

# The Intersection of Smart Grid and Buildings

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**TECHNOLOGICAL  
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**Driven to Discover<sup>SM</sup>**



## Electricity Demand and the Global Macro-Environment

# Cities with 10 Million People



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



Note: \* Mega city 10 million population or greater

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

## The Energy Gap

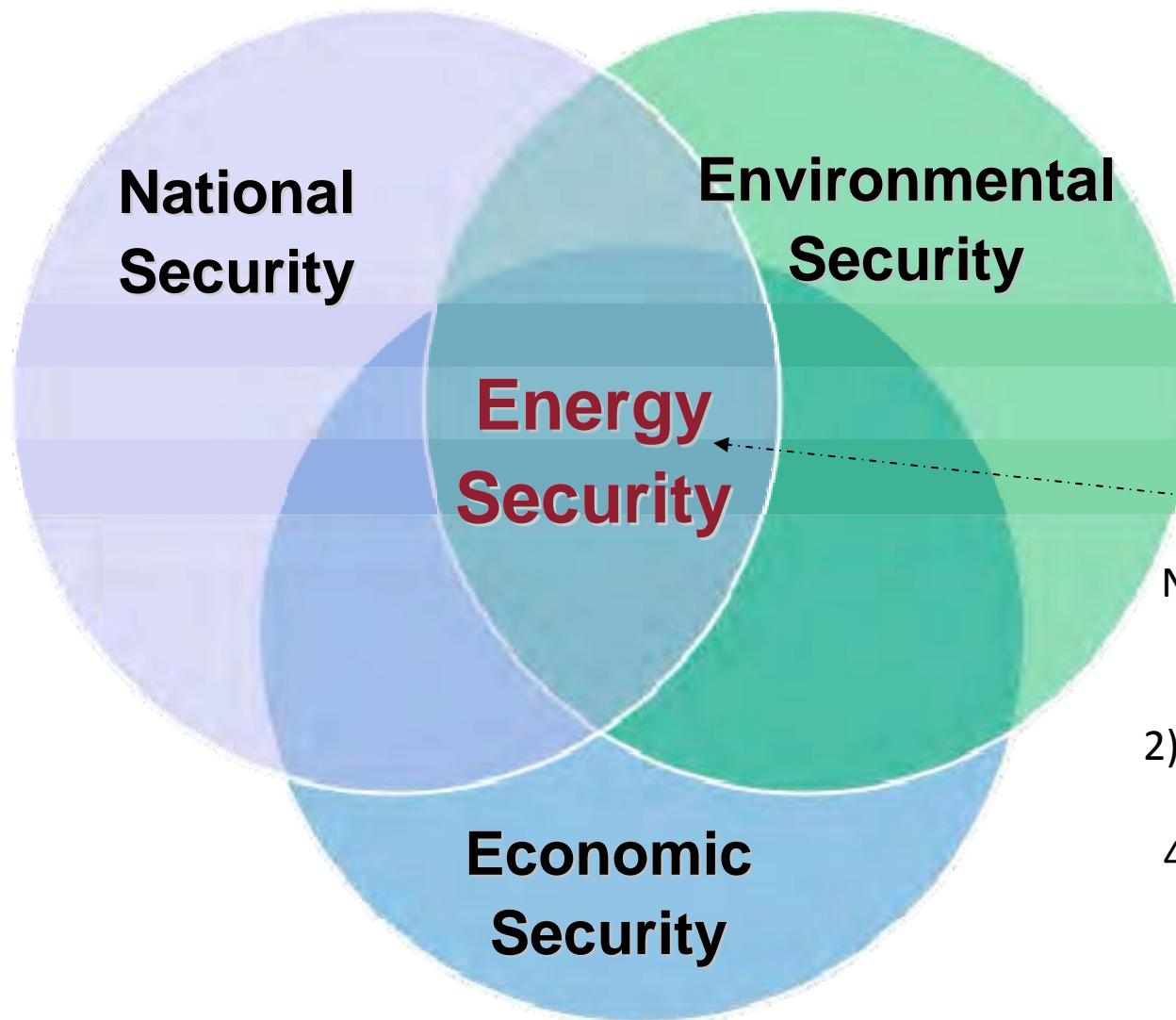


- Half the world's population subsists on agrarian or lower levels of energy access, and
- Their population density generally exceeds the carrying capacity of their environment



## Energy Security: System of Systems

# The Energy Crises Taught Us Interdependency



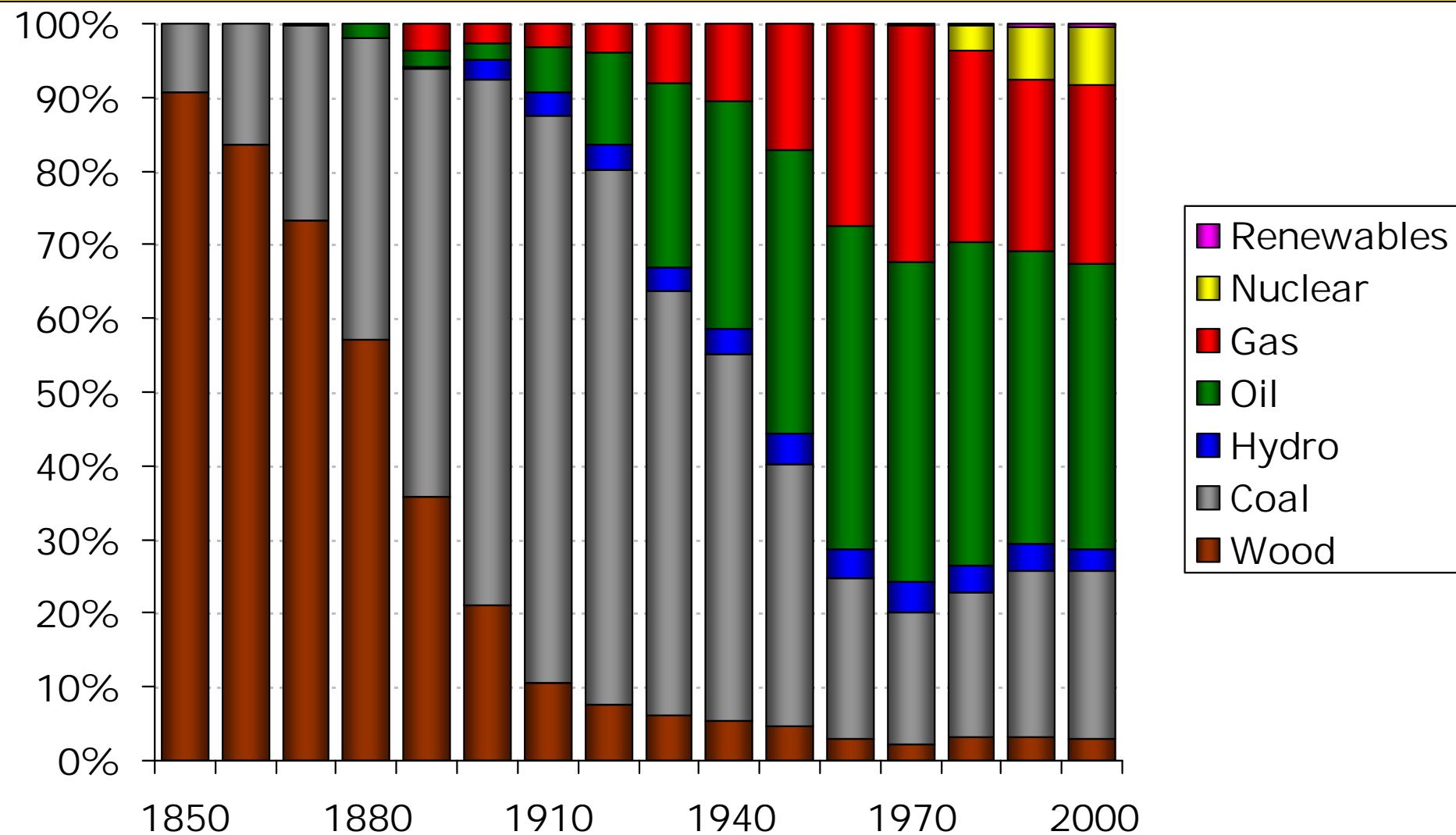
### System of Systems:

