Challenges in Reliability, Security, Efficiency, and Resilience of Energy Infrastructure: Toward Smart Self-healing Electric Power Grid

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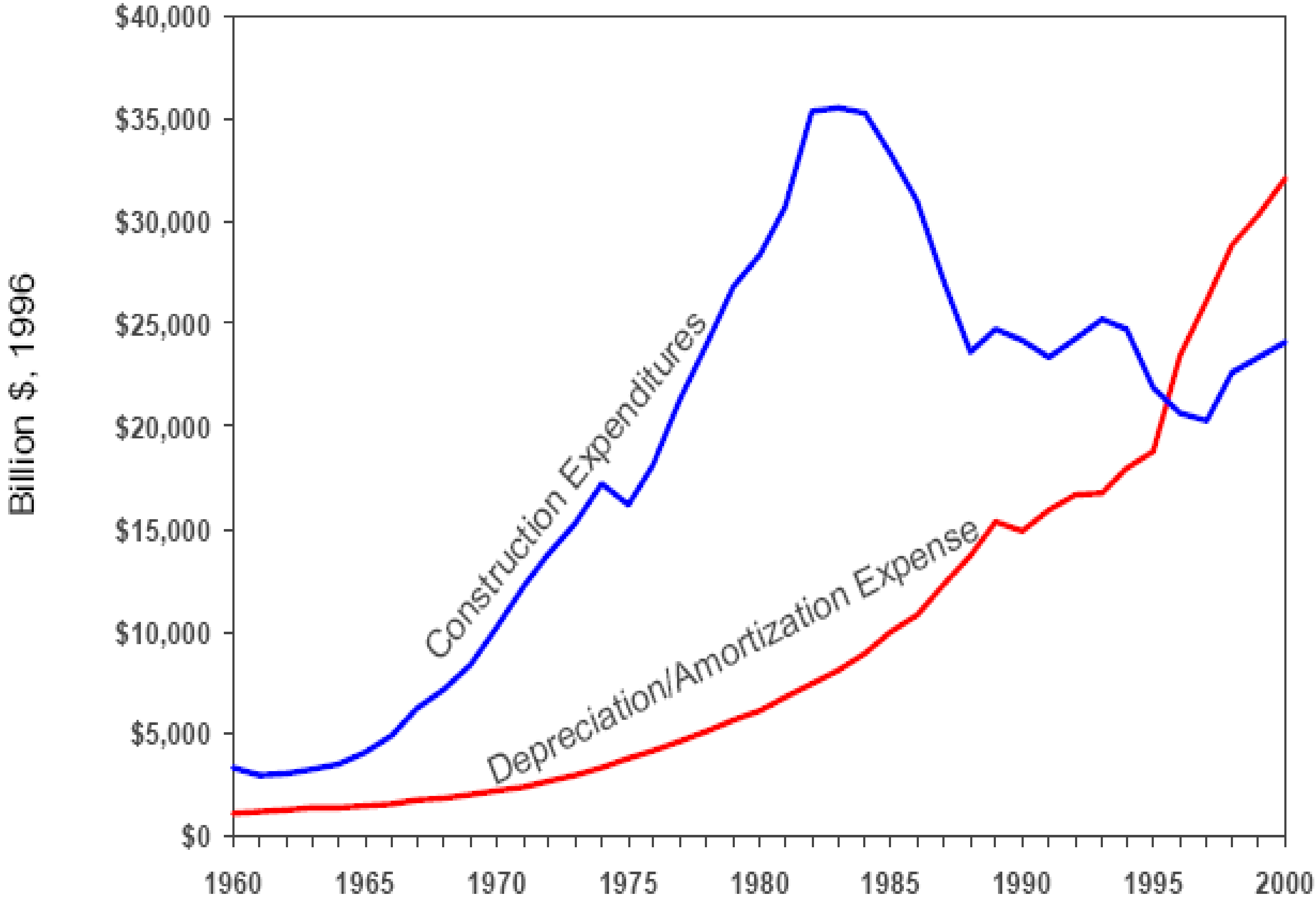
Utility construction expenditures



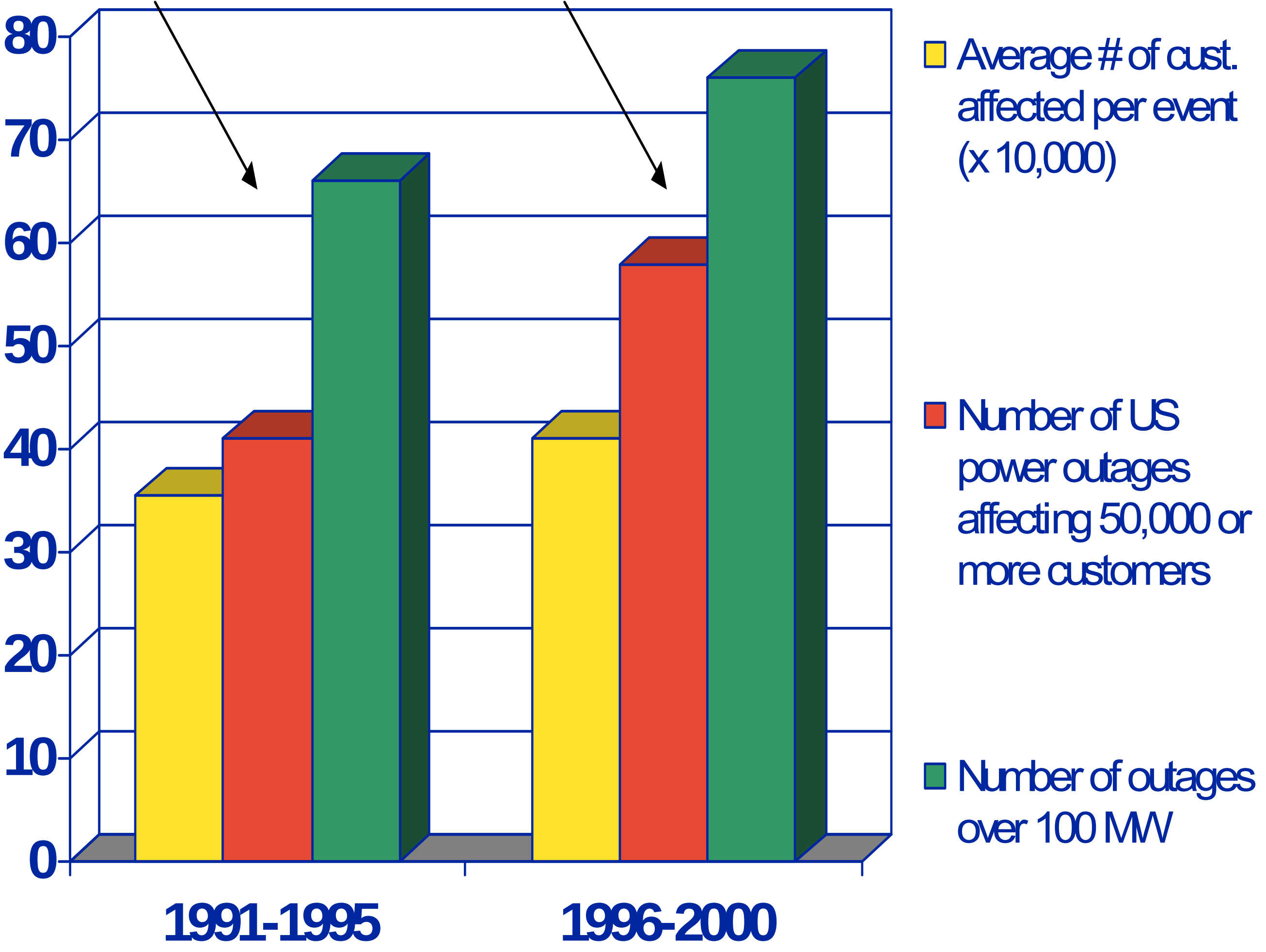
Source: "Historical Statistics of the Electric Utility Industry" and "EEI Statistical Yearbook" - EEI

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

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

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

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



Data courtesy of NERC's Disturbance Analysis Working Group database

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

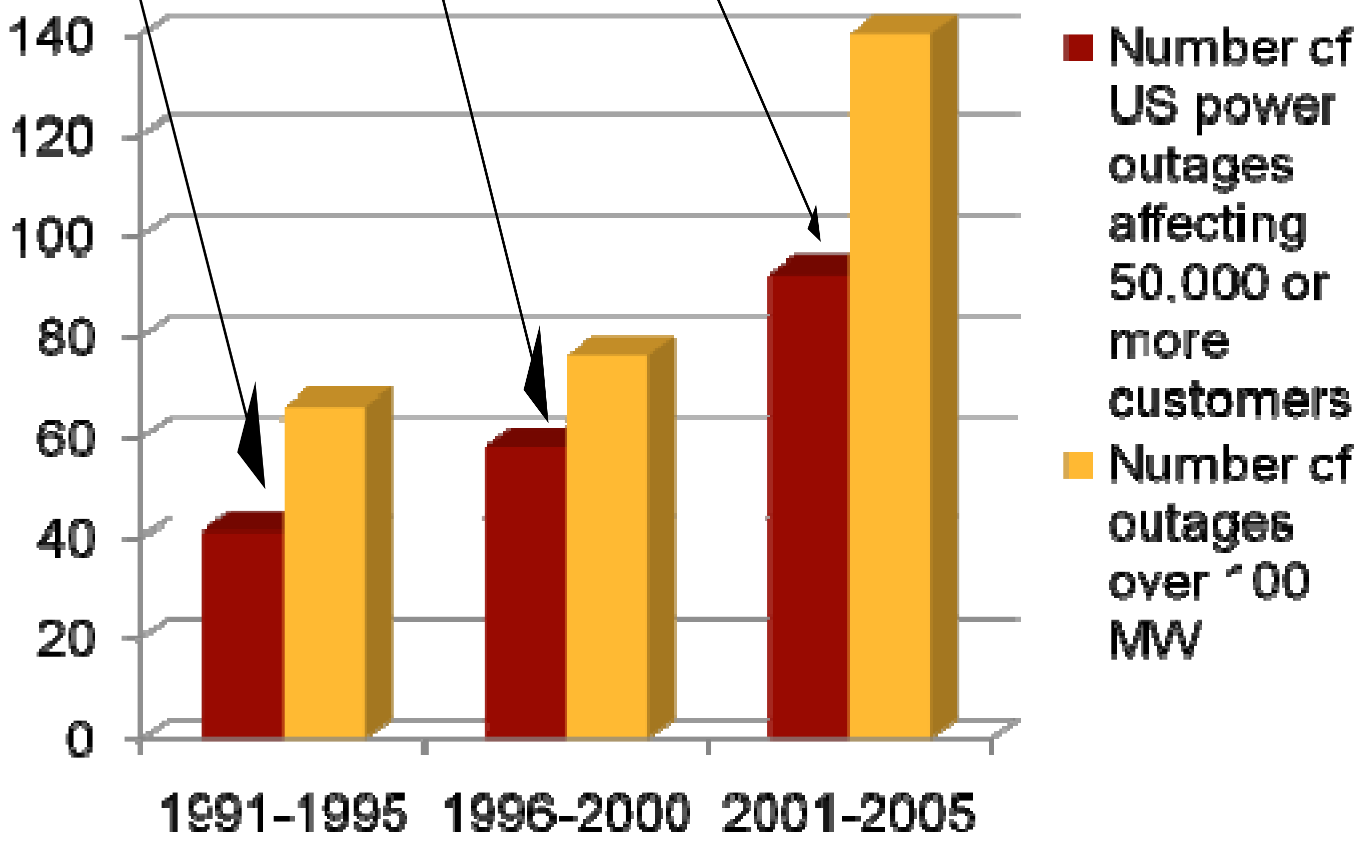
Historical Analysis of U.S. outages (1991-2005)

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

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

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

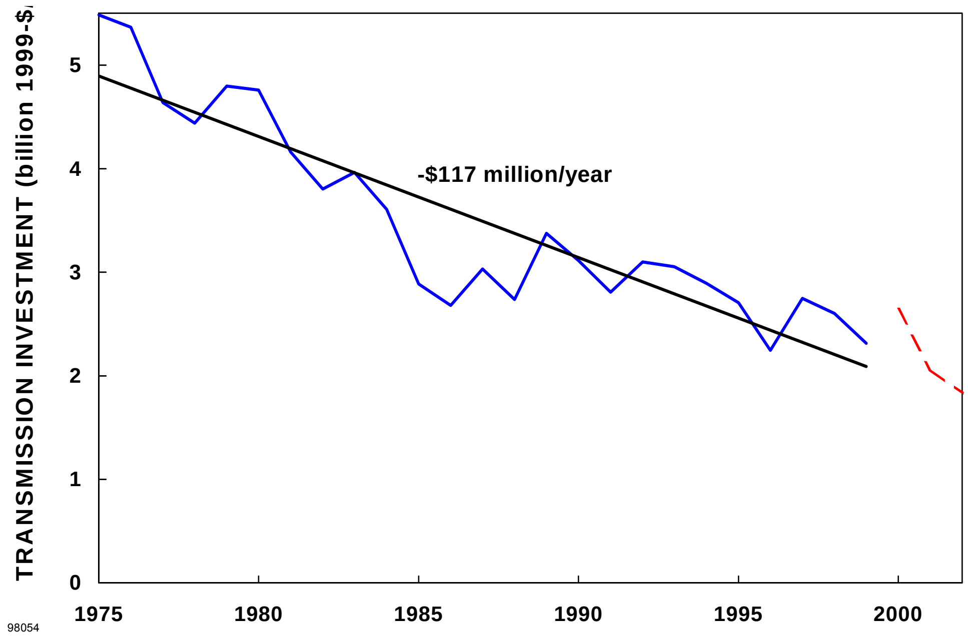
Result: Large blackouts are growing in number and severity.



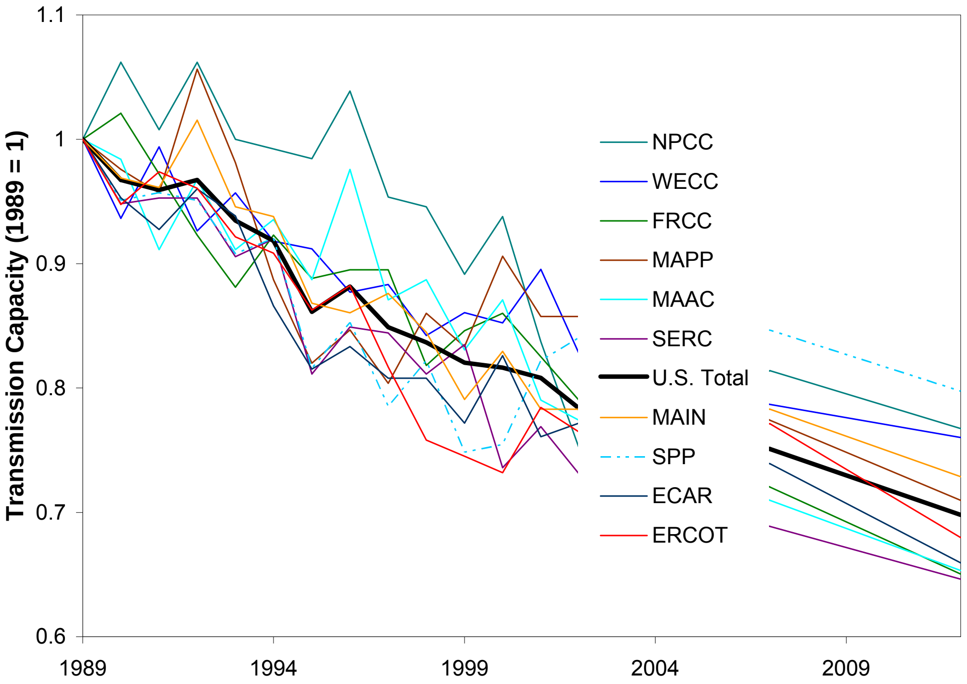
***Analyzing 2006 outages:**
24 Occurrences over 100 MW
34 Occurrences over 50,000* or more Consumers
Data courtesy of NERC's Disturbance Analysis Working Group database

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

Increasing Outage Events: Transmission Investment



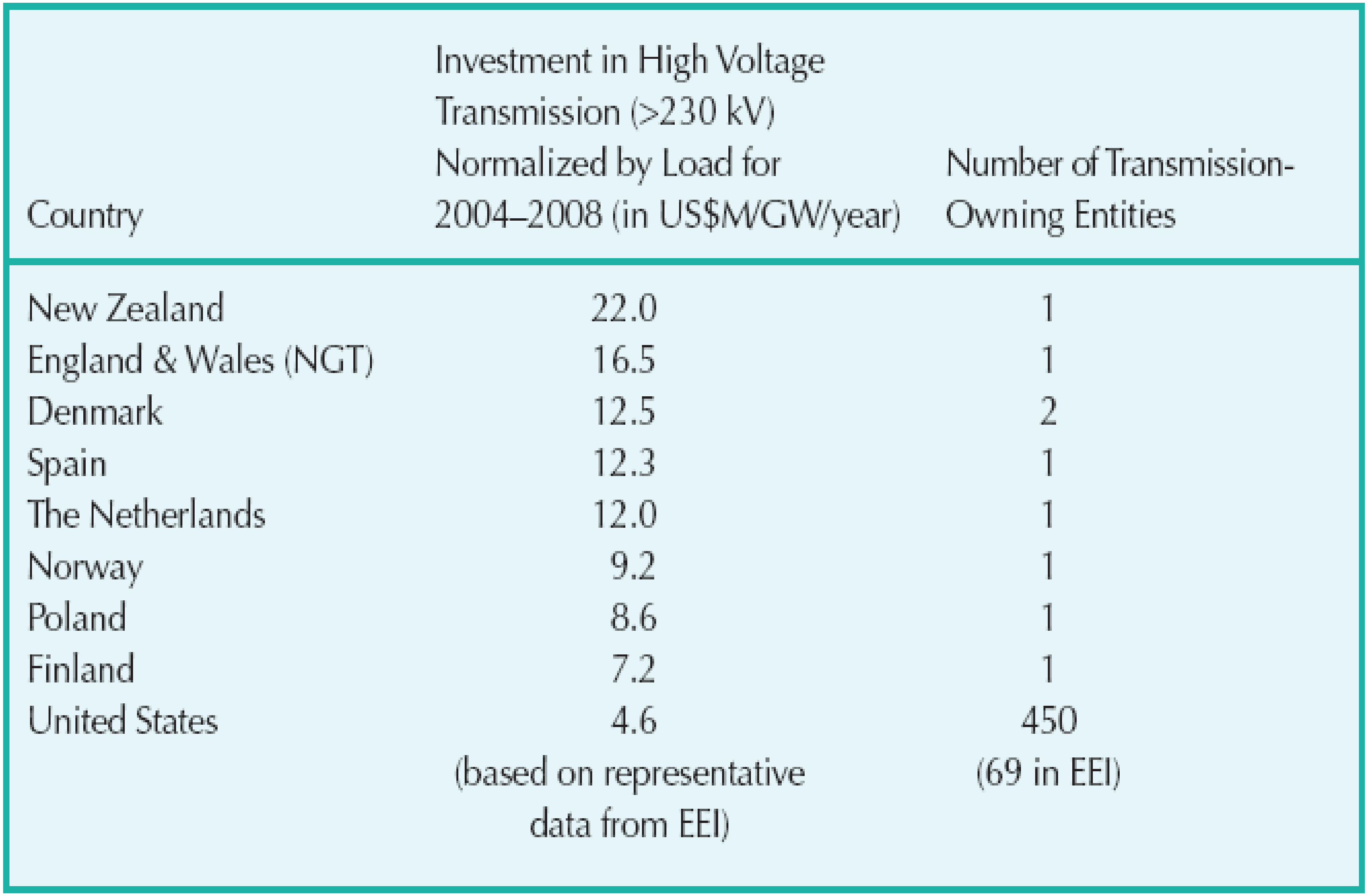
Transmission *investment* ($) since 1975



Transmission *capacity margin* in every NERC region since 1982

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

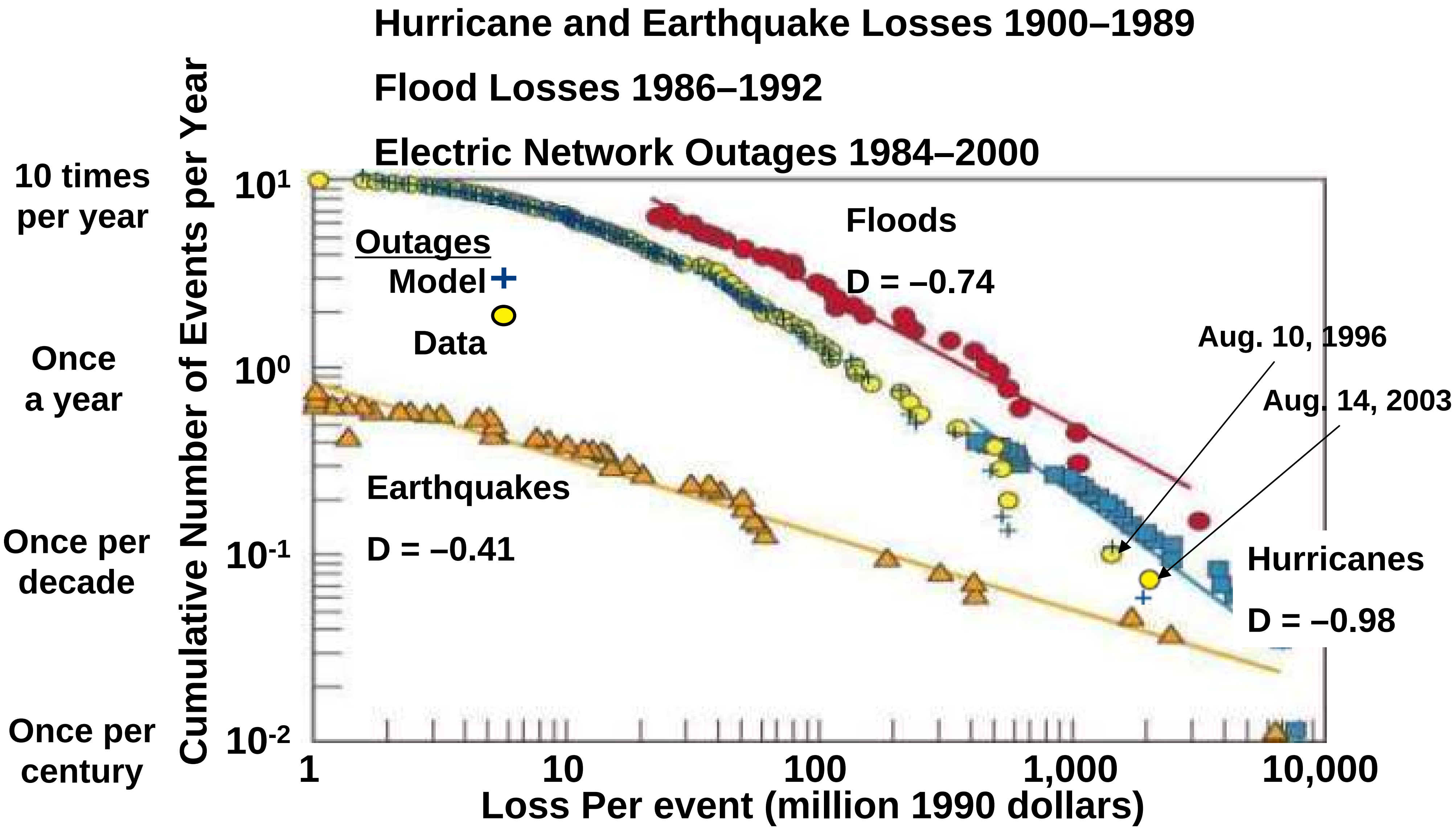
Transmission investment in the United States and in international competitive markets



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



Hurricane and Earthquake Losses 1900–1989

Flood Losses 1986–1992

Electric Network Outages 1984–2000

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.

