? Simply put, the electric power sector is uniquely foundational to every sector of our economy and quality of life. Virtually every crucial economic and social function in modern society depends on the secure, reliable delivery of electric energy, thus the urgent need for best practices in the operation of power and energy infrastructures. With a largely aging power infrastructure in the United States—particularly underground city networks—and limited resources to address the issue, we need a rational, evidence-based foundation for its operational integrity and security.

Trends such as urbanization, the power grid's interdependencies with other infrastructures (for example, water, gas, telecommunications) the extreme weather events that come with global climate change and the advent of terrorism all bring added urgency to our collective challenge.

The approach outlined in this feature is based on the familiar trio of technology, policy, and standards, but it also embraces a completely new outlook by all stakeholders towards our power infrastructure. Therefore, this feature closely reflects a report that an IEEE Joint Task Force provided to the U.S. Department of Energy (DOE) in the summer of 2014 on high priority issues for the White House's Quadrennial Energy Review (QER) to guide U.S. energy policy.

A GROWING NEED

In the U.S., the average system age is 40 to 60 years old. Fully 25 percent of our power assets are of an age in which condition is a concern. Power infrastructure build-outs in the U.S. largely ended in the 1980s. Moreover, according to the recently published book, "*Aging Power Delivery Infrastructures*", the current focus is on the maintenance and modernization of existing infrastructure, and maintenance needs alone are expected to double over the next two decades.



PRACTICAL STEPS

Achieving hardening and resiliency on the ground should be based on a particular utility's customers' needs, its legacy systems, location, and technology roadmap. Given the disparities between individual utilities, it is difficult to generalize, but a few universal concepts are worth discussion. Never forget that "resiliency" and "customers' needs" also cover the timely notification, through customers' preferred channels, of estimated time to restoration, which increases customer satisfaction.

Risk assessment of existing assets provides a data-based identification of weaknesses and a means of prioritizing maintenance, repair and replacement. Component and system failures are difficult to predict. However, it is possible to identify the components that, as a result of their location, configuration and electrical characteristics, pose the greatest risk for large-scale outages. Understanding these vulnerabilities can guide power grid investments.

Because the risk landscape is dynamic, risk assessment must be a perennial task. Additionally, adaptation strategies will shift as a utility invests in new technologies and operational practices change. Current and future investments in advanced metering infrastructure and distribution automation signal the beginning of a multi-decade, multi-billion-dollar effort to achieve an intelligent, secure, resilient, and self-healing system. The risk landscape will change as the power grid evolves.

Fortunately, risk assessment methods are well established, and they can be tailored to specific circumstances. Three figures offer insights related to this task. Figure 1, from the National Institute of Standards and Technology (NIST), provides a conceptual model for enterprise risk management.

Figure 2 is based on an adaptation of Dr. Steve Lee's work at EPRI on probabilistic risk assessment (PRA) as a part of the EPRI Grid Operations and Planning Task Force's Power Delivery Reliability Initiative, and my published works entitled, "*Fast Look-ahead Simulation, Modelling and Validation, January 2001 to May 2003*".