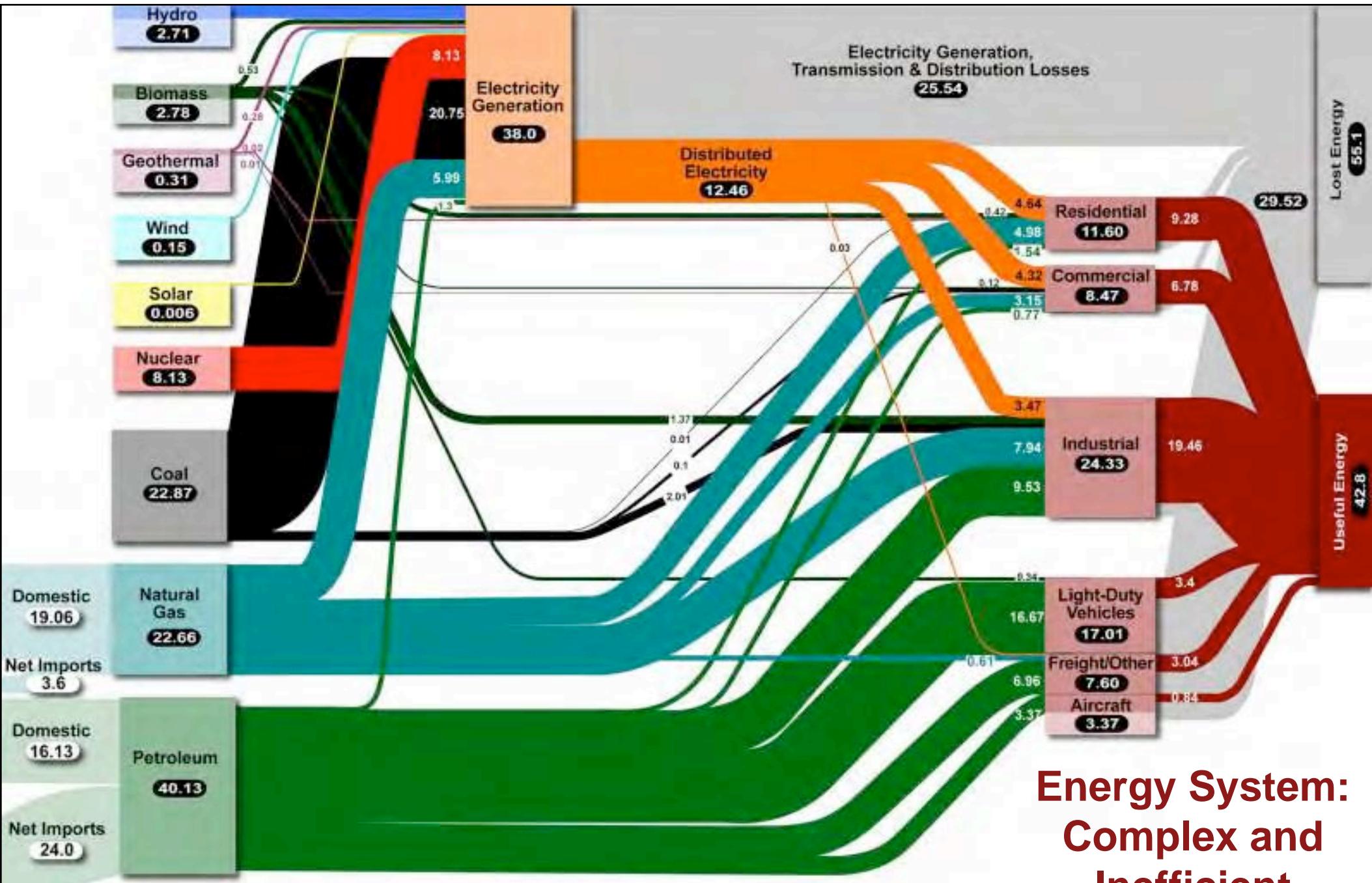
- No “magic bullets” but there are many innovative bullets, including:
  - 1) Green the power supply,
  - 2) Energy systems & end-use efficiency,
  - 3) Electrify transportation,
  - 4) Build a stronger & smarter grid with massive storage integrating greener electrical energy.



## **Focus: Energy Demand Growth and Fuel Substitution**

# U.S. Energy Supply Since 1850





## Energy System: Complex and Inefficient

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

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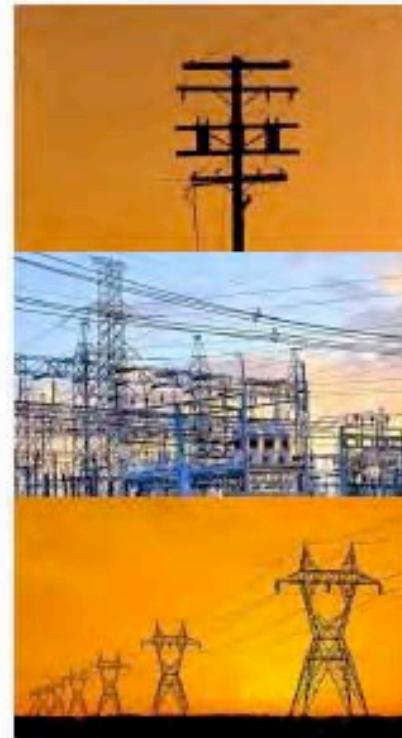


## Smart Grid: Technological Innovations

# End-to-end Electric Power System



## Generation



## Delivery

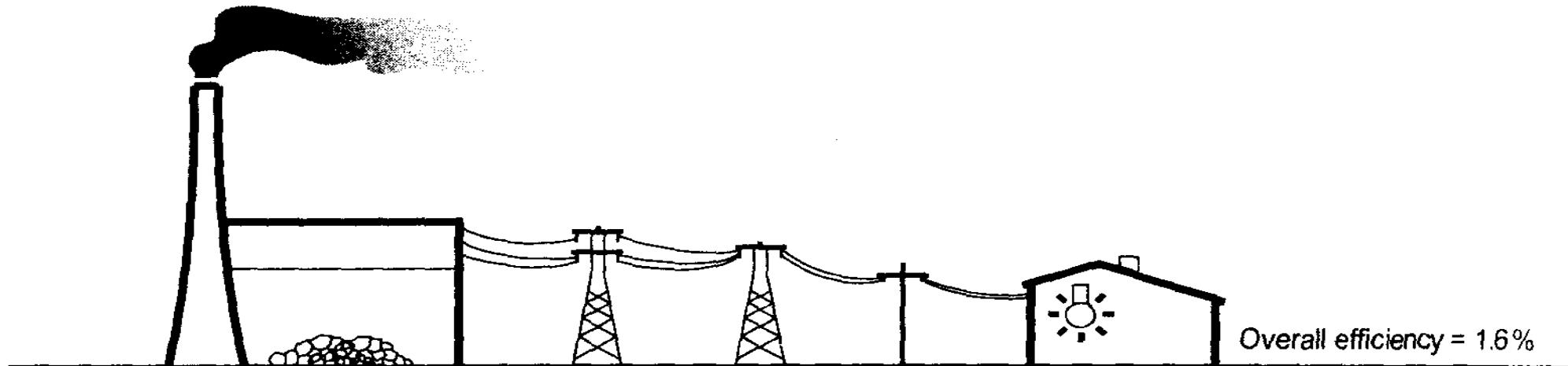


## Customer



## End-to-End Energy Inefficiency

**Losses as high as 98.4%**



Fuel = Coal

$E_0 = 1.00$

Power Plant

$E_1 = 0.35$

Transmission Lines

$E_2 = 0.90$

Light

$E_3 = 0.05$

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

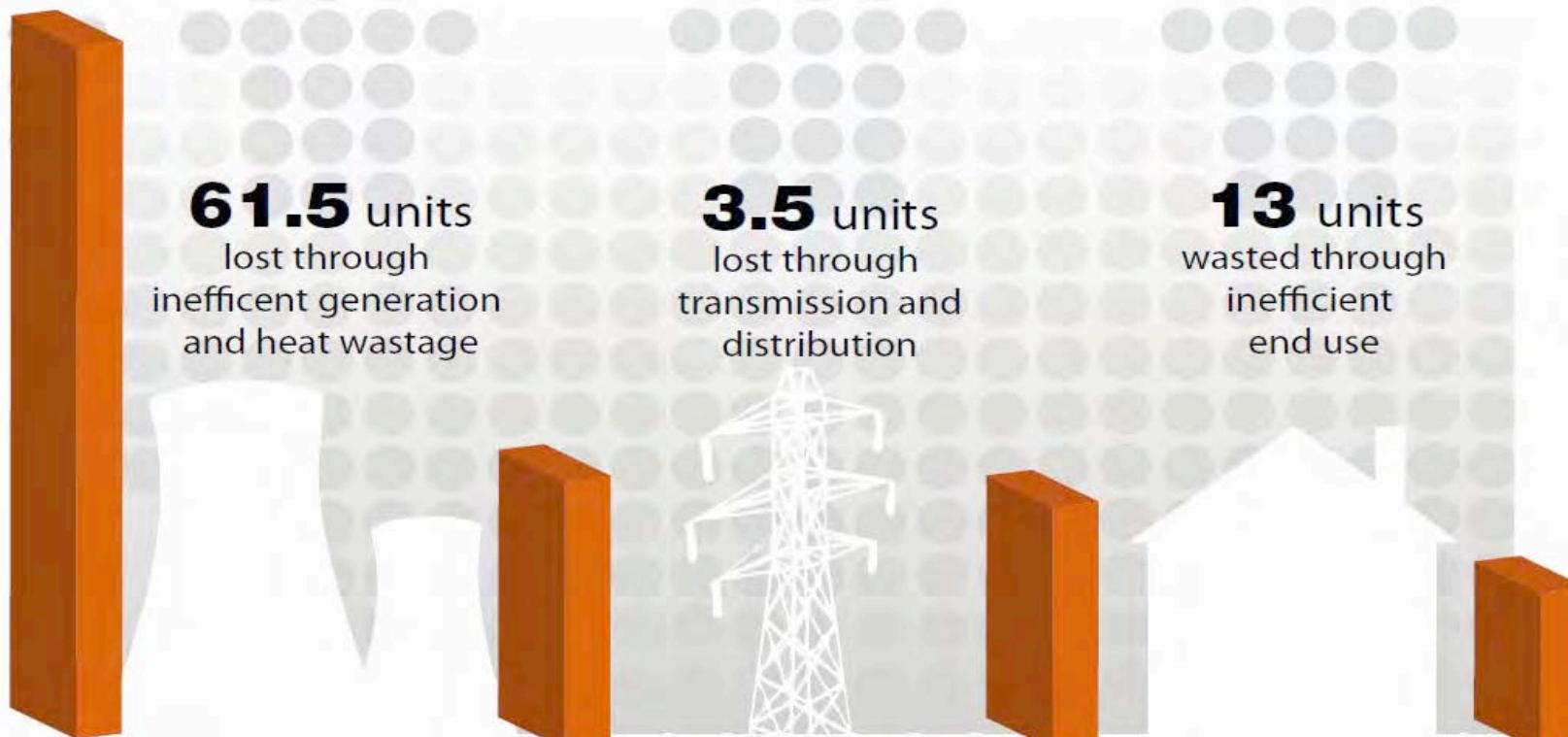
Opportunities to improve the situation:

- 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

**38.5** units  
fed to  
National Grid

**35** units  
of energy supplied

**22** units  
of energy actively  
utilised

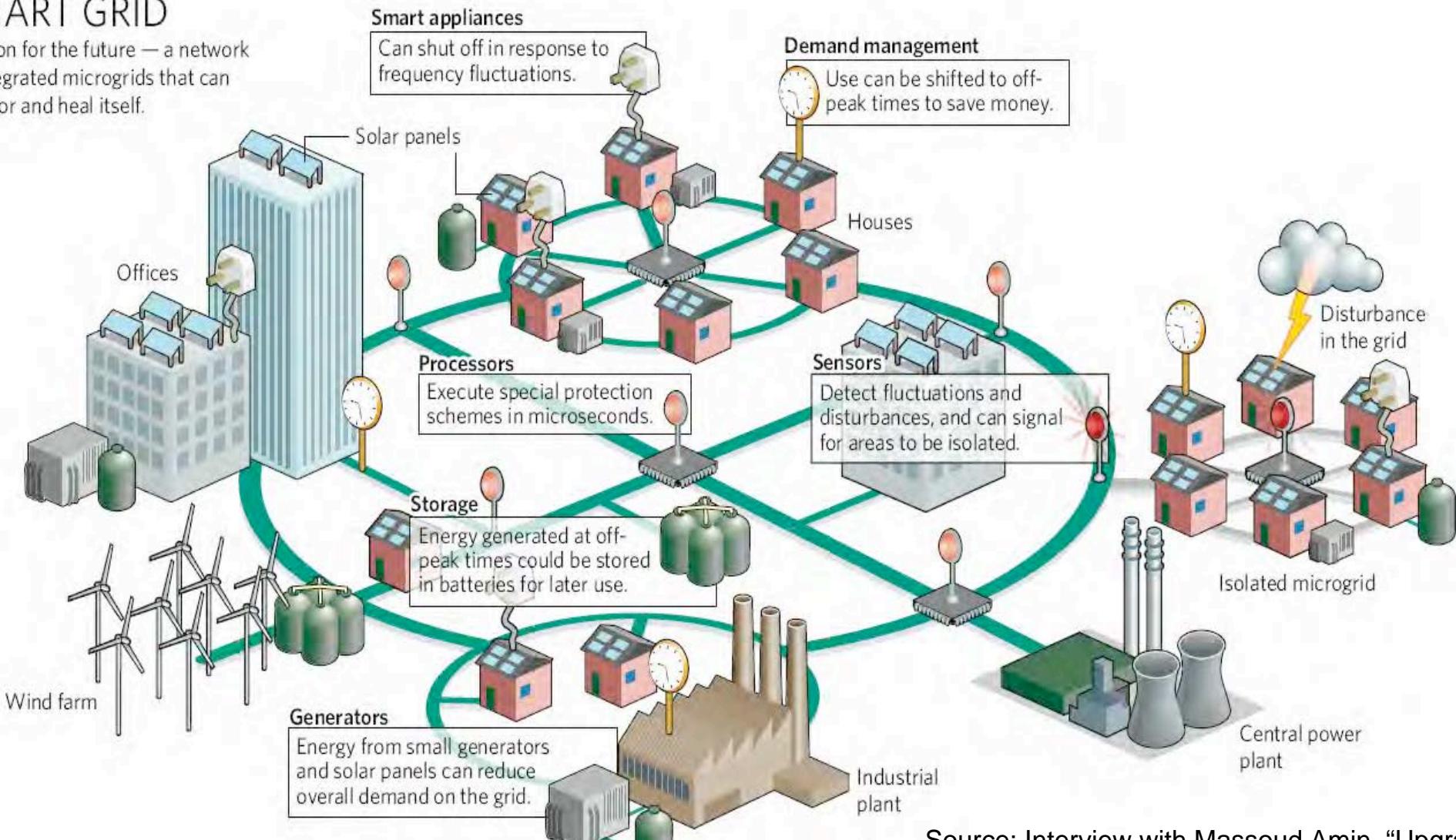


## Smart Grids

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

### SMART GRID

A vision for the future — a network of integrated microgrids that can monitor and heal itself.

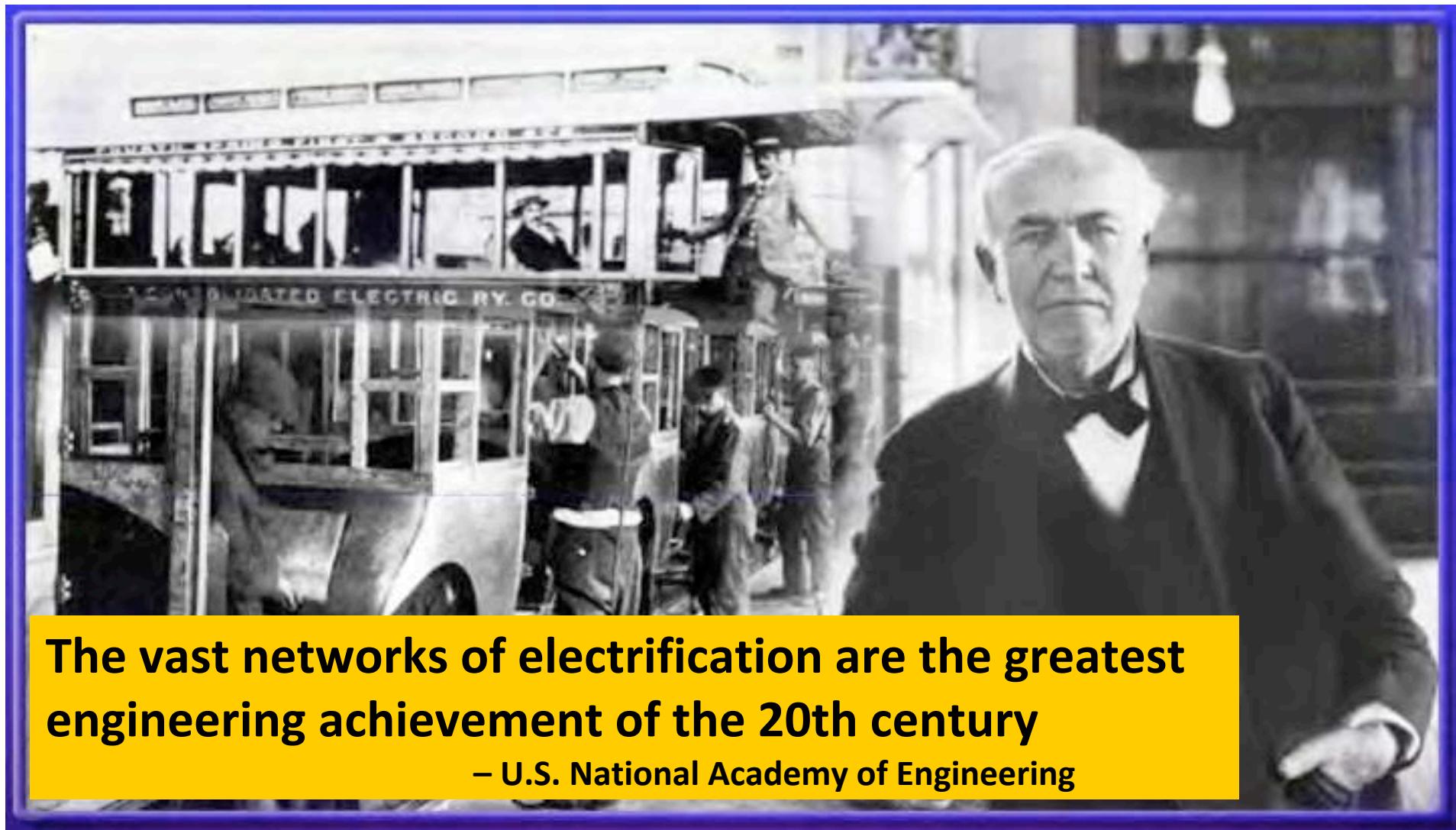


Source: Interview with Massoud Amin, "Upgrading the grid," *Nature*, vol. 454, 570–573, 30 July 2008