Change

One of my research areas: S&T Assessment, Scan & Map

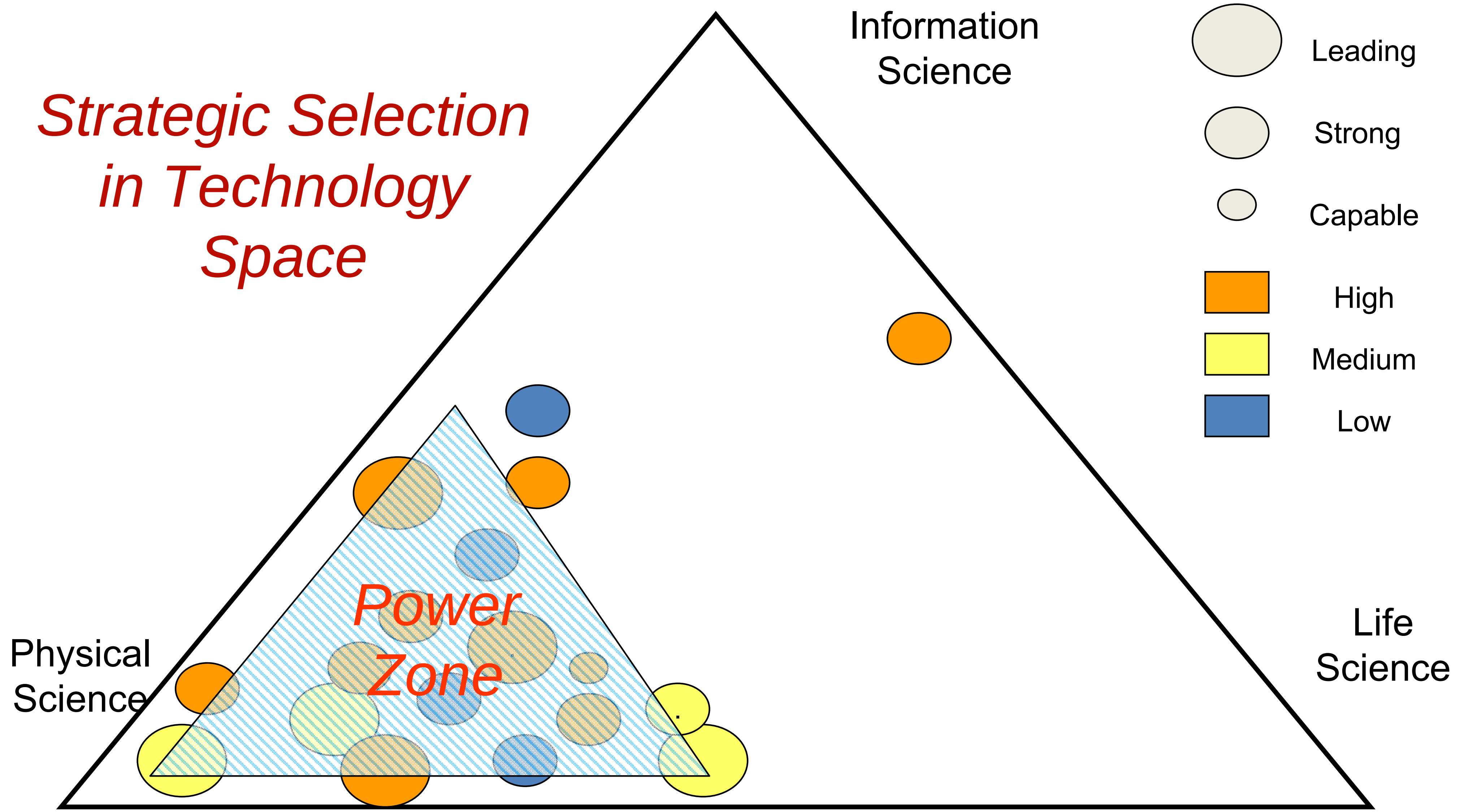
(April 2005-Feb 2006; Galvin Electricity Initiative)

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

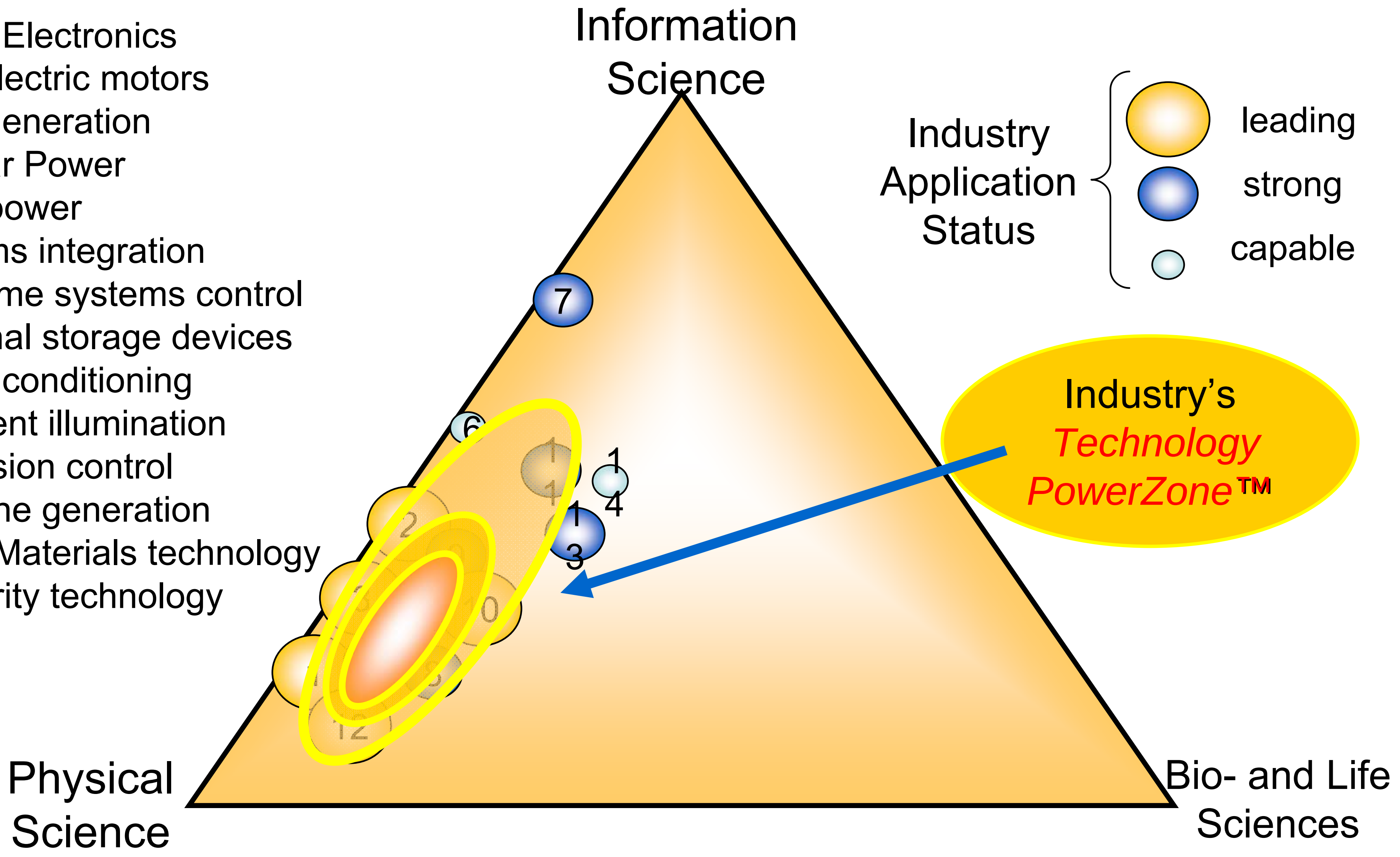


Strategic Selection in Technology Space

Examples of industry's technology strengths today

Examples include:

1. Power Electronics
2. Adv. Electric motors
3. Wind generation
4. Nuclear Power
5. Solar power
6. Systems integration
7. Real-time systems control
8. Personal storage devices
9. Power conditioning
10. Efficient illumination
11. Emission control
12. Turbine generation
13. Adv. Materials technology
14. Security technology



Information Science

Physical Science

Bio- and Life Sciences

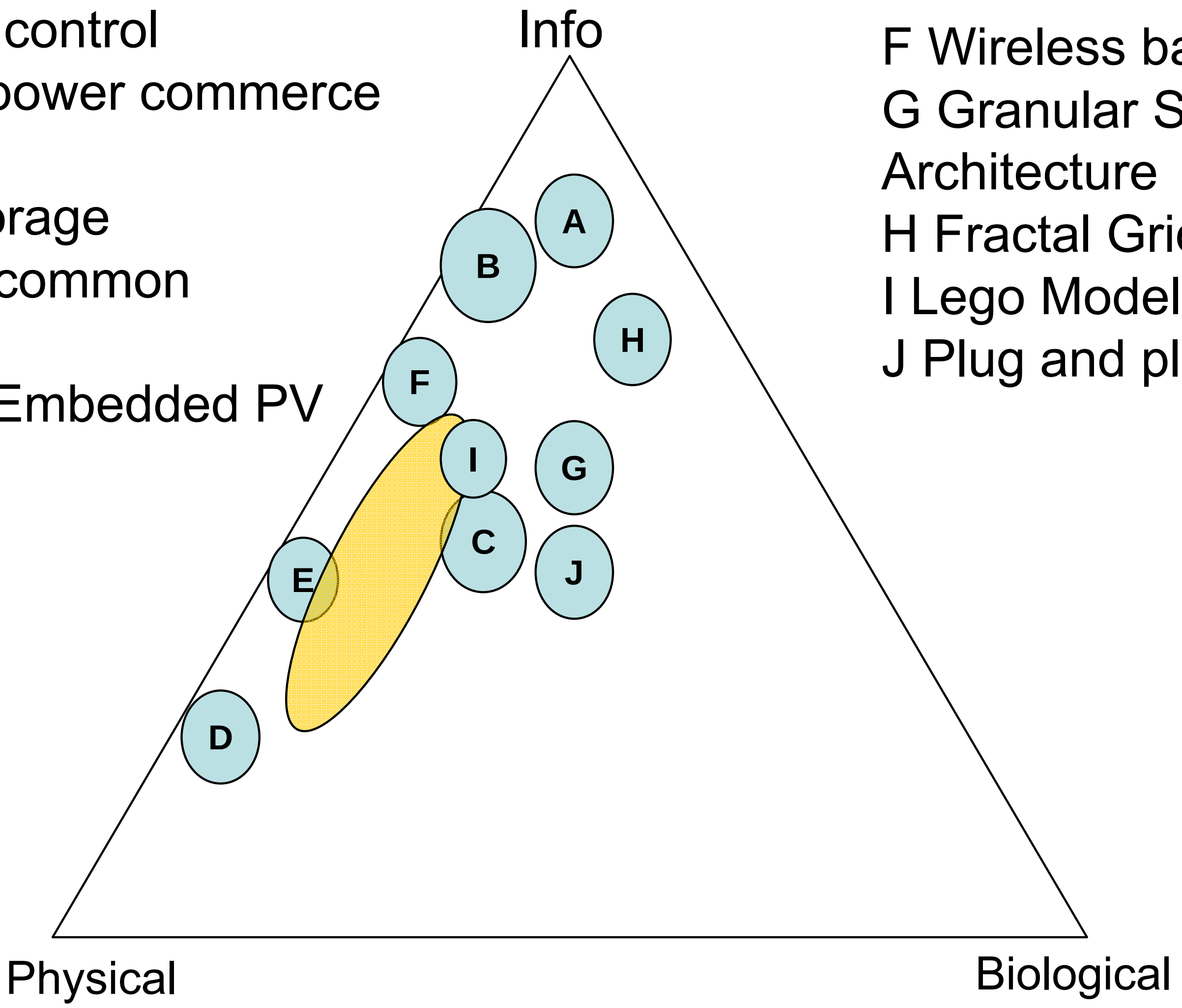
Industry Application Status

- leading
- strong
- capable

Industry's *Technology PowerZone™*

Expanding the Power Zone

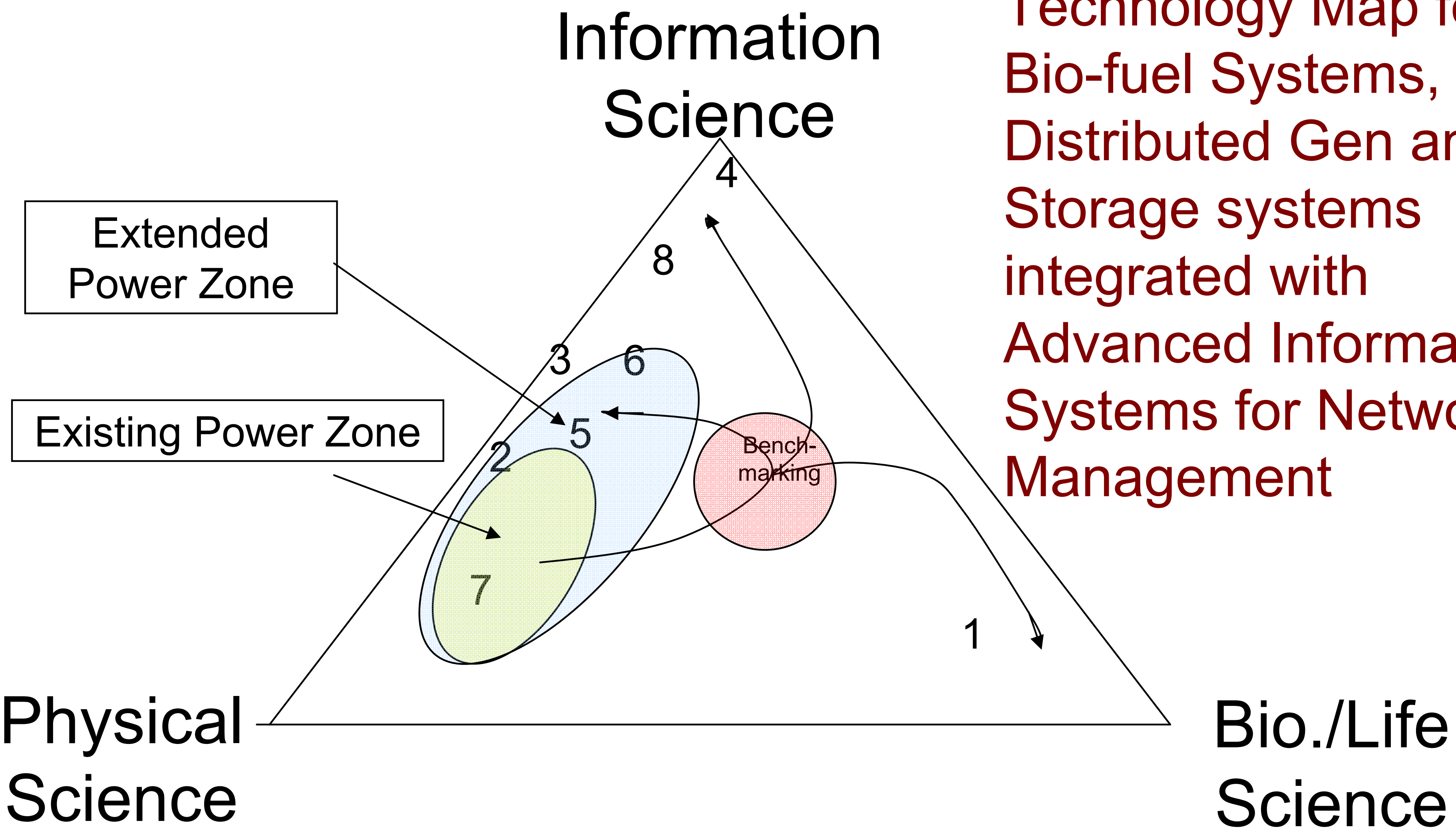
A. Distributed control
B. Electronic power commerce
C. Distributed generation/storage
D. Integrated common infrastructure
E. Integrated/Embedded PV



F Wireless backup
G Granular Semi-autonomous Architecture
H Fractal Grid Lego Model
I Lego Model
J Plug and play appliances

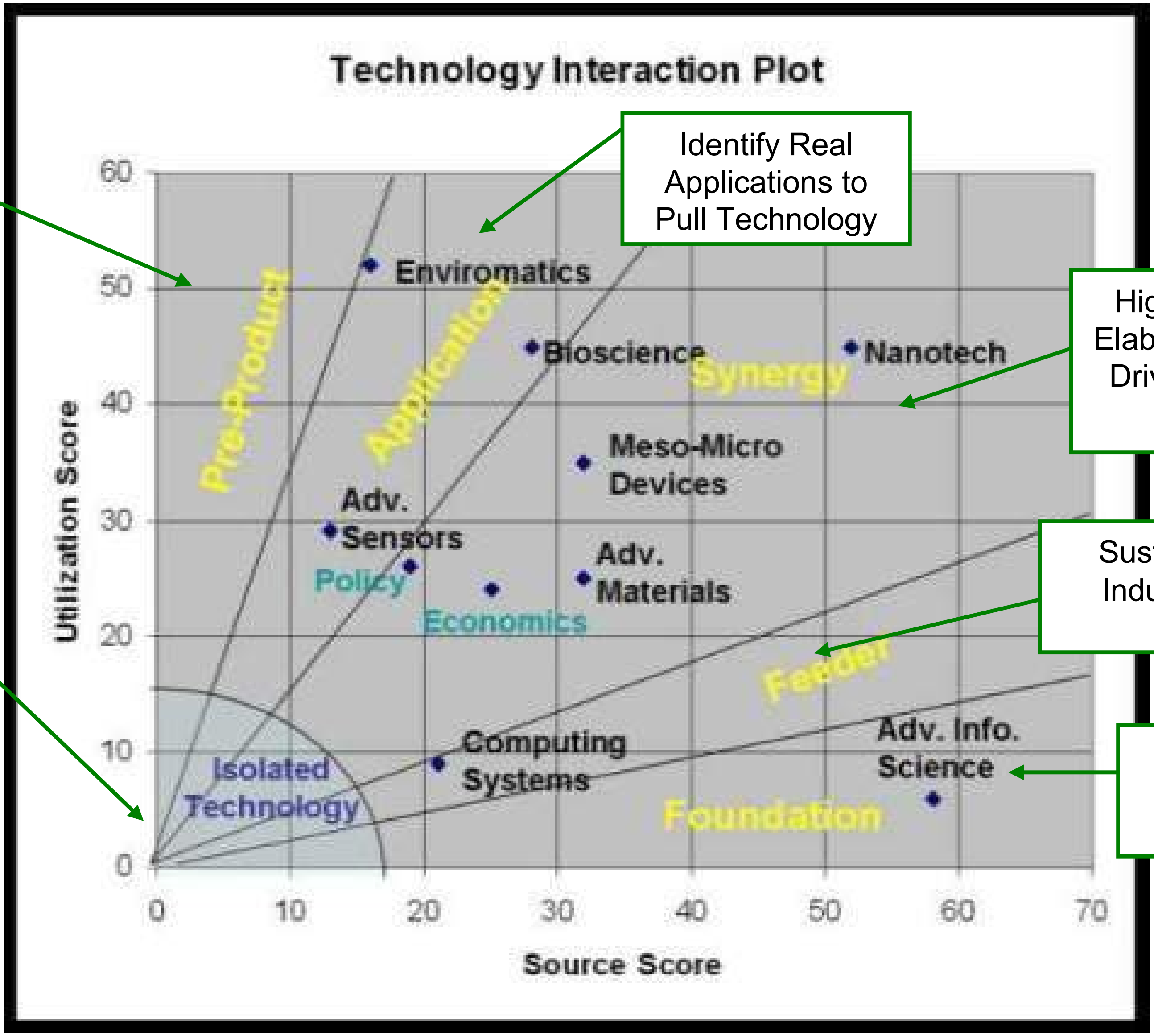
Technology Map for the Granular Semi-Autonomous Architecture

