Smart Grids: Enable Stronger, Smarter and More Secure Electric Power and Energy Infrastructure

S. Massoud Amin, D.Sc.
umn.edu/~amin

Meeting of the Minds 2011
Panel on Smart Grids – How Far Away Are We From the Reality?
Friday, Sept. 23, 2011

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

TECHNOLOGICAL LEADERSHIP INSTITUTE
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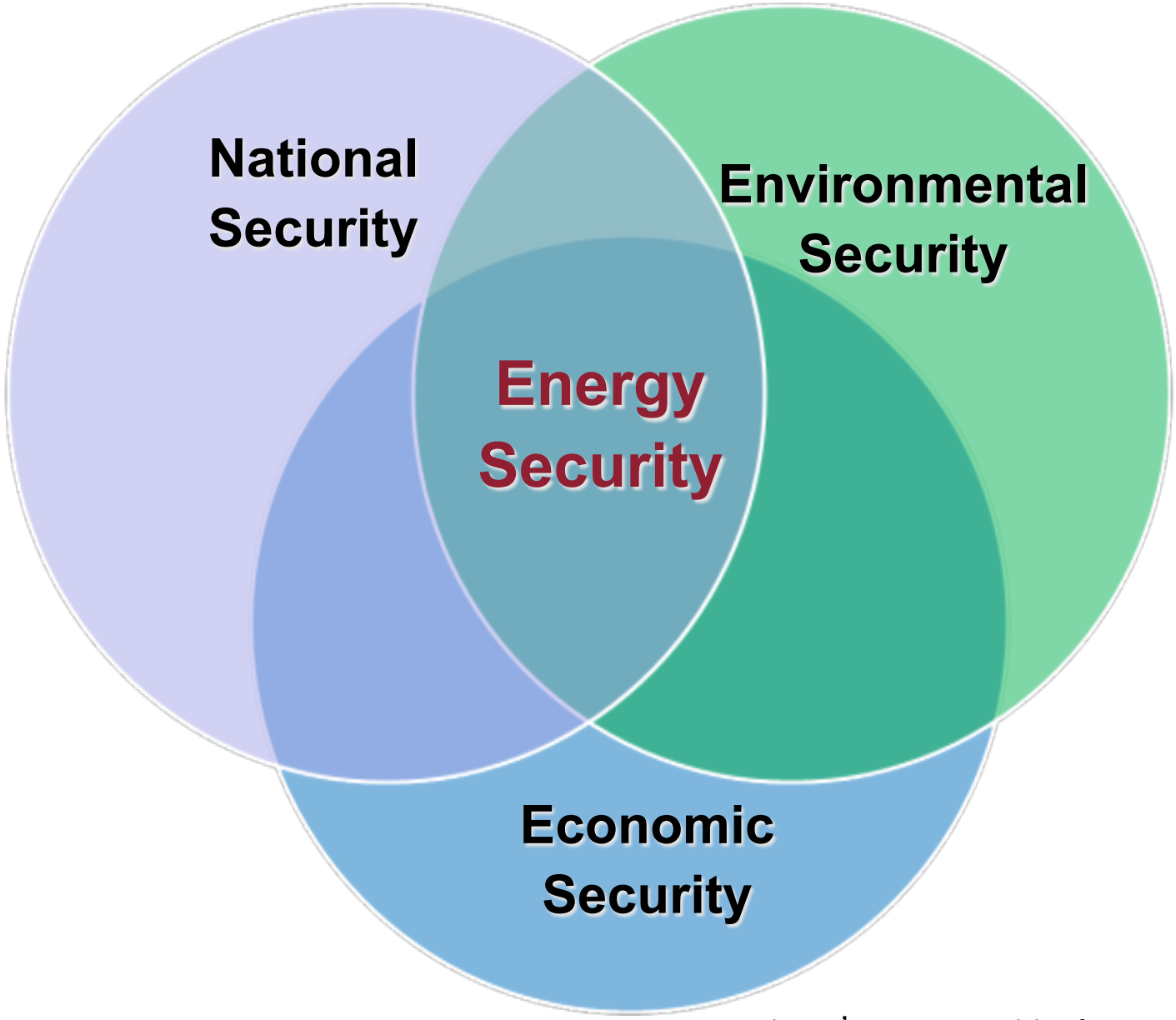
Mega Cities with 10 Million People:

Increasing demands/stress on lifeline Infrastructures

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

Note: * Mega city 10 million population or greater

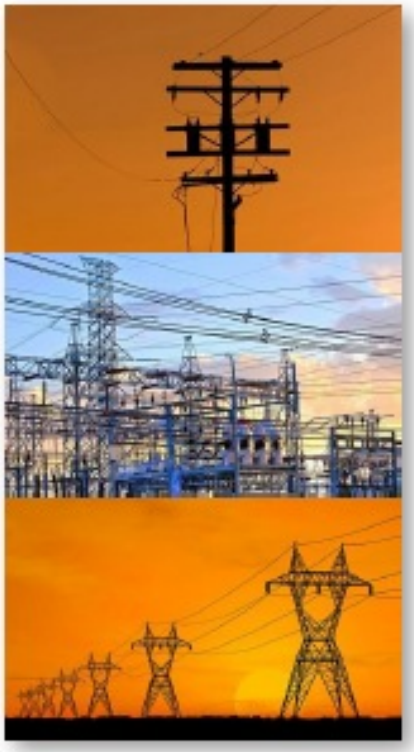
The Energy Crises Taught Us Interdependency



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

End-to-end Electric Power System

Generation

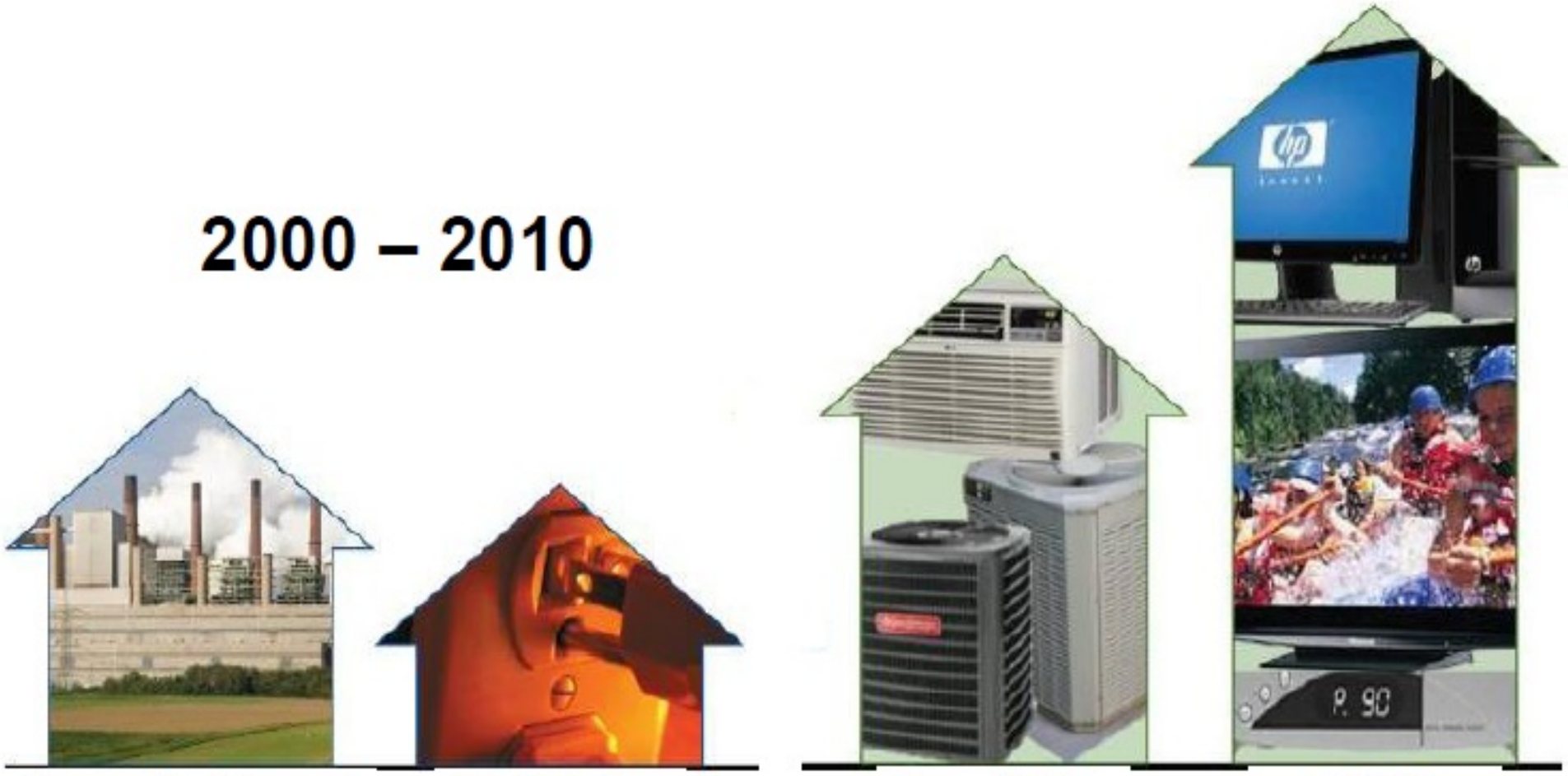


Delivery

Customer

Trends in Electricity Use (2000-2010)

Electronics and Continued Electrification Drive the Growth



Source: EPRI, 2011

Consumer Technology's Next Trend?

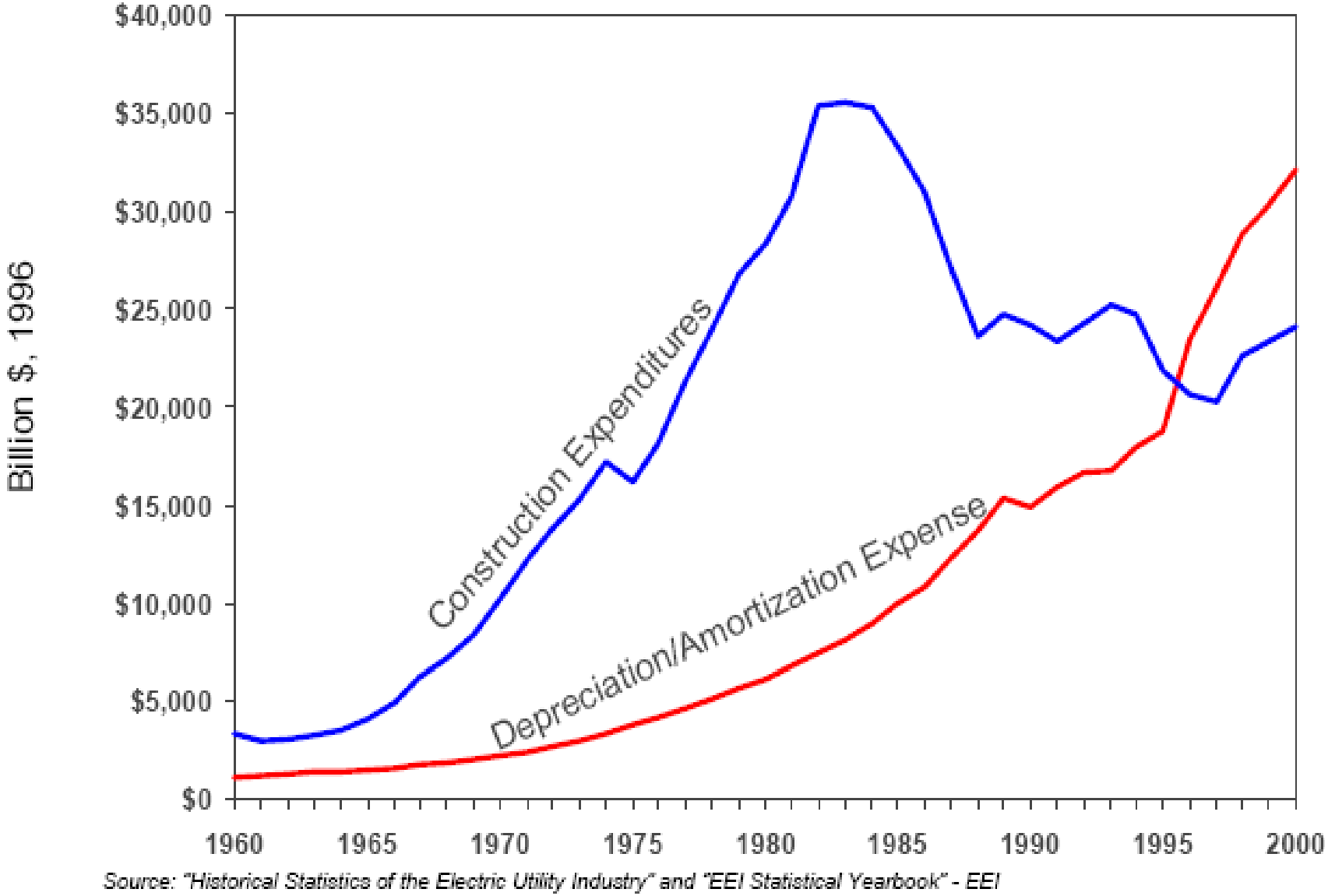
Digitization of Society…in its infancy

2011…one billion tweets sent every week!

At 0.025 watt-hours per tweet >>> 2500MWh

- **The Next "Industrial Revolution"…Data Centers**
  - Electric load expected to Double Every 5 Years…
  - By 2030 Could Reach 20% of Total U.S. Electricity Use
- How many watts used per iPhone, Smart Phone & Blackberry device?
- What infrastructure quality of service and security do we expect?

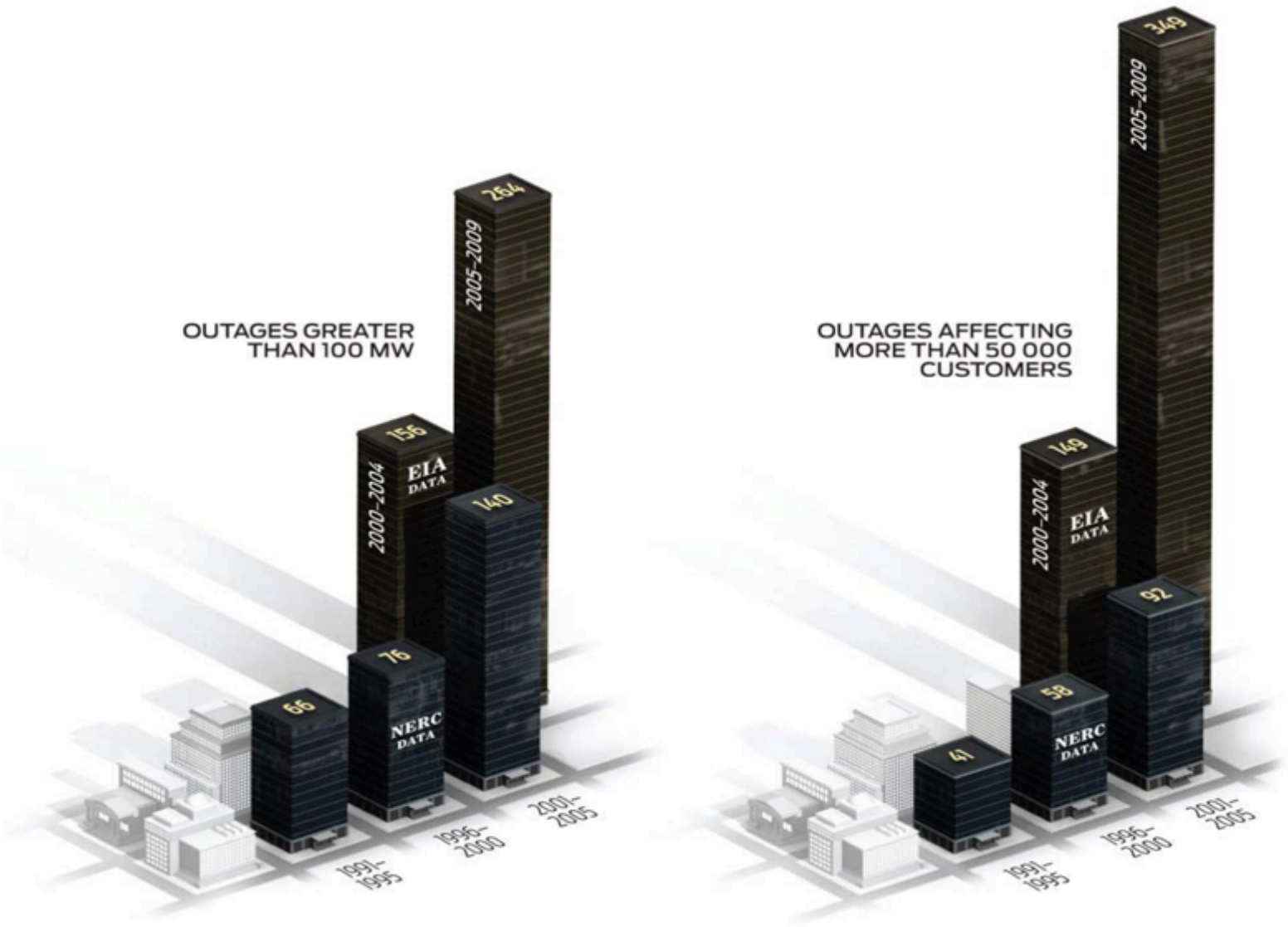
Utility Construction: Overharvesting



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

Less Reliable Grid

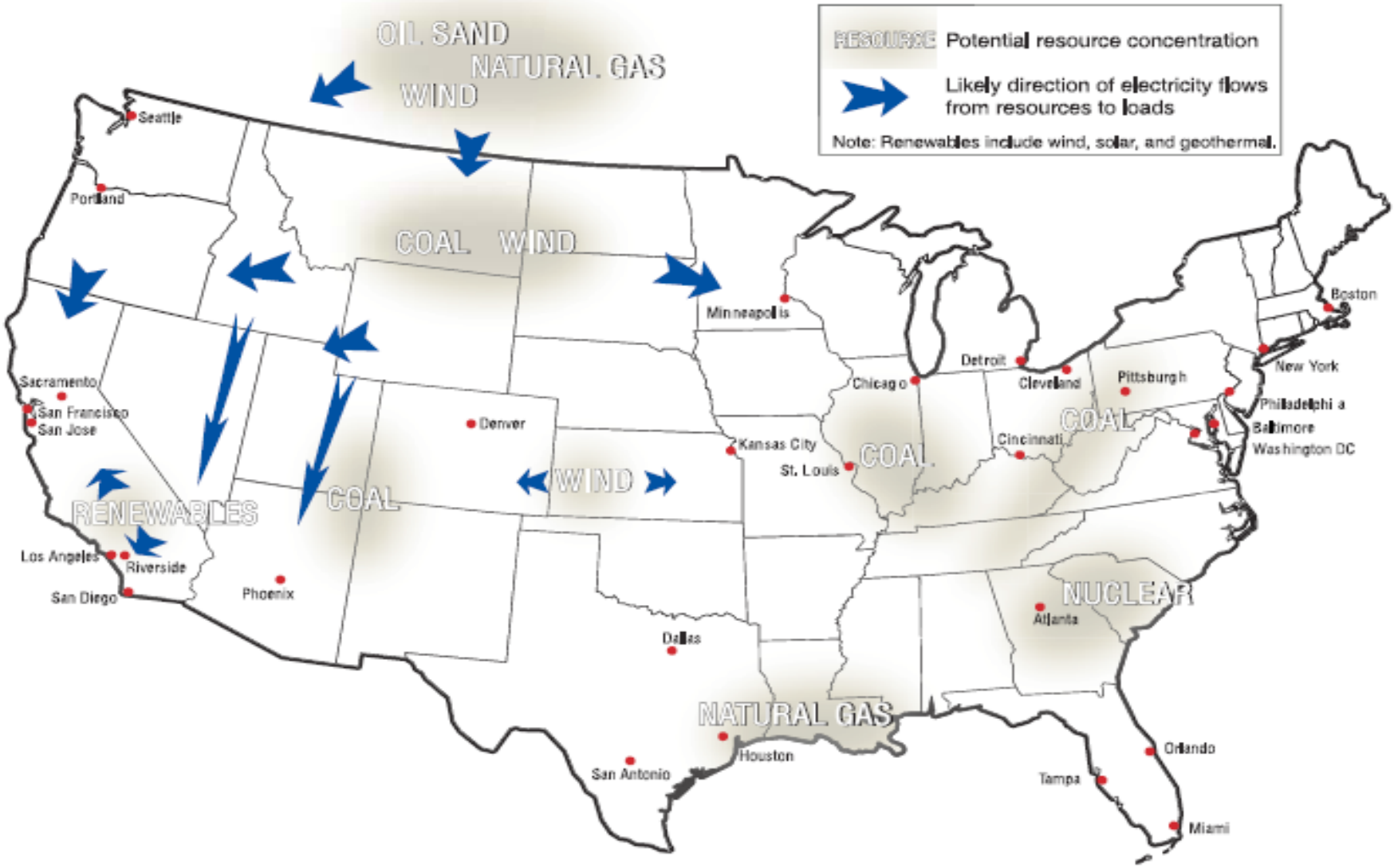
Power Outages have steadily increased



Source: Massoud Amin, "U.S. Electrical Grid Gets Less Reliable" IEEE Spectrum, January 2011