## North American Electric Power Grid: Greatest Engineering Achievement of the 20<sup>th</sup> Century

# Transforming Society



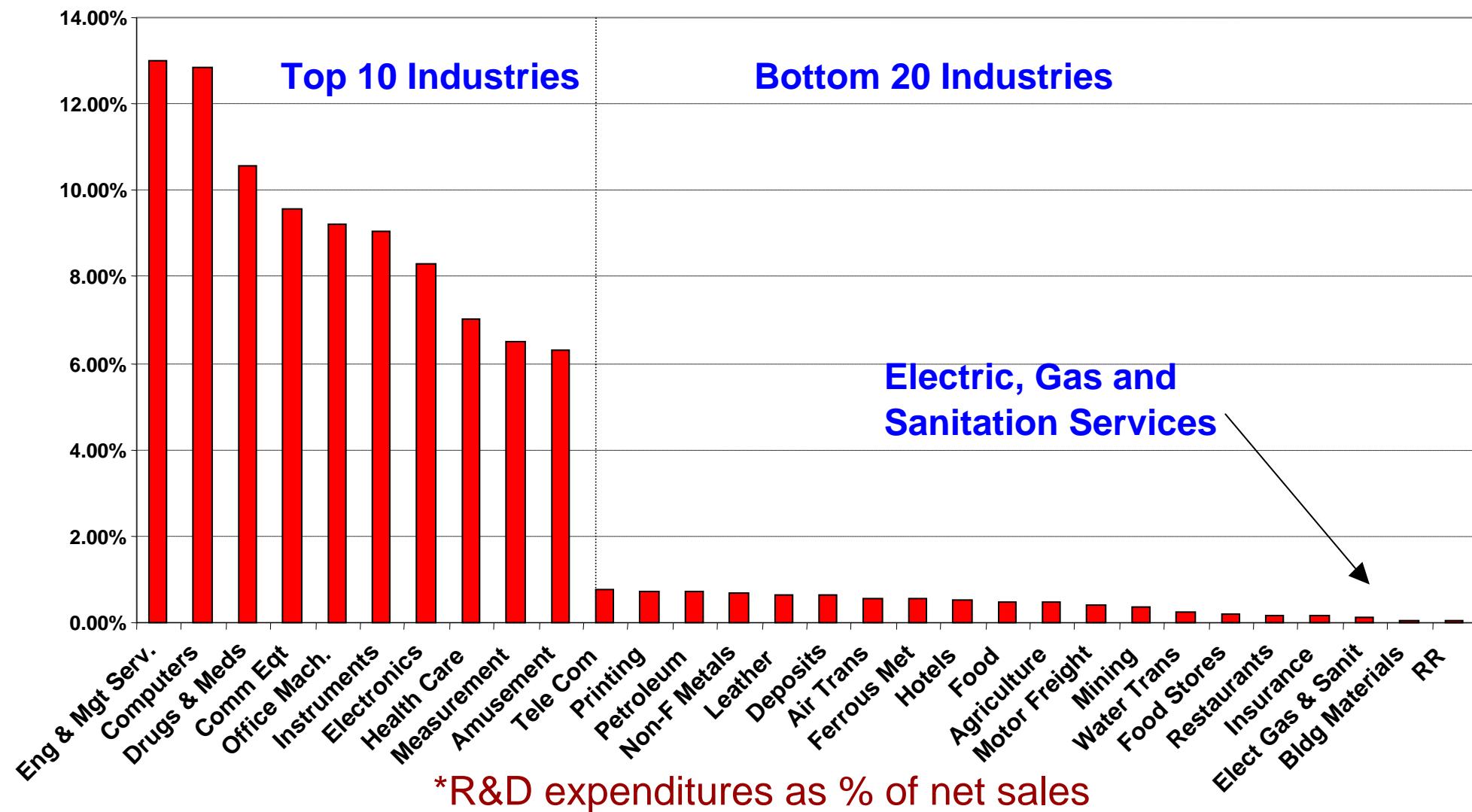
**The vast networks of electrification are the greatest engineering achievement of the 20th century**

– U.S. National Academy of Engineering



## R&D Expenditures... The Real World

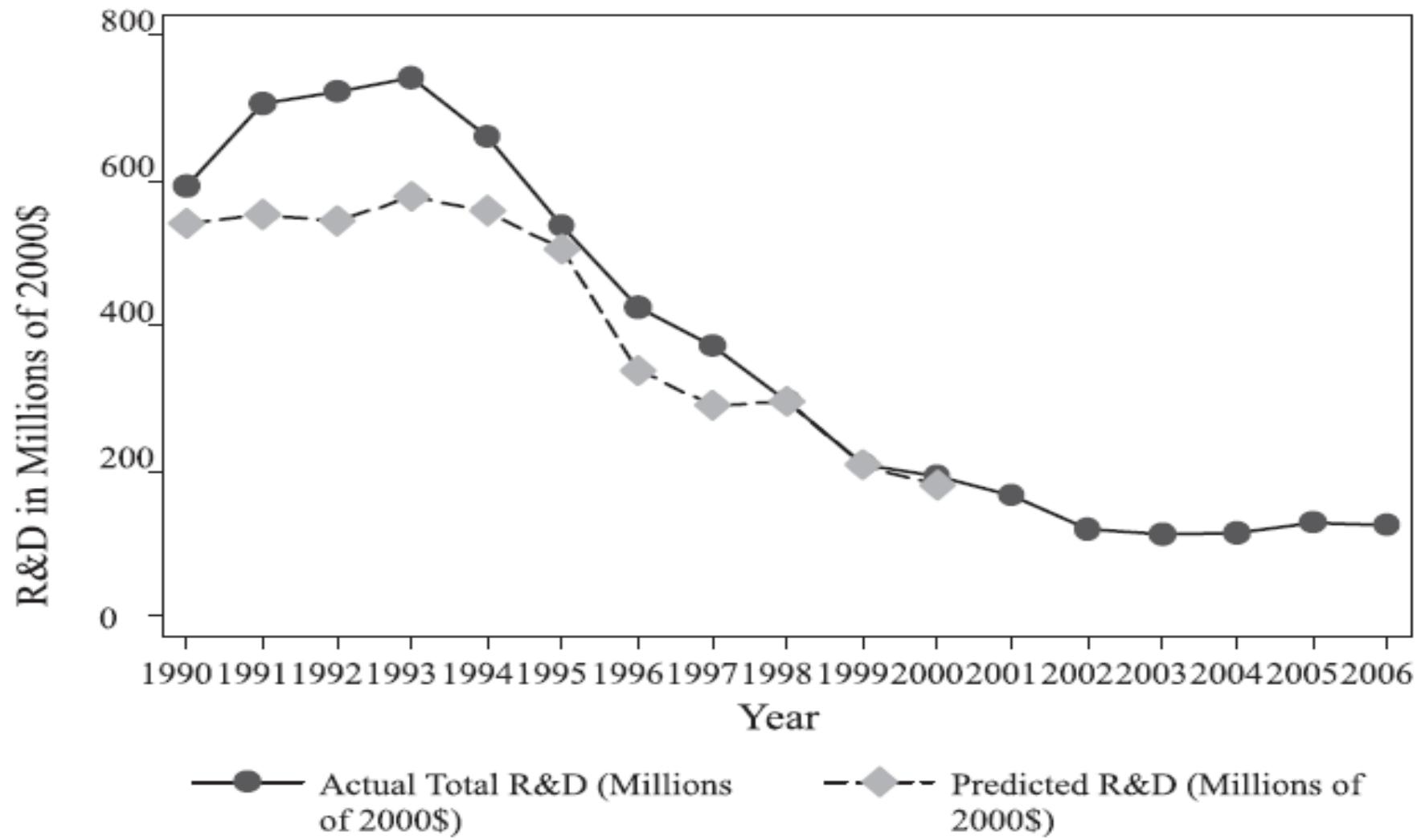
Pet food industry spends more in R&D than the electric power industry





