Transforming Public Policy:
Toward Smart Self-healing Critical National Infrastructures

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INSTITUTE OF TECHNOLOGY

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Driven to Discover

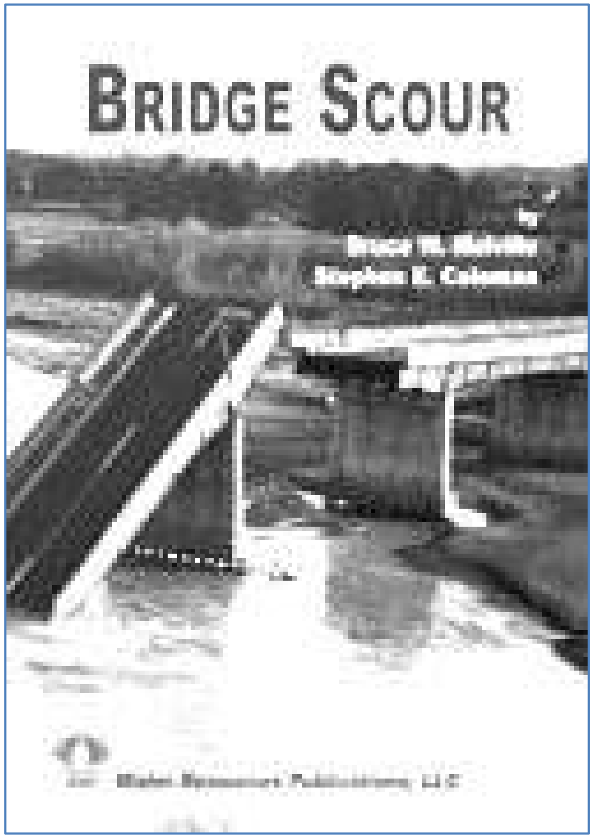
Context: What is "Infrastructure"?

Infrastructure is the linked socio-technological system of facilities and activities that provides the range of essential services generally necessary to support our economy and quality of life.

What is a socio-technological system?

Socio-technological systems include the physical infrastructure, the people and organizations who build, run, and use it, as well as the economic and legal conditions for operations.

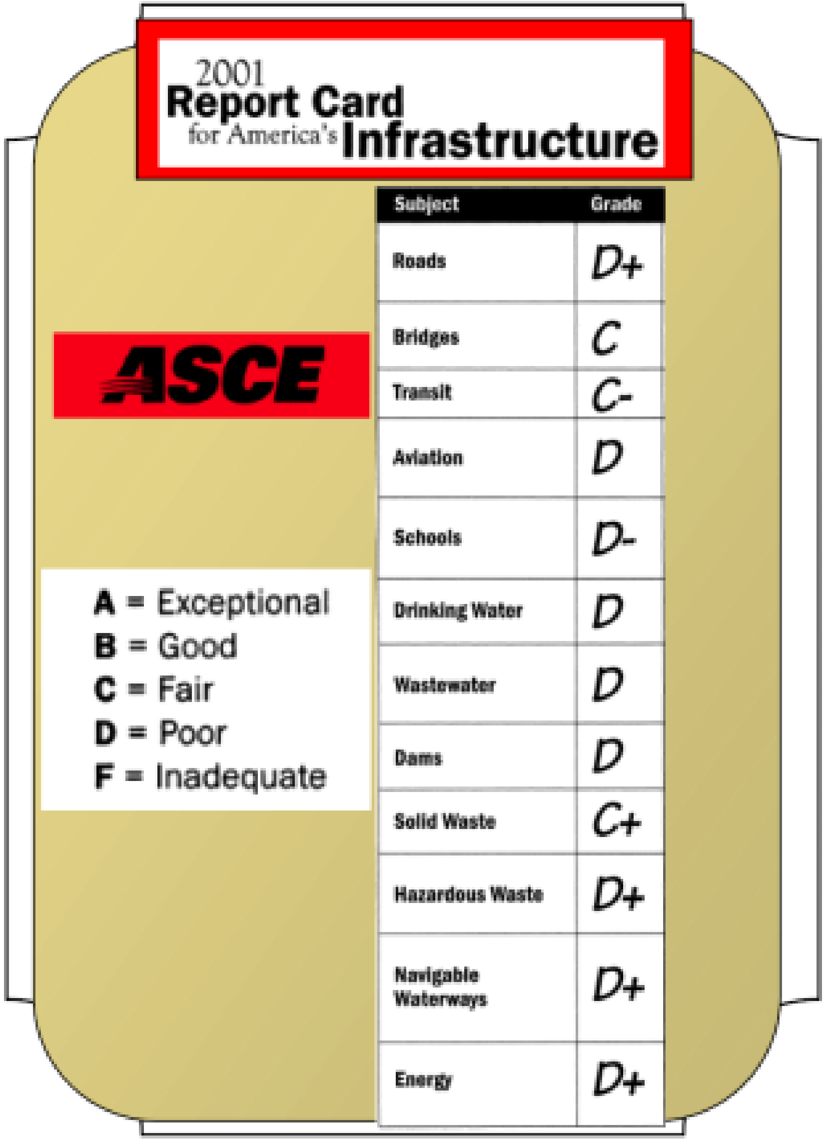
ASCE Grades U.S. Infrastructure a 'D'



"**Civil engineers** are the doctors of infrastructure,-- and We have a patient that's sick and getting sicker."

ASCE Executive Director James E. Davis

The ASCE estimates that it will take **$1.3 trillion** over the next five years to fix these problems

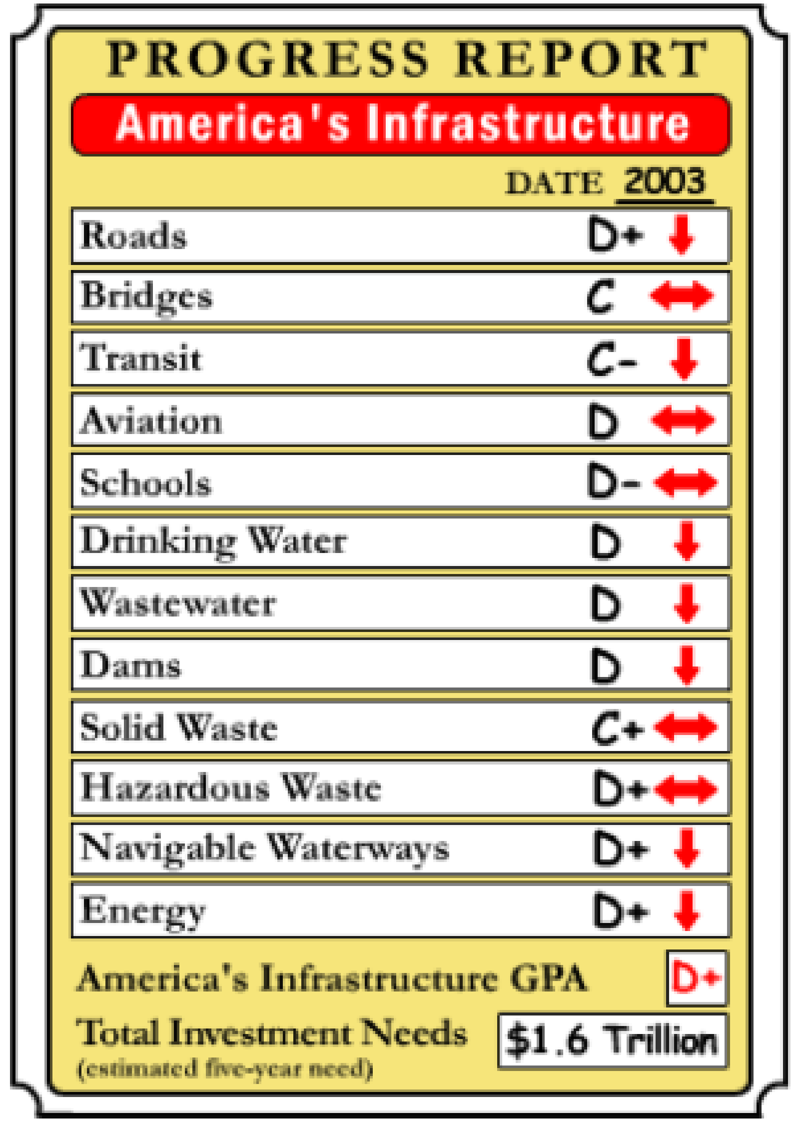


2001 Report Card for America's Infrastructure

ASCE

Subject	Grade
Roads	D+
Bridges	C
Transit	C-
Aviation	D
Schools	D-
Drinking Water	D
Wastewater	D
Dams	D
Solid Waste	C+
Hazardous Waste	D+
Navigable Waterways	D+
Energy	D+

A = Exceptional
B = Good
C = Fair
D = Poor
F = Inadequate



PROGRESS REPORT
America's Infrastructure
DATE 2003

Roads	D+	↓
Bridges	C	↔
Transit	C-	↓
Aviation	D	↔
Schools	D-	↔
Drinking Water	D	↓
Wastewater	D	↓
Dams	D	↓
Solid Waste	C+	↔
Hazardous Waste	D+	↔
Navigable Waterways	D+	↓
Energy	D+	↓

America's Infrastructure GPA: D+
Total Investment Needs (estimated five-year need): $1.6 Trillion

American Society of Civil Engineers' Report Card for America's Infrastructure: http://www.asce.org/reportcard/2005/index.cfm

Aging Infrastructure priorities

The link between Critical Infrastructure Protection (CIP) and aging infrastructure is recognized!

…While we've made tremendous progress hardening many of our national assets against terrorist attacks, as a nation we frankly haven't done a good job protecting our commonly used structures against simple wear and tear or threats from Mother Nature.

…At the end of the day, it's pointless to protect dams, bridges, and tunnels from terrorism if they could collapse on their own and kill just as many people as a terrorist attack.

…What I'm now urging is we take that same disciplined approach based on partnership, based when necessary on strong government action, based on clear eyed prioritization of risk, based upon a clear strategy for minimizing risk and based upon a commitment that we apply all of these strategies to the broader challenge of protecting and securing our infrastructure against a wide variety of threats, the threats that come simply with the passage of time or with Mother Nature.

-- Secretary Chertoff remarks to the Brookings Institute, August 2008

The Infrastructure Challenge

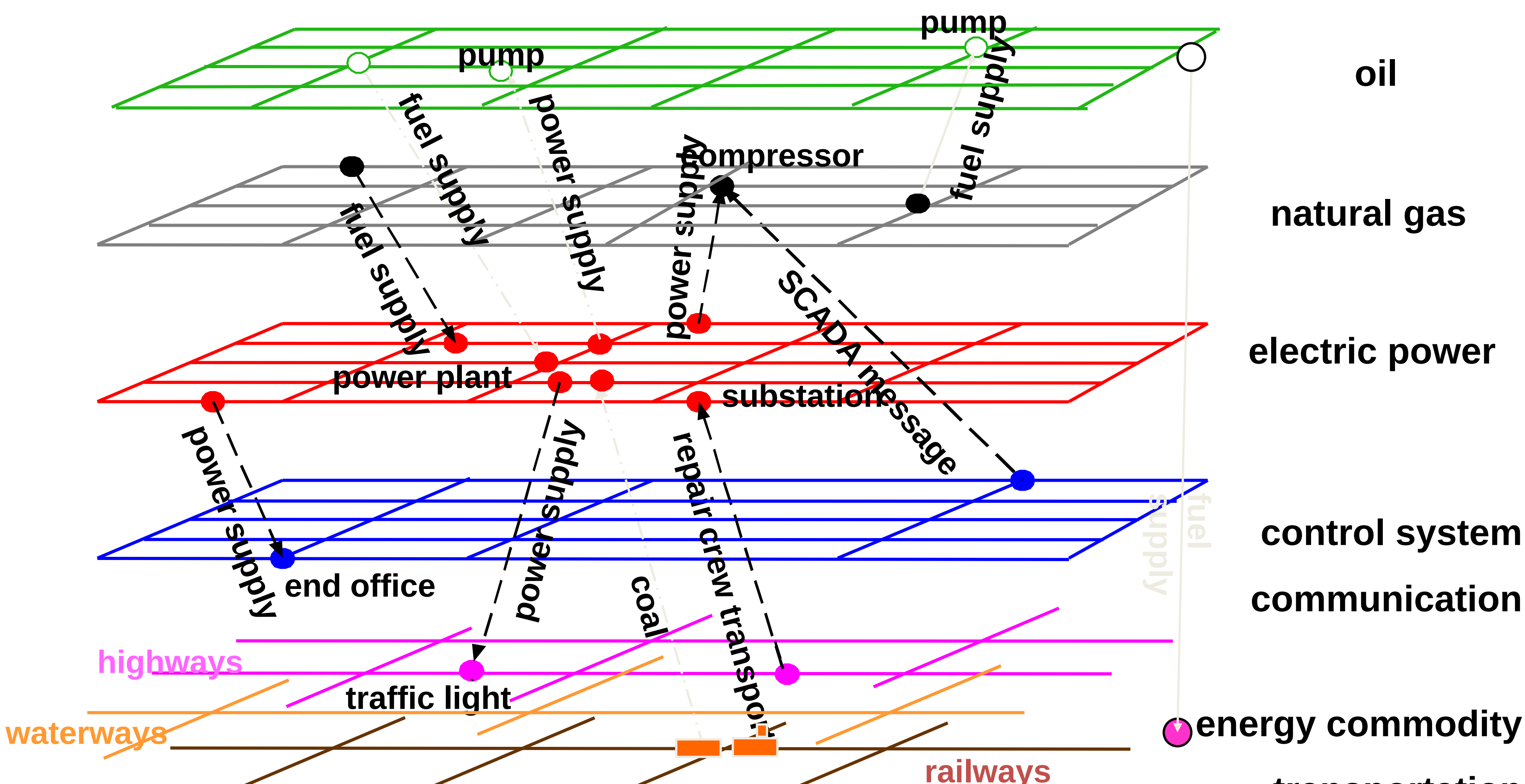
Will today's national and local infrastructure systems be left behind as a relic of the 20th century, or become the critical infrastructure supporting the digital society, a self-healing infrastructure?

Case Studies:

Interdependent Infrastructure Assessments

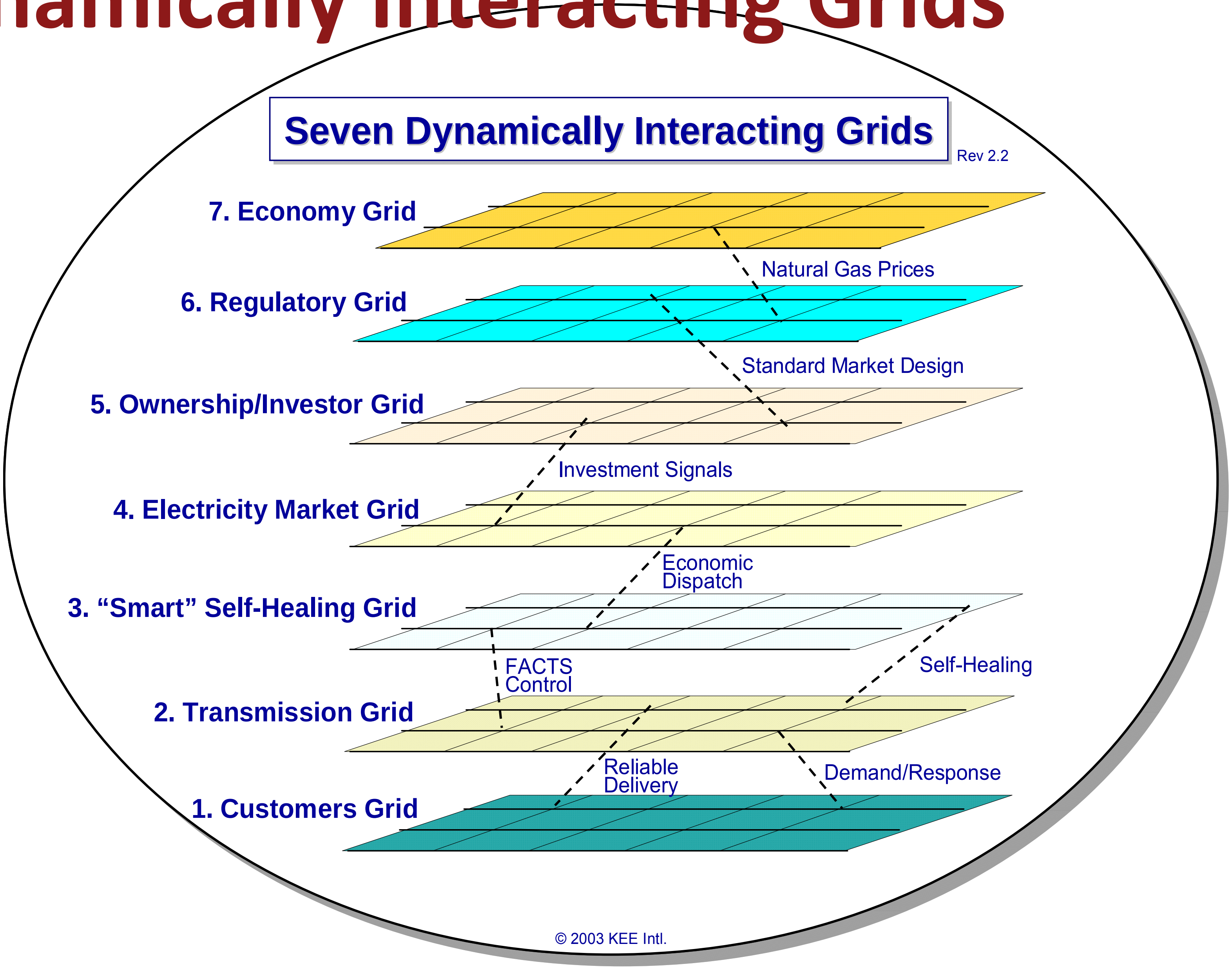
… and Global Transition Dynamics

Infrastructure Interdependencies



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

Interdependencies: Dynamically Interacting Grids



Globally Interlocked Dynamics:
Understanding the Full Impacts of Decision Pathways

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

Technology as a Hinge

- In the past, we have been unable to account for all areas on the interlocking fan
- Decisions have been made with incomplete information
- New technologies now permit us to identify forcing functions, critical junctures, and pinch points
- Goal: To target our constrained development resources to maximize benefit and minimize unintended consequences

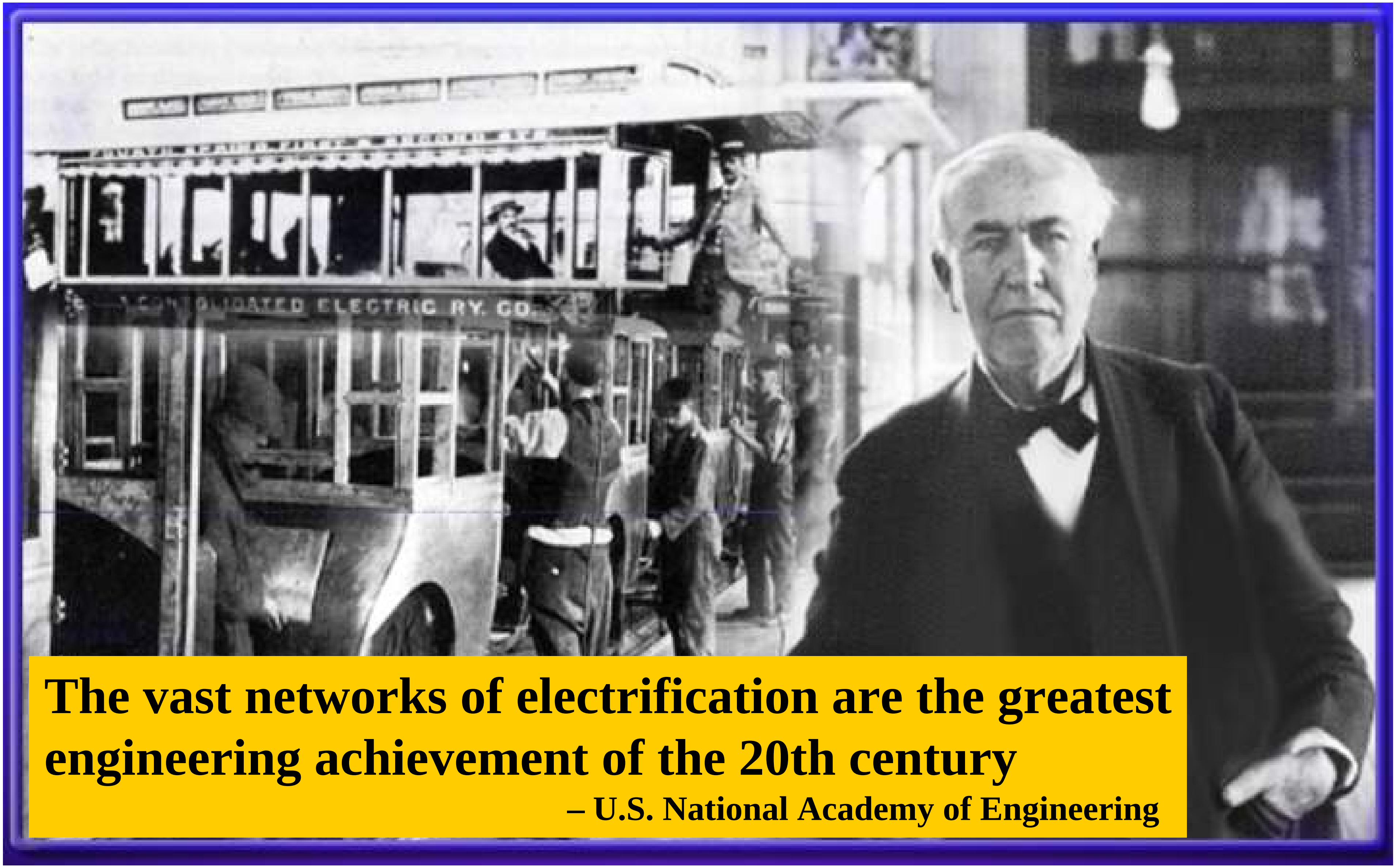
Technology is empowered by people:

Technology requires human skills, discipline and creativity to make it worth something

Case Studies:

Power and Energy

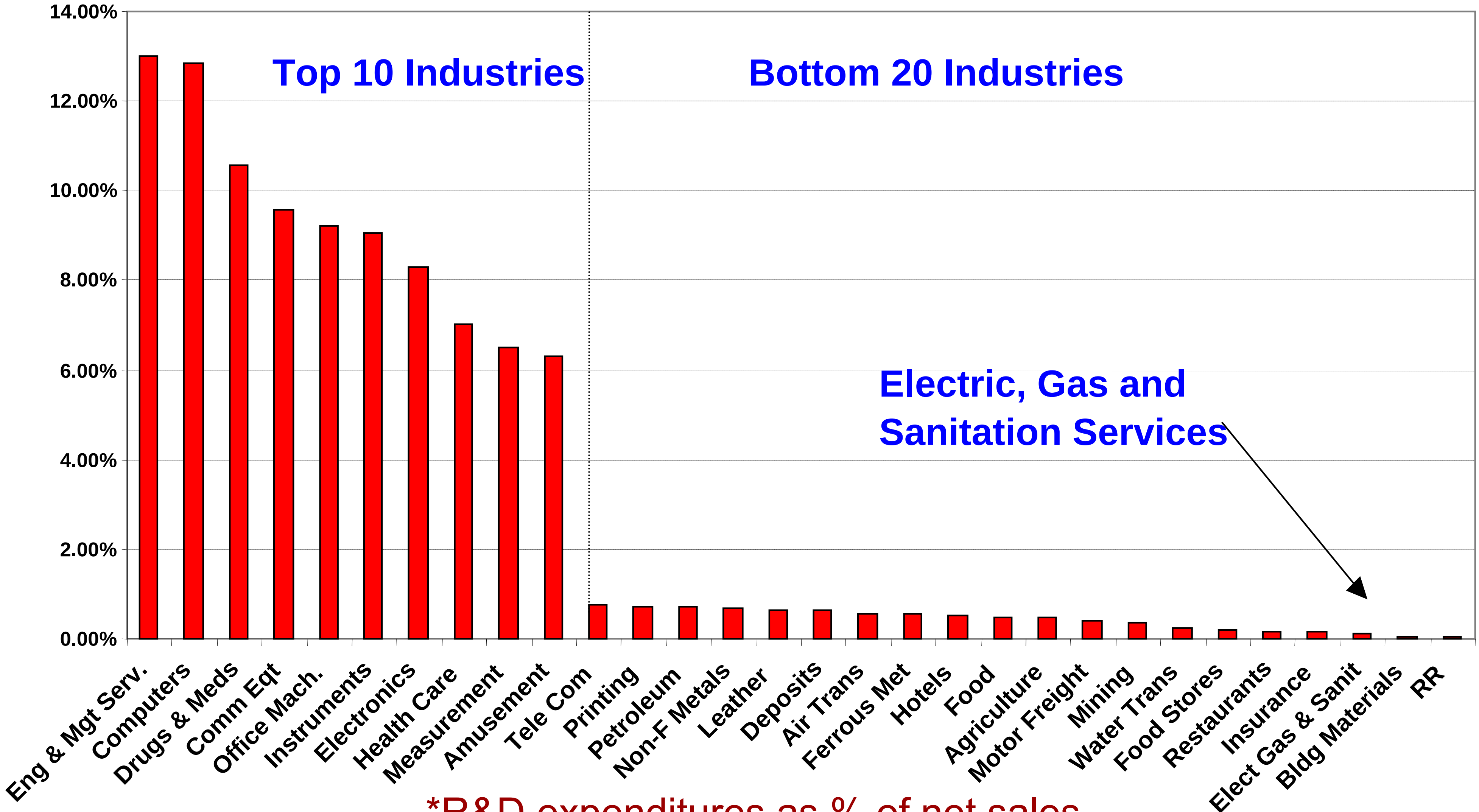
Transforming Society



The vast networks of electrification are the greatest engineering achievement of the 20th century

– U.S. National Academy of Engineering

Context: R&D Expenditures*

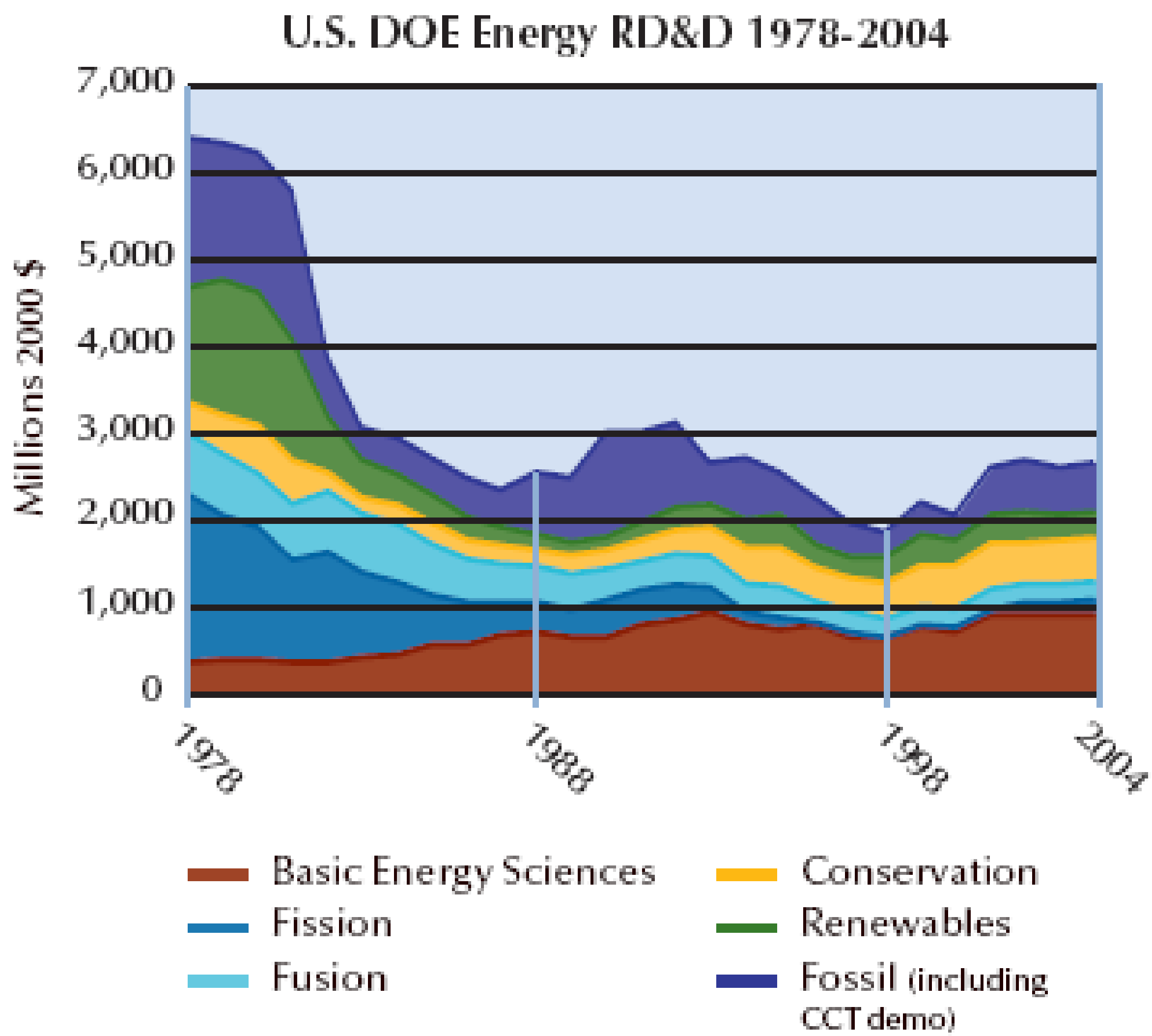


*R&D expenditures as % of net sales

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.

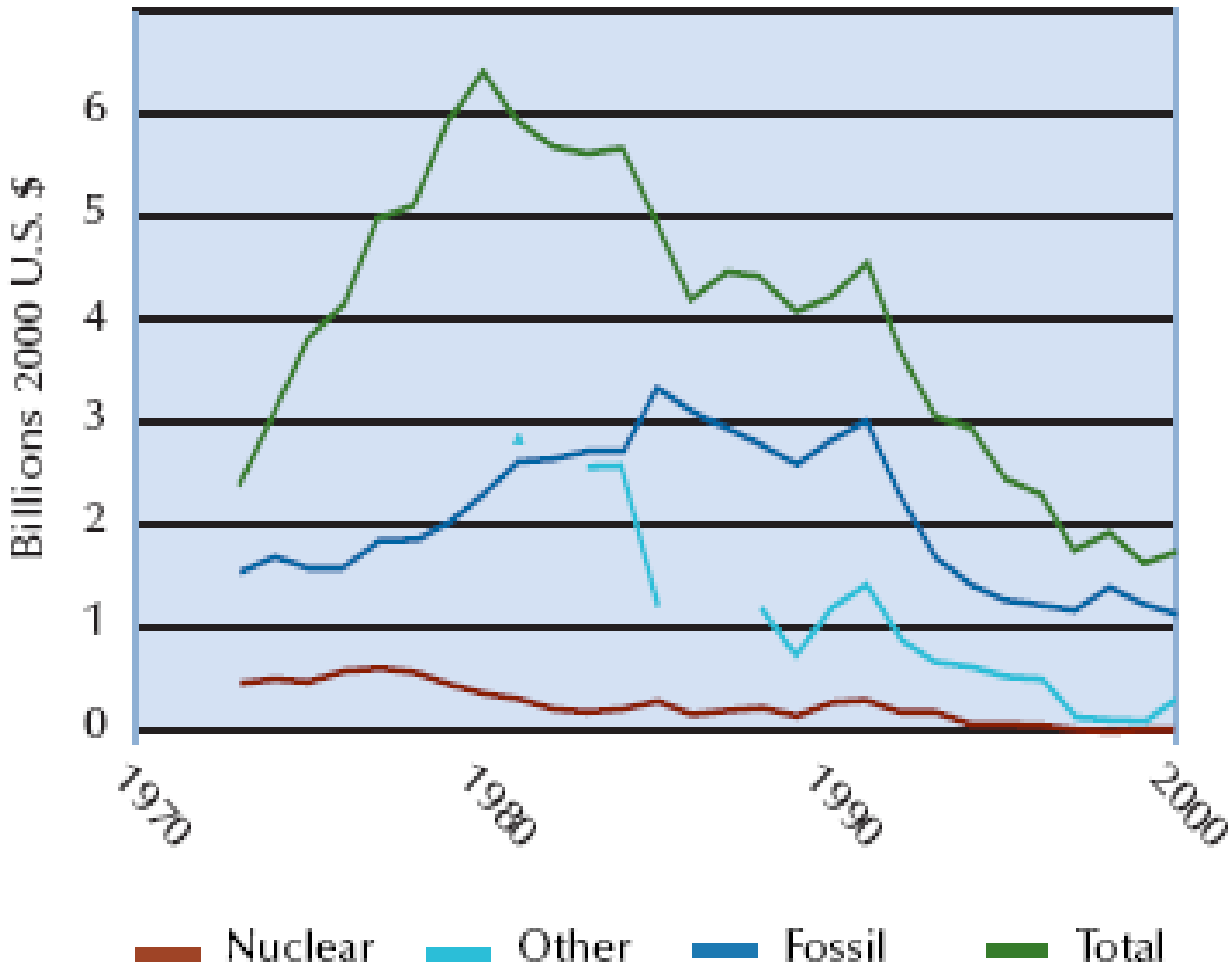
- The part of these appropriations devoted to applied energy-technology RD&D fell from $6.08 B to $1.80B.



Gallagher and Sagar, 2004

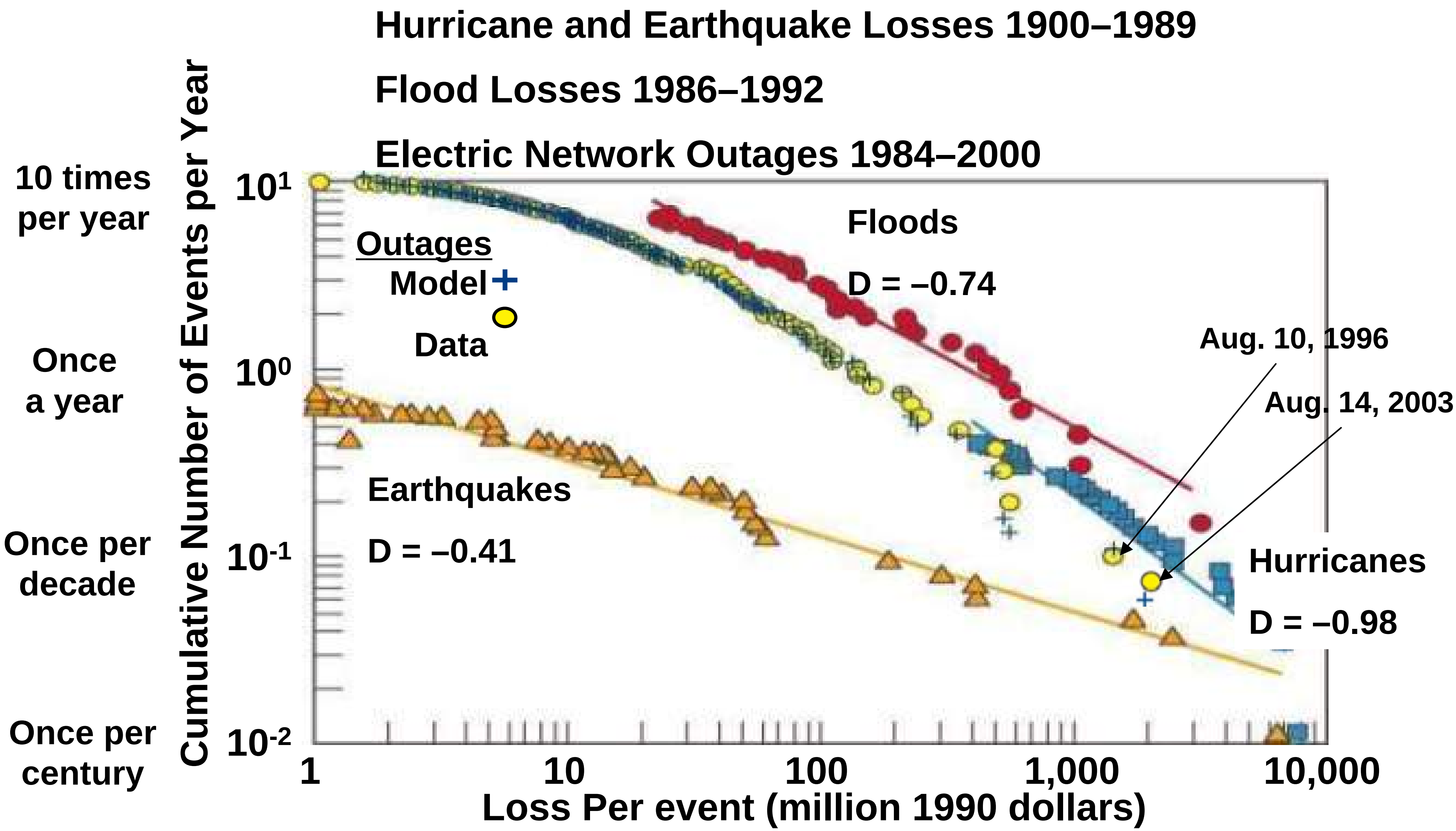
Private Sector Energy RD&D

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.

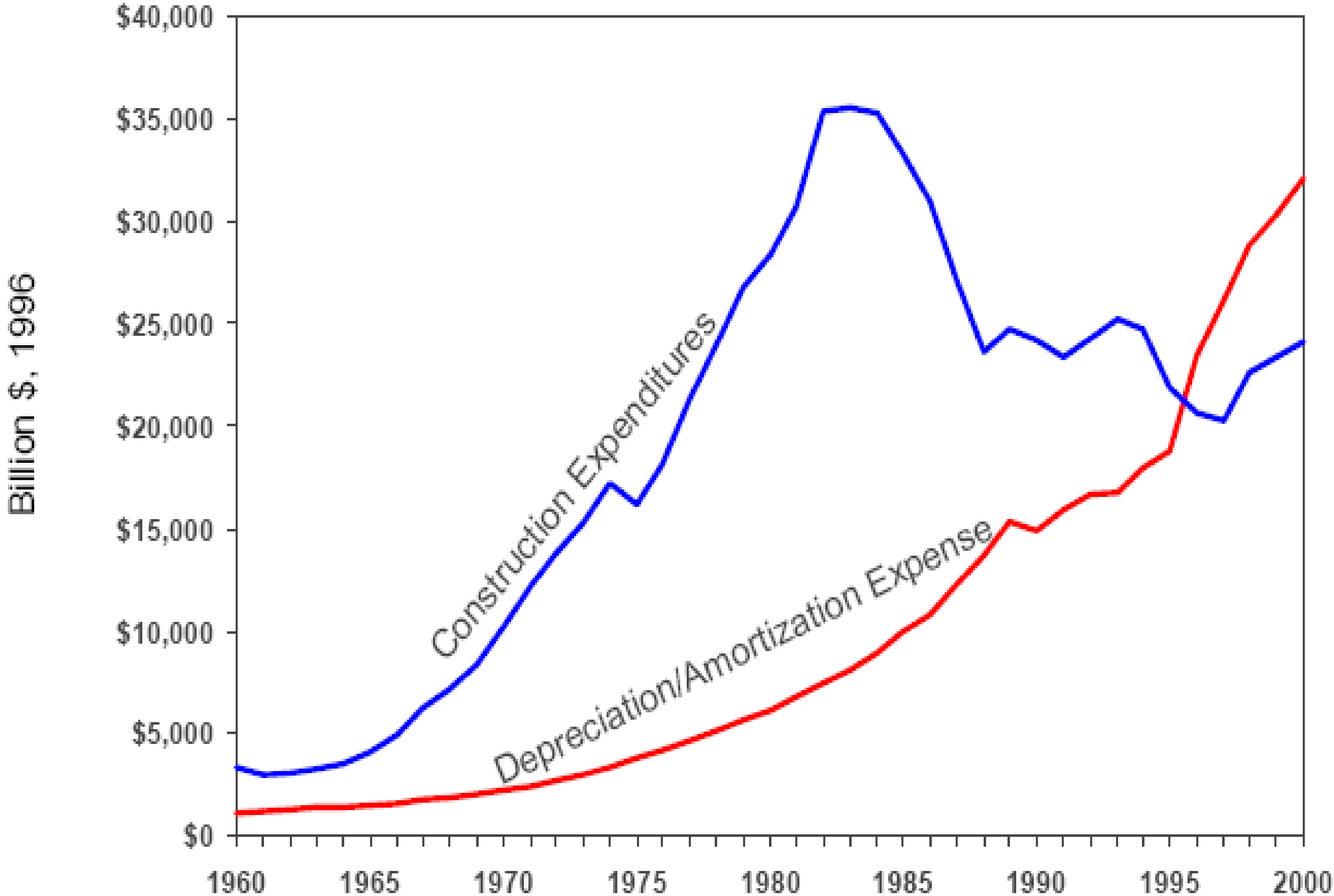


Dooley and Runci, 2004

Power Law Distributions: Frequency & impacts of major disasters



Utility construction expenditures



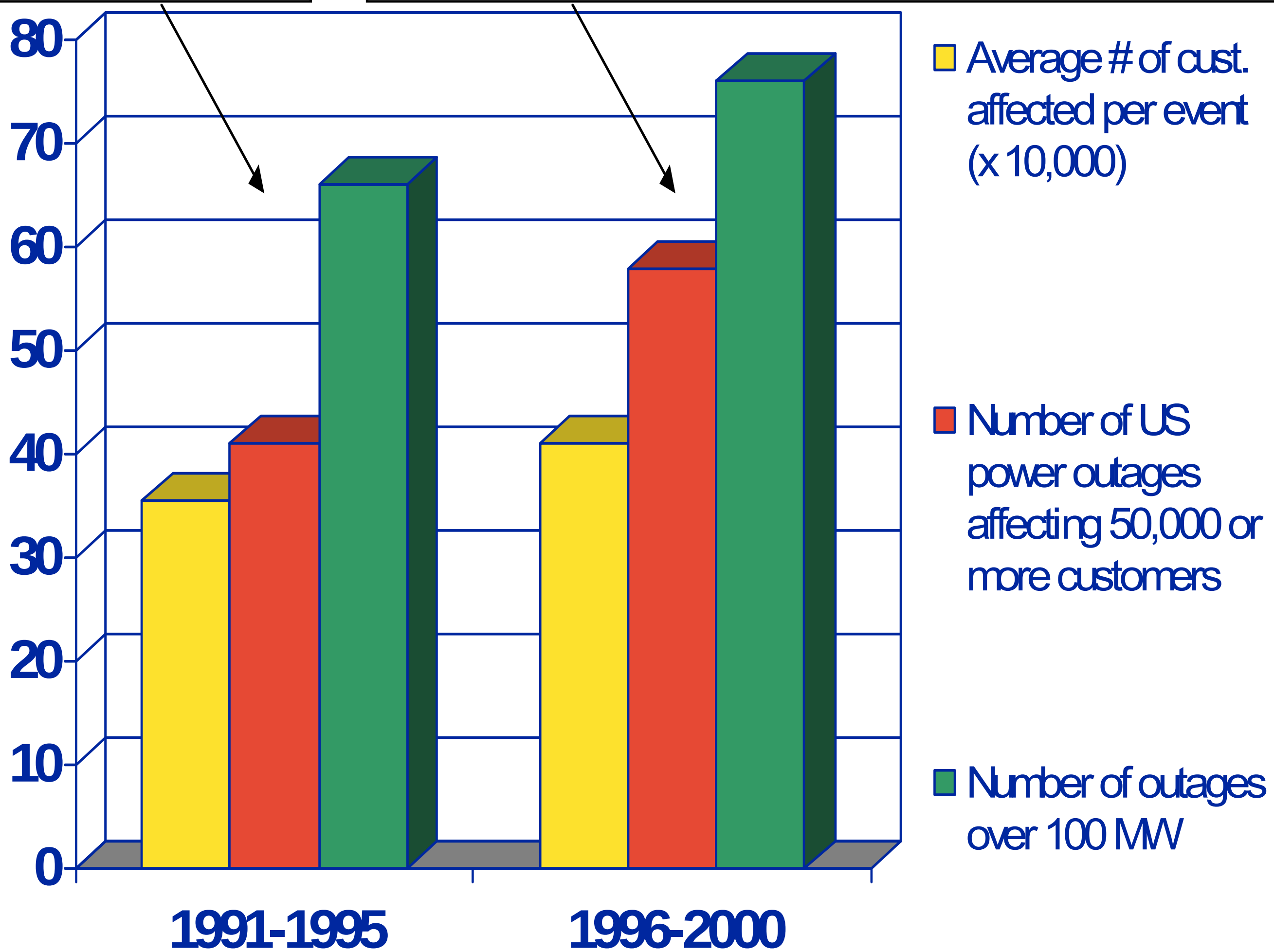
Source: "Historical Statistics of the Electric Utility Industry" and "EEI Statistical Yearbook" - EEI

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

1991-1995	1996-2000
66 Occurrences over 100 MW	76 Occurrences over 100 MW
798 Average MW Lost	1,067 Average MW Lost
41 Occurrences over 50,000 Consumers	58 Occurrences over 50,000 Consumers
355,204* Average Consumers Dropped	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.