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



Develop into Products

Identify Real Applications to Pull Technology

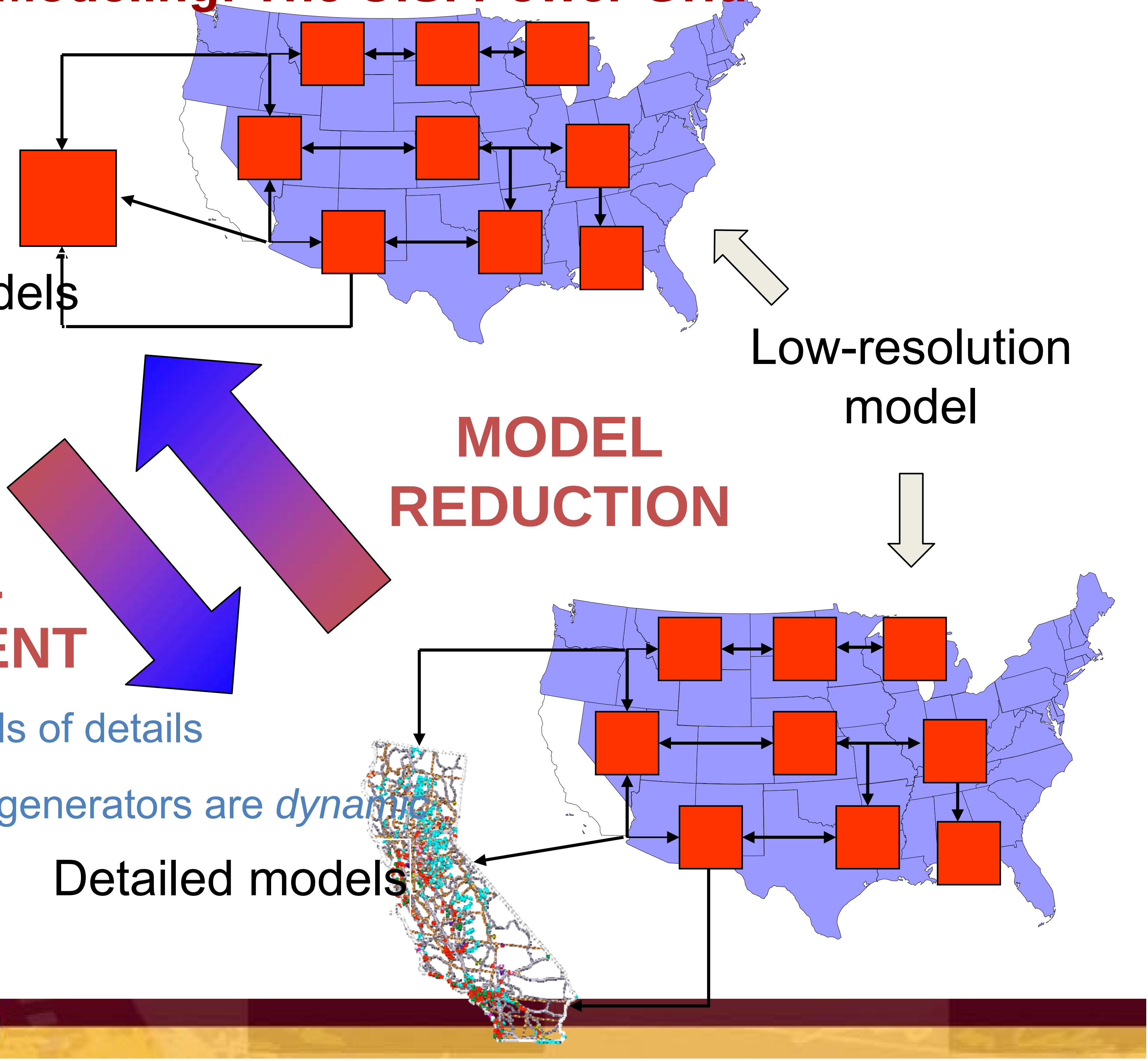
High Potential -- Elaborate, Expand, Drive Investment

Not strategic - evaluate as separate opportunity

Sustain and Grow- Industry and other resources

Alliances, Government, University

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



Simplified models

Low-resolution model

MODEL REDUCTION

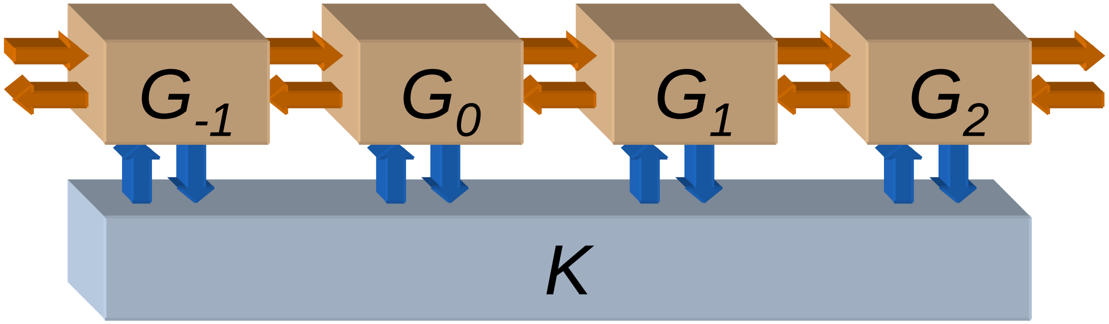
MODEL REFINEMENT

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

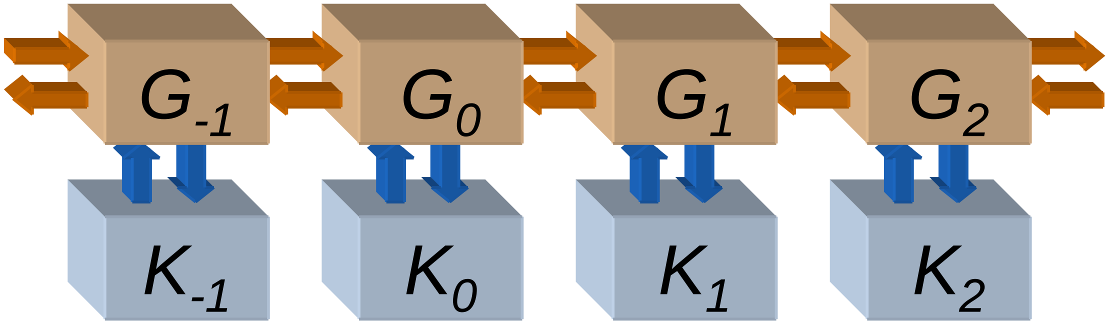
Detailed models

Control Strategies

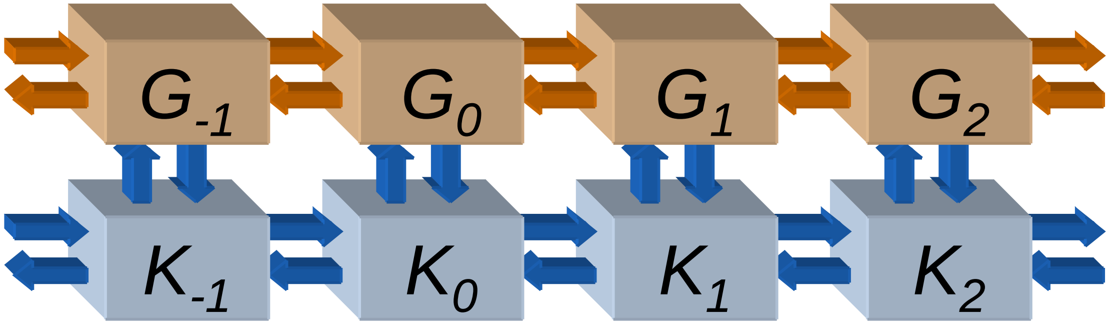
- Centralized



- Perfectly decentralized



- Distributed

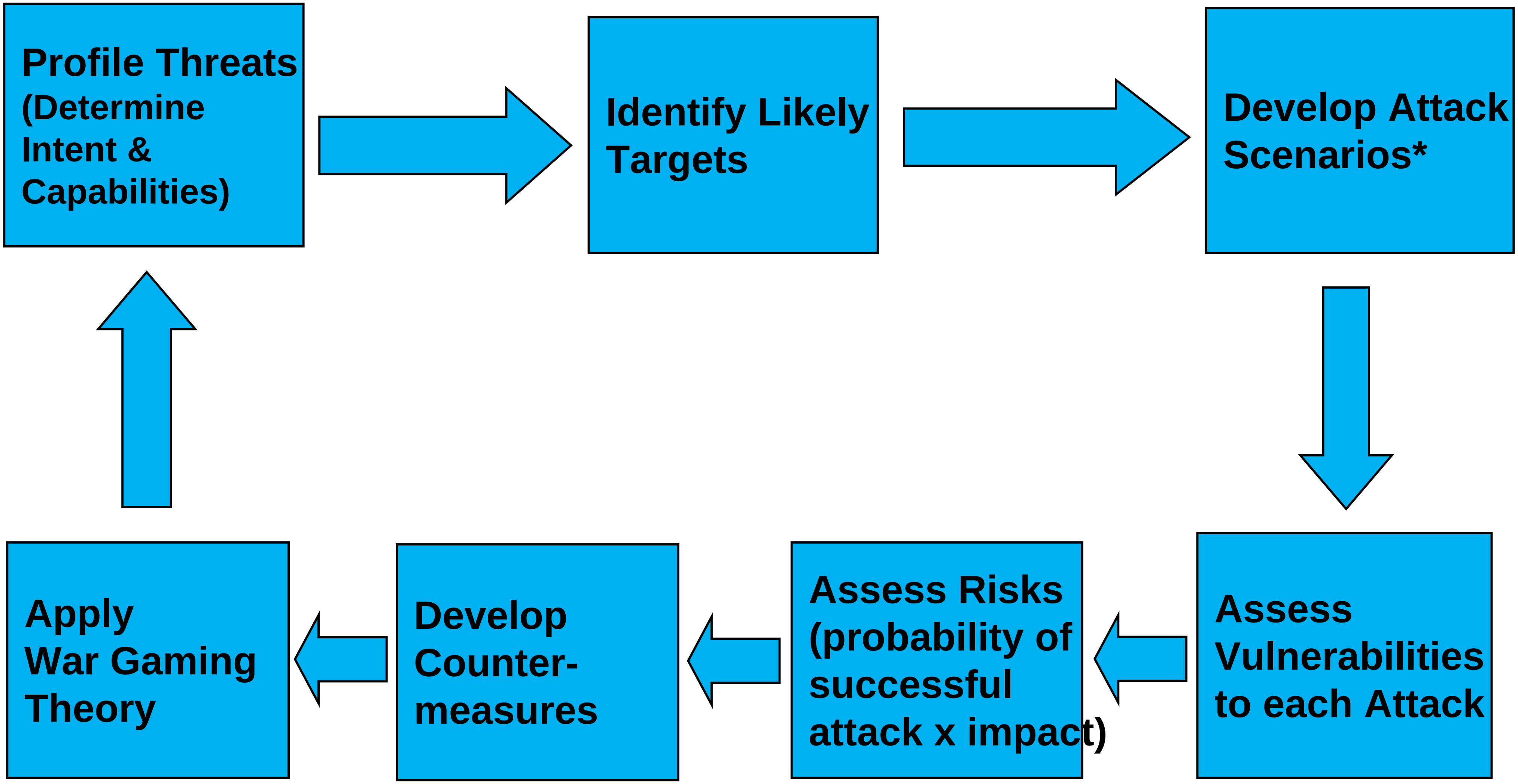


Look-Ahead Simulation Applied to Multi-Resolution Models

- 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)

What can be Done?
Vulnerability Assessment



Profile Threats (Determine Intent & Capabilities)

Identify Likely Targets

Develop Attack Scenarios*

Assess Vulnerabilities to each Attack

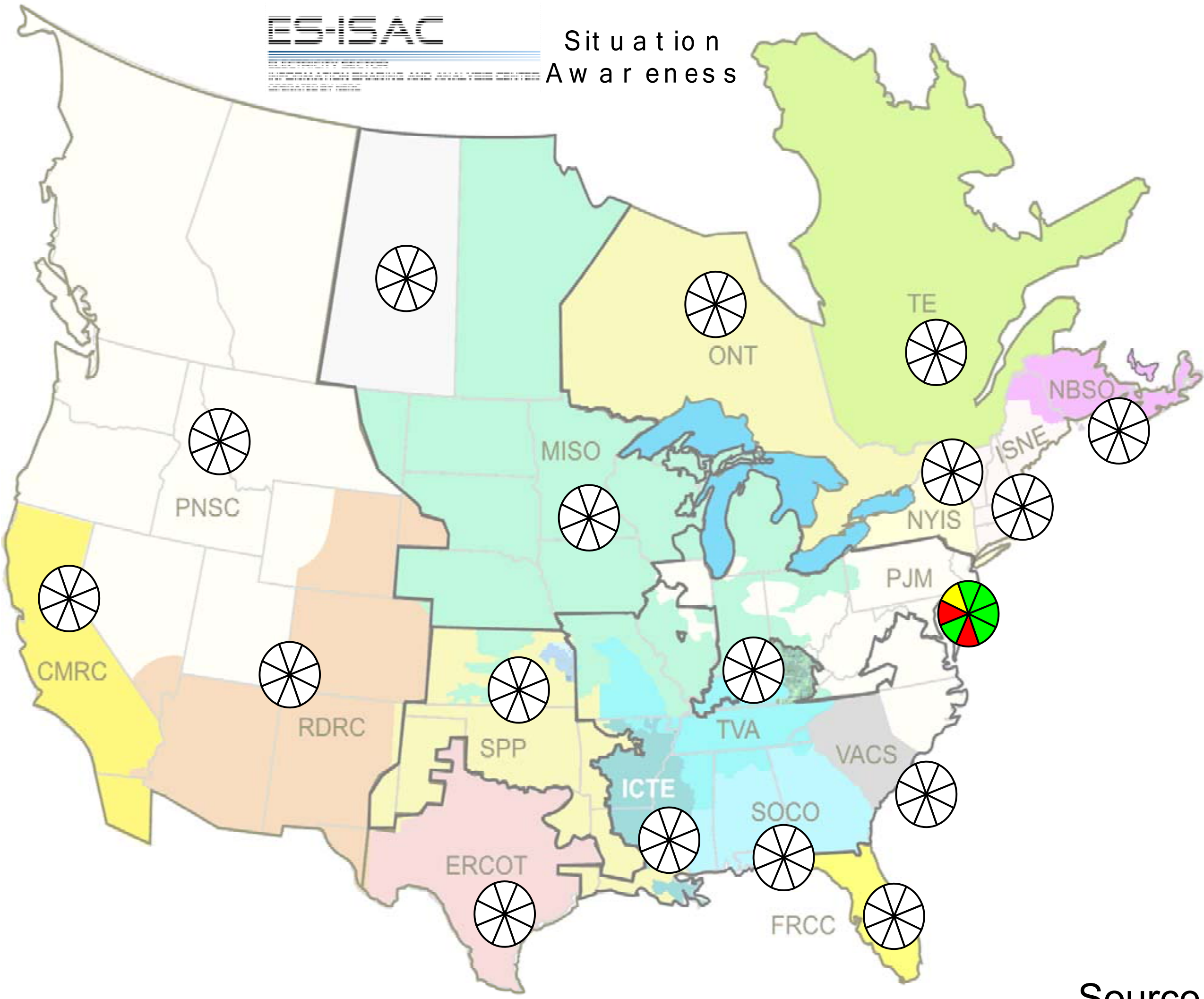
Assess Risks (probability of successful attack x impact)

Develop Counter-measures

Apply War Gaming Theory

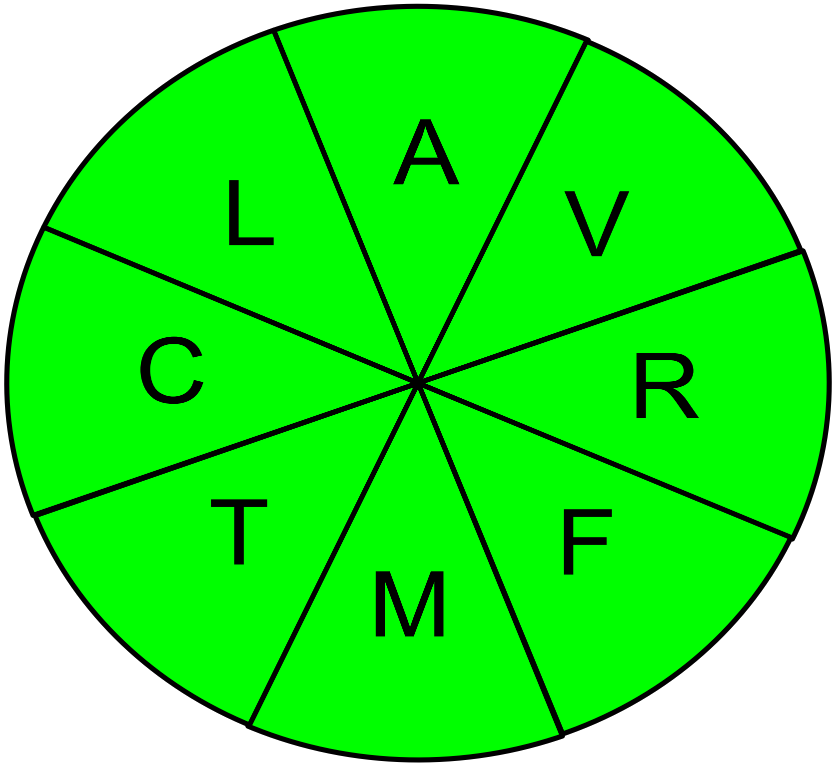
*Evolving spectra of targets and modes of attack

Situation Awareness Tool (SAT)



Source: NERC

Situation Awareness Tool (SAT)



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

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

Source: NERC

Foresight

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

USA TODAY

- “***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

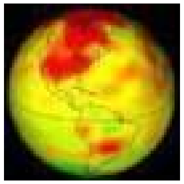
(July 22, 2008)

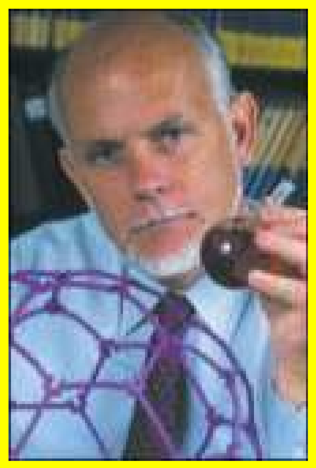
- ***“GM, utilities team up on electric cars:*** Partnership aims to tackle issues that will crop up when electric vehicles are rolled out… General Motors Corp. has joined with more than 30 utility companies across the U.S. to help work out electricity issues that will crop up when it rolls out new electric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

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)

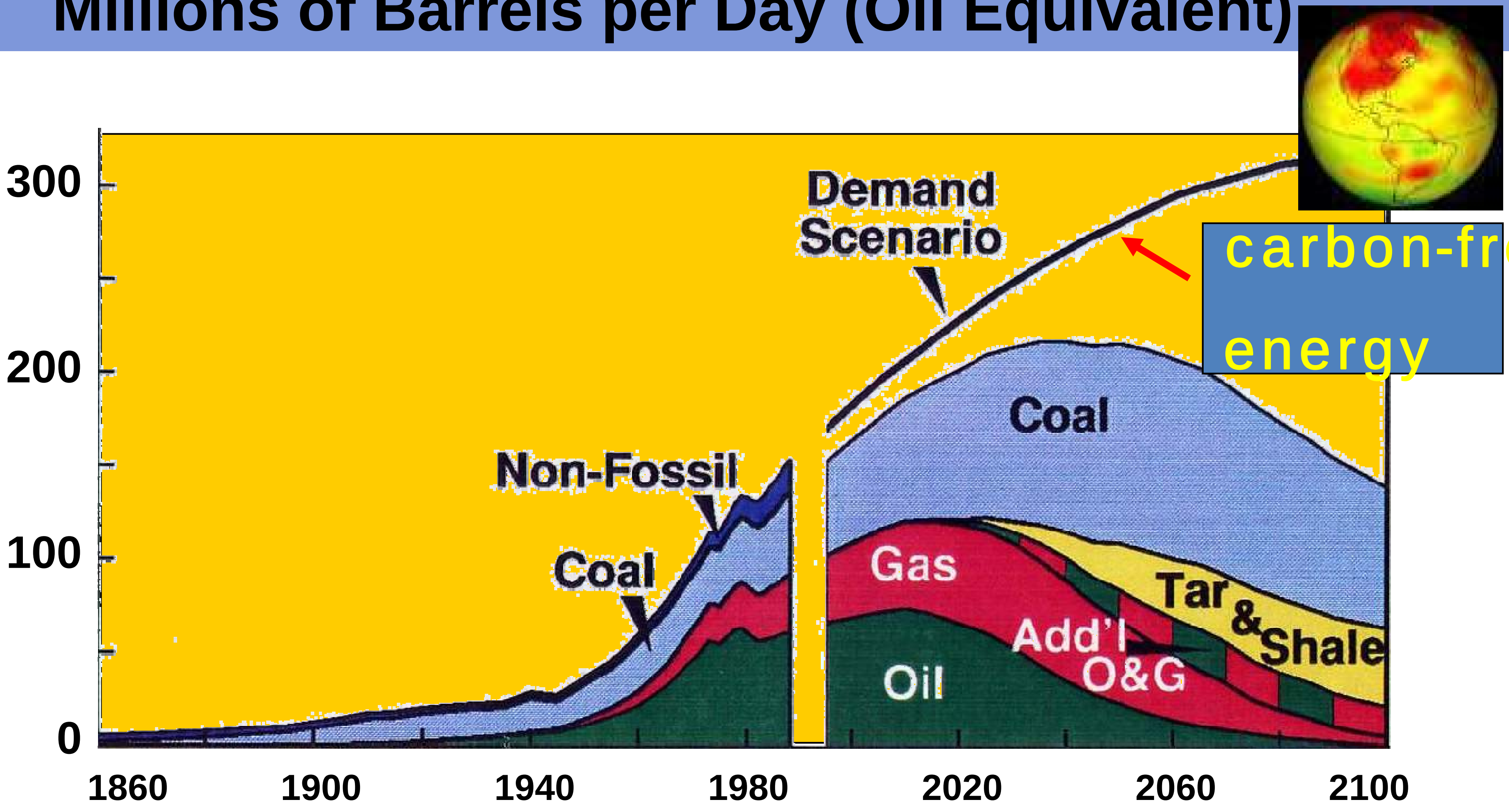
Nobel Prize 1996

"CIVIC SCIENTIST"

World Energy

Rick Smalley, Rice U.