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

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

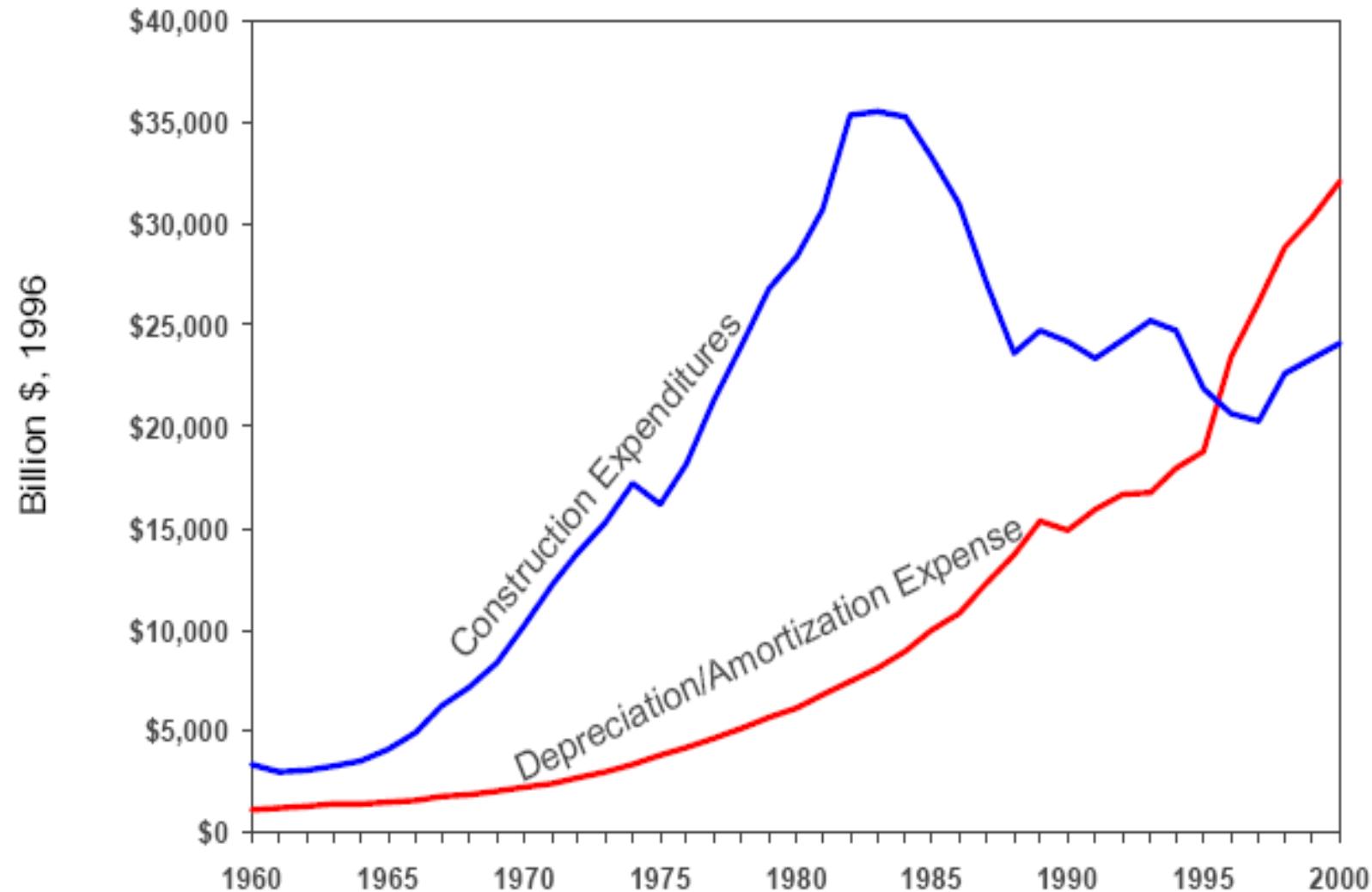


Source: "Powering Progress: Restructuring, Competition, and R&D in the U.S. Electric Utility Industry," by Paroma Sanyal and Linda Cohen, *The Energy Journal*, Vol. 30, No. 2, 2009.



## Utility construction

# Overharvesting



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



# Less Reliable Grid: Power Outages have steadily increased

OUTAGES GREATER THAN 100 MW



OUTAGES AFFECTING MORE THAN 50 000 CUSTOMERS



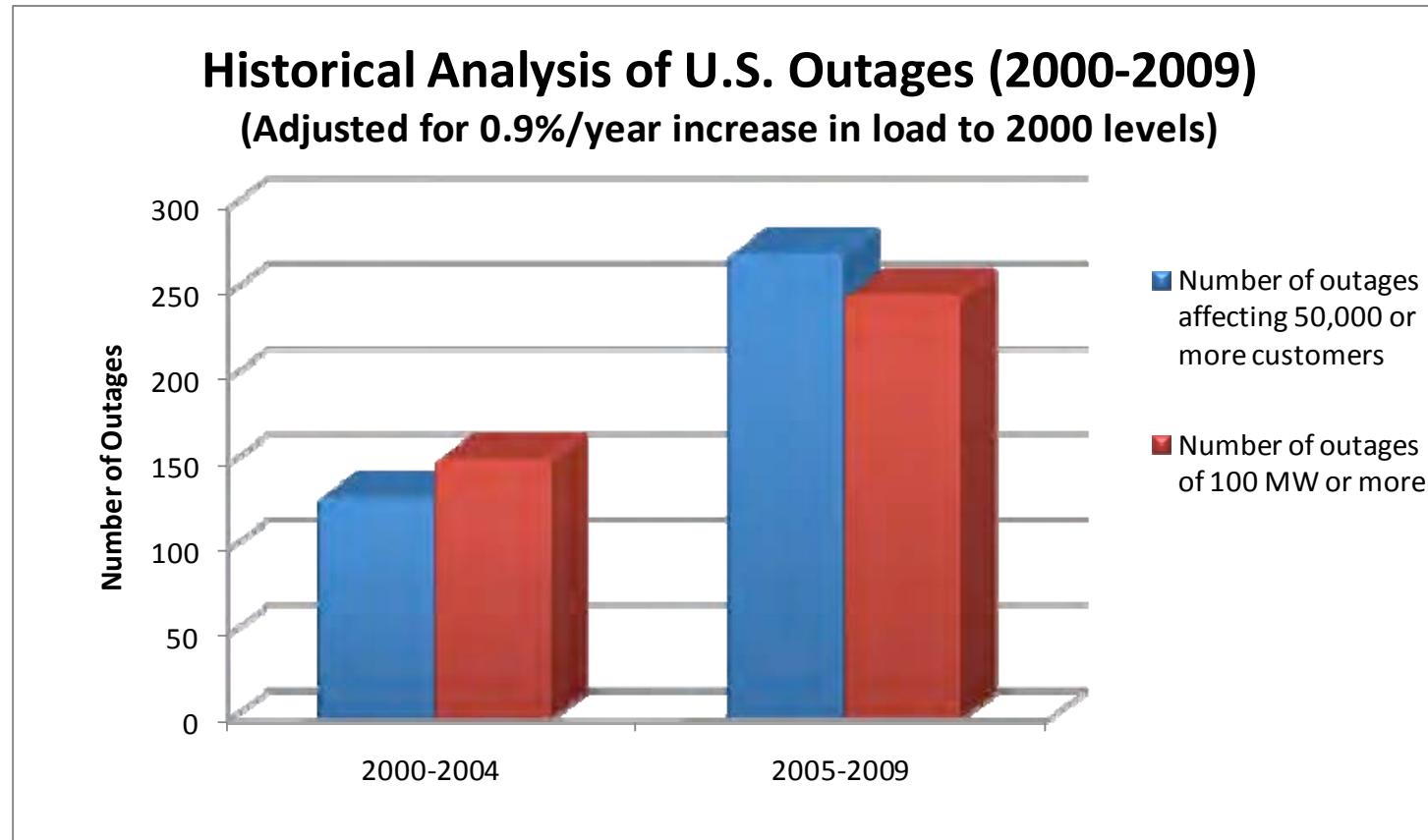
Source: Massoud Amin, "U.S. Electrical Grid Gets Less Reliable"