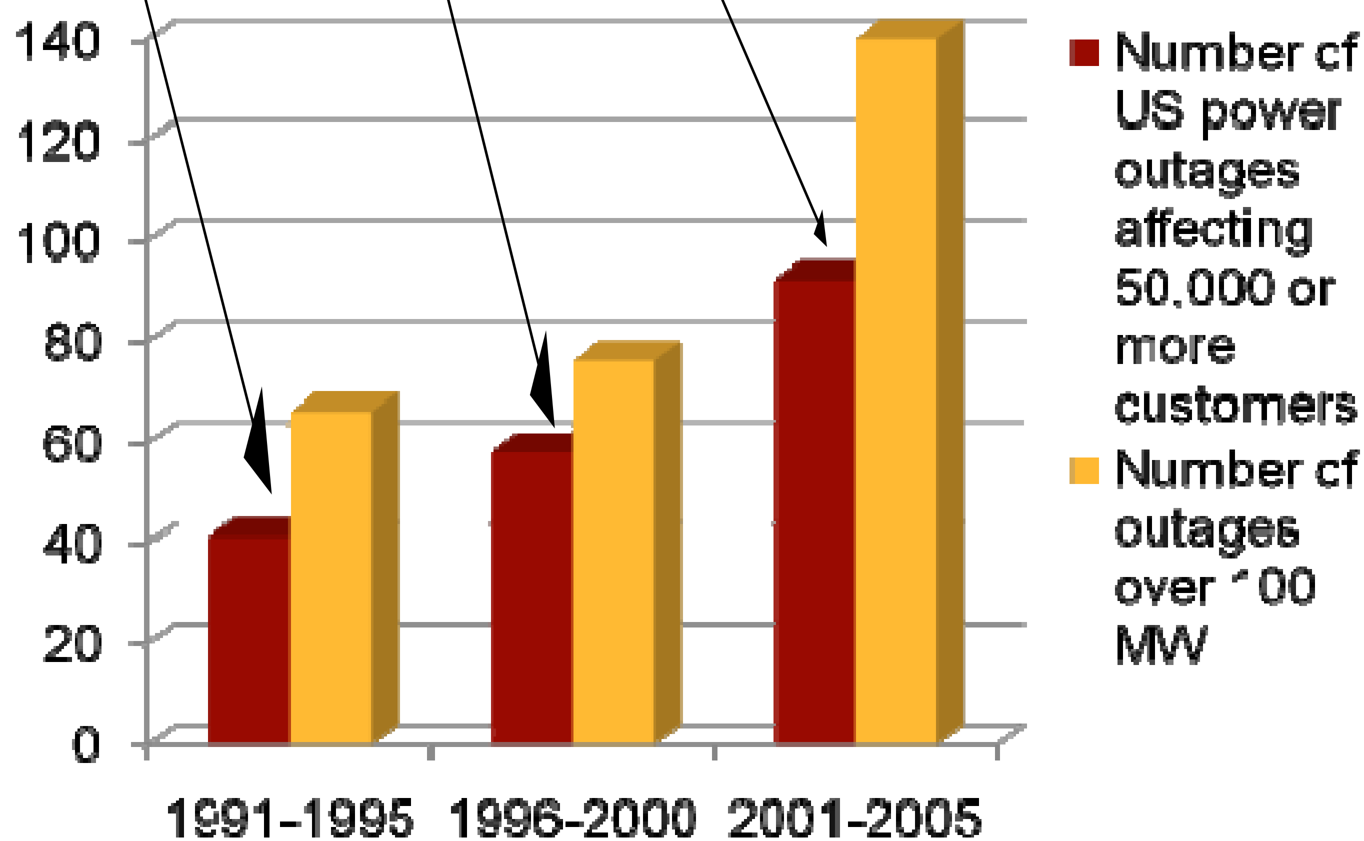
Historical Analysis of U.S. outages (1991-2005)

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

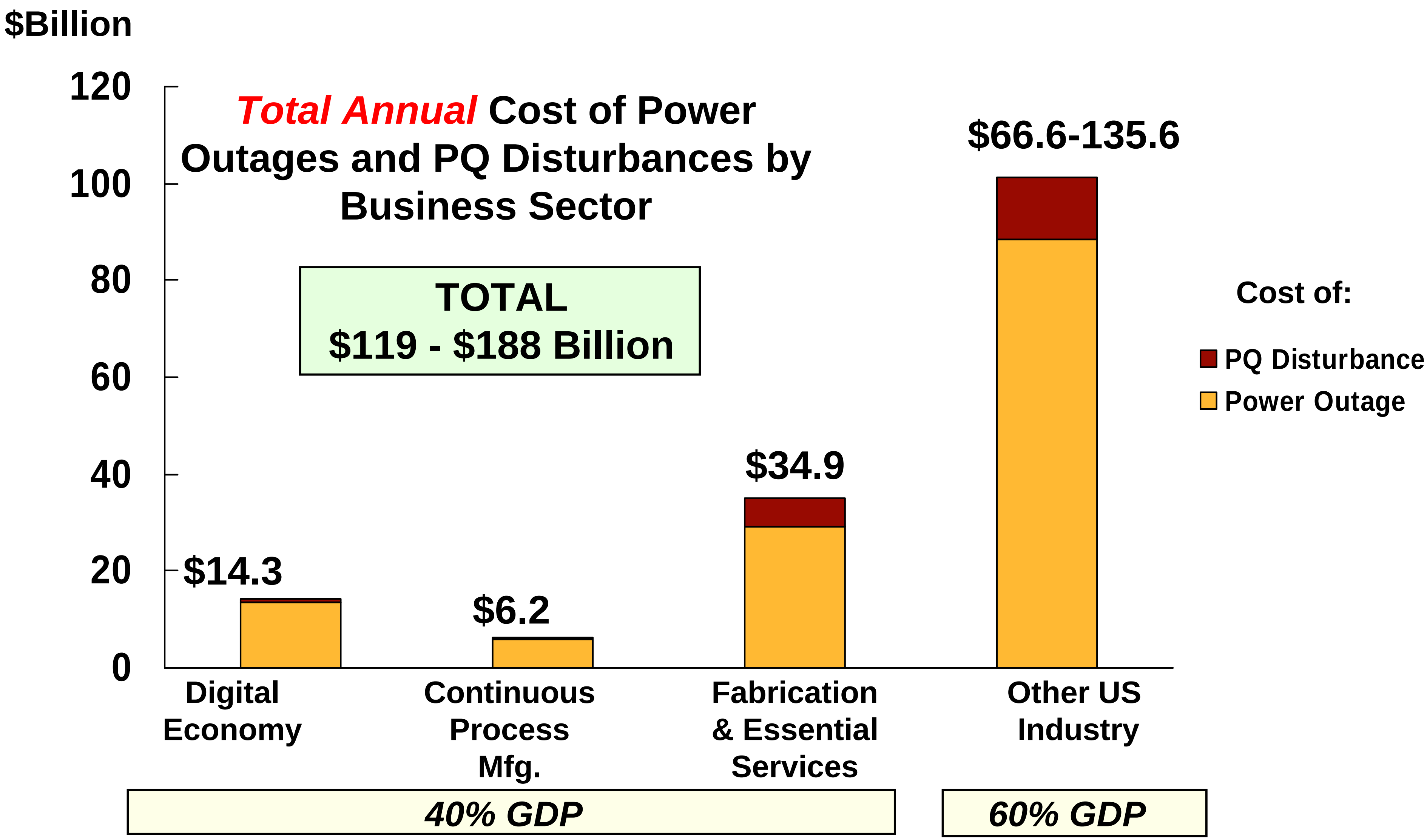
Result: Large blackouts are growing in number and severity.



***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.

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

Center for the Development of Technological Leadership

Transmission investment in the United States and in international competitive markets

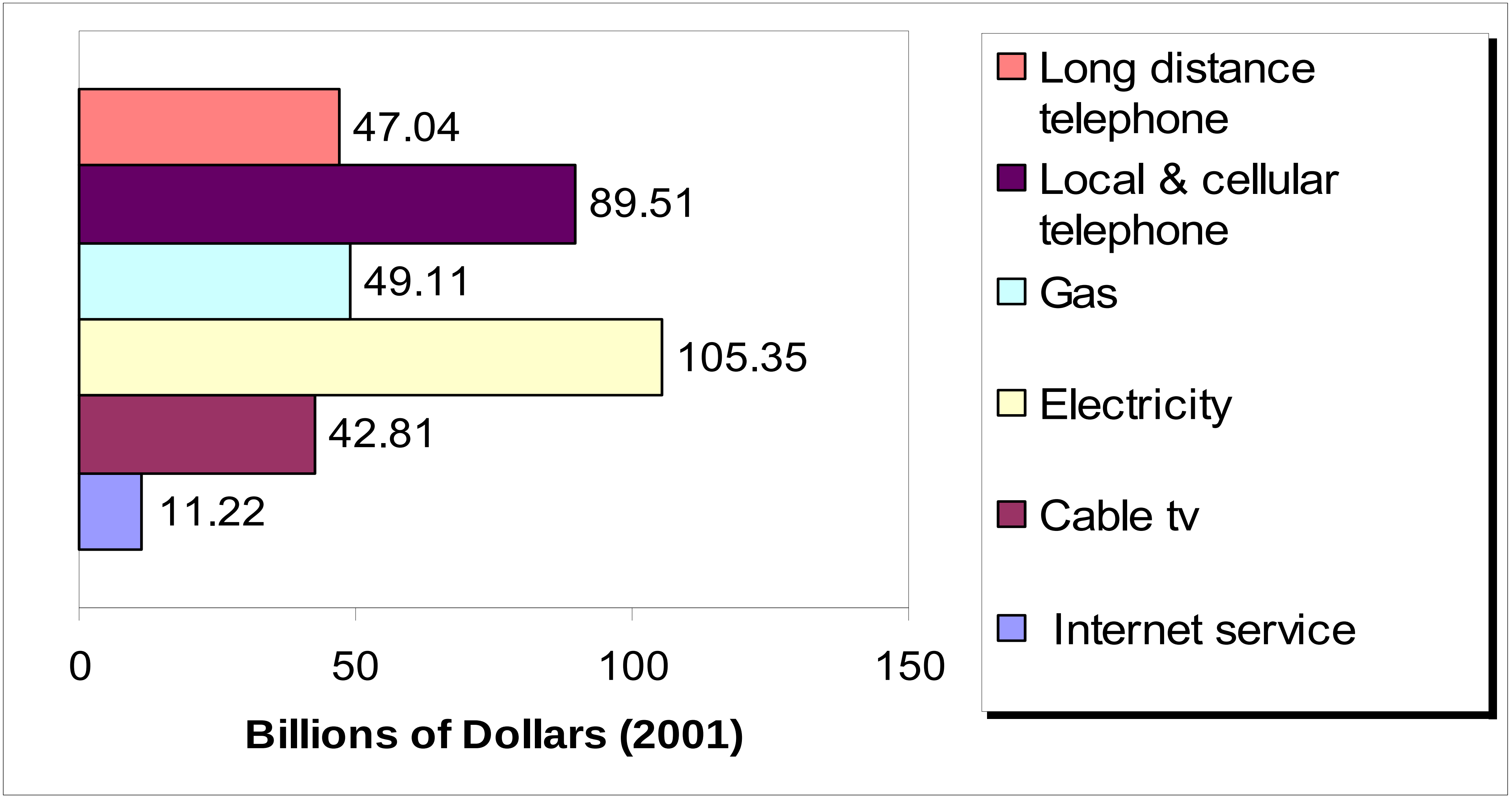
Country	Investment in High Voltage Transmission (>230 kV) Normalized by Load for 2004–2008 (in US$M/GW/year)	Number of Transmission-Owning Entities
New Zealand	22.0	1
England & Wales (NGT)	16.5	1
Denmark	12.5	2
Spain	12.3	1
The Netherlands	12.0	1
Norway	9.2	1
Poland	8.6	1
Finland	7.2	1
United States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

Source: IEEE PES, 2006

Increasing Demand for Security & Quality

- Power, communications, and computing are all converging, making entire systems as sensitive as the most sensitive component
- Secure and reliable combined electric power, communications, fuel supply, and financial networks are essential to today's microprocessor-based economy, public health and safety, and overall quality of life
- The demands of our secure digital economy are outpacing the electricity and communication infrastructures that supports it
- $75B-$180B in annual losses to U.S. from power outages and disturbances

Personal Consumption Expenditures (in Billions of 2001 U.S. Dollars)



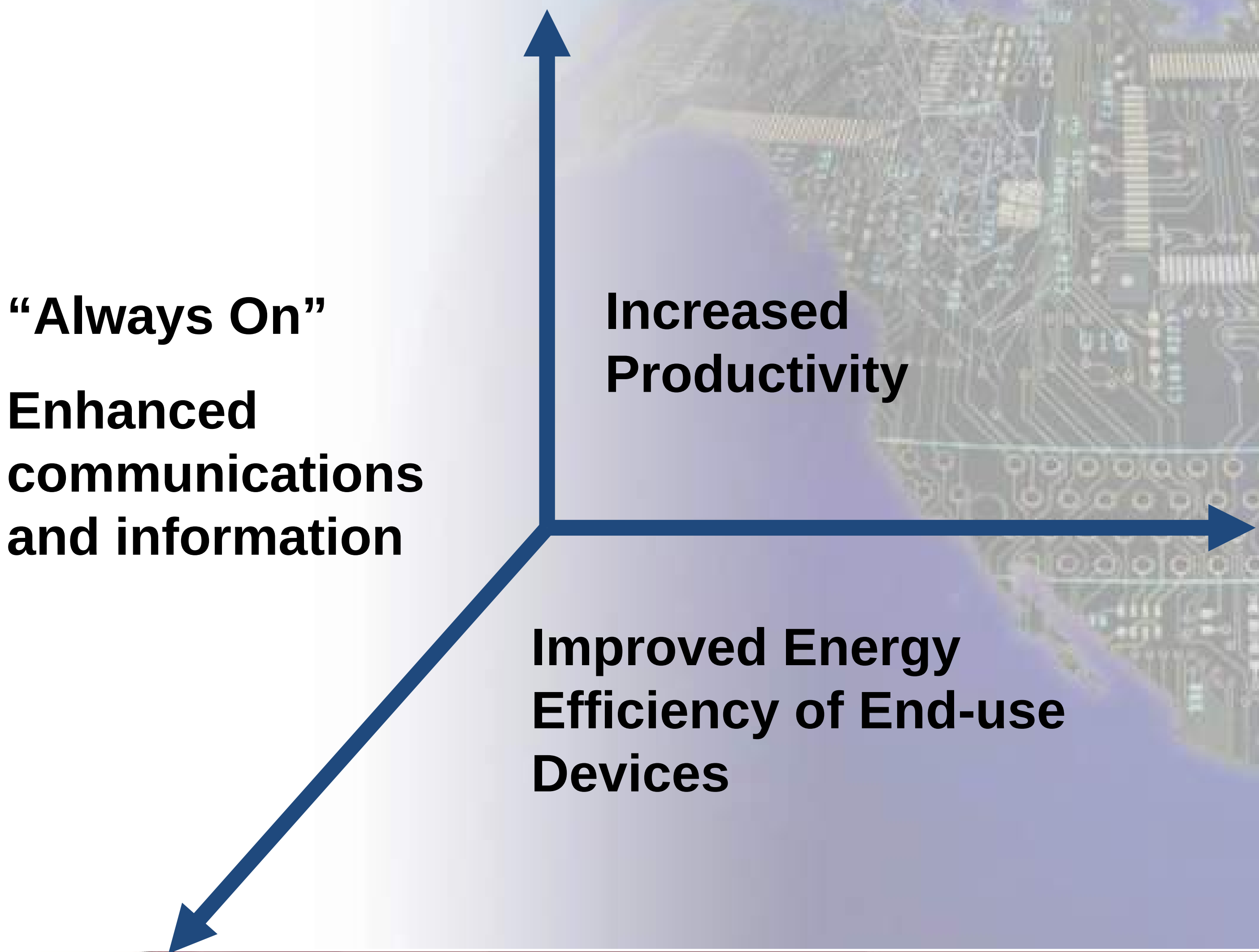
Source: US Dept of Commerce, Personal Expenditure Detail Data, File 206U, 01/03

Dimensions of the Digital Society: Benefits

Enhanced Quality of Life

Reduced Energy Demand

Increased Industrial Competitiveness



Context: IT interdependencies and impact

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

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

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

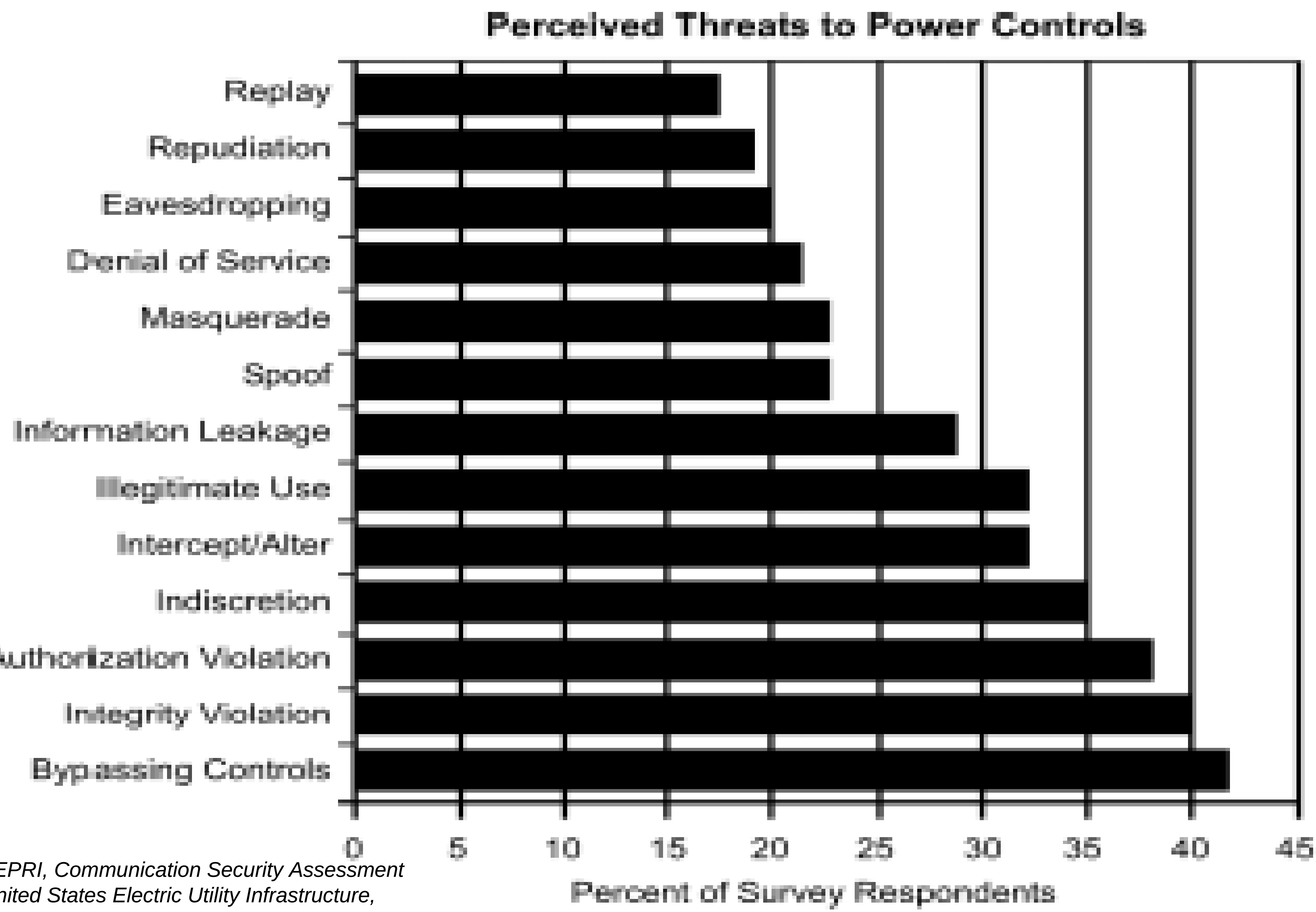
Assessing the Most Effective Security Investments: Probabilistic and dynamic assessments can offer strategic guidance on where and how to deploy security resources to greatest advantage.

Four Areas of Vulnerability

SQRA

- **Security of power delivery and market systems**
- **Quality of information and energy supplied**
- **Reliability of interdependent infrastructures**
- **Availability of affordable services**

Cyber Threats to Controls



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

Electric Company Vulnerability Assessment

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

Much of the above determined from over 1200 miles away.

Definition: Resilience

- **What is “Resilience”?**
  - 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** is the property of a material to absorb energy when it is deformed elastically and then, upon unloading to have this energy recovered. In other words, it is the maximum energy per volume that can be elastically stored. It is represented by the area under the curve in the elastic region in the Stress-Strain diagram.
  - **Resilience** in psychology is the positive capacity of people to cope with stress and catastrophe. It is also used to indicate a characteristic of resistance to future negative events. In this sense "resilience" corresponds to cumulative "protective factors" and is used in opposition to cumulative "risk factors".
  - The phrase "risk and resilience“ are commonly used terms, which are essentially synonymous within psychology, are "resilience", "psychological resilience", "emotional resilience", "hardiness", and "resourcefulness".
- **What is “Robustness”?**
  - The quality of being able to withstand stresses, pressures, or changes in procedure or circumstance. Assuring overall system stability and performance in presence of modeling uncertainty, disturbances and noise.
  - A system, organism or design may be said to be "robust" if it is capable of coping well with variations (sometimes unpredictable variations) in its operating environment with minimal damage, alteration or loss of functionality.

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 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.

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

EPRI/DoD Complex Interactive Networks (CIN/SI)

Underpinnings of Interdependent Critical National Infrastructures

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

Y2K2000-present

Enterprise Information Security (EIS)

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

2002-present

Infrastructure Security Initiative (ISI)

Response to 9/11 Tragedies

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

2001-present

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

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

Foundations: 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

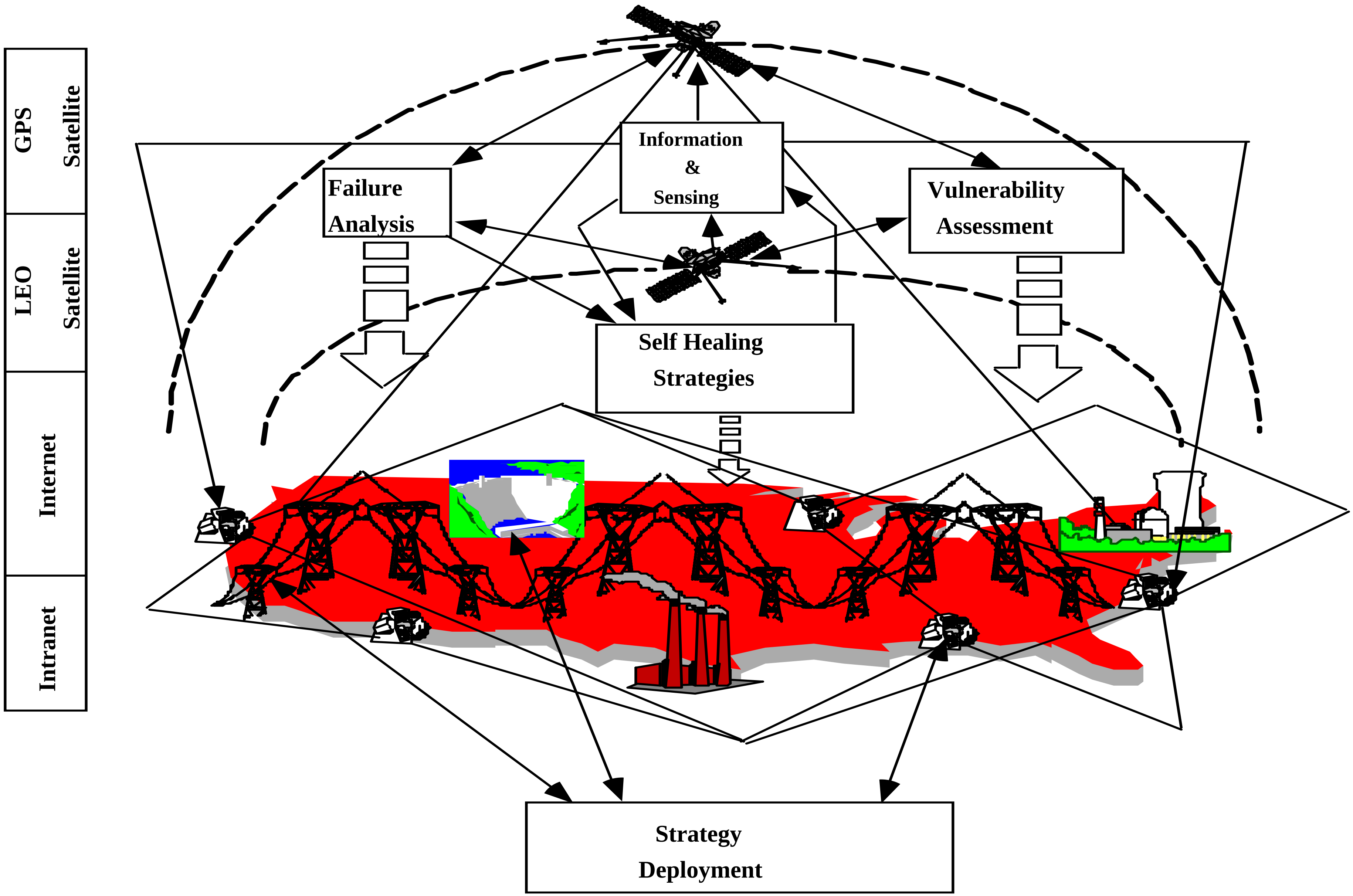
1999-2001: $5.2M / year — Equally Funded by DoD/EPRI

Complex interactive networks:

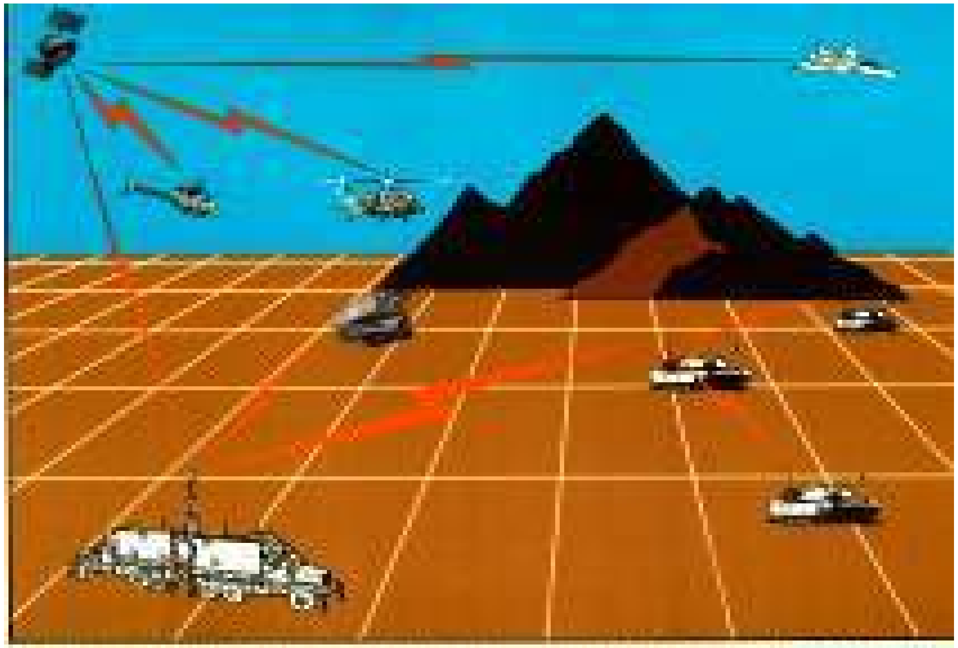
- *Energy infrastructure*: Electric power grids, water, oil and gas pipelines
- *Telecommunication:* Information, communications and satellite networks; sensor and measurement systems and other continuous information flow systems
- *Transportation and distribution networks*
- *Energy markets, banking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

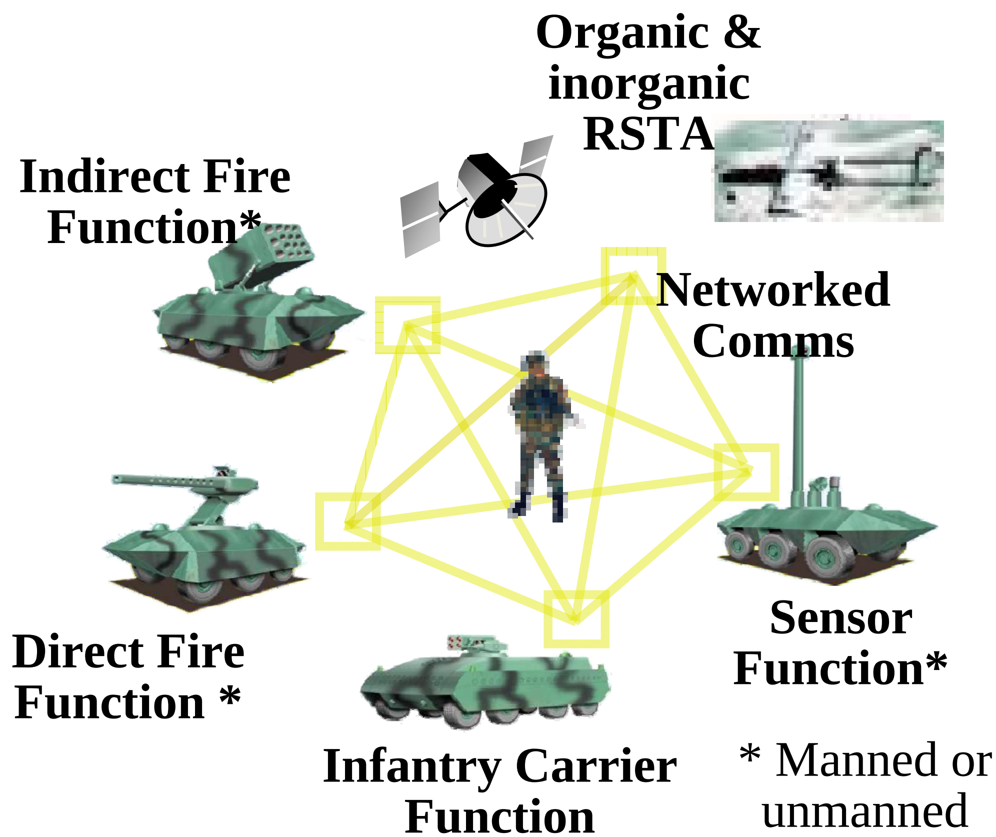
Develop tools that enable secure, robust and reliable operation of interdependent infrastructures with distributed intelligence and self-healing abilities

Complex Interactive Networks



Network Centric Objective Force





CIN/SI Funded Consortia

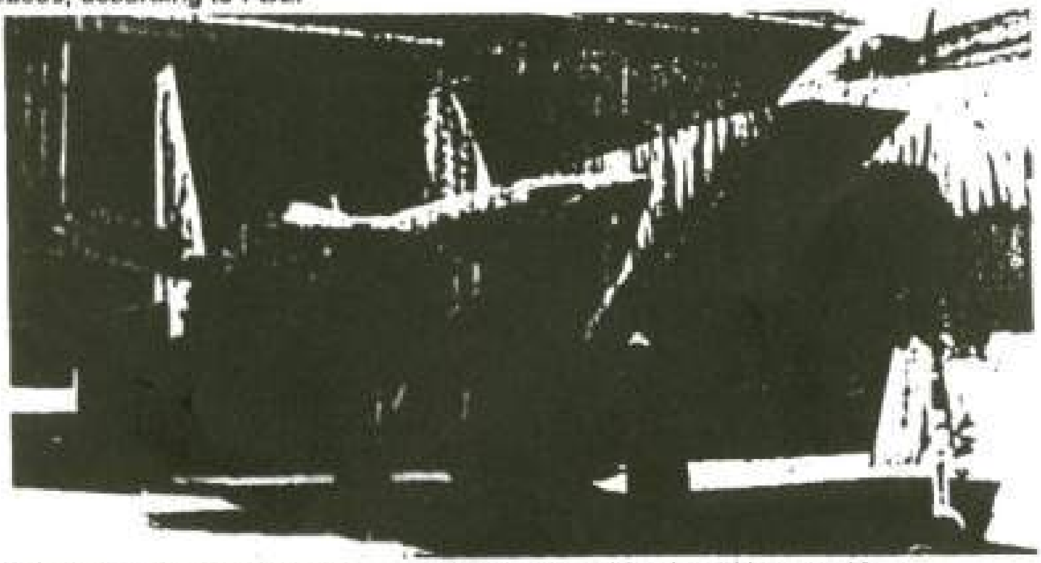
107 professors in 28 U.S. universities are funded: Over 360 publications, and 24 technologies extracted, in the 3-year initiative

- U Washington, Arizona St., Iowa St., VPI
- Purdue, U Tennessee, Fisk U, TVA, ComEd
- 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

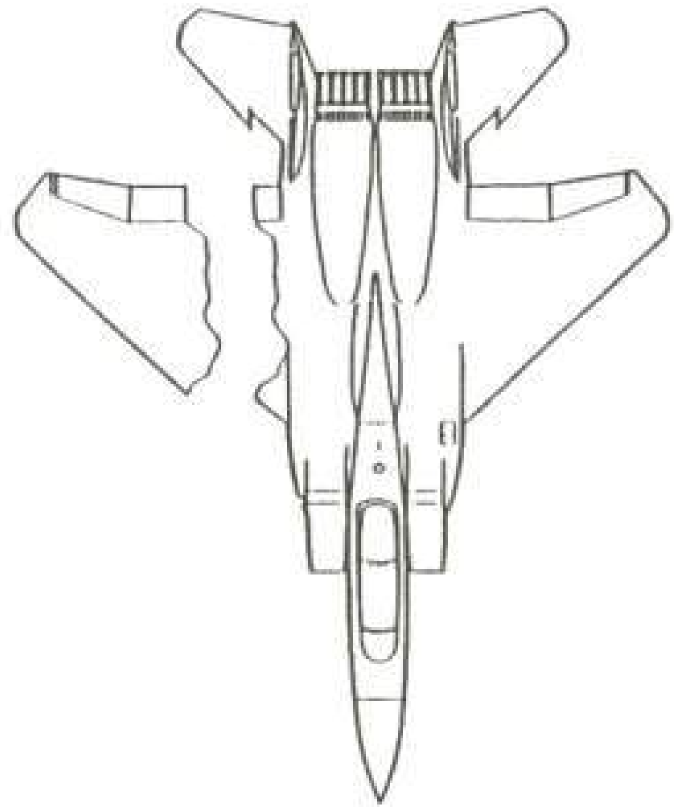
- Defense Against Catastrophic Failures, Vulnerability Assessment
- Intelligent Management of the Power Grid
- Modeling and Diagnosis Methods
- Minimizing Failures While Maintaining Efficiency / Stochastic Analysis of Network Performance
- Context Dependent Network Agents
- Mathematical Foundations: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

Background: The Case of the Missing Wing

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.

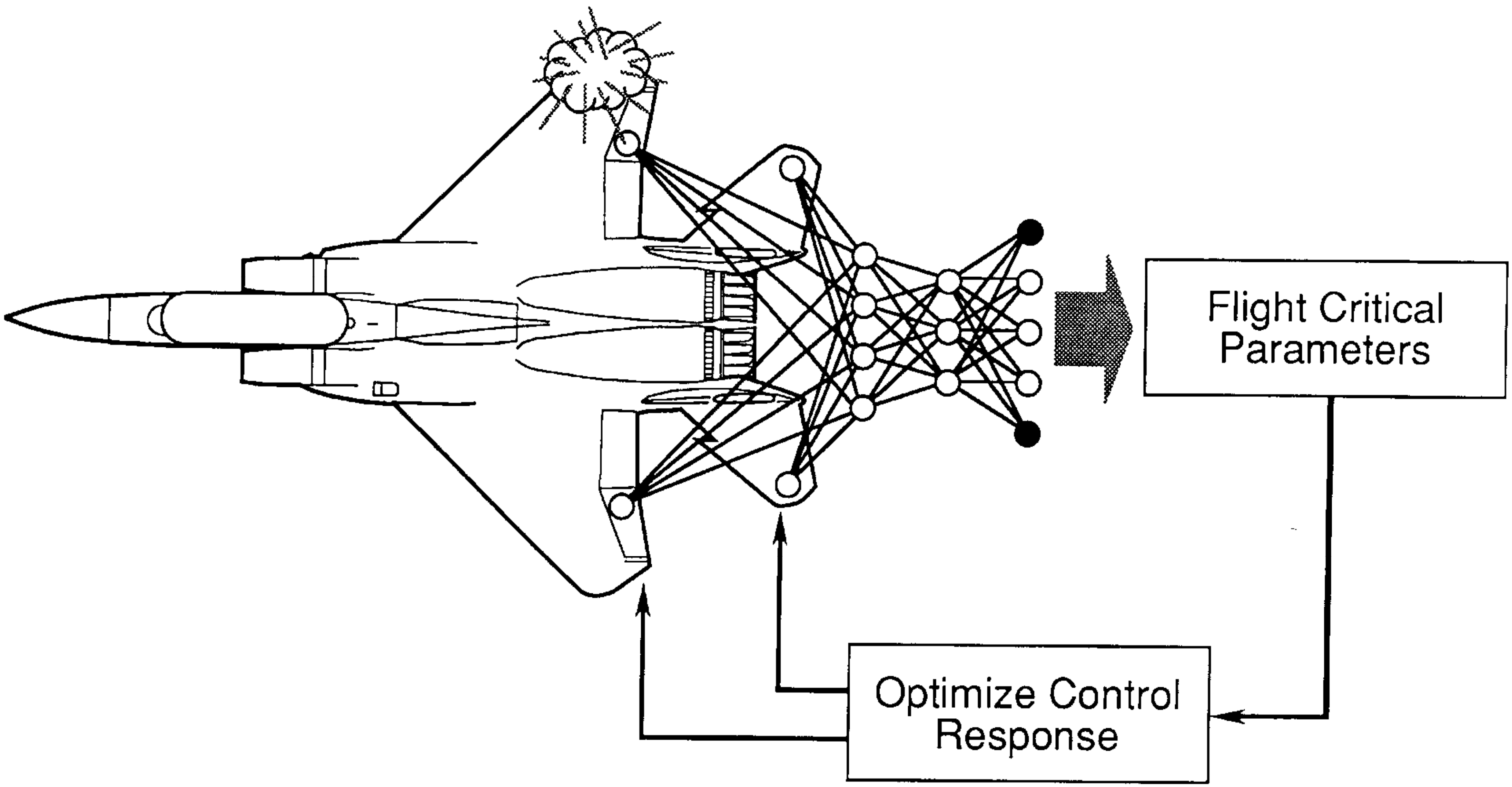


Only smart work by the pilot and the unique combination of interworking control surfaces on the F-15 brought this one back alive. With old-fashioned conventional ailerons and horizontal stabilizer, it couldn't have happened.



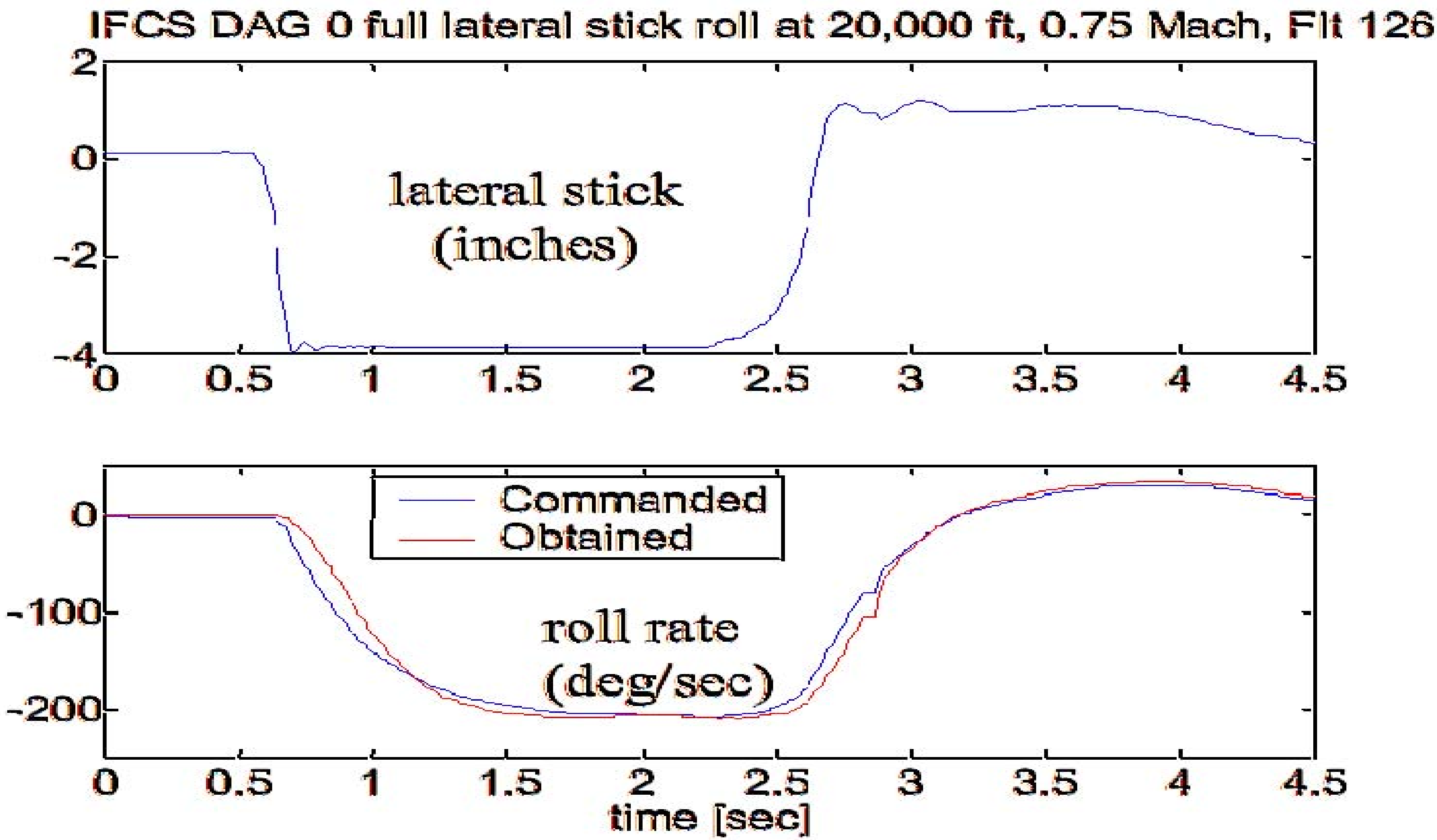
NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden Flight Research Center, Boeing Phantom Works, and Washington University in St. Louis.