Millions of Barrels per Day (Oil Equivalent)

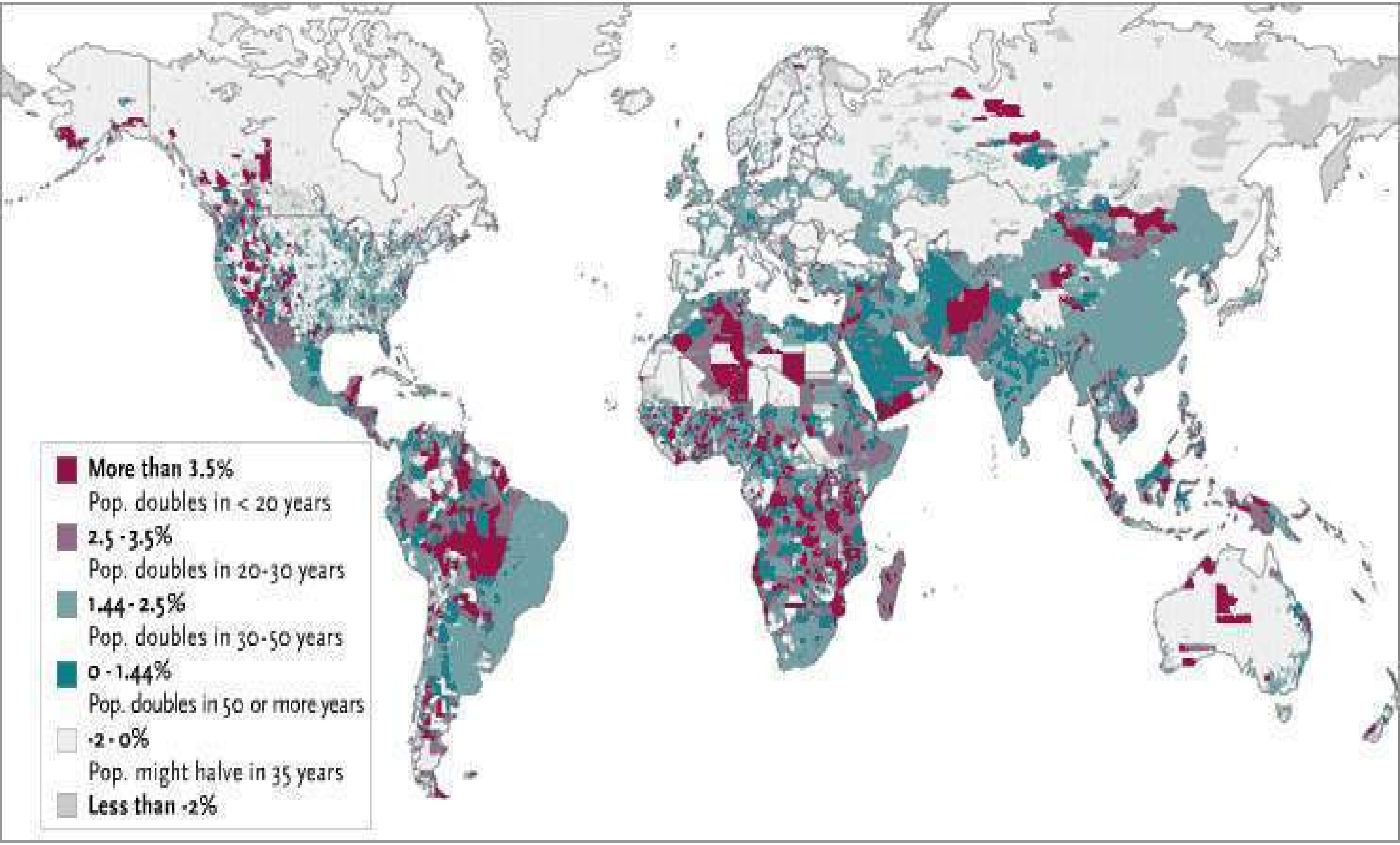


carbon-fr

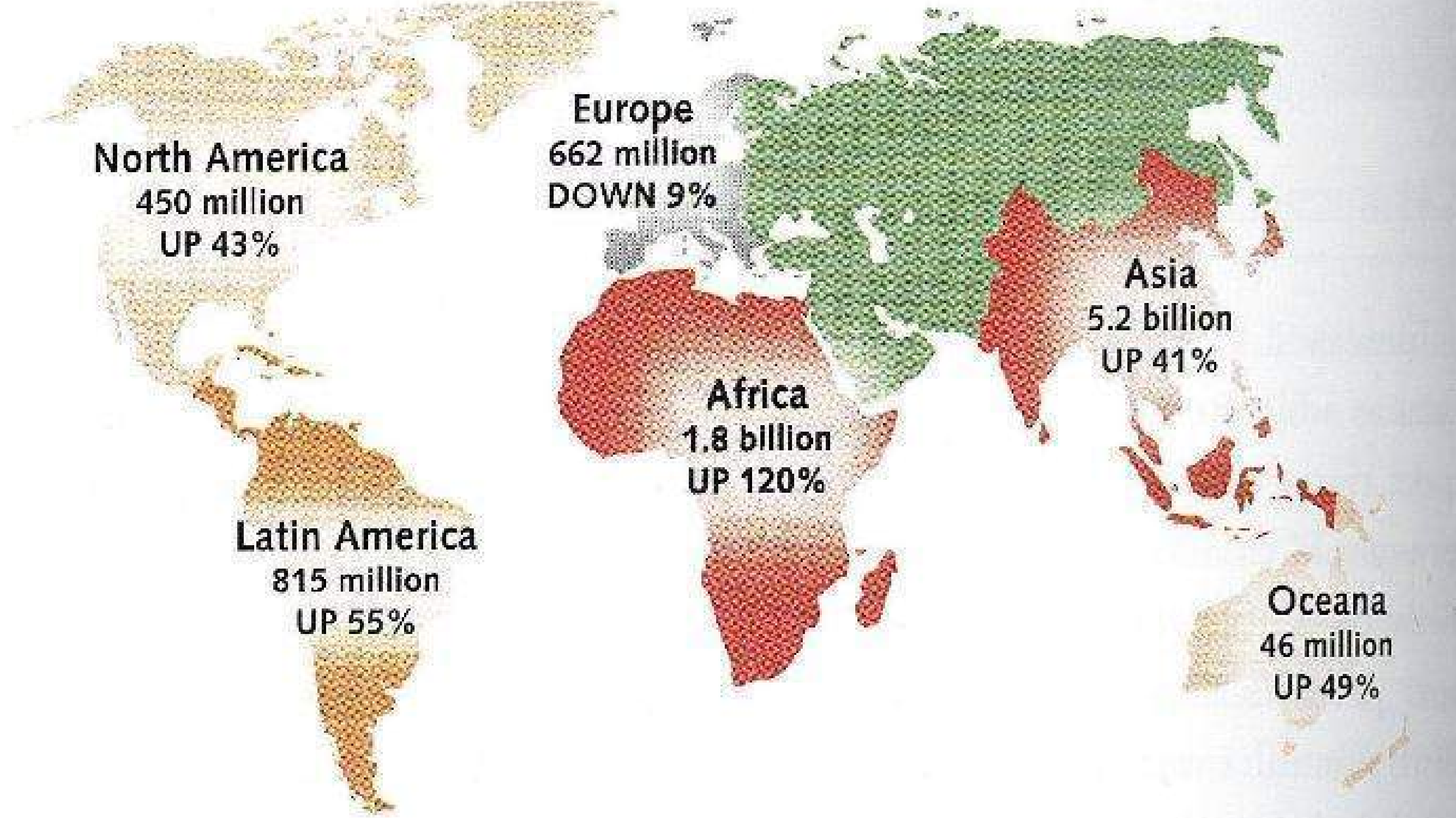
energy

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: Earth population growth

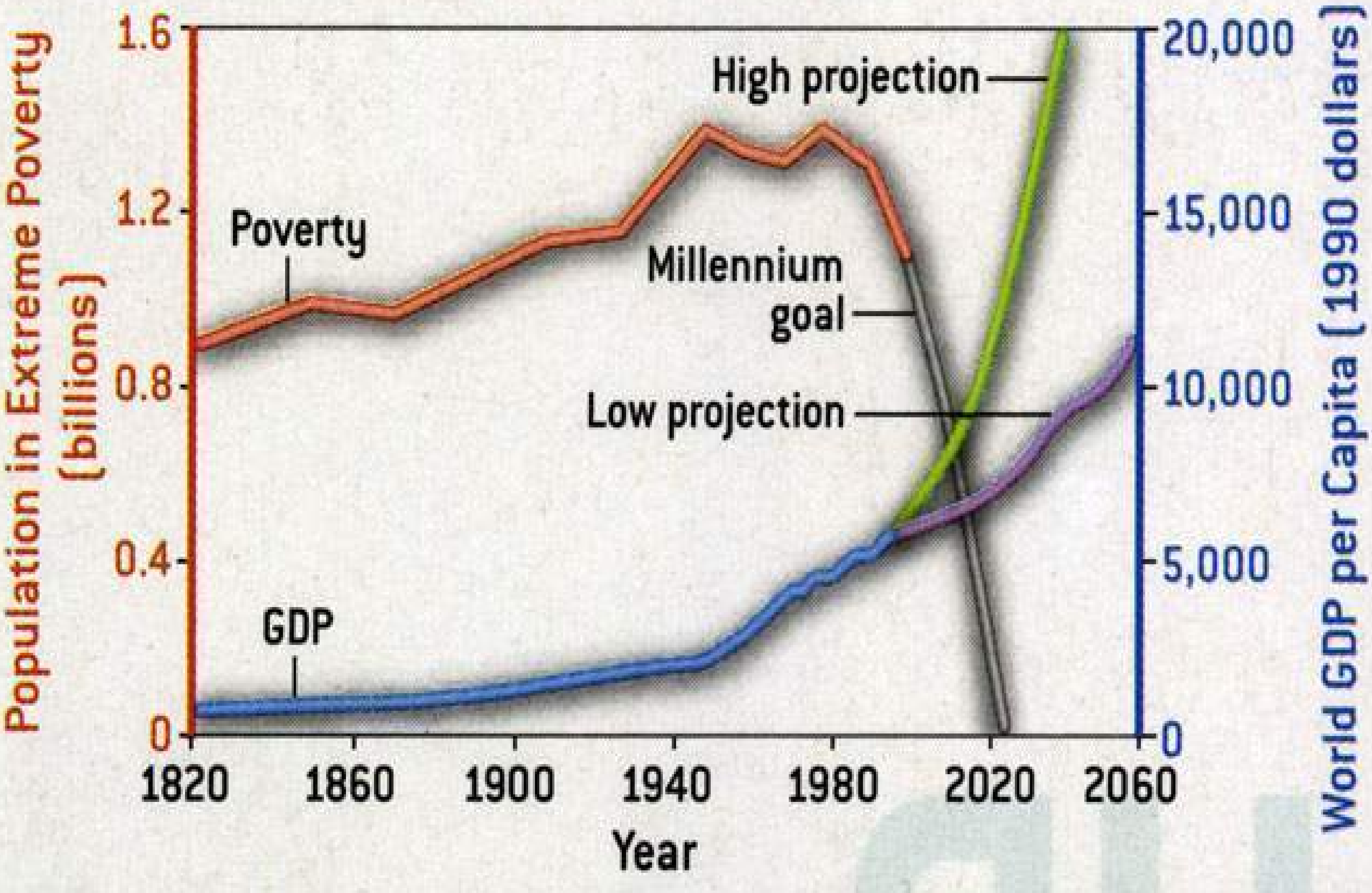


World Population in 2050

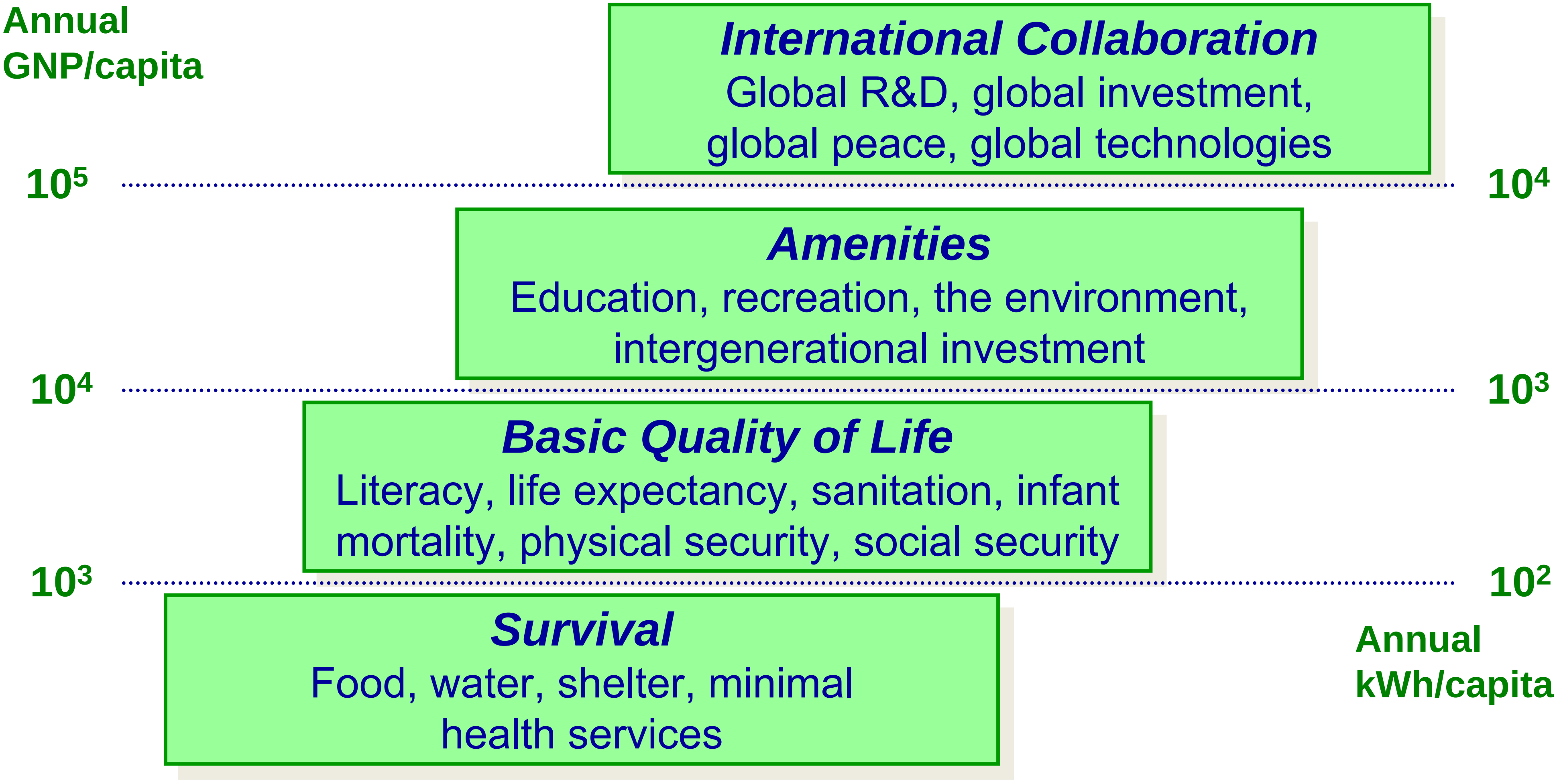


Source: Population Reference Bureau

… PROSPERITY IS SPREADING …



Social Conditions and Access to Electricity



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

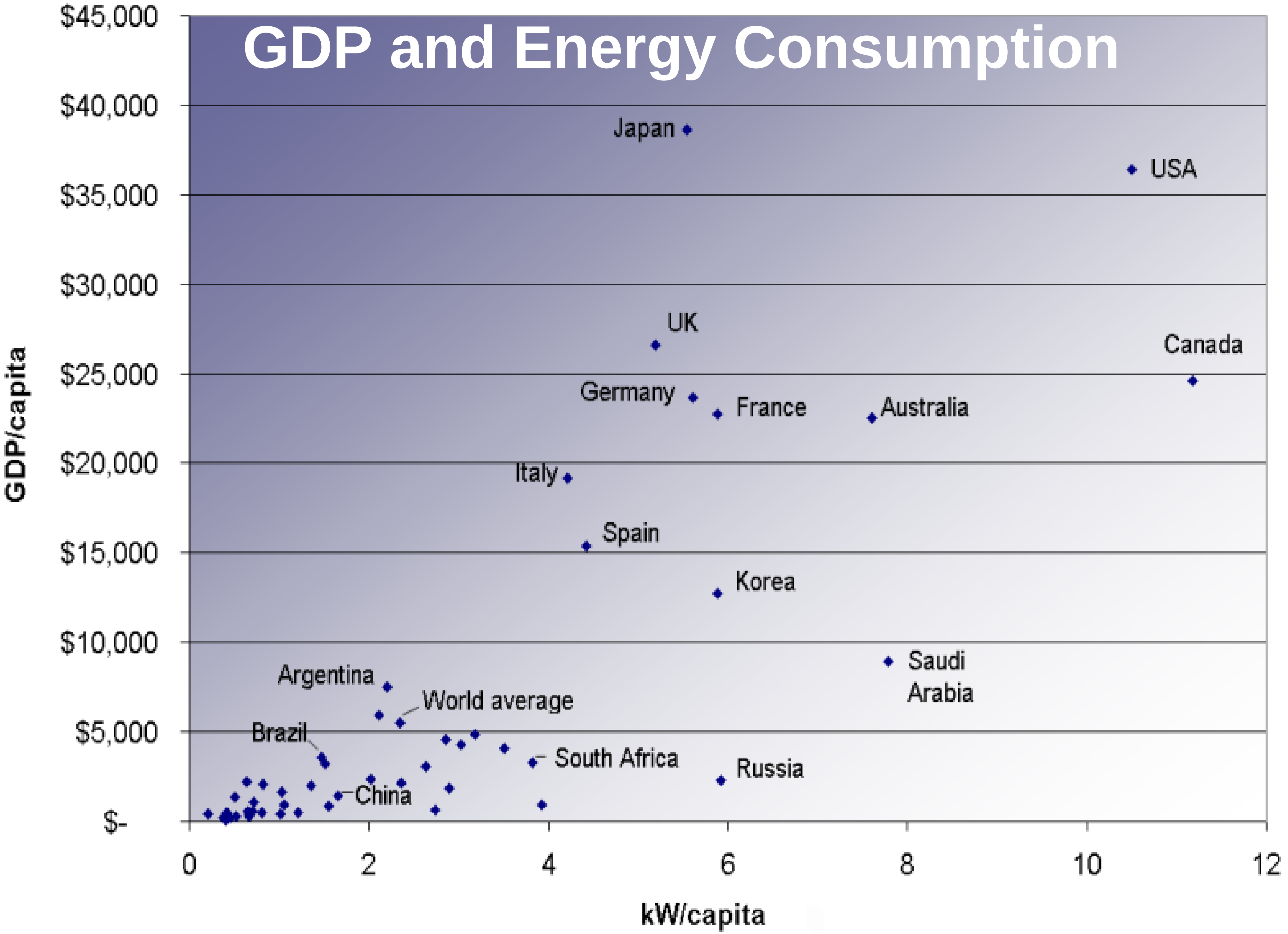
Amenities
Education, recreation, the environment, intergenerational investment