IEEE Spectrum, January 2011



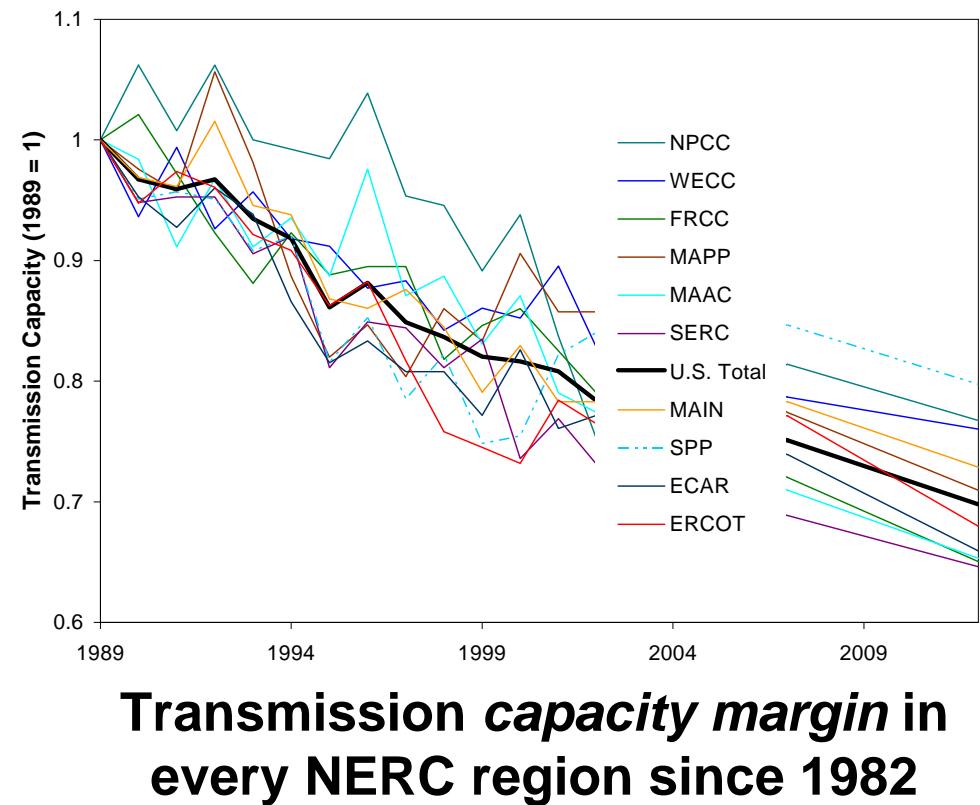
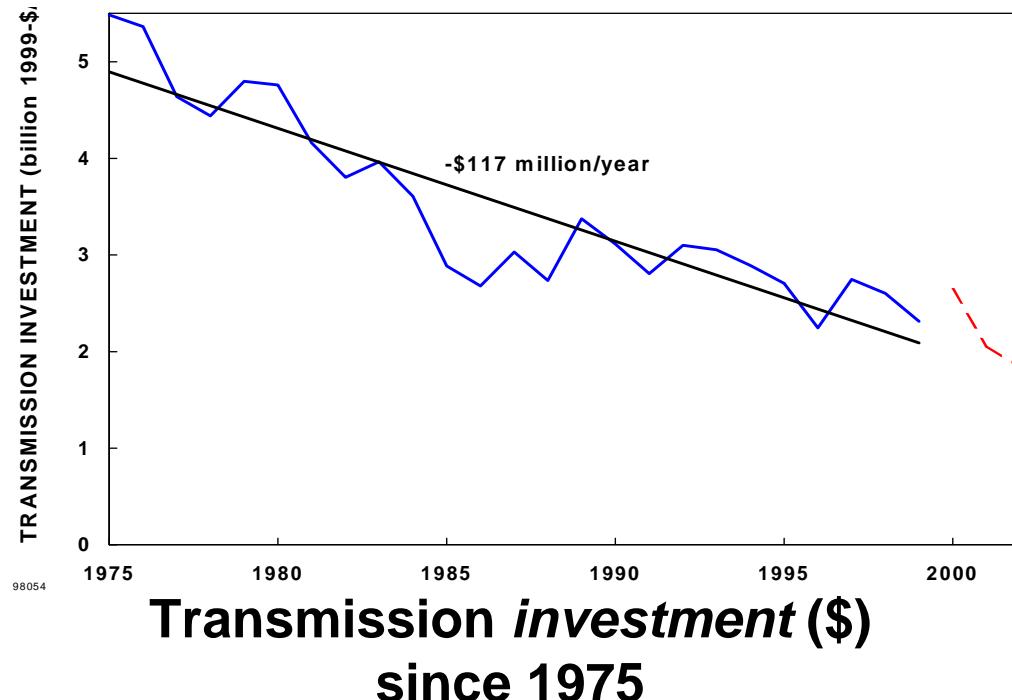
## Less Reliable Grid

**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

# Increasing Outage Events: Transmission Investment



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

## Grid Ownership & Investment in the U.S. and in International Competitive Markets

### North American Grid: Underinvested and a Complex Ownership

Country	Investment in High Voltage Transmission (>230 kV) Normalized by Load for 2004–2008 (in US\$M/GW/year)	Number of Transmission- Owning Entities
	(based on representative data from EEI)	
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	450 (69 in EEI)

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

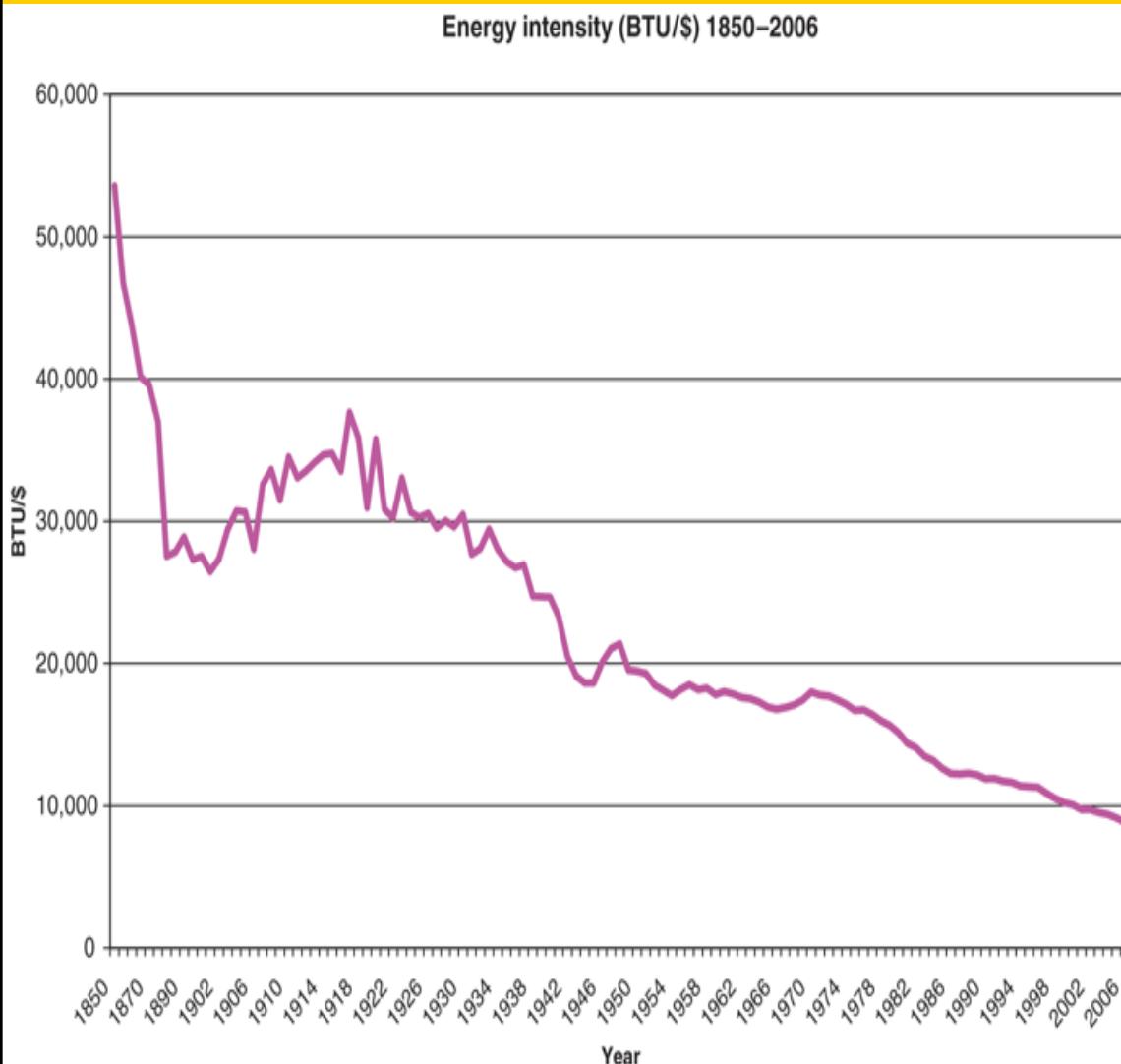
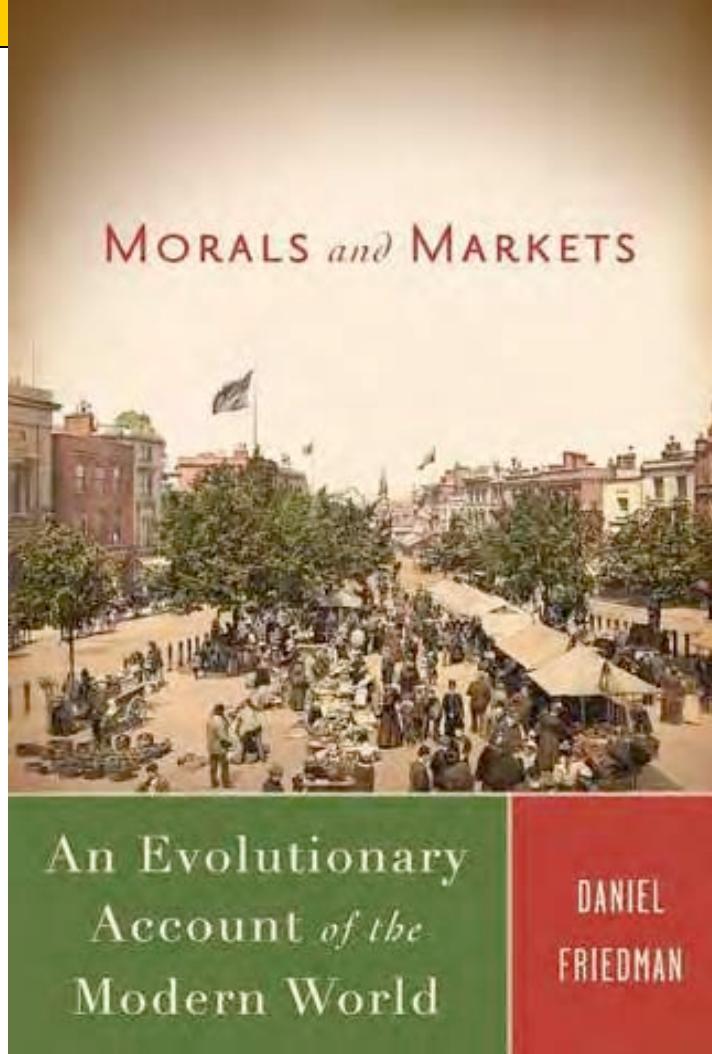
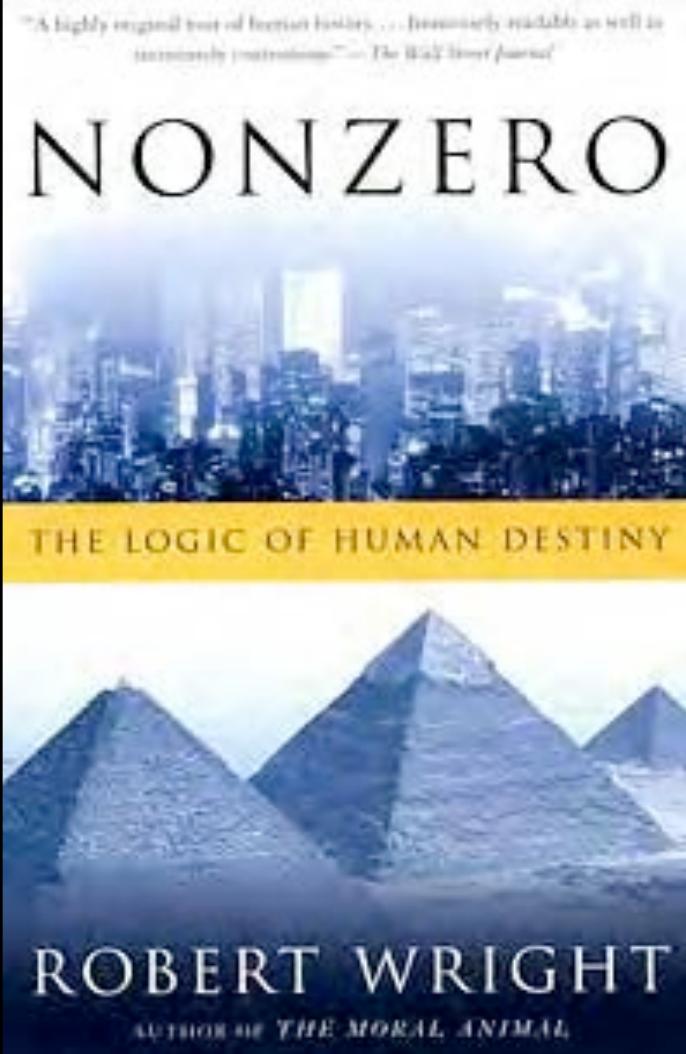