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



NASA/MDA/WU IFCS

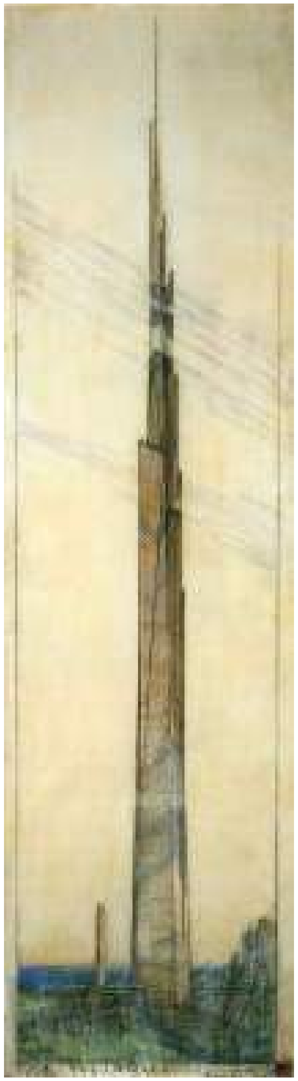
Roll Axis Response of the Intelligent Flight Control System



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.

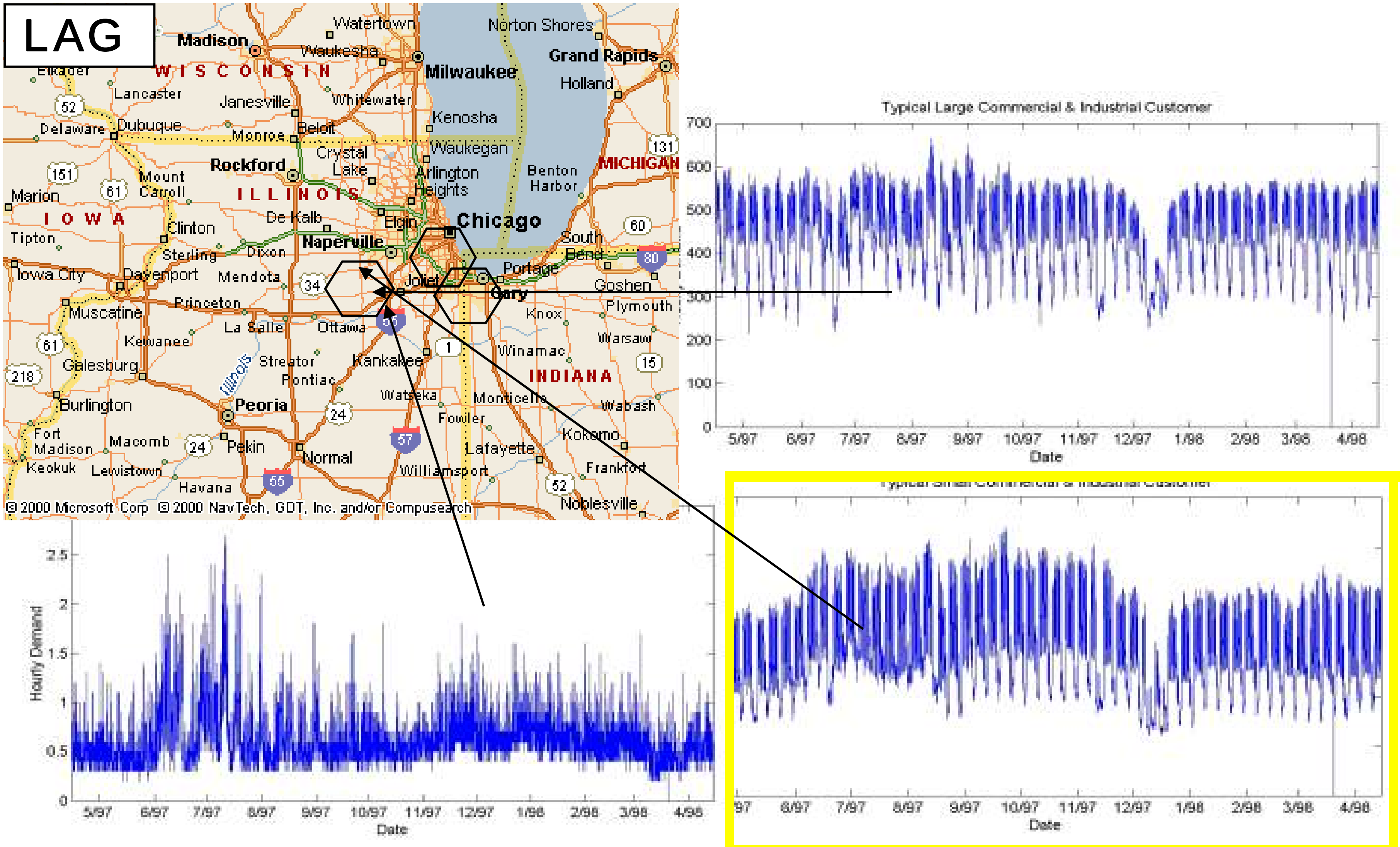
Self-healing Grid



Building on the Foundation:

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

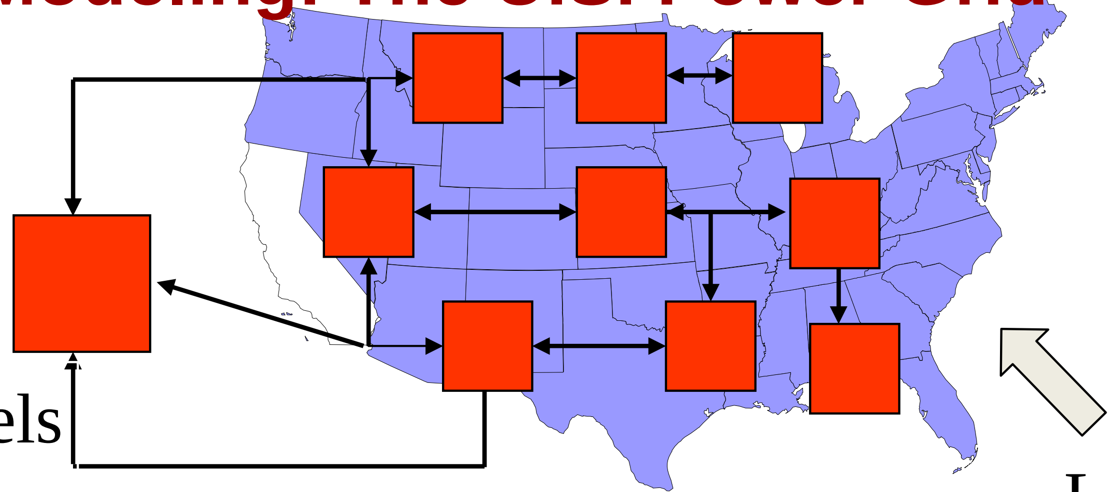
Local area grids (LAG)



Look-Ahead Simulation Applied to Multi-Resolution Models

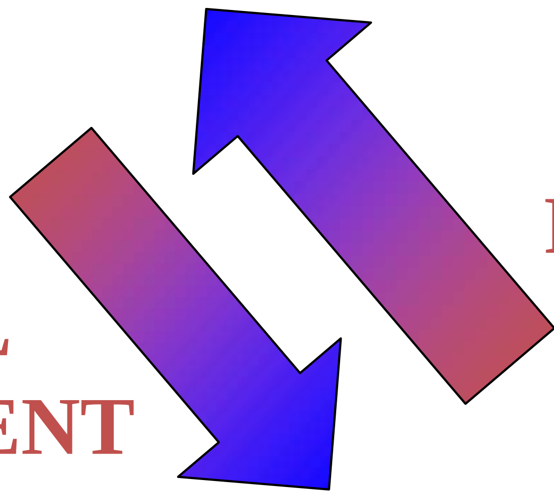
- Provides faster-than-real-time simulation
  - By drawing on approximate rules for system behavior, such as power law distribution
  - By using simplified models of a particular system
- Allows system operators to change the resolution of modeling at will
  - Macro-level (regional power systems)
  -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

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



Simplified models

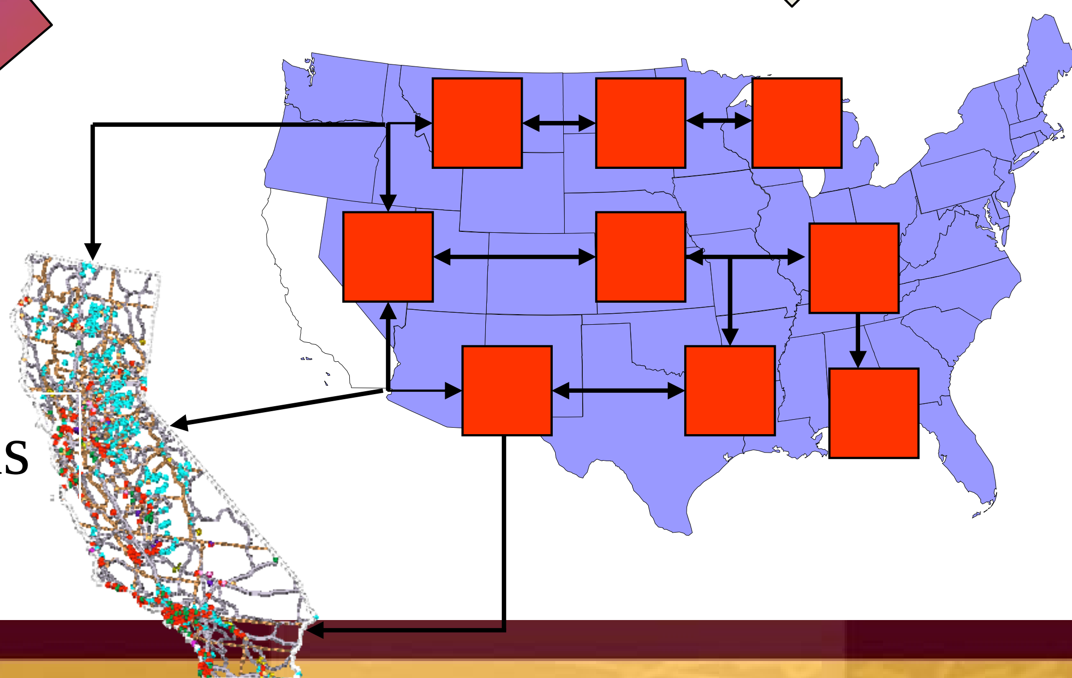
Low-resolution model



MODEL REDUCTION

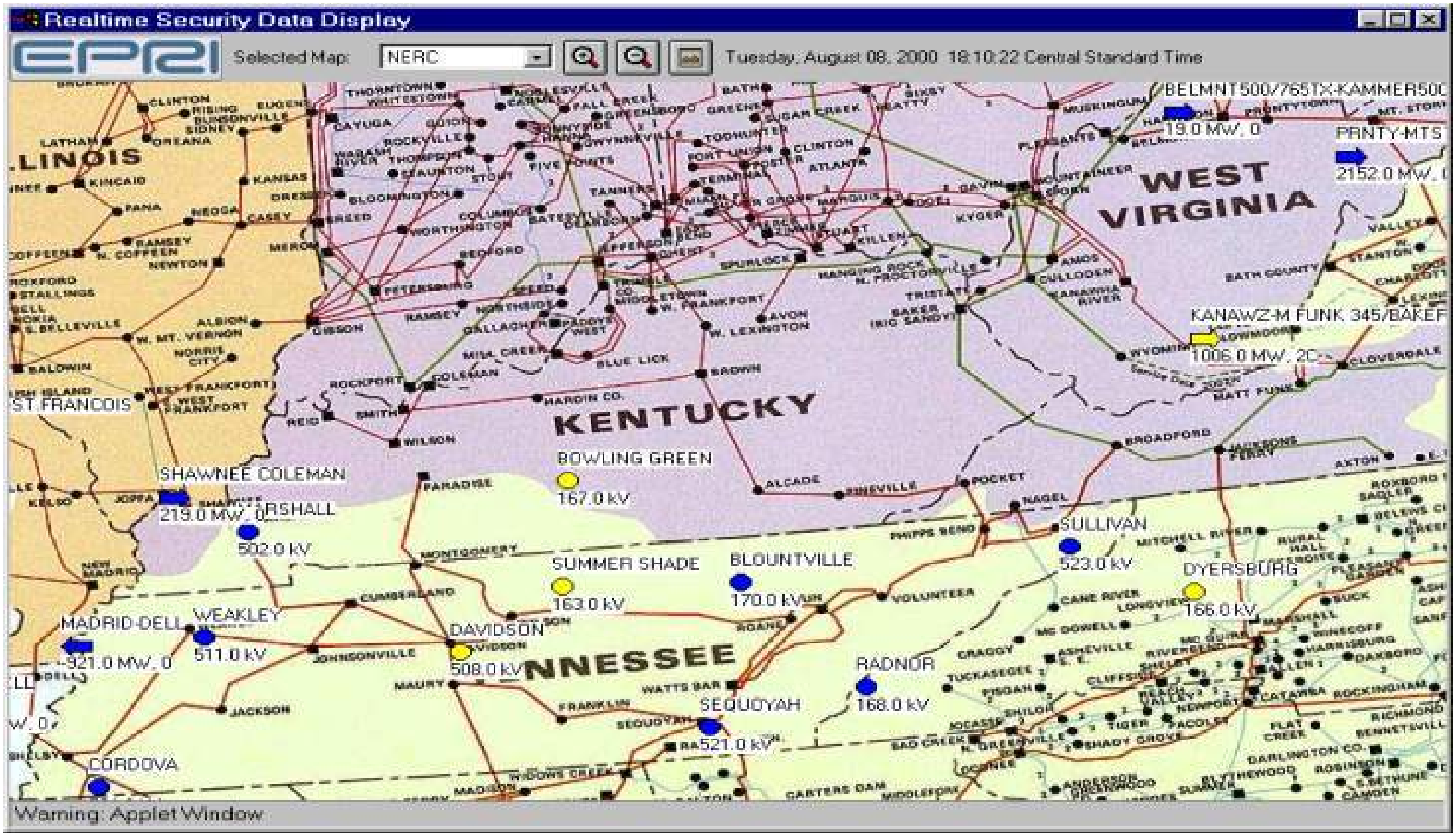
MODEL REFINEMENT

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



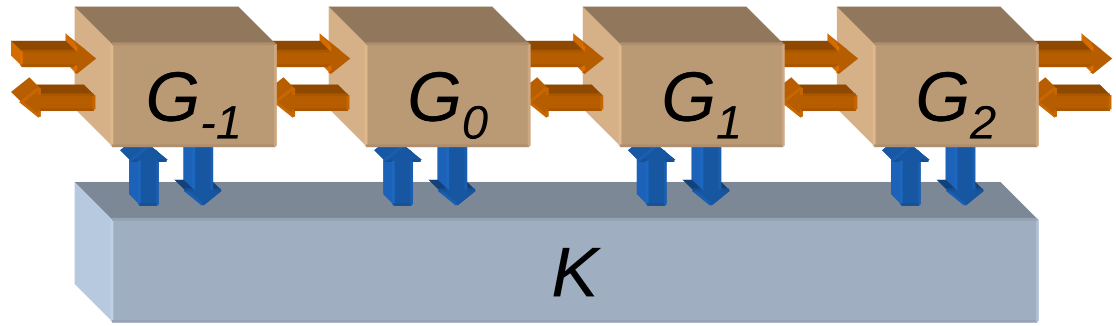
Detailed models

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

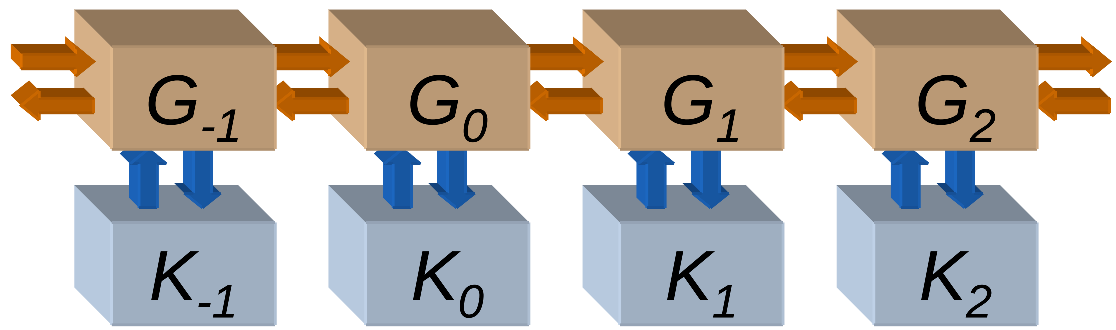


Control Strategies

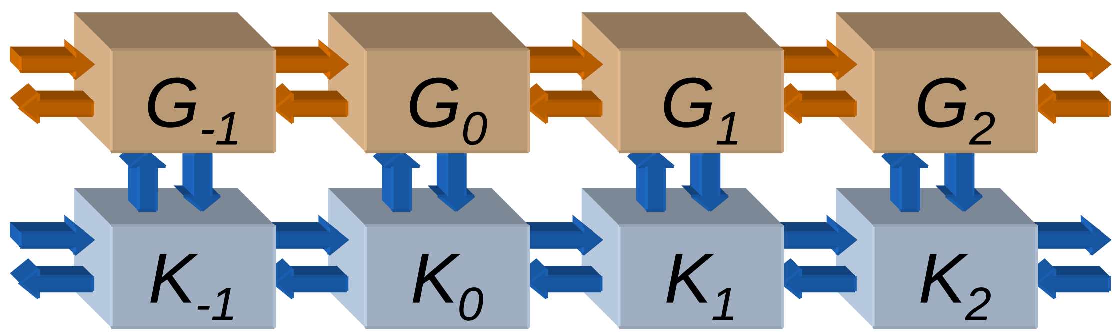
- Centralized



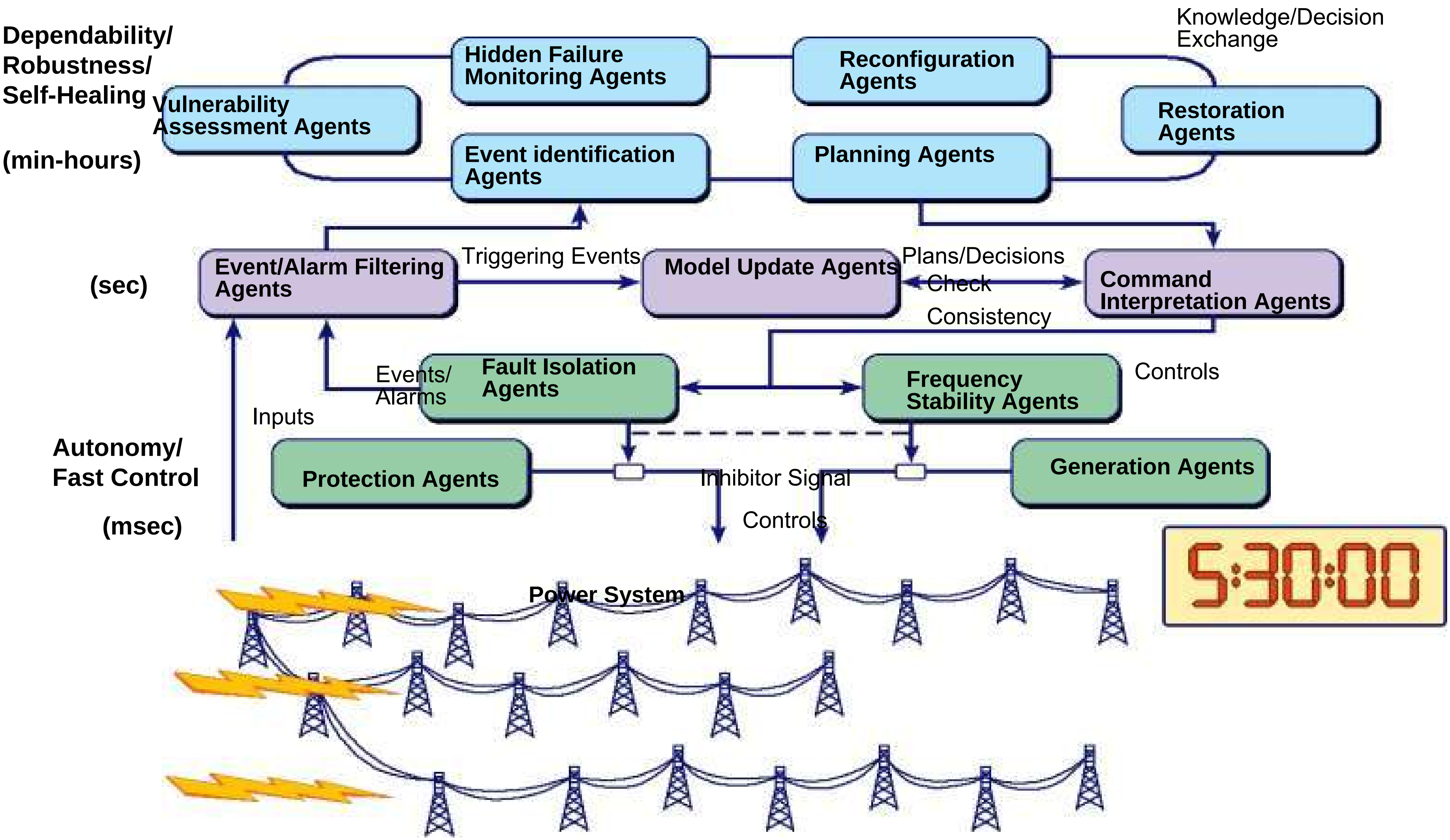
- Perfectly decentralized



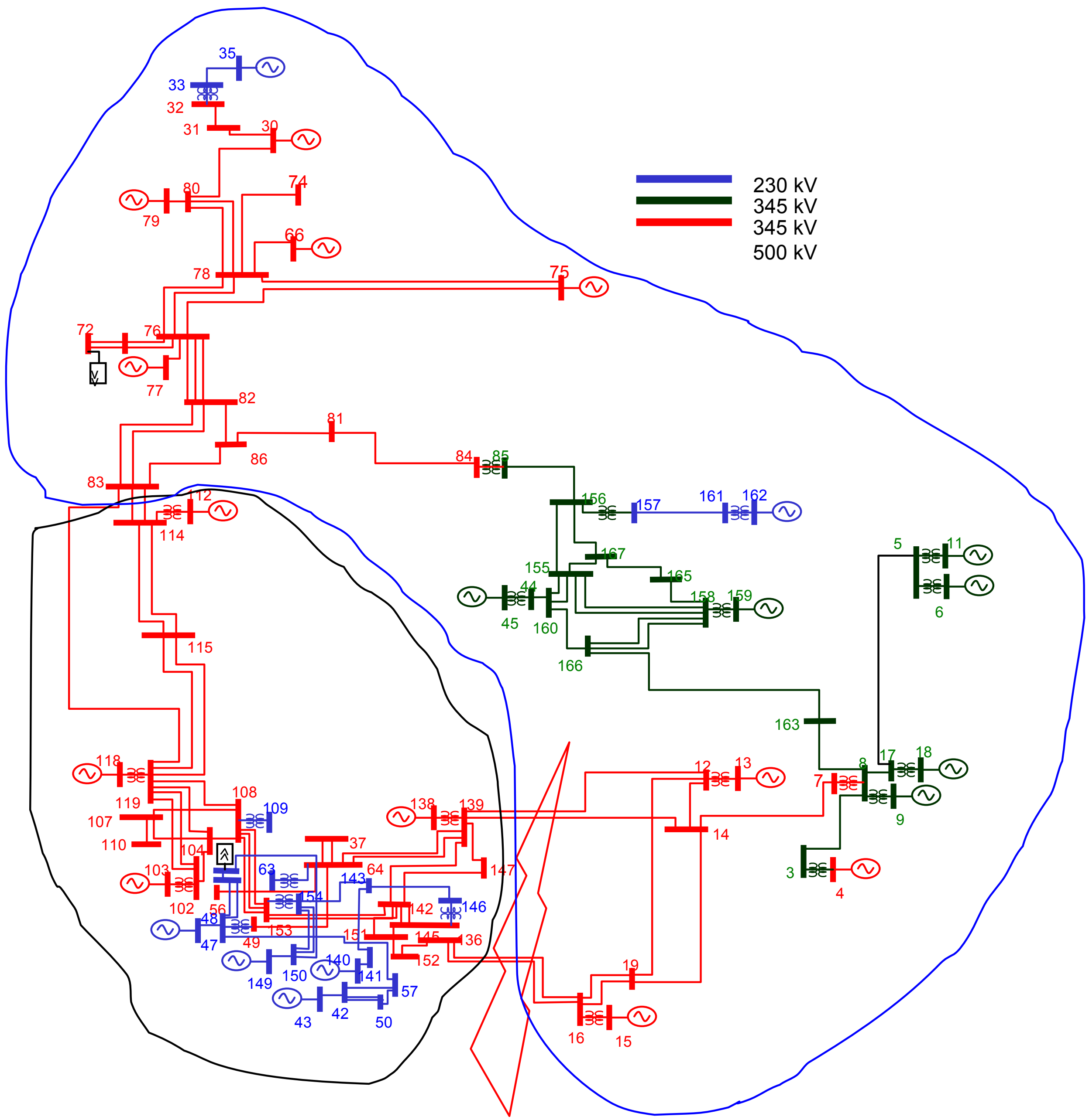
- Distributed



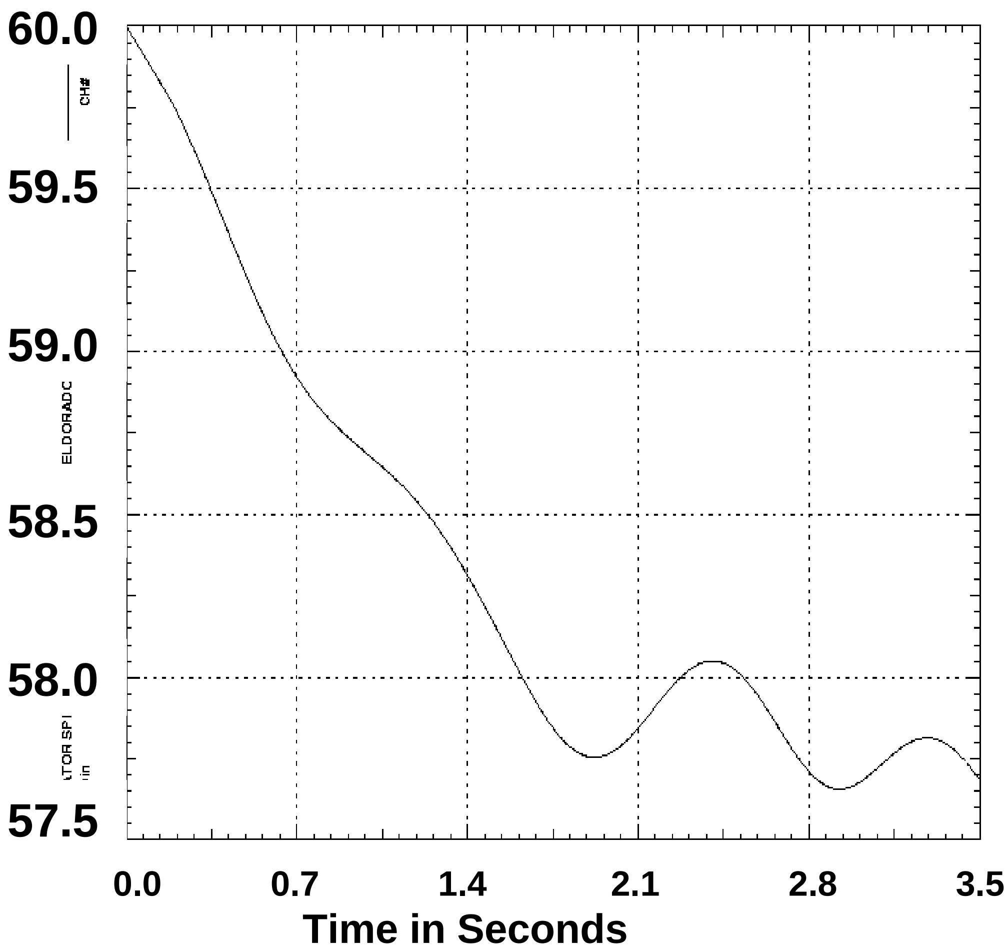
The Self-Healing Grid

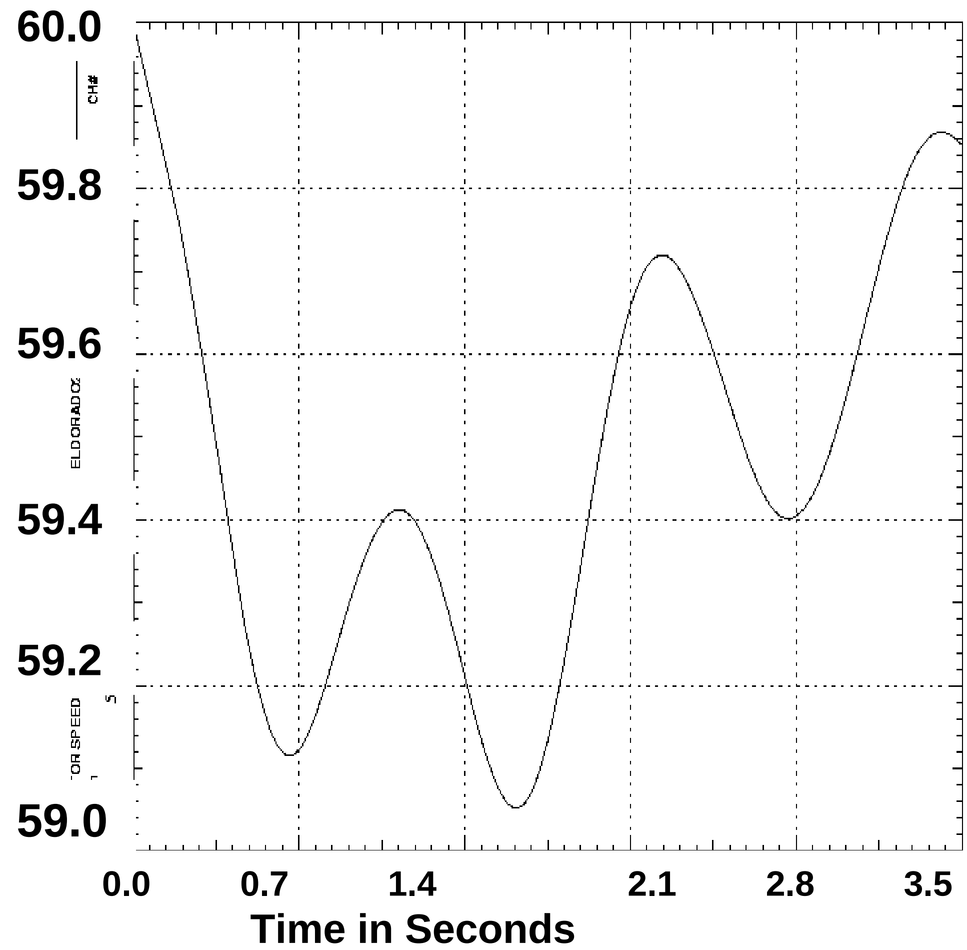


Islanding by Slow Coherency



Background: Simulation Result

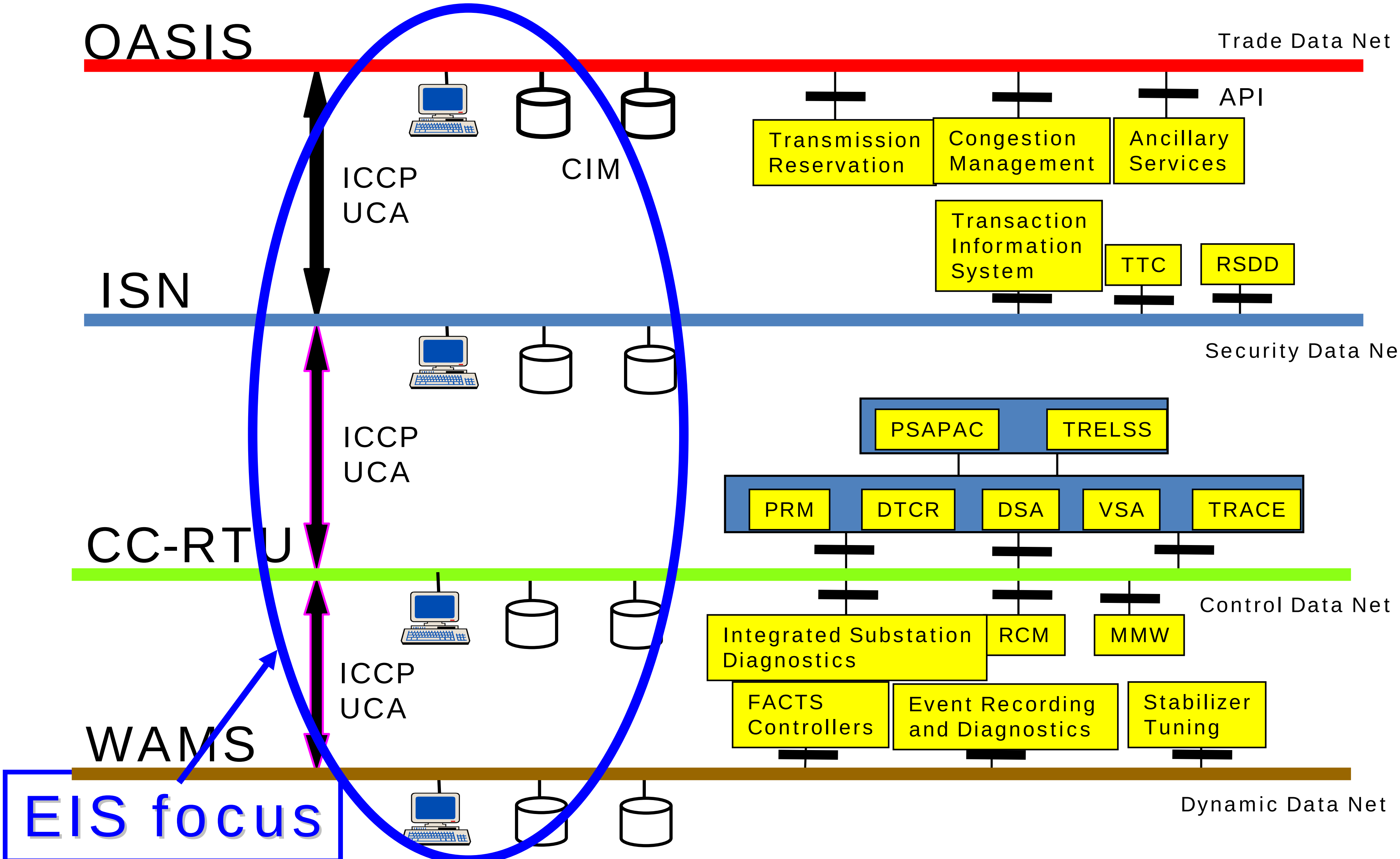




No Load Shedding Scheme

New Scheme

Information Networks for On-Line Trade, Security and Control



Prioritization: Security Index

General

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

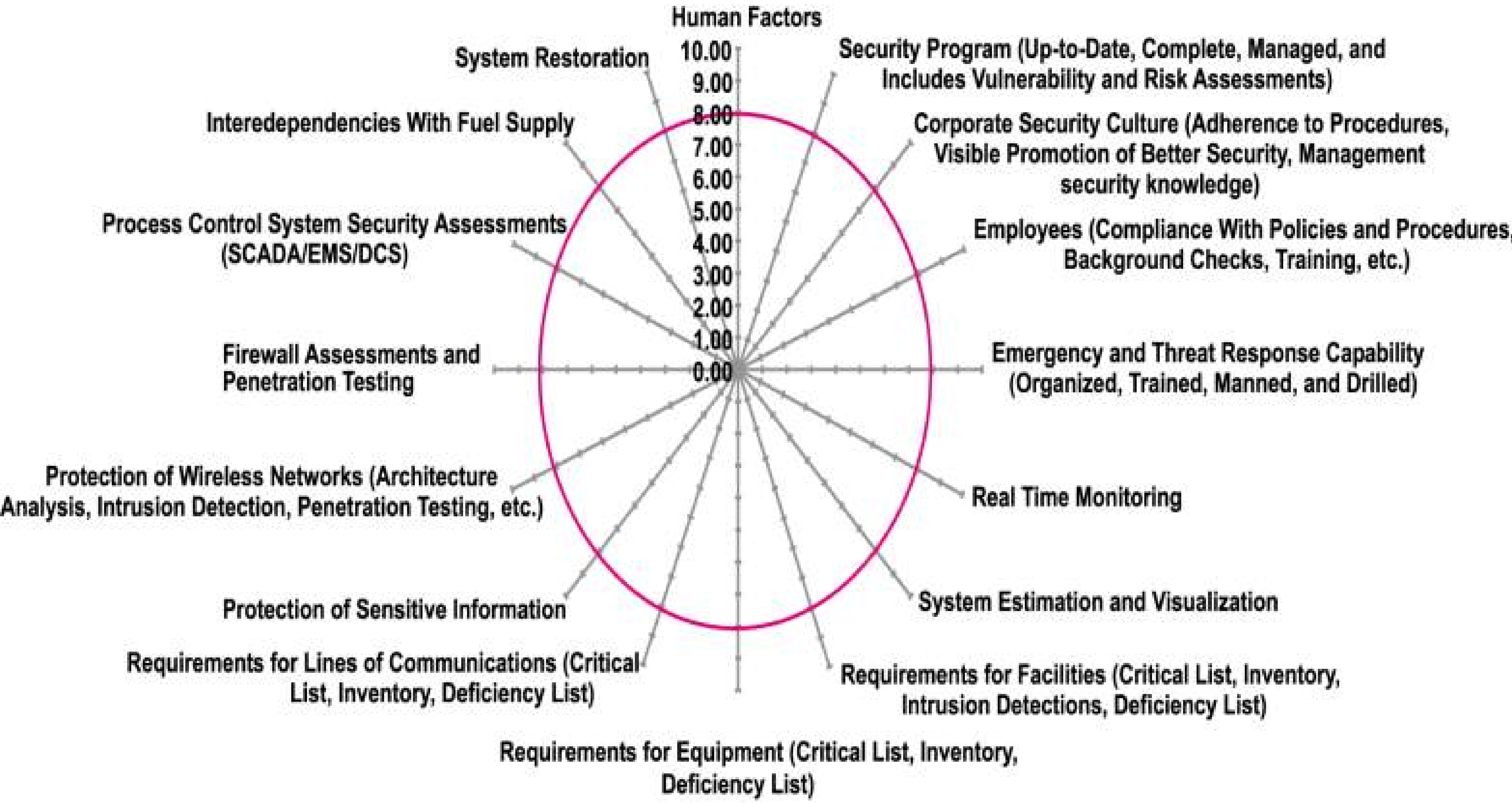
Physical

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

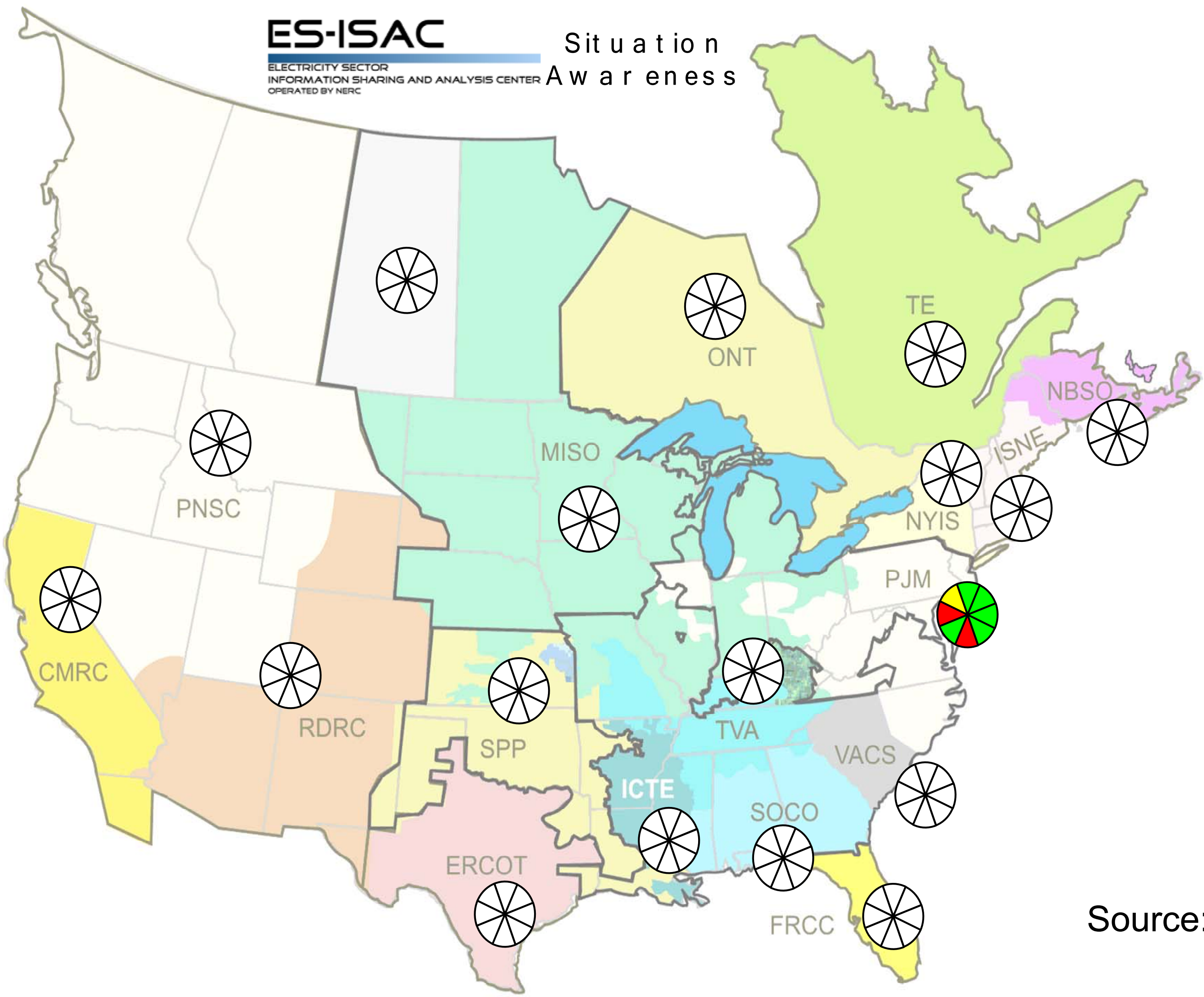
Cyber and IT

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

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

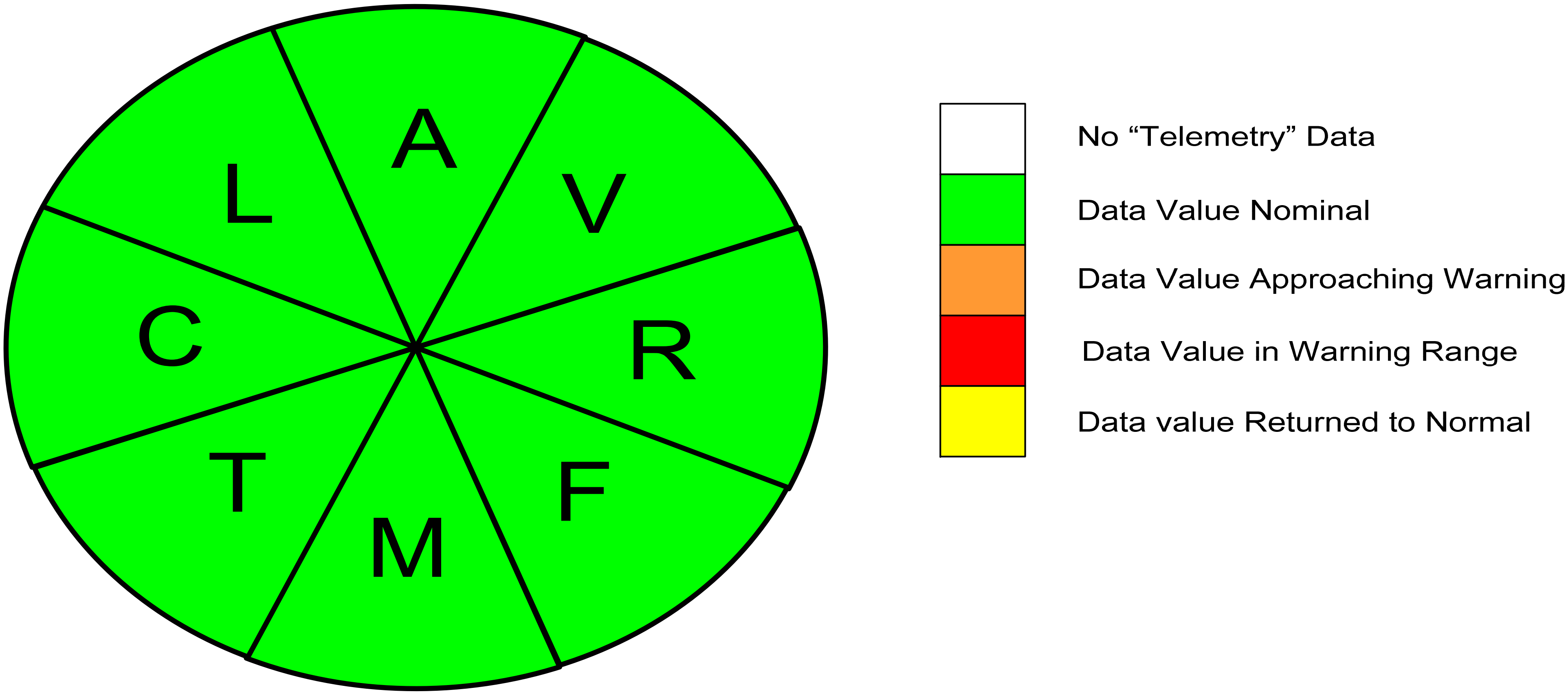


Situation Awareness Tool (SAT)