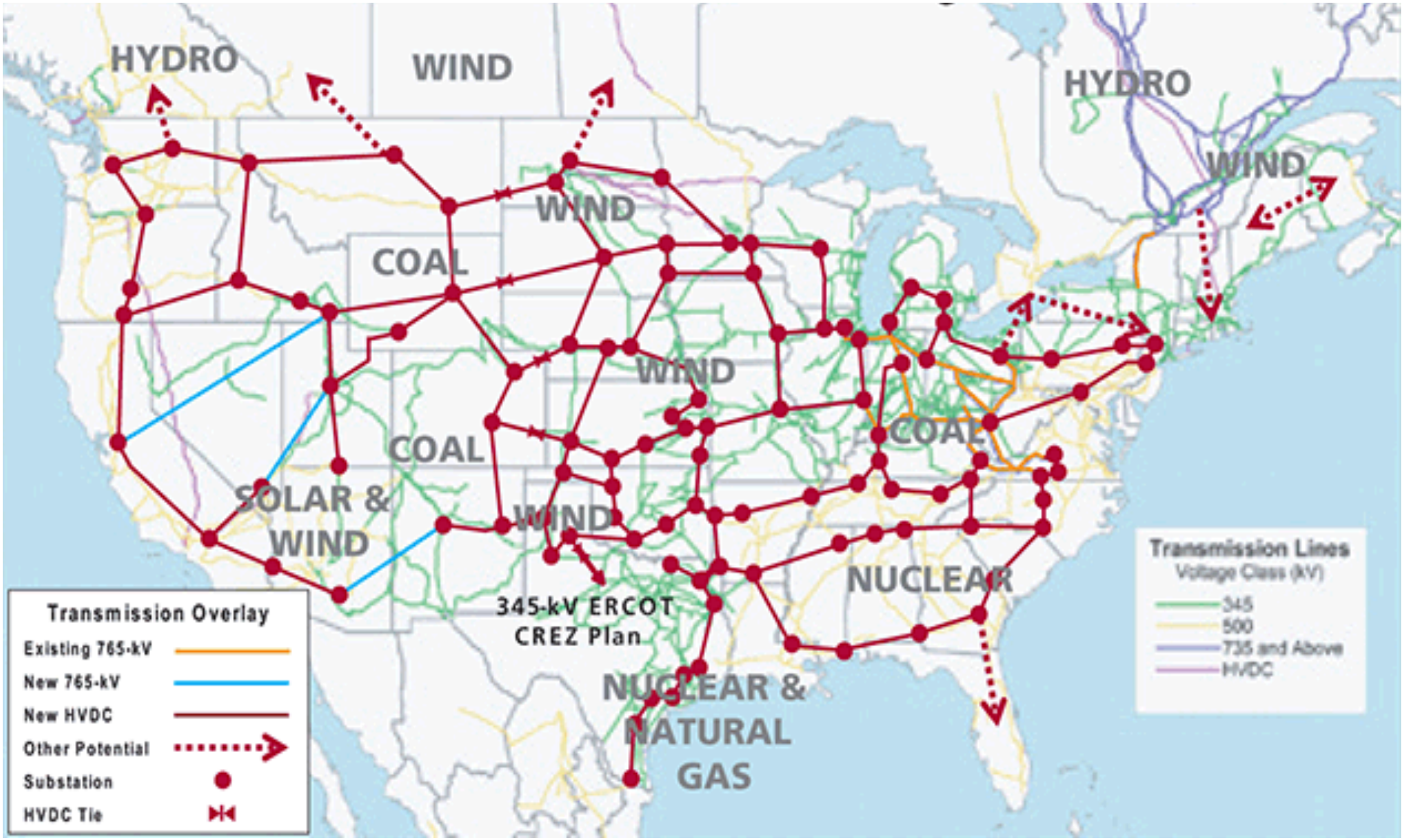
Emerging Supply and Demand Patterns

What is the most efficient carrier of energy? … electrons



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

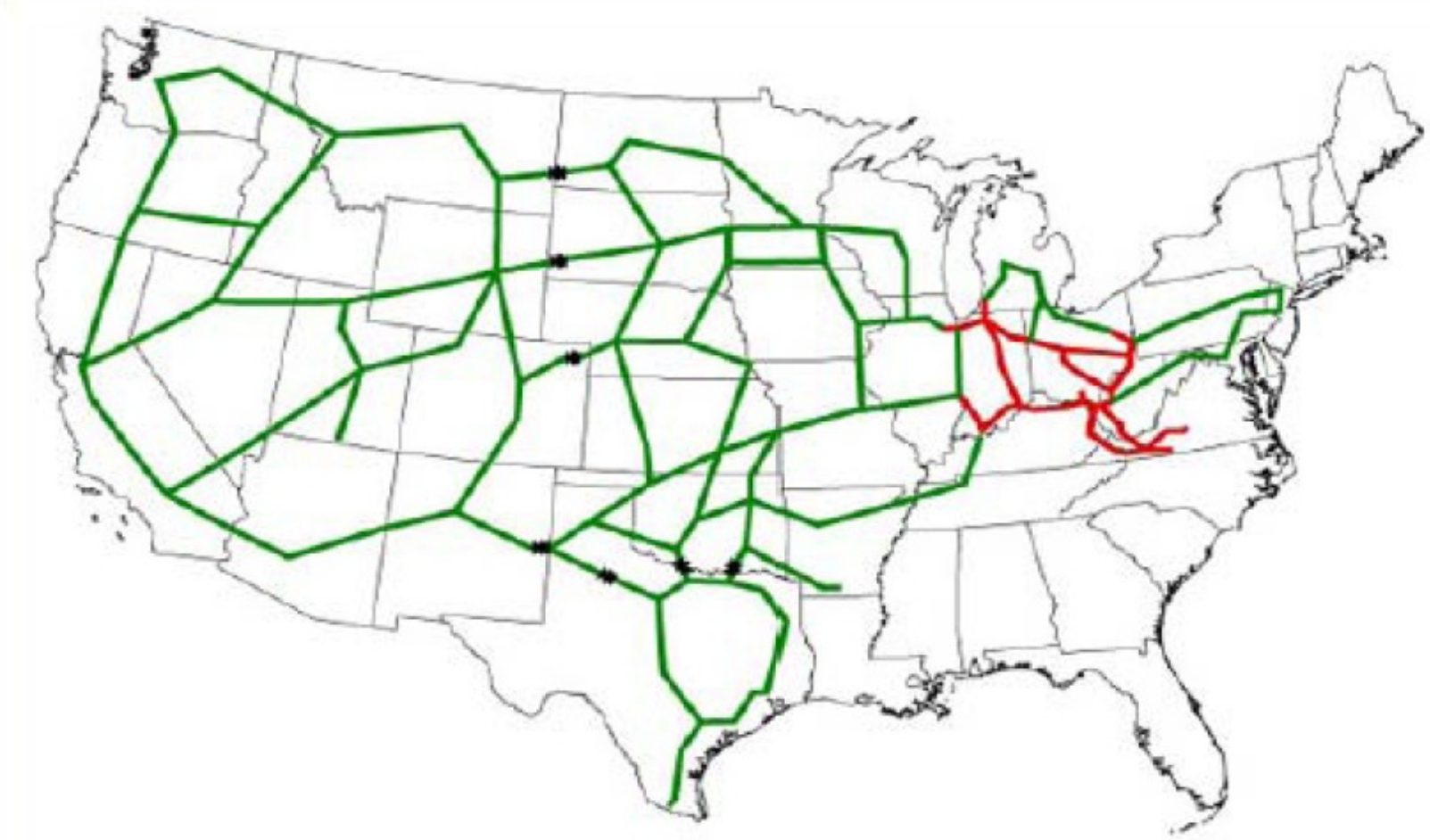
A Multi-layer Grid System in need of Strengthening and Protection



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

Stronger Grid

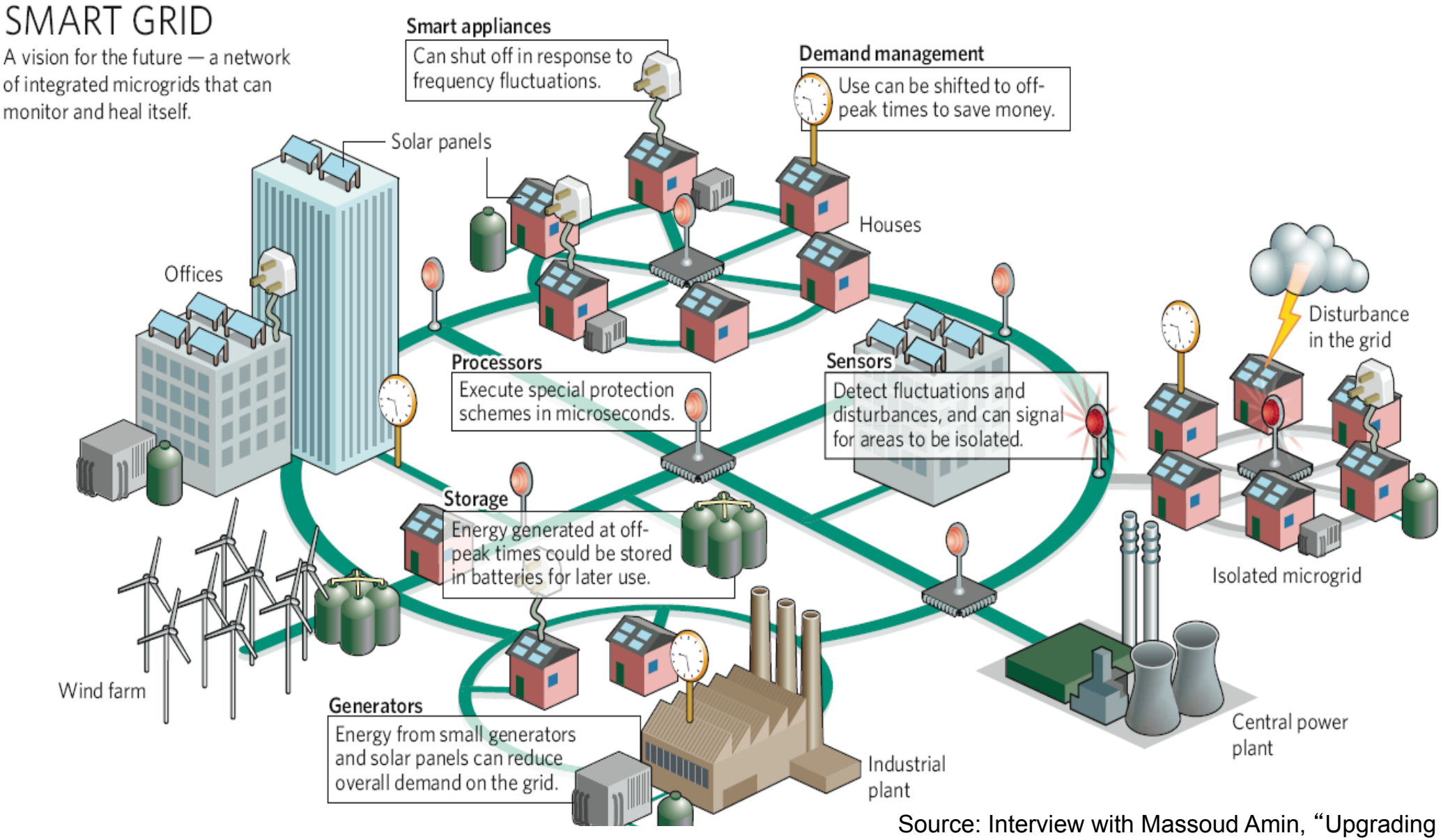
Transmission System Upgrade Assessments



New 765-kV lines are shown in green and new interties in black, complementing the existing 765-kV system shown in red, to facilitate deployment of up to 400 GW of additional wind capacity.

Sources: AEP 2007; DOE 2008

Integrate microgrids, diverse generation and storage resources into a smart self-healing grid system



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

Smart Grid Definitions

FERC: *"Grid advancements will apply digital technologies to the grid and enable real-time coordination of information from both generating plants and demand-side resources."*

DOE: *"A smarter grid applies technologies, tools, and techniques available now to bring knowledge to power – knowledge capable of making the grid work far more efficiently…"*

GE: *"The Smart Grid is in essence the marriage of information technology and process-automation technology with our existing electrical networks."*

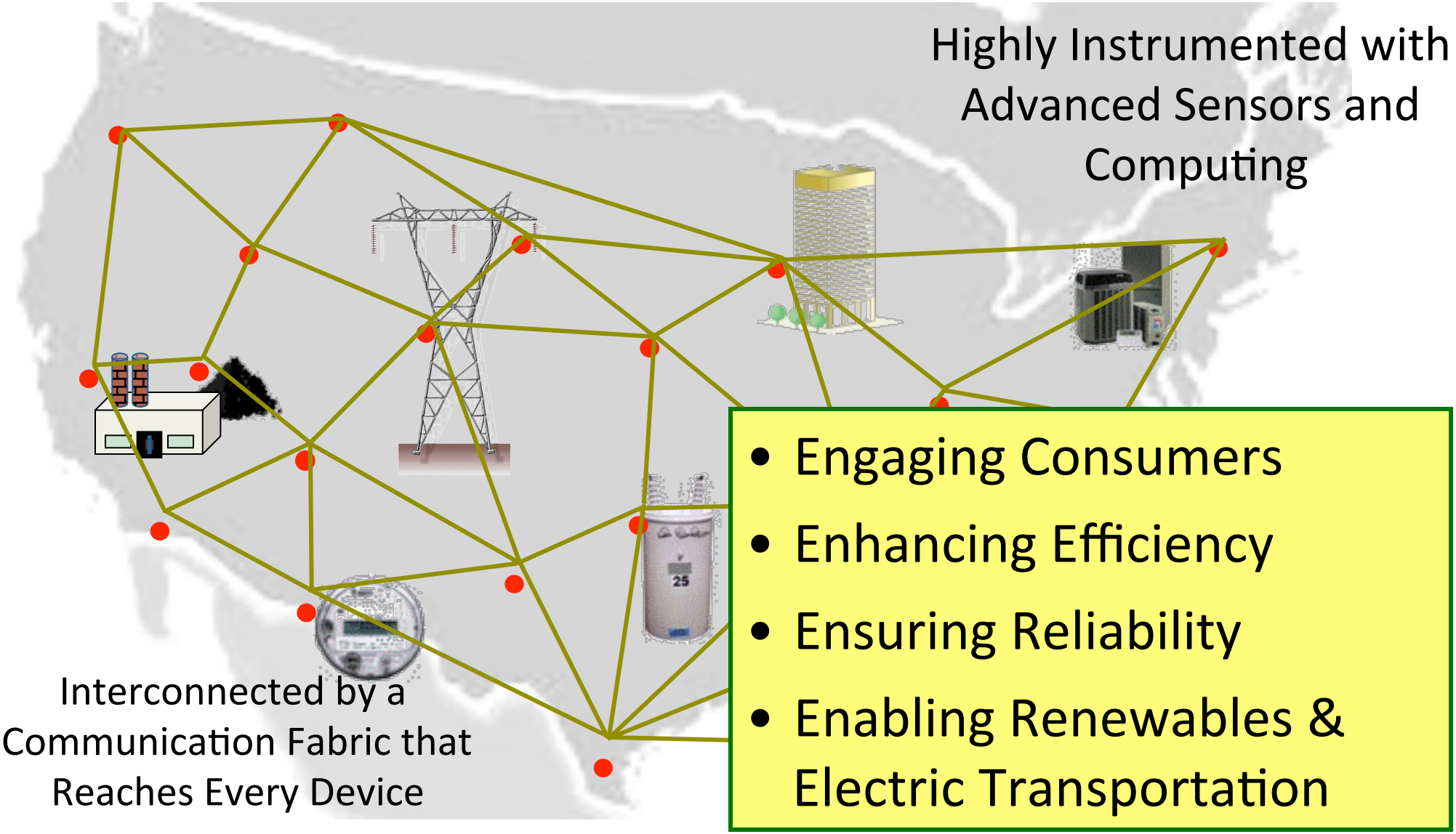
IEEE: *"The term 'Smart Grid' represents a vision for a digital upgrade of distribution and transmission grids both to optimize current operations and to open up new markets for alternative energy production."*

Wikipedia: *"A Smart Grid delivers electricity from suppliers to consumers using digital technology to save energy, reduce cost, and increase reliability."*

Functionality Common themes:	***Technology***	***Reliability***	***Efficiency***
	Two-way communication	***Interconnectivity***	***Demand response***
	Advanced sensors	***Renewable integration***	***Consumer savings***
	Distributed computing	***Distributed generation***	***Reduced emissions***

Many Definitions – But One VISION

Visualizing the Smart Grid

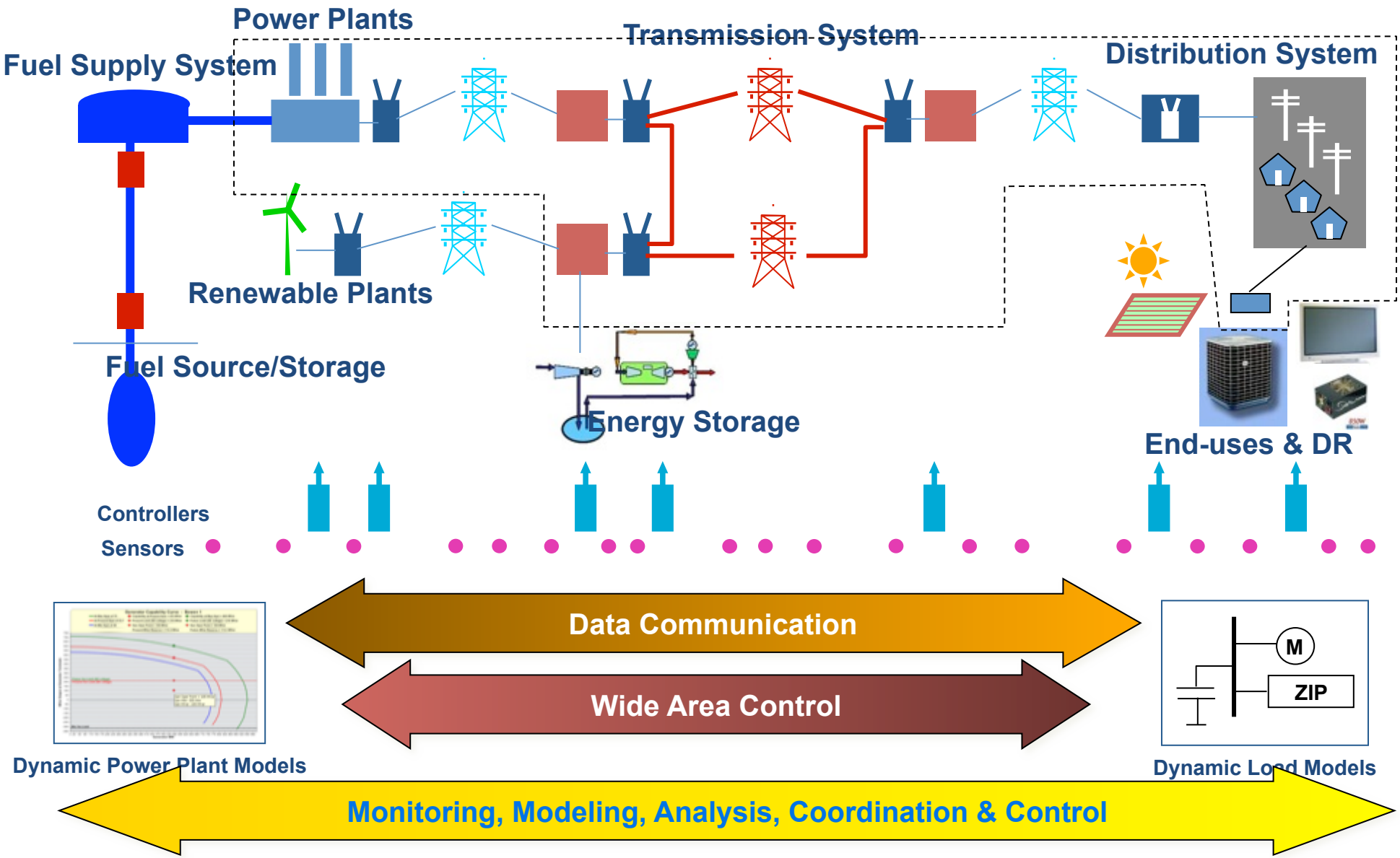


Highly Instrumented with Advanced Sensors and Computing

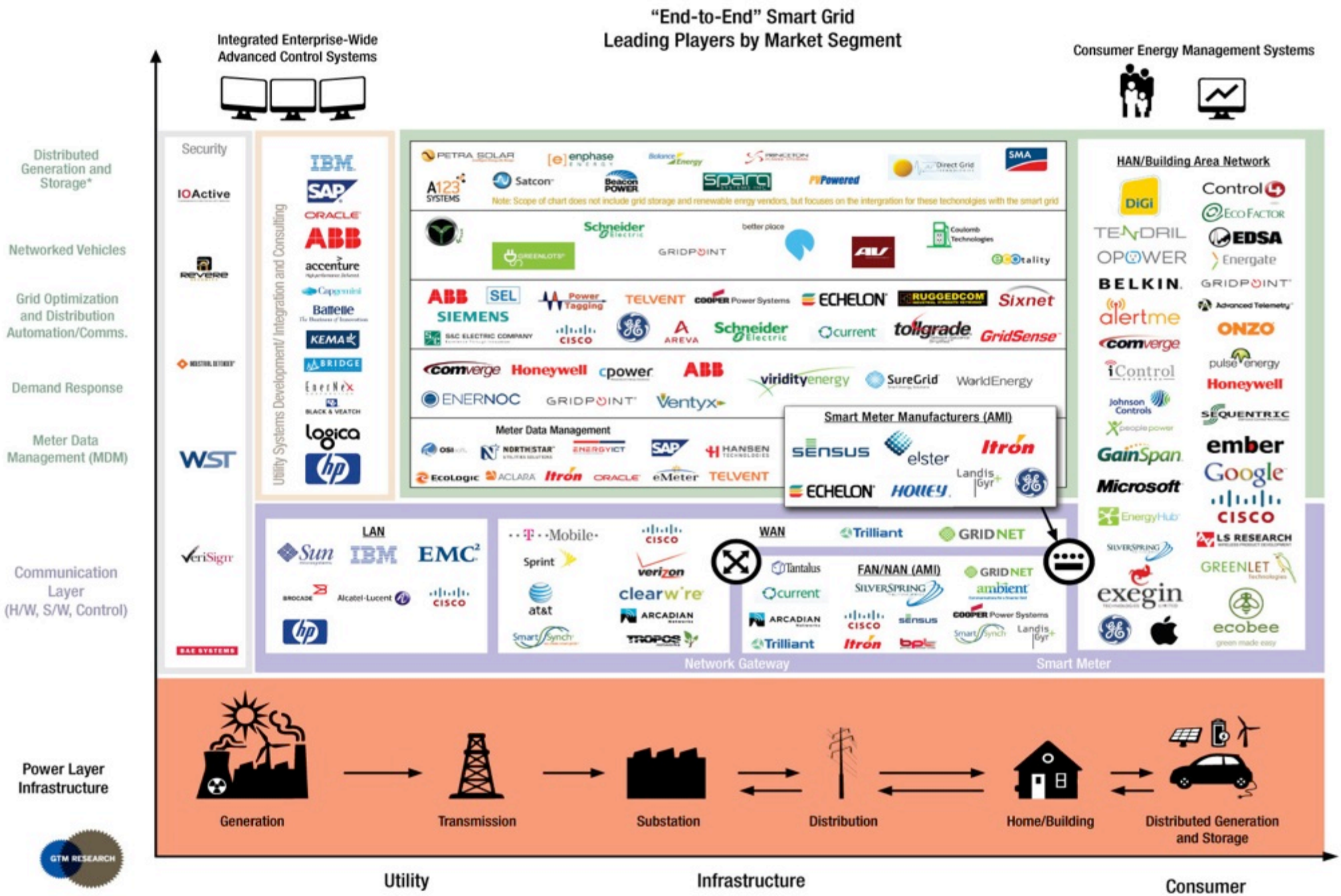
Interconnected by a Communication Fabric that Reaches Every Device

- Engaging Consumers
- Enhancing Efficiency
- Ensuring Reliability
- Enabling Renewables & Electric Transportation

End-to-End Power Delivery Operation & Planning



End-to-End Smart Grid Players/Opportunities



Investments in Smart Grid Technologies

- Factors that boost SG investment and technology in the short term:
  - Analytics: Mining data to increase understanding
  - Standards consolidation
  - Increasing penetration of solar and electric vehicles: Demand shifts, integrate new tools and technologies.