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

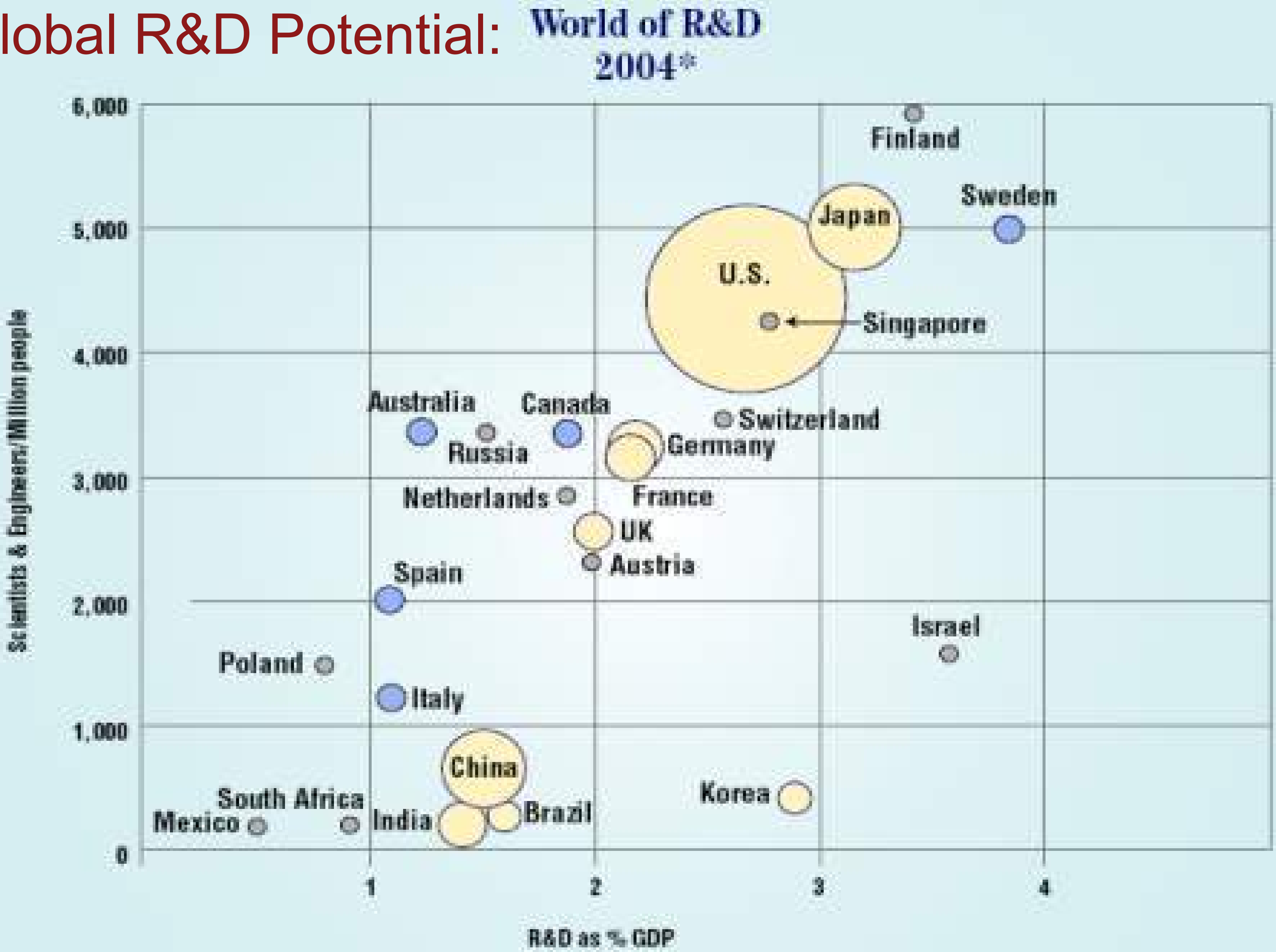
Survival
Food, water, shelter, minimal health services

Source: Dr. Chauncey Starr

GDP and Energy Consumption



Global R&D Potential:

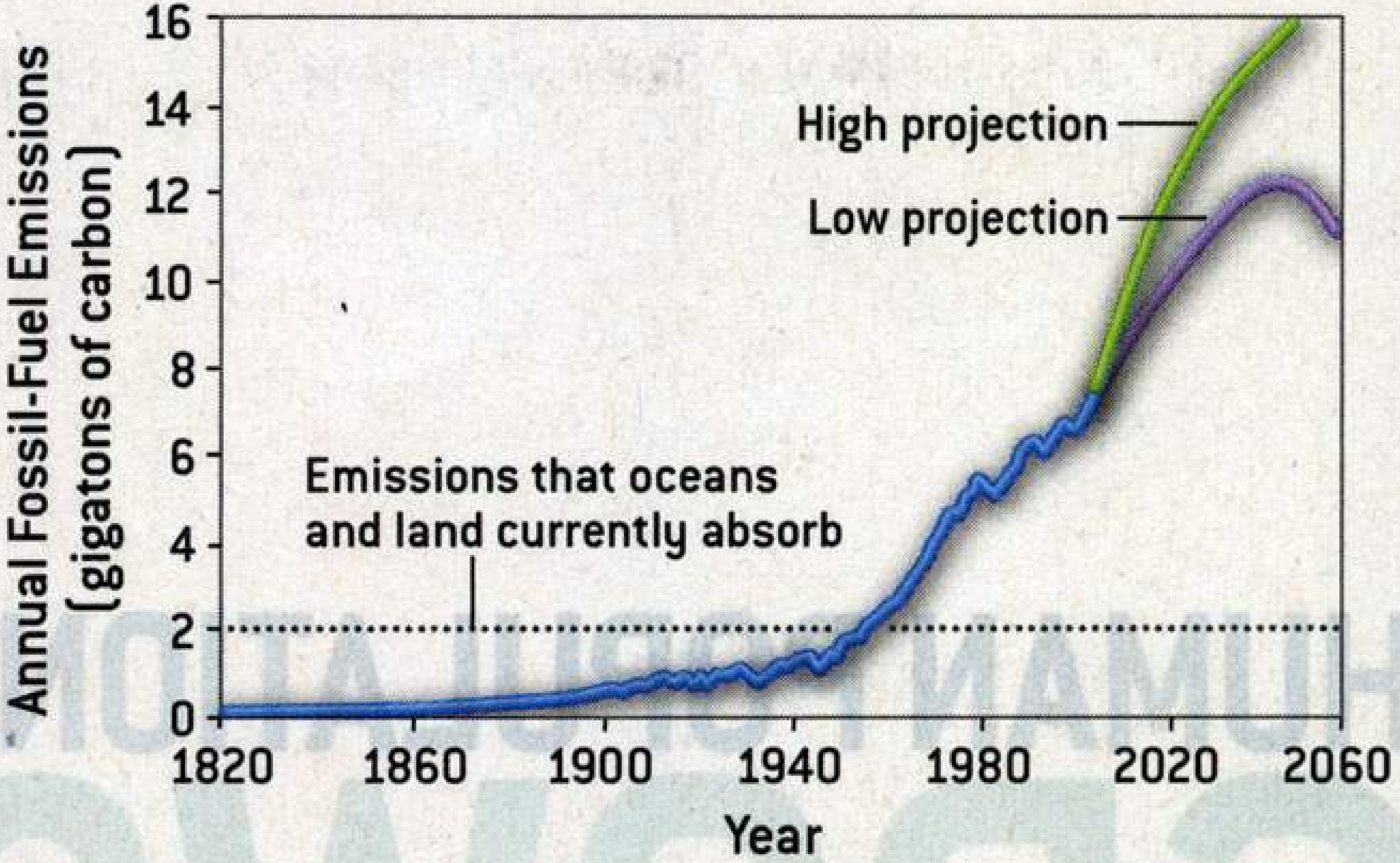


World of R&D 2004*

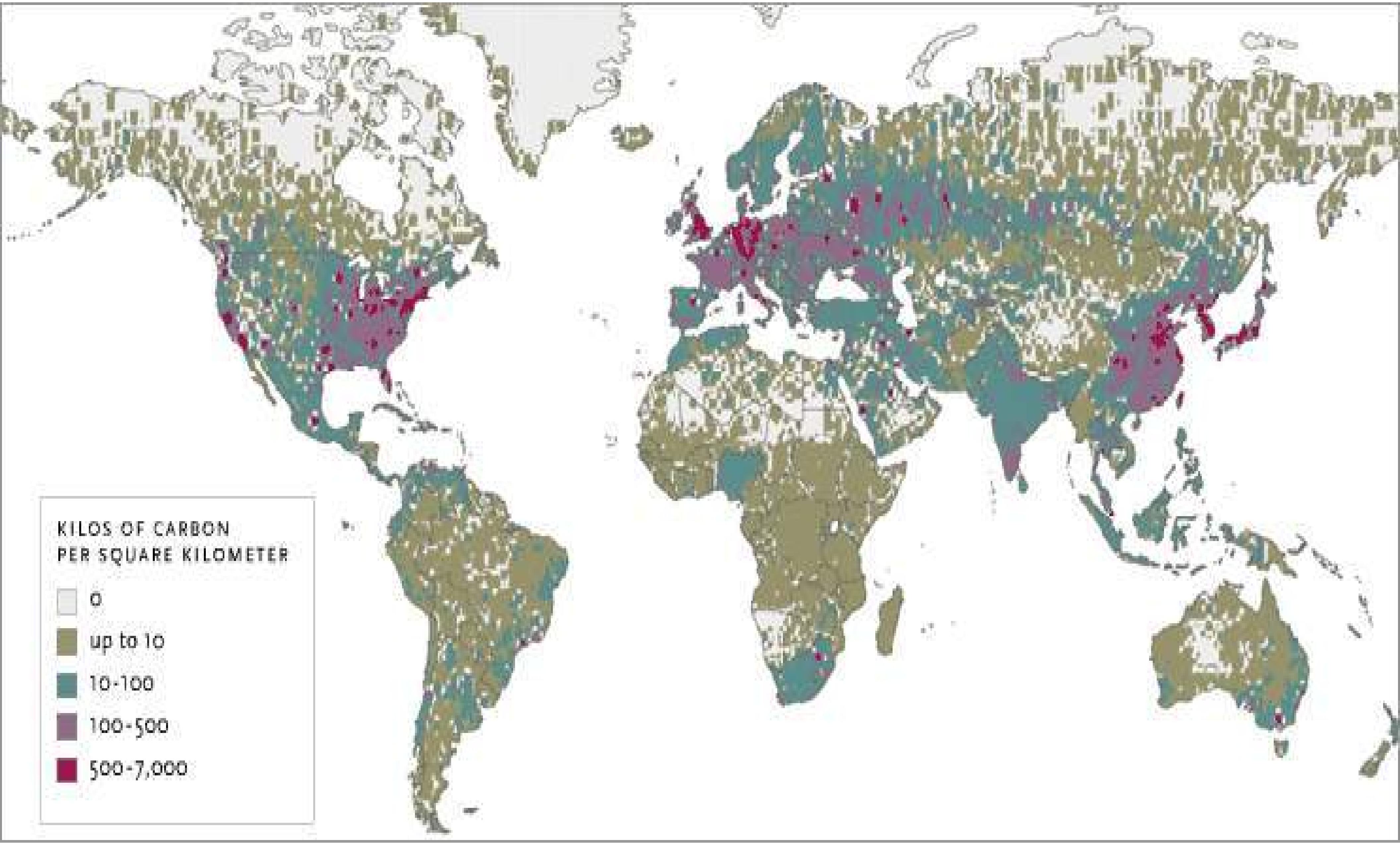
*Size of circle reflects relative amount of annual R&D spending by country noted.

Source: R&D Magazine, Battelle, OECD, World Bank, K4D, UNESCO

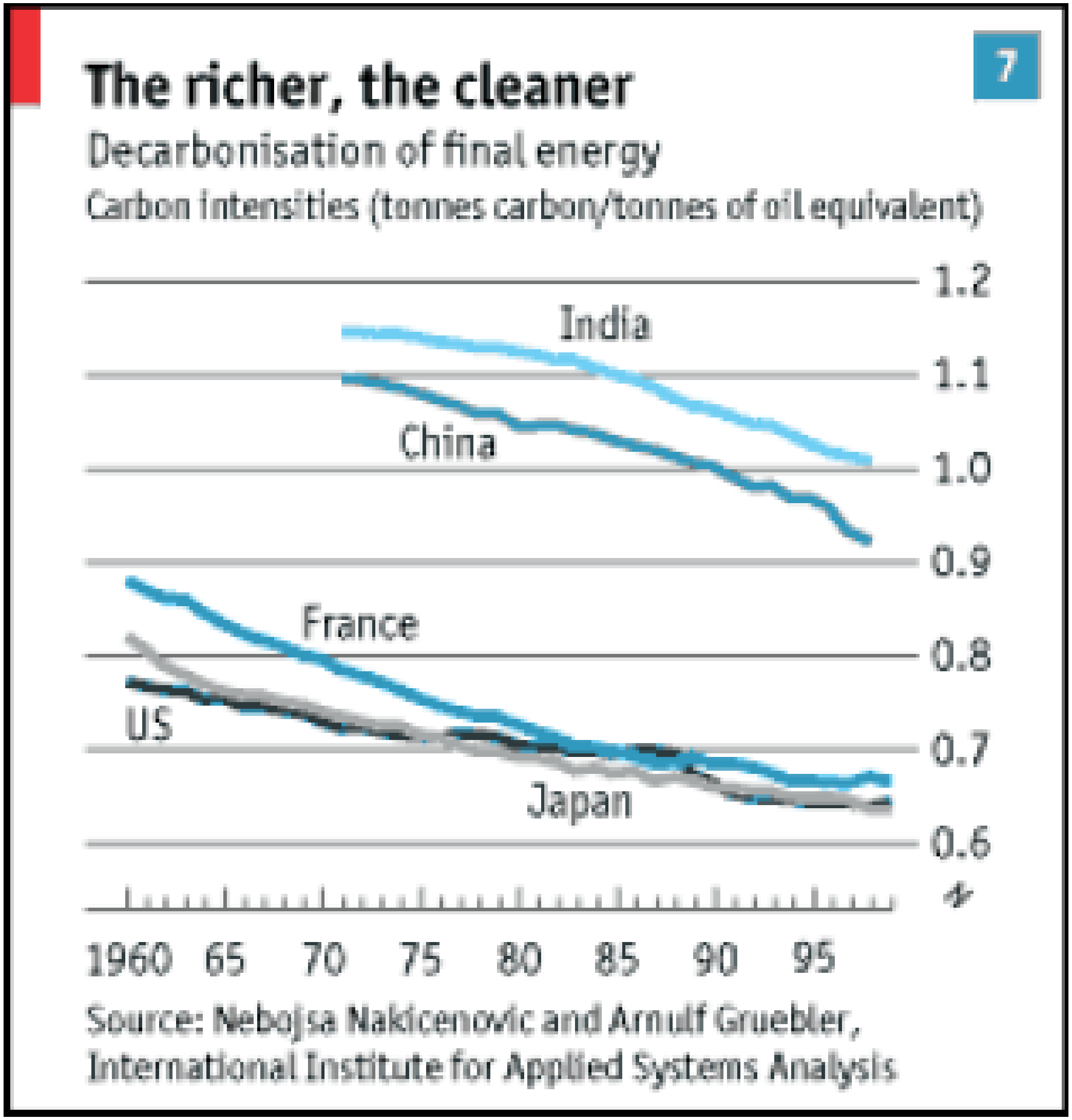
... BUT CO_2 EMISSIONS ARE TROUBLING



Context: Global Emissions



S&T for Sustainable Development



The richer, the cleaner

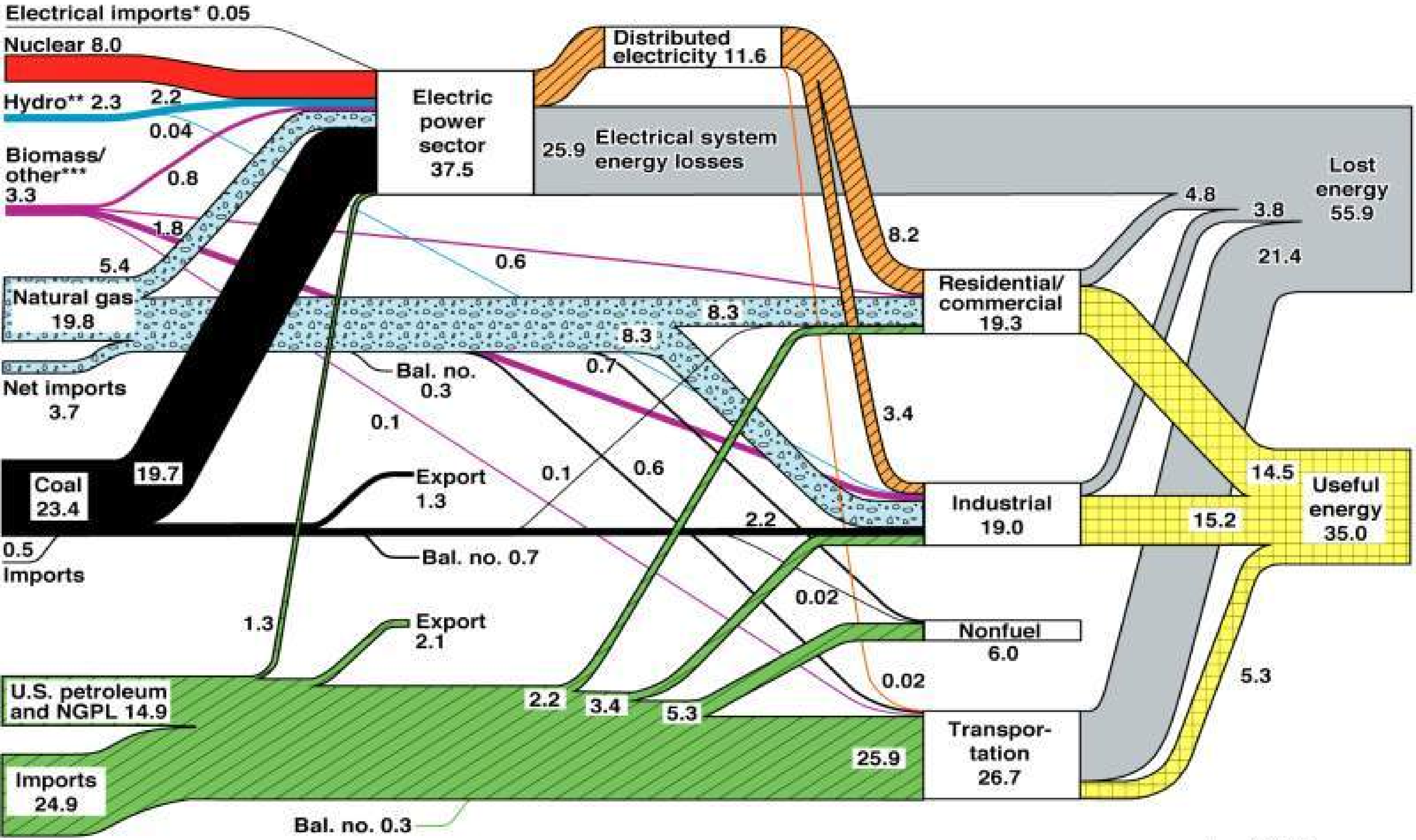
Decarbonisation of final energy

Carbon intensities (tonnes carbon/tonnes of oil equivalent)

Source: Nebojsa Nakicenovic and Arnulf Gruebler, International Institute for Applied Systems Analysis

Source: RFF, 2002

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

Big 4 issues automakers face in meeting those needs

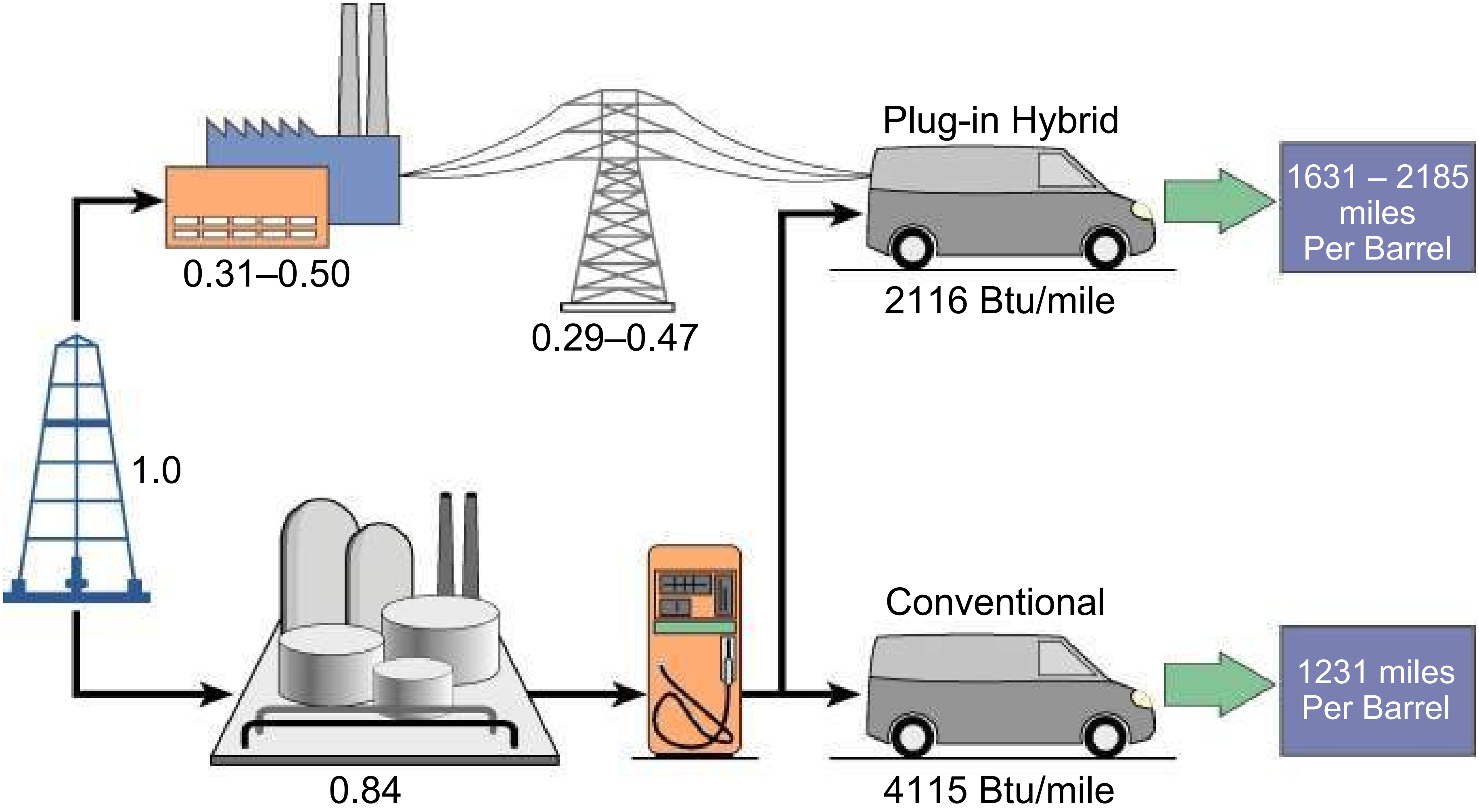
1. Energy diversity
2. Climate change
3. Population and Congestion
4. Air quality