Source: NERC

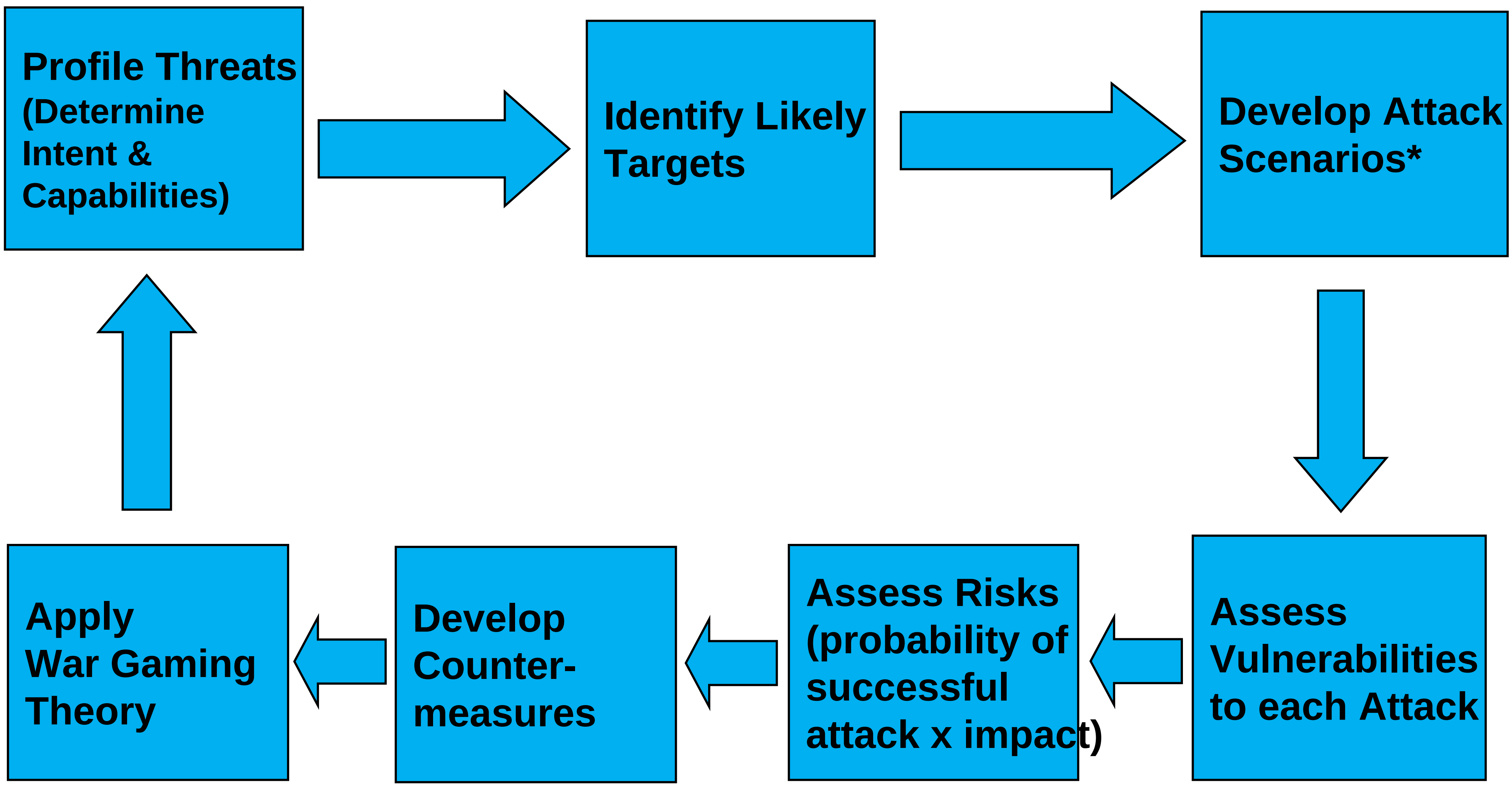
Situation Awareness Tool (SAT)



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

Source: NERC

What can be Done?
Vulnerability Assessment



*Evolving spectra of targets and modes of attack

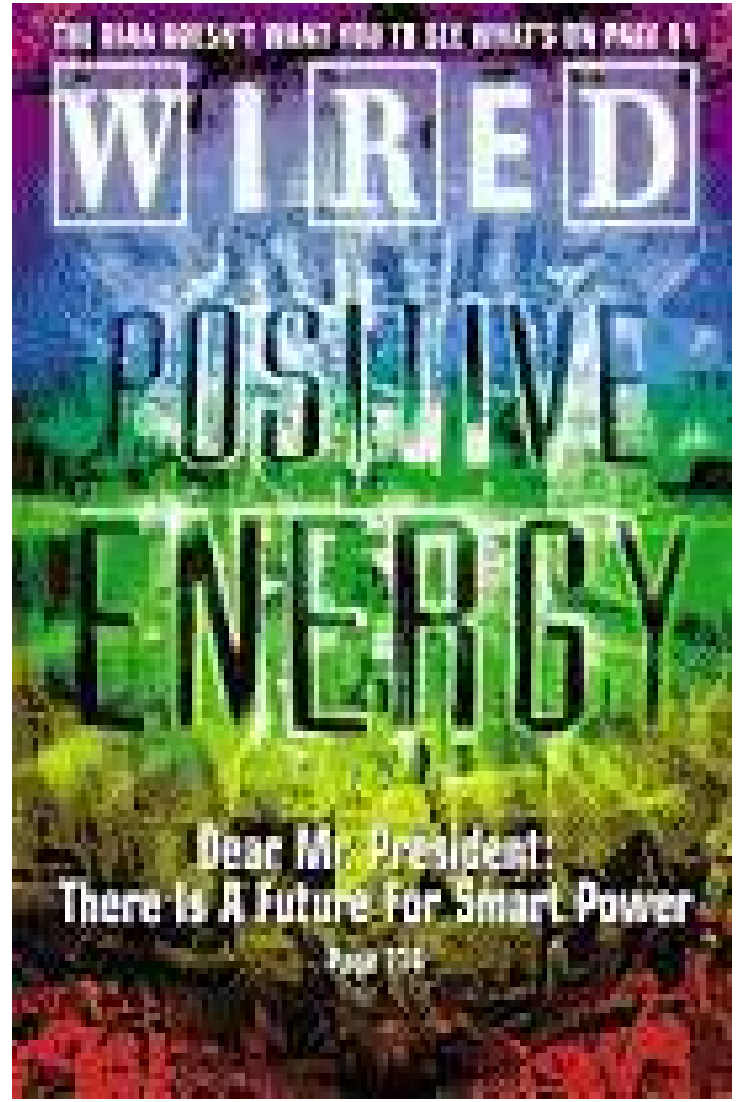
"… not to sell light bulbs, but to create a network of technologies and services that provide illumination…"

Smart Grid…

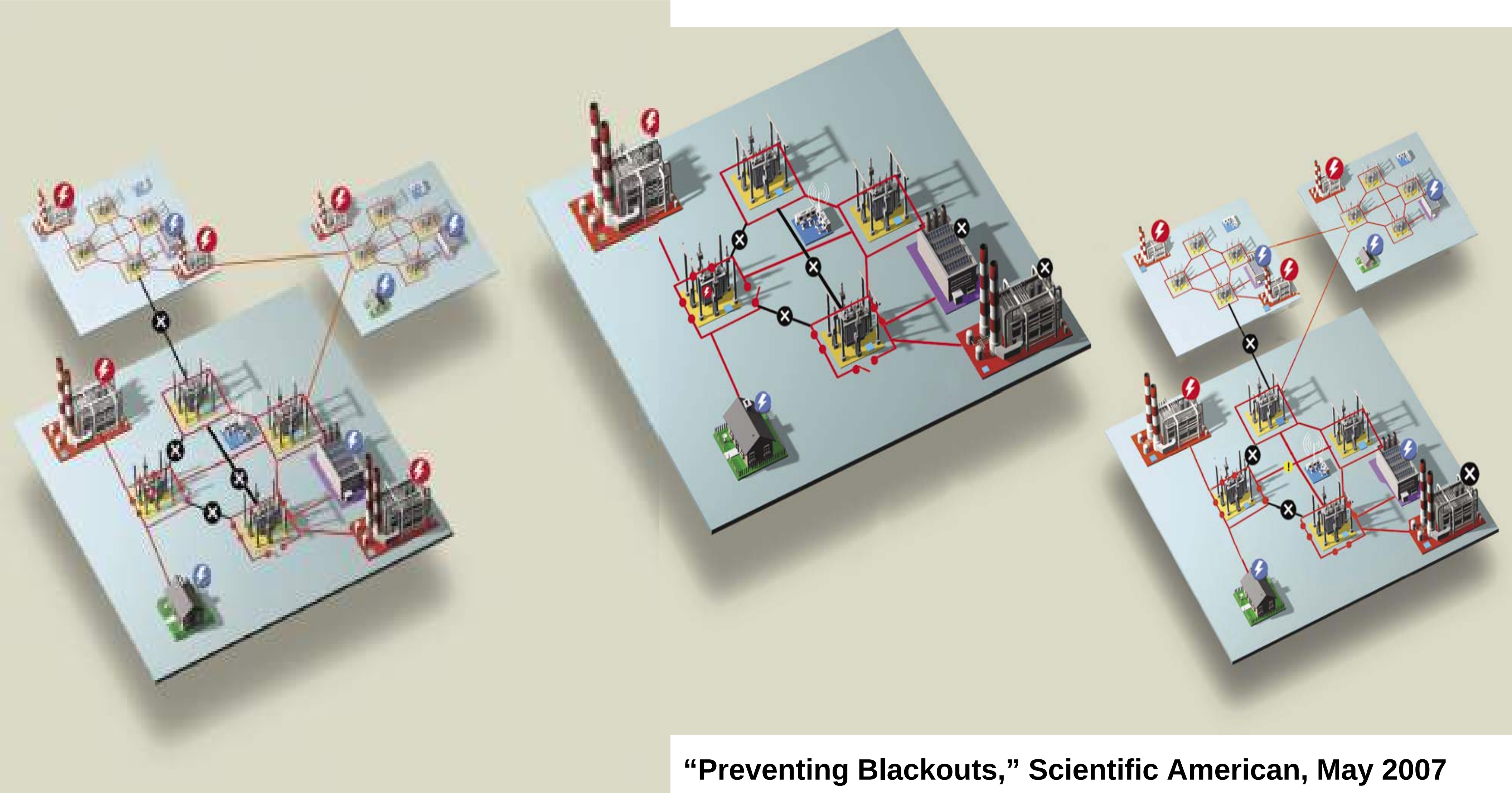
"The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming - and interconnected with everything else."

-- **The Energy Web,** Wired Magazine, July 2001

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



Smart Self-Healing Grid



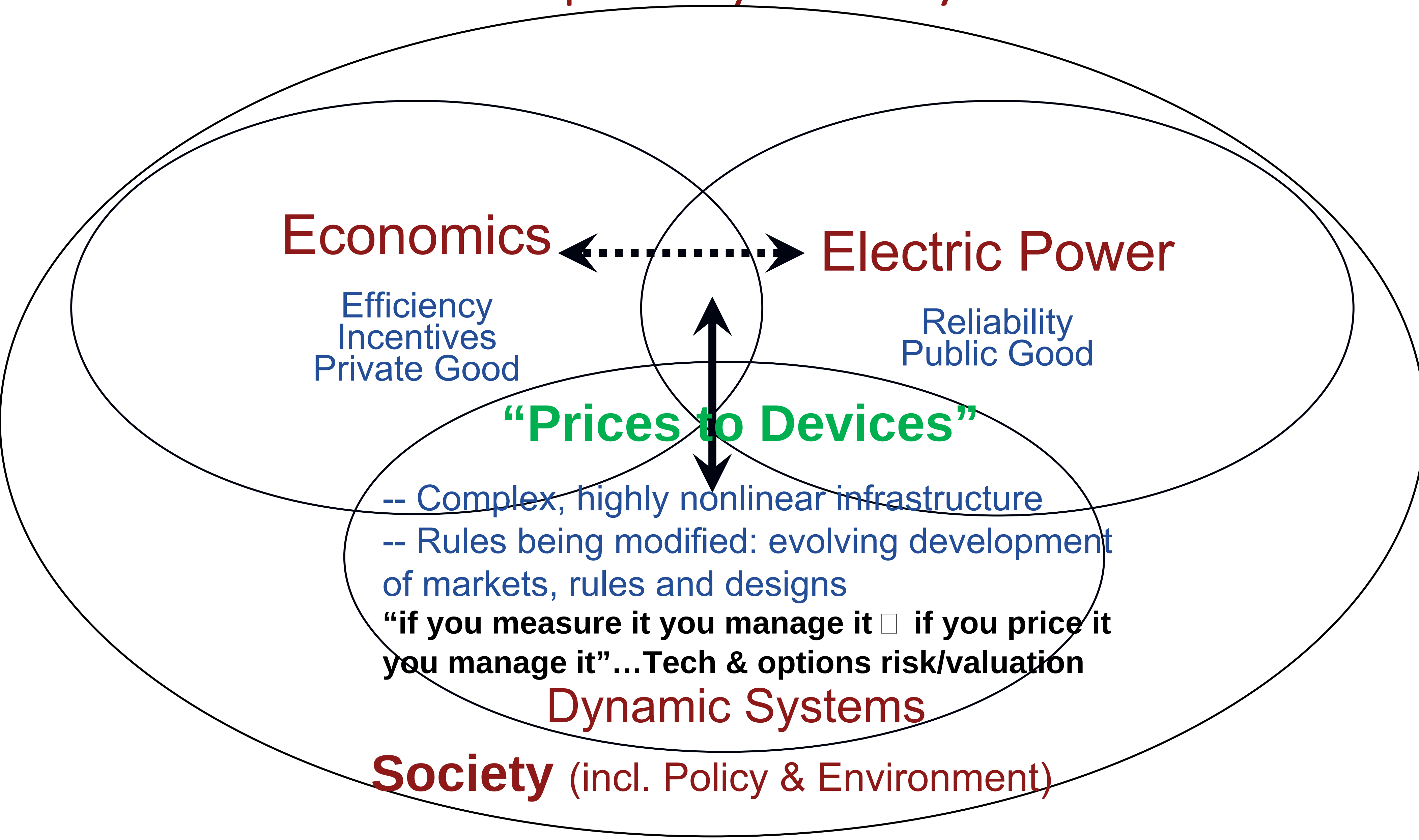
"Preventing Blackouts," Scientific American, May 2007

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

(July 22, 2008)

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

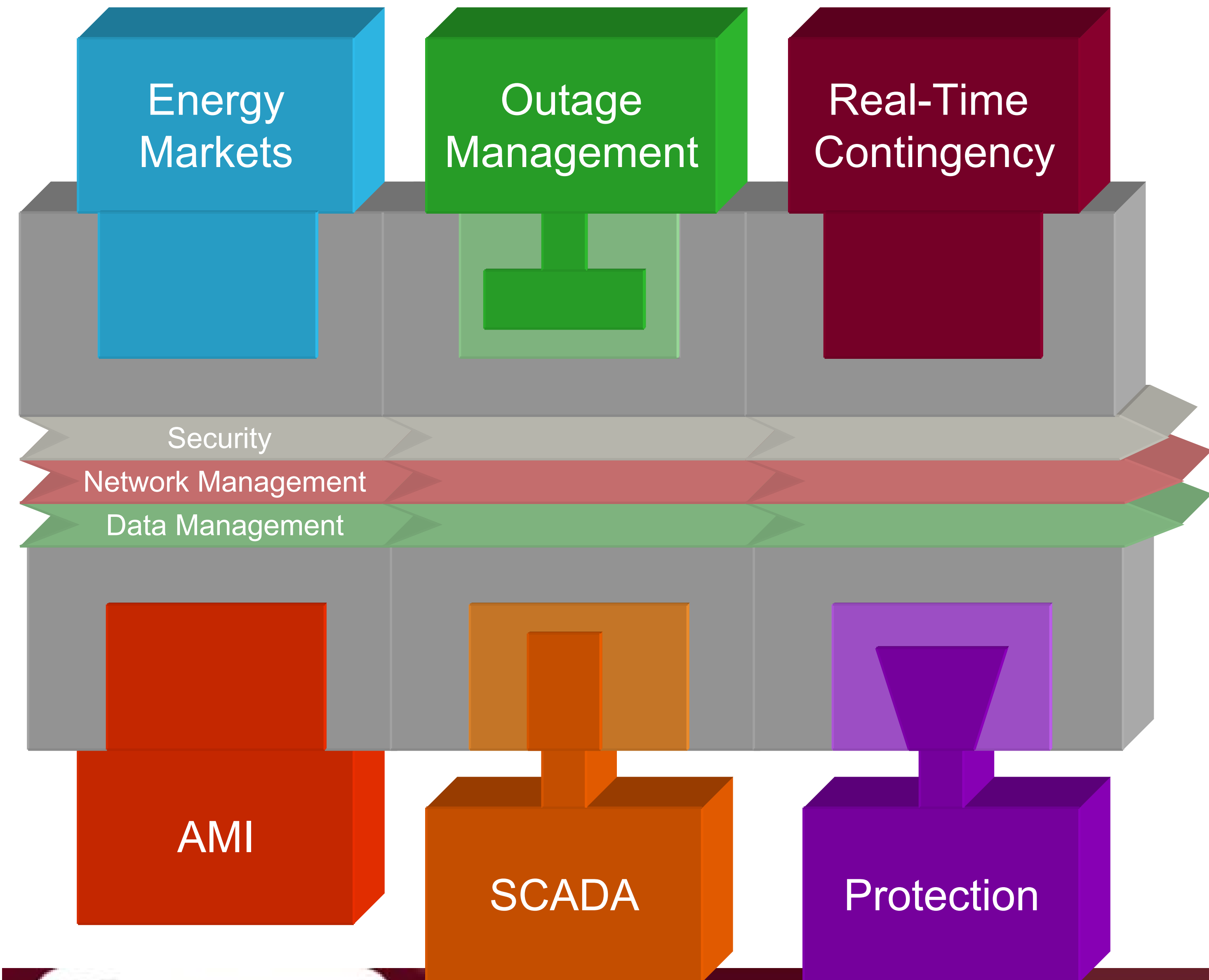
Economics, Efficiency, Environment, Energy Infrastructure, Communications & Adaptive Dynamic Systems



Center for the Development of Technological Leadership

Smart Grid: Enabling Multiple Applications

First Build the Right Foundation



Build The Right Foundation

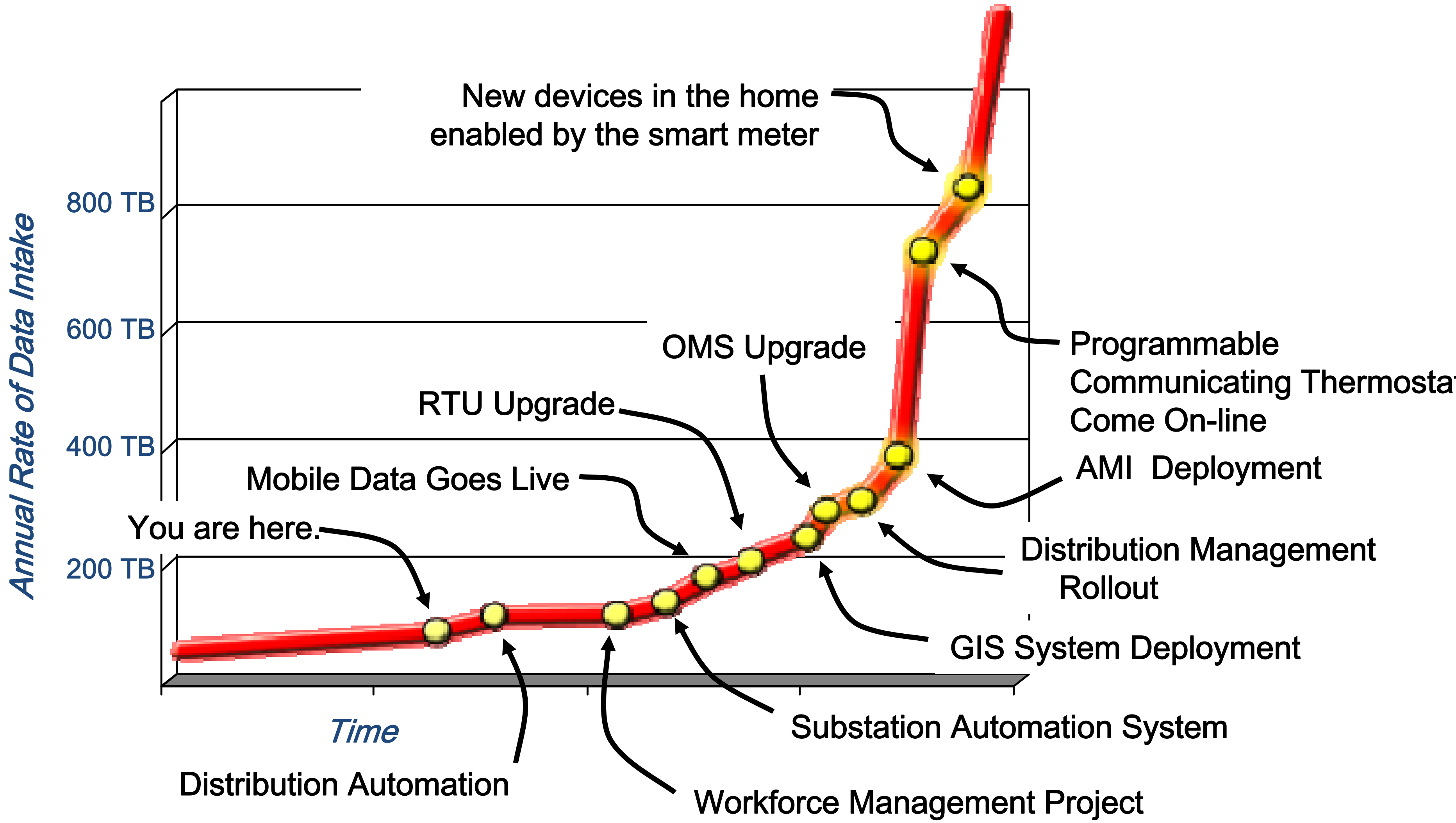
Security

Network Management

Data Management

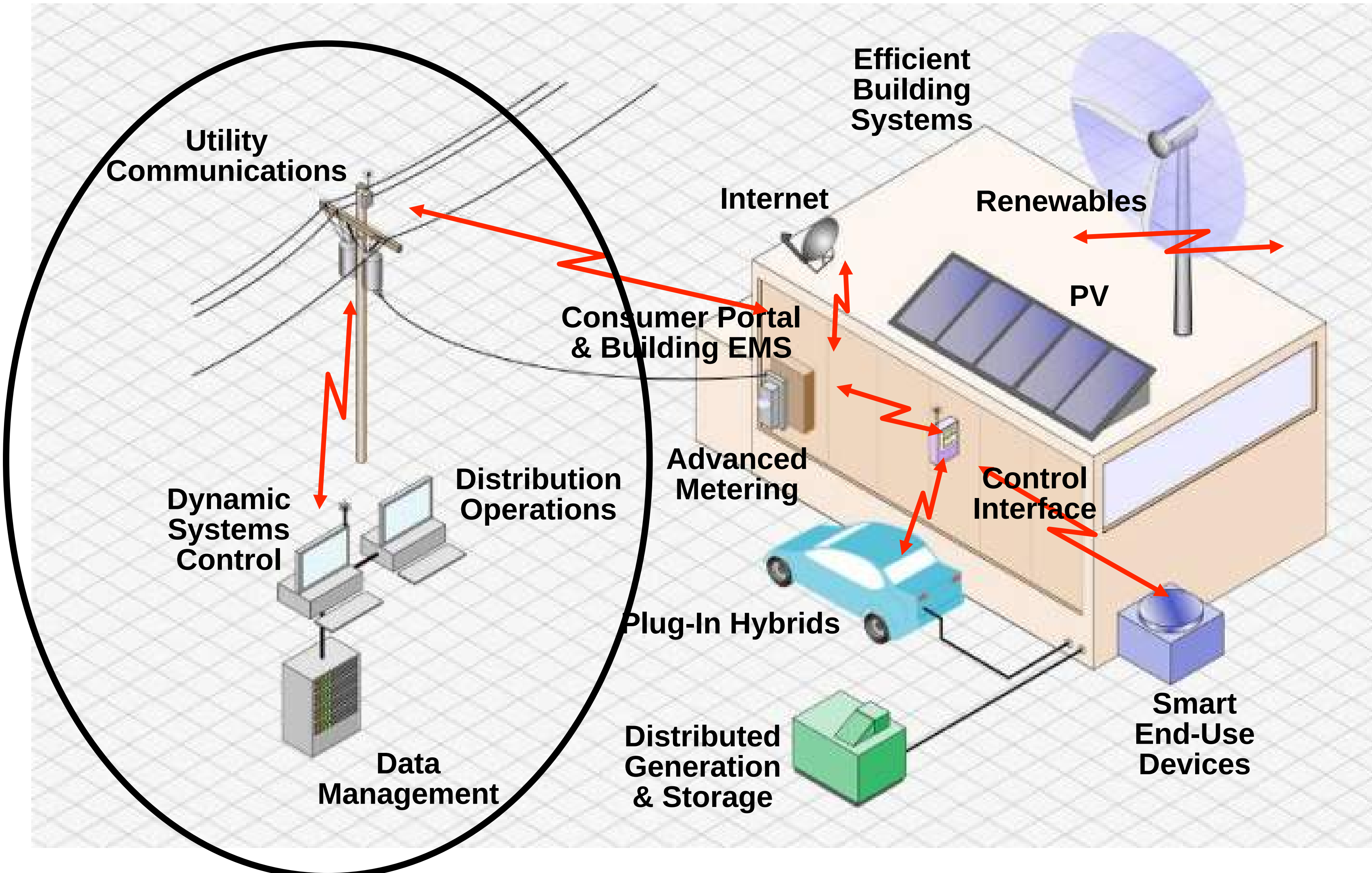
Interoperability

Smart Grid Field Data

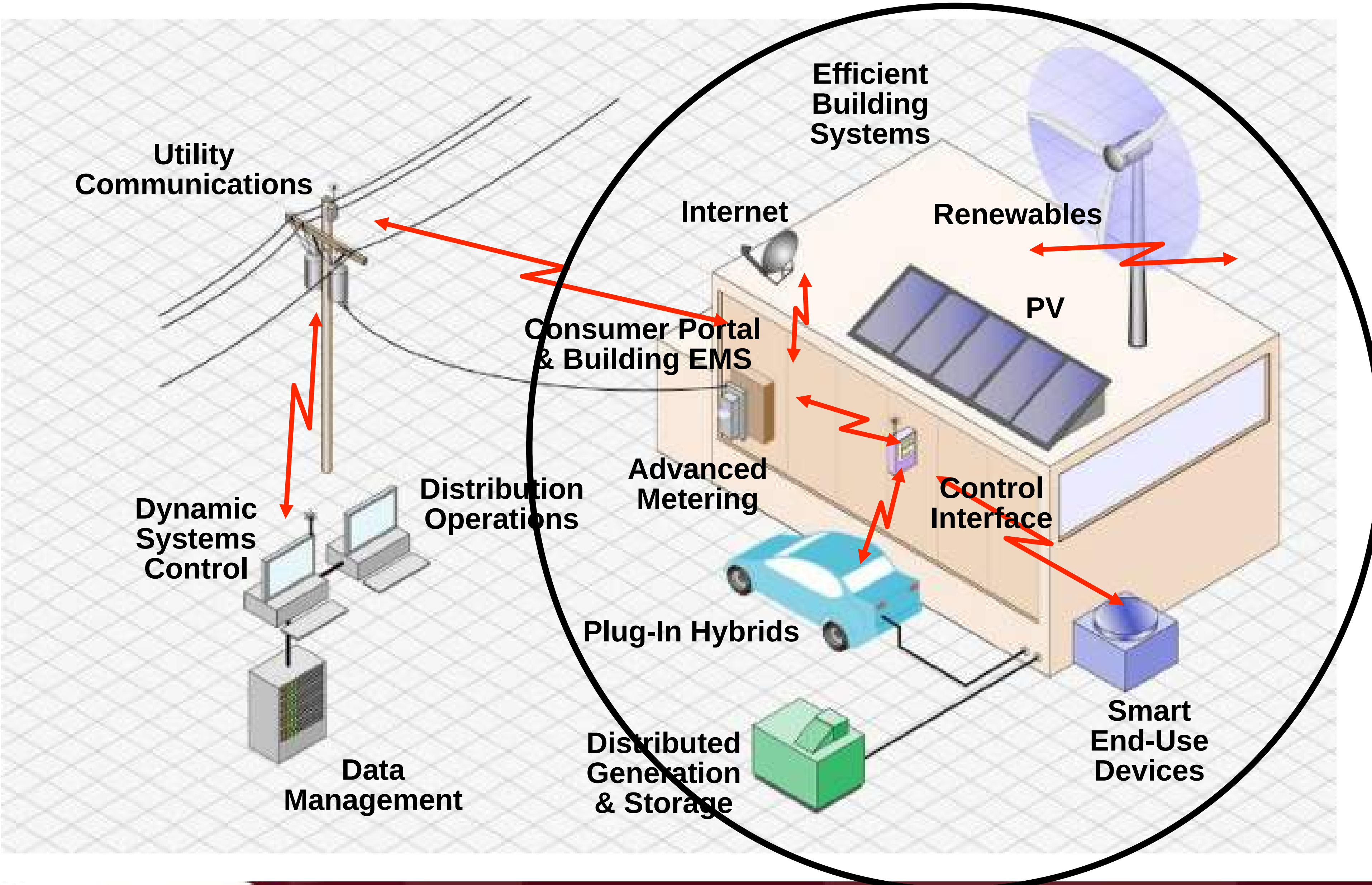


Tremendous amount of data coming from the field in the near future
- paradigm shift for how utilities operate and maintain the grid

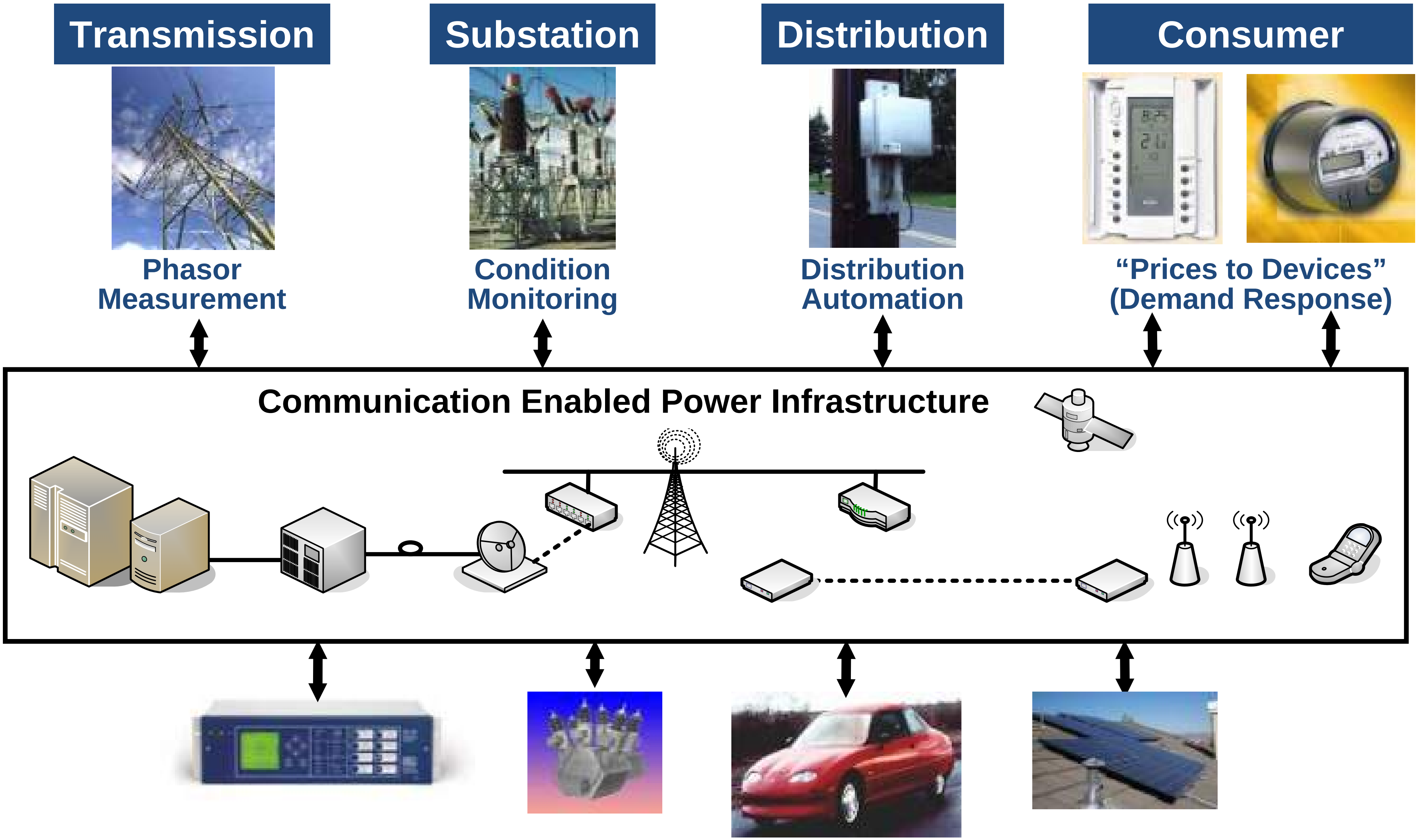
Smart Grids and Local Energy Networks

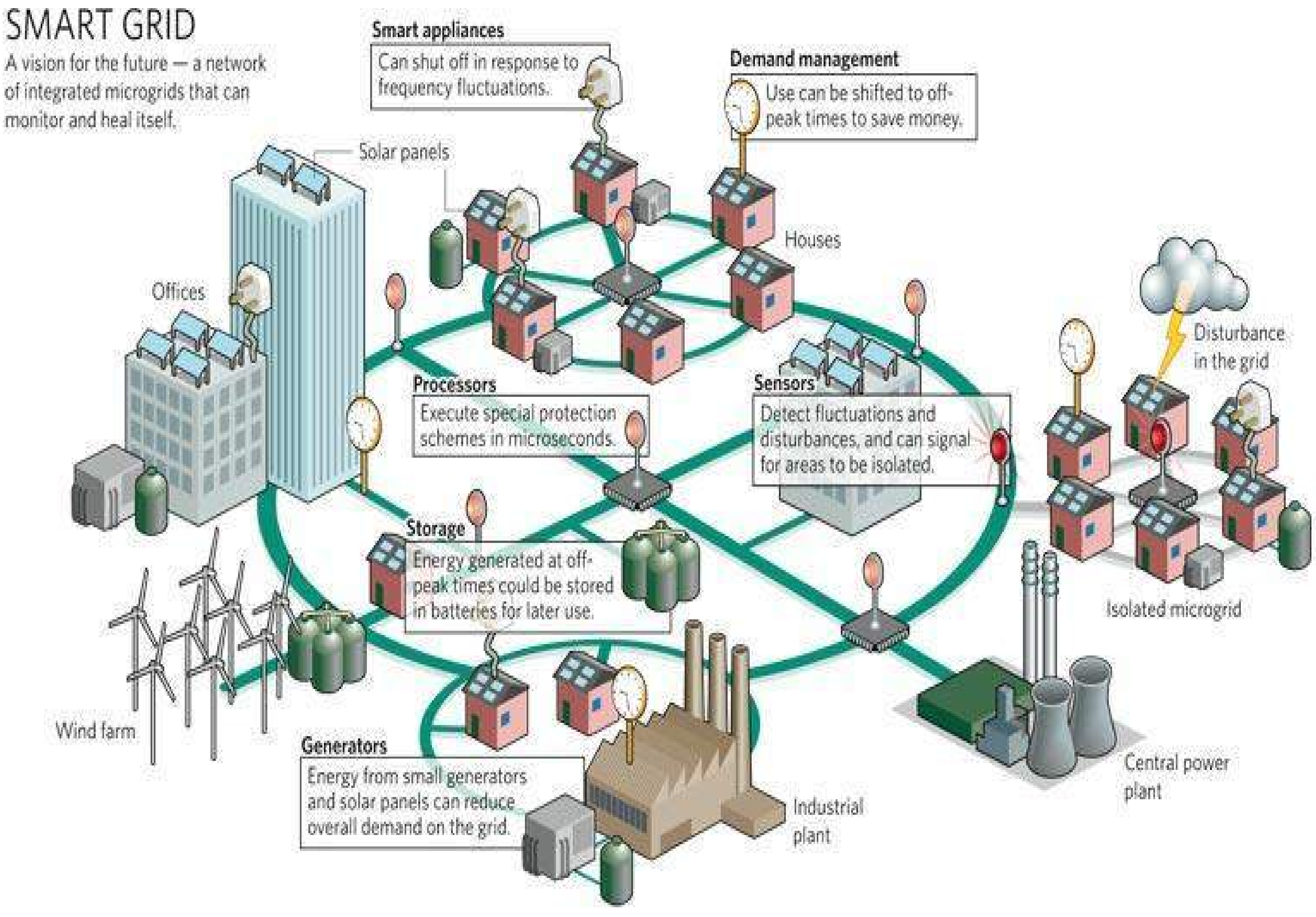


Smart Grids and Local Energy Networks



Smart Grid – Exchanging Information Seamlessly Across the Enterprise




SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.
Smart appliances
Can shut off in response to frequency fluctuations.
Demand management
Use can be shifted to off-peak times to save money.
Solar panels
Houses
Offices
Disturbance in the grid
Processors
Execute special protection schemes in microseconds.
Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.
Storage
Energy generated at off-peak times could be stored in batteries for later use.
Isolated microgrid
Wind farm
Generators
Energy from small generators and solar panels can reduce overall demand on the grid.
Industrial plant
Central power plant

Related on-going R&D include

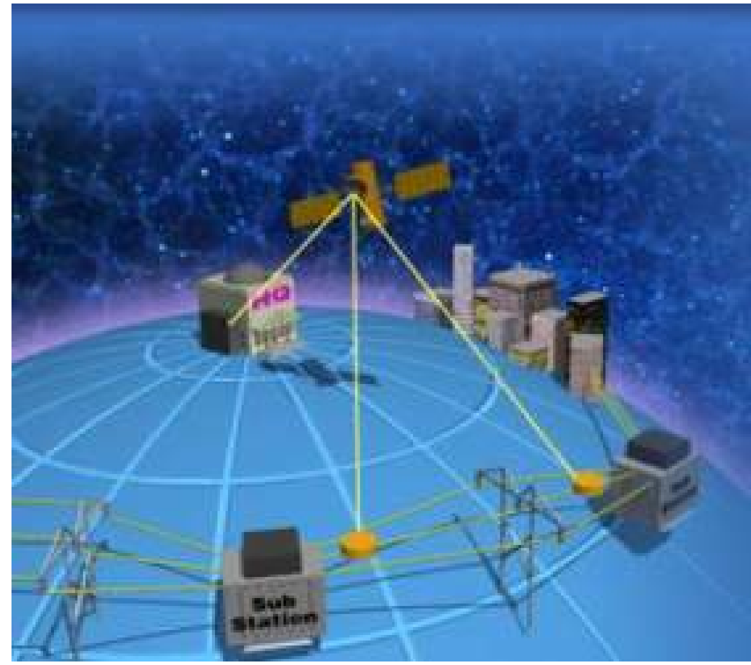
- EPRI: Intelligrid, Fast Simulation and Modeling
- Initiatives at several utilities, including Xcel, AEP, Austin Energy, ISOs, etc.)
- Energy Bill passed in December 2007: Title XIII Smart Grid, Sections 1301 -1309
  - Establishes a statement of policy supporting modernization of the grid; authorizes 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

The Challenge

Enabling/Creating a stronger, more secure, resilient, and more stable interdependent infrastructure that is vital to support the digital society

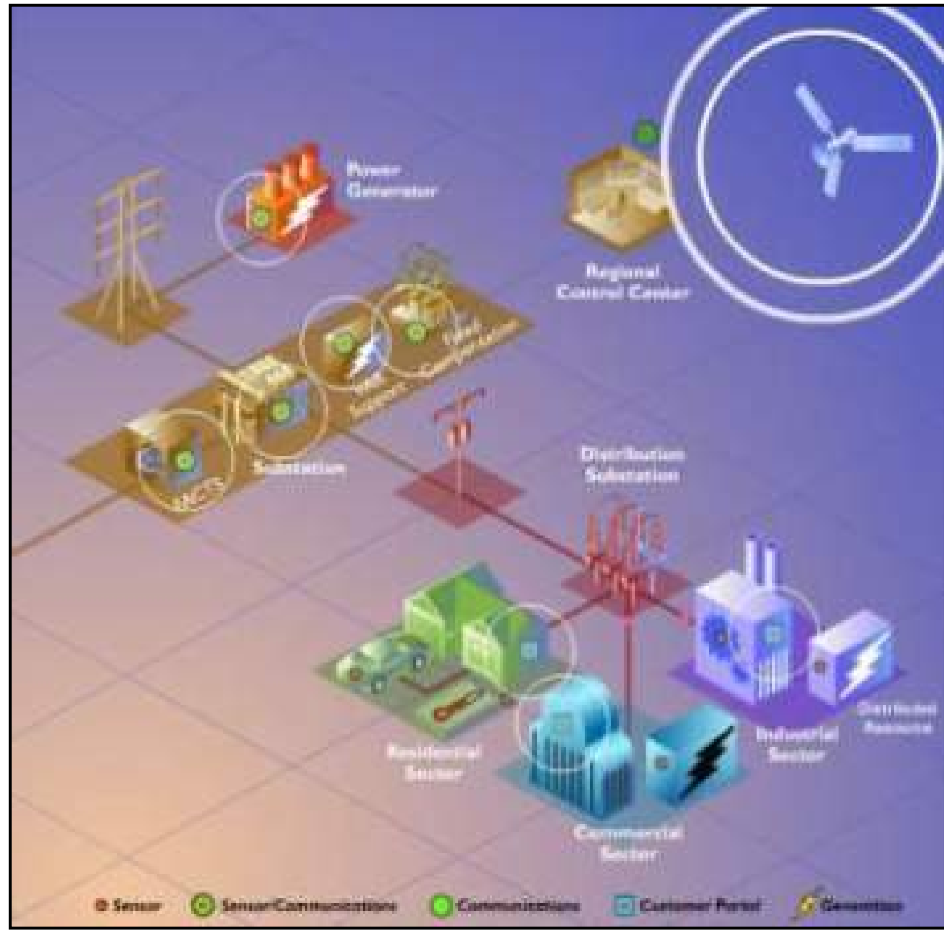
Key Technologies

- Communications
- Monitoring
- Embedded computing
  - Data to information, advanced operation & protection algorithms, etc.
- Advanced components
  - Superconductors, power electronics, storage, etc.
- Advanced configurations
  - Looped circuits, microgrids, DC service