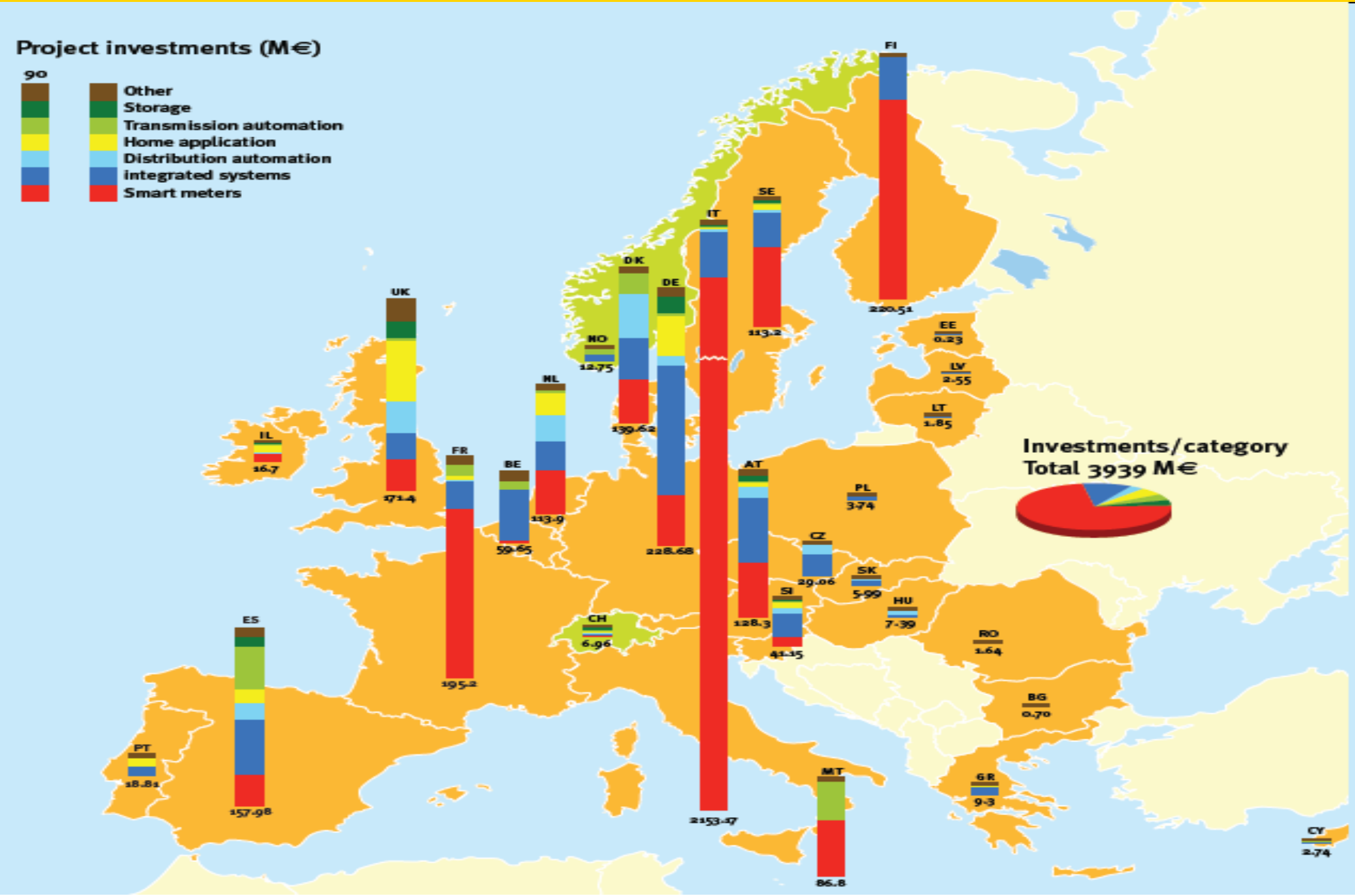
- Emerging markets could leapfrog other nations:
  - **U.S.** investment is at about $7 billion in smart grid technologies

  - **China** invested $7.3 billion; will spend $96 billion in smart grid technology by 2020
    - China's energy needs to double by 2020
    - Many changes will happen in the homes themselves:
    - China will account for 18.2% of global smart grid appliance spending by 2015.

  - **South Korea** at nearly $1 billion:
    - A $65 million pilot program on Jeju Island is implementing a fully integrated grid for 6,000 homes, a series of wind farms and four distribution lines. Its leaders plan to implement smart grids nationwide by 2030.

  - **Brazil**: 60% growth in electricity consumption between 2007 and 2017 with 16-34% increase in renewables from hydro, biomass and wind. But they have an aging grid that is currently a one-way power flow that needs to move in two directions.

Example: Smart Grid projects in Europe

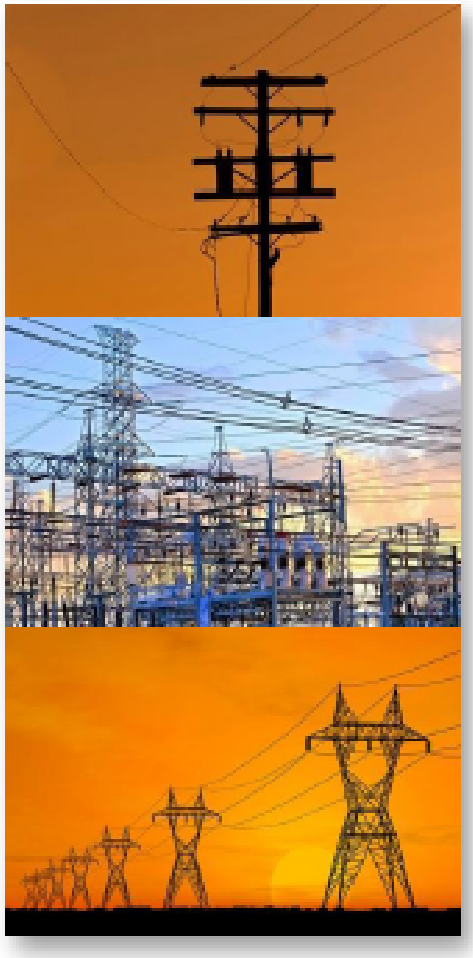


Smart Grid: Technological Innovations

Customer

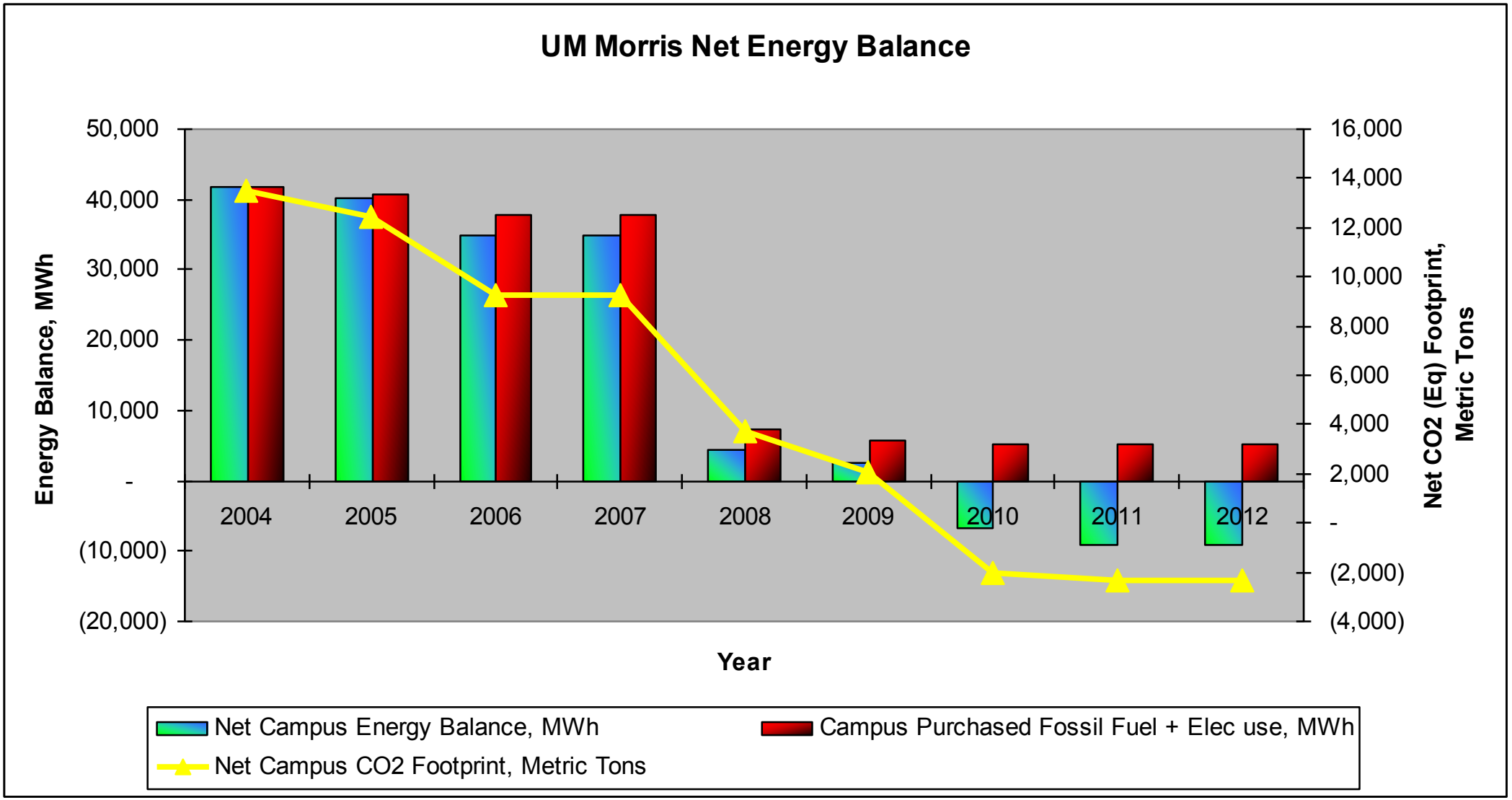
- Smart Appliances
- Electric Vehicles
- Energy Efficiency
- Demand Response
- Distributed Energy Resources

Smart Grid and Power Delivery



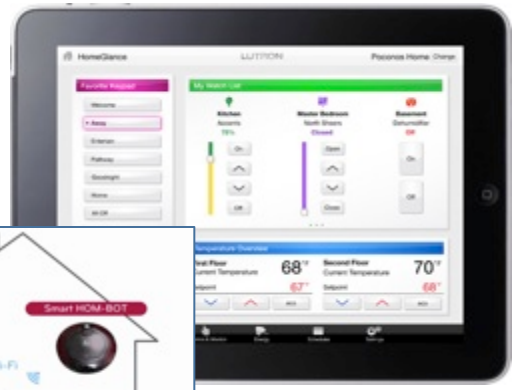
- Intelligent Sensors, Communication and Analysis
- Increase and Flexible Power Flow
- Secure From Cyber and Physical Attack

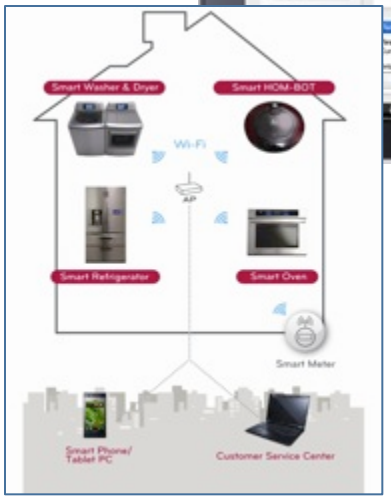
Going Carbon Negative…



Smart Grid Technologies for Homes at UMore Park

- Photovoltaic inverters
- Smart meters, in-home displays
- Grid-ready appliances
- Electric vehicle power charging station
- Battery storage backup
- Estimated costs: $10,670 to $27,190 per home





Smart Grids: Awareness, Costs and Benefits

Awareness:

- ~68% of consumers in the U.S. don't know what "Smart Grid" is…

Costs:

- $17-$24 billion/yr ($338 and $476 billion)

Benefits:

- Increases efficiency by 5% ($20.4 billion in savings annually)
- Reduces costs of outages by about $49 billion per year
- Reduces emissions by 12-18%
- Economic growth: Benefits could be as high as $2.3 trillion for the U.S.
- Our $14 trillion economy depends on reliable, disturbance-free electricity

The Emerging Smart Grid or Energy Web:

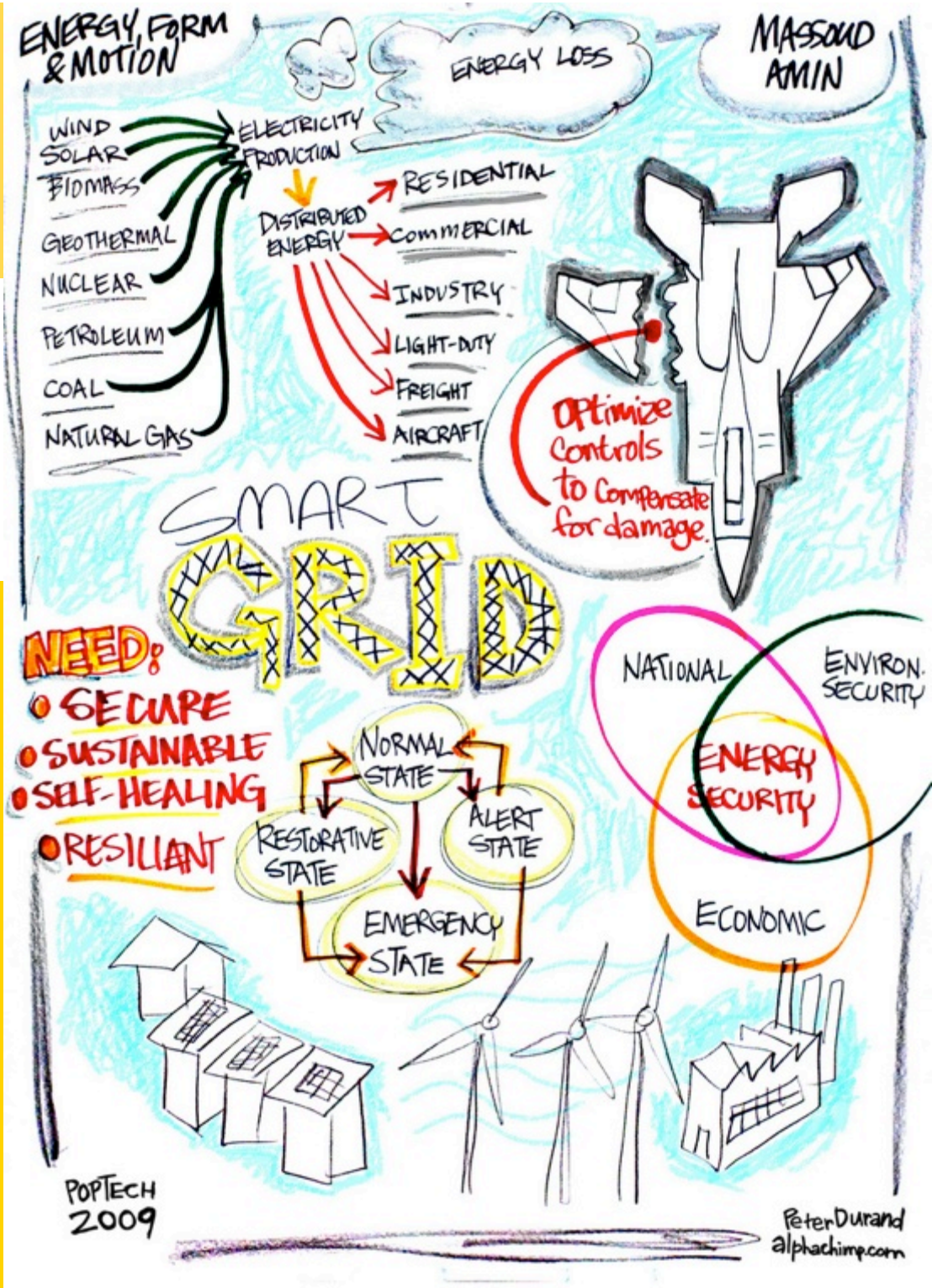
A Complex Adaptive Infrastructure System

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

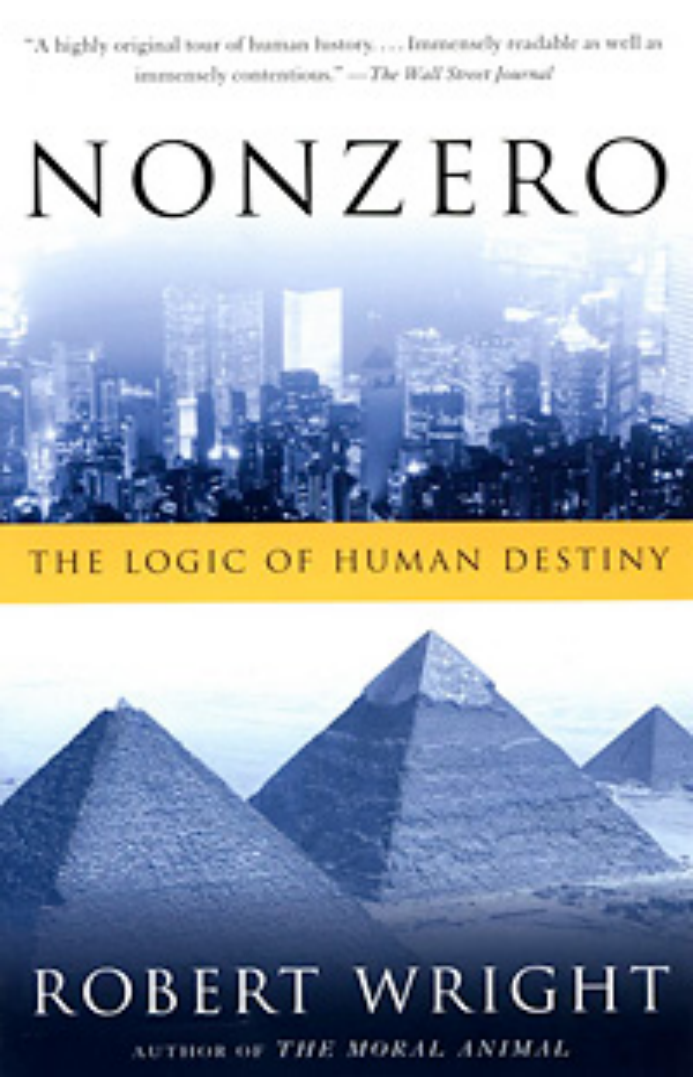
"The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming and interconnected with everything else."

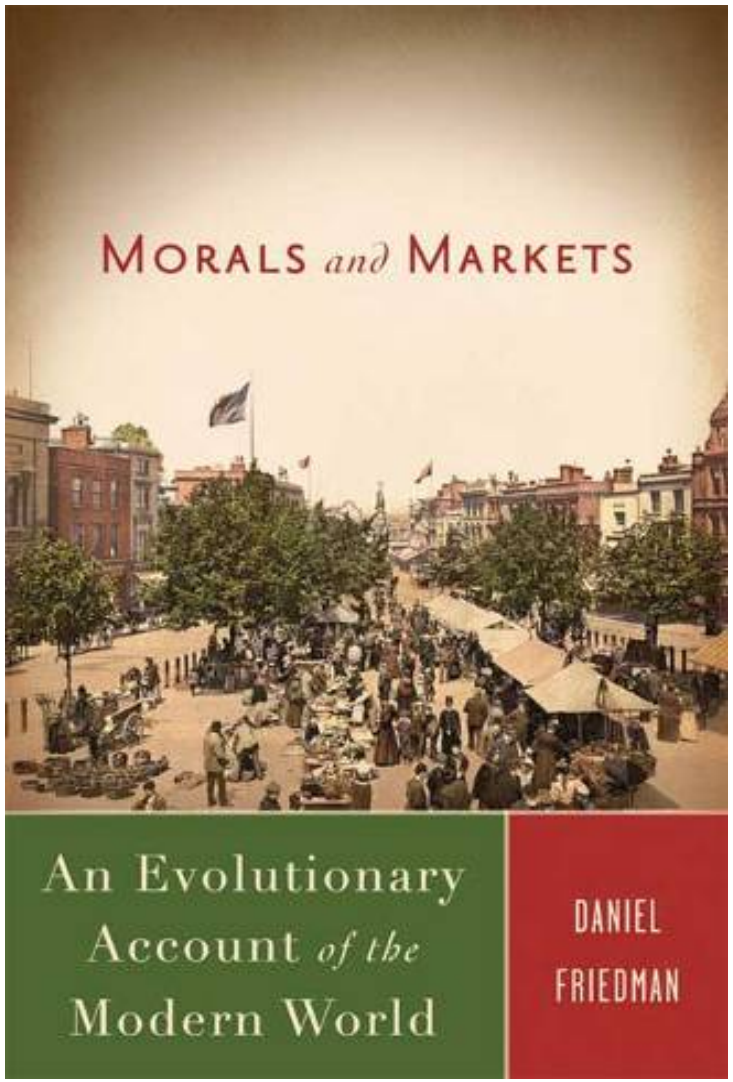
-- Wired Magazine, July 2001

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



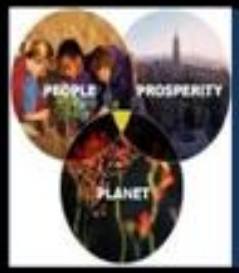
Cities are just the right scale for smart technologies to enable diverse value creation





Source: IBM, please also see Paul Romer's Charter Cities Video: http://www.ted.com/talks/paul_romer.html

Smart Grid Goals



Sustainable Electrical Power

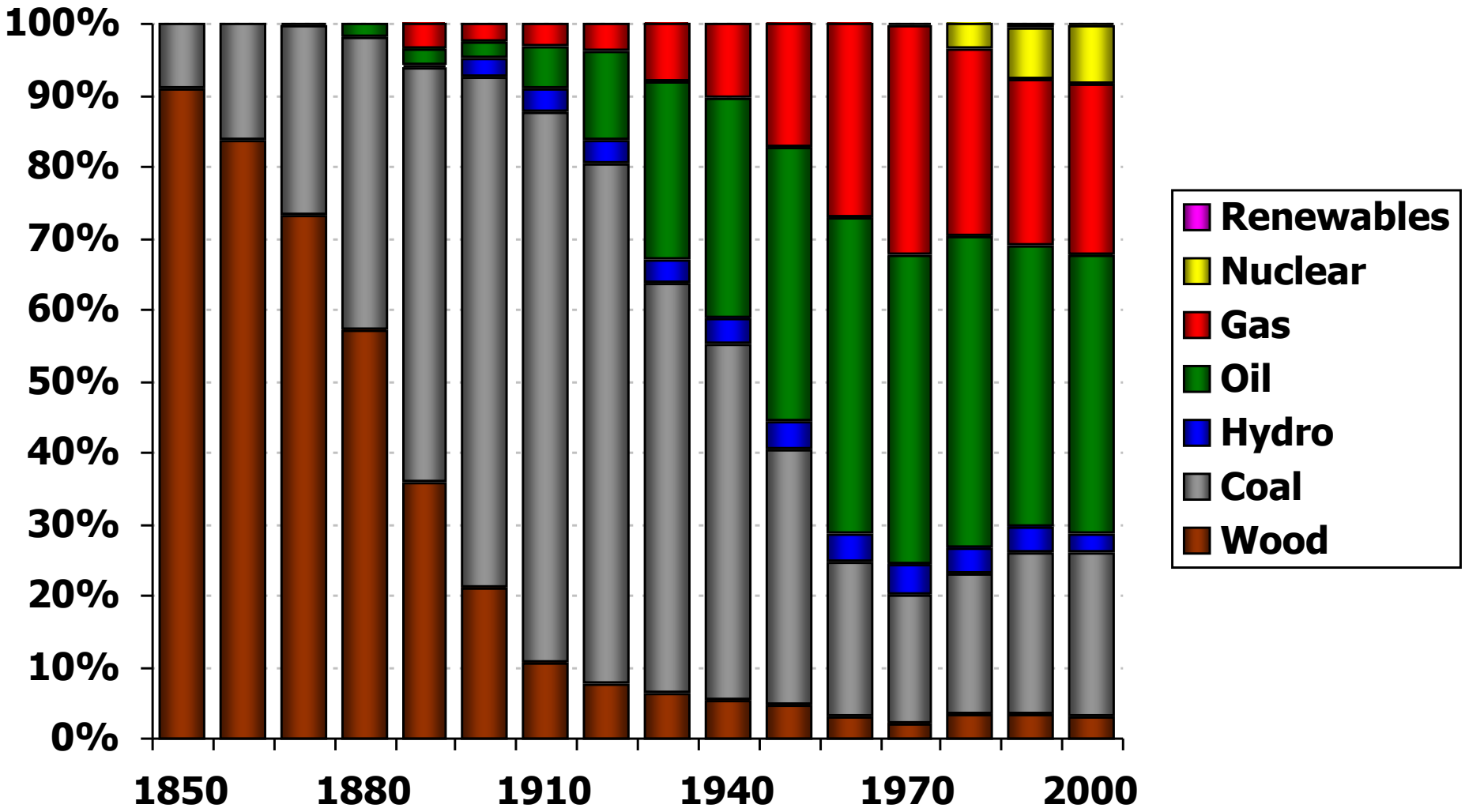
M. Amin, Chairman, IEEE Smart Grid Newsletter http://smartgrid.ieee.org/publications/smart-grid-newsletter


THANK YOU
MINNESOTA

Appendix

How did we get here?

