Our Nation's Energy Infrastructure:
Toward Stronger and Smarter Grid

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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.

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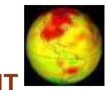
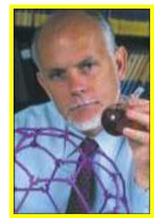
What Lies Ahead?

The world faces enormous challenges and opportunities – 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

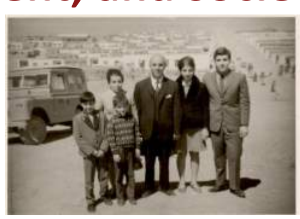




Rick Smalley, Rice U.
(1943-2005)
Nobel Prize 1996
"CIVIC SCIENTIST"

Observations on electrification, economic development, and societal transformation

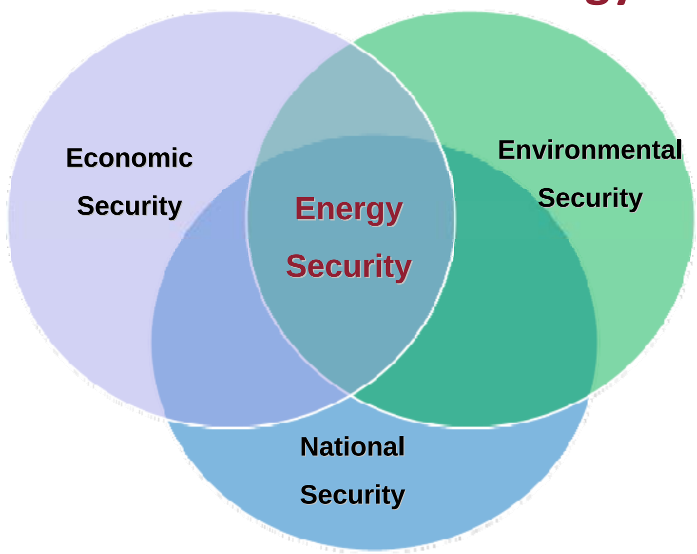
My father at the Mayo Clinic (pictured in Lake City, Minnesota on January 2, 1952)



Near Persepolis, Iran, March 1967

Minnesota, January 2005

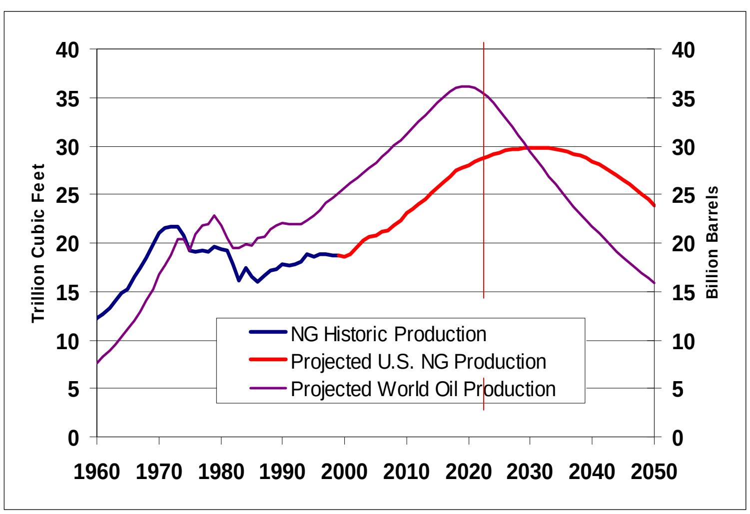
The Energy Nexus
What we've learned from Energy Crises



Source: RAND

Supply Considerations

Estimates of World Conventional Oil Production & U.S. Natural Gas Production

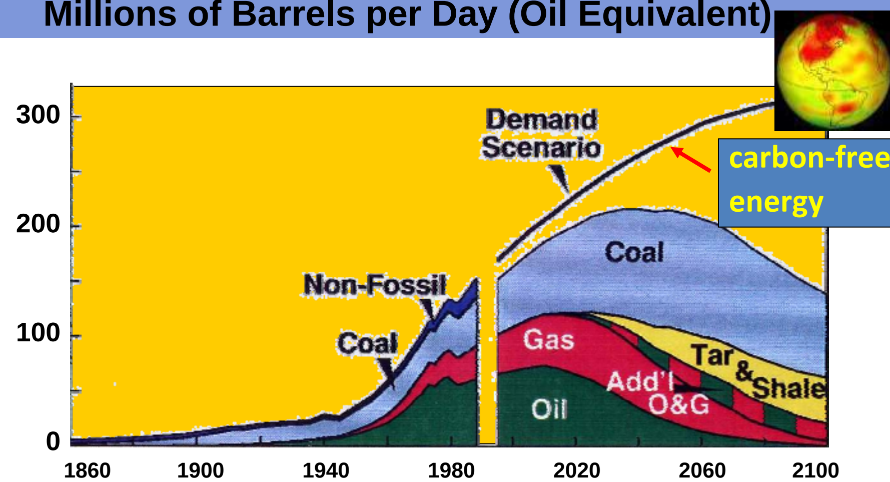


Source: U.S. Department of Energy

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).

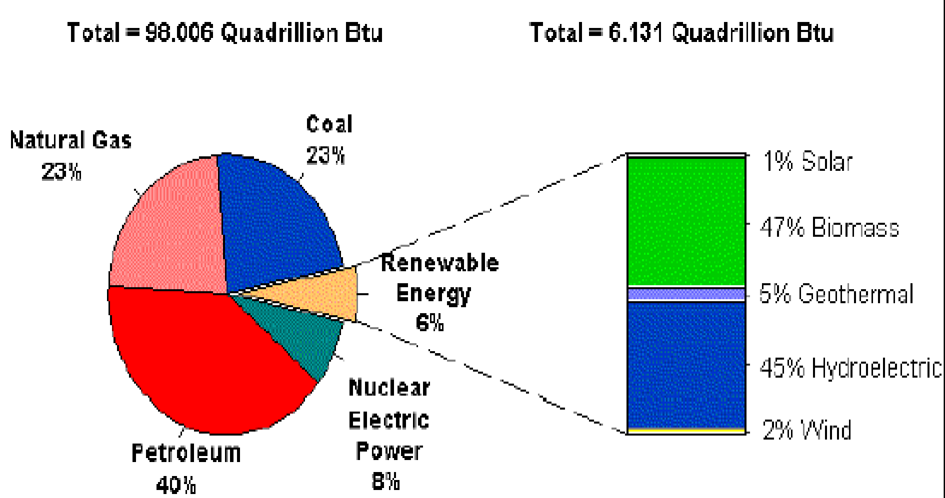
Goals and Recommendations (IEEE, Jan. 2009)

- **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**

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
  - Device monitoring and self-healing diagnostics
  - Communication infrastructure provides opportunities for monitoring and diagnostics
  - Distributed Sensing and Control
  - Alternative Smart Grid Architectures
  - Infrastructure Security: Controls, Communications and Cyber Security
  - Markets and Policy
  - Distributed generation and storage adds complexity

U.S. Energy Sources



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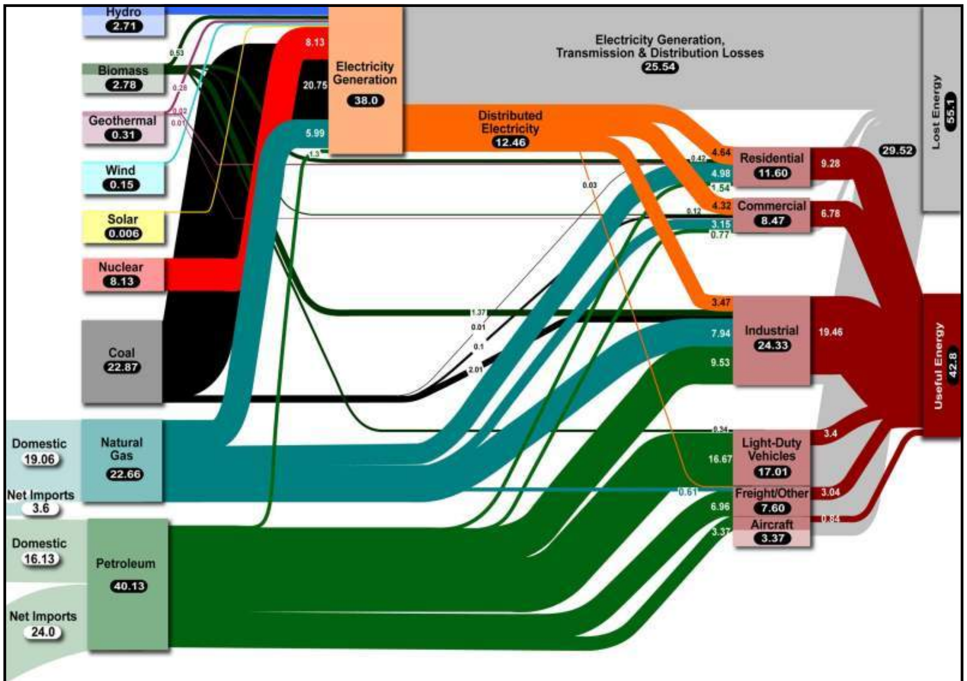
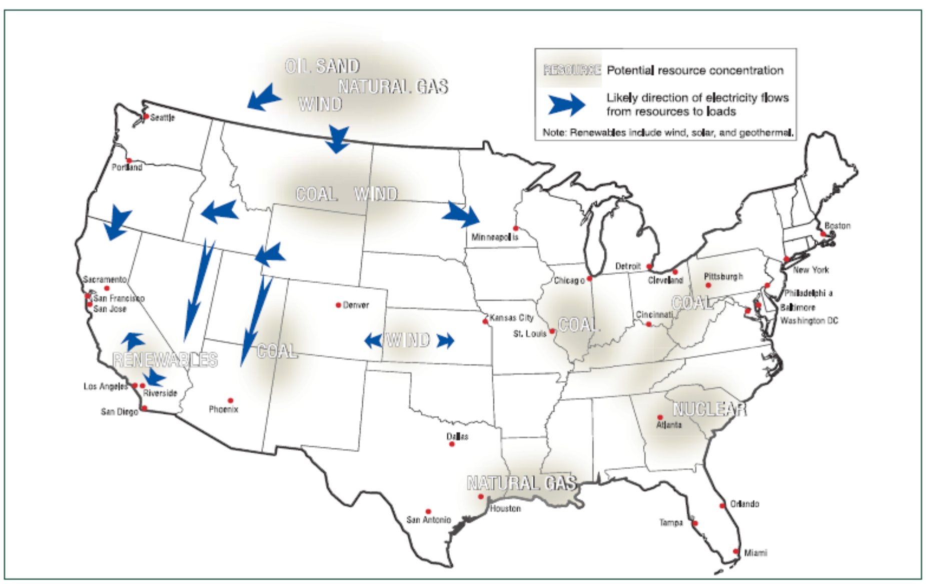


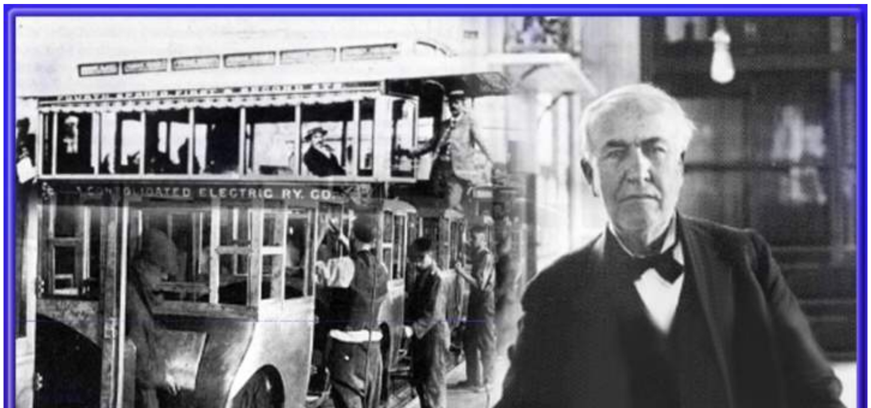
Energy map adapted from the U.S. DOE and LBNL