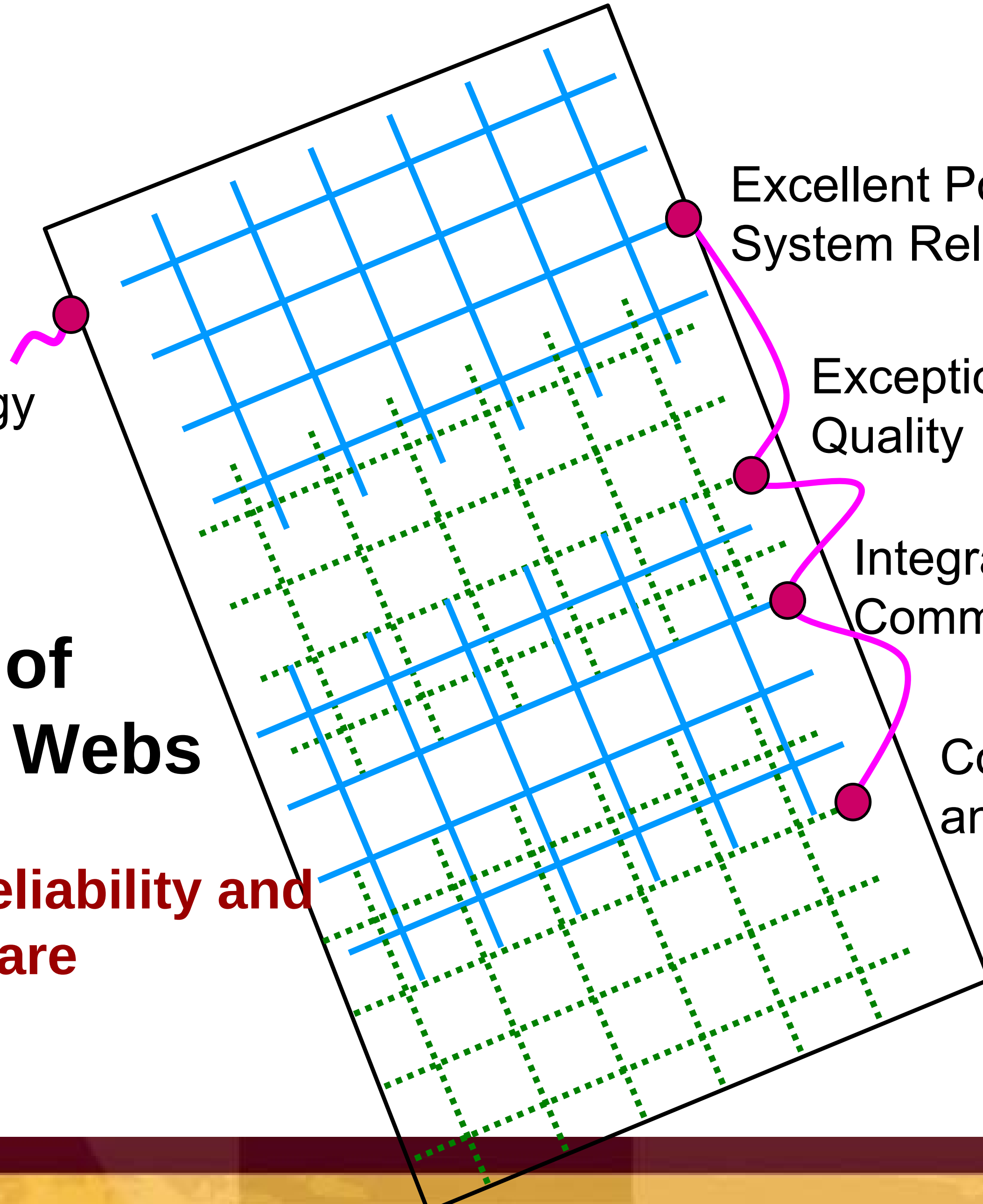


Tomorrow’s Grid

- **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



The Infrastructure for a Digital Society

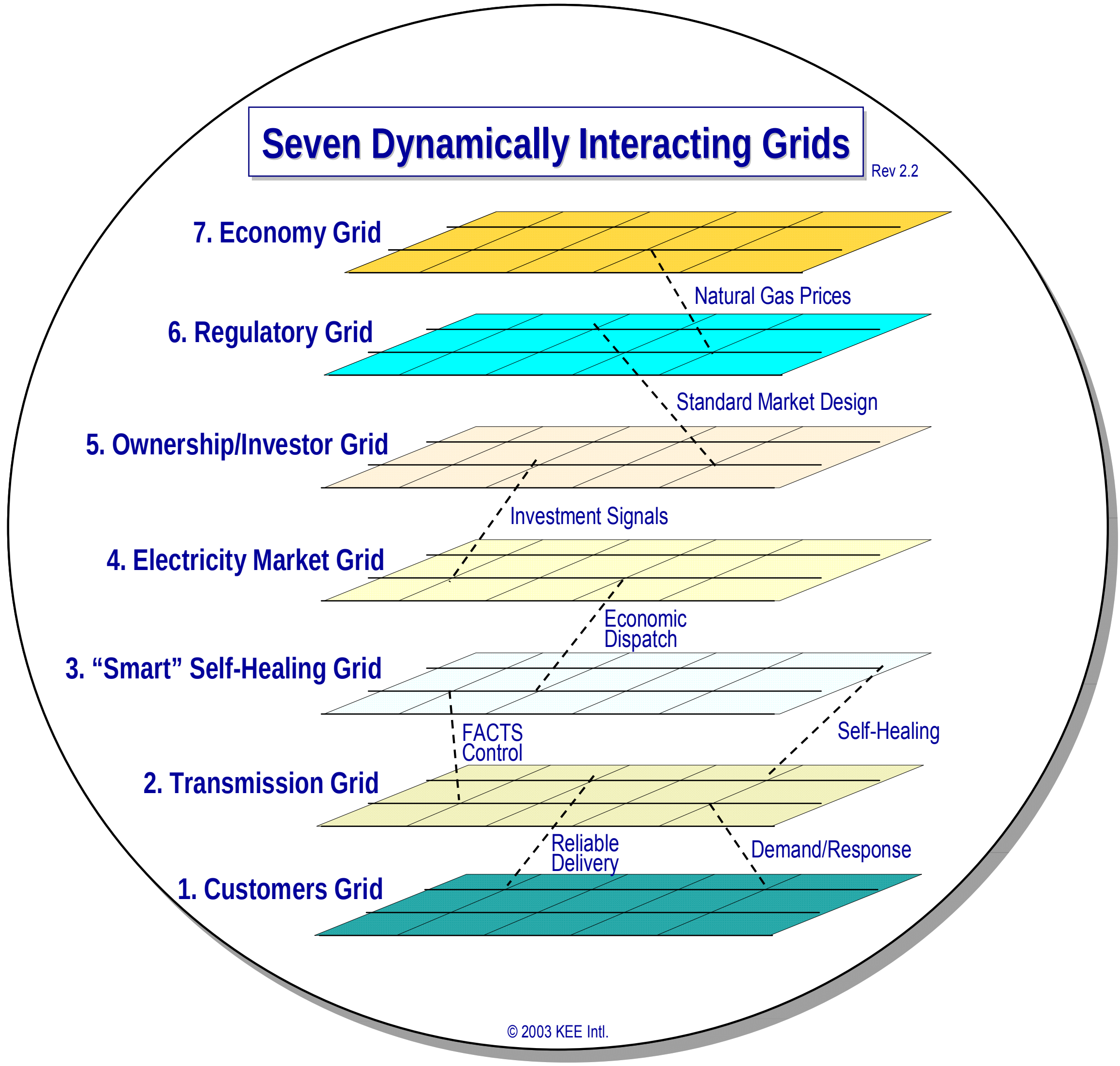


A Complex Set of Interconnected Webs

Security, Quality, Reliability and Availability (SQRA) are Fundamental

Technology development, transition and Implementation: … the really hard part

- Steps in Tech R&D and implementation
- Making the business case for the opportunity
- Have a plan …



Selected References

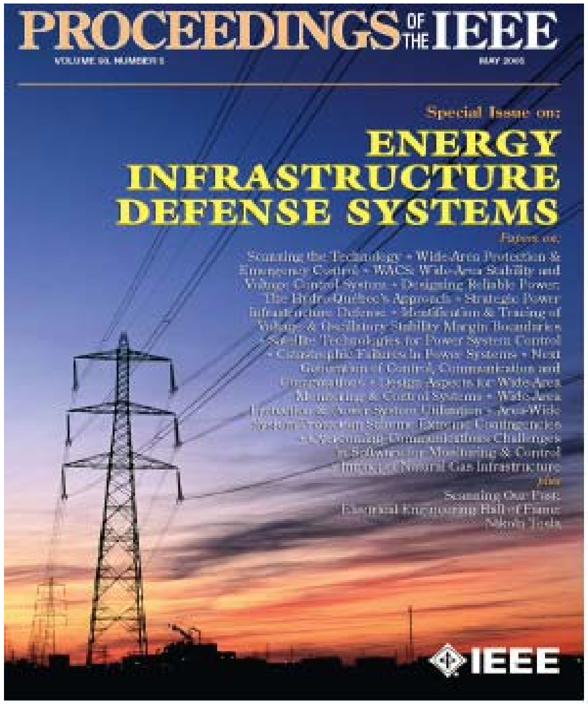
- **"New Directions in Understanding Systemic Risk",** with NAS and FRBNY Committee, National Academy of Sciences and Federal Reserve Bank of NY, Mar. 2007
- **"Complex Interactive Networks/Systems Initiative (CIN/SI): Final Summary Report",** Overview and Summary Final Report for Joint EPRI and U.S. Department of Defense University Research Initiative, EPRI, 155 pp., Mar. 2004
- **"Preventing Blackouts",** Scientific American, pp. 60-67, May 2007
- Special Issue of Proceedings of the IEEE on **Energy Infrastructure Defense Systems**, Vol. 93, Number 5, pp. 855-1059, May 2005
- Special issues of IEEE Control Systems Magazine on **Control of Complex Networks**, Vol. 21, No. 6, Dec. 2001 and Vol. 22, No. 1, Feb. 2002


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

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

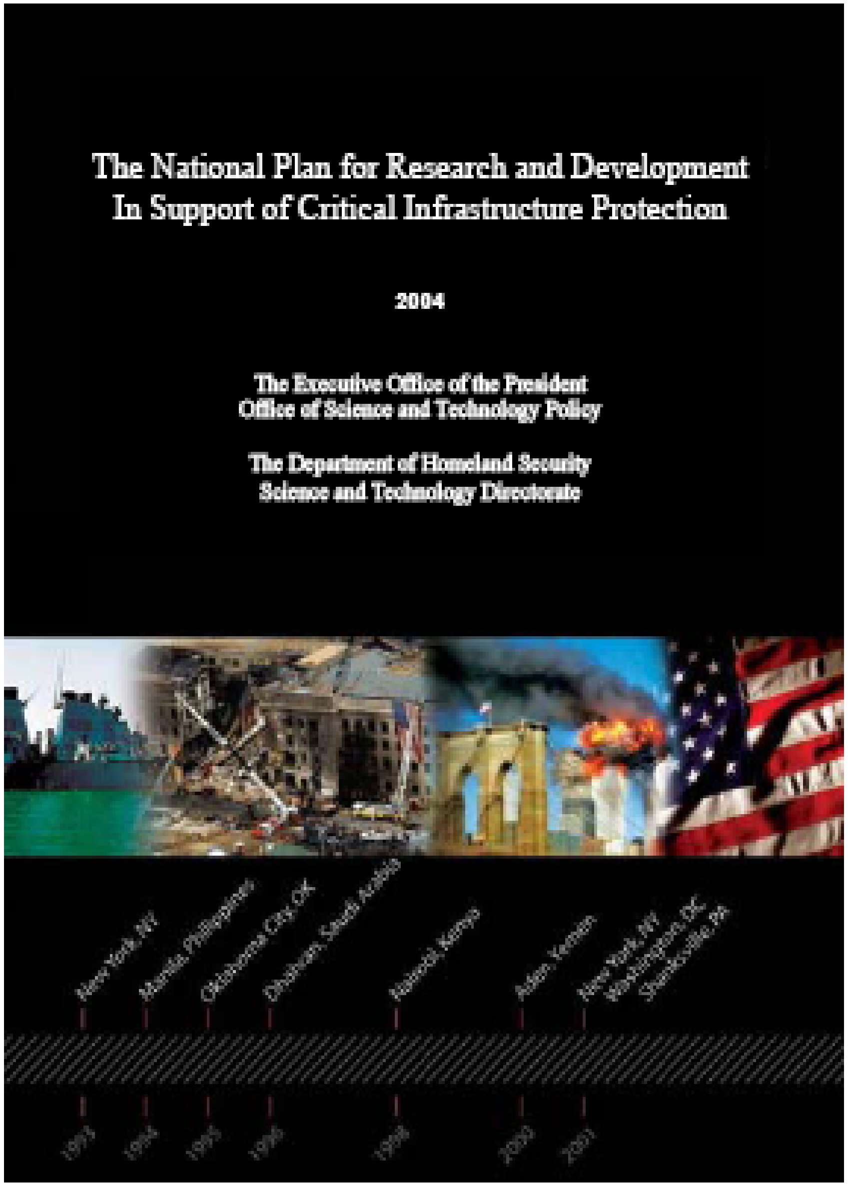
For the NAS book and complete FRBNY report please see:
Economic Policy Review, Federal reserve Bank of New York, Vol. 13, Number 2, Nov. 2007
New Directions for Understanding Systemic Risk, 108 pp. Nat'l Acad. Press, Washington DC, 2007

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



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).



Energy Foresight

Renewables/infrastructure integration, Electrification of transportation, and a few Global trends and Challenges

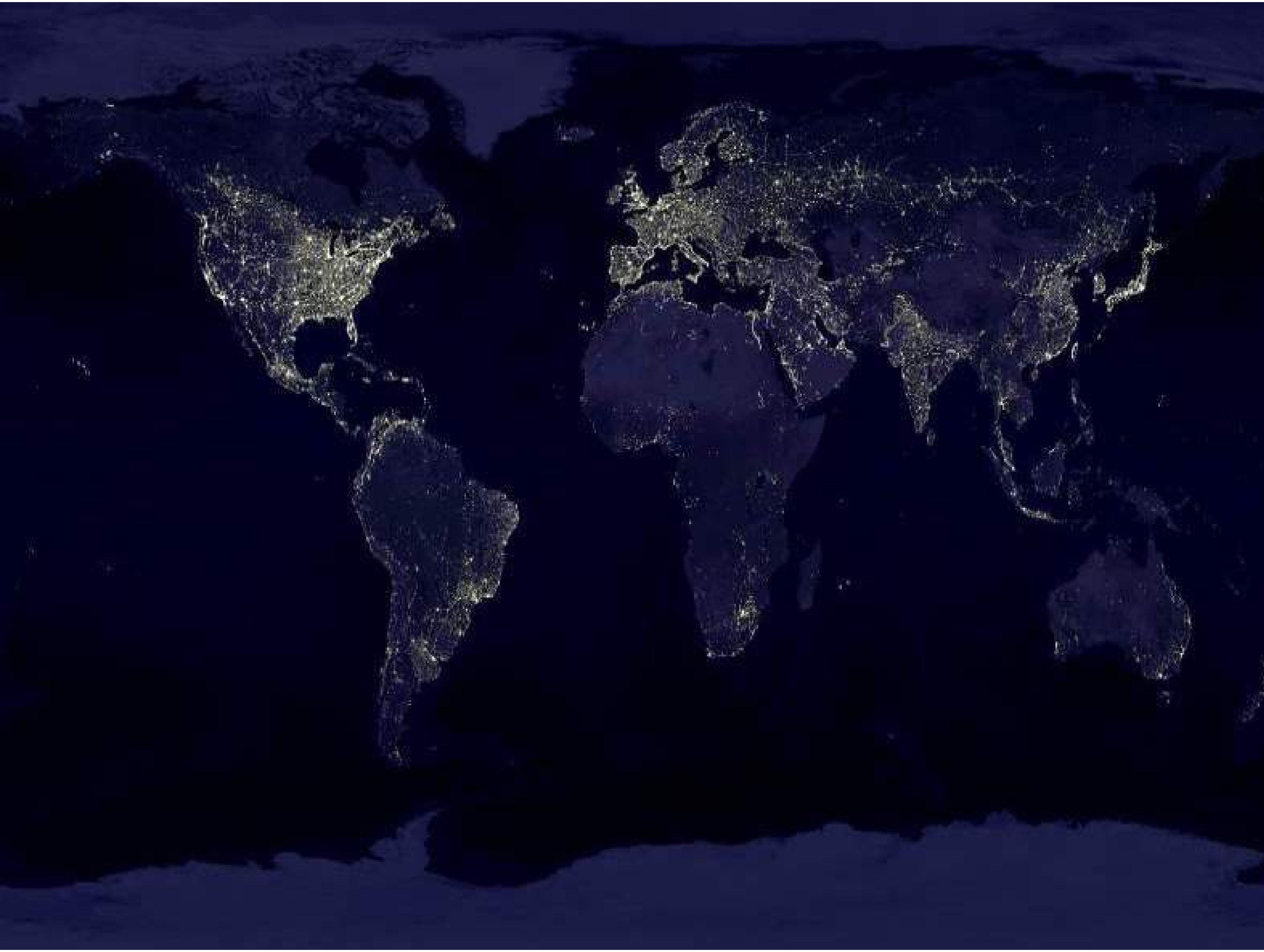
Context:

• In the U.S., we have:

- 2% of the World's oil reserve;
- 8% of World oil production;
- 5% of the World population;
- we consume 25% of World's production, and
- more than 2/3 of our consumption is imported.

• Emerging economies in creased demand are changing demand and the "balance," e.g. China,

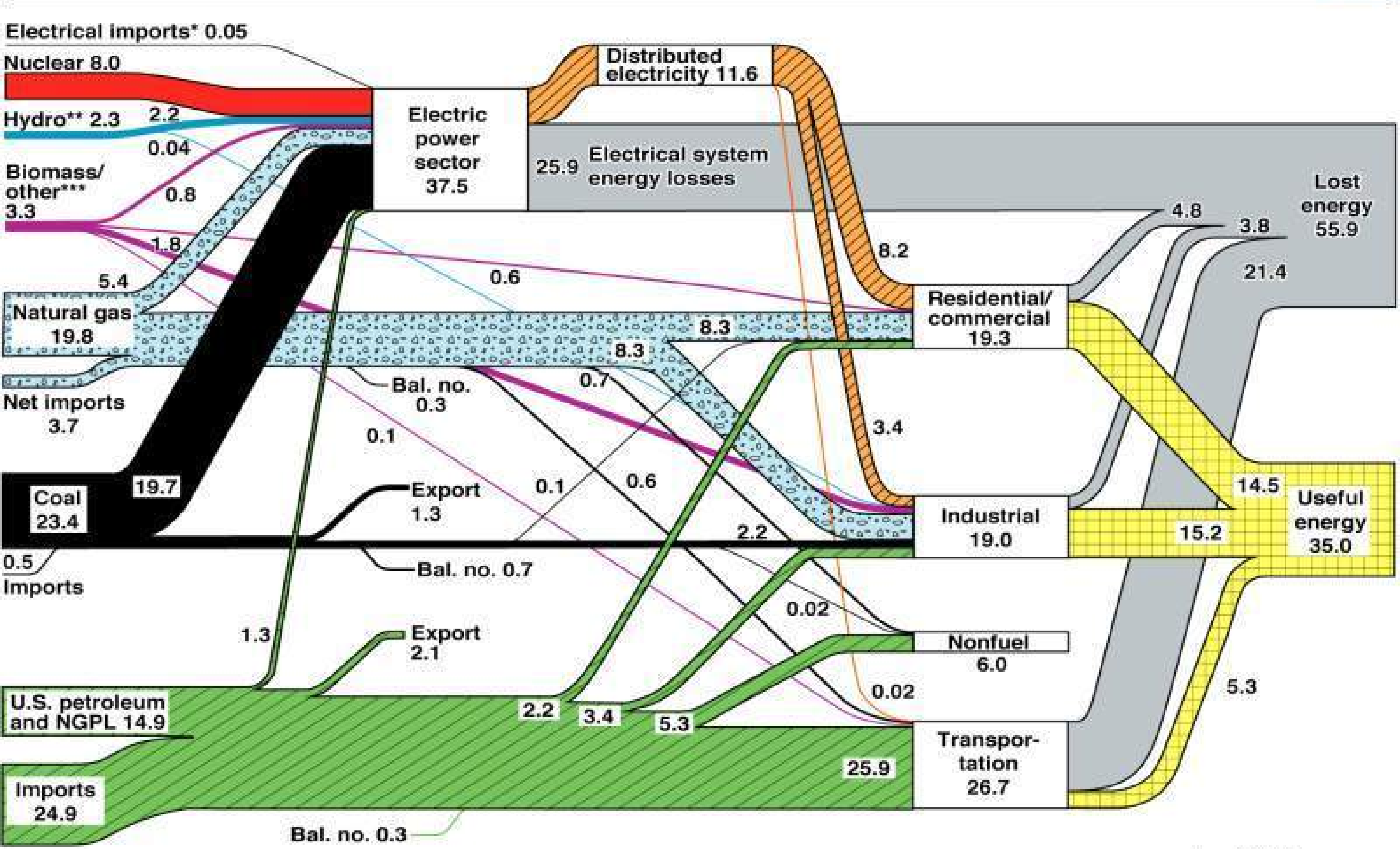
-China has bought excess capacity of Canada,
-Almost bought Unical; has major commitments from the MidEast.
- In 2005 we launched one new submarine, China launched 14 (albeit lower quality)…



The Energy Gap

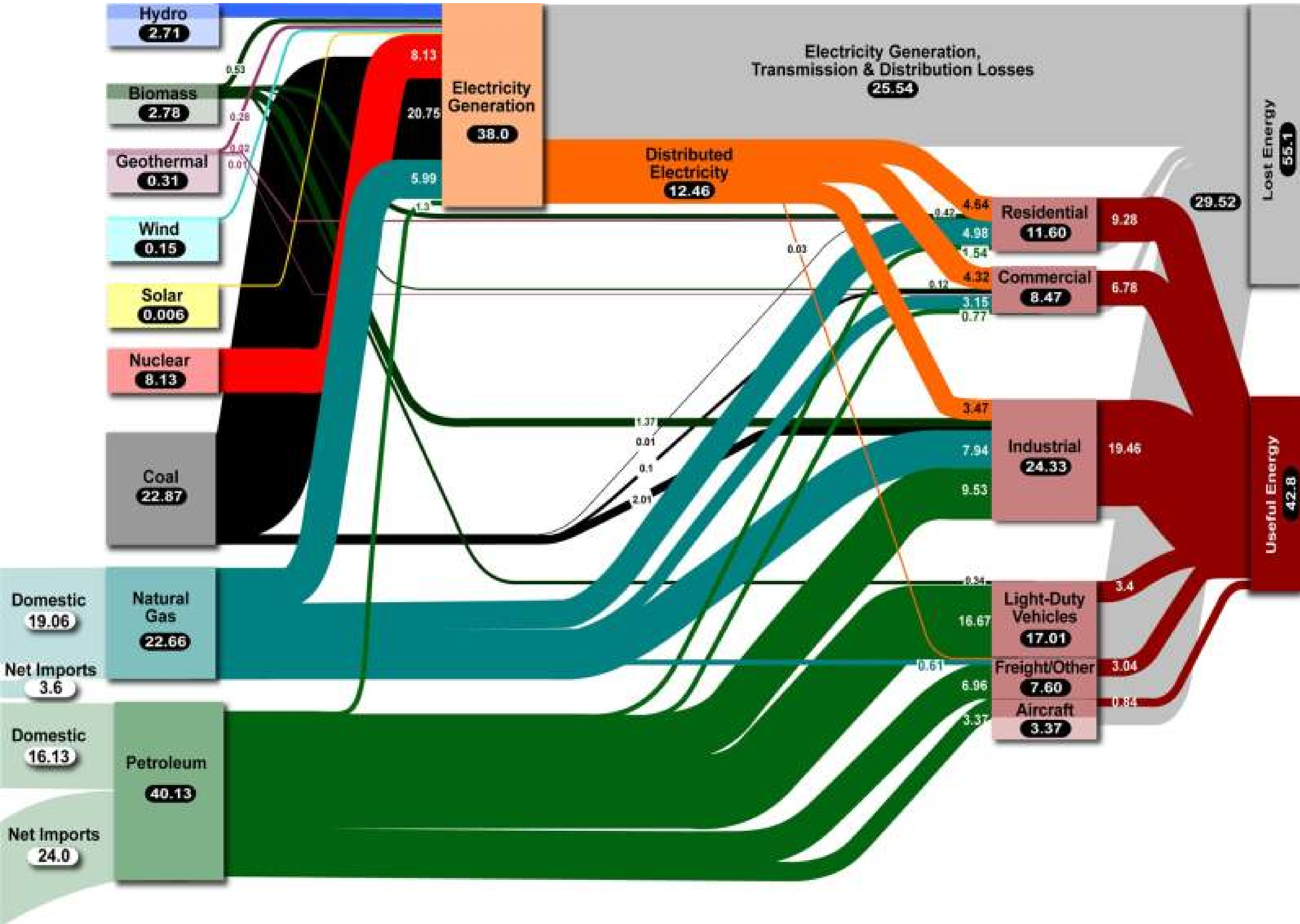
- Half the world's population subsists on agrarian or lower levels of energy access, and
- Their population density generally exceeds the carrying capacity of their environment

U.S. Energy Flow Trends – 2001
Net Primary Resource Consumption ~97 Quads



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2001*
*Net fossil-fuel electrical imports
**Includes 0.2 quads of imported hydro
***Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

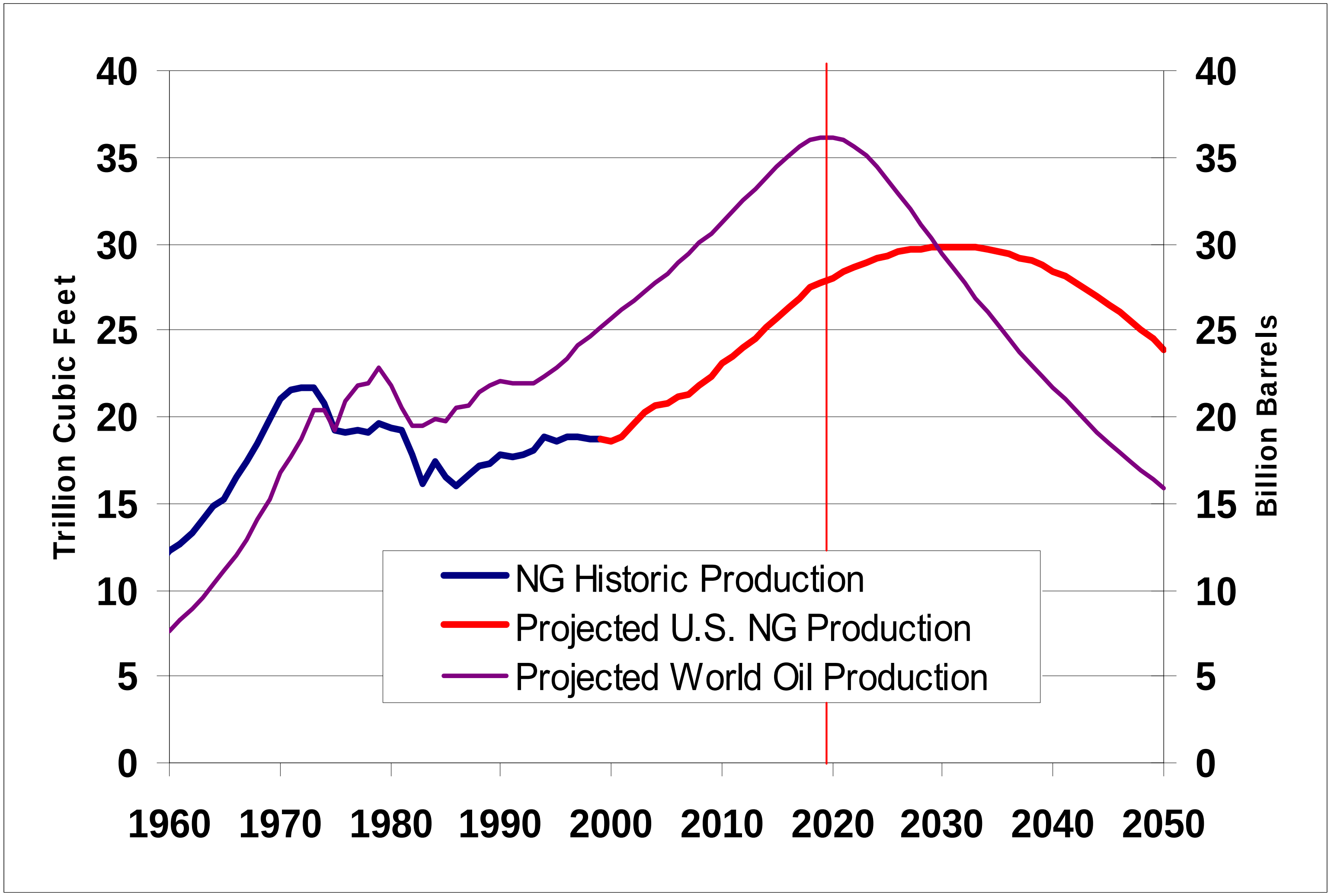
August 2003
Lawrence Livermore
National Laboratory
http://eed.llnl.gov/flow



Hydro
2.71
Biomass
2.78
Geothermal
0.31
Wind
0.15
Solar
0.006
Nuclear
8.13
Coal
22.87
Domestic
19.06
Net Imports
3.6
Natural Gas
22.66
Domestic
16.13
Net Imports
24.0
Petroleum
40.13
0.53
0.28
0.02
0.01
8.13
20.75
5.99
1.3
Electricity Generation
38.0
Electricity Generation, Transmission & Distribution Losses
25.54
Distributed Electricity
12.46
0.03
1.37
0.01
0.1
2.01
4.64
0.42
4.98
1.54
4.32
0.12
3.15
0.77
3.47
7.94
9.53
0.34
16.67
0.61
6.96
3.37
Residential
11.60
Commercial
8.47
Industrial
24.33
Light-Duty Vehicles
17.01
Freight/Other
7.60
Aircraft
3.37
9.28
6.78
19.46
3.4
3.04
0.84
29.52
Lost Energy
55.1
Useful Energy
42.8

Supply Considerations

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

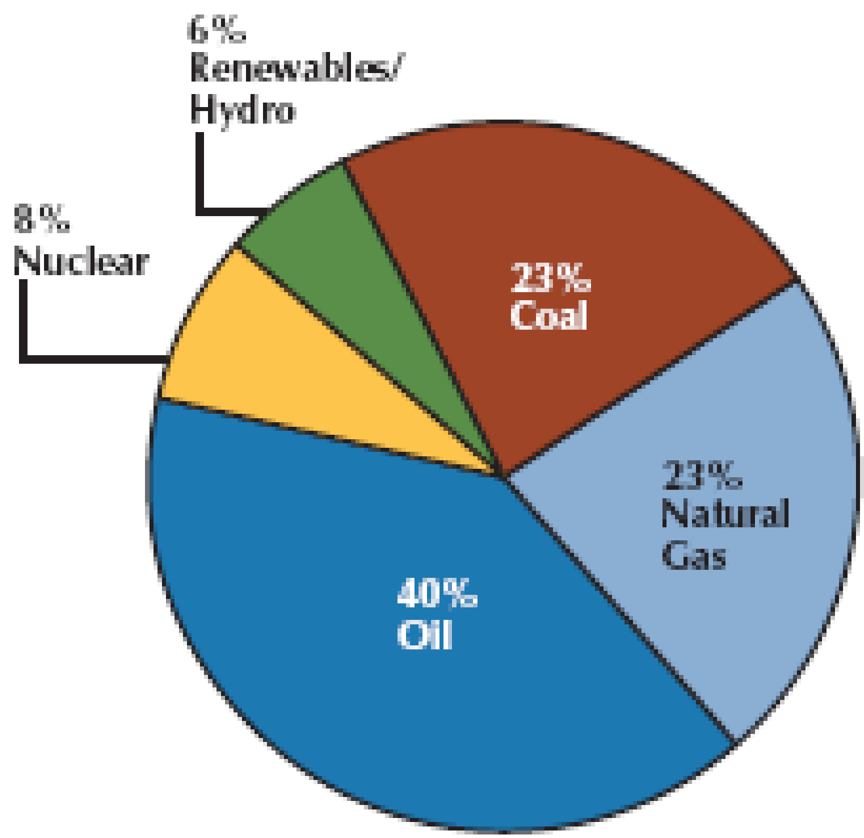


Source: Department of Energy

U.S. Energy Sources

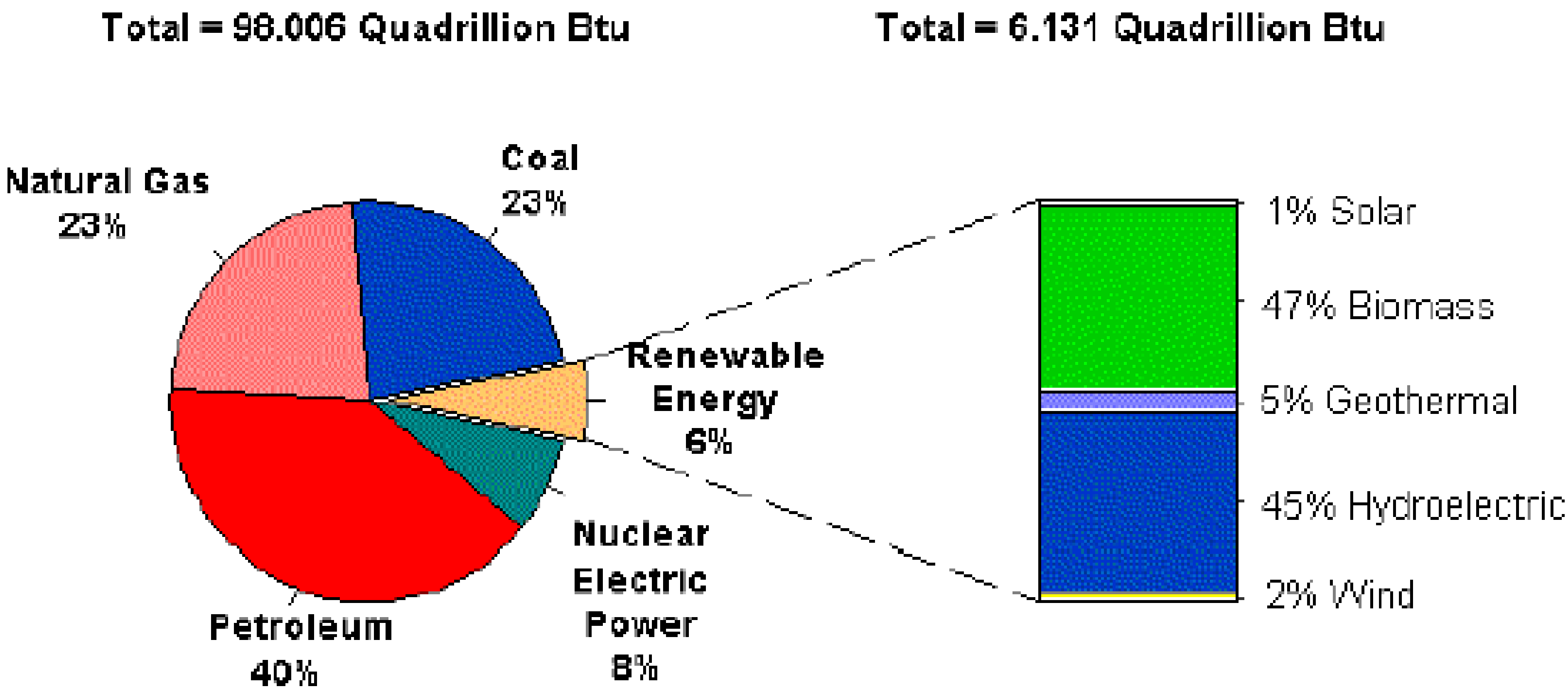
Total Domestic Energy Use by Source

The U.S. relies upon fossil fuels to meet over 85% of its total energy needs (2003).



Data Source: Energy Information Administration, 2004

U.S. Energy Sources

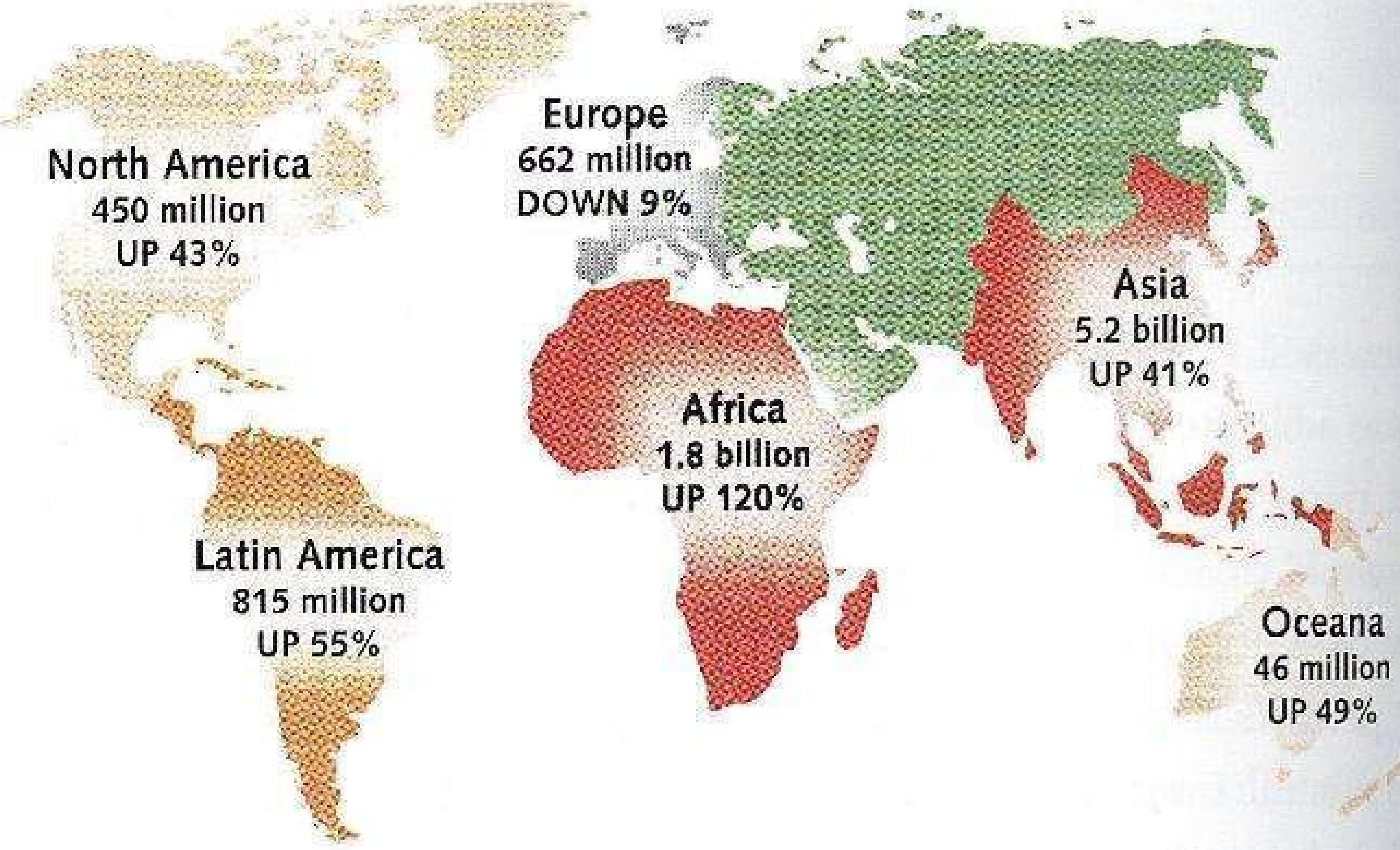


Context: Cities with 10 million people

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

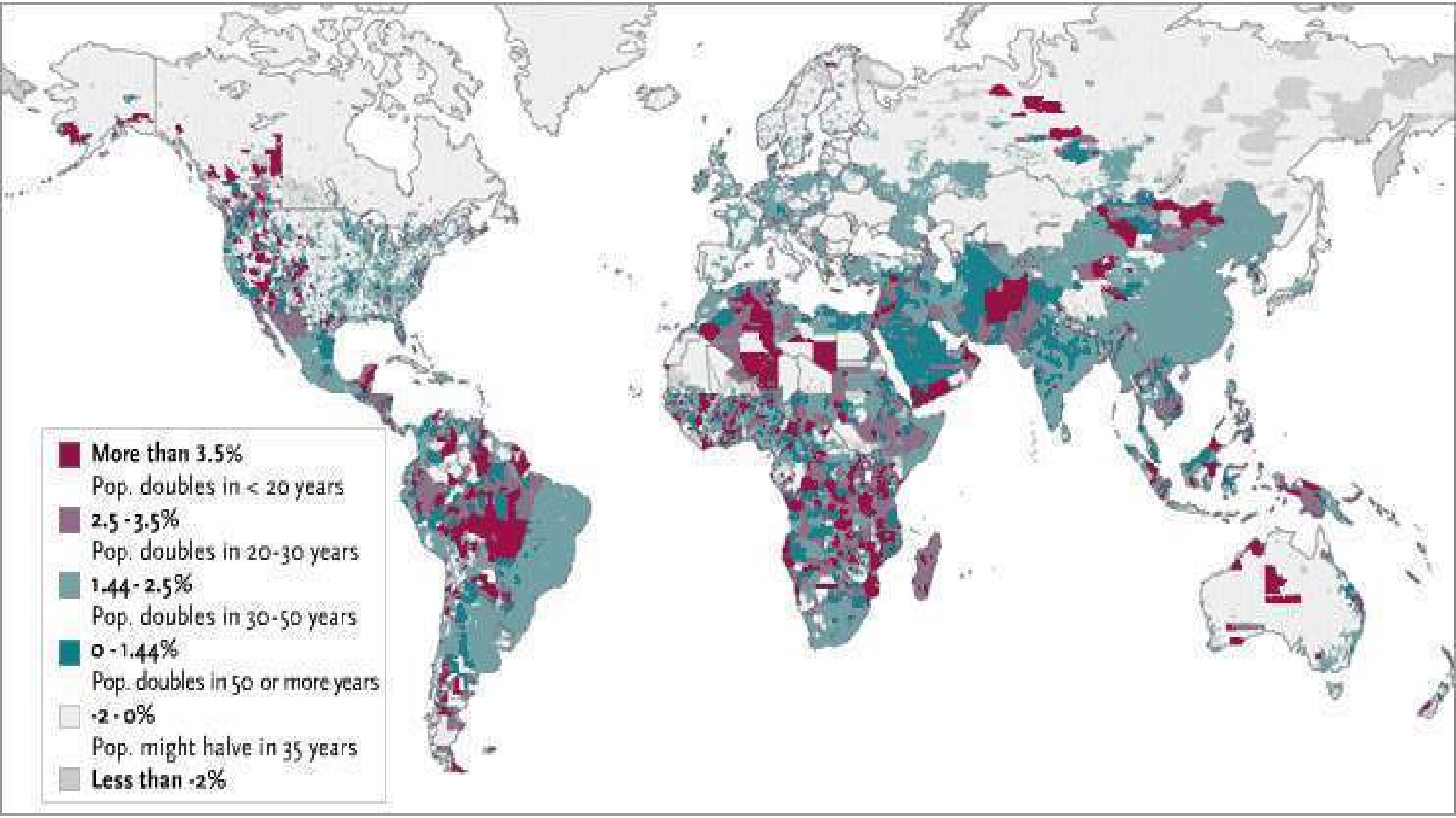
- Increased population creates need for more resources. World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity.