Context: US Energy Supply Since 1850



Author: Koonin Source: EIA

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

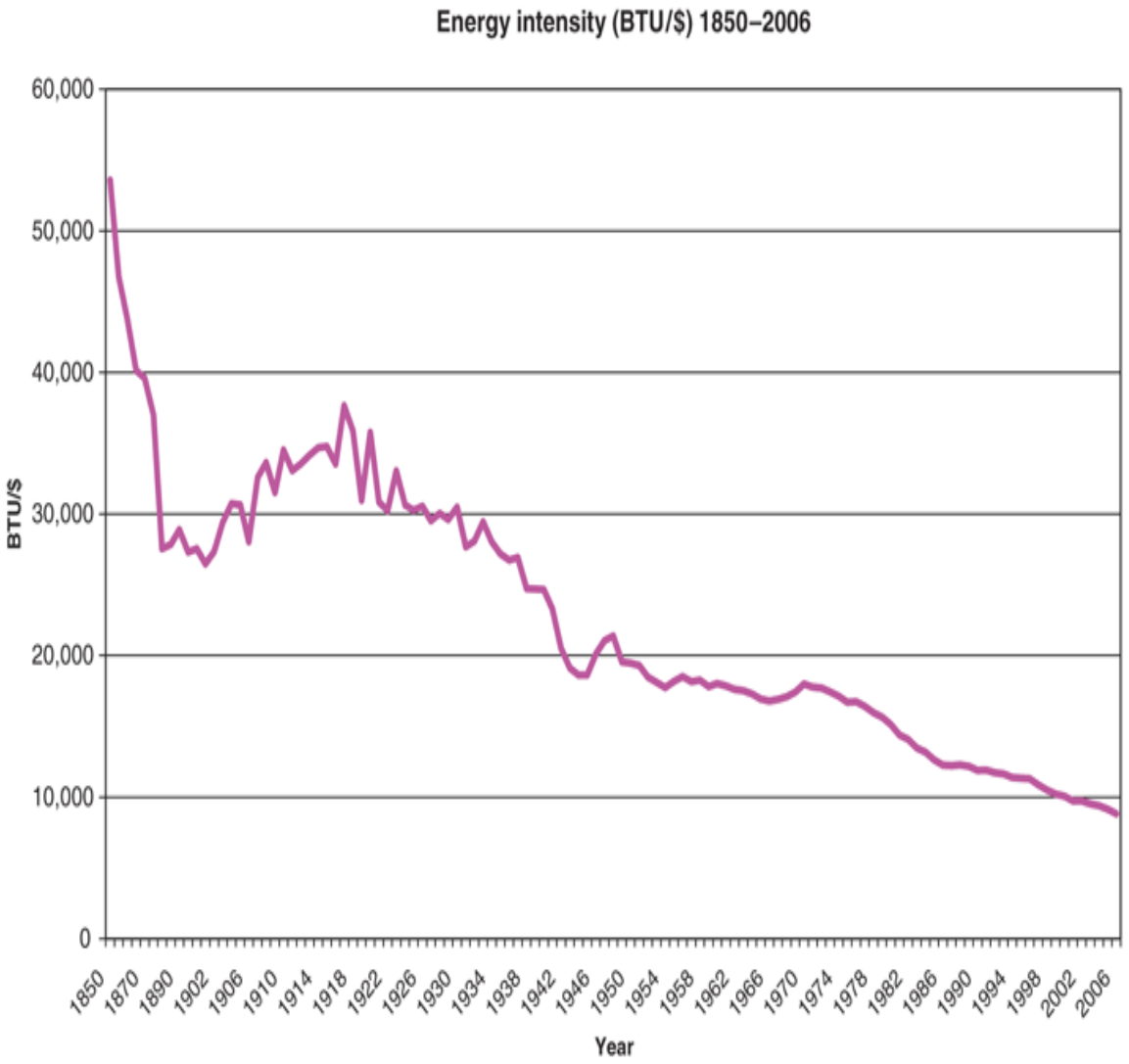
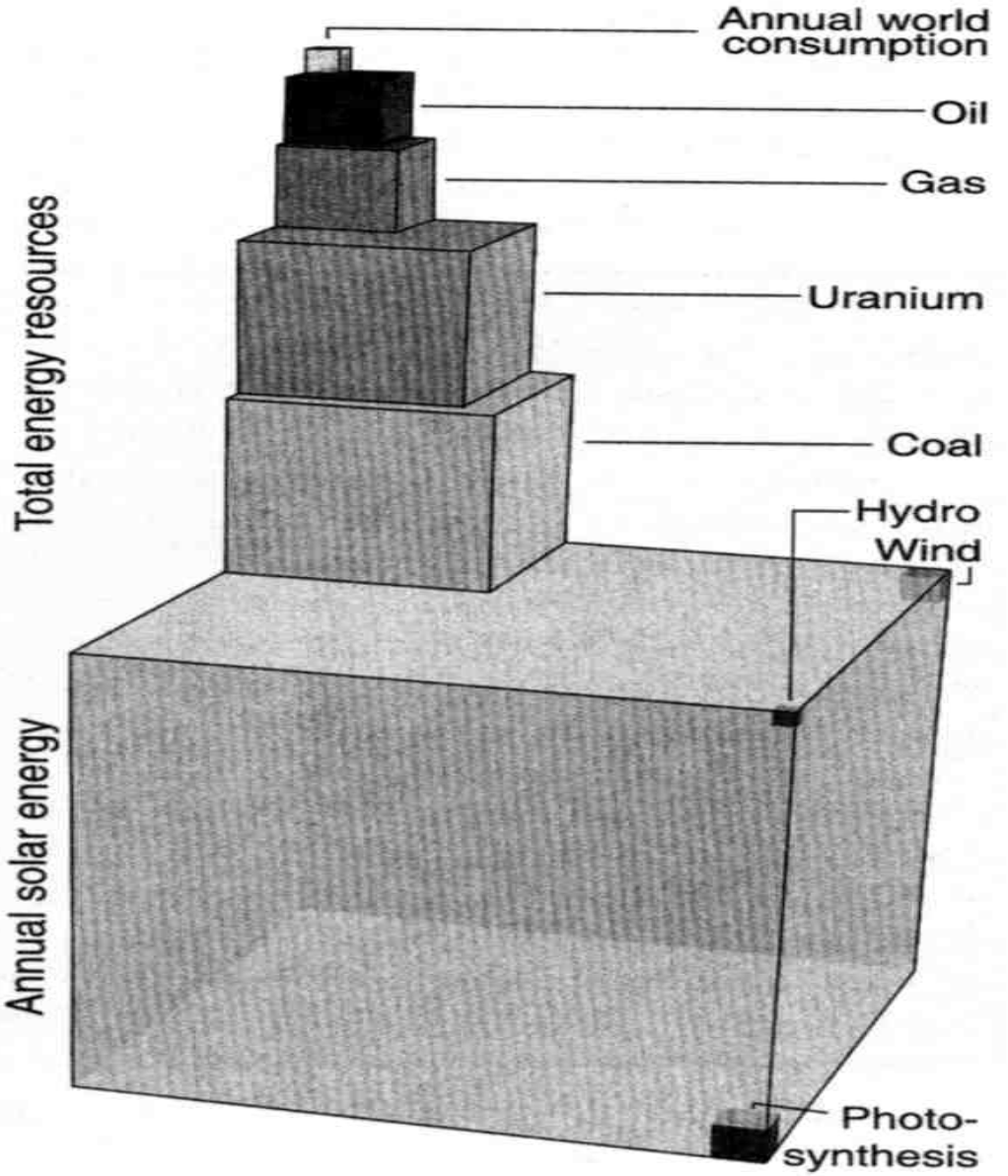


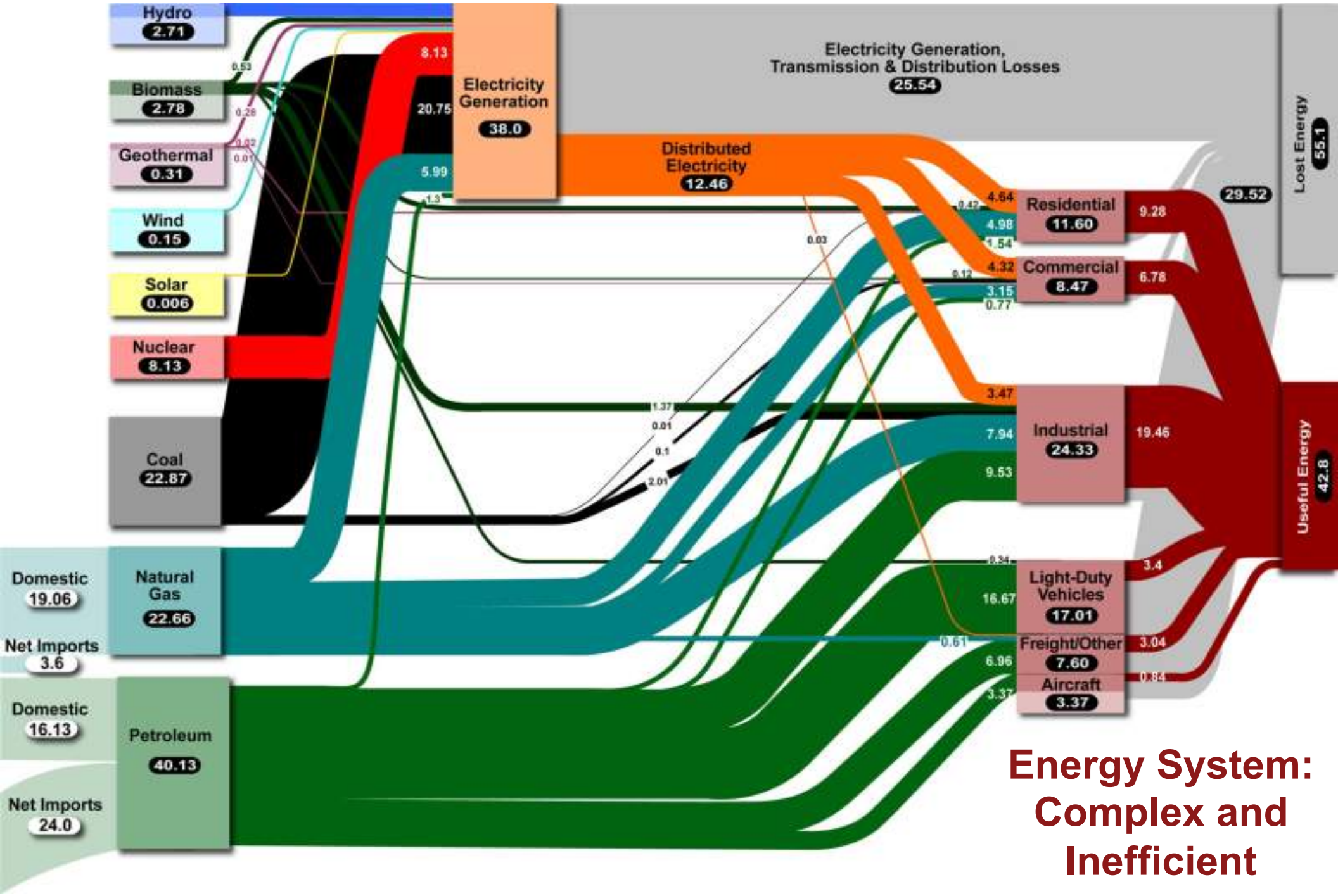
TABLE 1 Energy Use in 2005—Per Capita and Per Dollar of GDP

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

Source: EIA, 2009b,c.

Long Term Choices: Solar and Nuclear

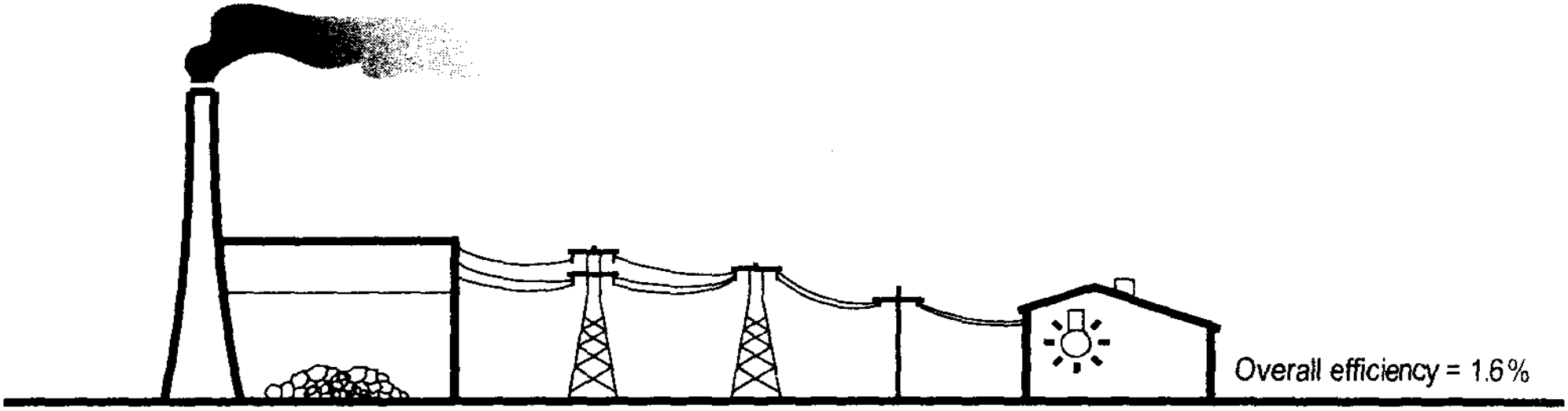




Energy System: Complex and Inefficient

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

End-to-End Energy Inefficiency
Losses as high as 98.4%



Fuel = Coal	Power Plant	Transmission Lines	Light
$E_0 = 1.00$	$E_1 = 0.35$	$E_2 = 0.90$	$E_3 = 0.05$

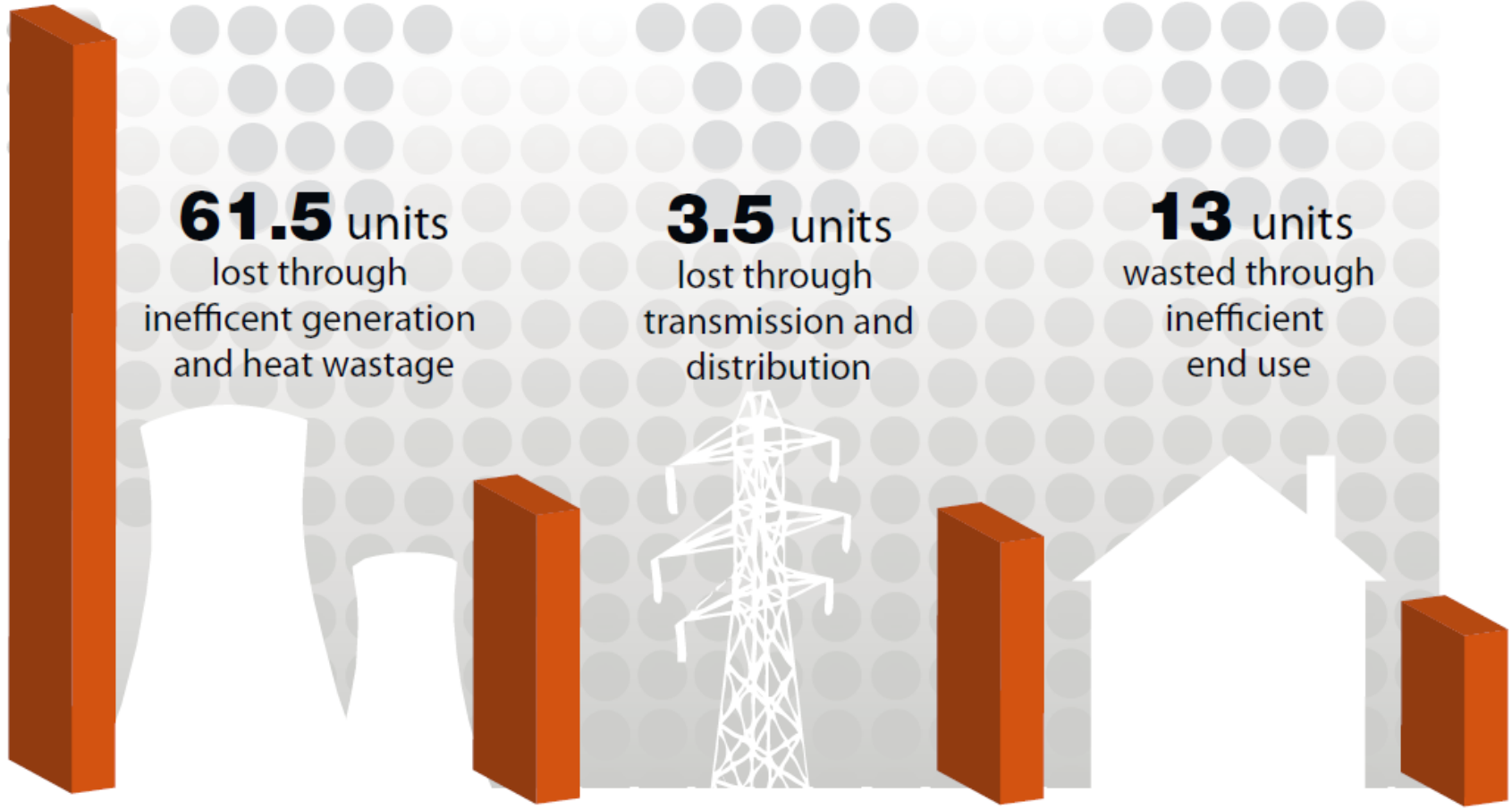
Overall Efficiency for Converting Chemical Energy To Light Energy = $E_1 \times E_2 \times E_3 = 0.35 \times 0.90 \times 0.05 = 0.016$

Opportunities to improve the situation:

- Use more efficient power plants, energy storage, modern transmission systems
- Use co-generation plants where useful (electricity and heat or desalination)
- Upgrade efficiency of use (change to many times more efficient LED or fluorescent lamps)

Source: NRC, 2009

End-to-End Energy Inefficiency



100 units
energy within fossil fuel

61.5 units
lost through inefficent generation and heat wastage

38.5 units
fed to National Grid

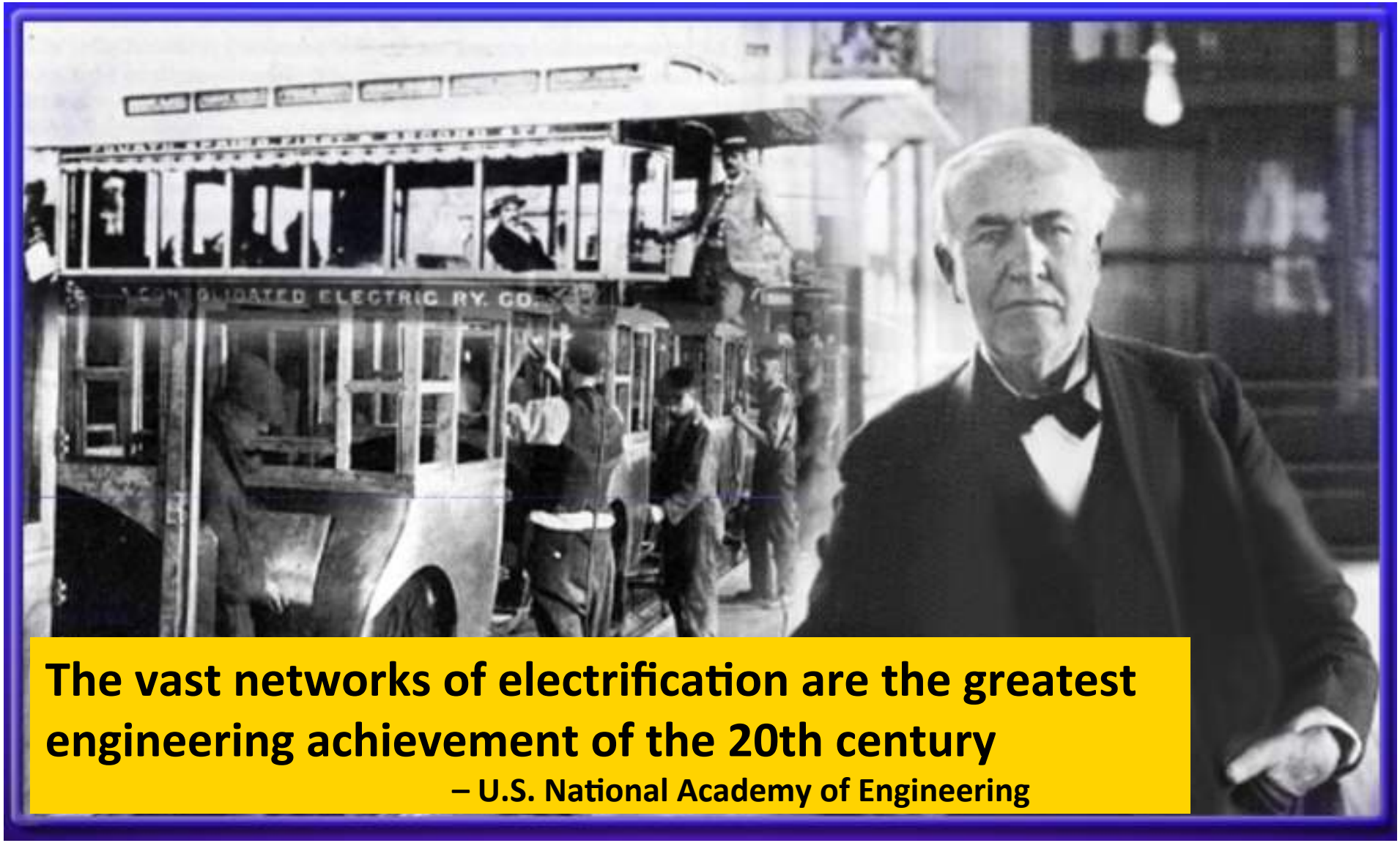
3.5 units
lost through transmission and distribution