Photo credit (stairs and door): Sigurd Decroos

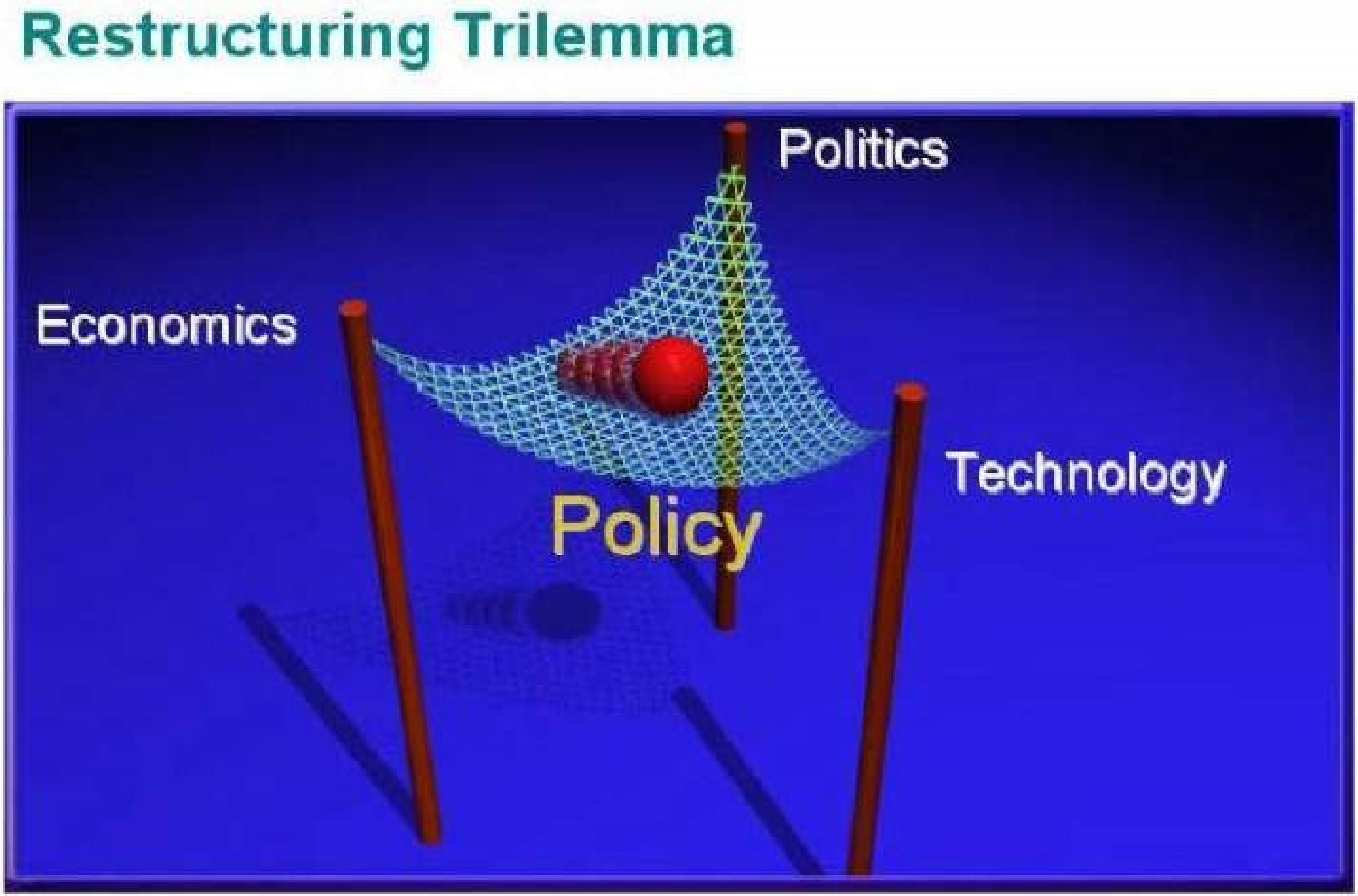
Figure 1

NIST: Enterprise-Wide Risk Management

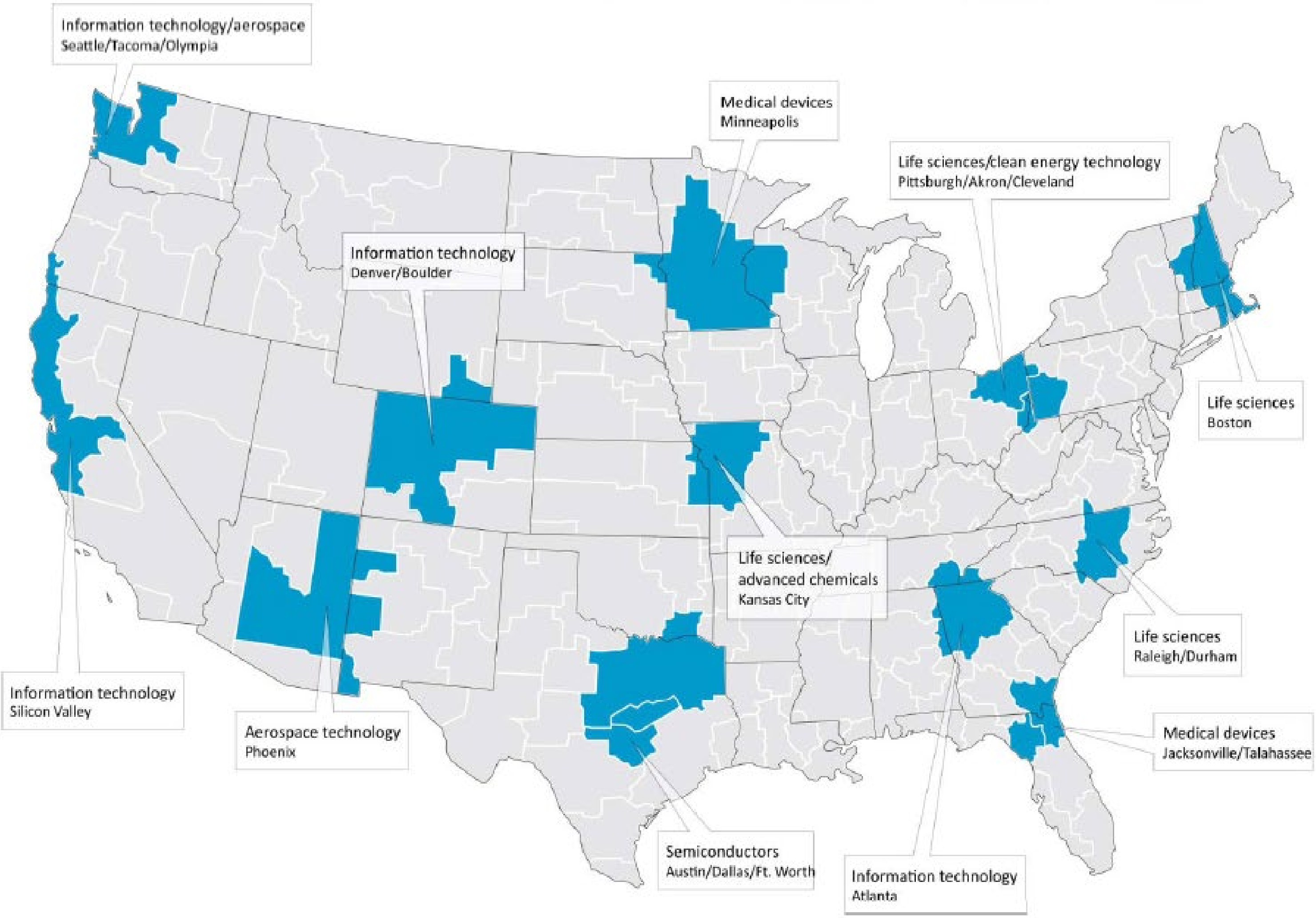
- Multi-tiered Risk Management Approach
- Implemented by the Risk Executive Function
- Enterprise Architecture and SDLC Focus
- Flexible and Agile Implementation

Enterprise risk management (conceptual model)
Source: ***National Institute of Standards and Technology (NIST)***

Unresolved Issues Cloud Planning for the Future



“Geography of Innovation*”



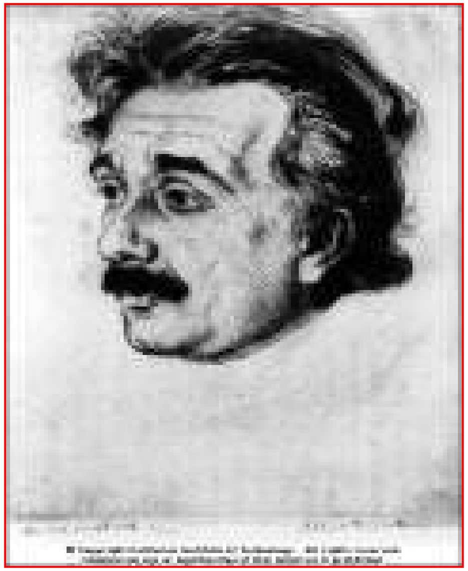
*Source: Cluster Mapping Project, Institute for Strategy & Competitiveness, Harvard Business School

Global Transition Dynamics: Integrated Systems Science for Understanding of Full Impacts of Decision Pathways

Electrification provides the essential foundation to transform global economies for sustainable development.

Albert Einstein's Advice for Scientists … on Intellectual Pursuits

"Concern for man himself and his fate must always constitute the chief objective of all technological endeavors… in order that the creations of our mind shall be a blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations."



(from address at Cal. Tech. On February 16, 1931; quoted in NYT, February 17 and 22, 1931; and page 247 of Calaprice's book)