Context: New patterns in power delivery



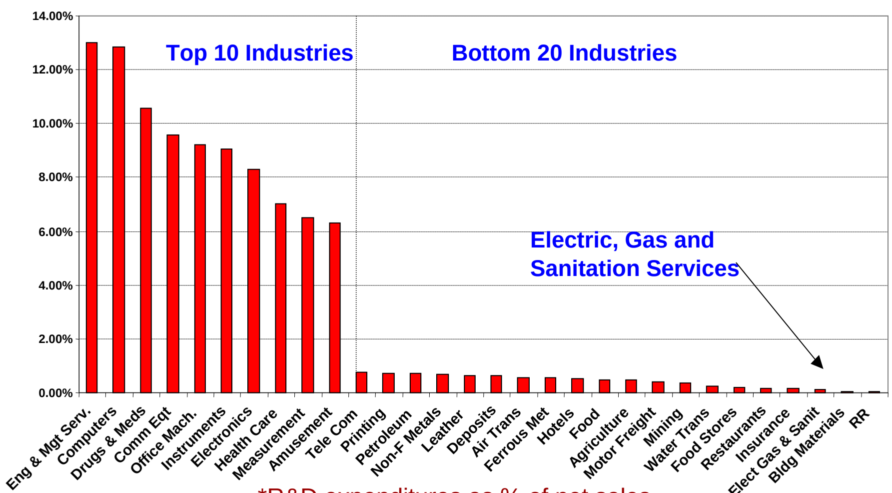
Map adapted from the U.S. DOE National Electric Transmission Congestion Study

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*

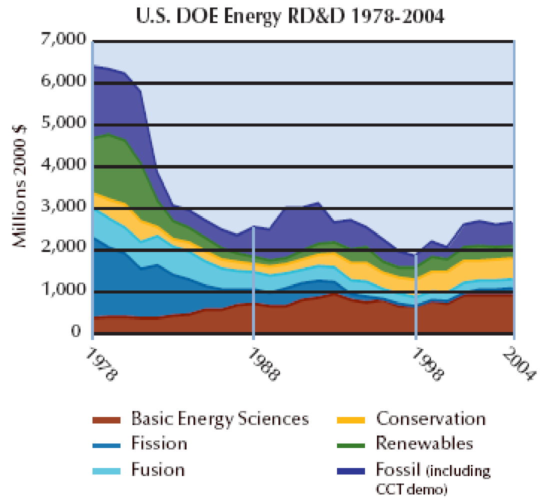


*R&D expenditures as % of net sales

Declining Public Support for Energy RD&D during the 25-years 1978-2004

•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.

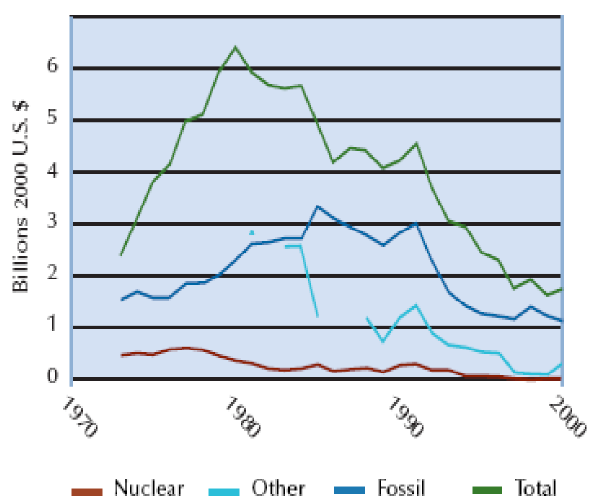
•The part of these appropriations devoted to applied energy-technology RD&D fell from $6.08 B to $1.80B.



Gallagher and Sagar, 2004

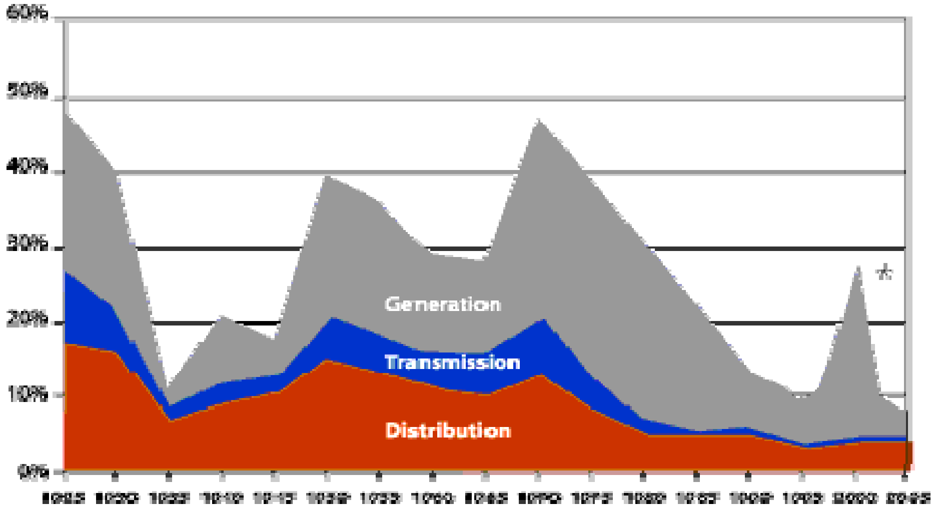
Private Sector Energy RD&D

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



Dooley and Runci, 2004

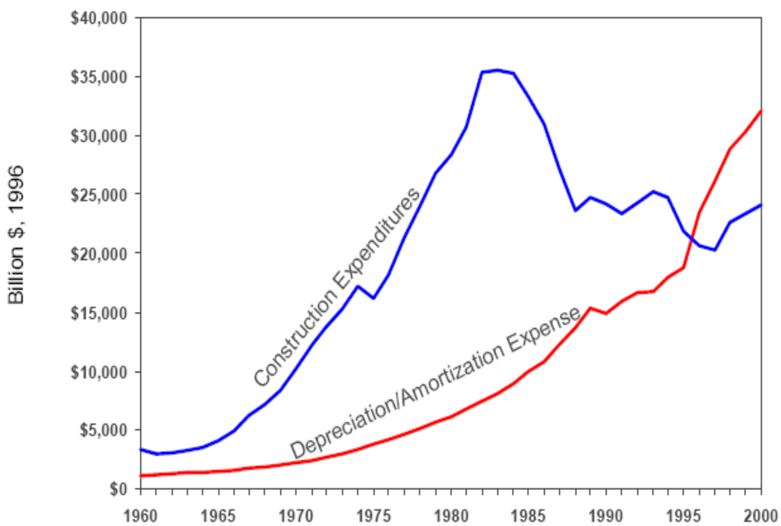
Capital Invested as % of electricity revenue



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

Capital invested as % of electricity revenues

Utility construction expenditures



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

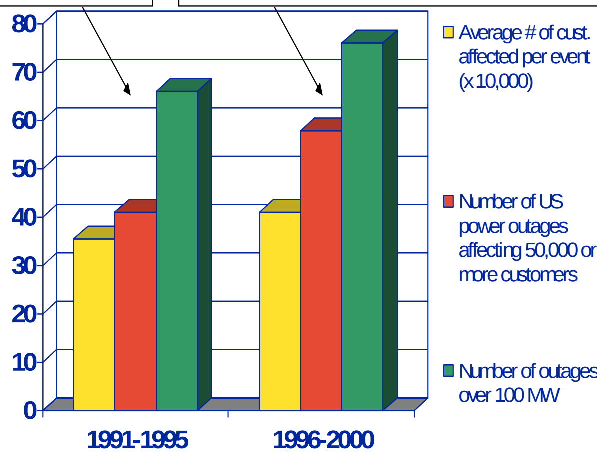
Historical Analysis of U.S. outages (1991-2000)

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

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

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

Data courtesy of NERC's Disturbance Analysis Working Group database



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

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

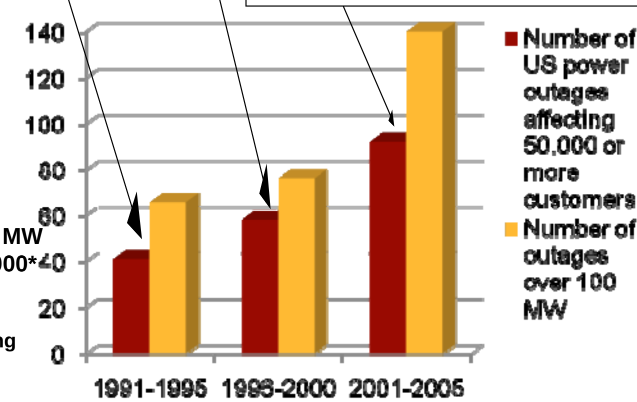
66 Occurrences over 100 MW
41 Occurrences over 50,000* Consumers

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

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

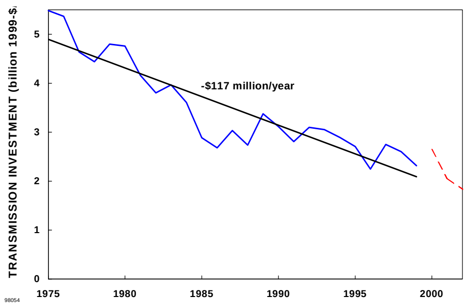
Result: Large blackouts are growing in number and severity.

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

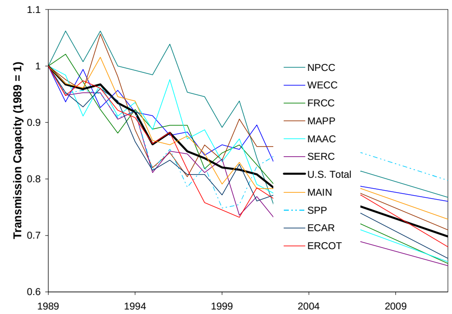


*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

Increasing Outage Events: Transmission Investment



Transmission *investment* ($) since 1975



Transmission *capacity margin* in every NERC region since 1982

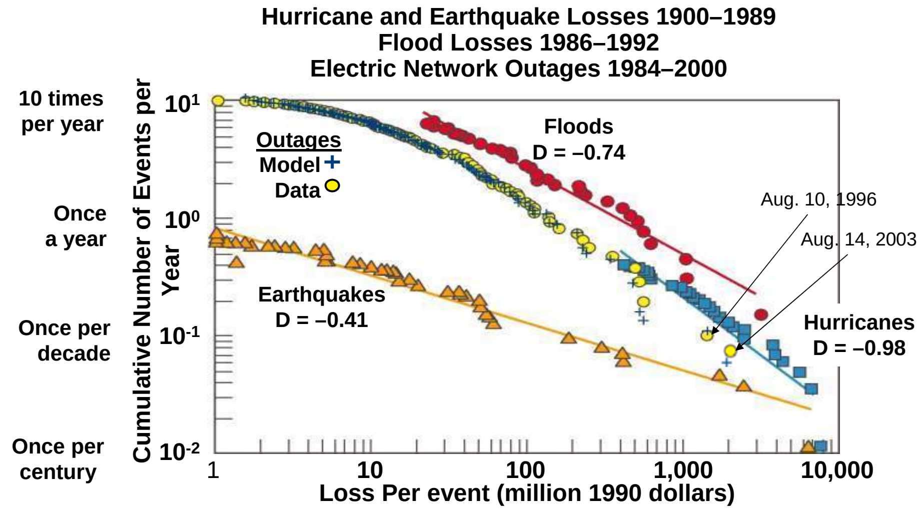
Transmission investment lags load growth and will remain very difficult in the future due to environmental, political, and cost issues.

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

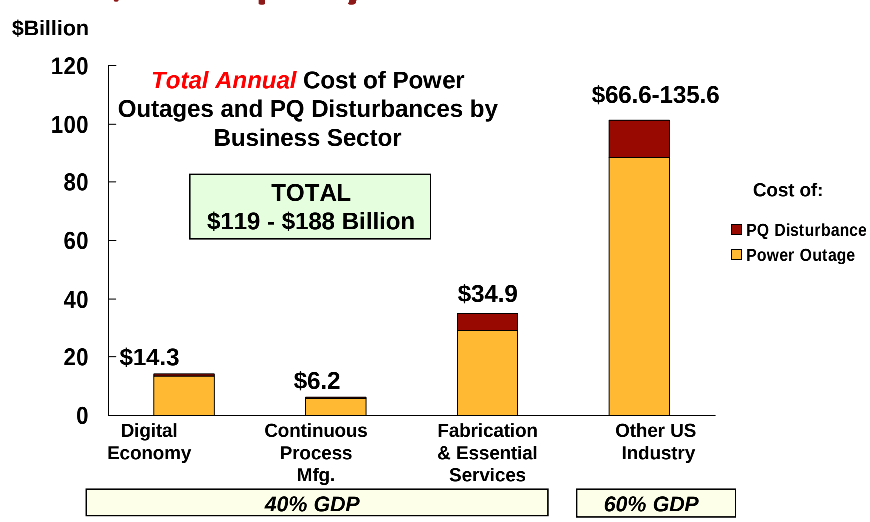
Country	Investment in High Voltage Transmission (>230 kV) Normalized by Load for 2004–2008 (in US$M/GW/year)	Number of Transmission-Owning Entities
New Zealand	22.0	1
England & Wales (NGT)	16.5	1
Denmark	12.5	2
Spain	12.3	1
The Netherlands	12.0	1
Norway	9.2	1
Poland	8.6	1
Finland	7.2	1
United States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

Source: IEEE PES, 2006

Power Law Distributions: Frequency & impacts of major disasters



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



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

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.