35 units
of energy supplied

13 units
wasted through inefficient end use

22 units
of energy actively utilised

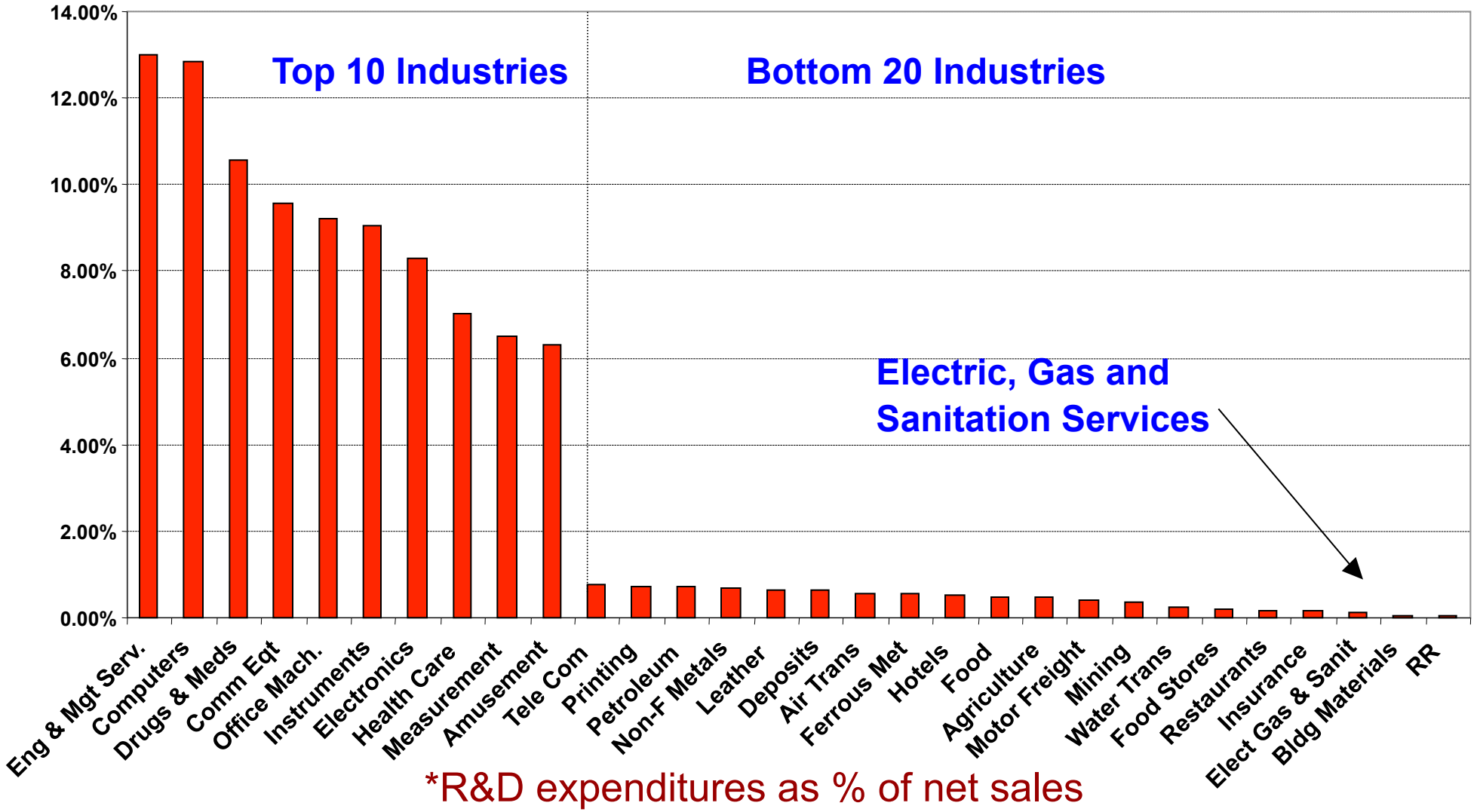
Context: Transforming Society



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

– U.S. National Academy of Engineering

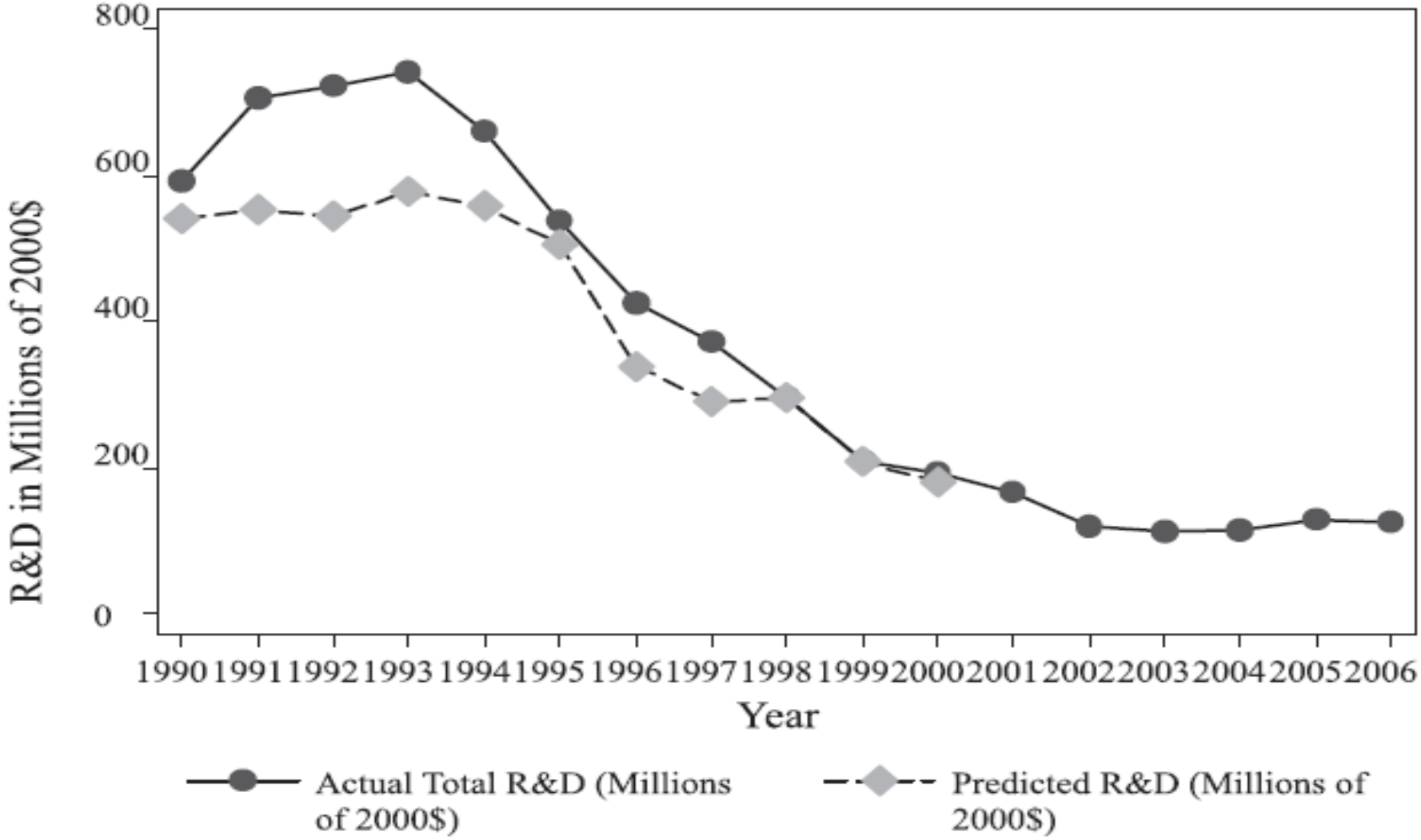
Context: R&D Expenditures*



*R&D expenditures as % of net sales

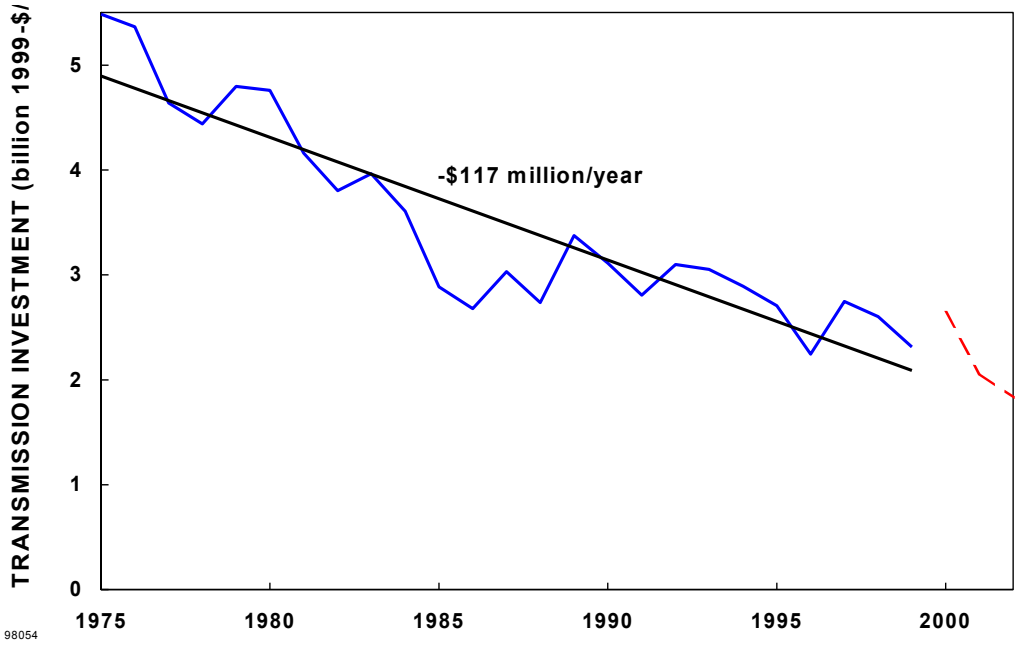
U.S. Electric Utilities R&D: 1990-2006

Annual R&D is the lowest rates of any major industrial sector with the exception of the pulp and paper

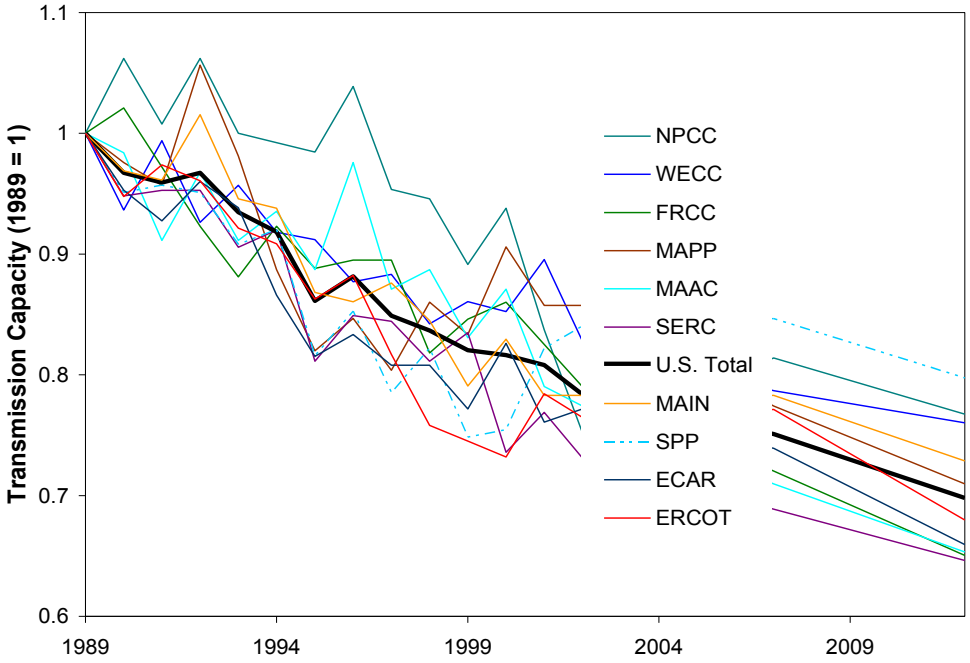


Source: "Powering Progress: Restructuring, Competition, and R&D in the U.S. Electric Utility Industry," by *Paroma Sanyal and Linda Cohen, The Energy Journal*, Vol. 30, No. 2, 2009

Increasing Outage Events: Transmission Investment



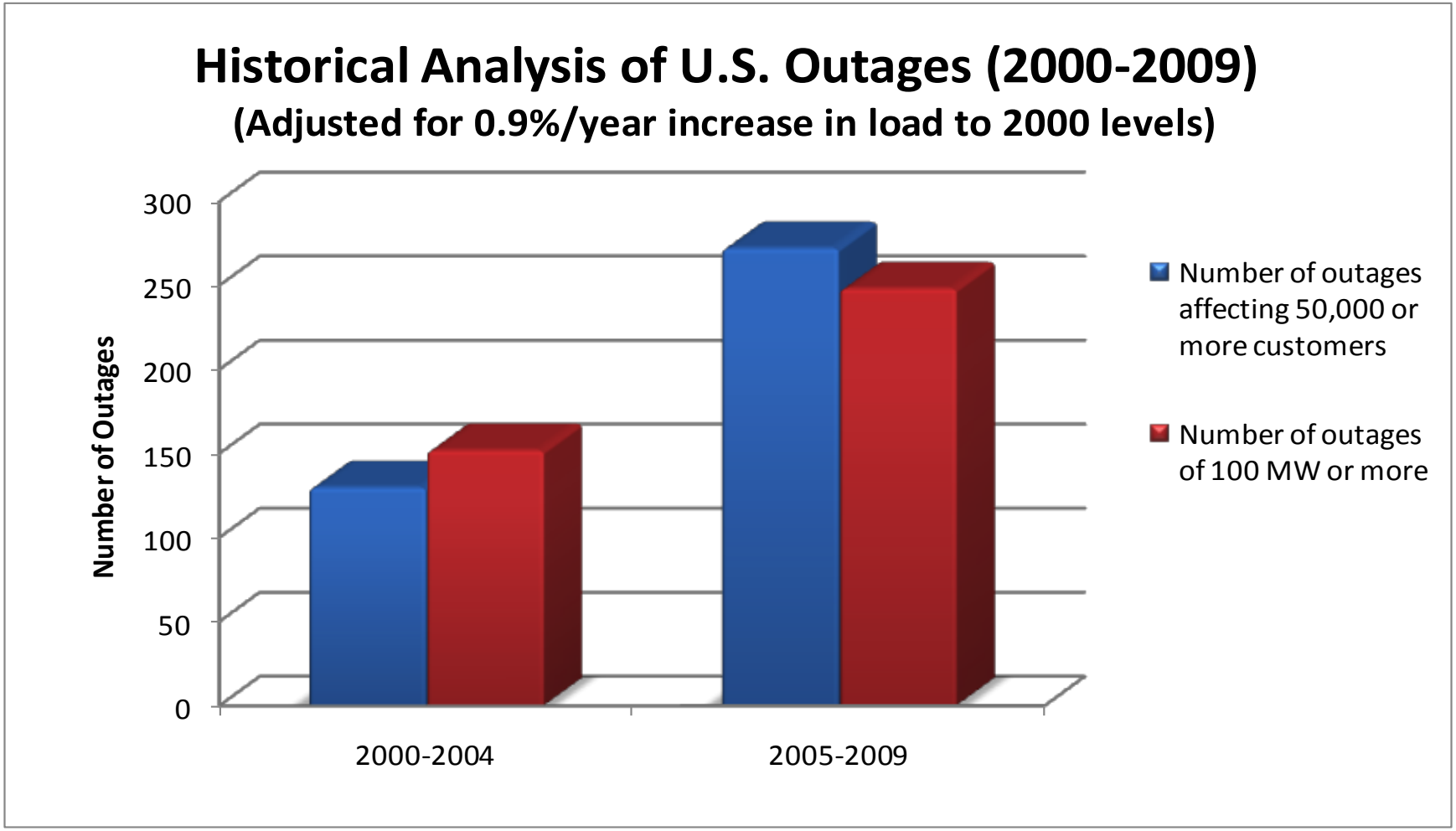
Transmission *investment* ($) since 1975



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.

U.S. Electric Power Outages over 100MW and affecting over 50,000 Consumers (2000-2009), adjusted 0.9% annual load increase



	Occurrences of 100MW or more	> 50,000 consumers
2000-2004	152	130
2005-2009	248	272

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

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

Source: IEEE PES

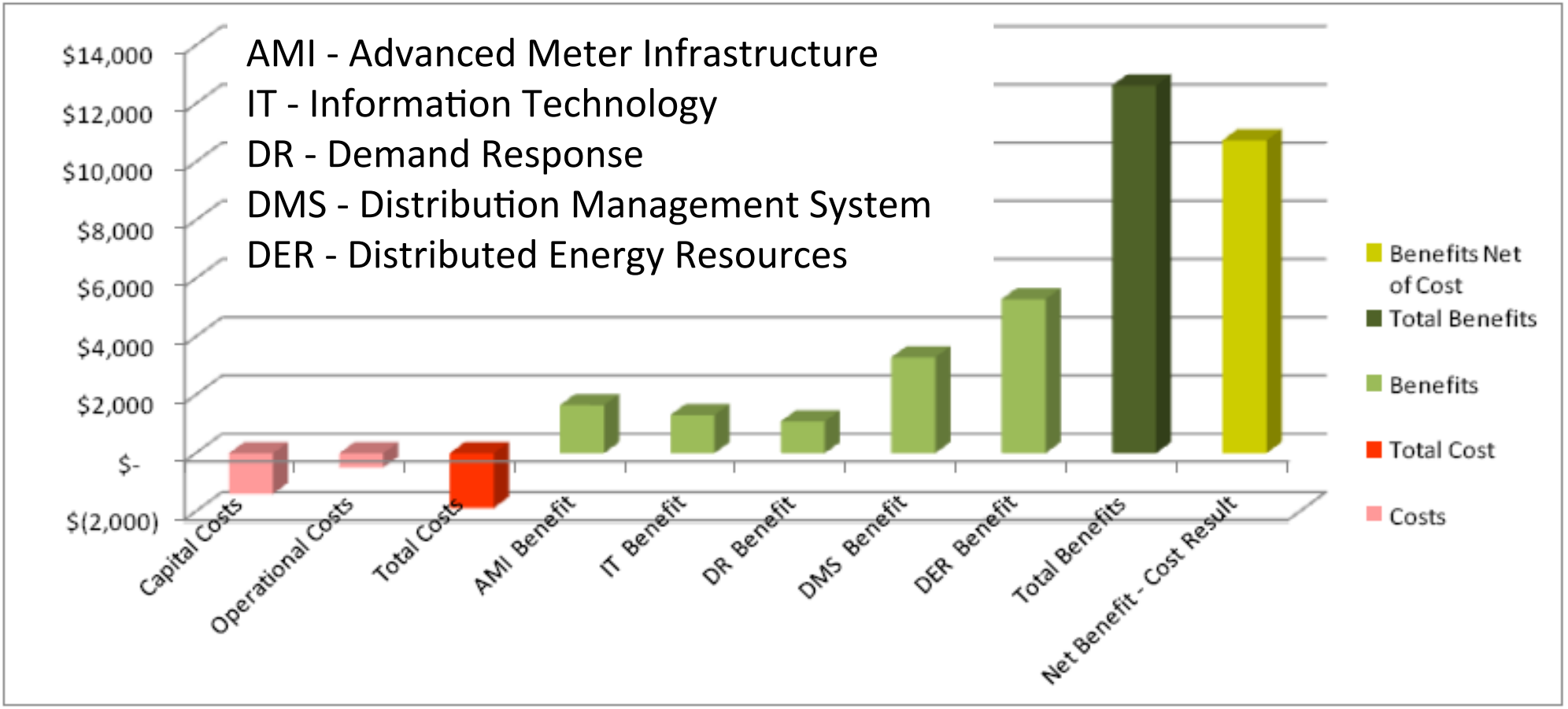
Integrate Dispersed Energy Sources into a Modern Grid to Provide Energy to Centers of Demand

Recommendations for moving to energy systems to meet demand of tomorrow

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

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

West Virginia Business Case



Source: National Energy Technology Laboratory

What are we doing at the UofM?

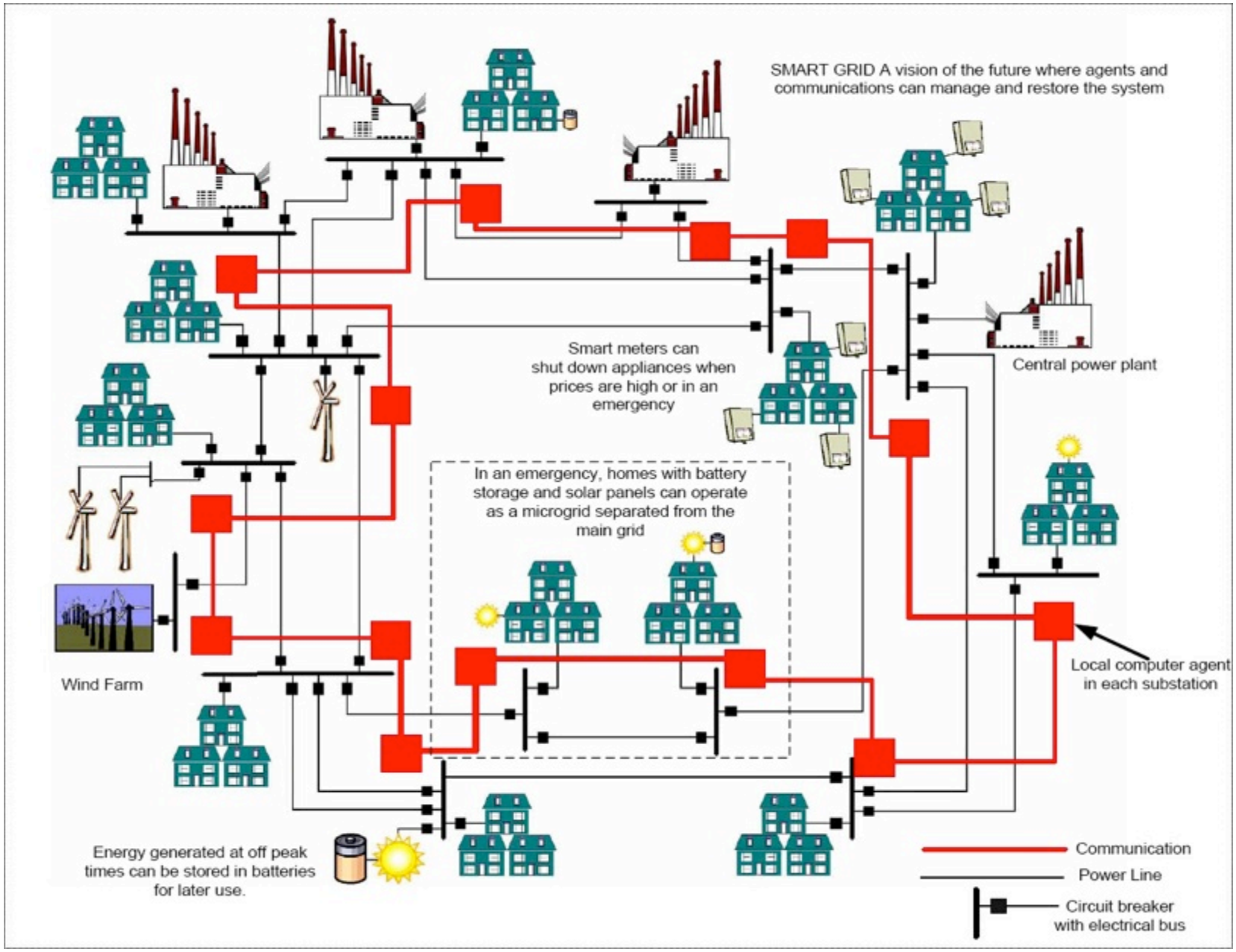
What are we working on at the U of Minnesota ?