TABLE 1 Energy Use in 2005—Per Capita and Per Dollar of GDP

	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

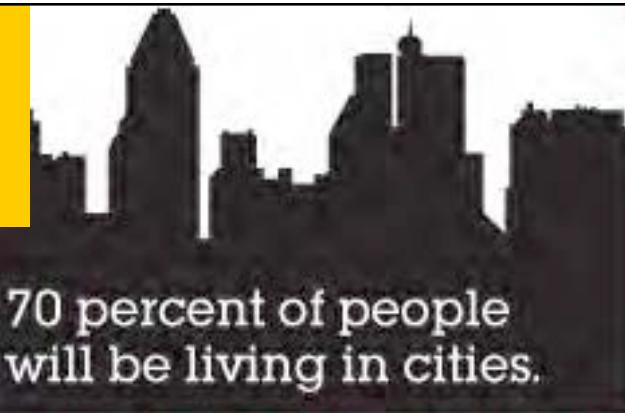
Source: EIA, 2009b,c.

# Technologies are diverse value creation mechanisms



Source: IBM, please also see Paul Romer's Charter Cities Video: [http://www.ted.com/talks/paul\\_romer.html](http://www.ted.com/talks/paul_romer.html)

# Smarter about education, safety, energy, water, food, transp., e-gov, ... Innovative Cities:



70 percent of people will be living in cities.

There will be at least 27 "megacities" of 10 million people, compared to 19 today.

'Cities are perfect for promoting change and renewable energies. Cities can serve as innovation platforms, creating clusters of business around green energy.'

Claude Turmes

Member of the European Parliament,  
Reuters, February 10, 2009

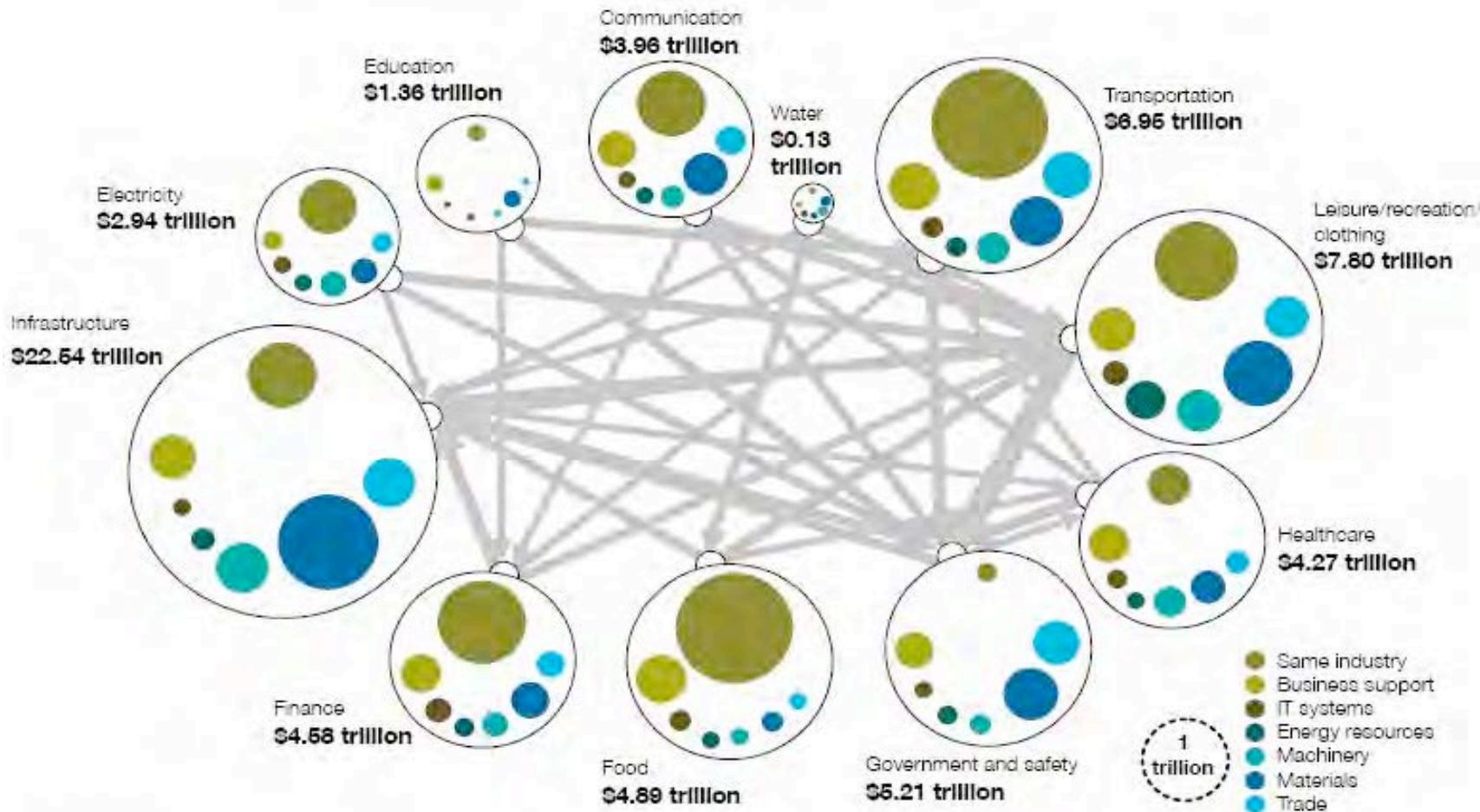
## Top 10 cities

Rank	Country	City	Rating
1	Canada	Vancouver	98.0
2	Austria	Vienna	97.9
3	Australia	Melbourne	97.5
4	Canada	Toronto	97.2
5	Canada	Calgary	96.6
6	Finland	Helsinki	96.2
7	Australia	Sydney	96.1
8=	Australia	Perth	95.9
8=	Australia	Adelaide	95.9
10	New Zealand	Auckland	95.7