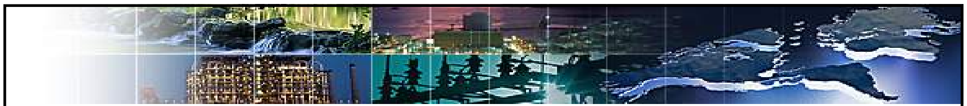
- *2) Investment Challenge*: Long-distance interstate routing, or "wheeling," of power, much encouraged by the federal government, has put the existing transmission network, largely built in the 1970 and 1980s in a time of sovereign utilities, under great stress. Money spent by power companies on research 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.



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 intel. & 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

Recent Directions: EPRI/DOD Complex Interactive Network/Systems Initiative

> **"We are sick and tired of them and they had better change!"**
> ***Chicago Mayor Richard Daley on the August 1999 Blackout***

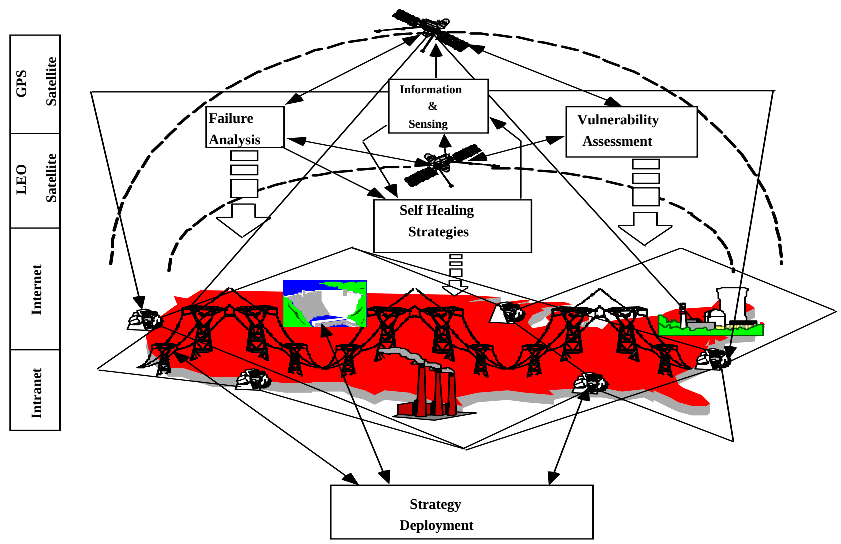
Complex interactive networks:

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

1999-2001: $5.2M / year —
Equally Funded by DoD/EPRI

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

Complex Interactive Networks



CIN/SI Funded Consortia

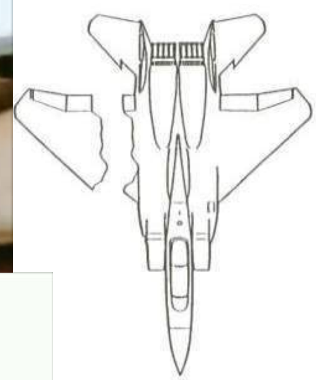
108 professors and over 240 graduate students in 28 U.S. universities were funded: Over 420 publications, and 24 technologies extracted, in the 3-year initiative

- 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

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



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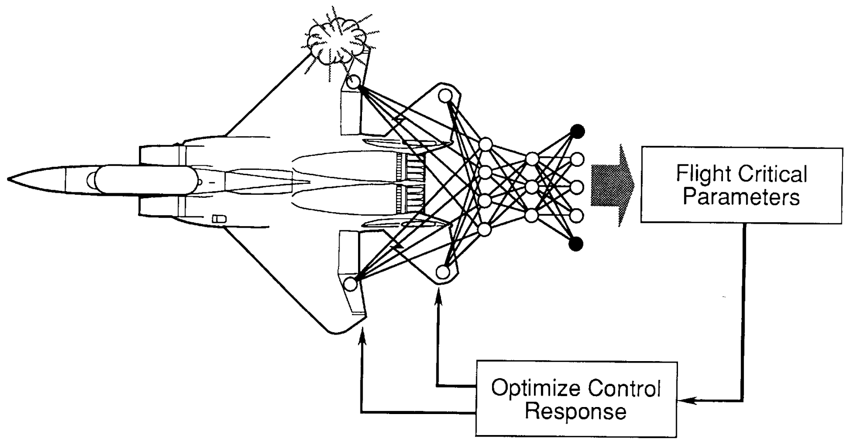
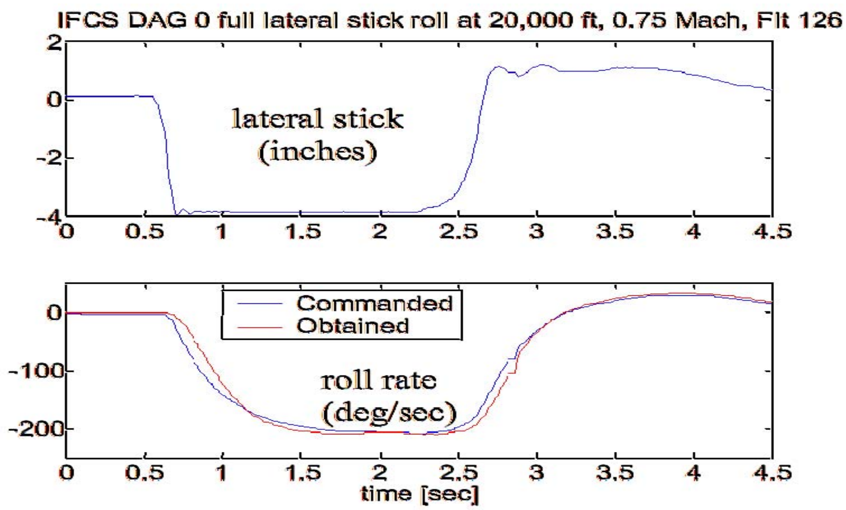
NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden, Boeing Phantom Works, and Washington University in St. Louis.

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



NASA/MDA/WU IFCS

Roll Axis Response of the Intelligent Flight Control System



Accomplishments in the IFCS program

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

Self-healing Grid (1998-present)

Building on the Foundation:

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

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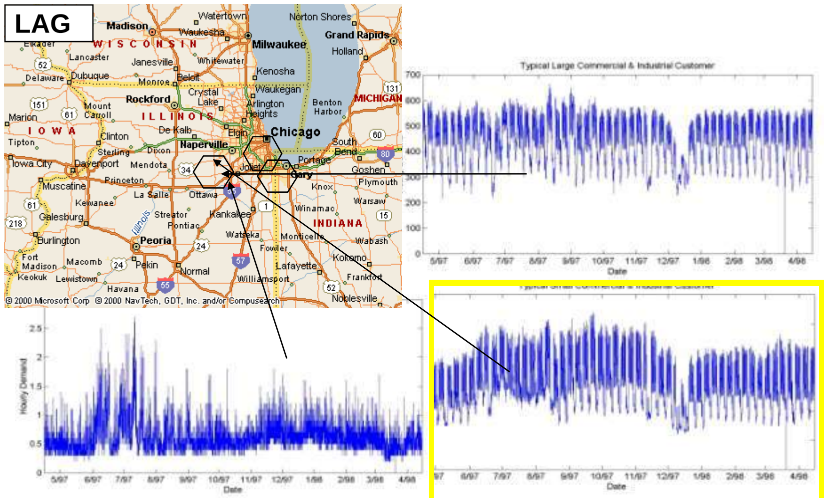
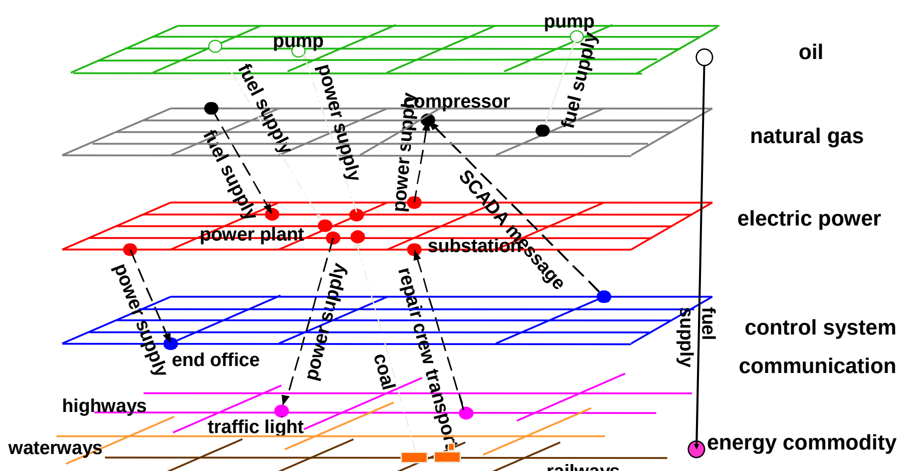
Local area grids (LAG)

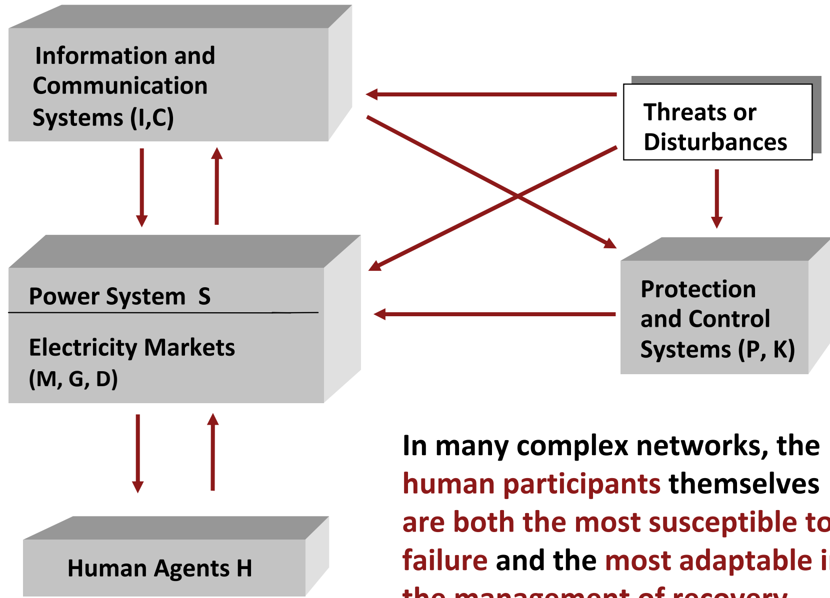


Infrastructure Interdependencies



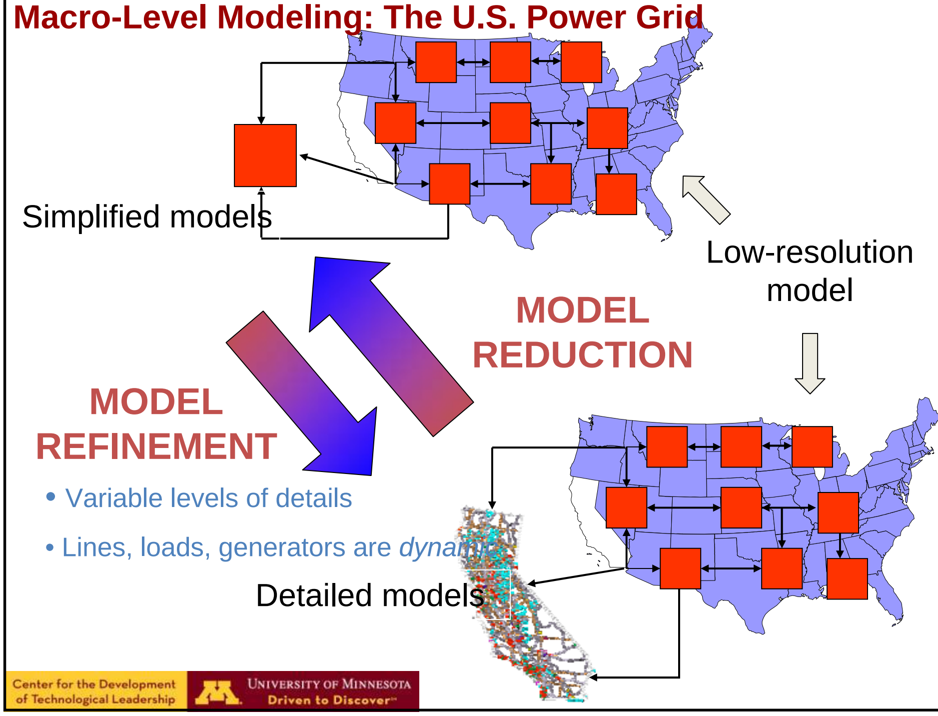
- Critical system components
- Interdependent propagation pathways and degrees of coupling
- Benefits of mitigation plans

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.