- Integrating PHEVs into the grid
- Grid agents as smart and distributed computer
- Fast power grid simulation and risk assessment
- More Secure and Smarter Grid
- Security of cyber-physical infrastructure

University of Minnesota Center for Smart Grid Technologies (2003-present)
Dept. of Electrical & Computer Engineering
Faculty: Professors Massoud Amin and Bruce Wollenberg
PhD Candidates/Research Assistants: Anthony Giacomoni, Jessie Gantz Laurie Miller, and Sara Mullen (PhD received 9/9, EPRI-Knoxville)
PI: M. Amin (support from EPRI, NSF, Honeywell, SNL, ORNL, and UofM start-up research funding)

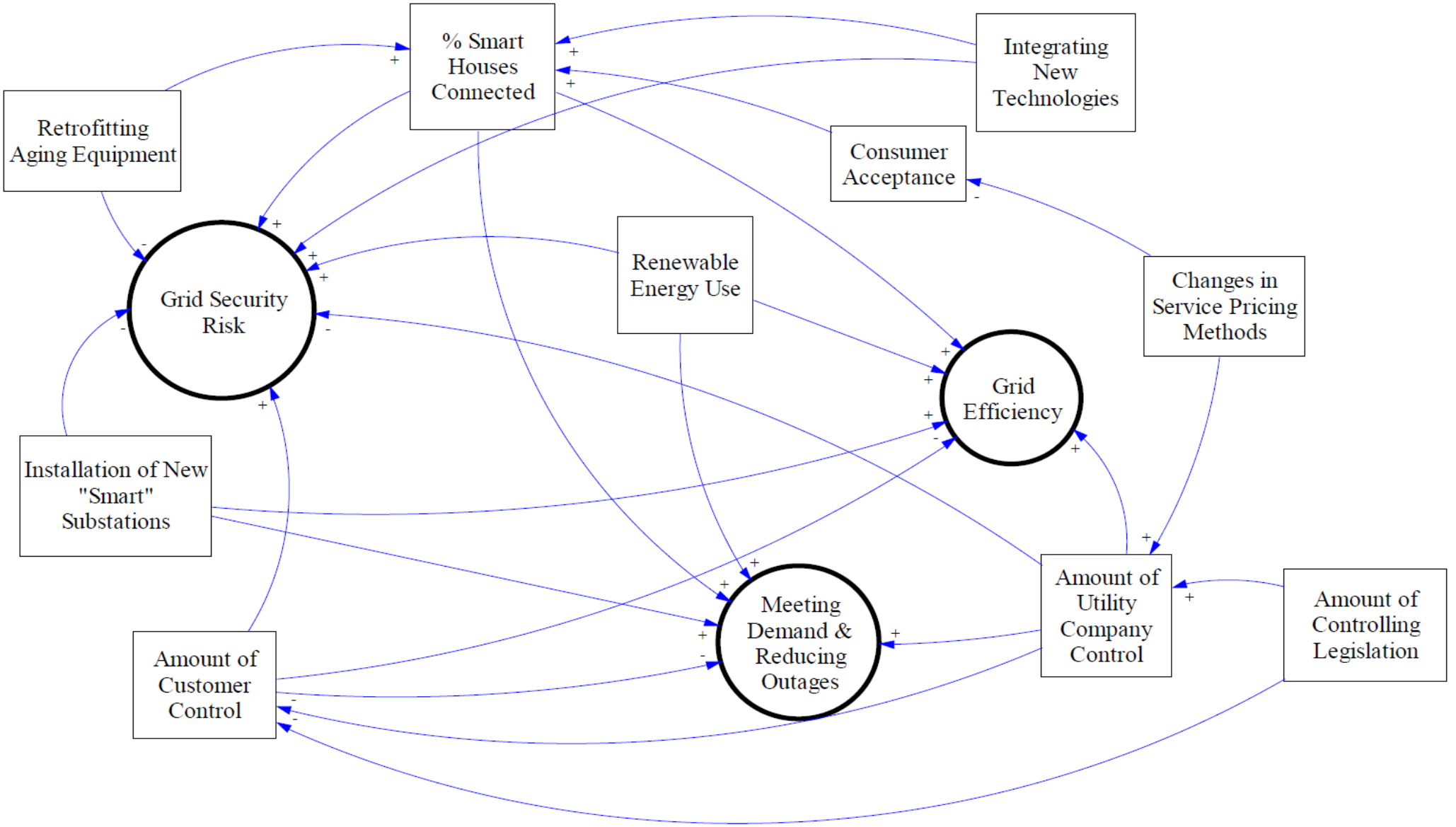
Center for Smart Grid Technologies

Our team's Smart Grid Research



Smart Grid Interdependencies

Security, Efficiency, and Resilience

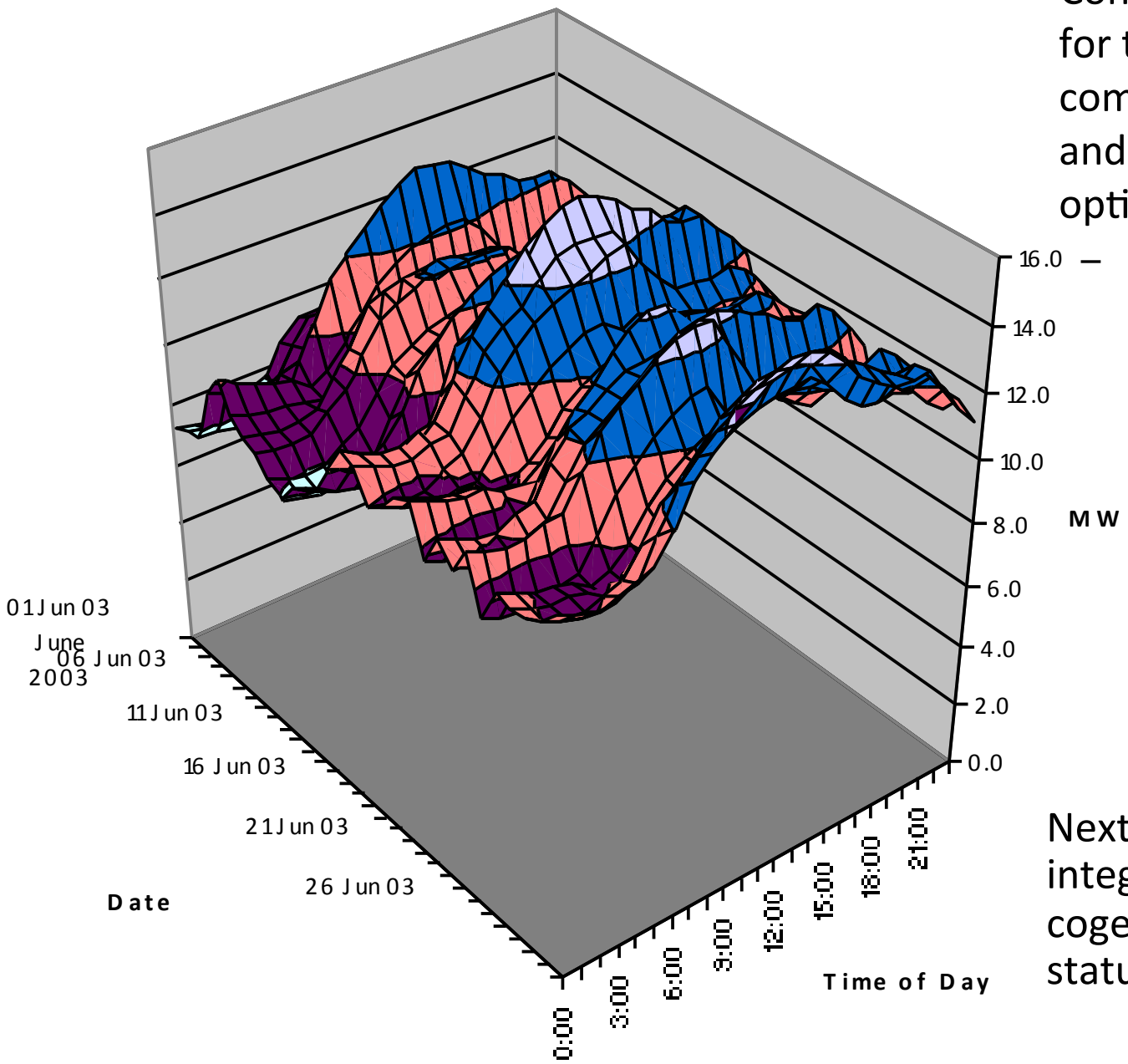


Minnesota Gets Smart

Vision for the Smart Grid U™

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

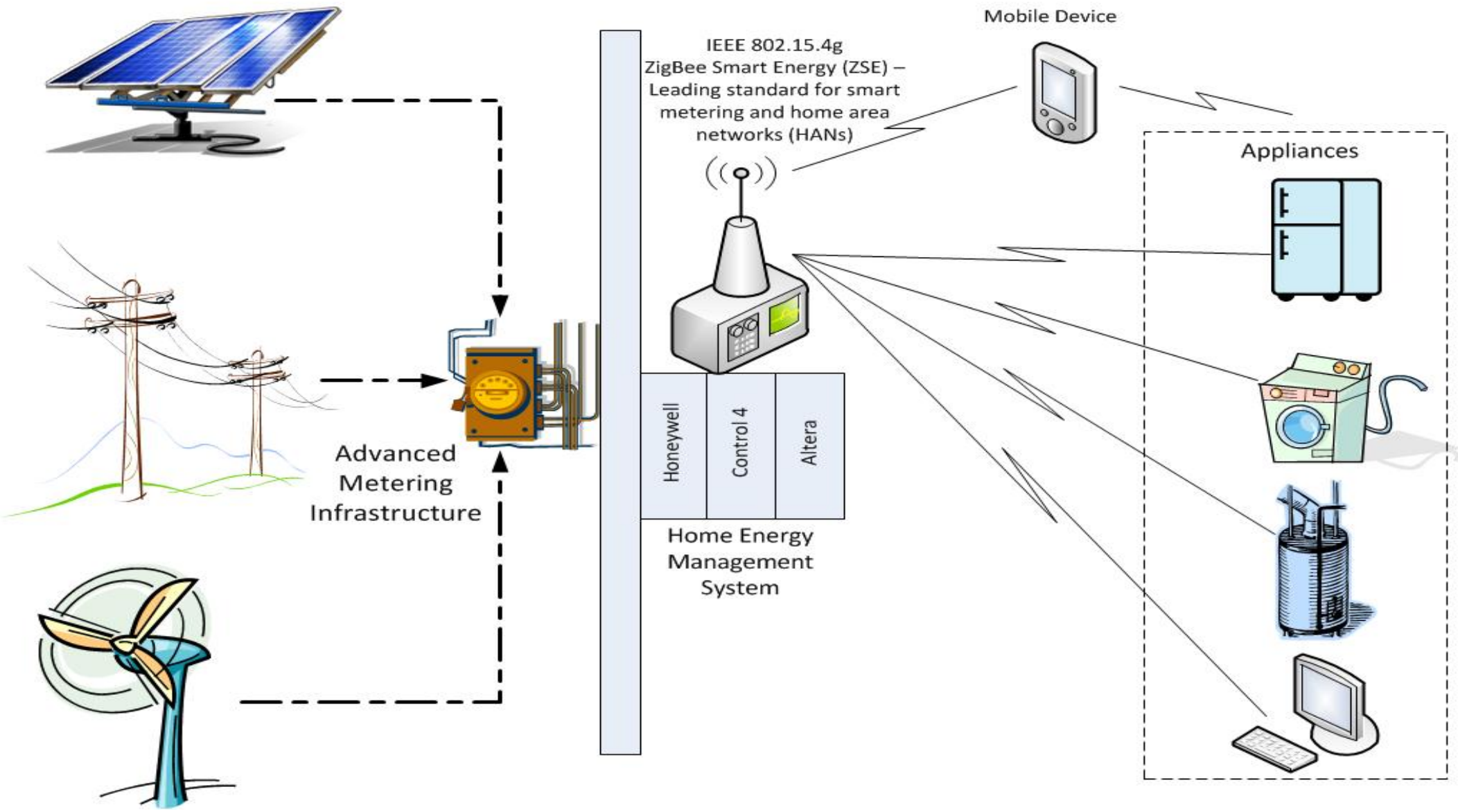
Smart Grid U™



- Control algorithms and interfaces for turning individual energy components (storage, generation and loads) into an integrated, optimized energy system.
  - E.g., demand surface plots of raw data for demands, emissions, & efficiency

Next steps: demonstrate ability to integrate renewables/storage, cogeneration and achieve NZE status.

Local System Communication Overlay



Key Findings - Smart Grid Minnesota

Existing Resources

- **Minnesota Wind Power Generation**
  - **4th in Nation in Total Installed Capacity – 2,192 MW**
  - **297.9 additional MW currently under construction**

    (Source – American Wind Energy Projects, January 2011)

State	Total Installed Capacity (MW)
Texas	10,085
Iowa	3,675
California	3,177
Minnesota	2,192
Washington	2,104

- **700 Mhz Licensed Wireless Grid Communication Network**
  - **First implemented by Great River Energy, then adopted by over a dozen Minnesota Co-ops**
  - **High-Reliability 2-Way Communication for Grid Monitoring and Control**
  - **Gaining broader recognition as a national model for reliable Smart Grid communication**

Key Findings - Smart Grid Minnesota

Technology and Service Providers, Projects

- **Technology and Service Providers** - with MN offices
  - **Cooper Power Systems -** grid demand management systems
  - **Digi International** - technology to help utilities monitor and adjust end-user consumption during peak demand events
  - **Ecologic Analytics** - software for meter data management (MDM) and decision management
  - **NorthWrite** - web-based energy monitoring and analysis tools (received $5 million ARRA for Idaho school efficiency project, Feb 2010)
  - **Open Access Technology International (OATI)** - software to track energy transmission and scheduling
  - **Open Systems International (OSI)** - software for energy management, communications, and cyber security

- **Smart Grid Projects - Existing**
  - **Great River Energy/Arcadian Networks** - 700 Mhz Licensed Wireless
  - **Xcel Wind Storage Project** - test of 1MW Battery Storage and grid integration at Luverne Wind Farm (with MinWind LLC)

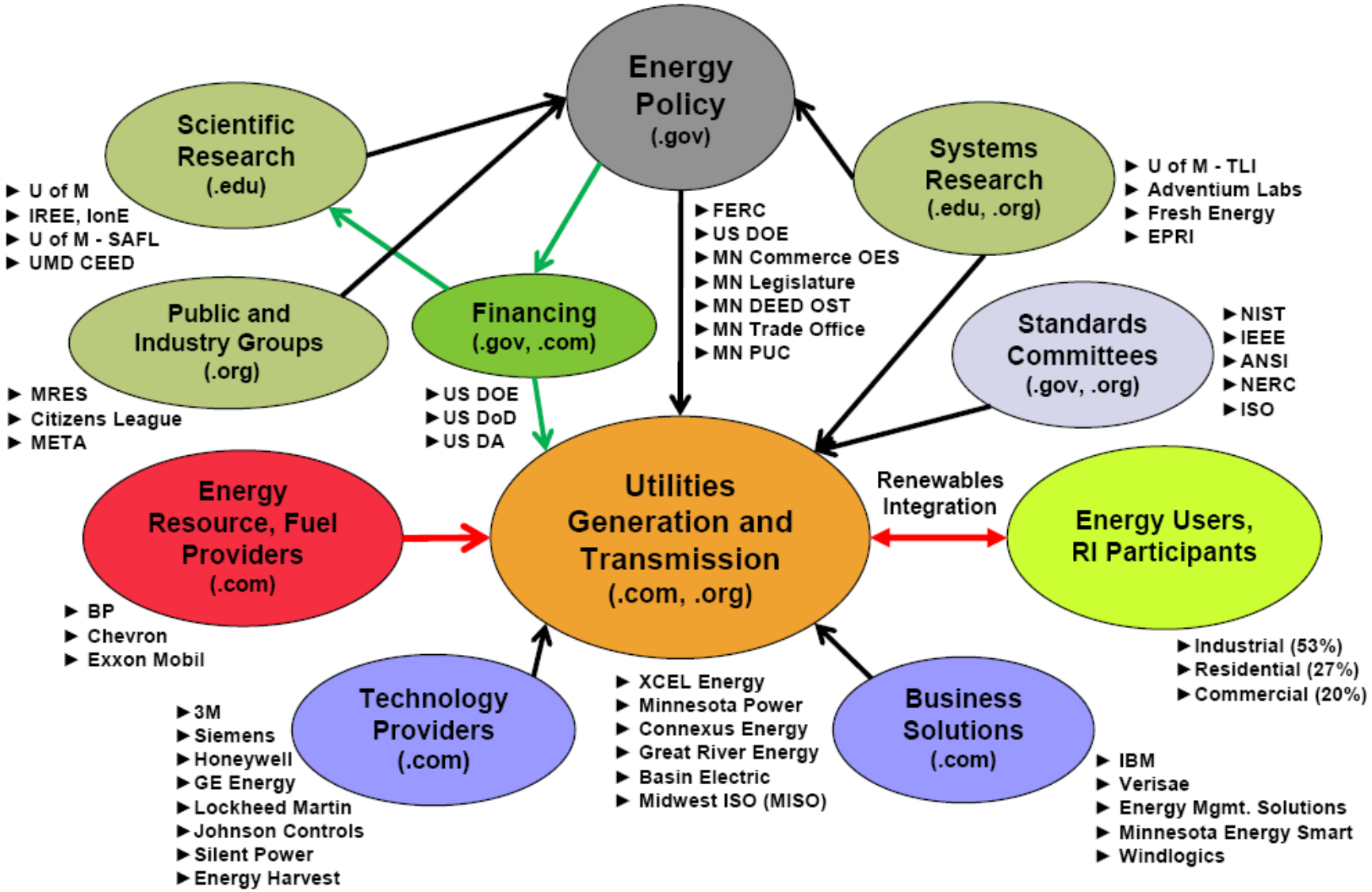
Key Findings - Minnesota Energy Sector

- **Renewable Energy Research at UMN**
  - 3 ARPA-E National Finalists (only 80 National Finalists from 3,700 applicants) - Awarded 1 of only 37 ARPA-E grants
    - Bacteria for high-volume, hydrocarbon feedstock production (*Grant Winner)
- Combining carbon sequestration with geothermal energy use
    - Reversing combustion by cycling CO2 and H20 back into higher energy density hydrocarbon fuels using only solar energy
  - IonE (IREE and NISE) - Renewable Energy and Sustainability Research

- **Resources**
  - UMN Wind Turbine Research Center - Received an $8M DOE grant to install a Siemens 2.3MW turbine for experimentation

- **Emerging Technology - Energy Storage**
  - Silent Power sub transmission scale storage
  - iCel Systems Energy Lab (St Paul) - Production facility for Lithium Ion battery storage
  - EcoVoltz - developing a lower cost flow battery solution for grid-level storage (searching for potential wind farm pilot sites)

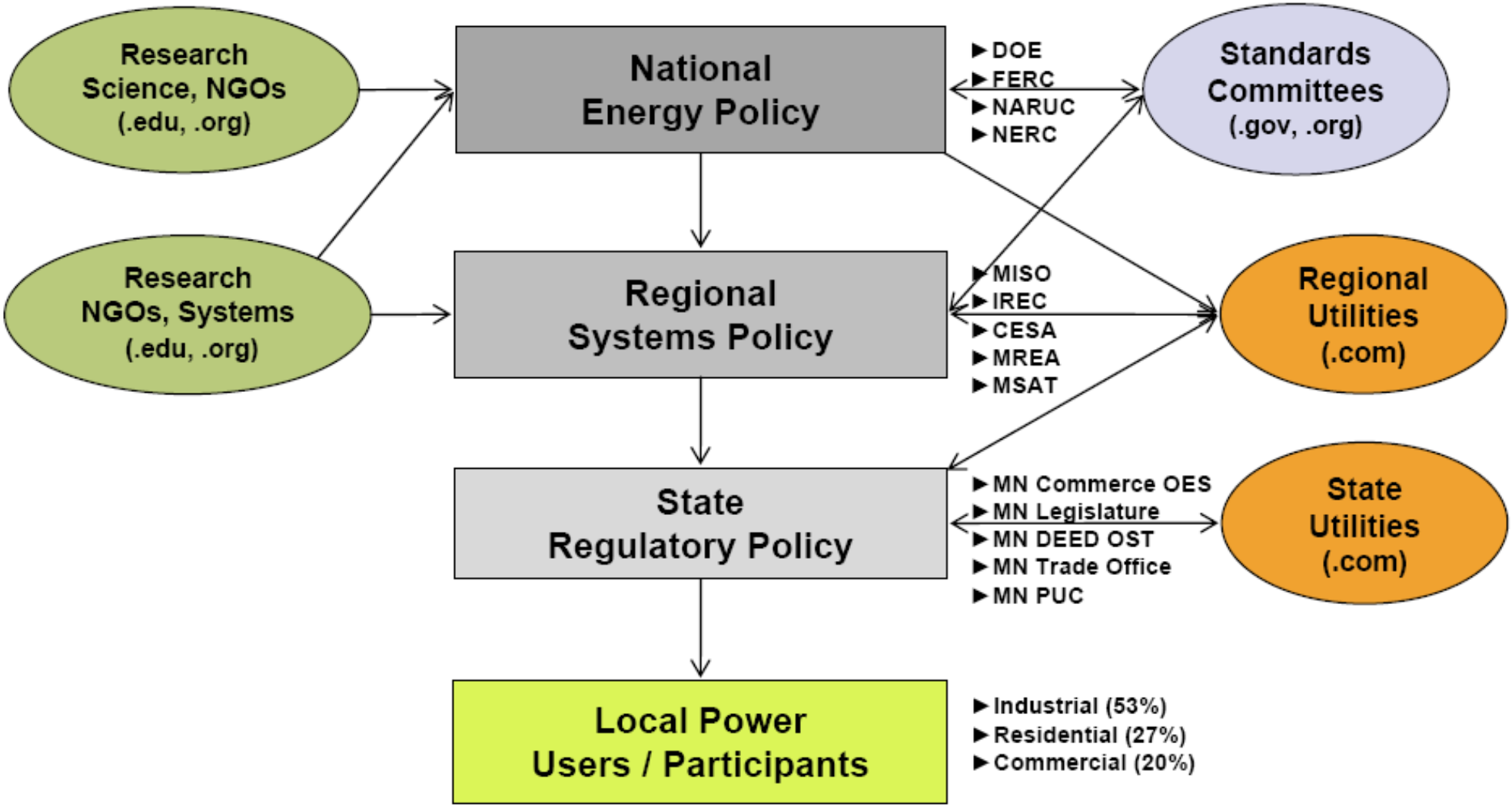
Midwest Regional Ecosystem - Stakeholders
(Objective: Long-Term Sustainability)



Source: Bill Bushnell

Smart Grid Systems View

Policy Perspective - Key Levels



Source: Bill Bushnell

Opportunity Statement

- Can the application of smart grid technologies, and more broadly, smart systems provide a method for managing the energy needs of the community?

What is Smart Grid?