World Population in 2050

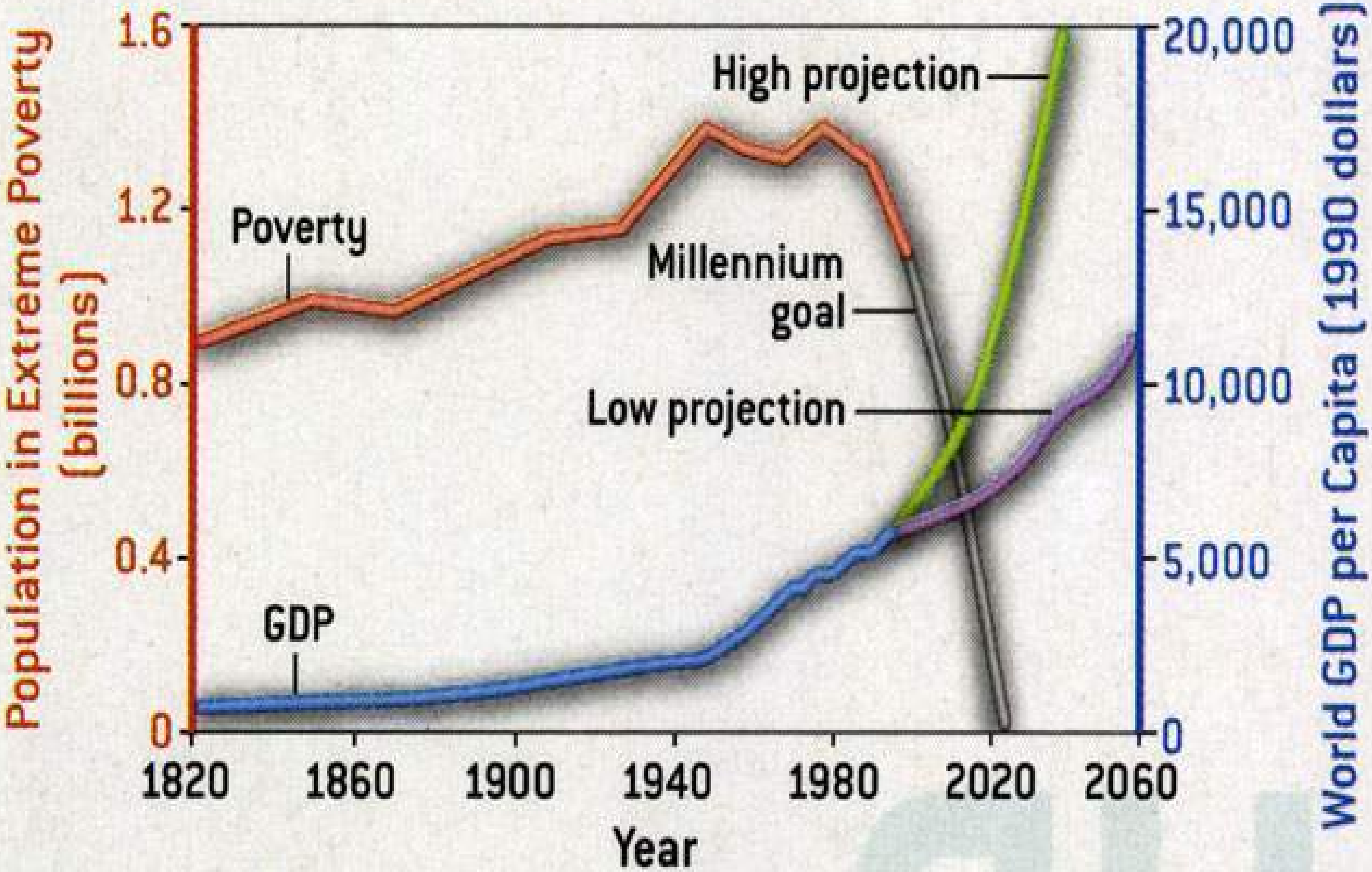


Source: Population Reference Bureau

Context: Earth population growth



... PROSPERITY IS SPREADING ...



Social Conditions and Access to Electricity

Annual GNP/capita

International Collaboration
Global R&D, global investment, global peace, global technologies

10^5 .... 10^4

Amenities
Education, recreation, the environment, intergenerational investment

10^4 .... 10^3

Basic Quality of Life
Literacy, life expectancy, sanitation, infant mortality, physical security, social security

10^3 .... 10^2

Survival
Food, water, shelter, minimal health services

Annual kWh/capita

Source: Dr. Chauncey Starr

Electricity Usage and GDP per capita

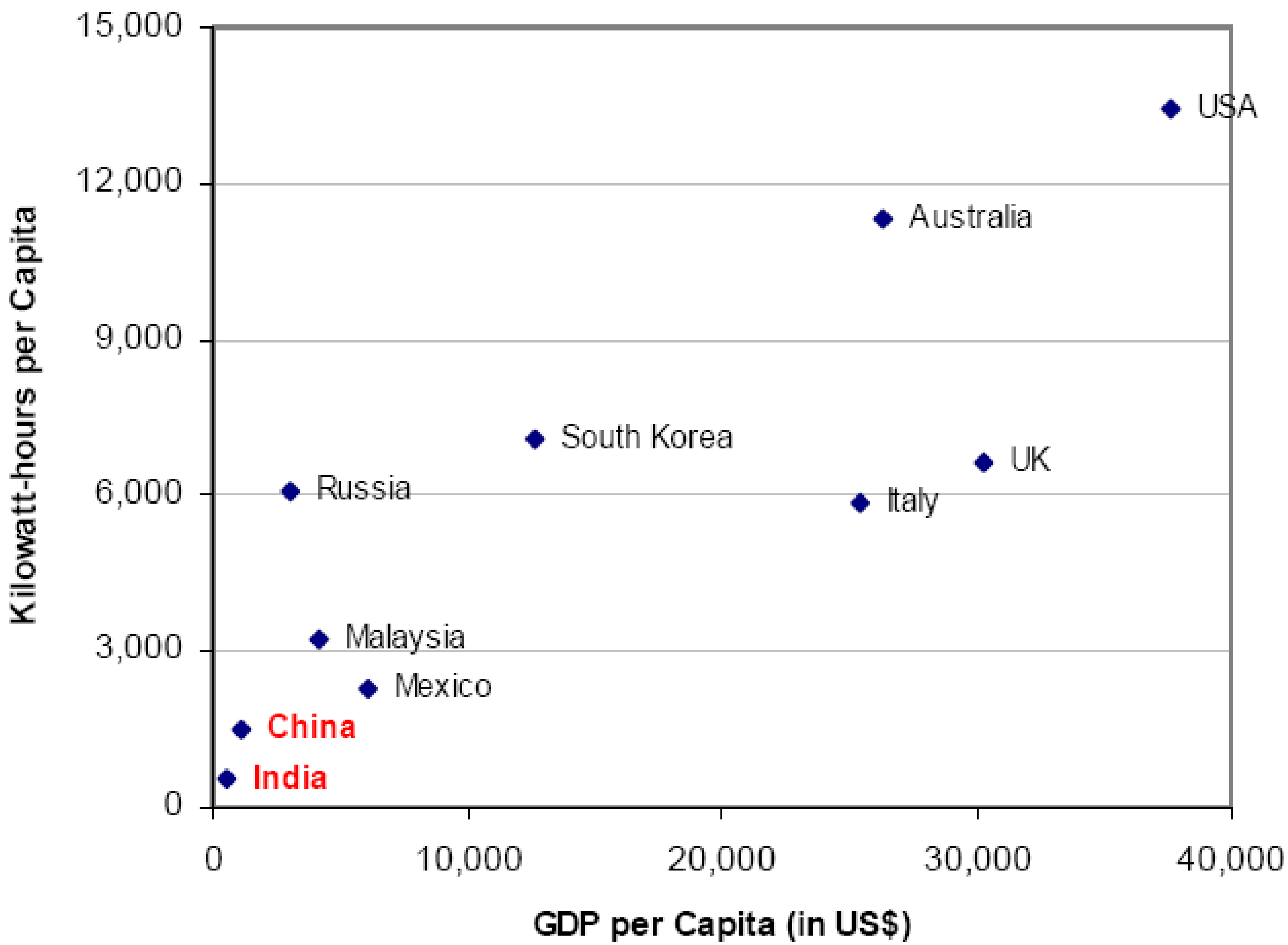
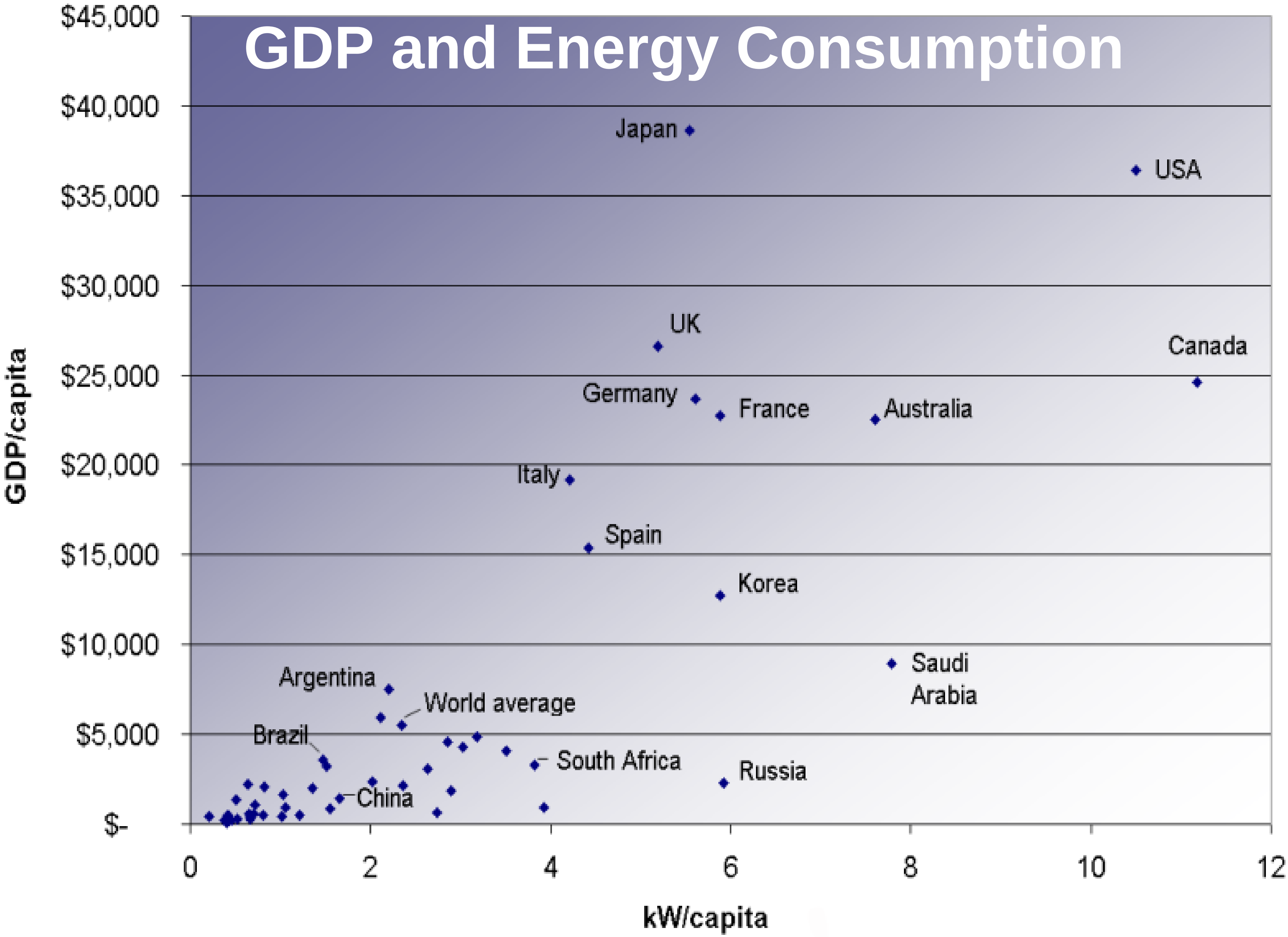


Figure 1: Electricity Usage Per Capita

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

GDP and Energy Consumption



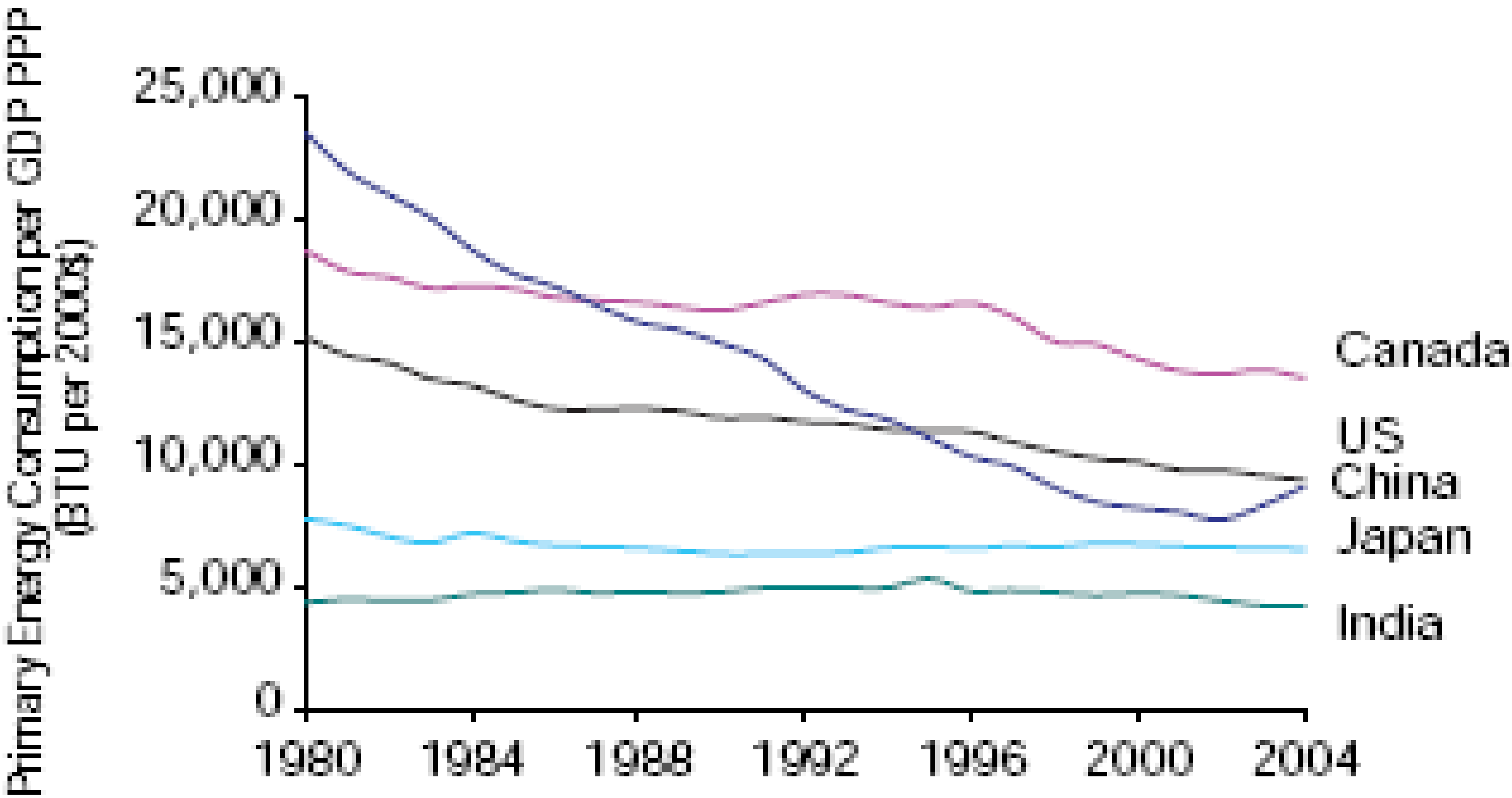


Figure 2. Total primary energy consumption per dollar of gross domestic product (GDP) (BTU per 2000 $) using purchasing power parity (PPP).[49]

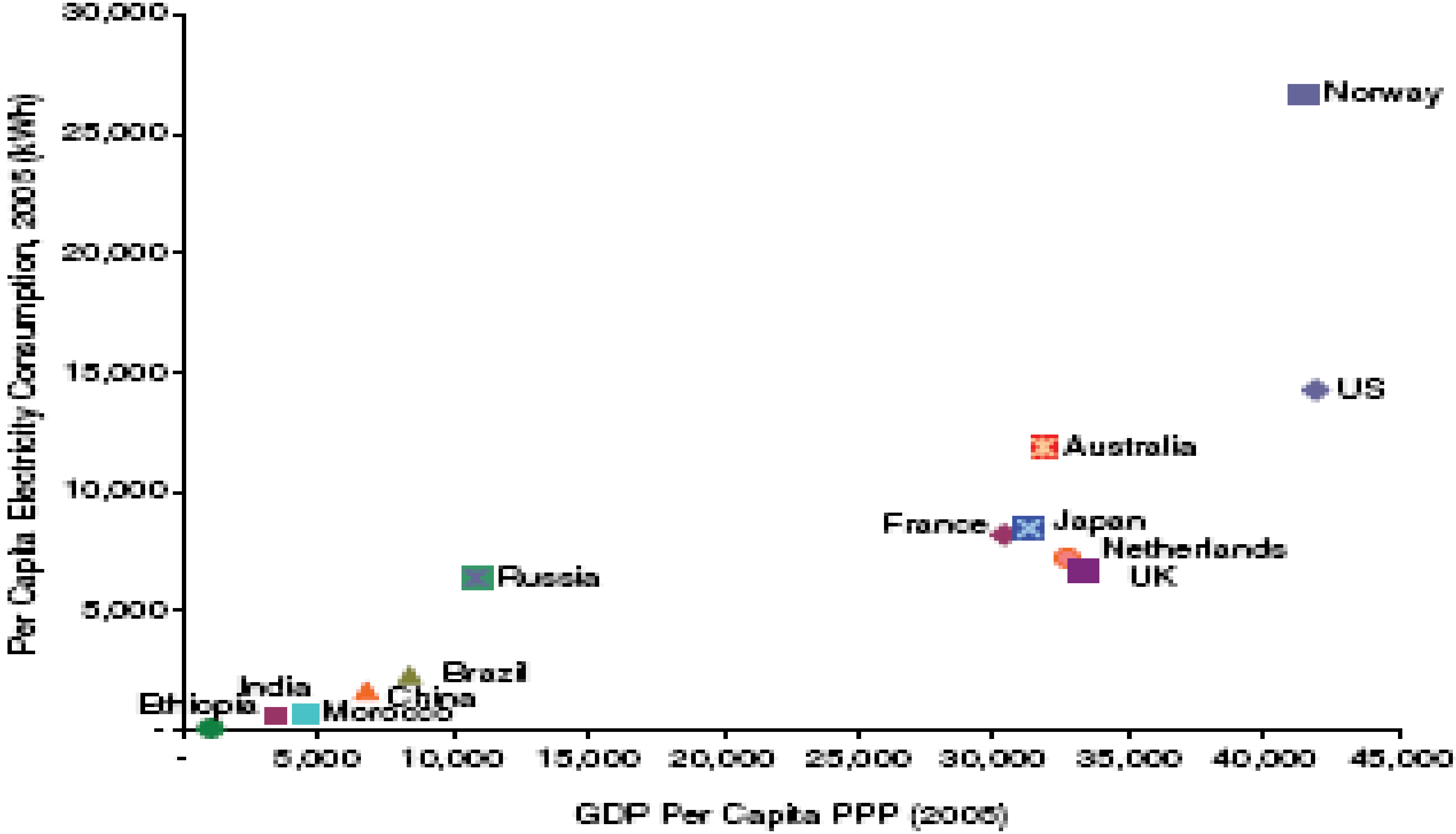


Figure 3. Per capita electricity consumption (kWh) versus GDP per capita purchasing power parity (PPP) of selected countries.[3]

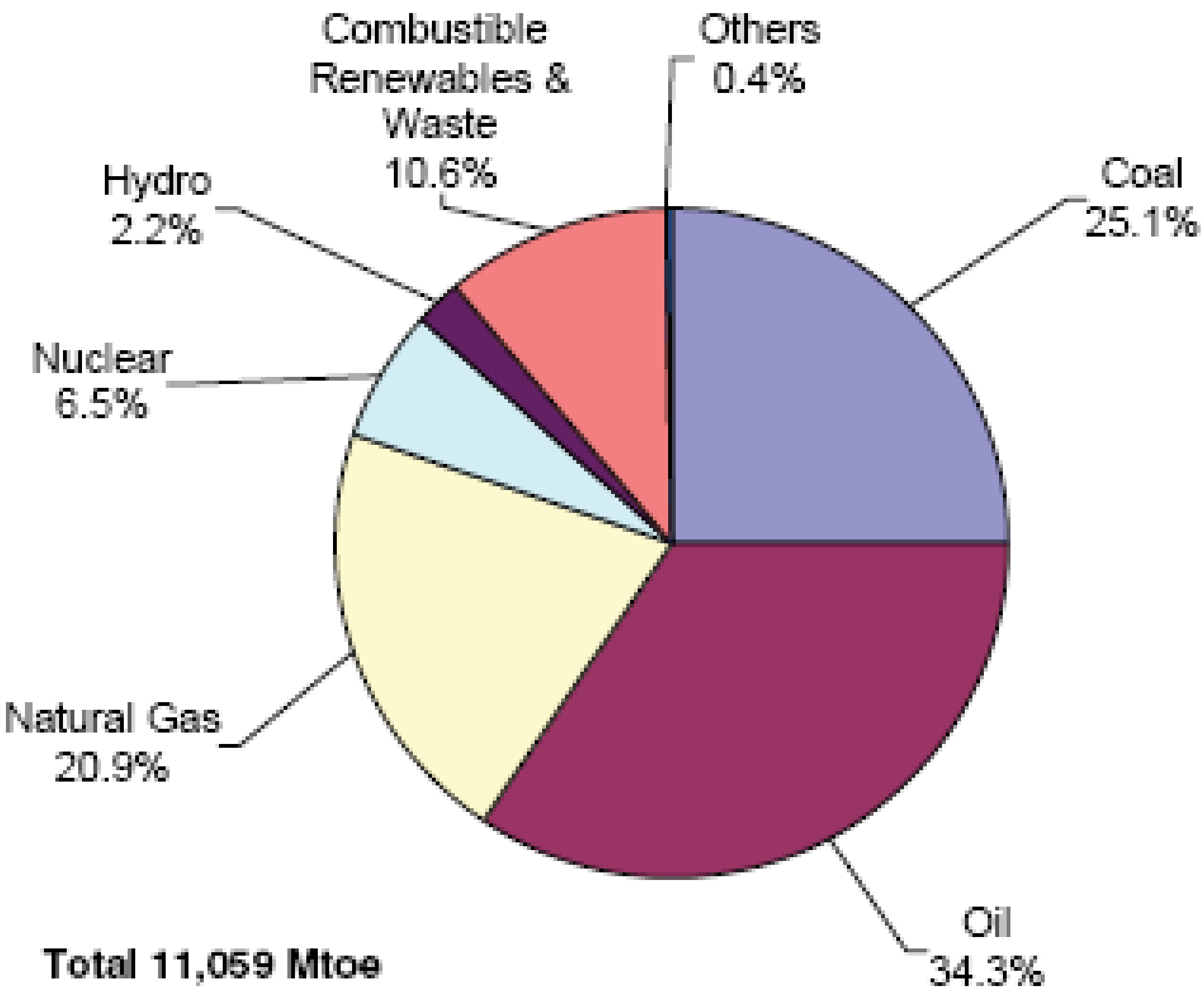
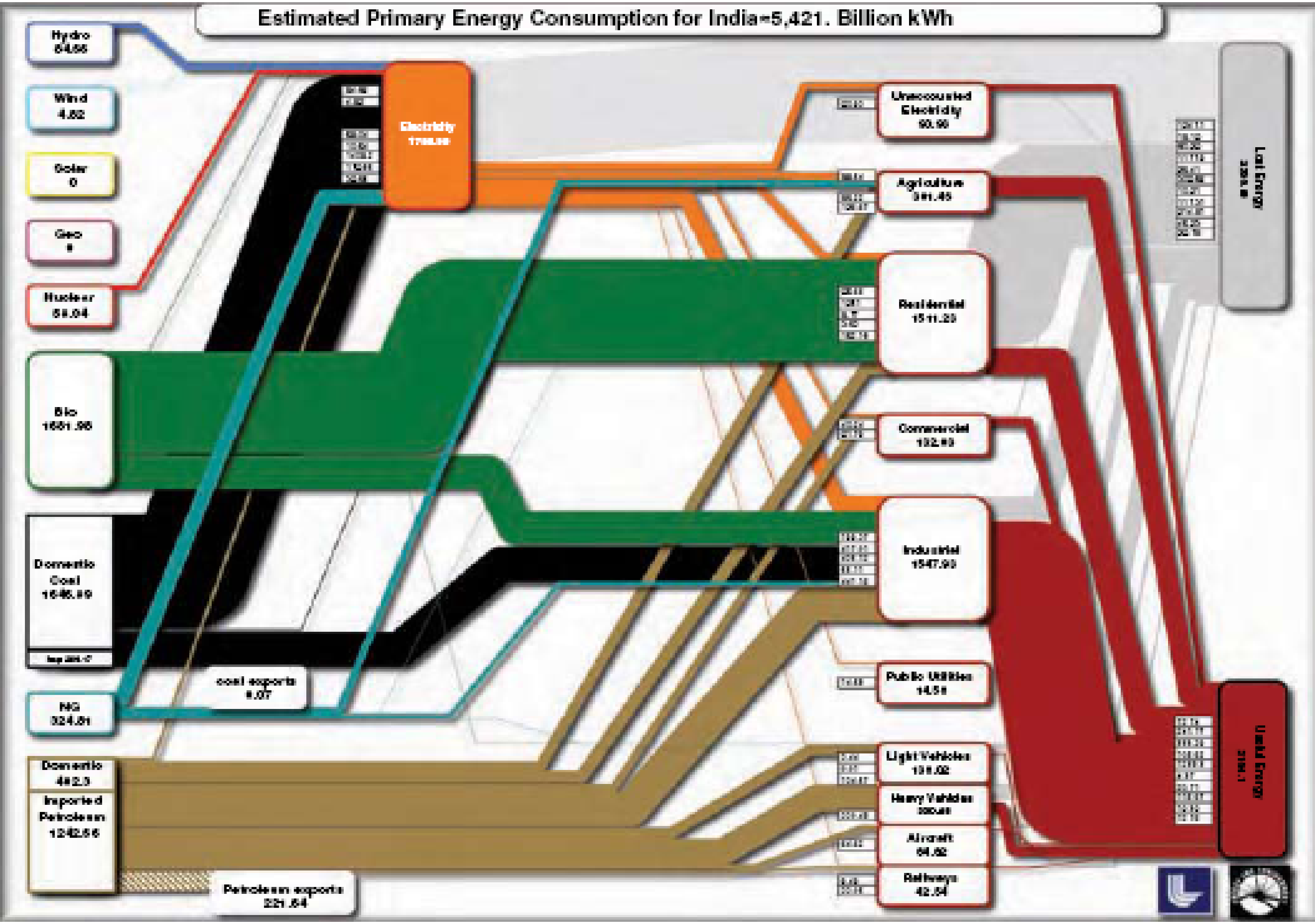
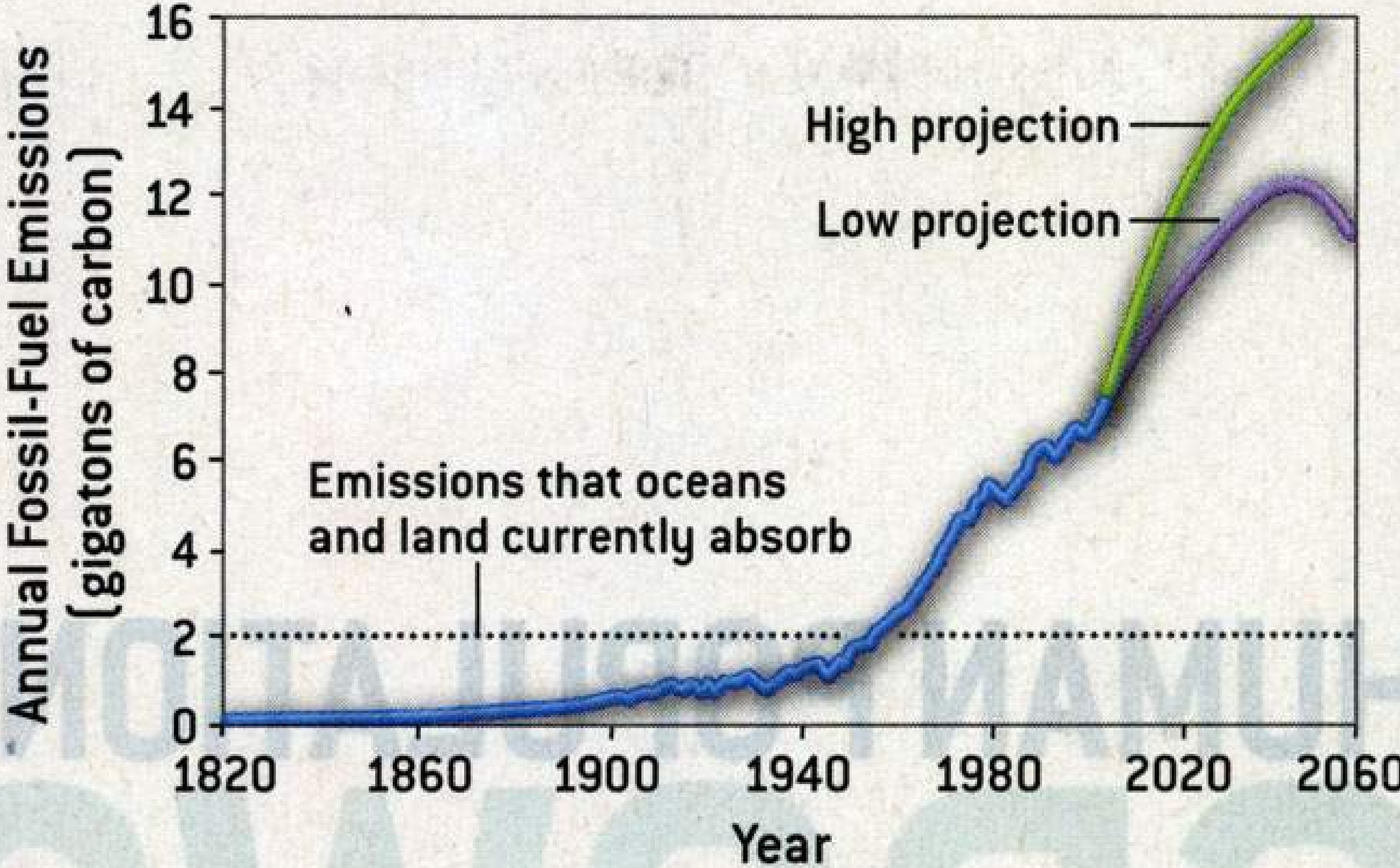


Figure 1. World total primary energy supply (2004) by source. *Note:* Mtoe is million tons of oil equivalent.[1]

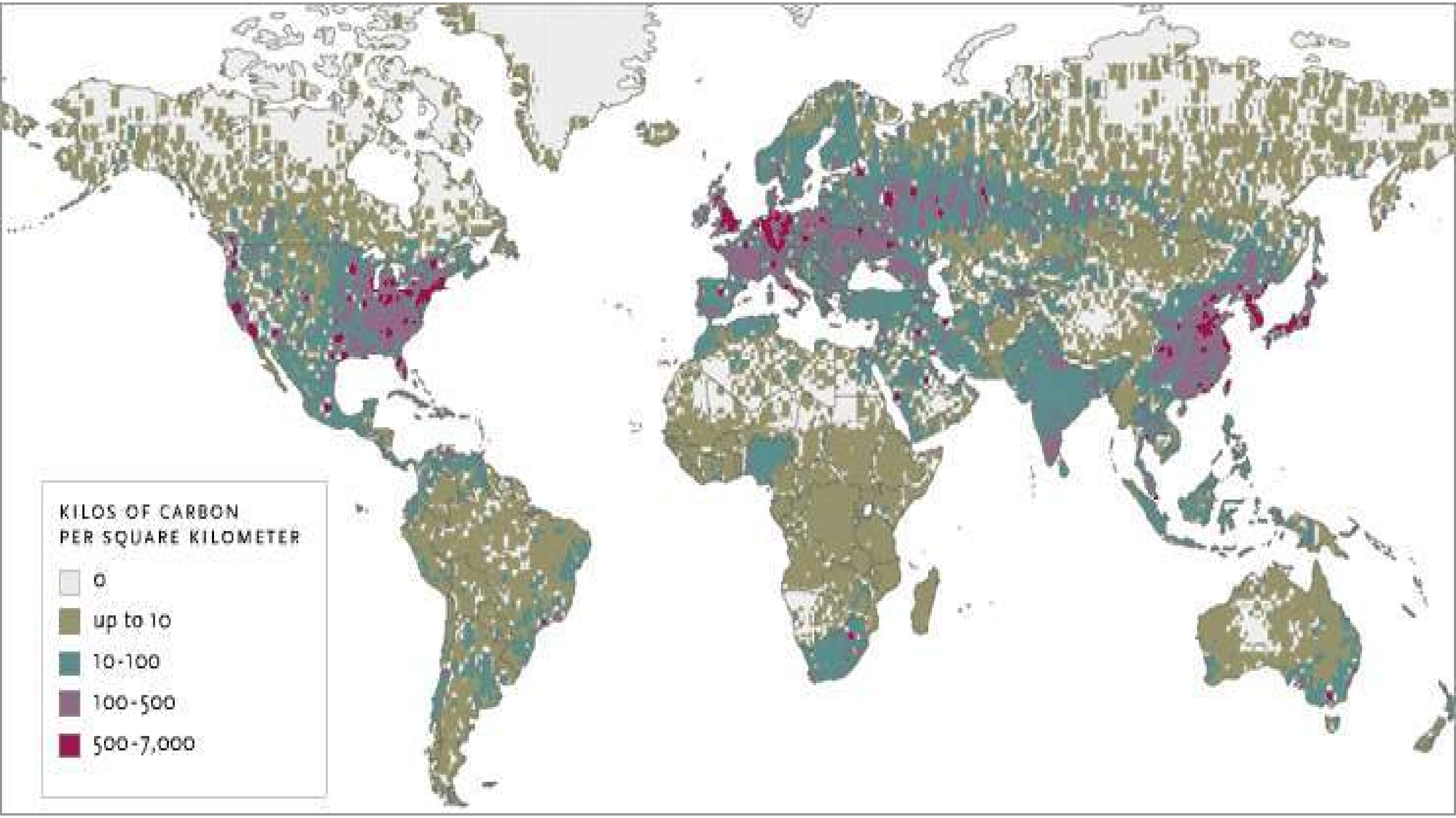


cdtl Center for the Development of Technological Leadership

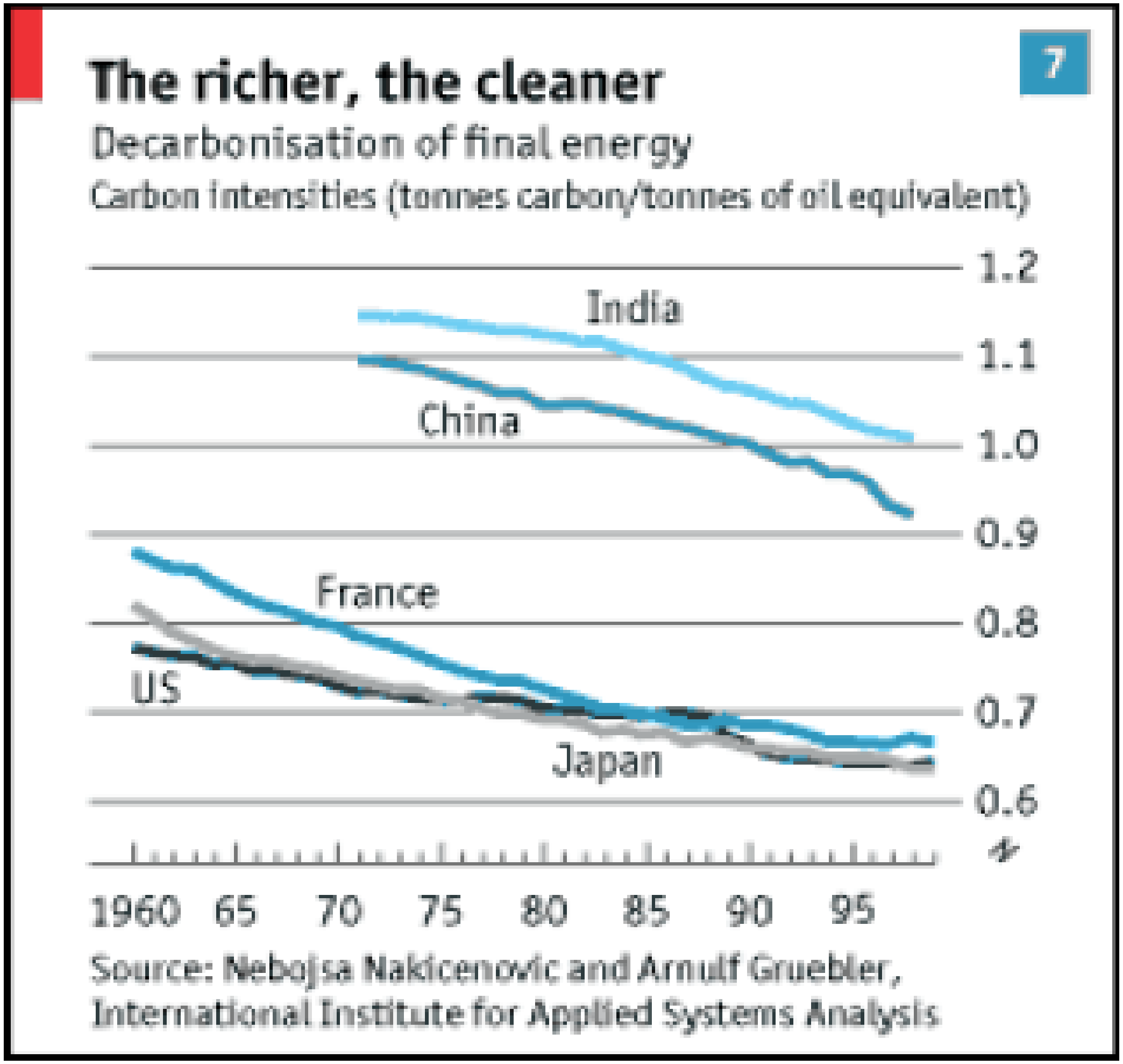
… BUT CO_2 EMISSIONS ARE TROUBLING



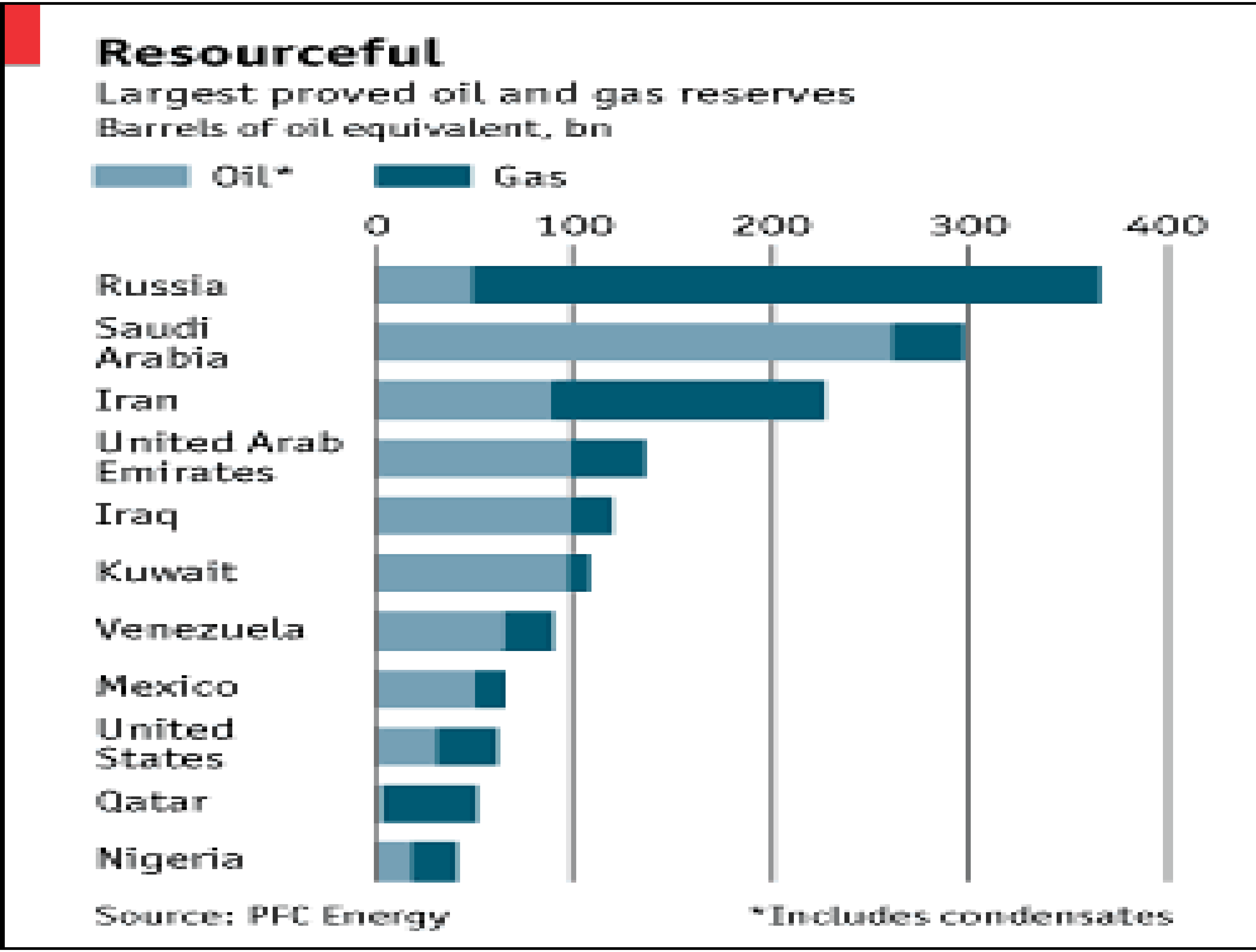
Context: Global Emissions



S&T for Sustainable Development



Source: RFF, 2002



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

World's 10 Most Profitable Companies

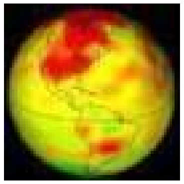
Rank (Country)	Profits in billion $
1. ExxonMobil (United States)	$ 40.61
2. Royal Dutch Shell (Netherlands)	$ 31.33
3. Gazprom (Russia)	$ 23.304
4. General Electric (United States)	$ 22.22
5. BP (United Kingdom)	$ 20.61
6. Total (France)	$ 19.247
7. HSBC Holdings (United Kingdom)	$ 19.14
8. Chevron (United States)	$ 18.70
9. PetroChina (China)	$ 18.21
10. Microsoft (United States)	$ 16.96

Source: Forbes, July 2008

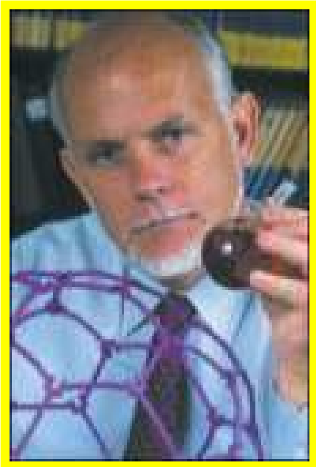
What Lies Ahead?