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



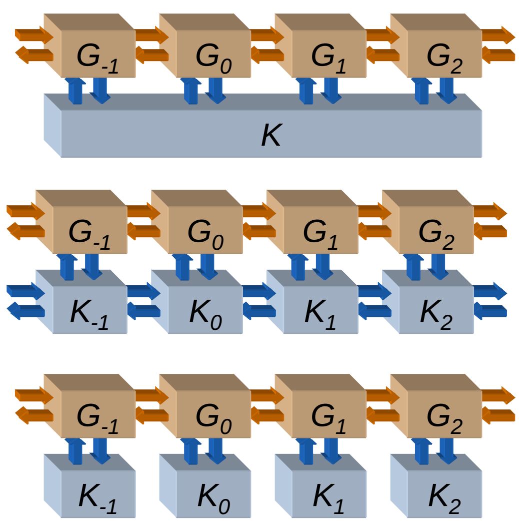
- Variable levels of details
- Lines, loads, generators are *dynamic*

Look-Ahead Simulation Applied to Multi-Resolution Models

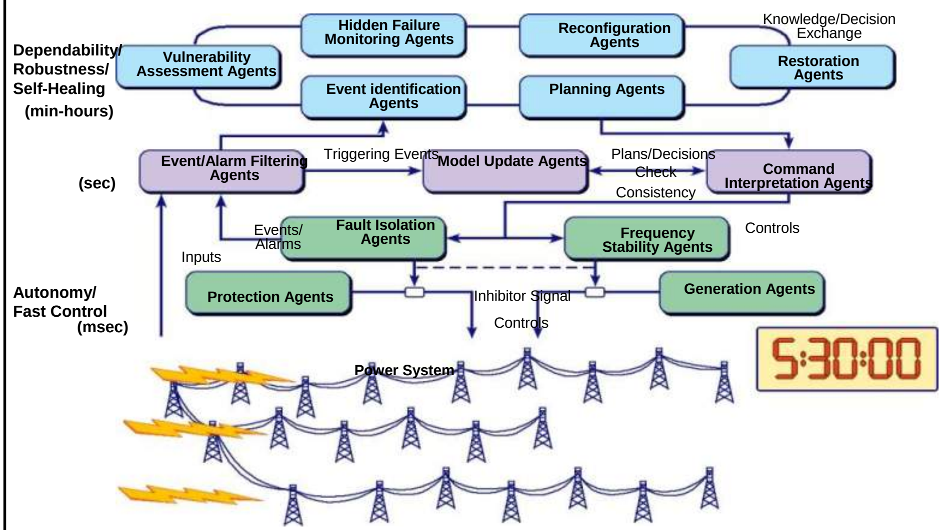
- Provides faster-than-real-time simulation
  - By drawing on approximate rules for system behavior, such as power law distribution
  - By using simplified models of a particular system
- Allows system operators to change the resolution of modeling at will
  - Macro-level (regional power systems)
  -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

Sensing and Control Strategies

- Centralized
- Distributed
- Perfectly decentralized

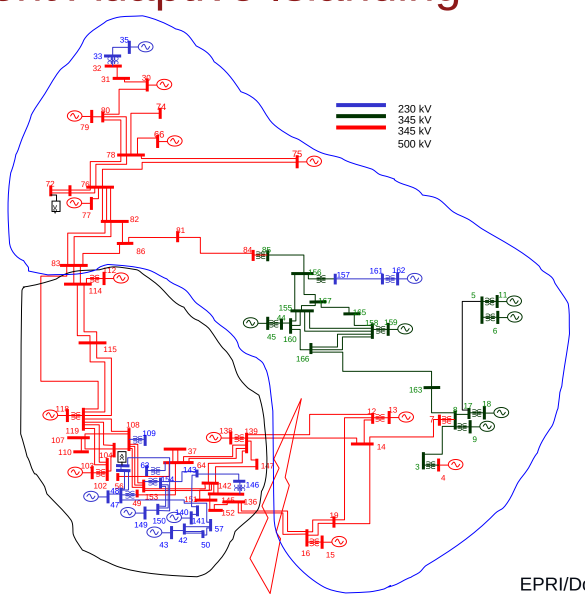


Background: The Self-Healing Grid



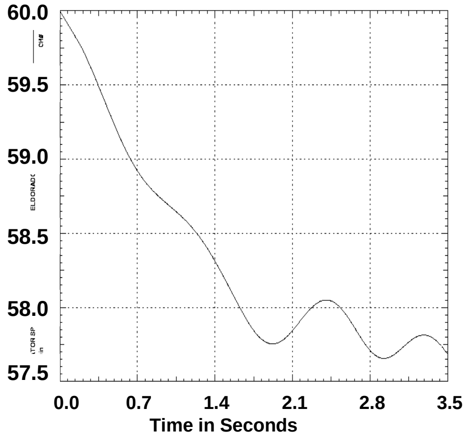
EPRI/DoD CIN/S Initiative

Background: The Self-Healing Grid
Intelligent Adaptive Islanding

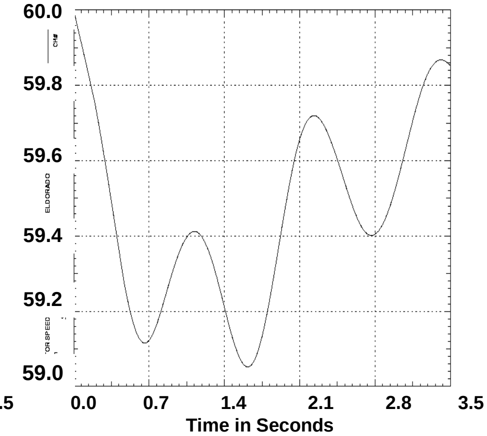


EPRI/DoD CIN/S Initiative

Background: Simulation Result



Past Scheme



New Scheme

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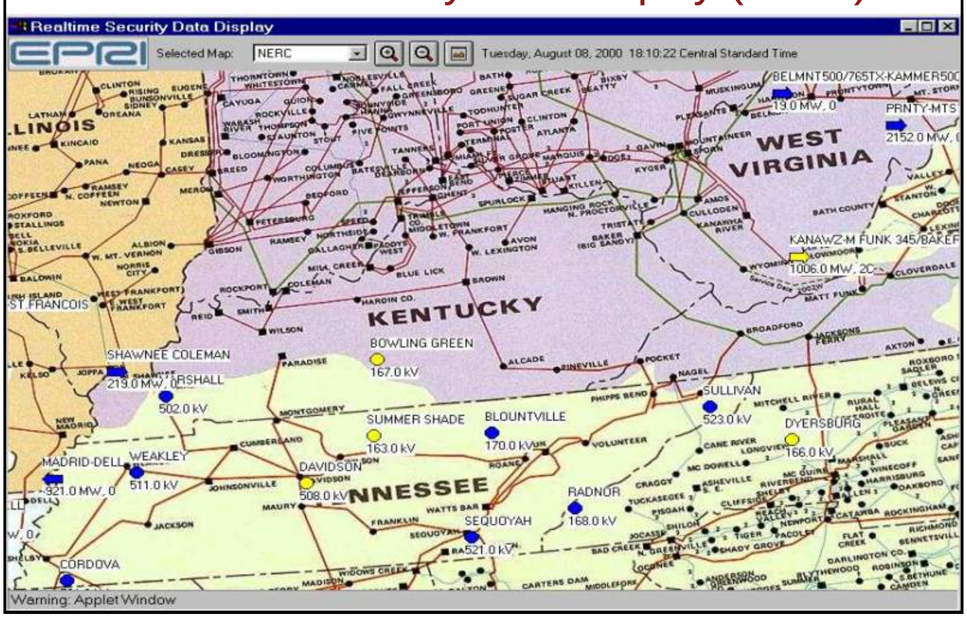
EPRI's Reliability Initiative-- Sample Screen of Real-time Security Data Display (RSDD)

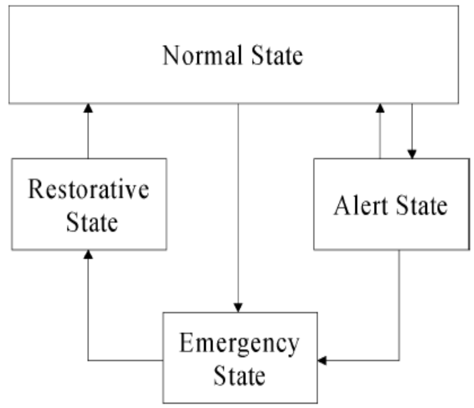


Understanding Complex Dynamical Systems

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

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

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



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

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

The Energy Web:

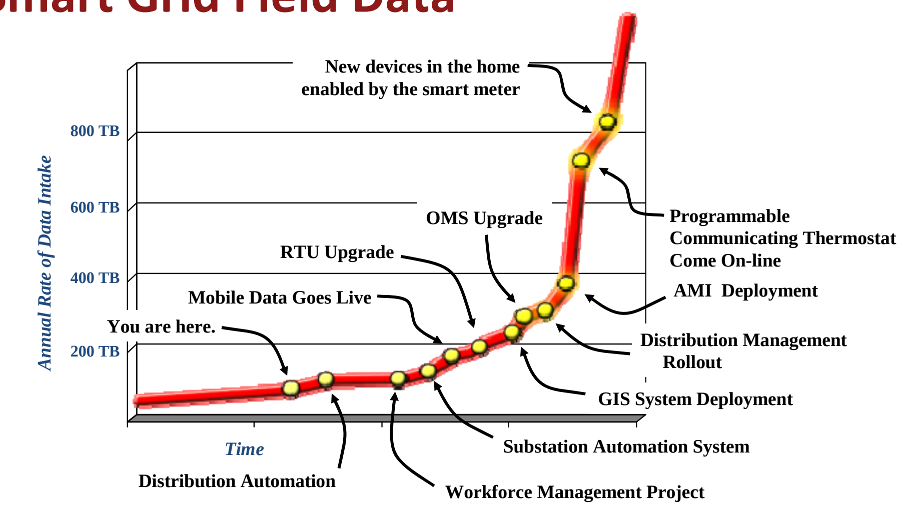
"The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming - and interconnected with everything else."

-- Wired Magazine, July 2001

http://www.wired.com/wired/archive/9.07/juice.html

Smart Grid

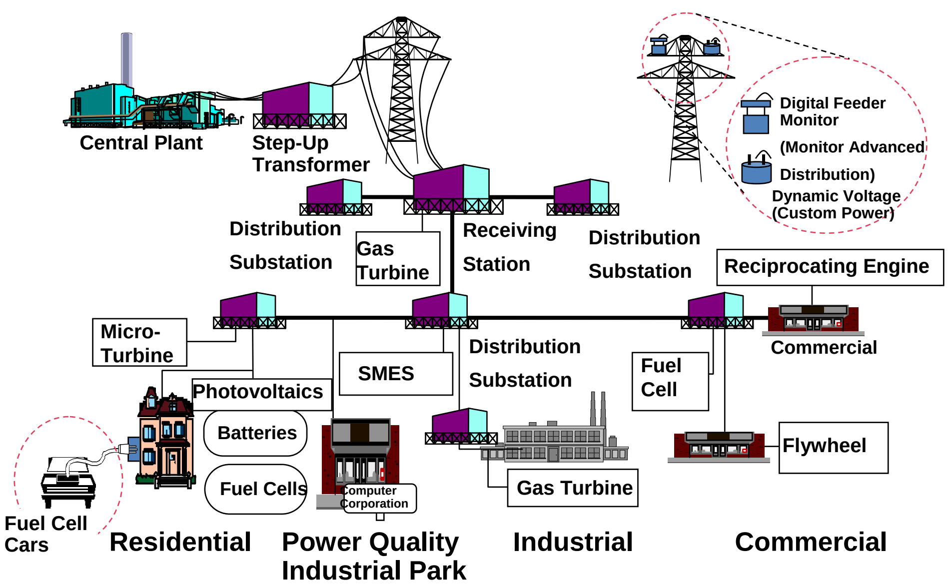
Smart Grid Field Data



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

Source: EPRI

Our Goal…Enabling the Future



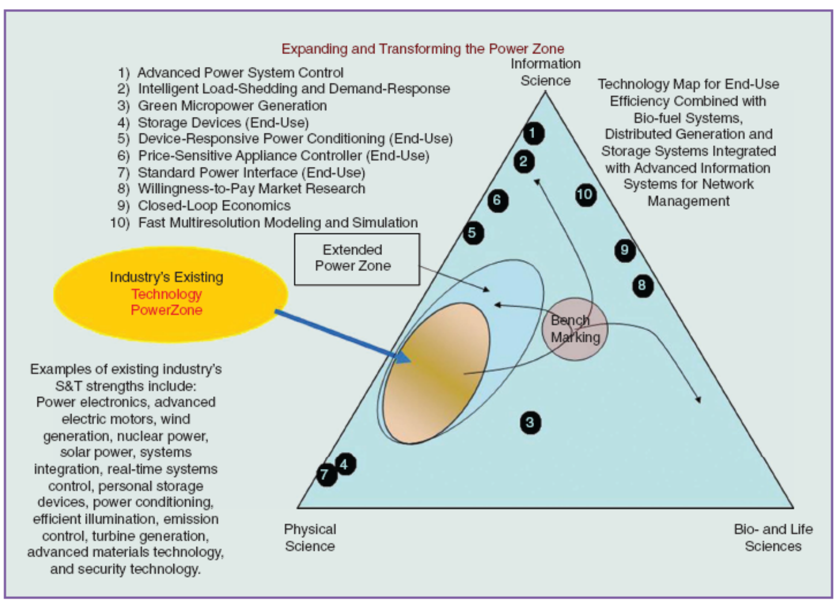
One of my research areas: S&T Assessment, Scan & Map
(April 2005-Feb 2006; Galvin Electricity Initiative)