- A collection of technologies that monitor and manage energy consumption
  - Support alternate sources of energy
  - Improve monitoring of systems
  - Provide better supply and demand data
  - Provide greater resiliency
  - Improve electrical security and reliability
  - Become a launch pad for innovation and jobs
- A critical component for building environmentally, socially, and economically sustainable communities, such as the one envisioned for UMore Park

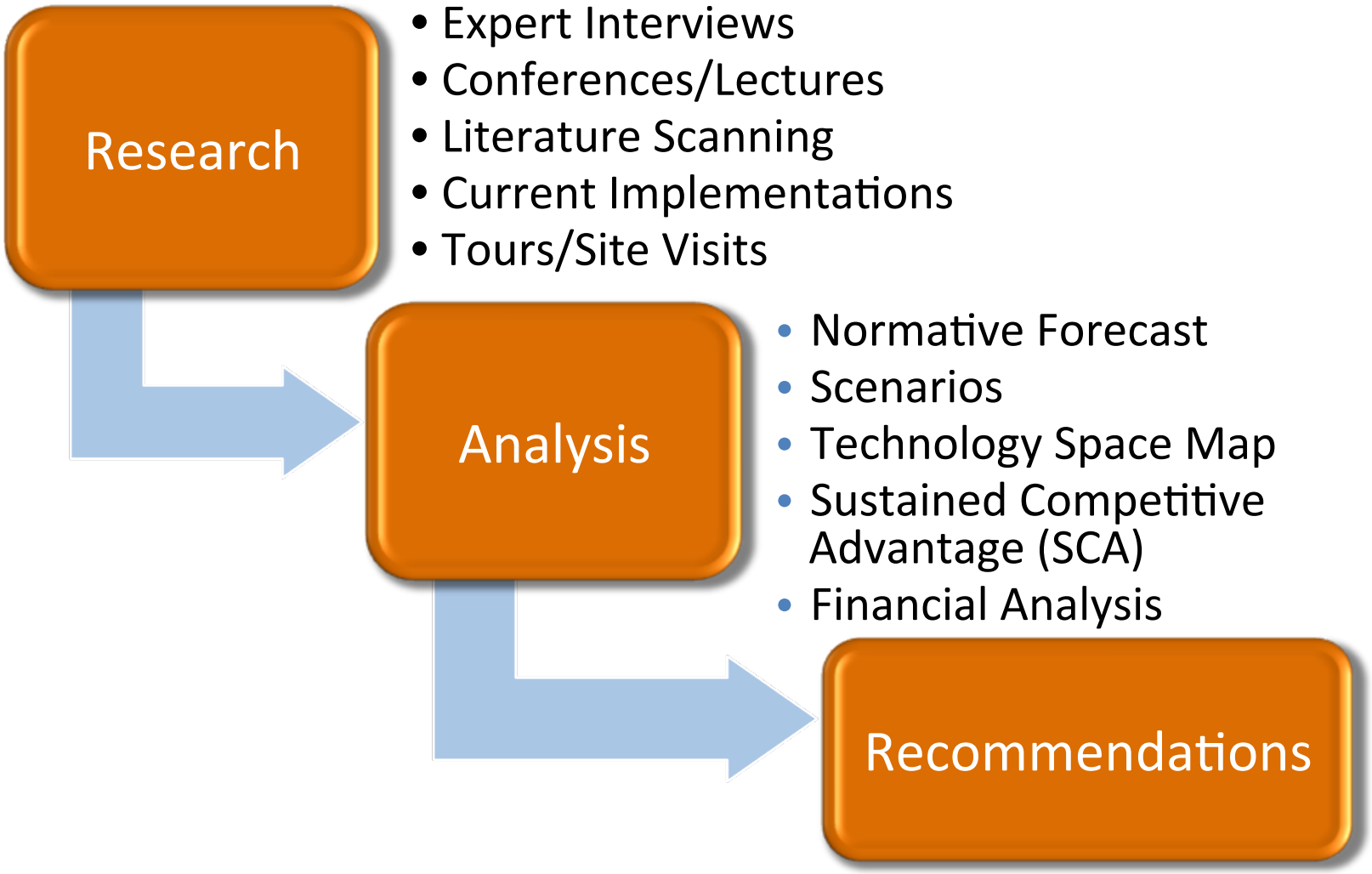
Smart Grid empowers consumers to take control of their energy use.

Master of Science in the Management of Technology (MOT) Overview

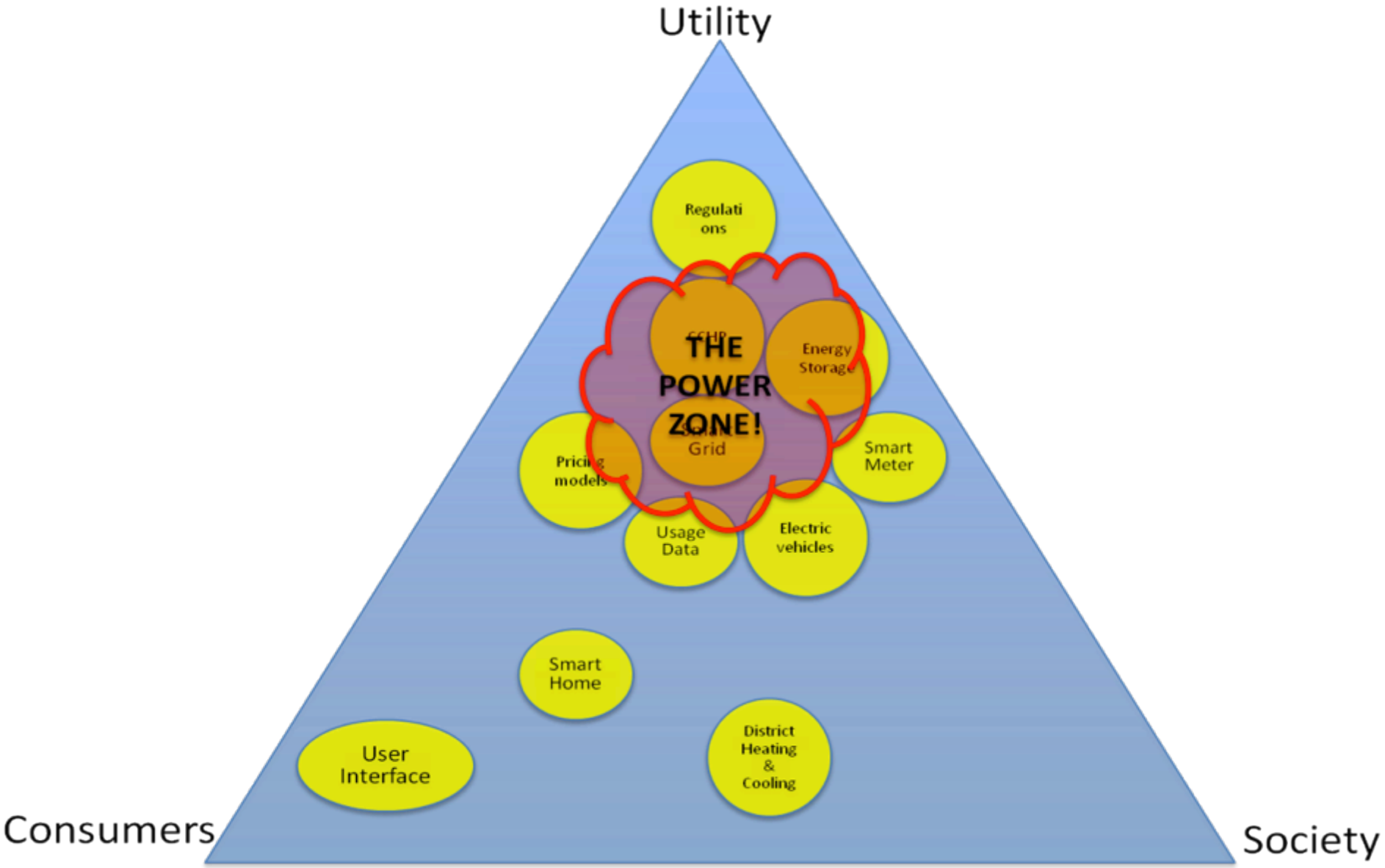
- Designed to equip full-time working professionals with the tools to clearly navigate the "grey zone" between business and science/engineering
  - Year 1 – focused on teaching business fundamentals
  - Year 2 – focused on merging science/engineering and business fundamentals to develop successful business strategy
- Develops leaders with the foresight and vision to develop robust strategies for the future

Approach – MOT Methodology

Capstone projects: Eric Bohnert, Andrew Fraser, Hope Johnson, Shanna Leeland

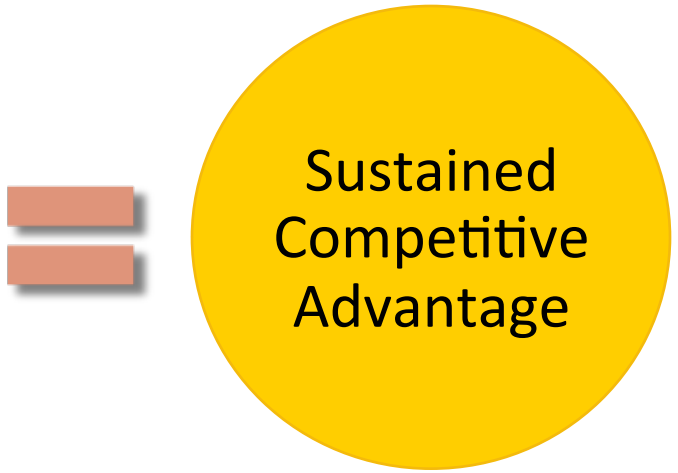


Analysis - Technology Space Map



Recommendations & Conclusions

"There is only one valid definition of business purpose: *to create a customer*" Peter Drucker



Recommendations & Conclusions

Making Moves

Business Strategy

- Differentiation is KEY!
- Co-branding with UMN
- Cost basis for land is low
- Experts for design

Corporate Strategy

- Partnerships to share risk
- Partnerships/JV
- Xcel
- CenterPoint Energy
- OEMs

Innovation Strategy

- Incorporating new technologies
- Scanning renewable technology

Recommendations & Conclusions

"innovations in renewable energy, education, environmental quality, transit, technology, housing and other University mission strengths"

Recommendation	Who	When	Cost	Benefits
Engage with Xcel – Develop Partnership	UMore Park Management	Ongoing	Low Cost – Time	High Potential
Engage with PUC – Change Utility Incentives	UMore Park Management	Ongoing	Low Cost – Time	High for UMore and Consumers
Build Smart Homes	UMore Park & Developer or Builder	Pre Phase I	X% above target cost	Consumer can save money, increased efficiency, home security, peace of mind
District Model – Business Plan	UMore Park or Subsidiary	Pre-Phase I	Explore–L/M Start–M/H Run–L/M	Save Money for consumer, maximize efficiency, lower emissions
Monitor Technology Opportunities	UMore Park & Academic Affairs	Ongoing	Low cost	Supports academic mission, improves product long-term

Smart Grid Technologies for Homes

- Photovoltaic inverters
- Smart meters, in-home displays
- Grid-ready appliances
- Electric vehicle power charging station
- Battery storage backup
- Estimated costs: $10,670 to $27,190 per home

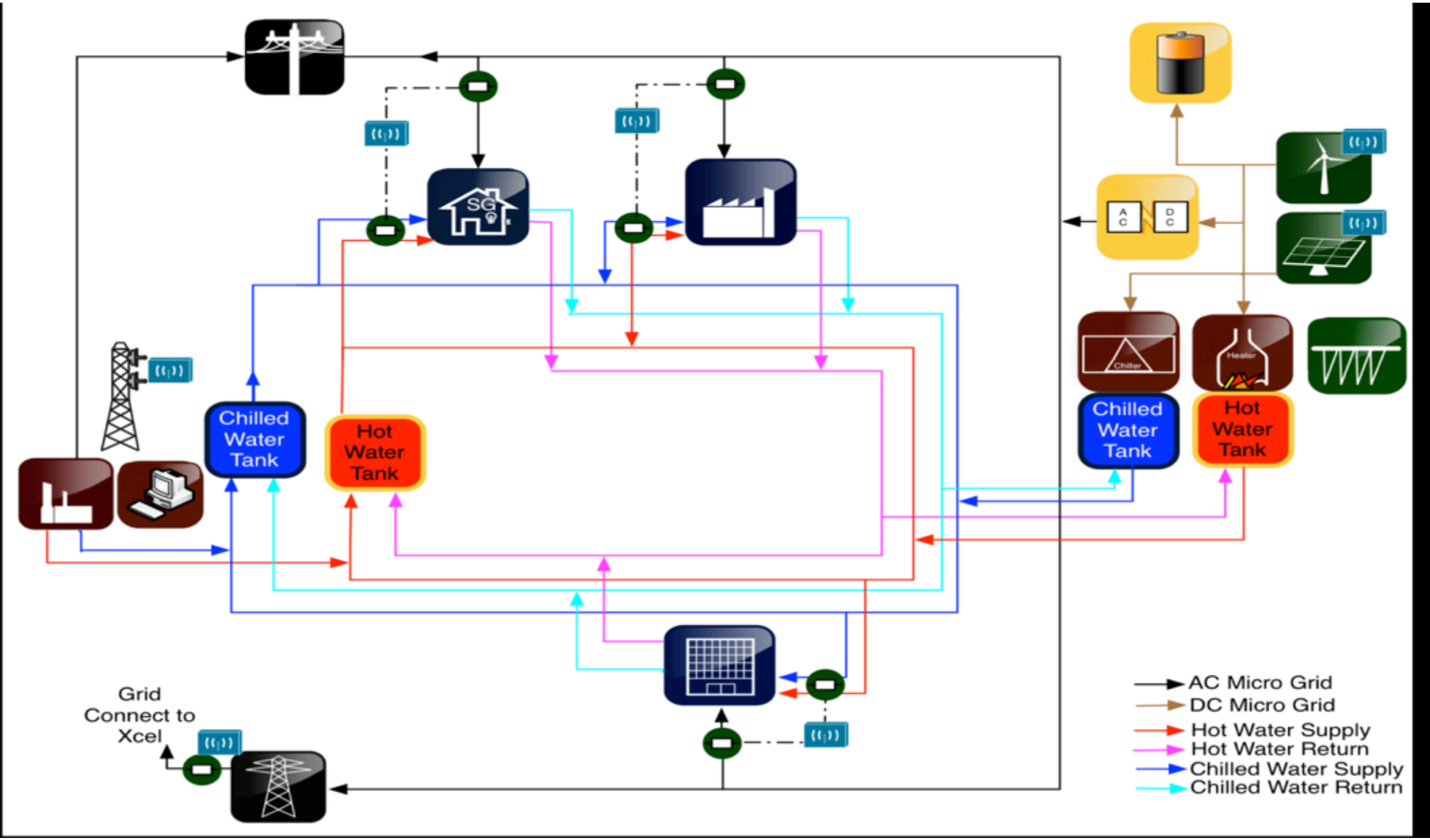
Estimated Prices for Energy-Efficient, Smart Grid Ready Homes in UMore Park

Estimates for Lot Sizes and Home Prices in UMore Park (Maxfield Research, Inc., 2010)						
	Square Foot Range			Estimated Home Pricing		
	Low	High	Average	Low	High	Average
Small Lot	1,600	2,500	2,050	$225,000	$350,000	$287,500
Traditional	1,800	2,800	2,300	$225.000	$410.000	$317,500
Large Lot	2,800	4,500	3,650	$450,000	$725,000	$587,500

Estimates for Energy-Efficient, Smart Grid Ready Homes in UMore Park						
	Price Ranges			Cost Over Traditional Home		
	Low	High	Average	Low	High	Average
Small Lot	$244,920	$379,920	$312,420	$19,920	$29,920	$24,920
Traditional	$244,920	$444,720	$344,820	$19,920	$34,720	$27,320
Large Lot	$487,920	$784,920	$636,420	$37,920	$59,920	$48,920

Average prices are within range of the low-high estimated home prices for UMore Park