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

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



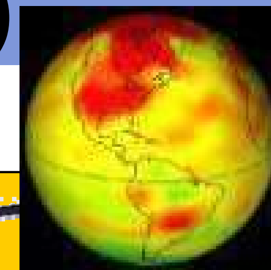
Rick Smalley, Rice U.
(1943-2005)
Nobel Prize 1996
"CIVIC SCIENTIST"

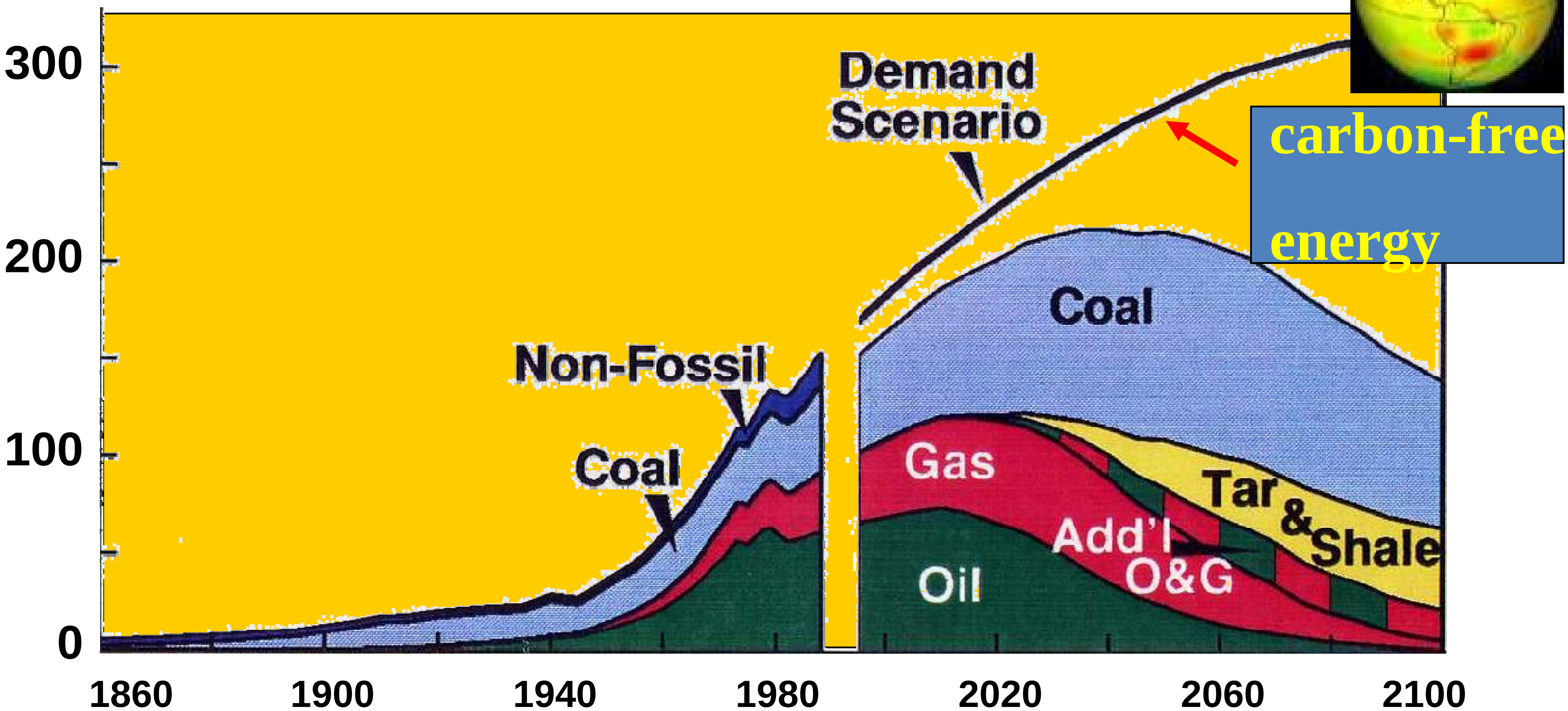


World Energy

Rick Smalley, Rice U.

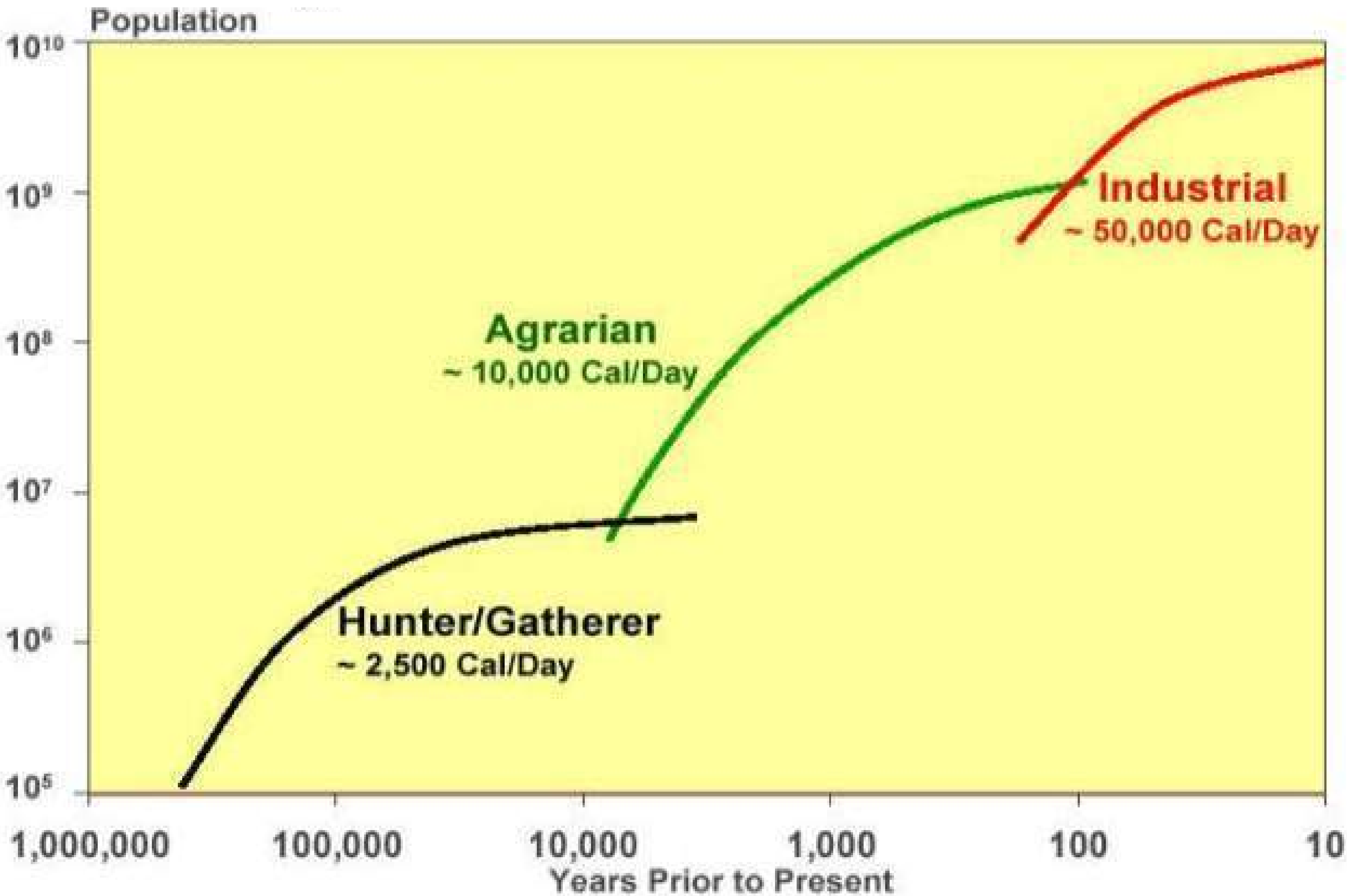
Millions of Barrels per Day (Oil Equivalent)



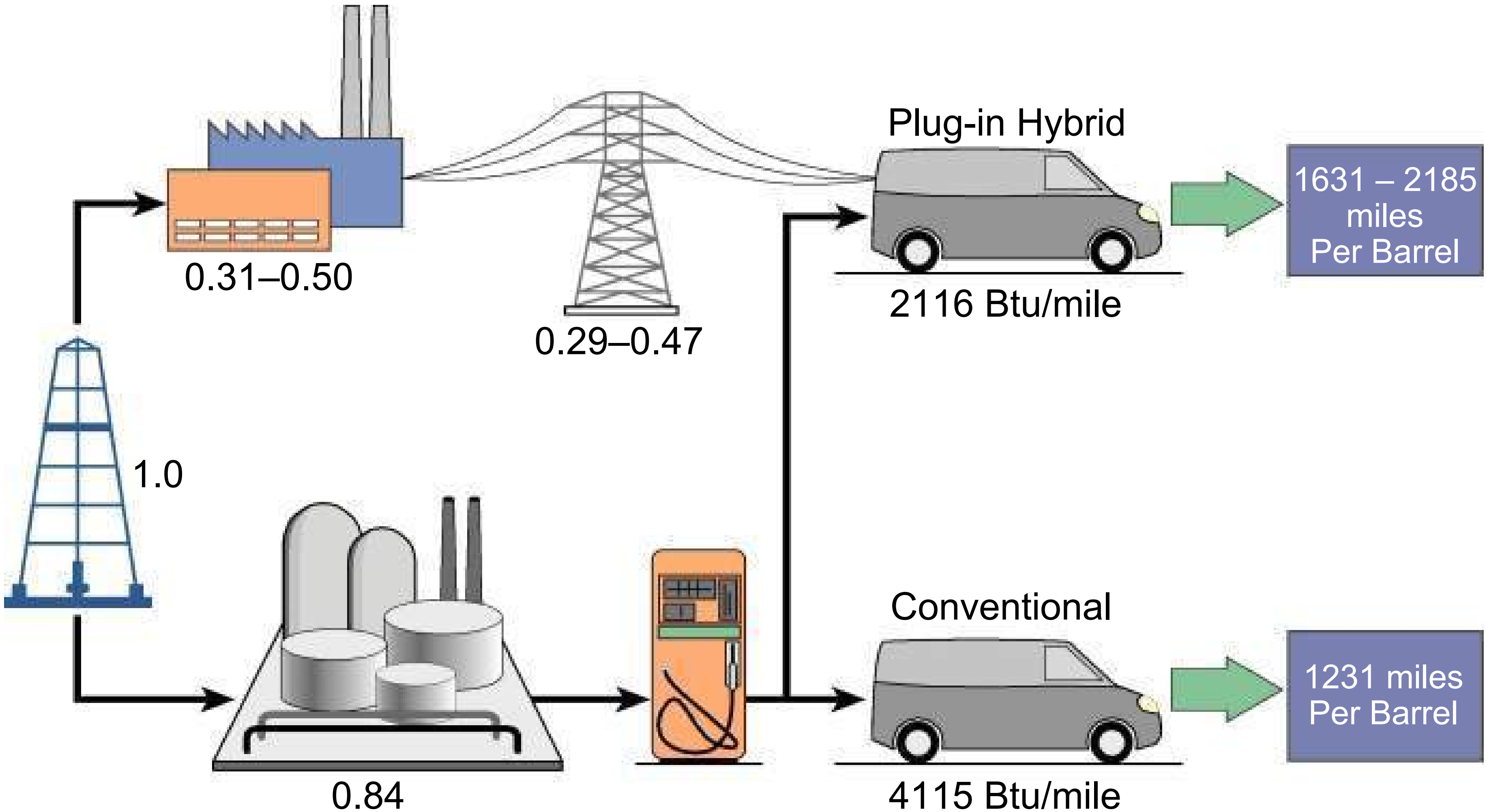


Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

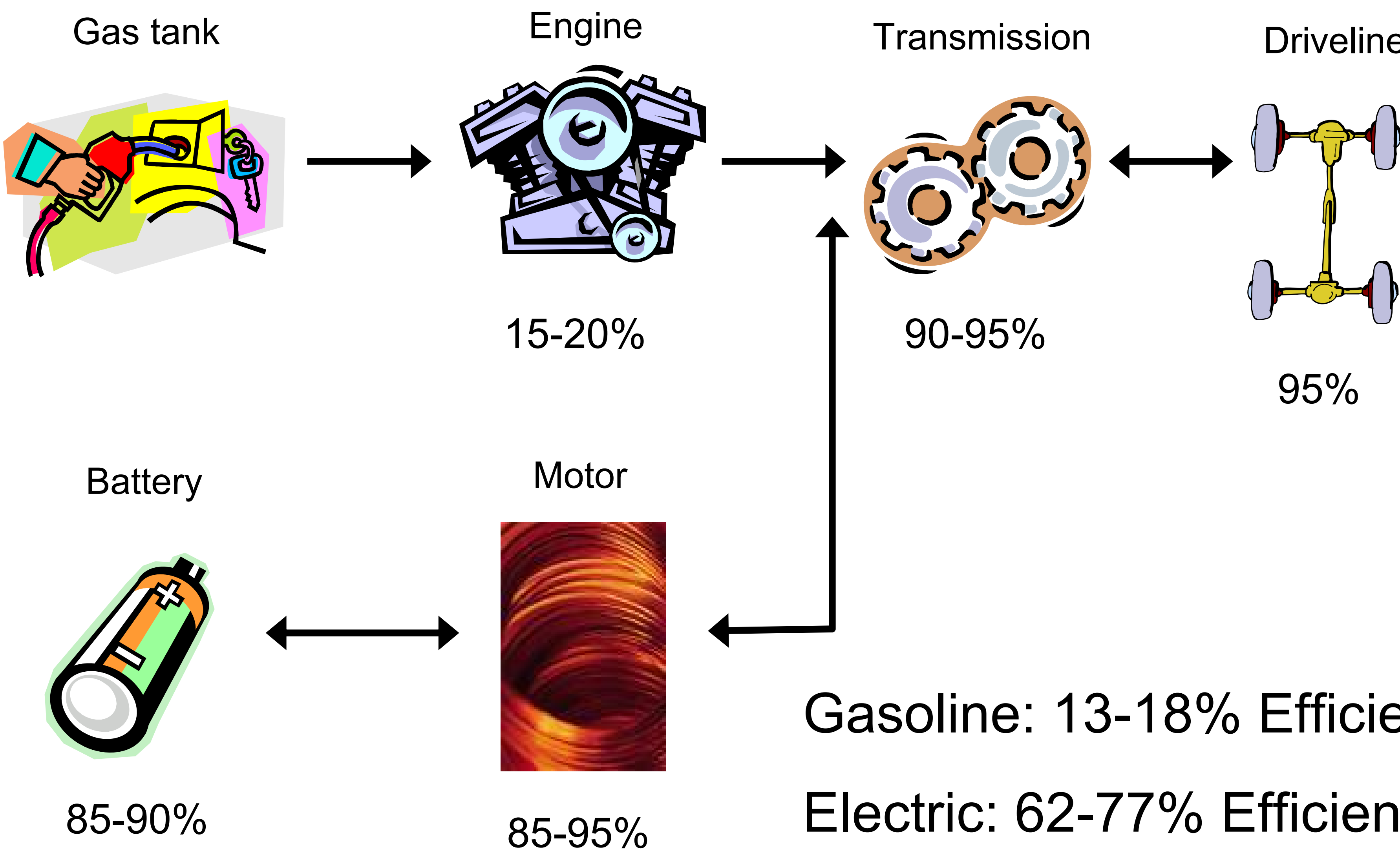
Context: Cycles of demographic Growth



Full Fuel Cycle Efficiency Comparison



Hybrid Vehicle Efficiency



Gasoline: 13-18% Efficient

Electric: 62-77% Efficient

"Electrifying America's Transportation: A Value Proposition for Electric Drive Vehicles"

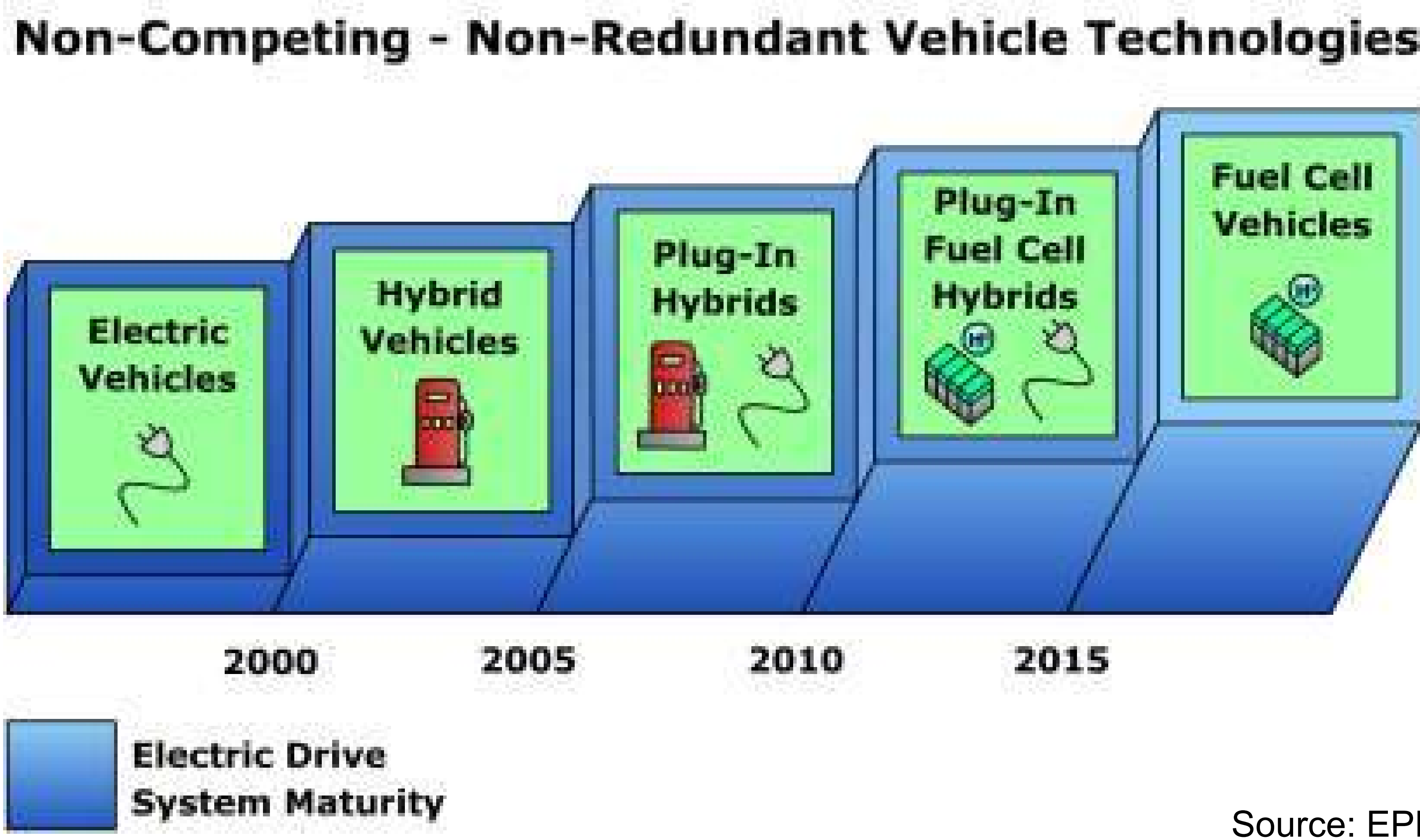
A study by Professor James A. Weinbrake, James Madison University, 2002

Sponsored by EPRI's Technology Roadmap Project

- Assumes by 2025
  - Half of all cars are Hybrids
  - Half of those are plug-in Hybrids
- Based on DOE – EIA projections for energy use

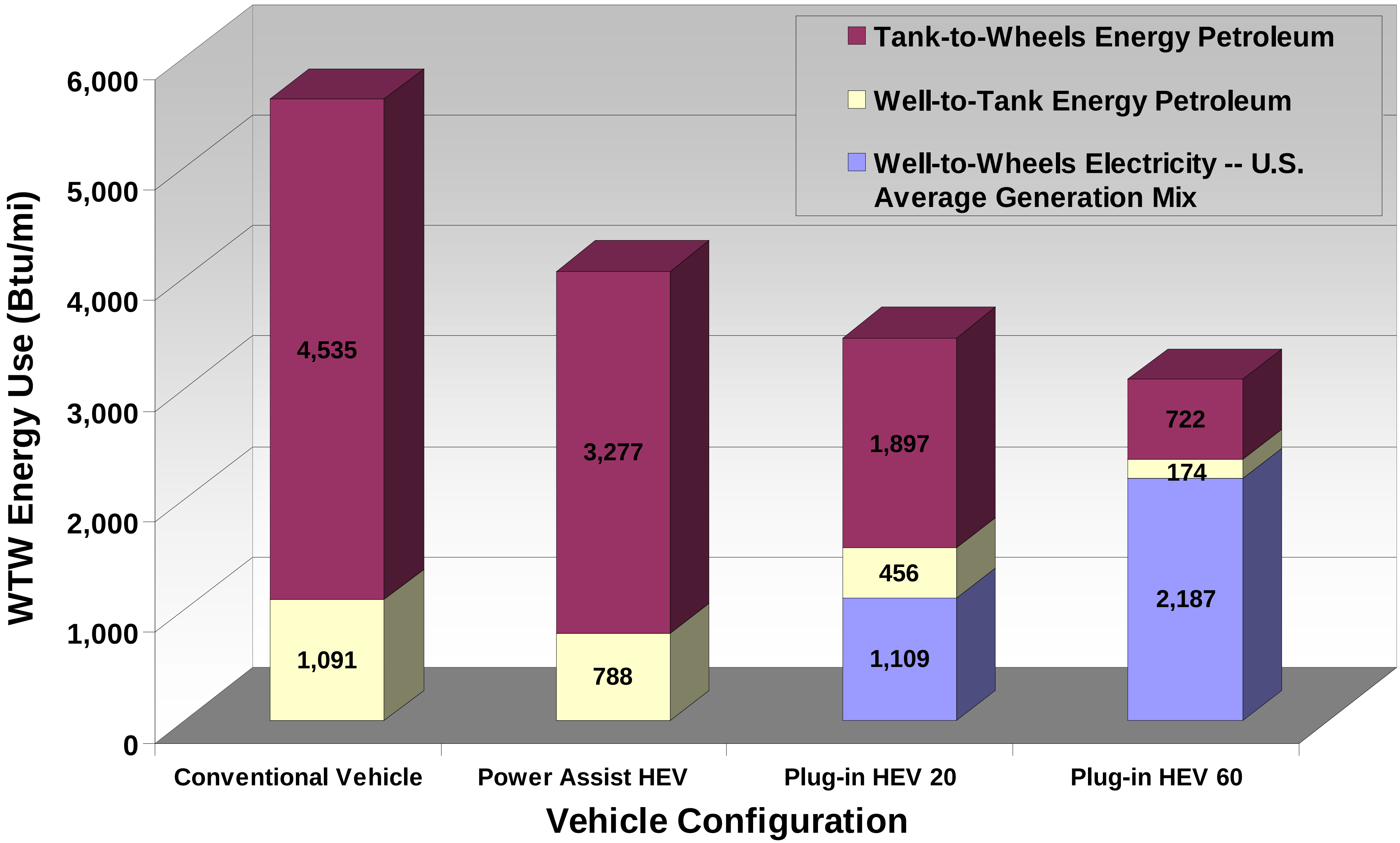
Net Economic Benefits	Billion $/year (2002 $)
Oil Use	- 4 M bbl/day
GDP Impact	+ $ 38 B/year
Environmental	+ $ 9 B/year
Labor	+ 440,000 Jobs/yr

Market Transformation of Electric Drive Vehicles

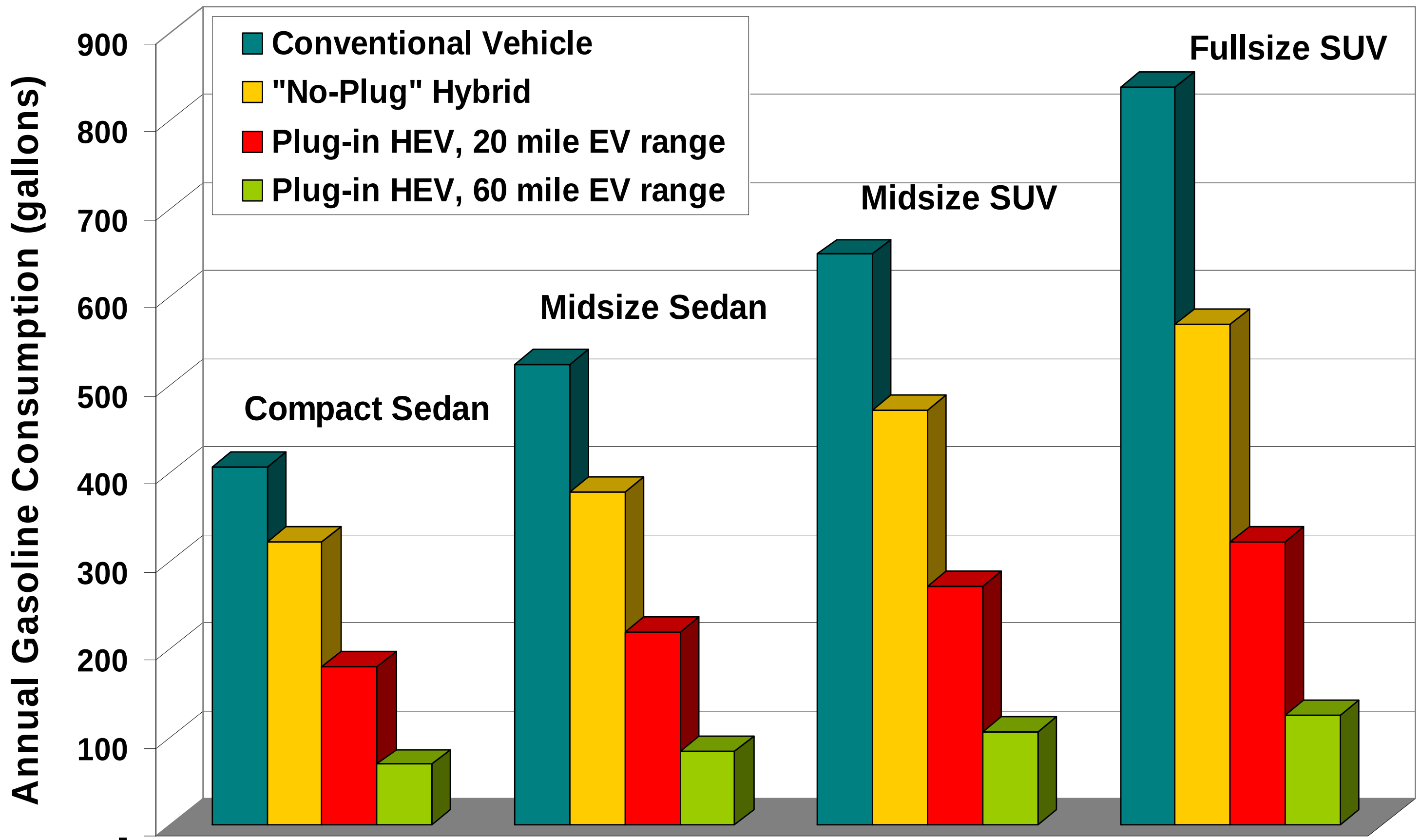


Source: EPRI

Well-to-Wheels Energy Use— Midsize Sedan

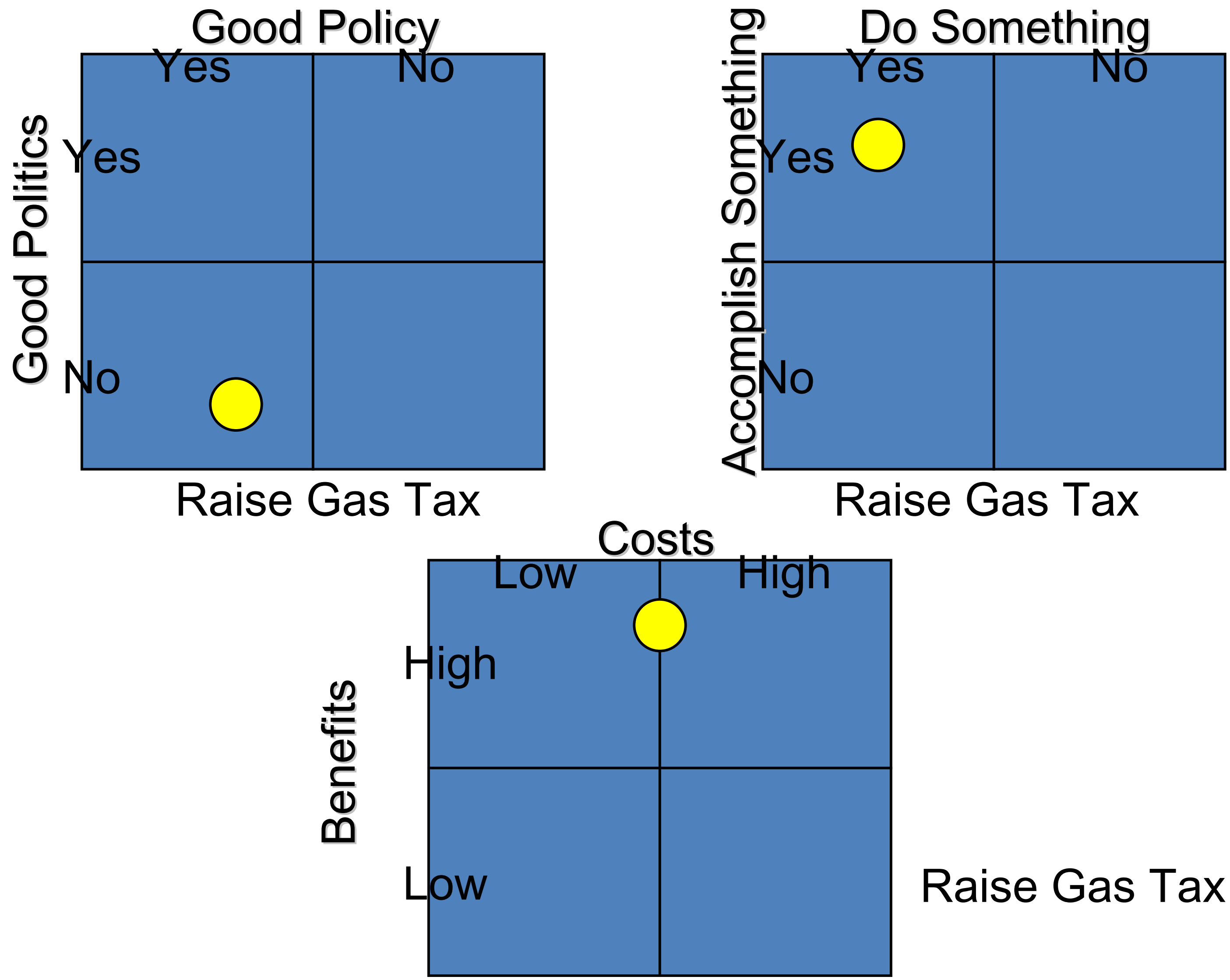


Petroleum Reduction

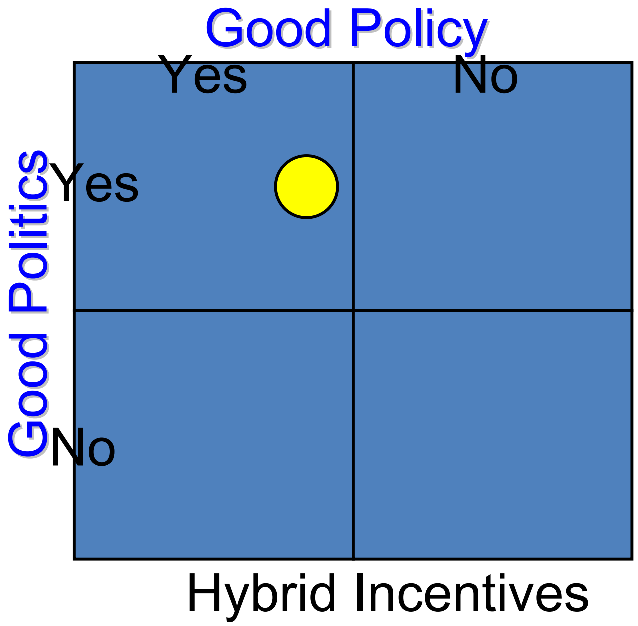


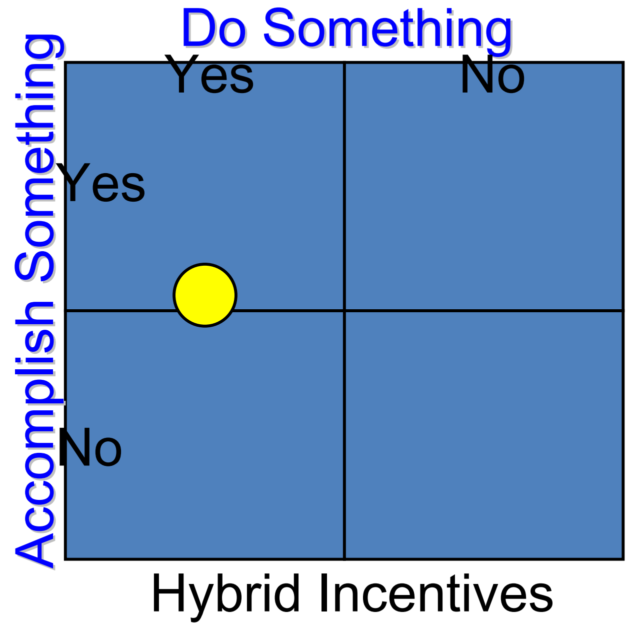
Up to 85% reduction in gasoline use and trips to gas station (HEV60).

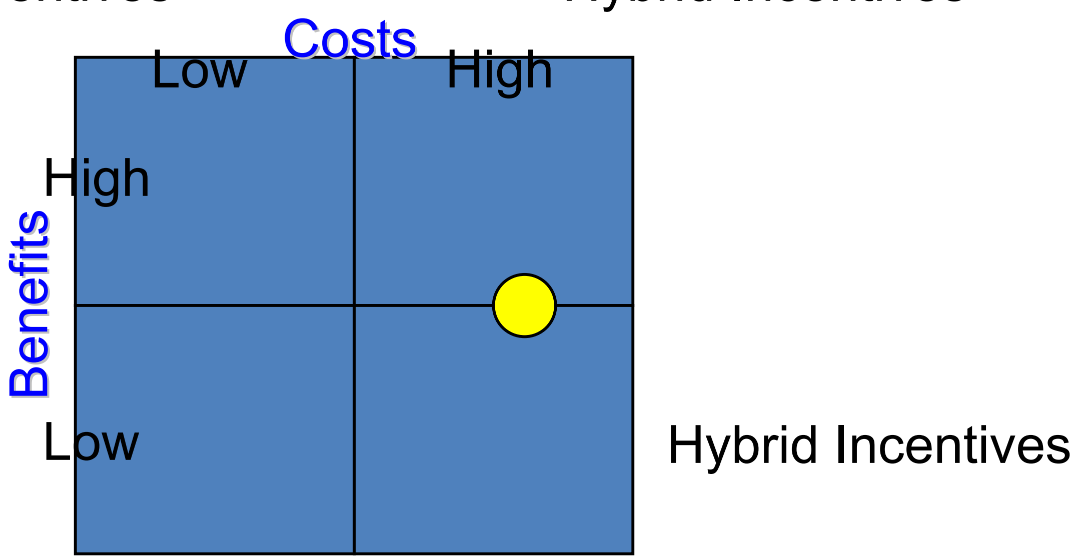
Alternative Selection: Raise Gas Tax



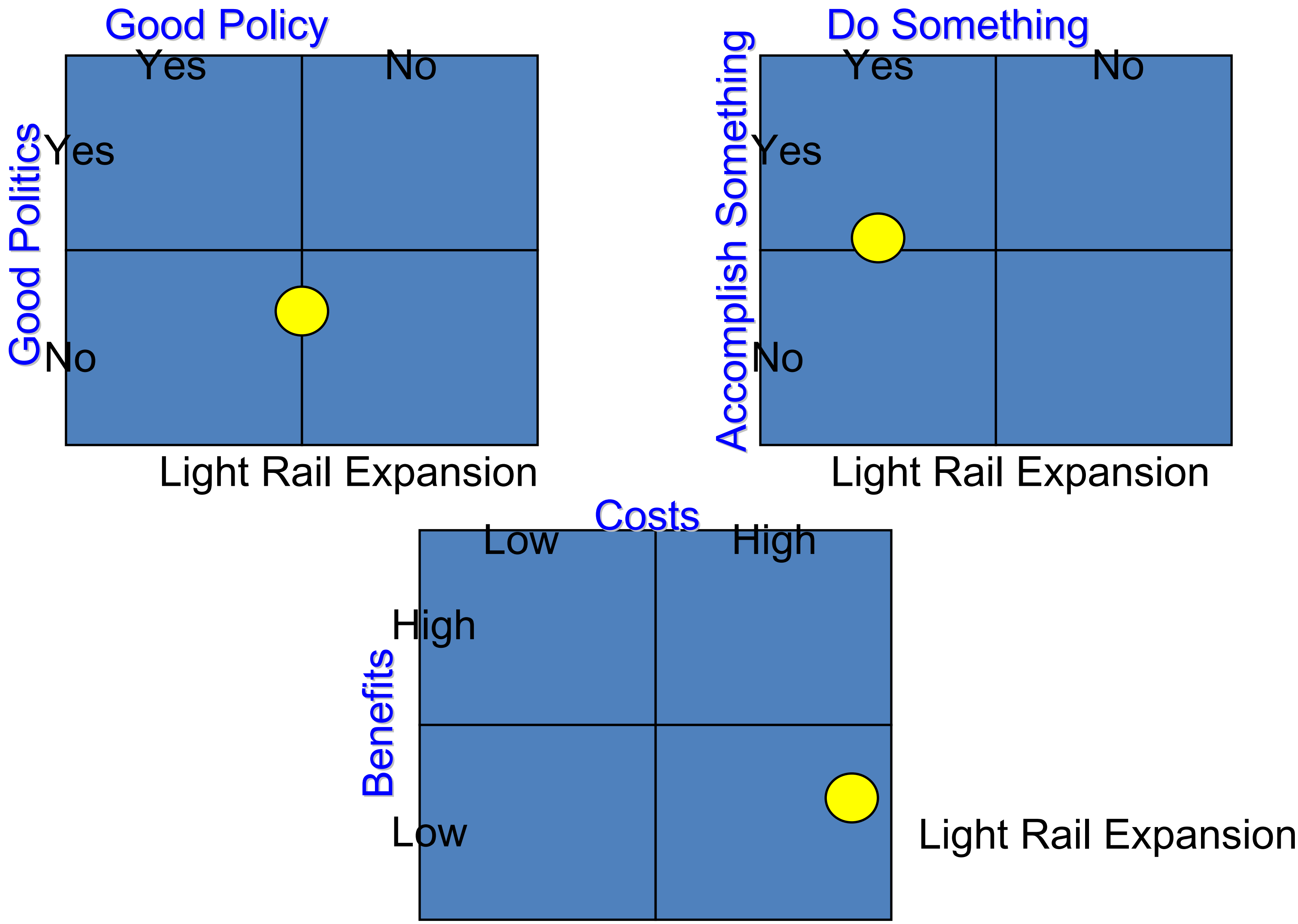
Alternative Selection:
Incentives for Hybrid Vehicles







Alternative Selection: Light Rail Expansion



My Plug-in Hybrid Electric Vehicle

- **Convenient Re-charging… Anytime and Anywhere**
  - Vehicle meter "handshakes" with network-connected "socket" to identify vehicle and billing information
  - Re-charges with kWh measured by vehicle meter
  - Electronic billing transaction debits vehicle owner's account and credits "socket" owner's account

- **Distributed Energy Storage**
  - Sell stored battery energy to the grid
  - Utilize stored battery energy for short-term back-up power

- **Distributed Generation**
  - Utilize internal combustion engine for longer-term backup power

Consumers will demand these conveniences
…will the Electricity Efficiency Infrastructure be ready?