Objectives:

- Identify the most significant Science & Technology innovations which would meet energy service needs over the next 10 or 20 years;
- Determine Science & Technologies areas and concepts which address customer aspirations and hopes; when conceived, they will lead to:
  - Technologies that encourage job creation and address the needs of the society;
  - An energy system so robust and resilient that it will not fail;
  - A totally reliable, secure communication system that will not fail.

Source: Galvin Electricity Initiative www.galvinelectricity.org

One of my research areas: S&T Assessment, Scan & Map
(April 2005-Feb 2006; Galvin Electricity Initiative)



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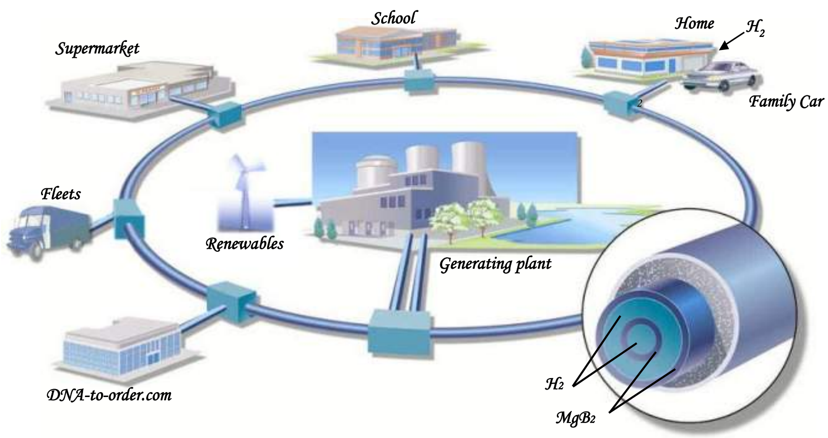
… including the Long Term…



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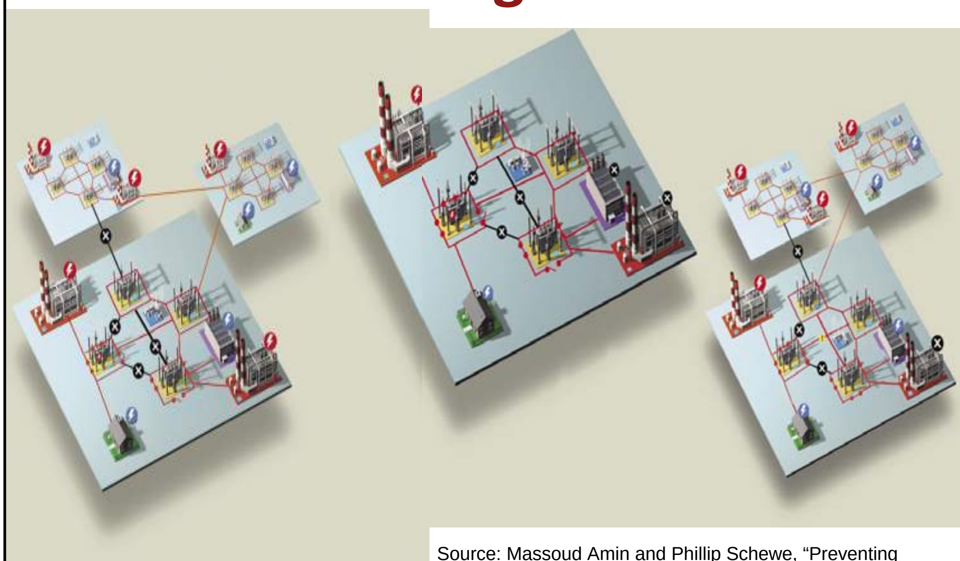
Smart Self-Healing Grid



Source: Massoud Amin and Phillip Schewe, "Preventing Blackouts," Scientific American, May 2007

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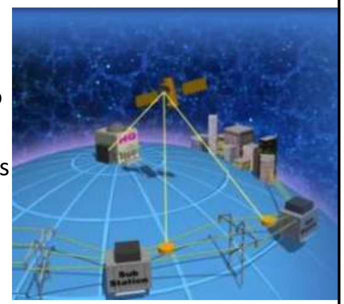
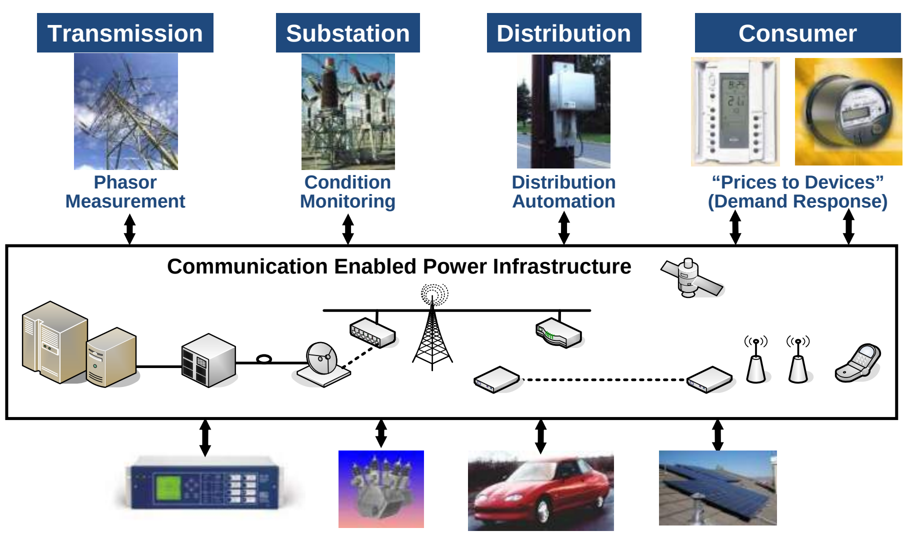
The Power Delivery System of the Future: *Characteristics*



Power delivery system of the future will be:

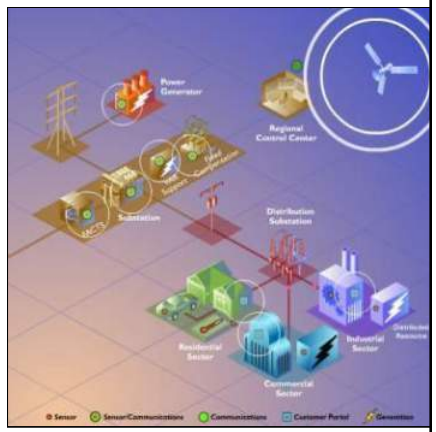
- **Intelligent:** autonomous digital system identifies surges, outages → **Predictive** rather than reactive, to prevent emergencies
- **Resilient:** "self-healing" and adaptive - instantaneous damage control
- **Reliable:** dynamic load balancing
- **Flexible:** accommodates new off-grid alternative energy sources
- **Interactive** with consumers and markets
- **Optimized** to make best use of resources and equipment
- **Integrated,** merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
- **Secure:** less vulnerable to attacks

Smart Grid – Exchanging Information Seamlessly Across the Enterprise

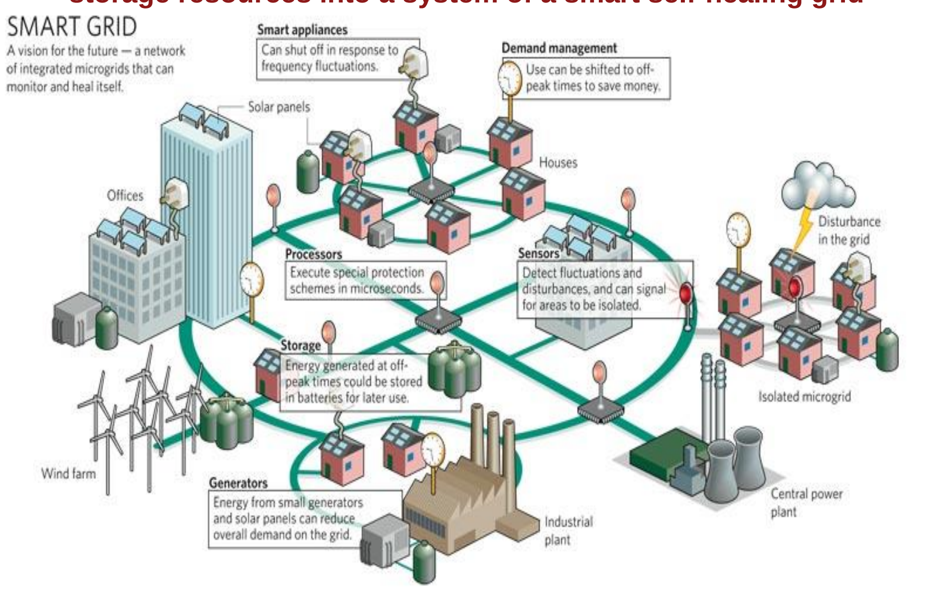


Tomorrow's Grid

- **Smart**
  - with sensors
- **Flexible and Resilient**
  - an intelligent network with real-time monitoring and control
- **Self Healing and Secure**
  - capable of predicting or immediately containing outages with adaptive islanding and fast isolation or sectionalizing
- **Established Standards**
  - enabling "plug and play" distributed resources, integrated renewables, with digital appliances and devices

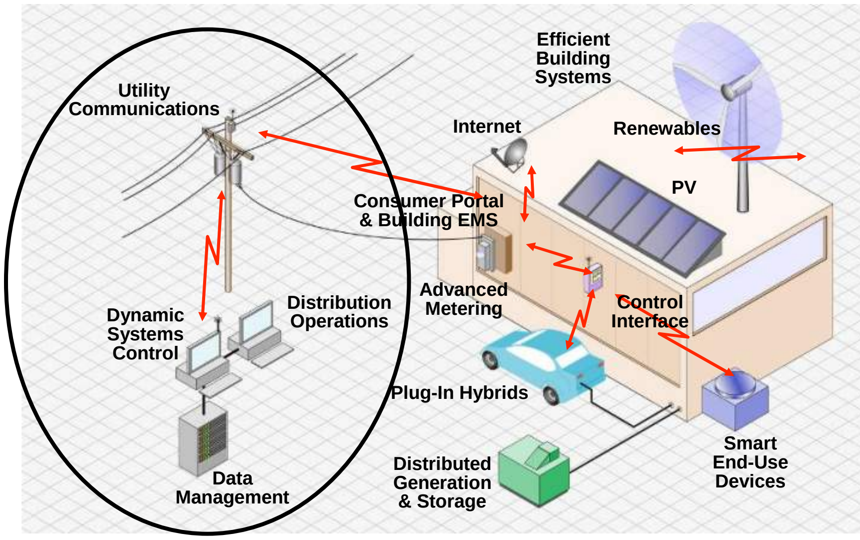


Infrastructure integration of microgrids and diverse generation and storage resources into a system of a smart self-healing grid