Transportation Fuel Options that Meet These Challenges are Limited

1. **Electricity** (plugging into the grid): Requires "greening the grid" and solving storage/battery issues
2. **Liquids from coal**: Without CCS*, this would be worse than gasoline from a climate standpoint
3. **Biofuels**: UCS study on biofuels suggested that they could perhaps meet 30 to 50% of U.S. transportation fuel needs. We'll still need that other 50%!
4. **Hydrogen**: Made from renewable and low-carbon sources

*CCS: Carbon Capture and Sequestration

Full Fuel Cycle Efficiency Comparison



Plug-in Hybrid

0.31–0.50

0.29–0.47

2116 Btu/mile

1631 – 2185 miles Per Barrel

1.0

Conventional

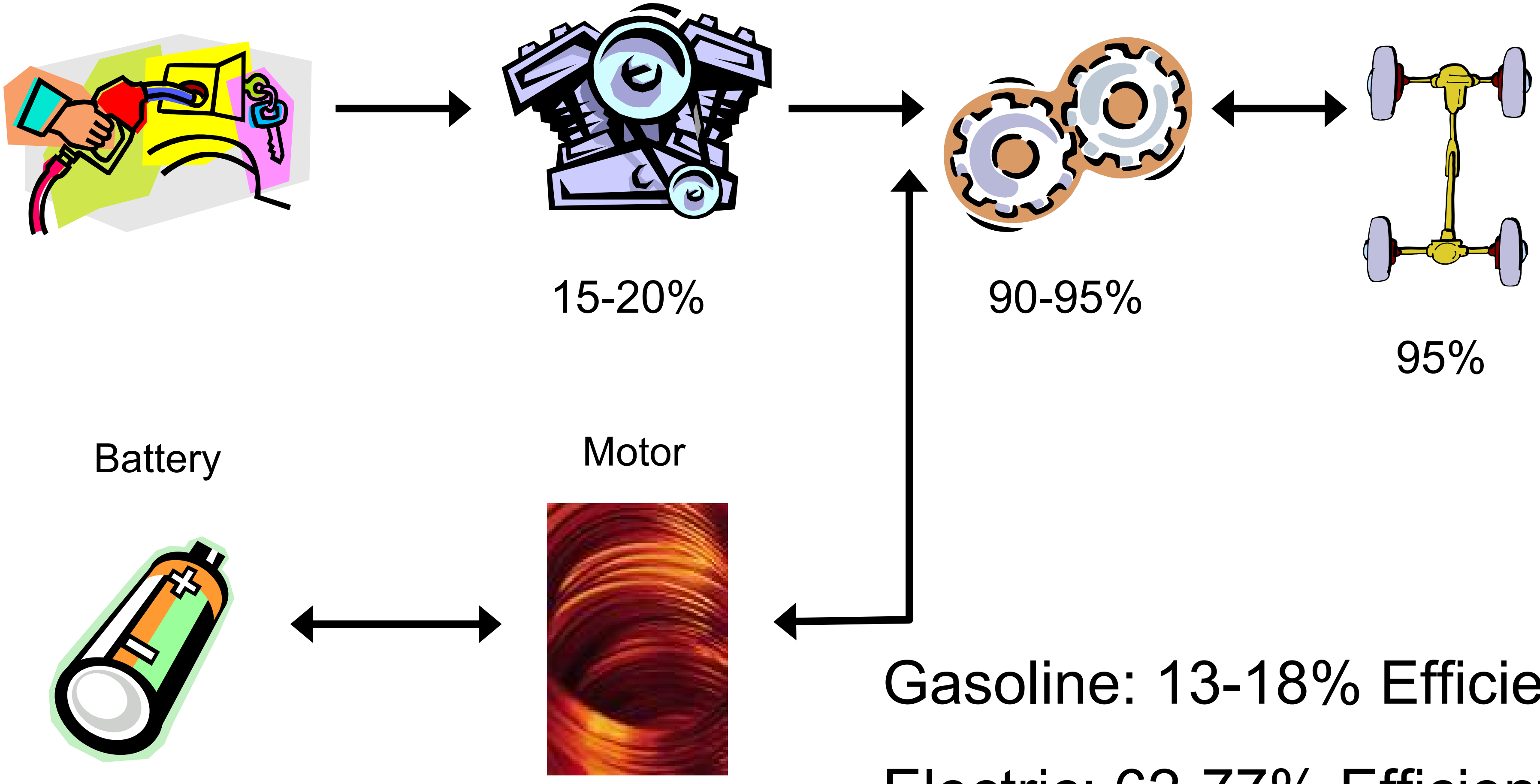
0.84

4115 Btu/mile

1231 miles Per Barrel

Source: EPRI

Hybrid Vehicle Efficiency



Gas tank

Engine

15-20%

Transmission

90-95%

Driveline

95%

Battery

85-90%

Motor

85-95%

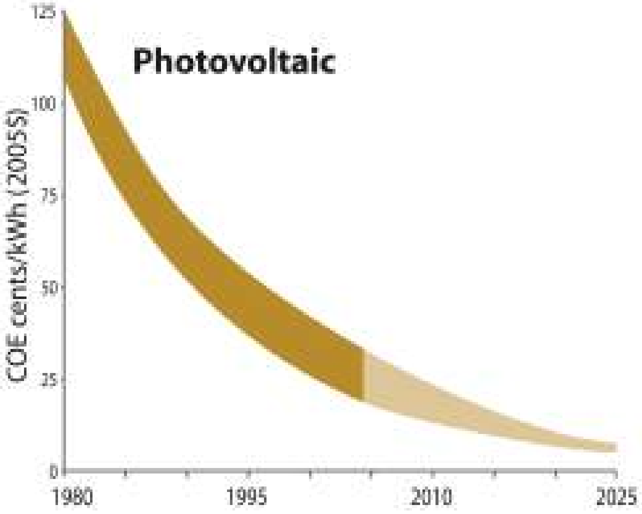
Gasoline: 13-18% Efficient

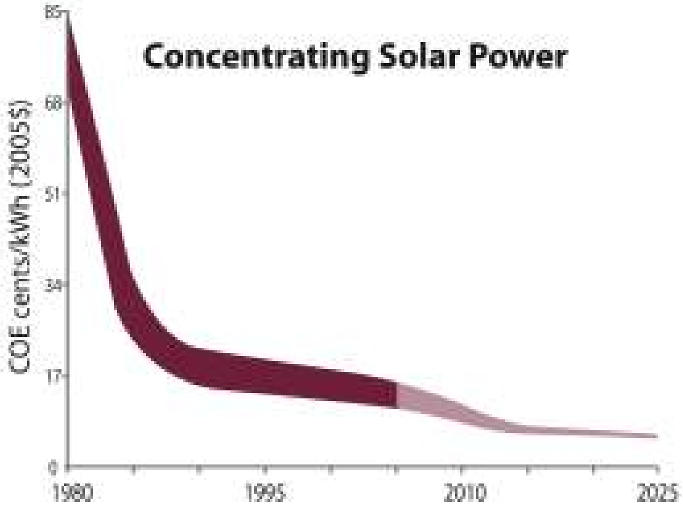
Electric: 62-77% Efficient

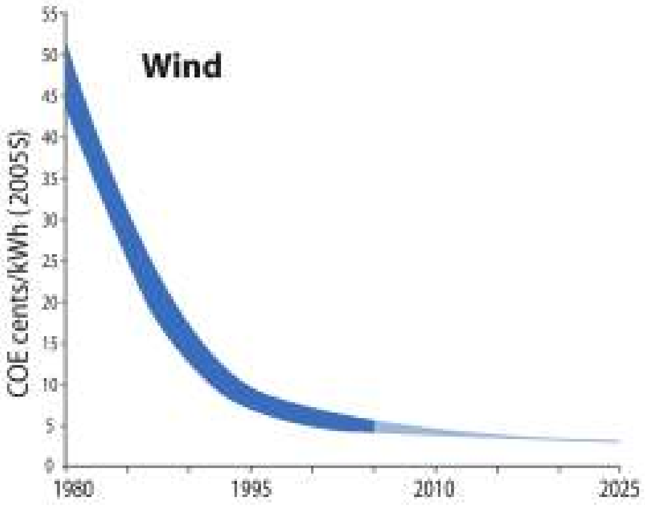
Source: EPRI

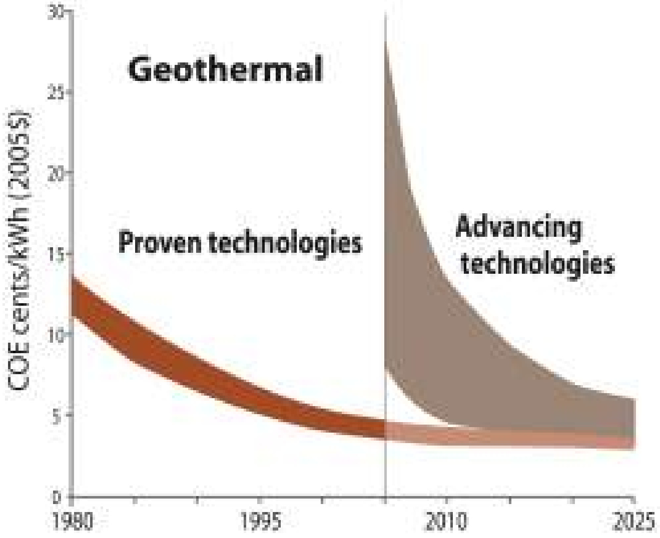
Renewable Energy Cost Trends

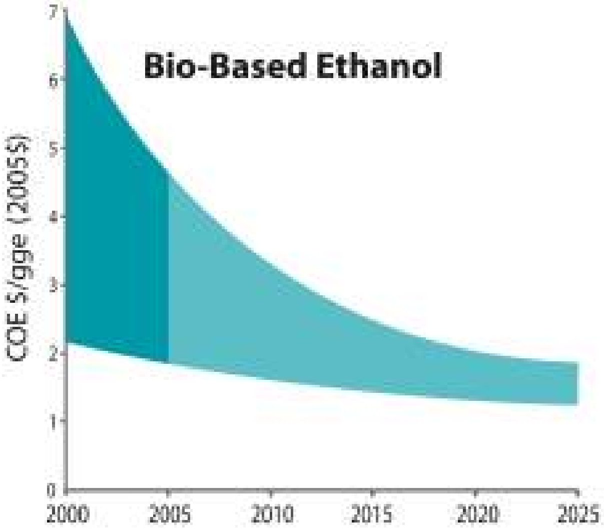
Levelized cost of energy in constant 2005$[1]







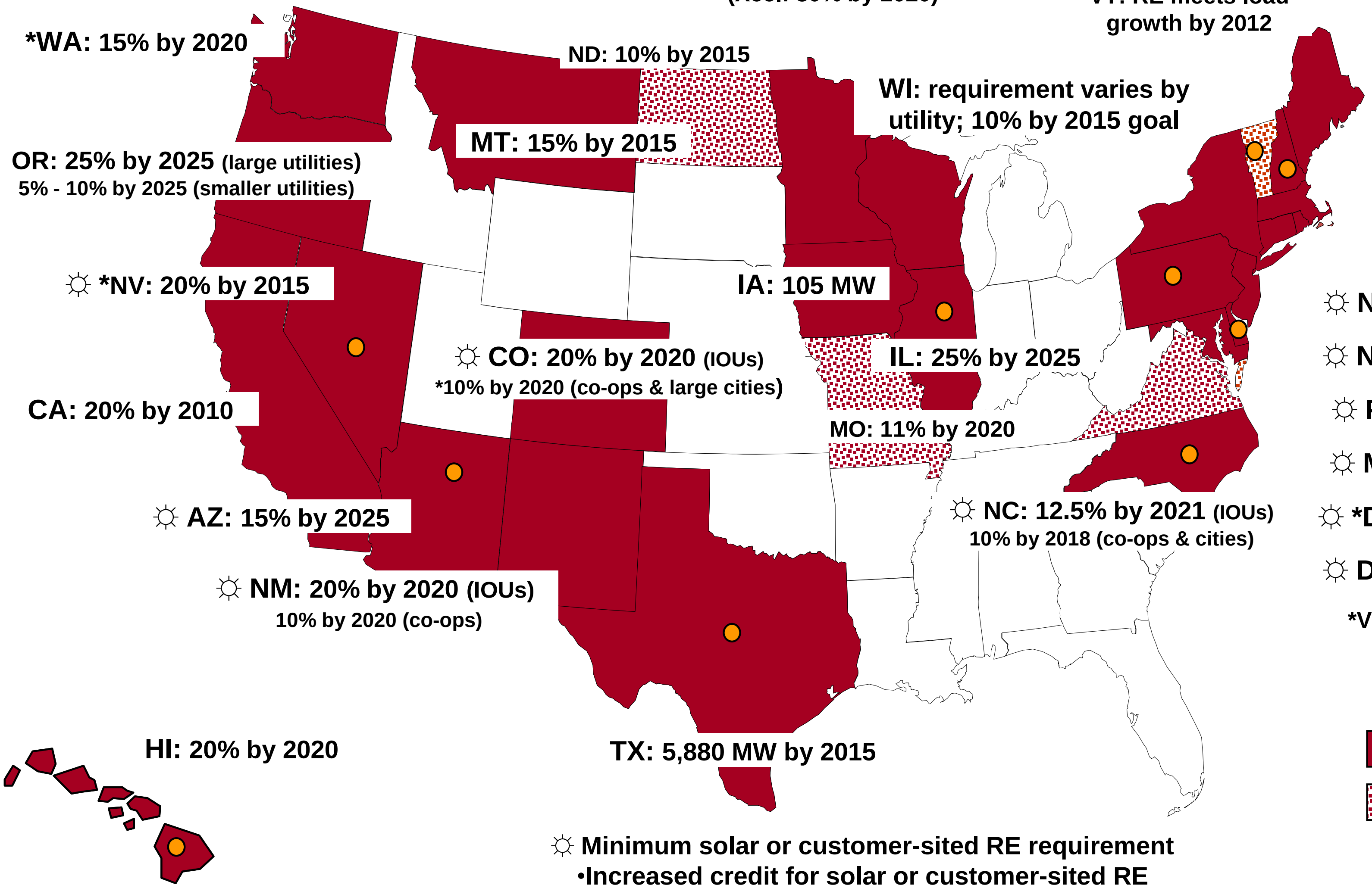




Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

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

Renewables Portfolio Standards



MN: 25% by 2025
(Xcel: 30% by 2020)

VT: RE meets load growth by 2012

ME: 30% by 2000
10% by 2017 - new RE

*WA: 15% by 2020

ND: 10% by 2015

☼ NH: 23.8% in 2025

WI: requirement varies by utility; 10% by 2015 goal

MA: 4% by 2009 +
1% annual increase

MT: 15% by 2015

OR: 25% by 2025 (large utilities)
5% - 10% by 2025 (smaller utilities)

RI: 16% by 2020

CT: 23% by 2020

☼ *NV: 20% by 2015

IA: 105 MW

☼ NY: 24% by 2013

☼ CO: 20% by 2020 (IOUs)
*10% by 2020 (co-ops & large cities)

IL: 25% by 2025

☼ NJ: 22.5% by 2021

CA: 20% by 2010

MO: 11% by 2020

☼ PA: 18% by 2020

☼ MD: 9.5% in 2022

☼ AZ: 15% by 2025

☼ NC: 12.5% by 2021 (IOUs)
10% by 2018 (co-ops & cities)

☼ *DE: 20% by 2019

☼ NM: 20% by 2020 (IOUs)
10% by 2020 (co-ops)

☼ DC: 11% by 2022

*VA: 12% by 2022

HI: 20% by 2020

TX: 5,880 MW by 2015

🟥 State RPS

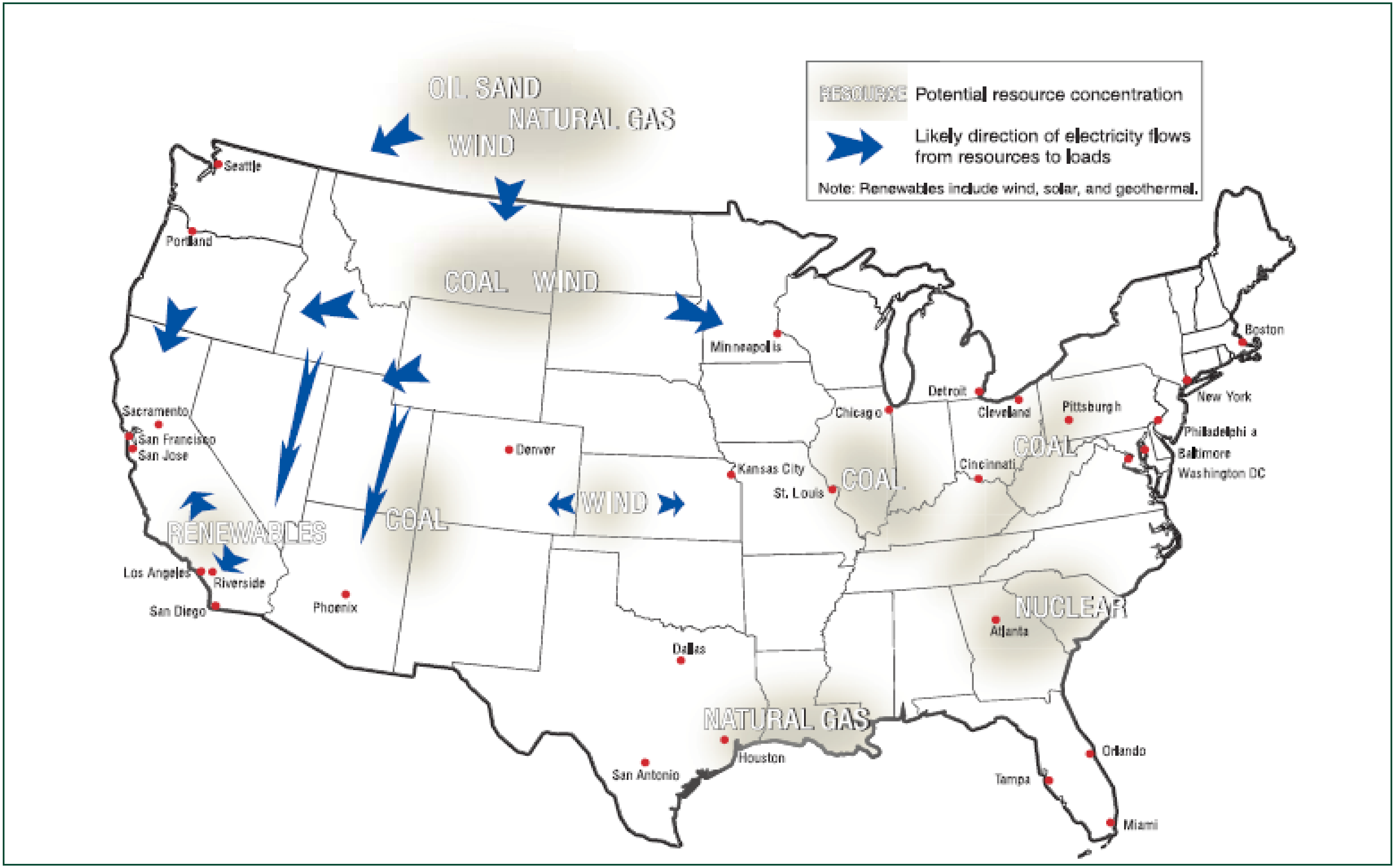
▨ State Goal

● Solar water heating eligible

☼ Minimum solar or customer-sited RE requirement
•Increased credit for solar or customer-sited RE

Information courtesy of the Department of 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

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.

Plug-In Hybrid Electric Vehicles as a Distributed Energy Resource

Problem:

Design the control for a Plug-In Hybrid Electric Vehicle (PHEV) energy management system to optimize the energy used to support the reliable operation of the bulk electric power system.