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

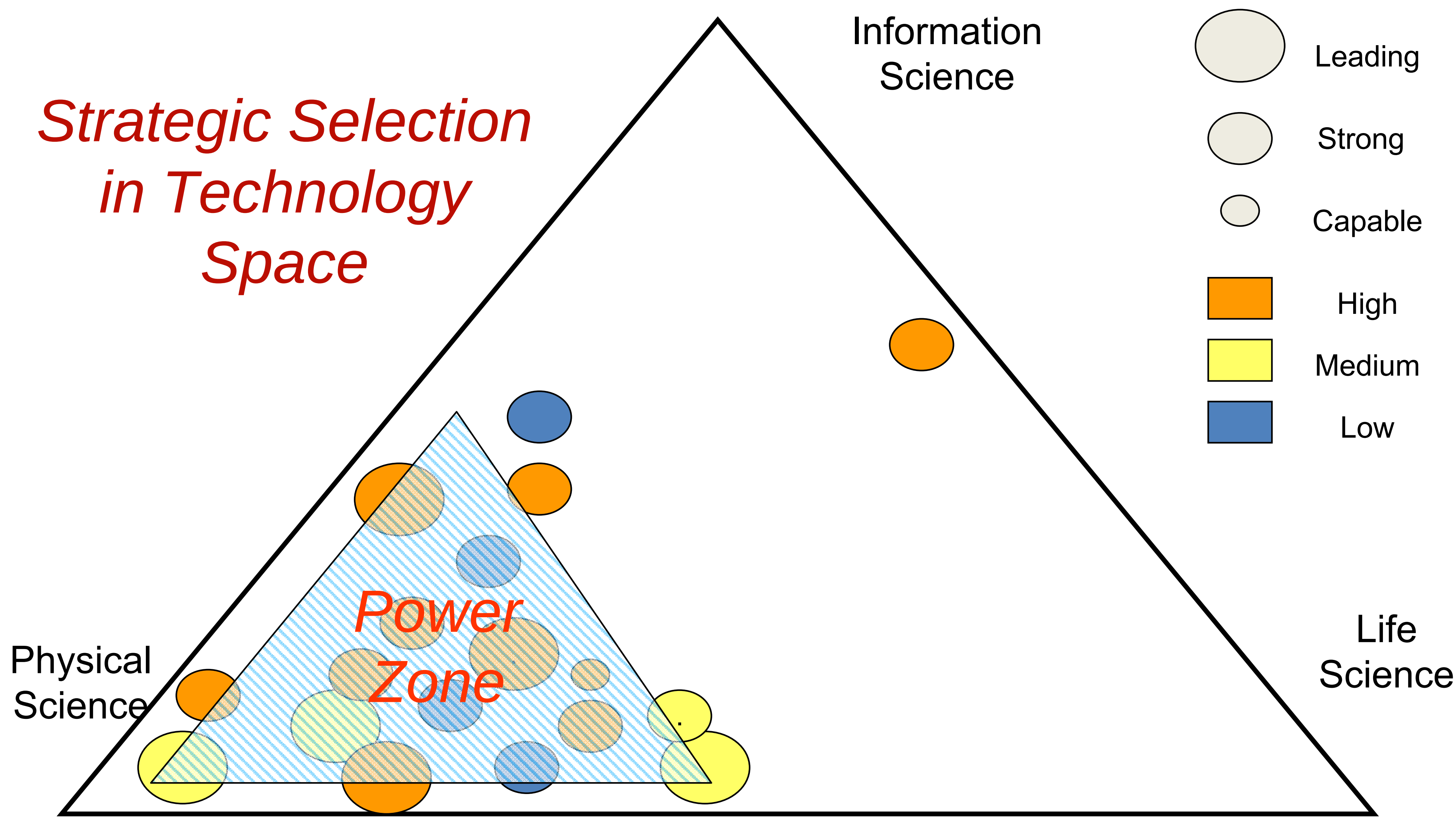
One of my research areas: S&T Assessment, Scan & Map
(April 2005-Feb 2006; Galvin Electricity Initiative)

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

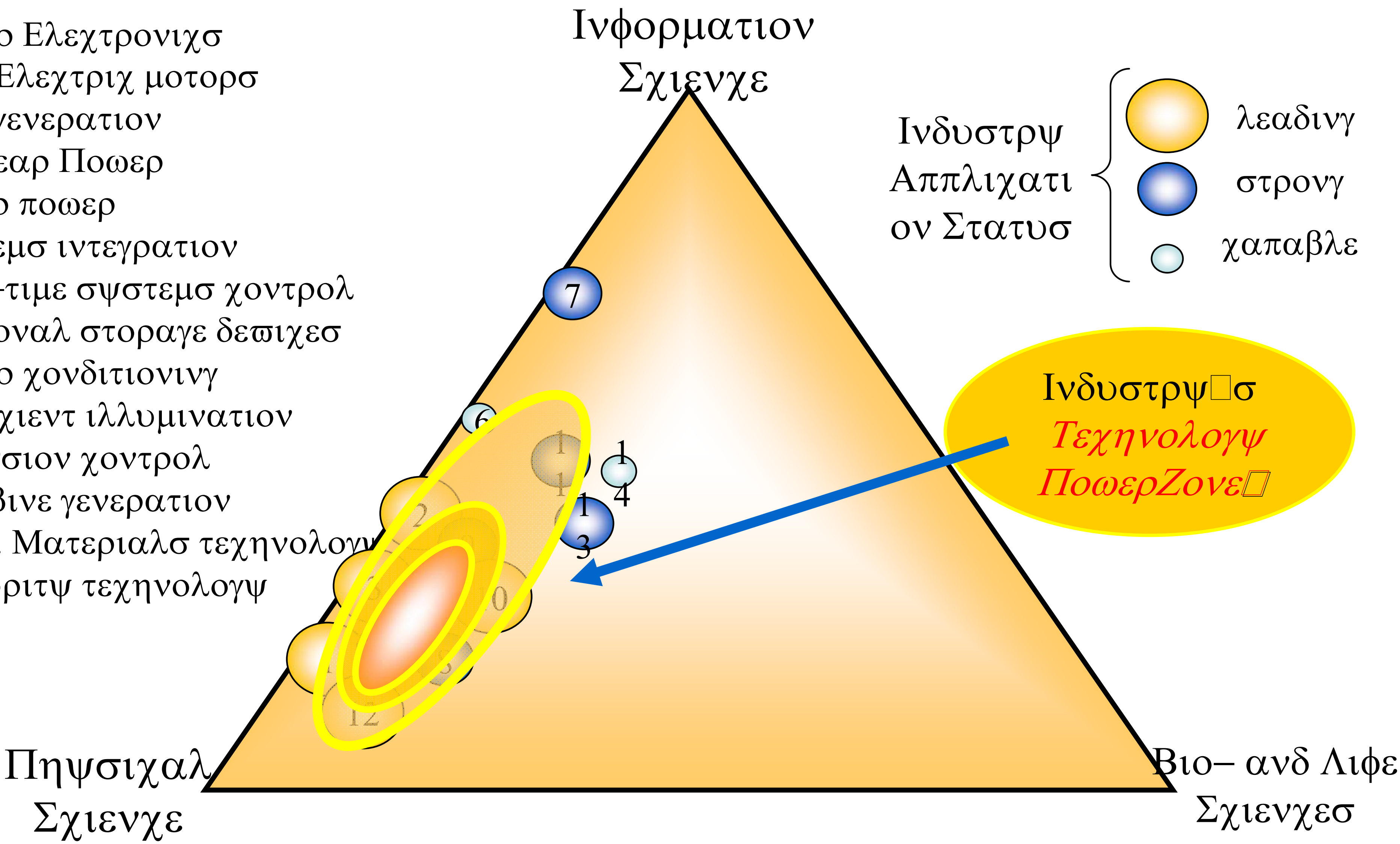
Technology Scanning Process - Evaluation



Examples of industry’s technology strengths today

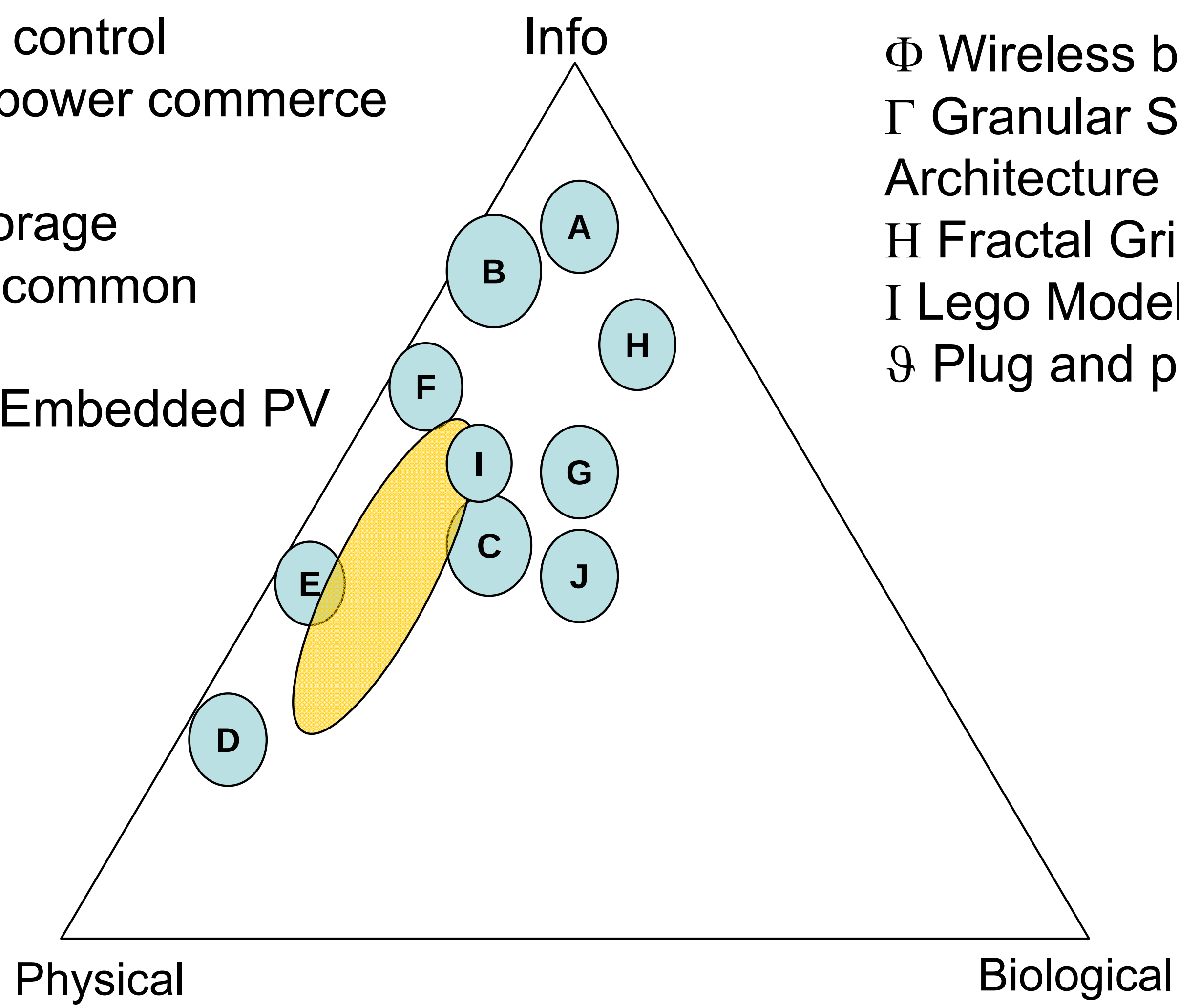
Εξαμπλεσ ινχλυδε:

1.Ποωερ Ελεχτρονιχσ
2.Αδϖ. Ελεχτριχ μοτορσ
3.Ωινδ γενερατιον
4.Νυχλεαρ Ποωερ
5.Σολαρ ποωερ
6.Σψστεμσ ιντεγρατιον
7.Ρεαλ–τιμε σψστεμσ χοντρολ
8.Περσοναλ στοραγε δεϖιχεσ
9.Ποωερ χονδιτιονινγ
10.Εφφιχιεντ ιλλυμινατιον
11.Εμισσιον χοντρολ
12.Τυρβινε γενερατιον
13.Αδϖ. Ματεριαλσ τεχνολογψ
14.Σεχυριτψ τεχνολογψ



Expanding the Power Zone

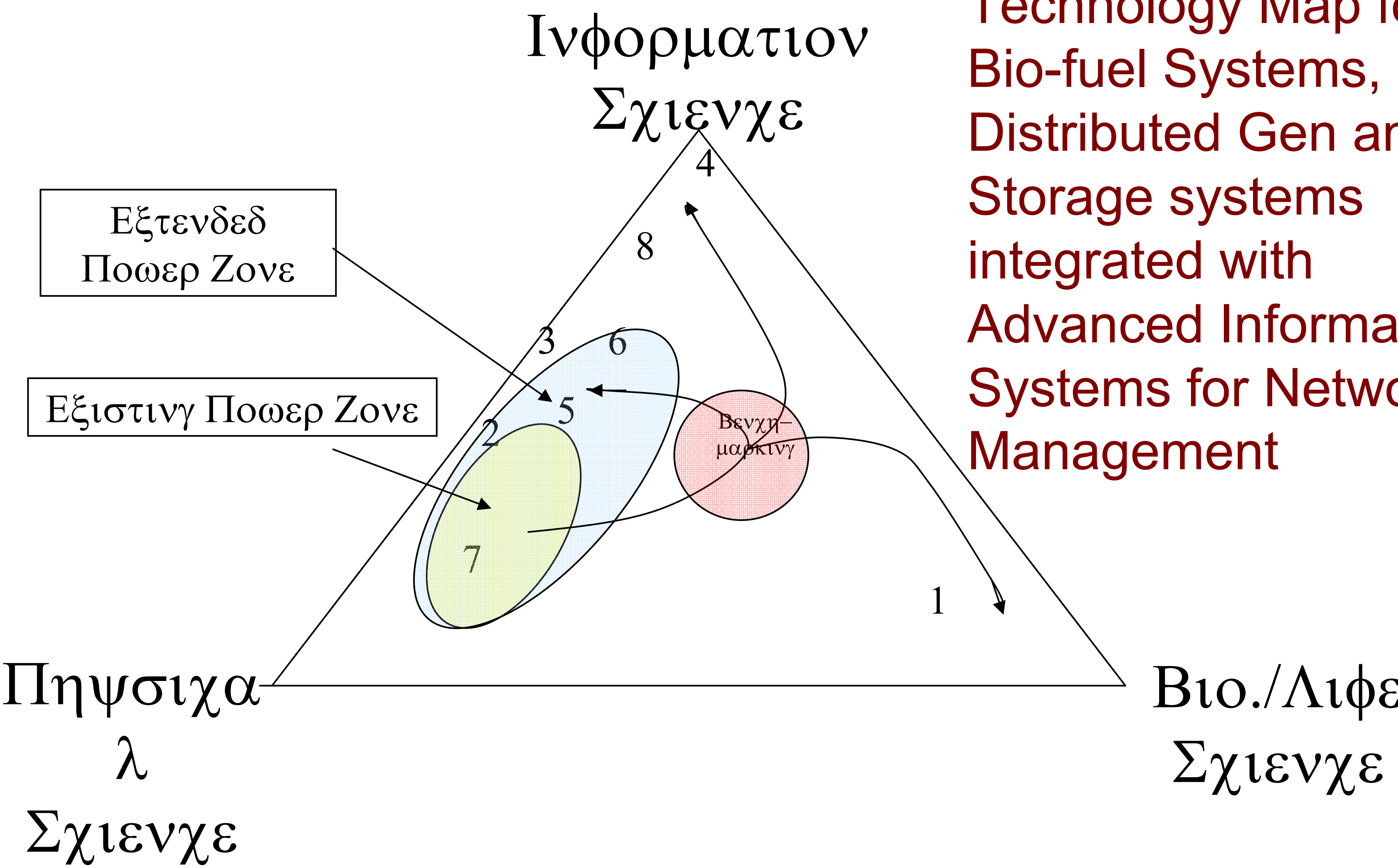
A. Distributed control
B. Electronic power commerce
C. Distributed generation/storage
D. Integrated common infrastructure
E. Integrated/Embedded PV



Φ Wireless backup
Γ Granular Semi-autonomous Architecture
Η Fractal Grid Lego Model
Ι Lego Model
ϑ Plug and play appliances

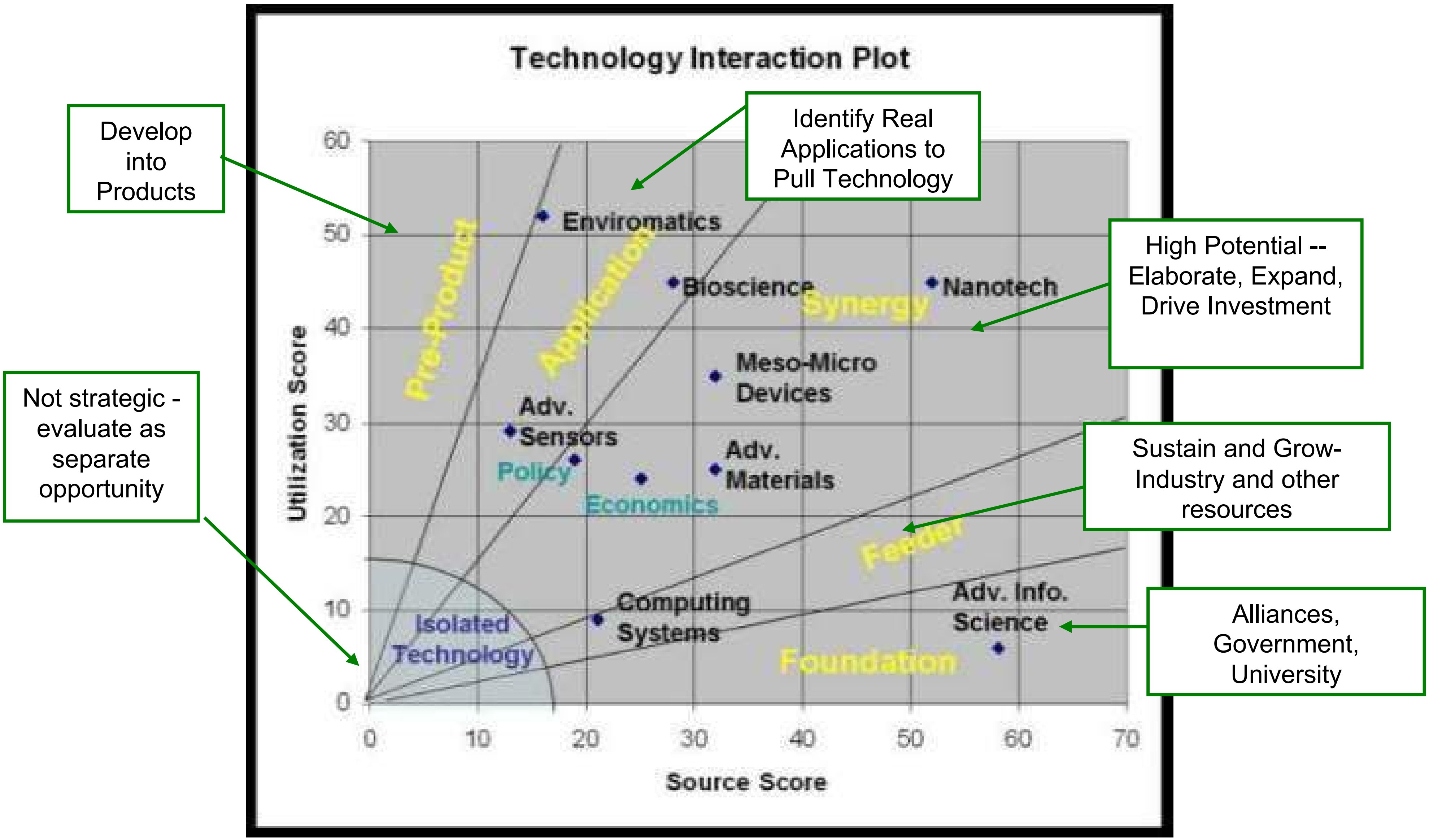
Technology Map for the Granular Semi-Autonomous Architecture

Expanding and Transforming the Power Zone



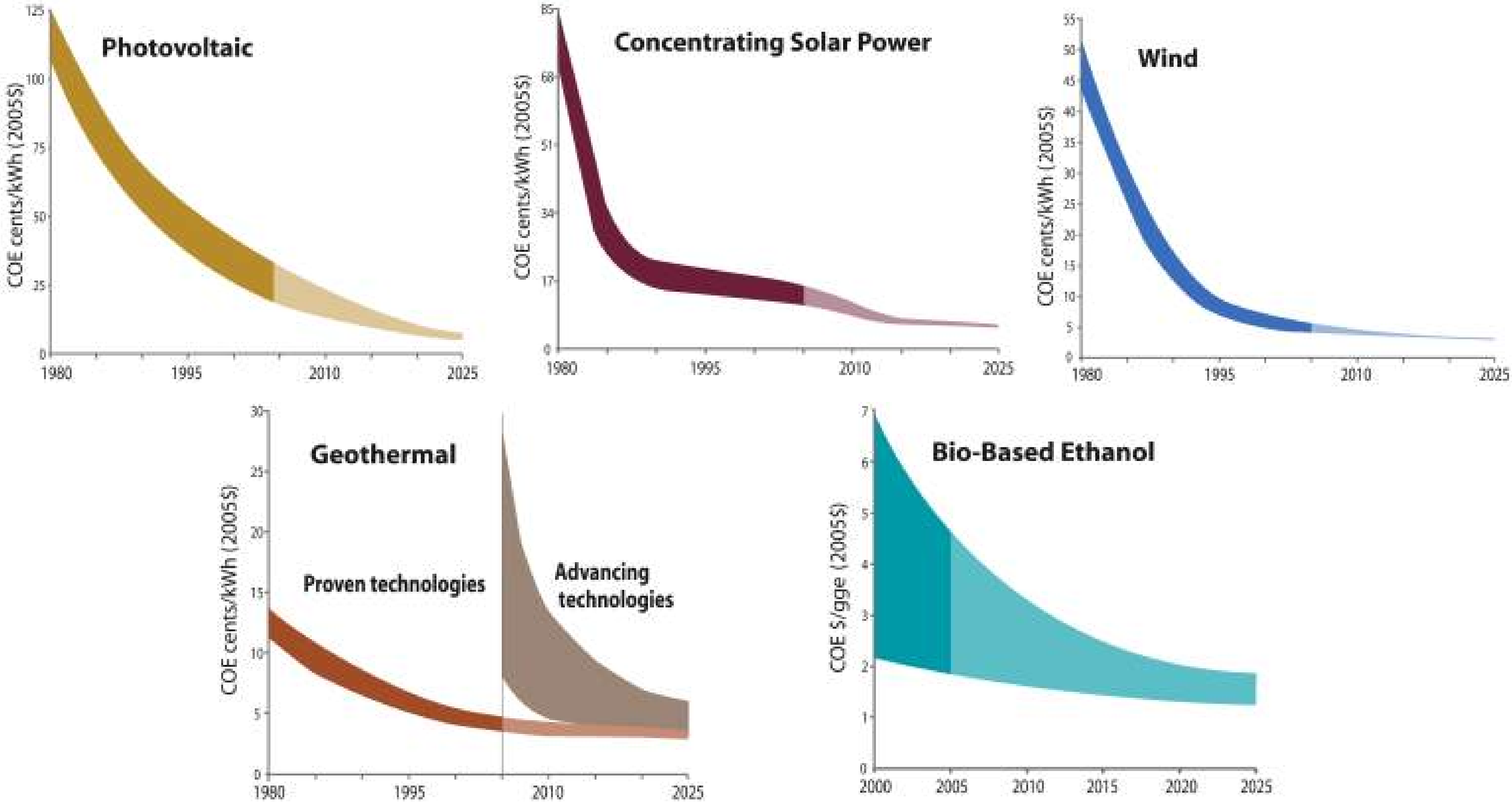
Technology Map for Bio-fuel Systems, Distributed Gen and Storage systems integrated with Advanced Information Systems for Network Management

R& D Strategies and Examples of Technology areas



Renewable Energy Cost Trends

Levelized cost of energy in constant 2005$[1]

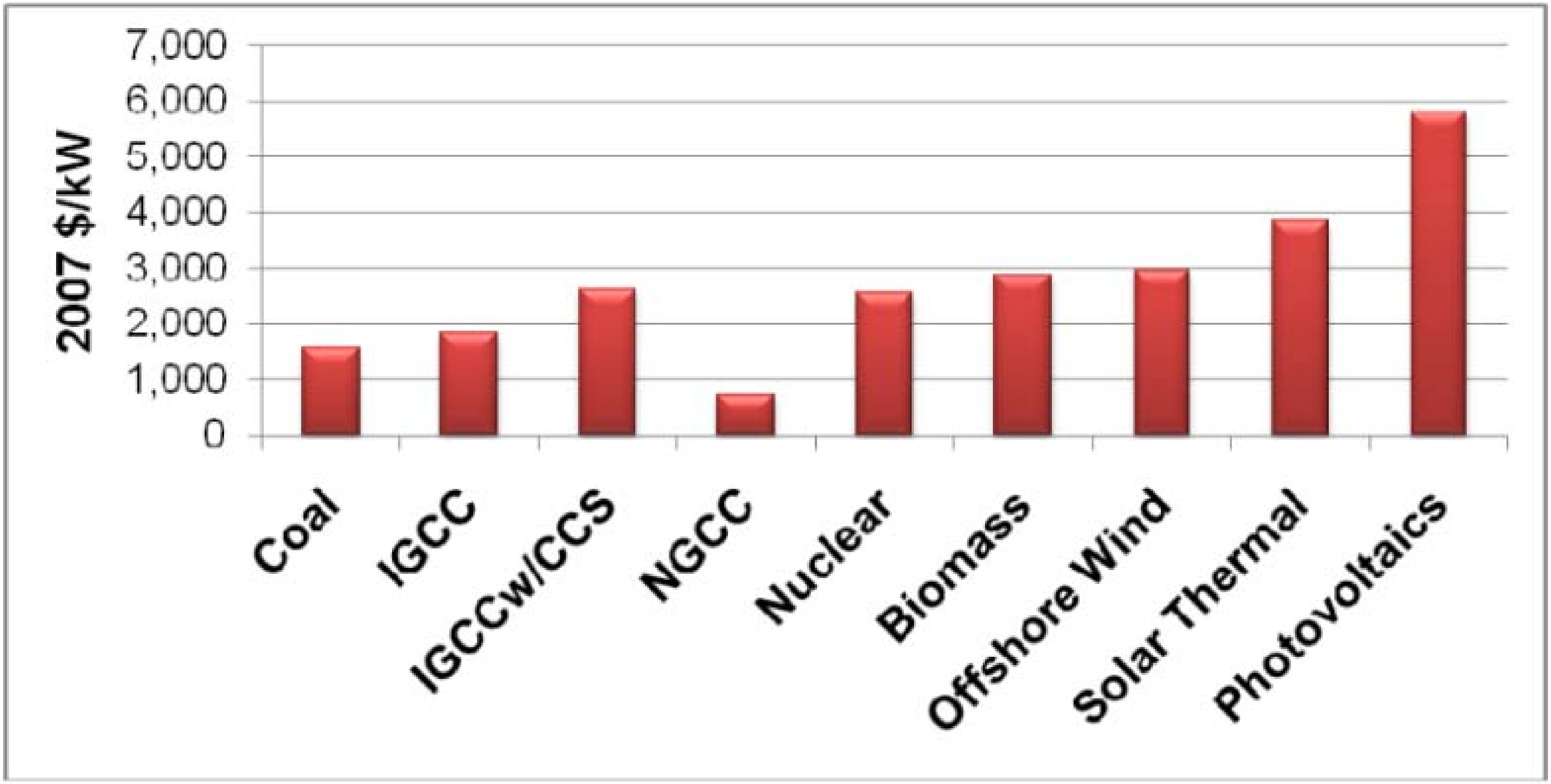


Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

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

Estimated Costs of New Electric Generation

(Sources: U.S. Energy Information Administration and Management Information Services, Inc, 2008)



Midwest Wind vs. Transmission Lines

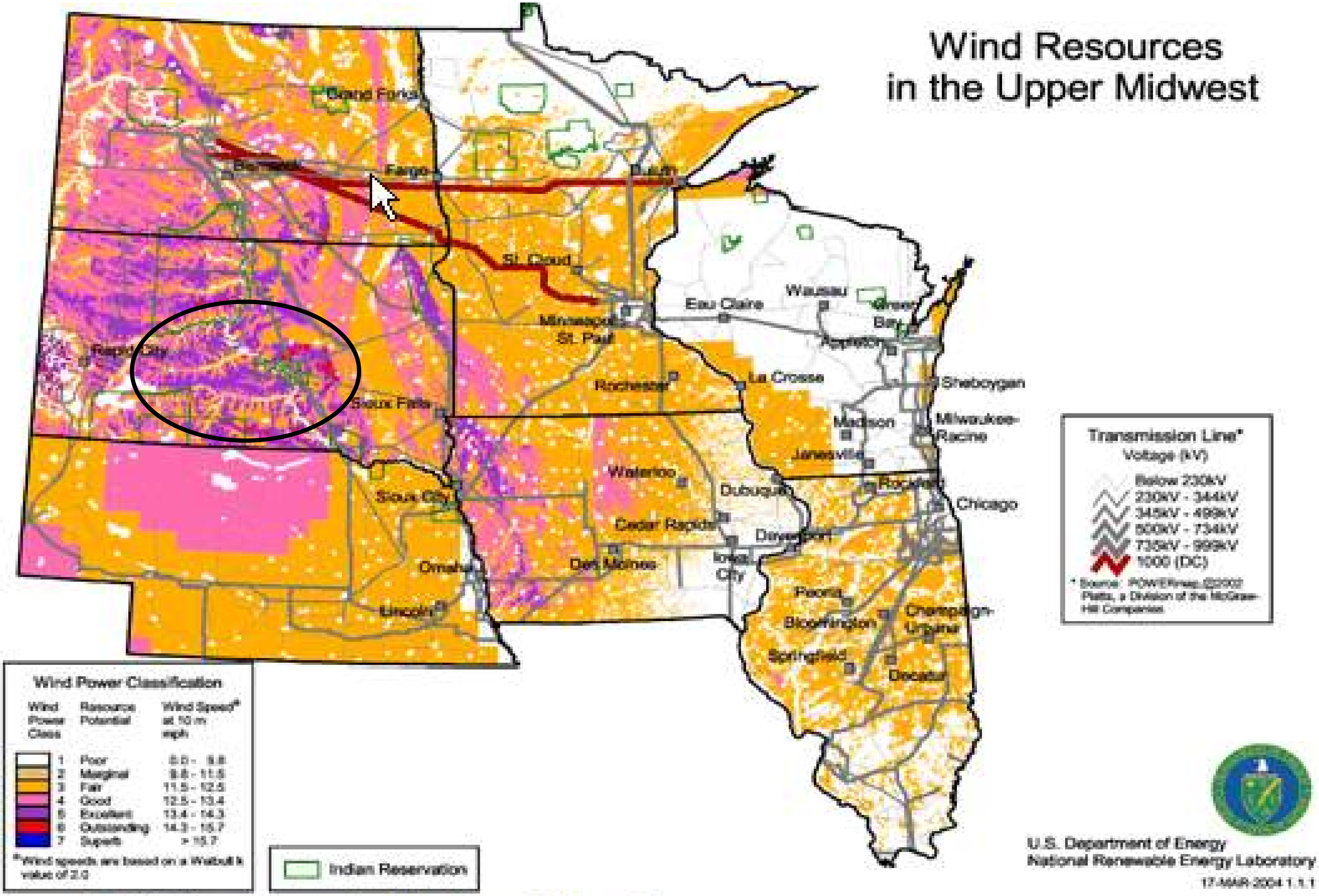
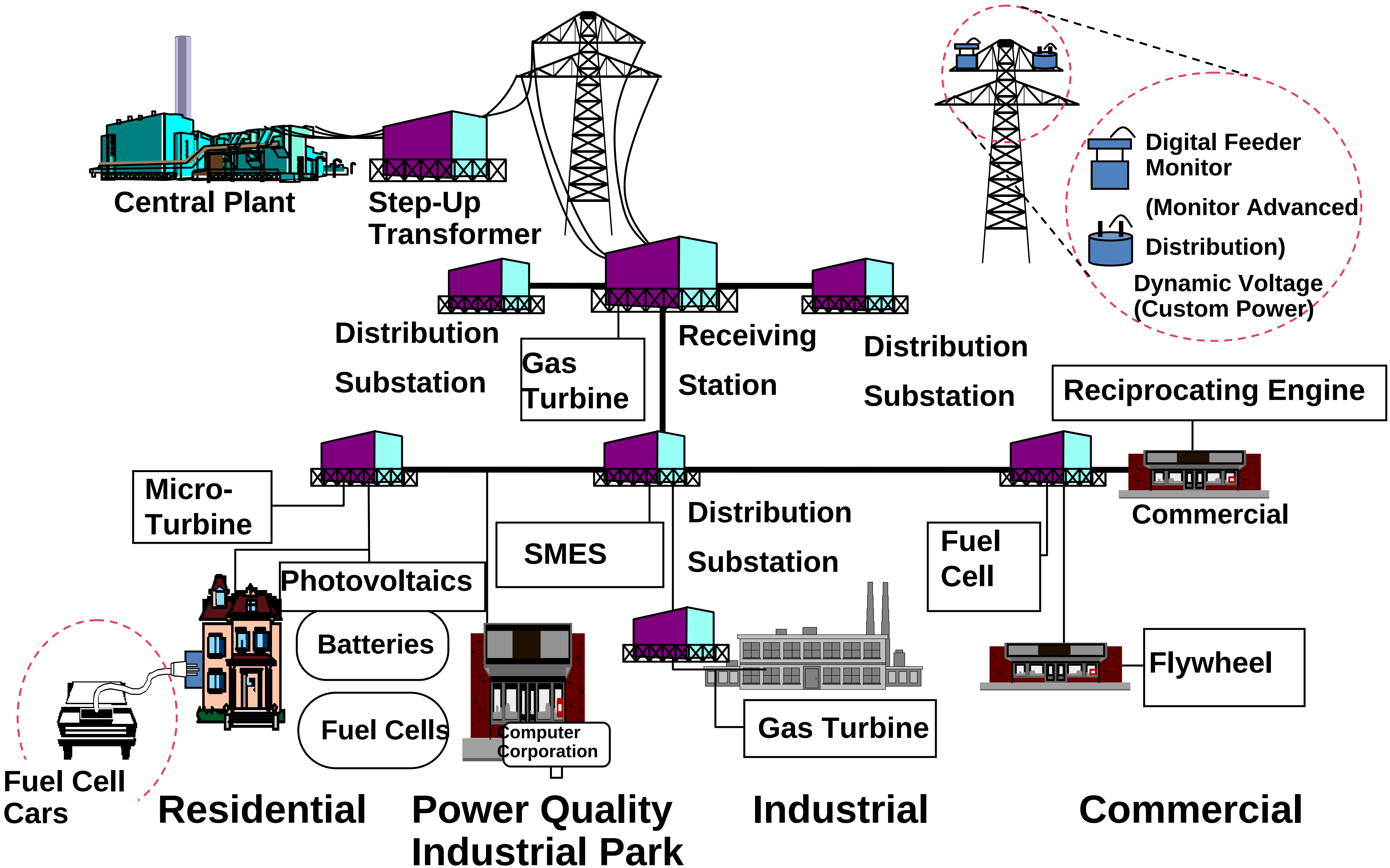


Figure 1: Wind resources in the Upper Midwest.

…The Future is Bright…

Courtesy FPL Energy

Our Goal...Enabling the Future



Technologies that may Fill the Gaps

Technologies that may make sense anyway:

- End-use efficiency
- Plant improvement
- Nuclear
- Renewables
- Biomass

Technologies for a carbon-constrained world:

- Capture and disposal
- Tree planting and soil carbon

Technology Breakthroughs

- Zero Emission Power Plants (ZEPPs)
- Low-temperature water splitting

Zero-emission power plant (ZEPP)

hydrocarbon feedstock. steel axle rotating as fast as 3,000 rpm. The way around

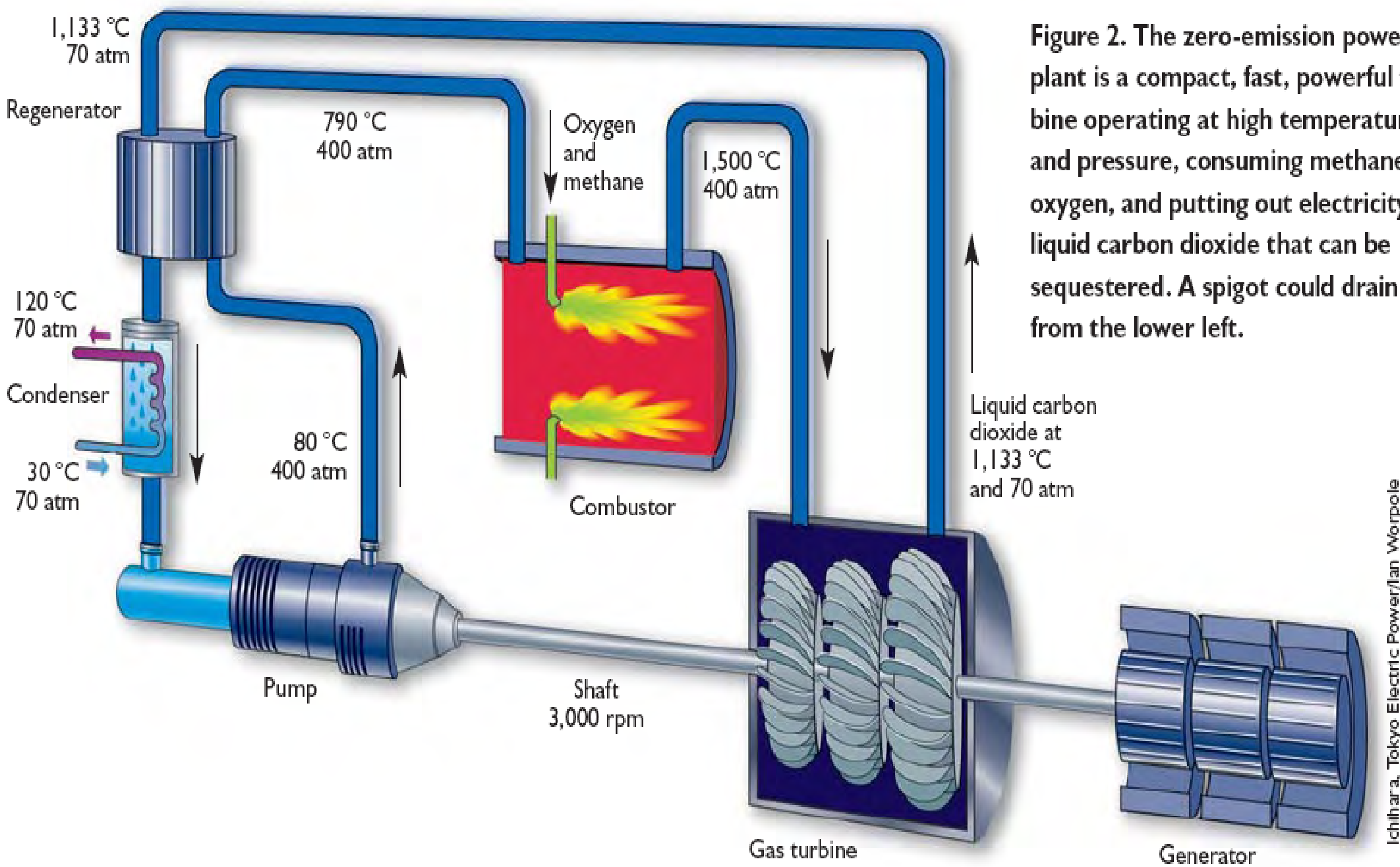


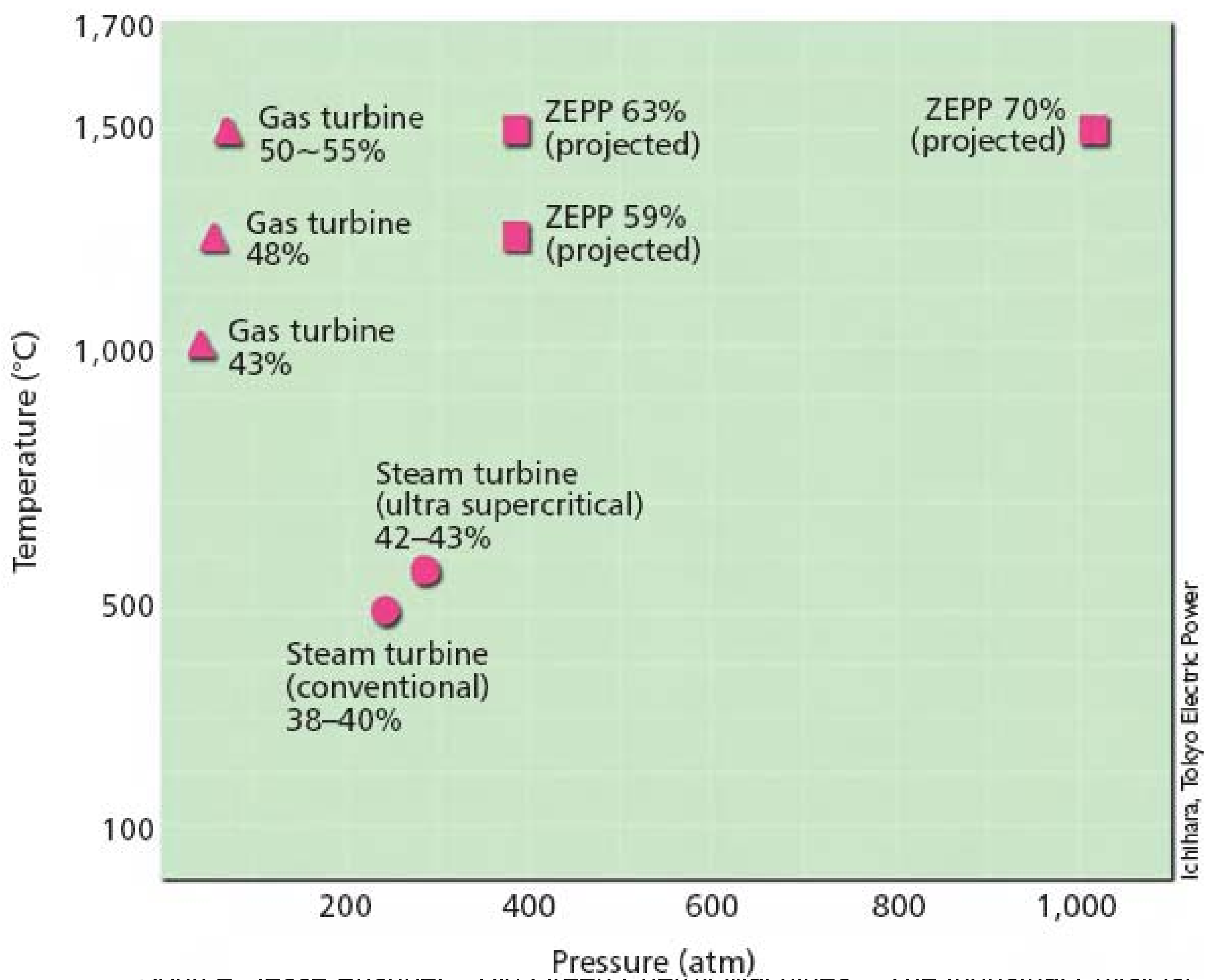
Figure 2. The zero-emission power plant is a compact, fast, powerful turbine operating at high temperature and pressure, consuming methane and oxygen, and putting out electricity and liquid carbon dioxide that can be sequestered. A spigot could drain CO_2 from the lower left.

Source: Jesse Ausubel, " Big Green Energy Machines," The Industrial Physicist, Oct./Nov. 2004, American Institute of Physics. Diagram courtesy of Tokyo Electric Power

“Super Grid”

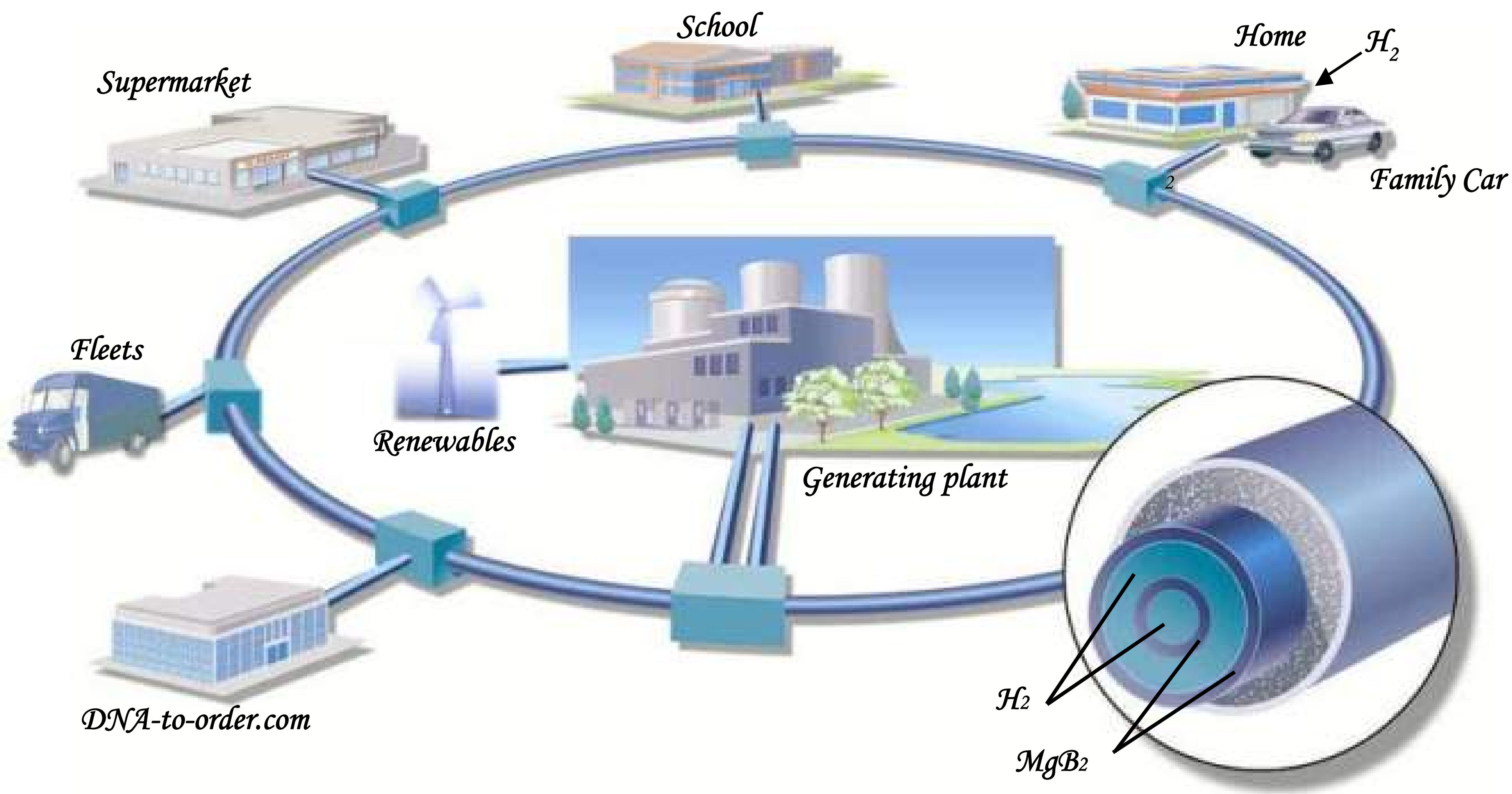
Source: Jesse Ausubel, “ Big Green Energy Machines,” The Industrial Physicist, Oct./Nov. 2004, AIP

Efficiency of power generation increases with operation at higher pressures and temperatures



Source: Jesse Ausubel, "Big Green Energy Machines," The Industrial Physicist, Oct./Nov. 2004, AIP

… including the Long Term…



Challenge & Opportunity

Three Primary Motivations

- Energy Security: Moderate consumption of petroleum-based transportation fuels
- Global Warming: Reduce CO2 emissions
- Environment: Attain air quality targets in critical areas. Reduce well-to-wheels criteria emissions

Transportation Sustainability – Four Options (for the Vehicle)

- Energy efficiency improvements
- Biofuels
- Electricity (Renewable or near-zero emitting)
- Hydrogen (Also renewable or near-zero emitting)

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 mean 40 years at 2% growth rate per year.

- 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?

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

- Broad range of R&D including end-use and system efficiency,
- What will the overall, integrated system/infrastructure look like?