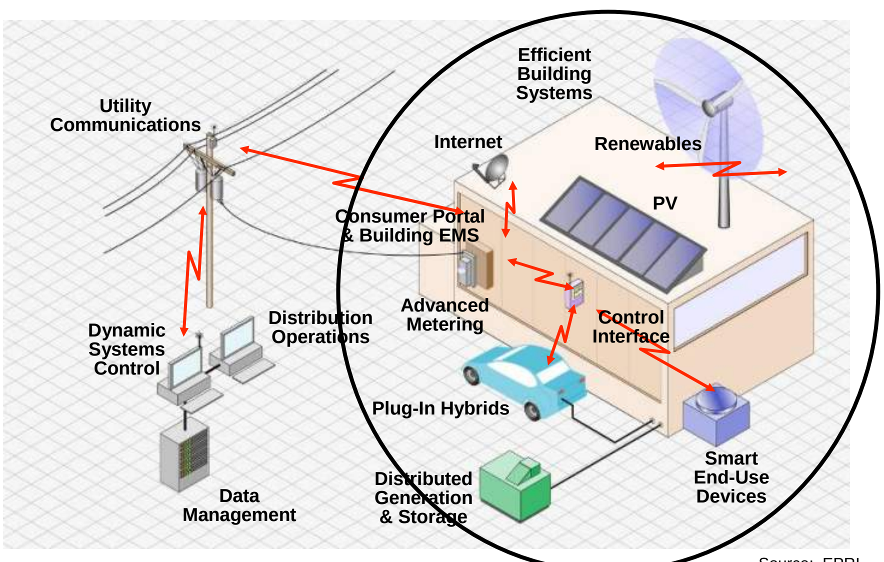
Source: Interview with Massoud Amin, "Upgrading the grid," *Nature,* vol. 454, pp. 570–573, 30 July 2008

Smart Grids and Local Energy Networks



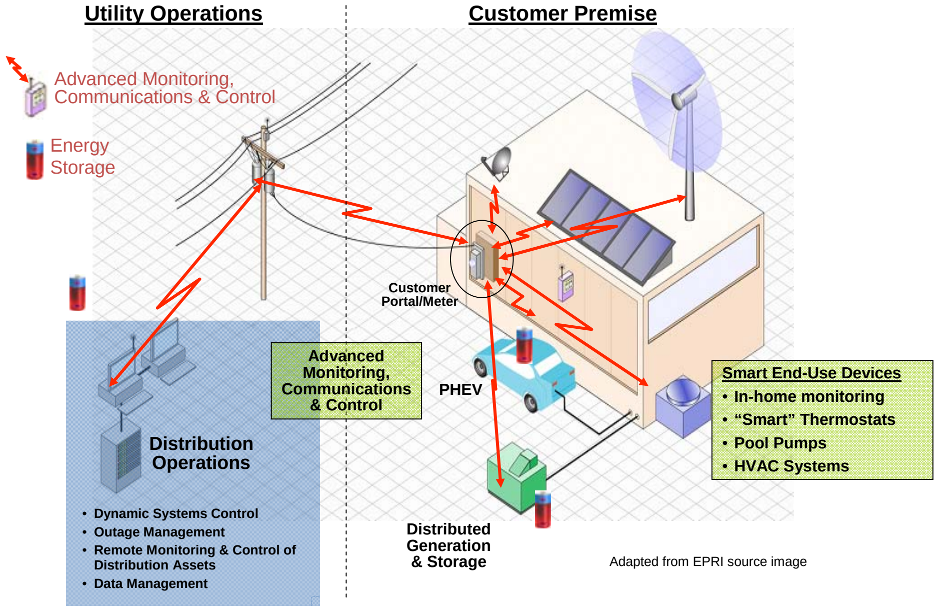
Source: EPRI

Smart Grids and Local Energy Networks



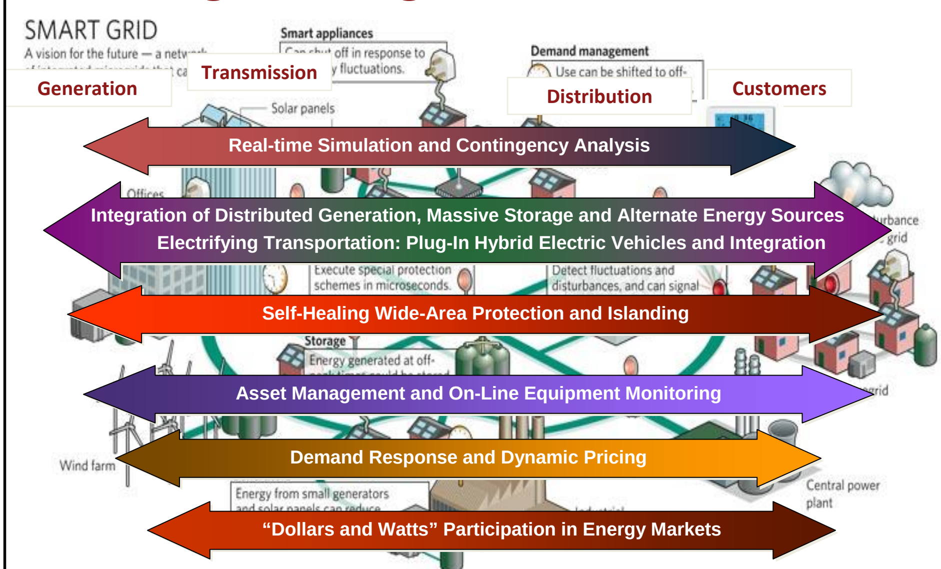
Source: EPRI

Distribution Operations of the Future

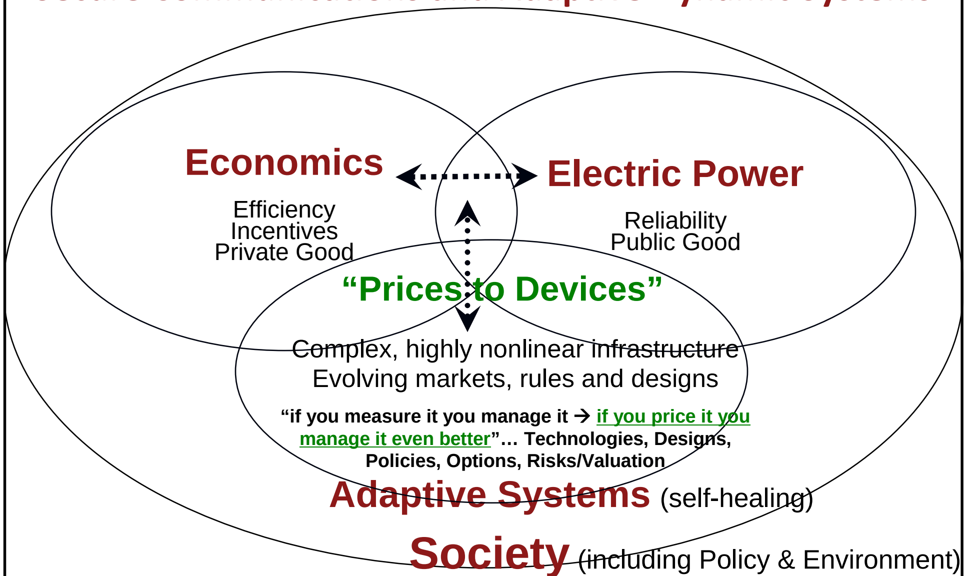


Adapted from EPRI source image

Enabling a Stronger and Smarter Grid



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



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
  - Device monitoring and self-healing diagnostics
  - Communication infrastructure provides opportunities for monitoring and diagnostics
  - Distributed Sensing and Control
  - Alternative Smart Grid Architectures
  - Infrastructure Security: Controls, Communications and Cyber Security
  - Markets and Policy
  - Distributed generation and storage adds complexity

Related on-going R&D include

- EPRI: Intelligrid, Fast Simulation and Modeling
- Initiatives at several utilities, including Xcel, AEP, Austin Energy, ISOs, etc.)
- 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
- Smart Grid Newsletter

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.

M. Amin's summary of the stimulus plan funding for Smart Grid

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.

Foresight

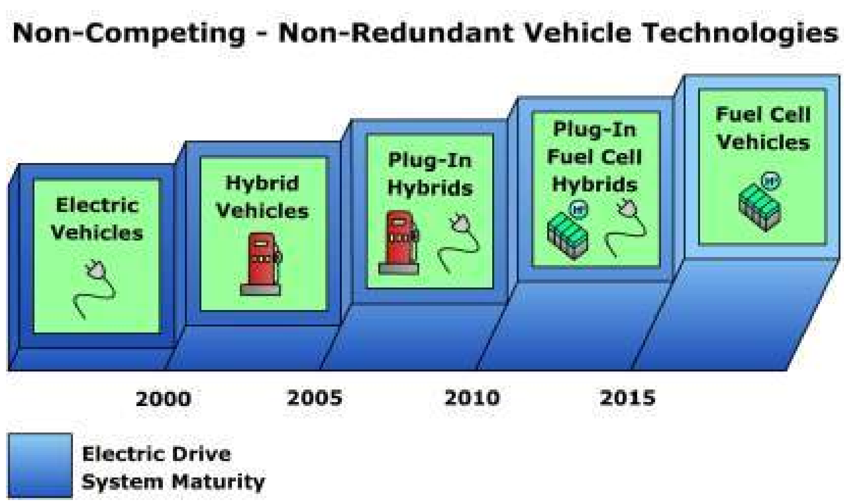
Renewables/infrastructure integration,
Electrification of transportation

- "***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…"

CNNMoney.com A Service of CNN, Fortune & Money (July 22, 2008)

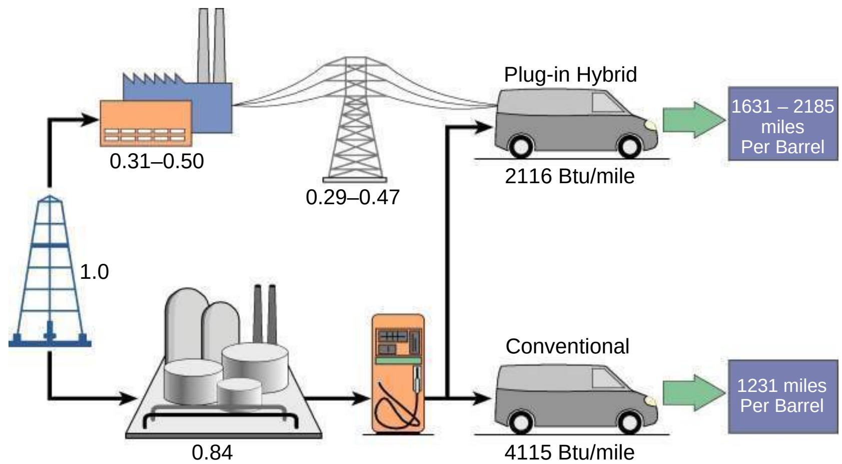
- "***GM, utilities team up on electric cars:*** Partnership aims to tackle issues that will crop up when electric vehicles are rolled out… General Motors Corp. has joined with more than 30 utility companies across the U.S. to help work out electricity issues that will crop up when it rolls out new electric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