Results:

- Visualization of energy flow in segment of Minnesota's distribution system and impact of PHEV supplying power back to the electric grid
- Control strategy for aggregation of PHEVs to meet ancillary service needs of local electric energy system
- Optimize energy supplied by individual vehicles to minimize impact on driver and battery lifetime

Approach:

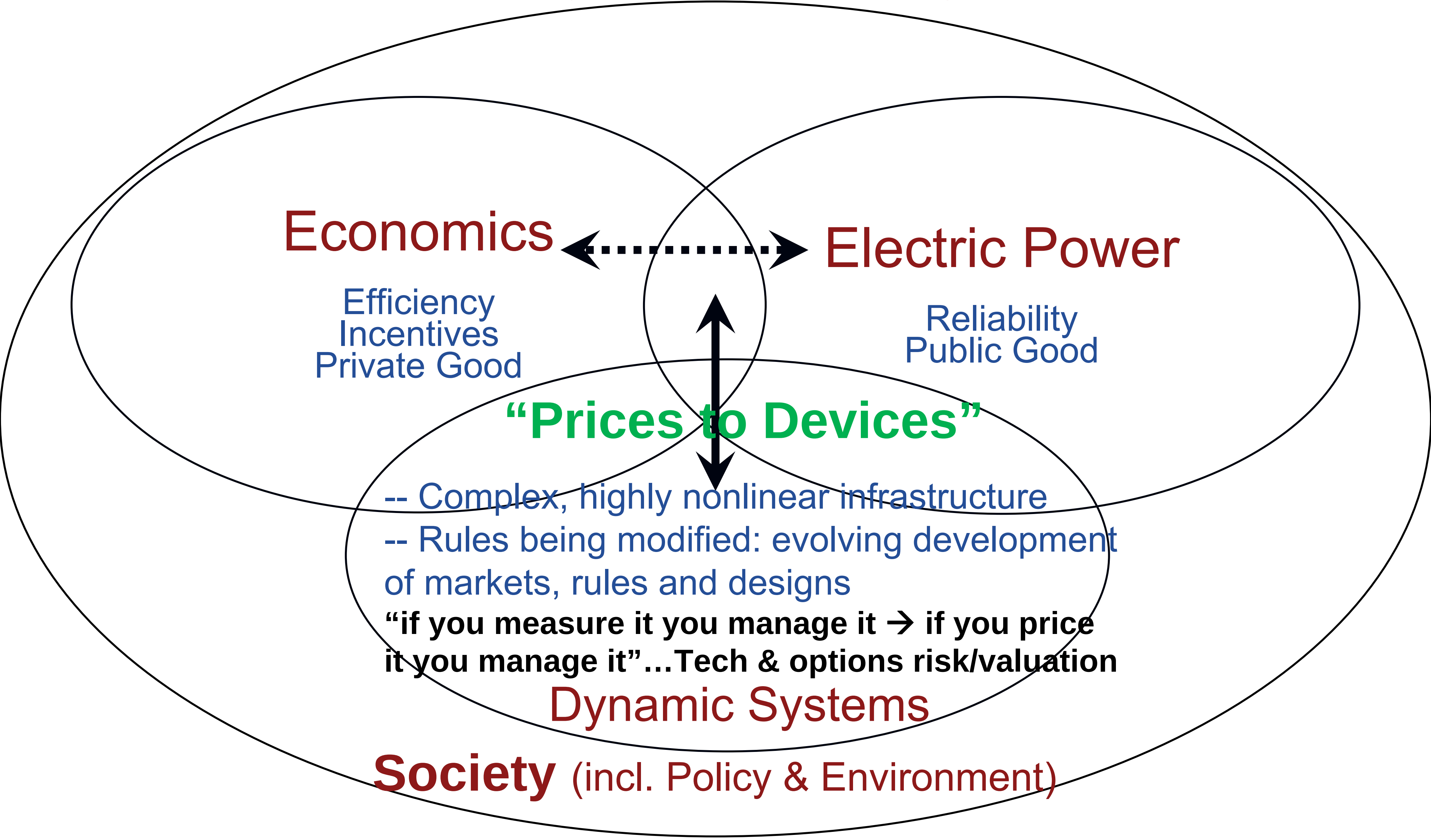
- Model the energy storage and associated control in PHEV to simulate response of aggregated PHEVs to ancillary service needs of local system
- Design the control to meet the owner's driving energy needs and meet specific local energy system need by coordinating with nearby PHEVs

Next Steps:

- Work with Minnesota Department of Commerce to assess the best target markets for PHEV in MN, based on trip trends and vehicle functions. This study will assess vehicles for personal use as well as vehicle fleets used in the commercial, transportation and industrial sectors.

University of Minnesota: PhD candidate Ms. Sara K. Mullen, Faculty members: Professors Massoud Amin and Bruce Wollenberg

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



Economics

Efficiency
Incentives
Private Good

Electric Power

Reliability
Public Good

“Prices to Devices”

-- Complex, highly nonlinear infrastructure

-- Rules being modified: evolving development of markets, rules and designs

“if you measure it you manage it → if you price it you manage it”…Tech & options risk/valuation

Dynamic Systems

Society (incl. Policy & Environment)

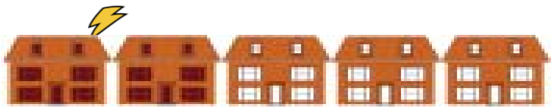
University of Minnesota PhD candidate Ms. Laurie E. Miller, Faculty members: Professors Massoud Amin and Bruce Wollenberg

The **Smart Grid** is:

Intelligent: autonomous digital system identifies surges, outages
Resilient: "self-healing"- instantaneous damage control
Flexible: accommodates new off-grid alternative energy sources
Reliable: dynamic load balancing
Secure: less vulnerable to terrorist attack

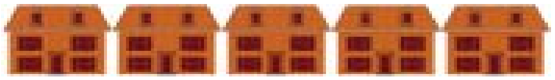
Large blackouts happen in cascade, but the **Smart Grid** will use distributed agents to halt cascades.

Simulated blackout:



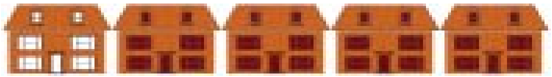
A storm causes a temporary loss of some power lines. Frequency climbs since there is more generation than load. One generator reaches its frequency limit and shuts down. The automated protection system restores connections to the areas that had lost power.

Without agent intervention:

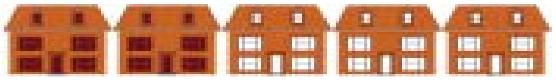


Too few seconds have passed for the control center to act. But the remaining four generators cannot handle the total system load: **Blackout.**

One hour later:

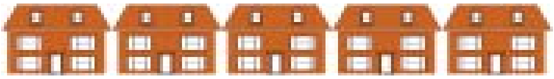


With agent intervention:

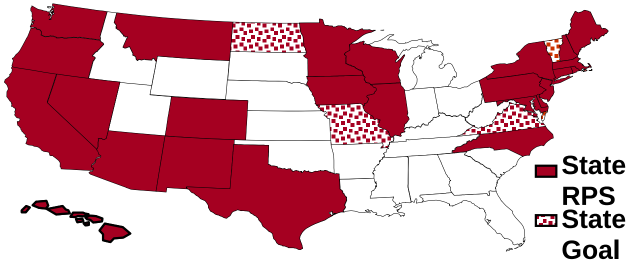


The agents see the sudden plunge in system frequency and order all neighborhoods to shut off 10% of remaining power. The frequency stabilizes and the agents restore the load they shed within seconds. The control center deals with the original power outage.

One hour later:



Renewables are coming:



Information courtesy of the Department of Energy

And so is the data:

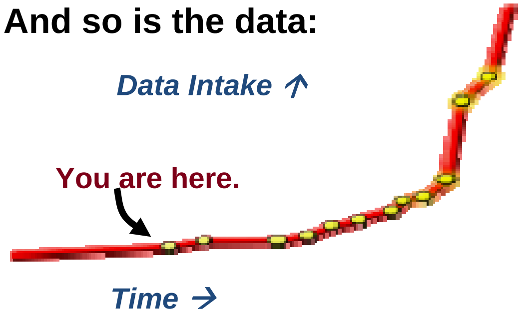
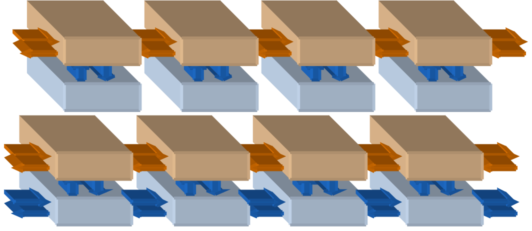


Image courtesy of EPRI

With the **Smart Grid**, we will be ready.



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Nutaro, J., Miller, L., Mullen, S., Kuruganti, P., Shankar, M. "Integrated modeling of the electric grid, communications, and control". *19th Mini EURO Conference on Operational Research Models and Methods in the Energy Sector* (ORMMES'06). University of Coimbra, Portugal. 6-8 September 2006.
Amin, M. and Schewe, P. "Preventing blackouts," *Scientific American*, May 2007, pp. 60-67.
Amin, M. and Wollenberg, B. "Toward a smart grid," *IEEE Power and Energy Magazine*, Vol.3, No 5, pp. 34-38, Sept/Oct. 2005.

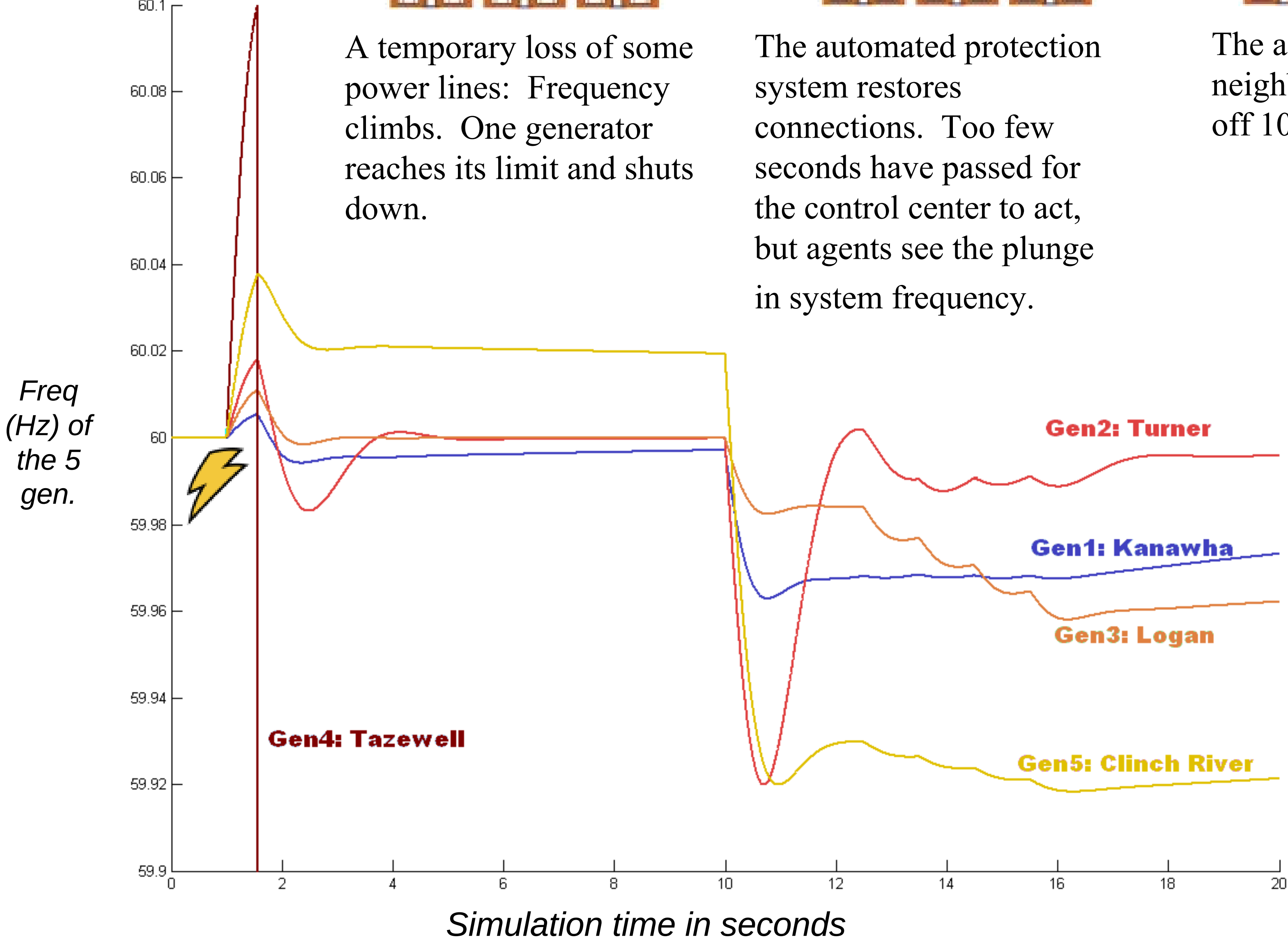
Support from EPRI, ORNL, and NSF for this work is gratefully acknowledged

Distributed sensing and control via Agent-based Frequency control

A temporary loss of some power lines: Frequency climbs. One generator reaches its limit and shuts down.

The automated protection system restores connections. Too few seconds have passed for the control center to act, but agents see the plunge in system frequency.

The agents order all neighborhoods to shut off 10% of power.



The frequency stabilizes and the agents restore the load they shed within seconds. Blackout is averted and the control center deals with the original power outage.

Support from EPRI, ORNL, and NSF for this work is gratefully acknowledged

Present scheme for control of a power system

- All real time information is gathered and sent to a central site
- Central site maintains data base to model the power system network (updated by hand)
- Software applications control system through commands sent back to the plants and substations
- Data describing the power system must be up to date and accurate

Xcel Energy Control Room Minneapolis

Smart Power System Technology

- All substation and power plant components have an embedded processor with ability to connect to fiber communications
- Each high voltage connection has a parallel information connection
- Device processors have permanent information on device parameters, status and analog measurements from the device

Smart Grid requirements

- Act as fast as the protection system
- No central computing site
- Spans the entire power grid

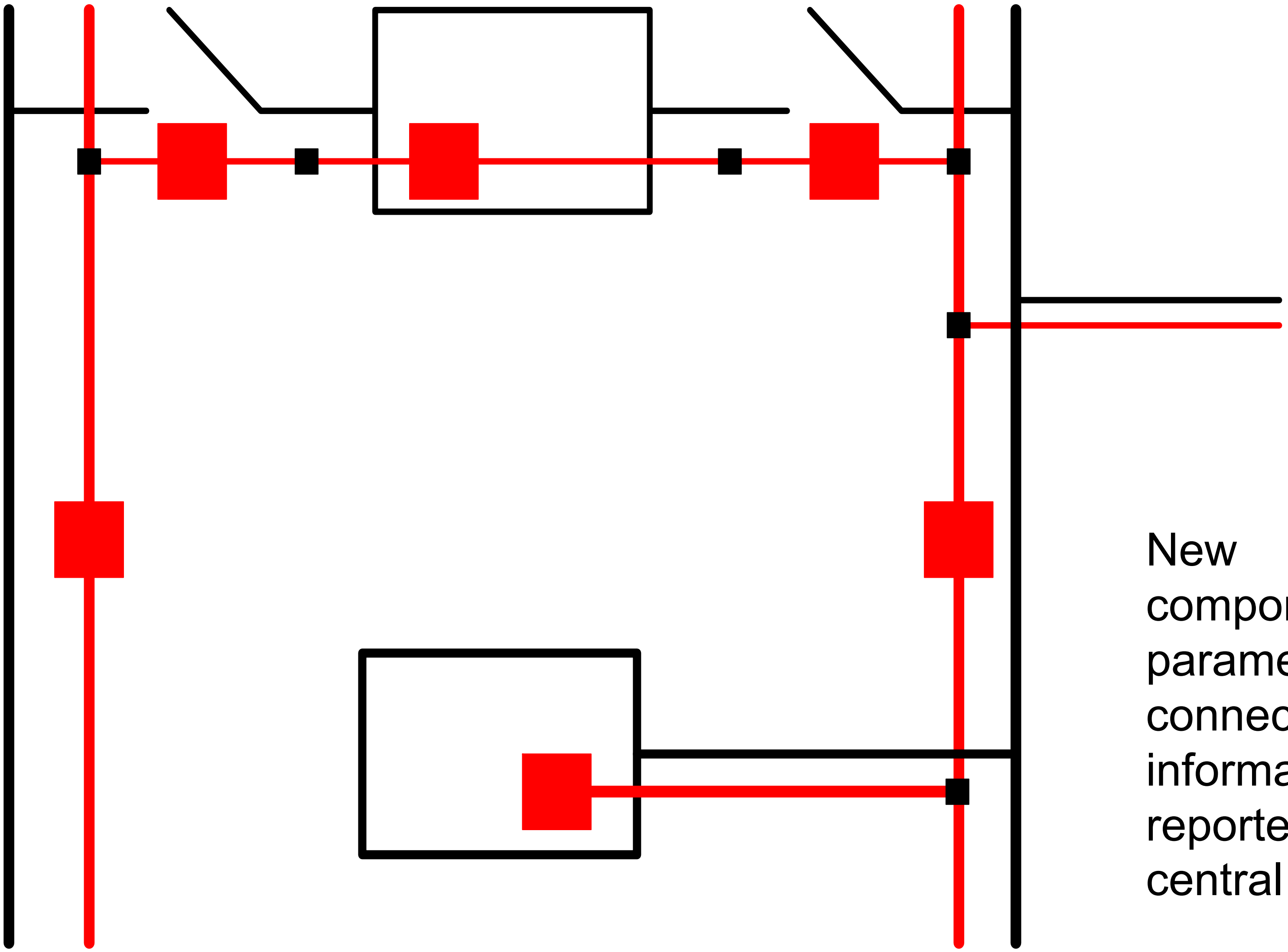
Keeping a central computing database up to date

- Problem:
  - New equipment is installed in a substation
  - Its connection to other equipment must be recorded along with all parameters describing the new equipment
  - The central computer's database must be updated and the substation one line diagrams updated for system operators
- This often takes too much time and errors can be made

Future smart grid scheme: “Plug and Play” substations

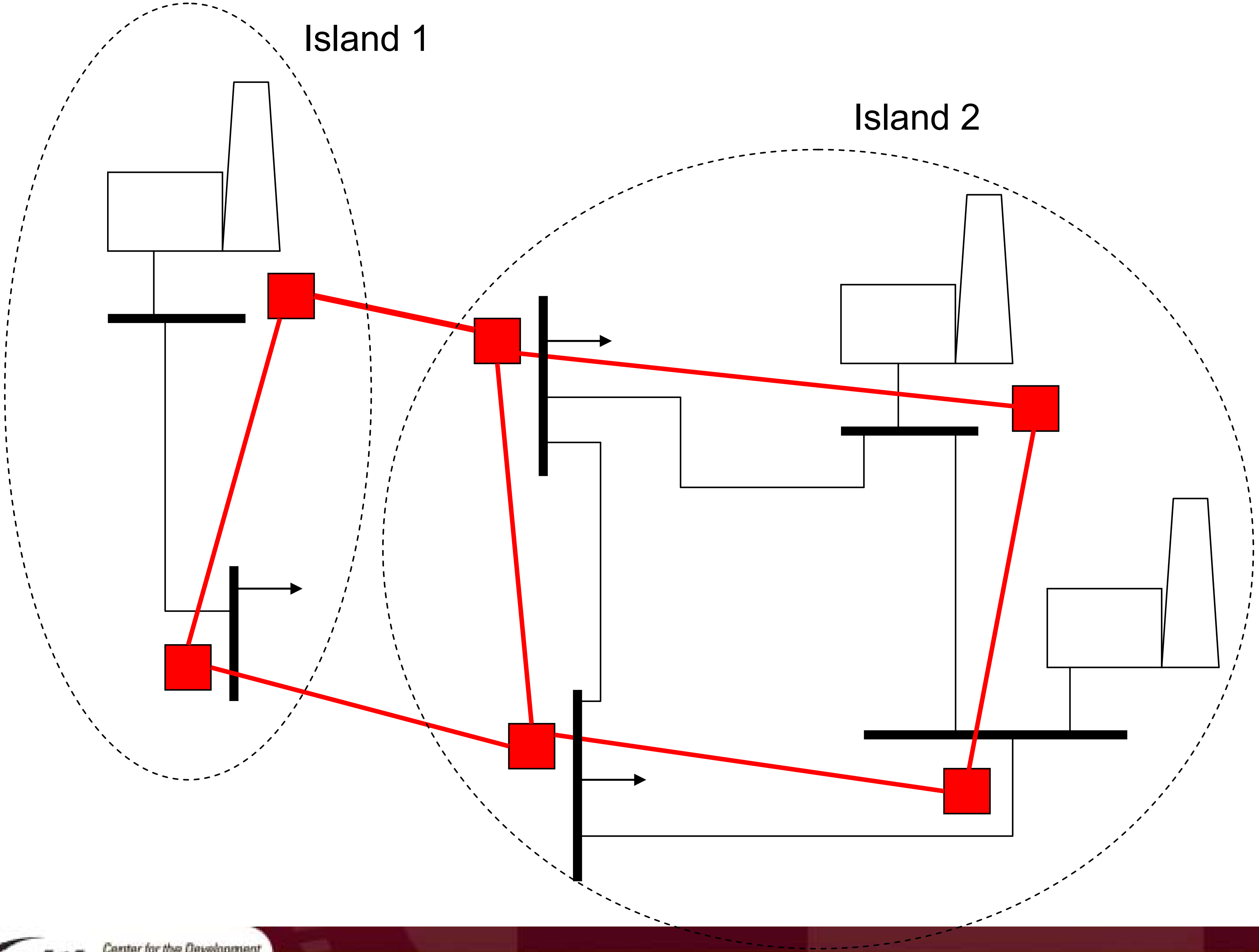
- Each component’s processor acts as an independent agent
- Each component knows what other components it is connected to and can communicate with those components’ processors
- Central site data base updated automatically when new devices are connected
- Fast control can be achieved when necessary through agents’ local decisions