A District Energy Model



Smart Grid U™

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

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

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

An Engine for Economic Growth

Macroeconomic Rationale

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

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

   Y = GDP

   R = R&D

   K = physical capital

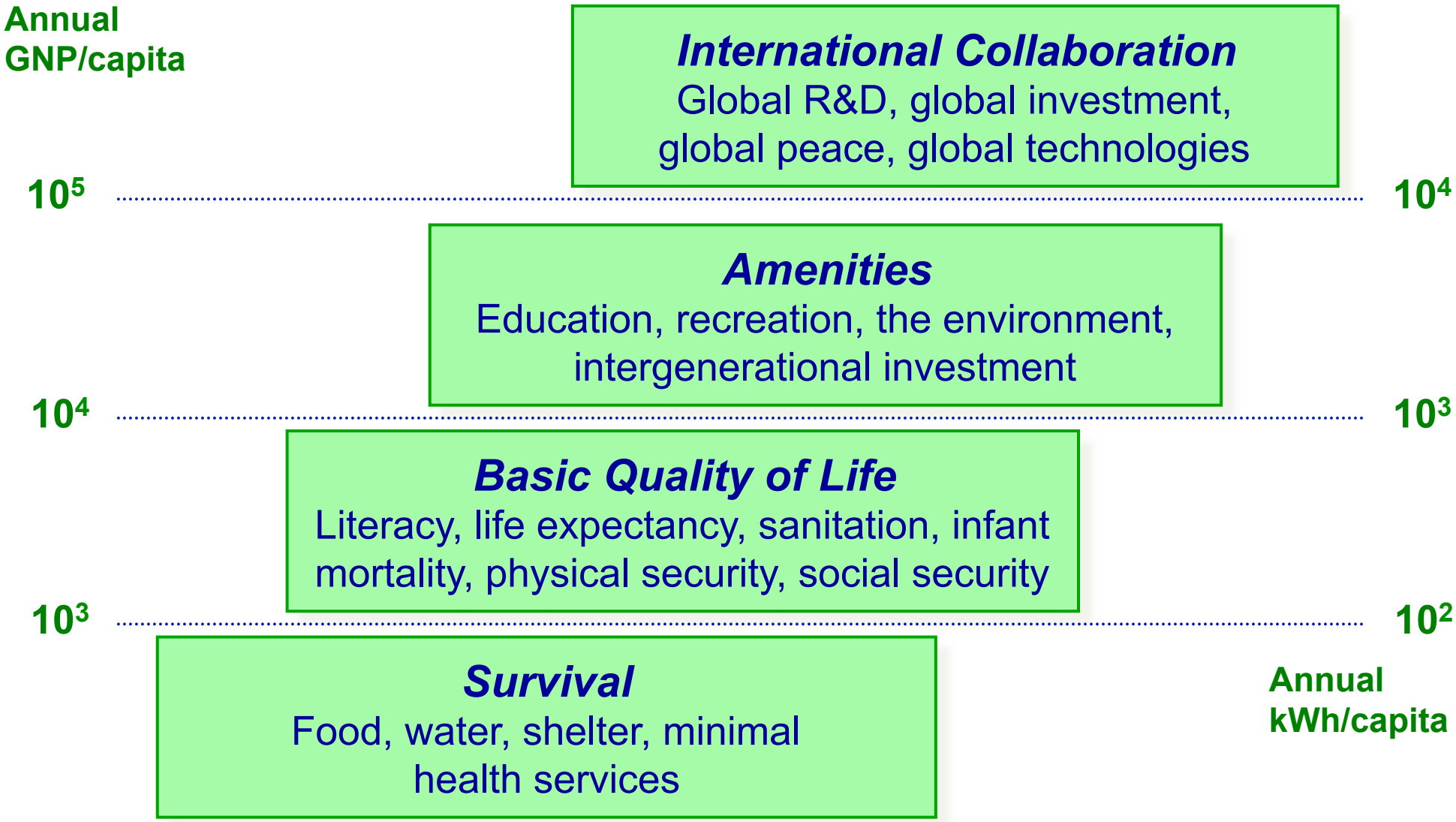
   H = human capital

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

GDP Density

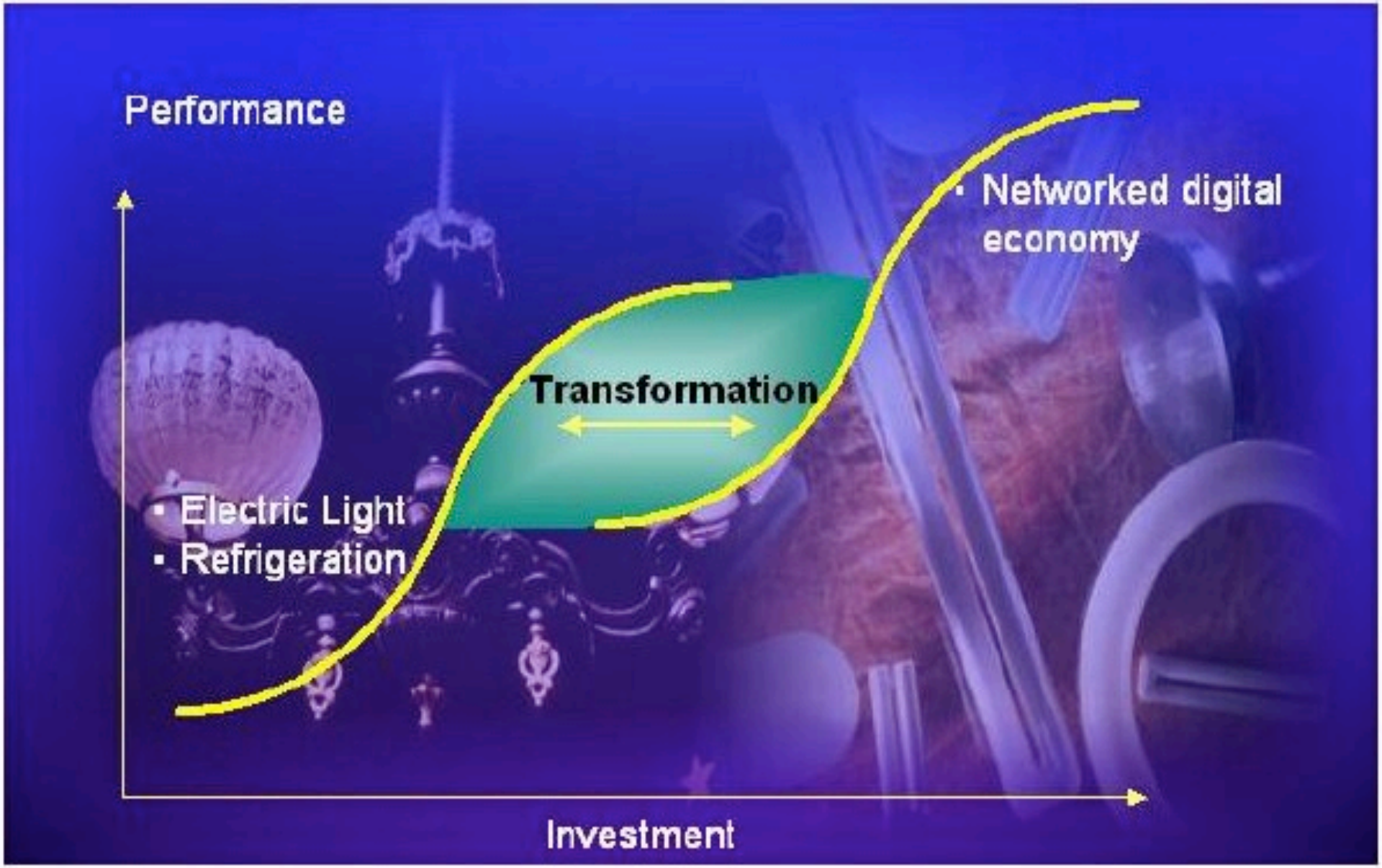
Satellite picture of the earth at night

Social Conditions and Access to Electricity

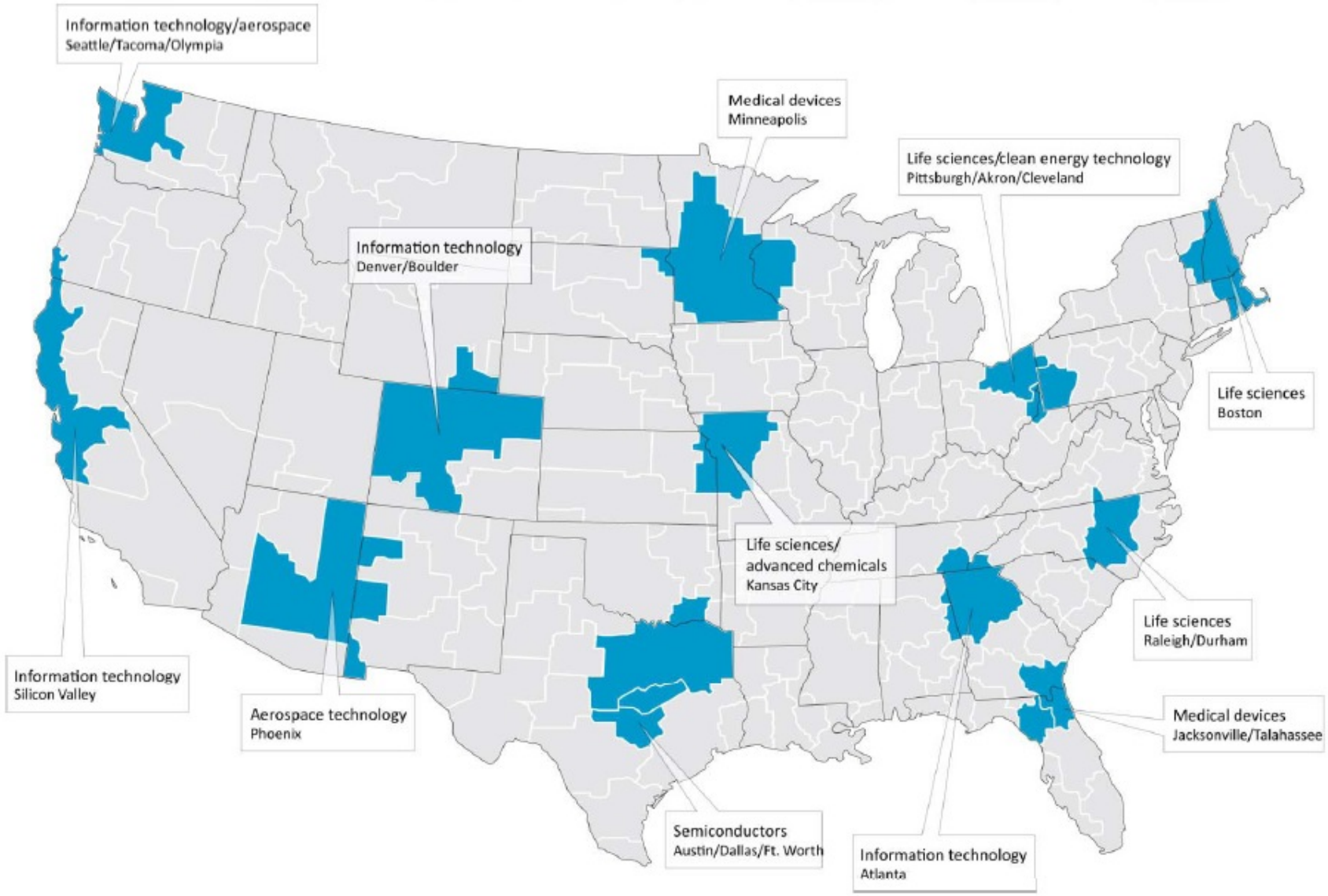


Source: Chauncey Starr

Breaking the Limits on Electricity Value



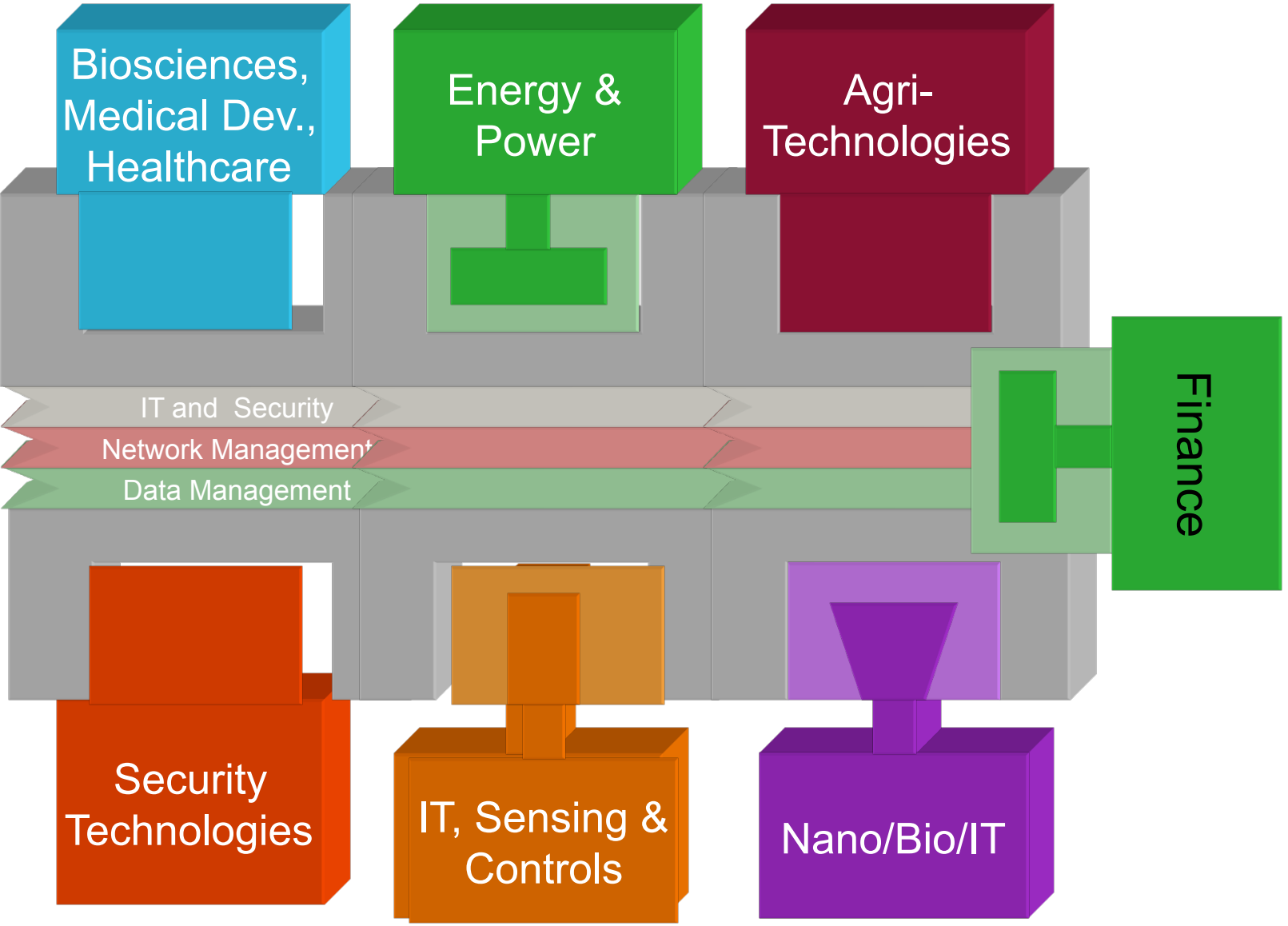
"Geography of Innovation*"



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

Minnesota's Technological Leadership Role:

Enabling Economic Growth→ First Build the Right Foundation



Build The Right Foundation

Security

Network Management

Data Management

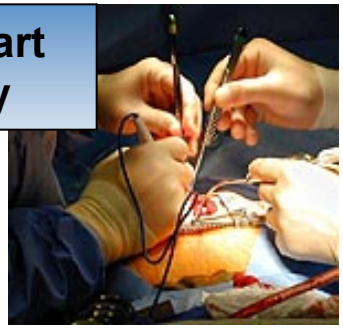
Interoperability

Entrepreneurship:

- College of Science and Engineering Founders2005 Survey of alumni who have started businesses:
  - 15,000 alumni responded
  - 3,024 have founded one or more companies
  - 2,600 active companies in Minnesota (employing 175,000 in Minnesota), with annual global revenue of $90B ($46B in Minnesota)
  - with Faculty also active in start-ups, often with former graduate students.

A Minnesota Engine for Economic Growth

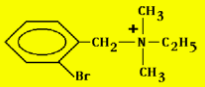
Open Heart Surgery



Pacemaker

Taconite

Brethylium



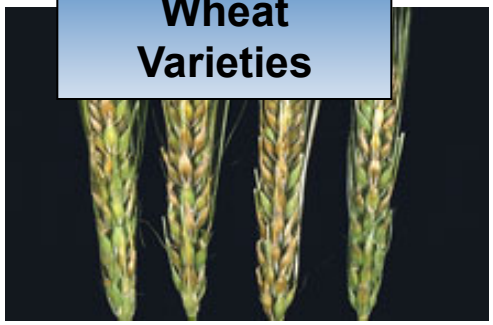
Ziagen

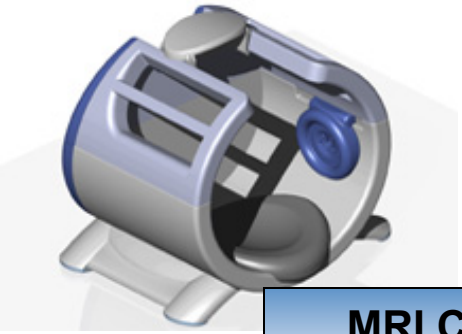
ZIAGEN
abacavir sulfate 300 mg
ONE TABLET TWICE A DAY

Navigus

Vest Airway Cleaning System

Wheat Varieties





MRI Coil

Grape/Wine Varieties

INGELVAC

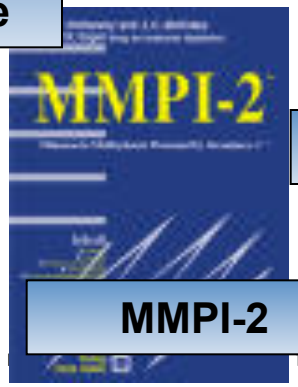
PRRS Vaccine

Flight Data Recorder

Gentle Leader Head collar

Radius Plate

Heads-up Display



MMPI-2

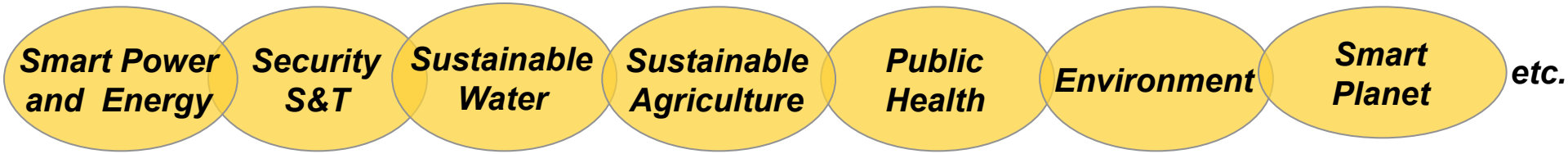
Seatbelt

ation form ation.

An 'About FACE' is Required

- Focus
- Alignment
- Collaboration
- Execution

Begin with a 360 ***Systems' Approach*** *and the End Goal in Mind:*
Focus on a few big 'problems that matter' to our nation and the world in the next half century



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

Smart Sensor Technology

Smart Grid

Smart Bio

Smart Ag

Smart Distribution

Smart Networks

Global Transition Dynamics

Understanding the Full Impacts of Decision Pathways: Global Transition Dynamics

Goal: Target constrained development resources to maximize benefit and minimize unintended consequences

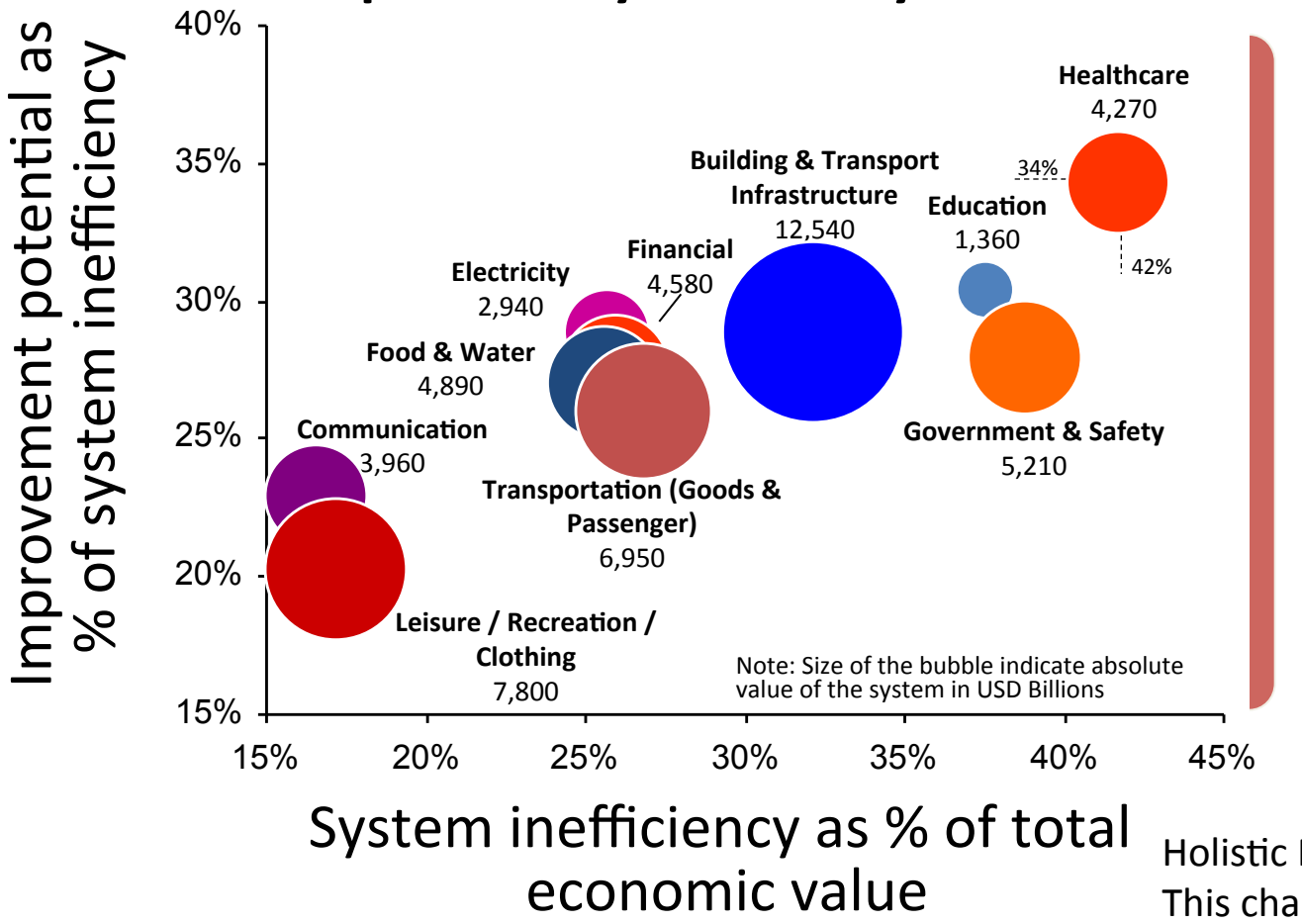
"Global Transition Dynamics Unfolding the Full Social Implications of National Decision Pathways,"

(Chauncey Starr and Massoud Amin), Sept 2003

Decision Real Life Picture

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

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



Global economic value of

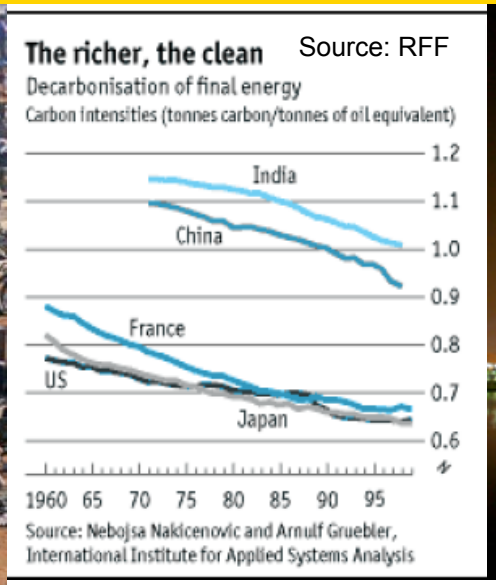
System-of-systems	**$54 Trillion** 100% of WW 2008 GDP
Inefficiencies	**$15 Trillion** 28% of WW 2008 GDP
Improvement potential	**$4 Trillion** 7% of WW 2008 GDP

How to read the chart:

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

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

"Trilemma" of Interlocking Sustainability Issues: Economic Aspirations of Rapidly Expanding Populations, Environmental Quality, and Natural Resource Consumption… Population, Poverty and Pollution



Trilemma of Sustainability

Population, Poverty and Pollution:

Science and technology hold the key to managing this trilemma -- allowing prosperity to grow most efficiently, while reducing humankind's environmental footprint and resource demands.


LEADERSHIP

Bottom Line:

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

-- Peter Drucker

Policy

Policy, Science and Technology Must Support This Transformation: Recommendations

- Establish the "Smart Grid" and "self-healing" interdependent infrastructure security & protection as national priorities
- Authorize increased funding for R&D and demonstrations of the "Smart Grid", and interdependency R&D, resilience/security
- Revitalize the national public/private electricity infrastructure partnership needed to fund the "Smart Grid" deployment

M. Amin's briefing at the U.S. Congressional R&D Caucus (www.researchcaucus.org) on March 26, 2009

Enabling a Stronger and Smarter Grid:

- Broad range of R&D including end-use and system efficiency, electrification of transportation, stronger and smarter grid with massive storage

- Sensing, Communications, Controls, Security, Energy Efficiency and Demand Response *if architected correctly* could assist the development of a smart grid

- Smart Grid Challenge/Opportunity areas include:
  - Distributed Control
  - Grid Architectures
  - Cyber Security

M. Amin's briefing at the U.S. Congressional R&D Caucus (www.researchcaucus.org) on March 26, 2009

… a few Smart Grid nuggets

- **IEEE Smart Grid Newsletter:**
  - A monthly publication, the IEEE Smart Grid Newsletter features practical and timely technical information, and forward-looking commentary, on Smart Grid developments and deployments around the world.
  - Designed to foster greater understanding and collaboration between diverse stakeholders, the newsletter brings together experts, thought-leaders, and decision-makers to exchange information and discuss issues affecting the evolution of the Smart Grid.
  - To subscribe (free of charge) to the IEEE Smart Grid Newsletter, please visit http://smartgrid.ieee.org/publications/smart-grid-newsletter
  - For details on all IEEE Smart Grid, please visit http://smartgrid.ieee.org/

- For additional pertinent information, presentations, selected videos, and publications, please see http://umn.edu/~amin

Selected References

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

- **"Securing the Electricity Grid,"** (Amin), *The Bridge,* the quarterly publication of the National Academy of Engineering, Volume 40, Number 1, Spring 2010
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- **"The Electric Power Grid: Today and Tomorrow,"** MRS Bull., Vol. 33, No. 4, pp. 399-407, April 2008
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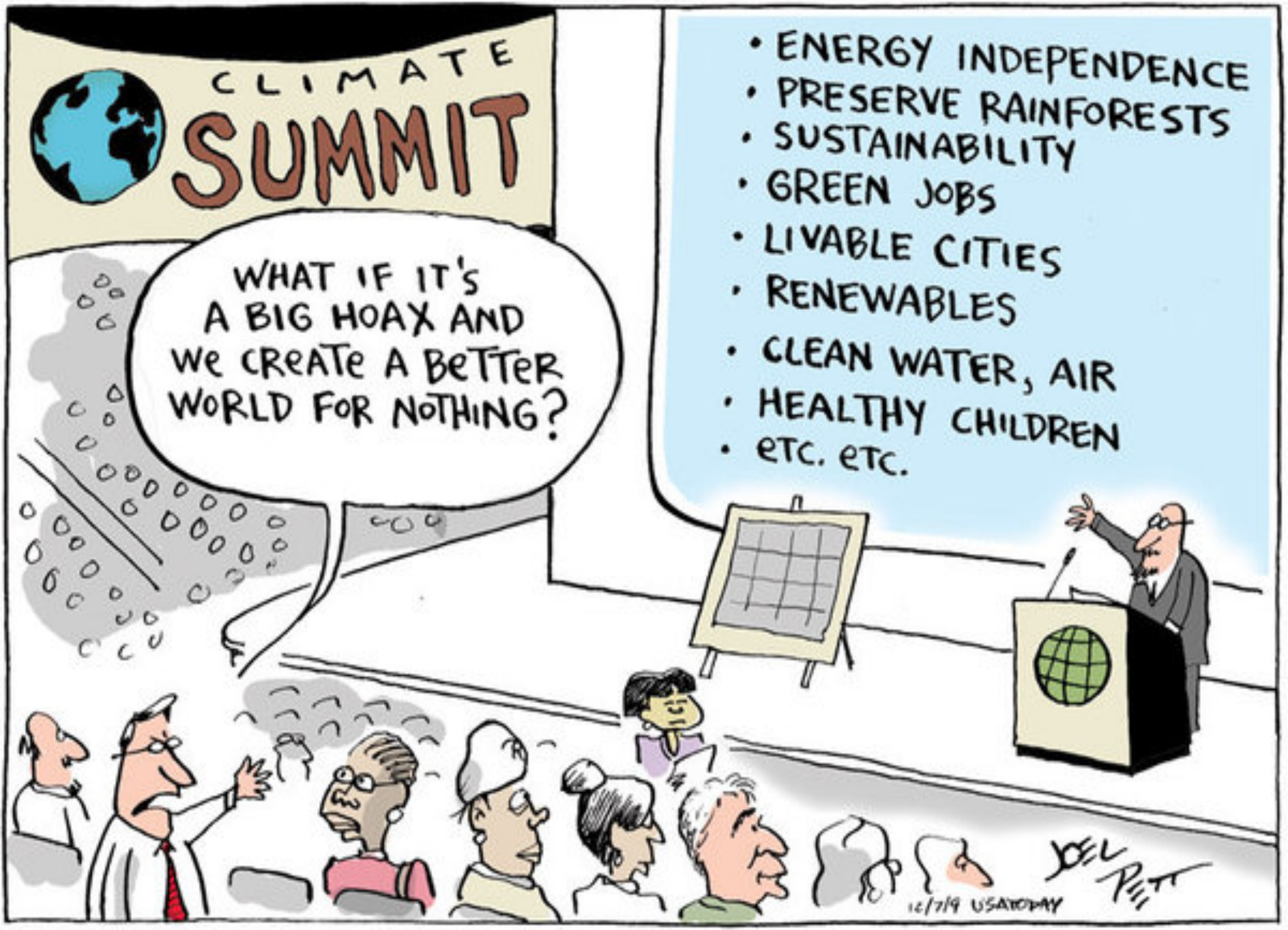
- **"Complex Interactive Networks/Systems Initiative (CIN/SI): Final Summary Report",** Overview and Summary Final Report for Joint EPRI and U.S. Department of Defense University Research Initiative, EPRI, 155 pp., Mar. 2004
- **"North American Electricity Infrastructure: Are We Ready for More Perfect Storms? ,"** IEEE Security and Privacy, Vol. 1, no. 5, pp. 19-25, Sept./Oct. 2003
- **"Toward Self-Healing Energy Infrastructure Systems,"** IEEE Computer Applications in Power, pp. 20-28, Vol. 14, No. 1, Jan 2001


CLIMATE
SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• ETC. ETC.
12/7/19 USATODAY
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