Market Transformation of Electric Drive Vehicles

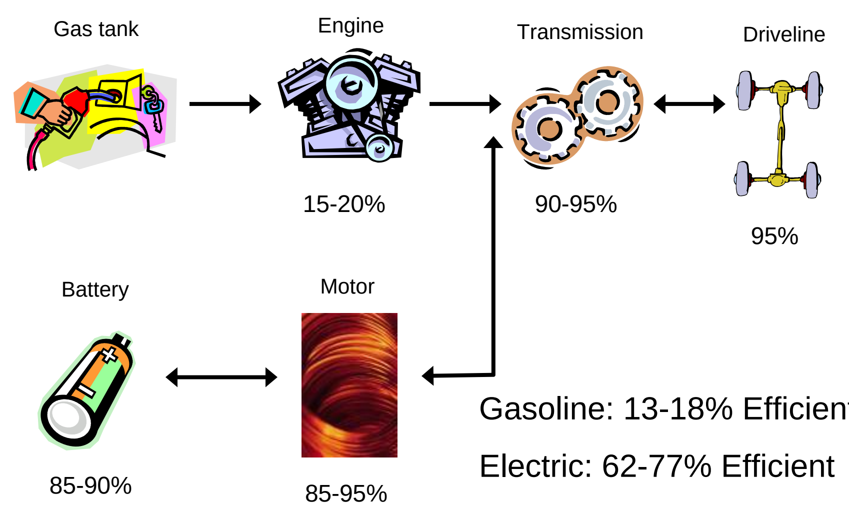


Source: EPRI

Full Fuel Cycle Efficiency Comparison



Hybrid Vehicle Efficiency



Gasoline: 13-18% Efficient

Electric: 62-77% Efficient

Rule of three

Efficient and Smart End-use Devices

The "Killer App" for the Electricity Efficiency Infrastructure

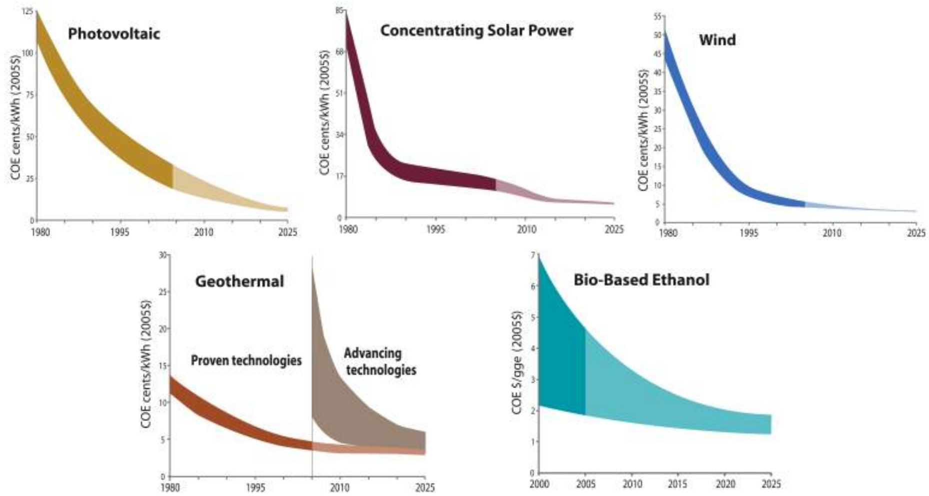
"Toyota sees hybrids playing a starring role in 21st century"

"Toyota is pursuing a plug-in hybrid…"

USA Today July 19, 2006

Renewable Energy Cost Trends

Levelized cost of energy in constant 2005$[1]

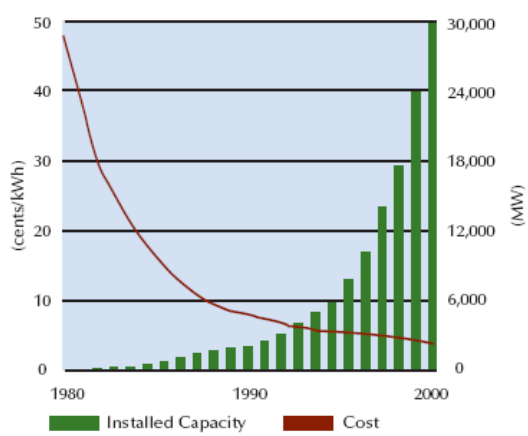


Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

[1]These graphs are reflections of historical cost trends NOT precise annual historical data.

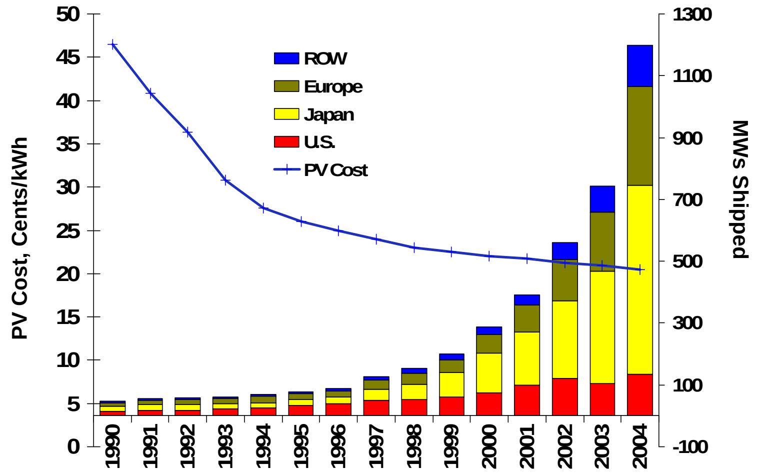
Declining Cost of Wind Power

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

PV Costs and Shipments



Source for market data: Paul Maycock, PV News, Volume 24, No. 2 February 2005

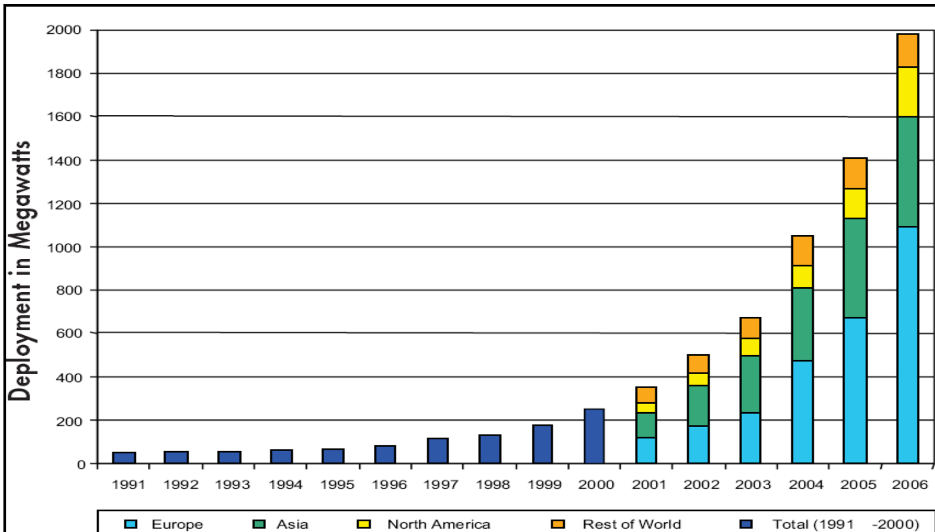


Figure 1
World PV Installations by Year, 1991-2006. Data for the years 1991-2000 are expressed as worldwide totals, while data for subsequent years specify where the PV was deployed. Japan accounts for nearly all of Asia's capacity, Germany and Spain dominate in Europe, and California is the largest PV market in North America. (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

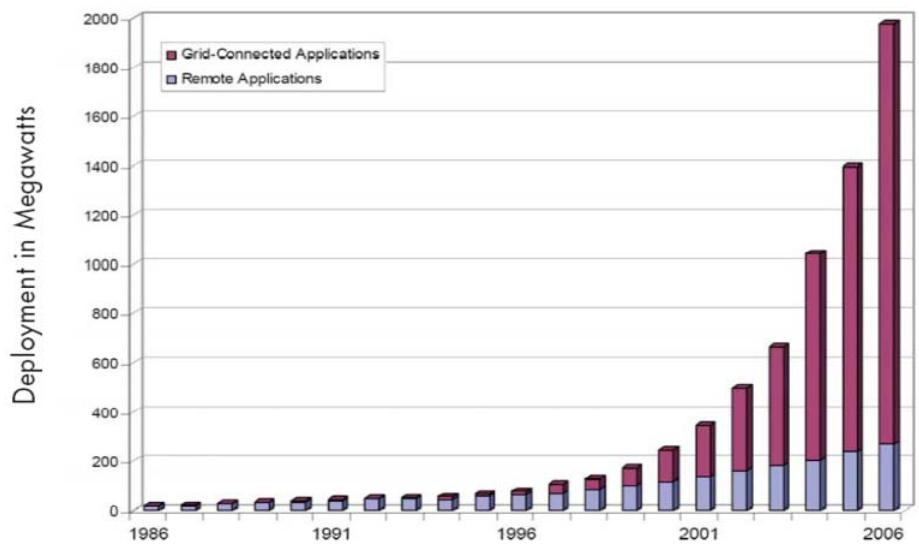


Figure 9
Proportion of Grid-Connected vs. Off-Grid PV Applications Worldwide, 1986-2006 (Source: Navigant Consulting PV Service Practice)

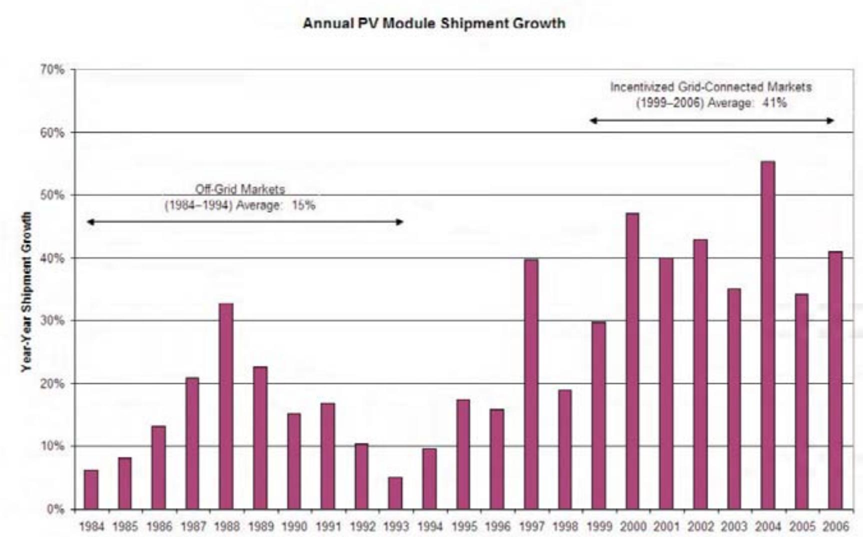


Figure 10
Before incentives for grid-tied systems in Japan, Germany, and California took effect, annual PV module shipments grew at 15% on average, mainly in off-grid applications. Subsidies boosted average annual growth to 41% overall. (Data source: Navigant Consulting PV Service Practice)

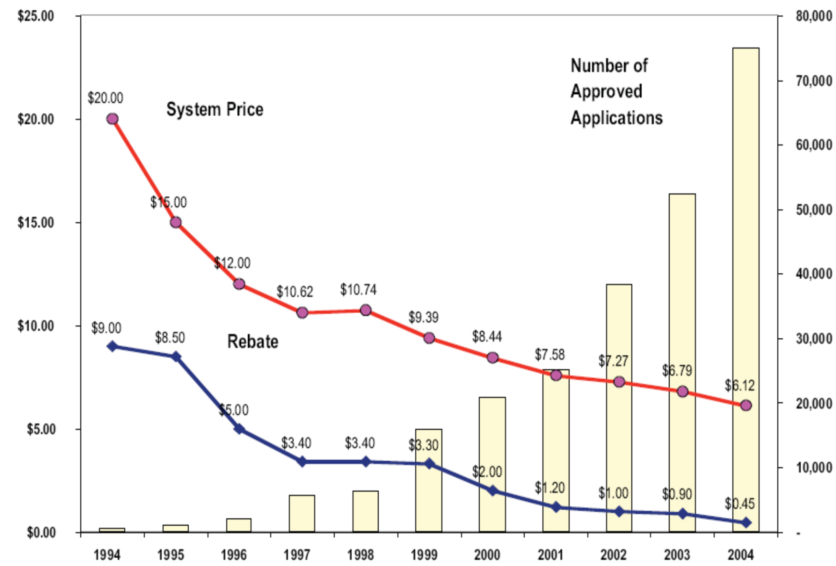


Figure 11
Japanese PV Program Rebates and Participation, 1994-2004 (Source: California Energy Commission)

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.

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.pdf

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.