New component is also connected to information layer

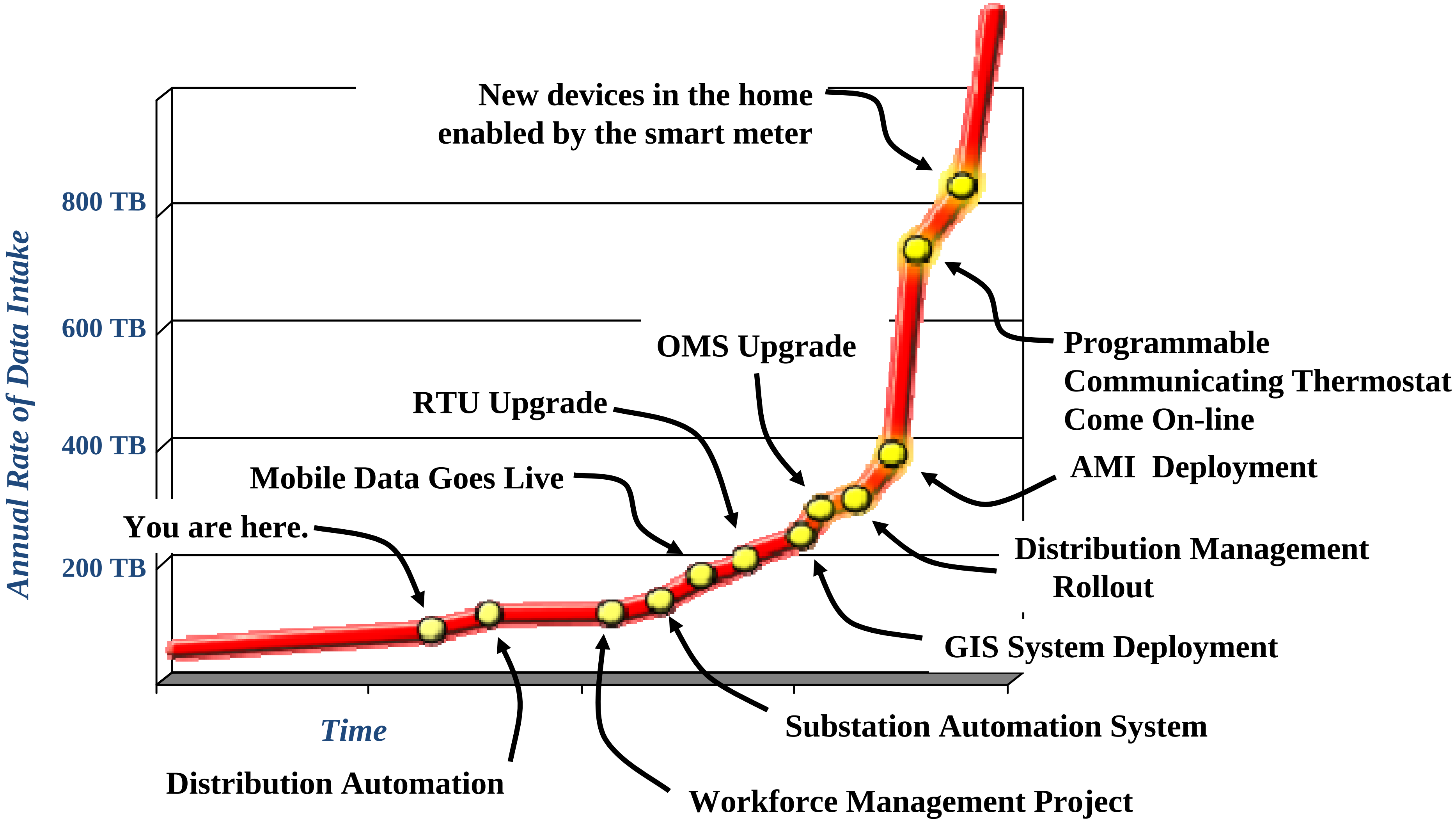


New component’s parameters and connection information reported to central database

Self Healing Grid example



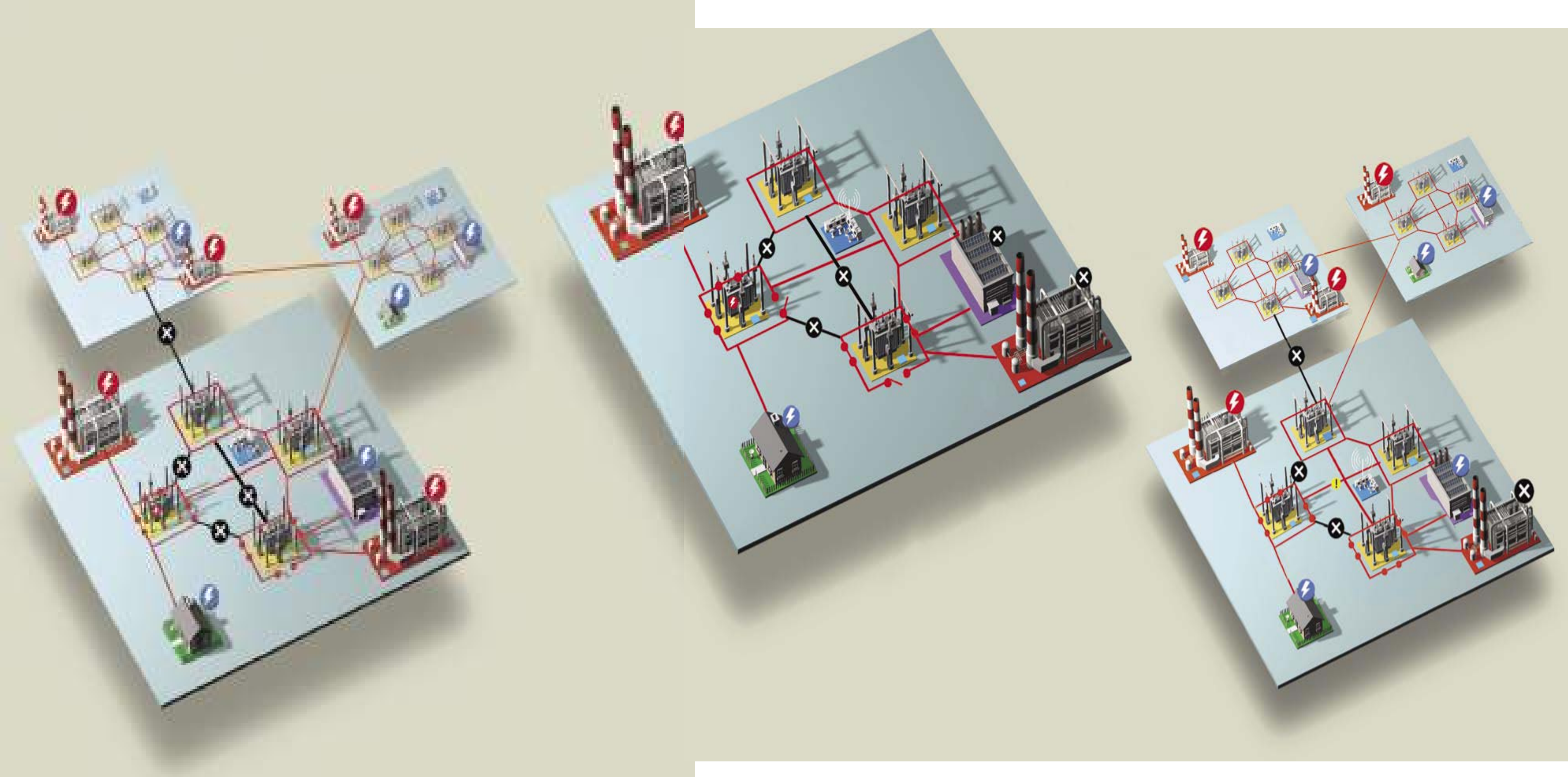
Smart Grid Field Data



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

Source: EPRI

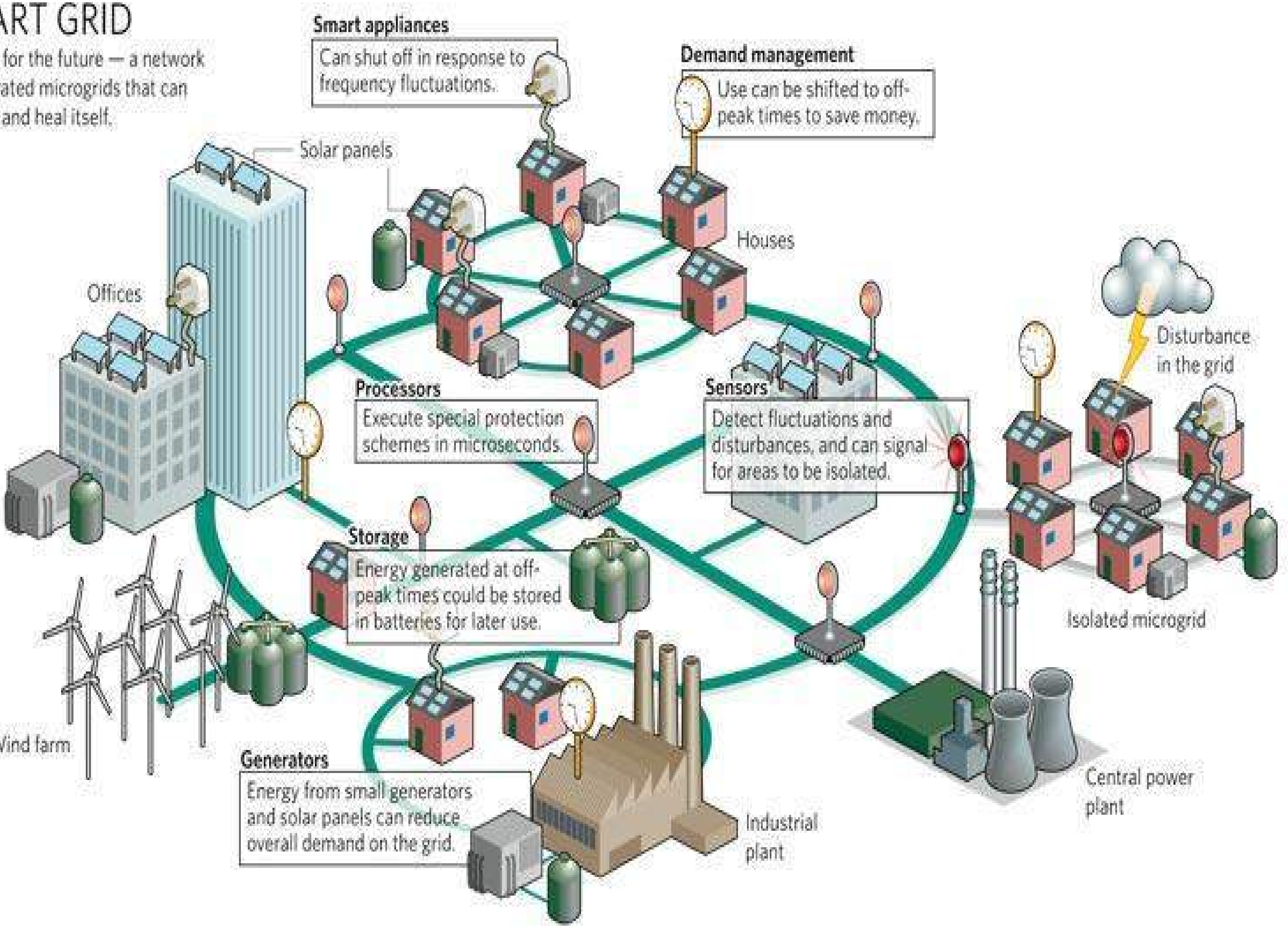
Smart Self-Healing Grid



“Preventing Blackouts,” Scientific American, May 2007

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.

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.

Generators

Energy from small generators and solar panels can reduce overall demand on the grid.

Related on-going R&D include

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

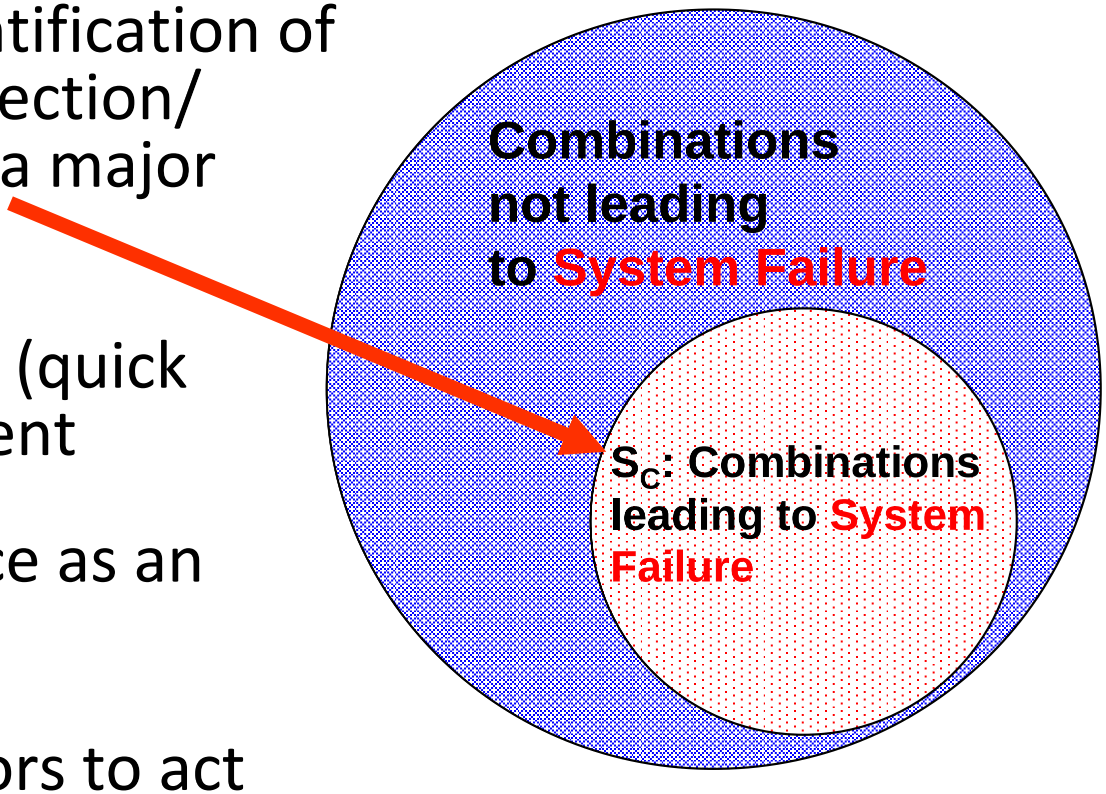
- Energy Bill passed in December 2007: Title XIII Smart Grid, Sections 1301 -1309
  - Establishes a statement of policy supporting modernization of the grid; authorizes a biennial status report and survey of barriers to modernization
- US Department of Energy: Gridwise and Modern Grid Initiatives

- University of Minnesota Center for Smart Grid Technologies

- Smart Grid Newsletter

Another Persisting Challenge

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

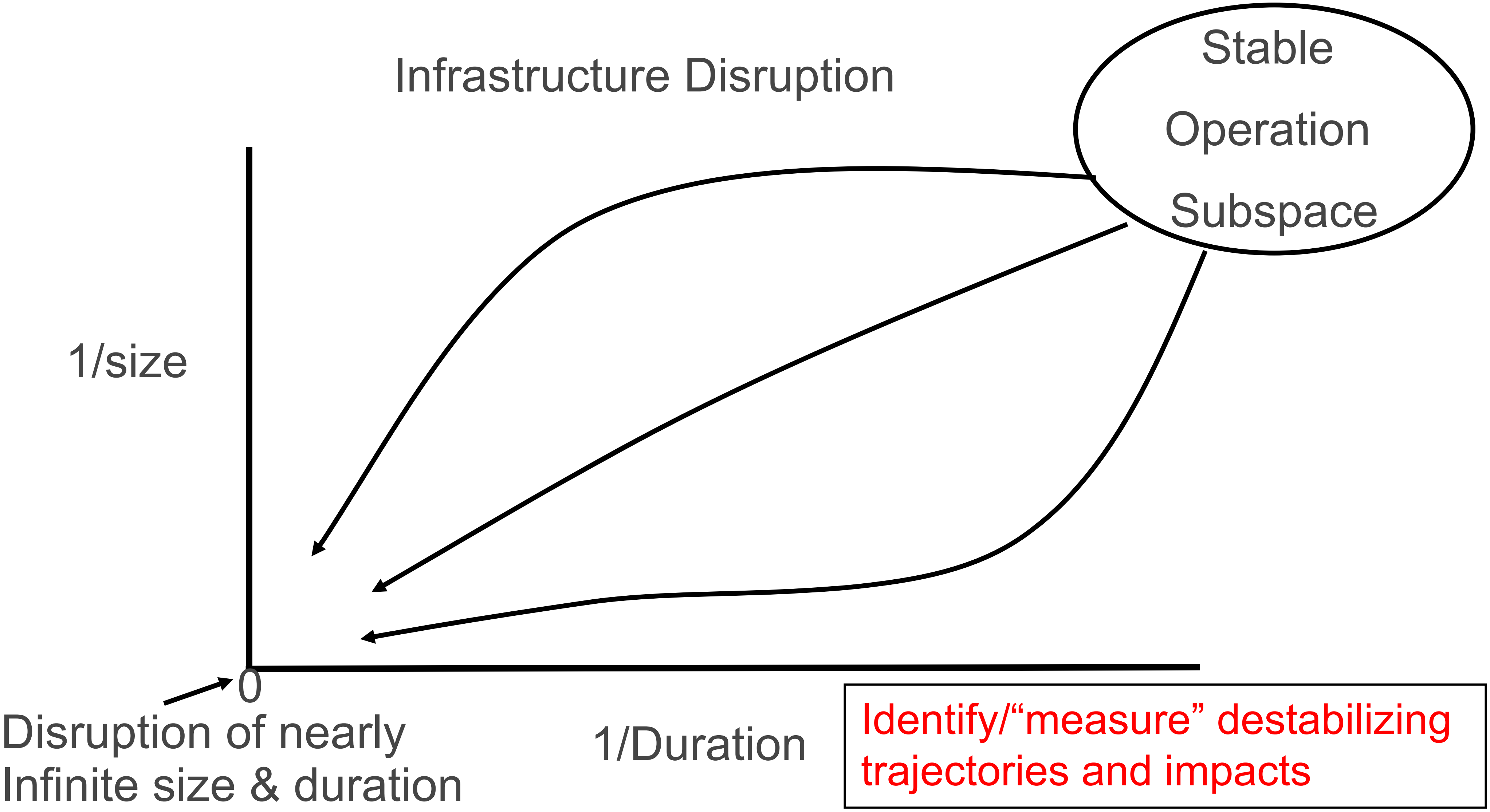


Combinations not leading to System Failure

S_C: Combinations leading to System Failure

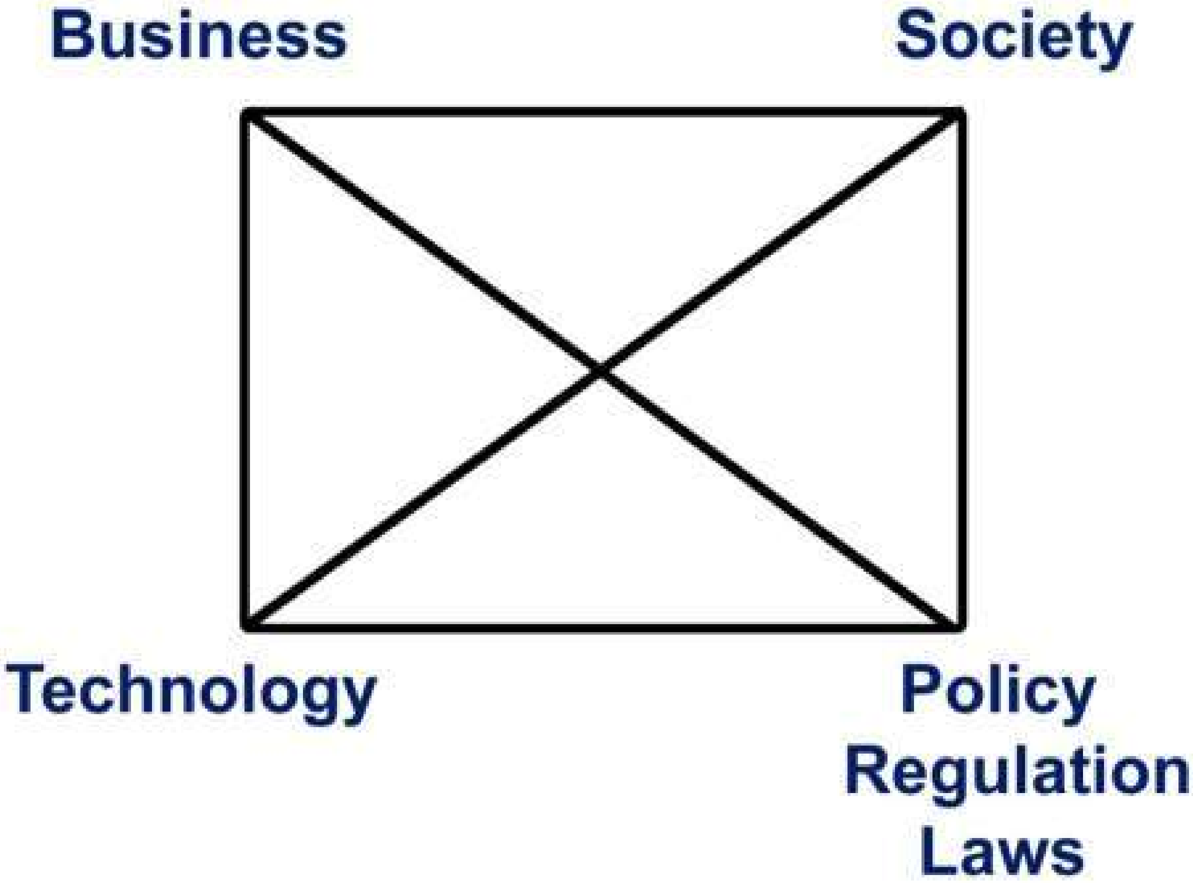
Which trajectories lead to catastrophic failures?

An Assessment Methodology



Identify/“measure” destabilizing trajectories and impacts

Technology/Business/Policy Map



Business

Society

Technology

Policy
Regulation
Laws

Discussion and the Road Ahead:

- What are the key issues facing our society?
    - **What is your vision for the future– what will it look like or how will it perform in 2010-2025?**
    - **What are the difficult challenges to overcome to achieve your vision?**
    - **What enabling technologies and policies are needed to address these?**
    - **What critical issues should we consider in beginning plans for 2010 and beyond?**

May others benefit from your lead.

Thank you