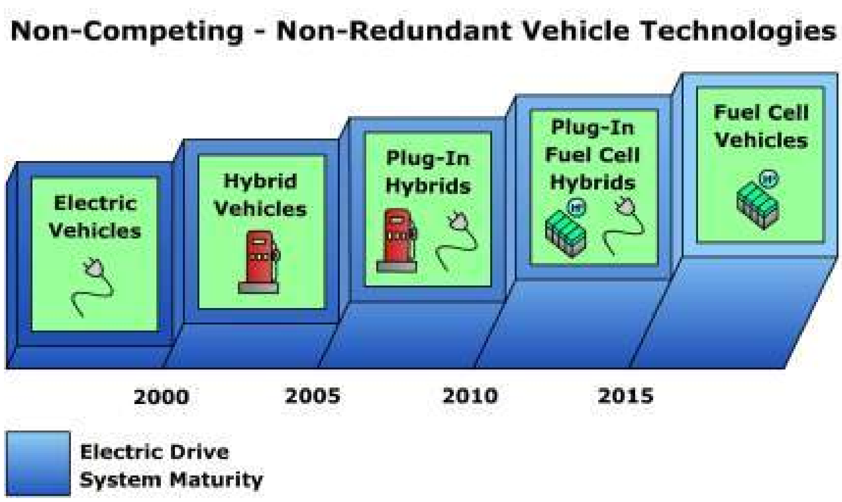
Portugal relies heavily on imported fossil fuels and has implemented aggressive incentives for renewable energy installations. A key component of Portugal's "Energy Efficiency and Endogenous Energies" (E4) program is a $0.317/kWh to $0.444/kWh feed-in tariff for both ground-mounted and rooftop solar 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

Market Transformation of Electric Drive Vehicles

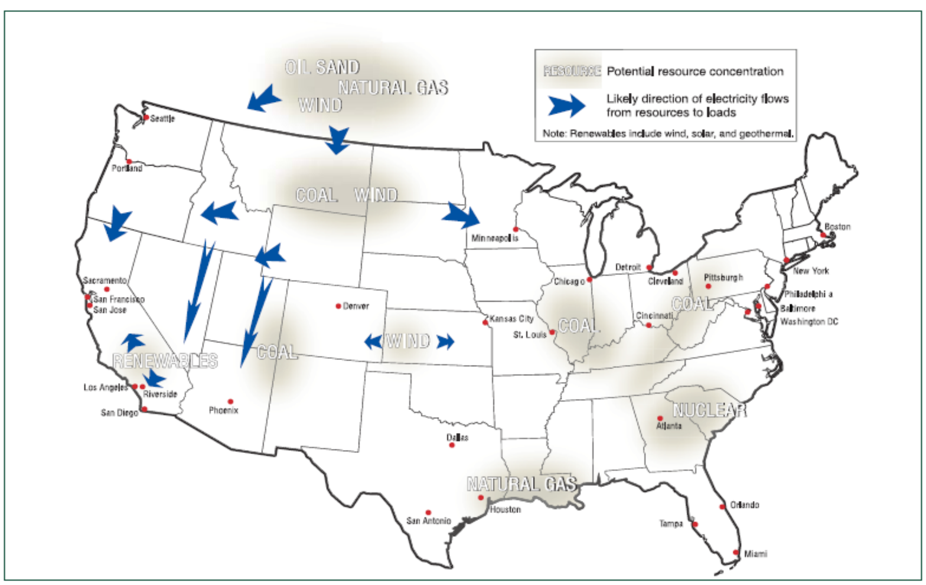


Source: EPRI, July 2000

...The Future is Bright...

Courtesy FPL Energy

Context: New patterns in power delivery

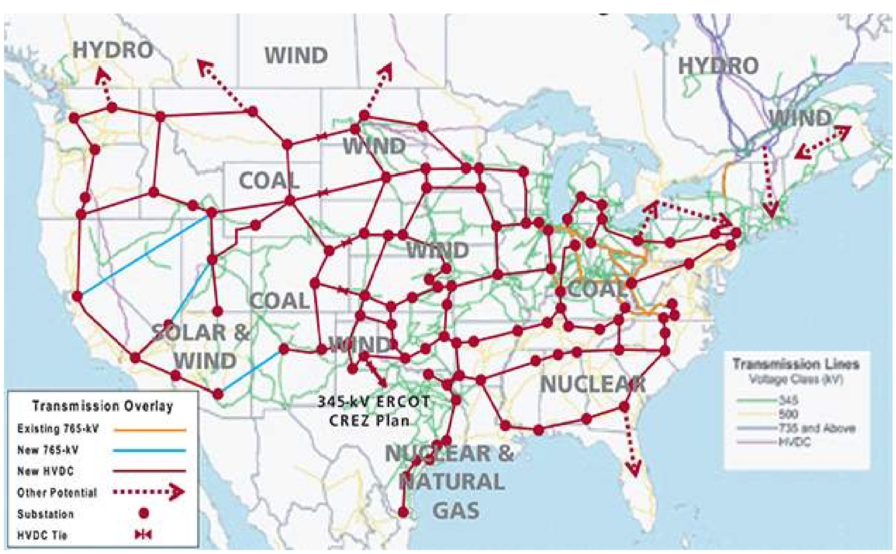


Map adapted from the U.S. DOE National Electric Transmission Congestion Study

Context: New patterns in power delivery

- More efficient to move electrical power through the transmission system than to ship fuels the same distance;
- Transition from fossil fuel-based power generation to fluctuating energy sources such as wind, sun, and wave power introduces challenging demands on the storage, dispatch, operation and integration with the power grid;
- Integration of energy resources and demands will require interconnected transmission network, a **Smart Grid,** that is:
  - **Intelligent:** autonomous digital system identifies surges, outages
    → **Predictive** rather than reactive, to prevent emergencies
  - **Resilient:** "self-healing" and adaptive - instantaneous damage control
  - **Reliable:** dynamic load balancing
  - **Flexible:** accommodates new off-grid alternative energy sources
  - **Interactive** with consumers and markets
  - **Optimized** to make best use of resources and equipment
  - **Integrated**, merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
  - **Secure:** less vulnerable to attacks and destabilizers

Enabling a Stronger Grid



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A look ahead… possible future

- The North American electric power system grew organically in response to customers' demands over the last hundred years without a conscious awareness and analysis of the system-wide implications of its current evolution under the forces of deregulation, system complexity, power-market impacts, terrorism, and human error.
- This system can grow and possibly improve performance through incremental technology adoption—a diffusion dynamic that may not be fast and effective enough to meet the needs of the 21st century.
- 'Pushing harder' will likely have limited effect on this dynamic. In contrast, the system best meeting the various consumers' needs for the 21st century will need to be:
  - Scalable, Robust, and Multimodal
  - Able to rapidly and effectively exploit technology breakthroughs
  - Capable of meeting diverse consumers' needs and give them service choices
  - Ready to provide market dynamics such as elasticity between price and performance
  - Economically and politically aligned to give simultaneous incentives to the major providers, users, and stakeholders.

For the Good of the Grid

Toward Increased Efficiencies and Integration of Renewable Resources for Future Electric Power Networks

by S. Massoud Amin

THE EXISTING ELECTRICITY INFRASTRUCTURE EVOLVED TO ITS TECHNOLOGY composition today from the convolution of several major forces, only one of which was technologically based. Today opportunities and challenges persist in world-wide electric power networks, including reducing transmission congestion, increasing system/cyber security, and increasing overall system and end-use efficiency while maintaining reliability. And many other challenges engage those who plan for the future of the power grid: producing power in a sustainable manner (embracing renewable fuels while accounting for their scalability limitations; e.g., increased use of land and natural resources to produce higher renewable electricity will not be sustainable, and lowering emissions from existing generators), delivering electricity to those who don't have it (not just on the basis of fairness but also because electricity is the most efficient form of energy, especially for things like lighting), using electricity more wisely as a tool of economic development, and pondering the possible revival of advanced nuclear reactor construction.

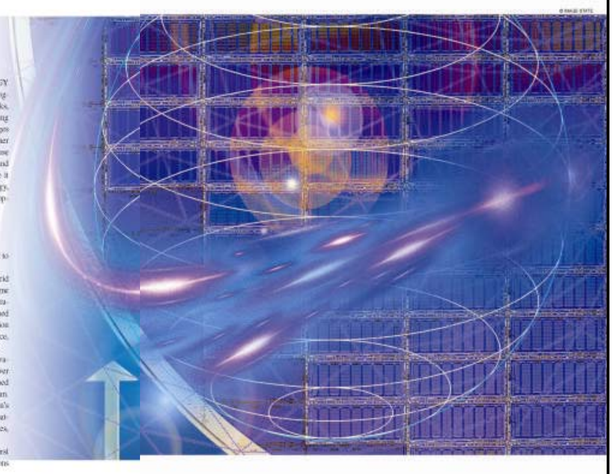
Conservation and Efficiency: Where Are We and How Did We Get Here?

To prepare for a more efficient, resilient, secure, and sustainable electrical system, it is helpful to remember the historical context, associated pinch-points, and forcing functions.

As the readers of *IEEE Power & Energy Magazine* know, the trends of worldwide electrical grid deployment, costing trillions of dollars and reaching billions of people, began very humbly. Some obvious electrical and magnetic properties were known in antiquity. In the 17th and 18th centuries, partially through scientific experiments and partially through parlor games, more was learned about how electric charge is conducted and stored. But only in the 19th century, with the creation of powerful batteries, and through insights about the relations between electric and magnetic force, could electricity in wires service large-scale industries—first the telegraph and then telephones.

And only in the 1880s did the first grids come into being for bringing electrical energy to a variety of customers for a variety of uses, at first mostly for illumination but later for turning power machines and moving trolley cars. The most important of these early grids, the first established big city grid in North America, was the network built by Thomas Edison in lower Manhattan. From its power station on Pearl Street, practically in the shadow of the Brooklyn Bridge, Edison's company supplied hundreds and then thousands of customers. Shortly thereafter, Edison's patented devices, and those of his competitors, devices such as bulbs, generators, switching devices, generators, and motors, were in use in new grids in towns all over the industrialized world.

From a historical perspective the electric power system in the United States evolved in the first half of the 20th century without a clear awareness and analysis of the system-wide implications



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november/december 2008
IEEE power & energy magazine

Selected References

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

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

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

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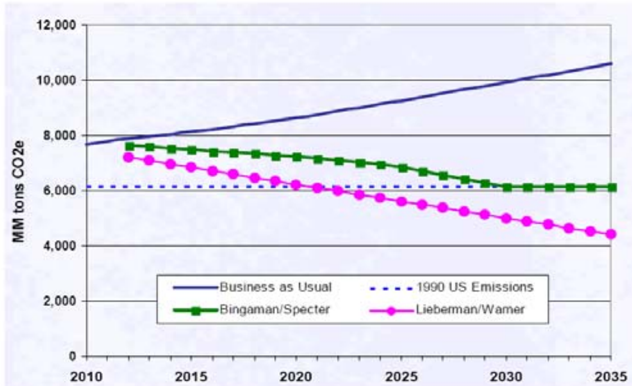
Discussion and the Road Ahead:

- What are the key energy, environmental and economic issues facing MN, our region, our nation, and the world?
  - **What is your vision for the future– what will it be or how will it perform in 2010-2015?**
  - **What are the difficult challenges to overcome to achieve your vision?**
  - **What enabling technologies and policies are needed to address these?**
  - **What critical issues should we consider in beginning plans for 2009 and beyond?**

...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.

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.

M. Amin's summary of the stimulus plan funding for Smart Grid

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.

M. Amin's summary of the stimulus plan funding for Smart Grid

Macroeconomic Rationale

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

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

   Y = GDP

   R = R&D

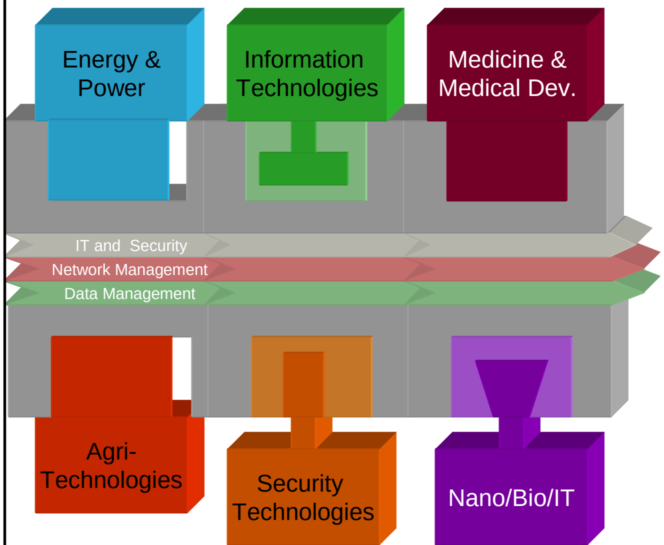
   K = physical capital

   H = human capital

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

Minnesota's Technological Leadership Role:

Enabling Economic Growth→ First Build the Right Foundation



Build The Right Foundation

Security

Network Management

Data Management

Interoperability

Center for the Development of Technological Leadership

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Bottom Line:

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

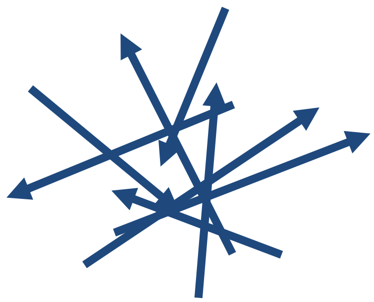
-- Peter Drucker

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
    - 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 with massive storage
- Need new technologies analogous to putting the "man on the moon," with the urgency of the Manhattan Project.

When Innovation *Doesn't Matter*

Remember Your Vector Math Class!



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Bubble-up Innovation
Many Types

When organizations "peanut-butter" innovation, nothing of significance happens

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**

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May others benefit from your lead.
Thank you