Source: IBM and Economist

# Holistic Modeling:

The world as a \$54 trillion system of systems (Korsten & Seider 2010)



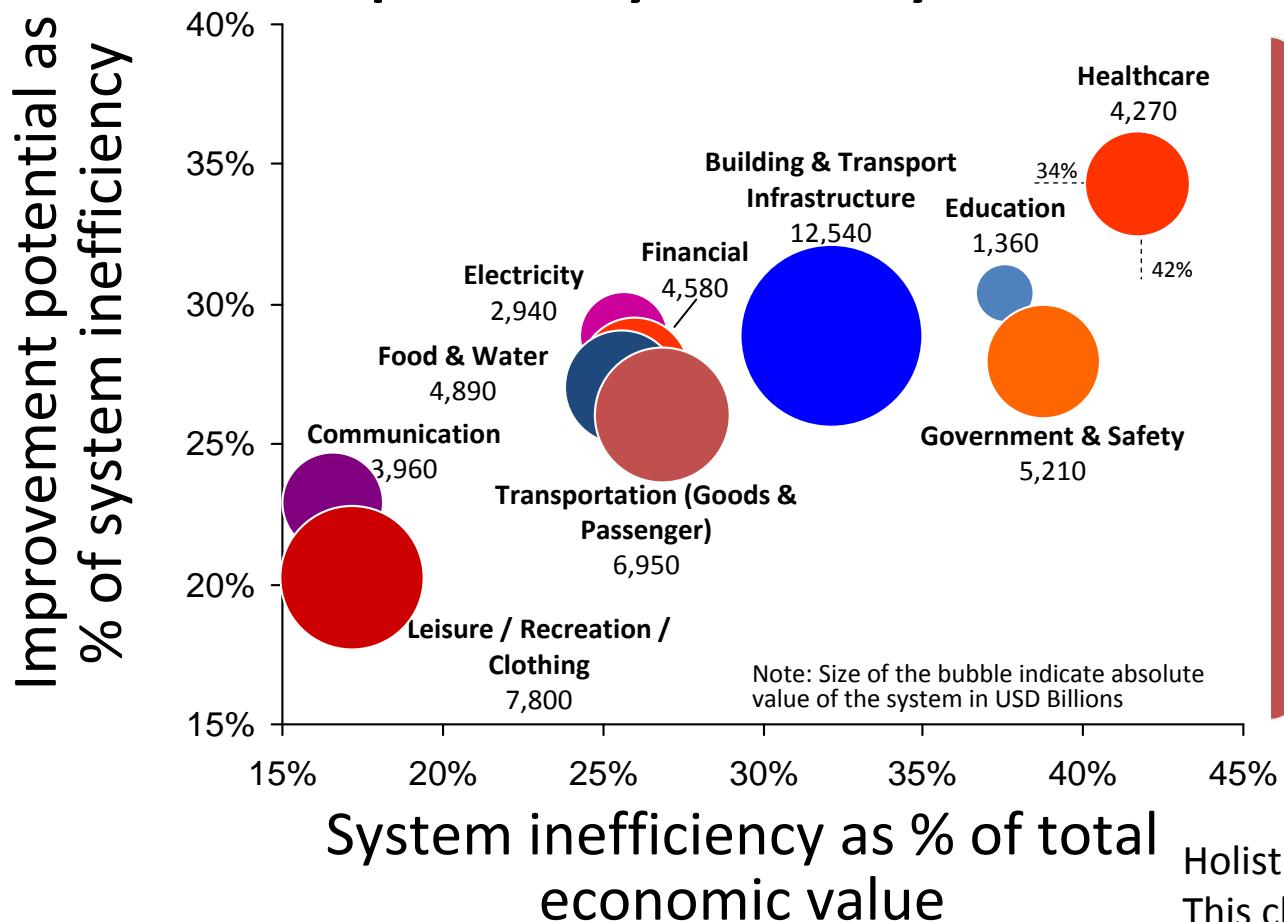
Note: Size of bubbles represents systems' economic values. Arrows represent the strength of systems' interaction.

Source: IBM Institute for Business Value analysis of Organisation for Economic Co-operation and Development (OECD) data.

Figure 1: We live and work within a complex, dynamic and interconnected US\$54 trillion system of systems.

**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

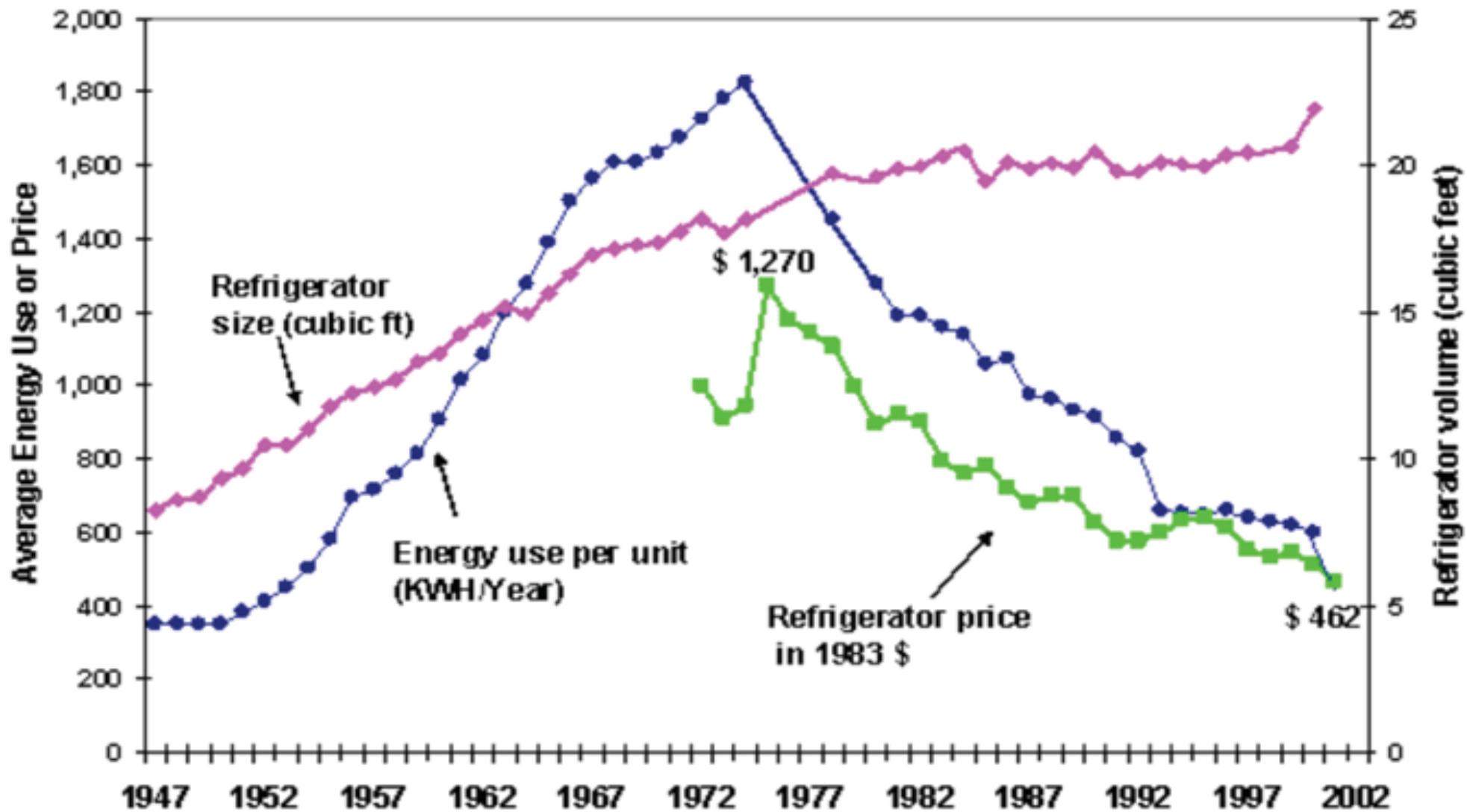
System-of-systems	<b>\$54 Trillion</b> 100% of WW 2008 GDP
Inefficiencies	<b>\$15 Trillion</b> 28% of WW 2008 GDP
Improvement potential	<b>\$4 Trillion</b> 7% of WW 2008 GDP

### 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

# Example: Energy Efficiency of refrigerator



# Example: Energy Use in Buildings

**81 million single-family houses, 25 million multifamily residences, 7 million mobile homes, together with 75 billion sqft of commercial floor space...**

**... account for 73% of electricity use and 40% of total energy use in the U.S.**

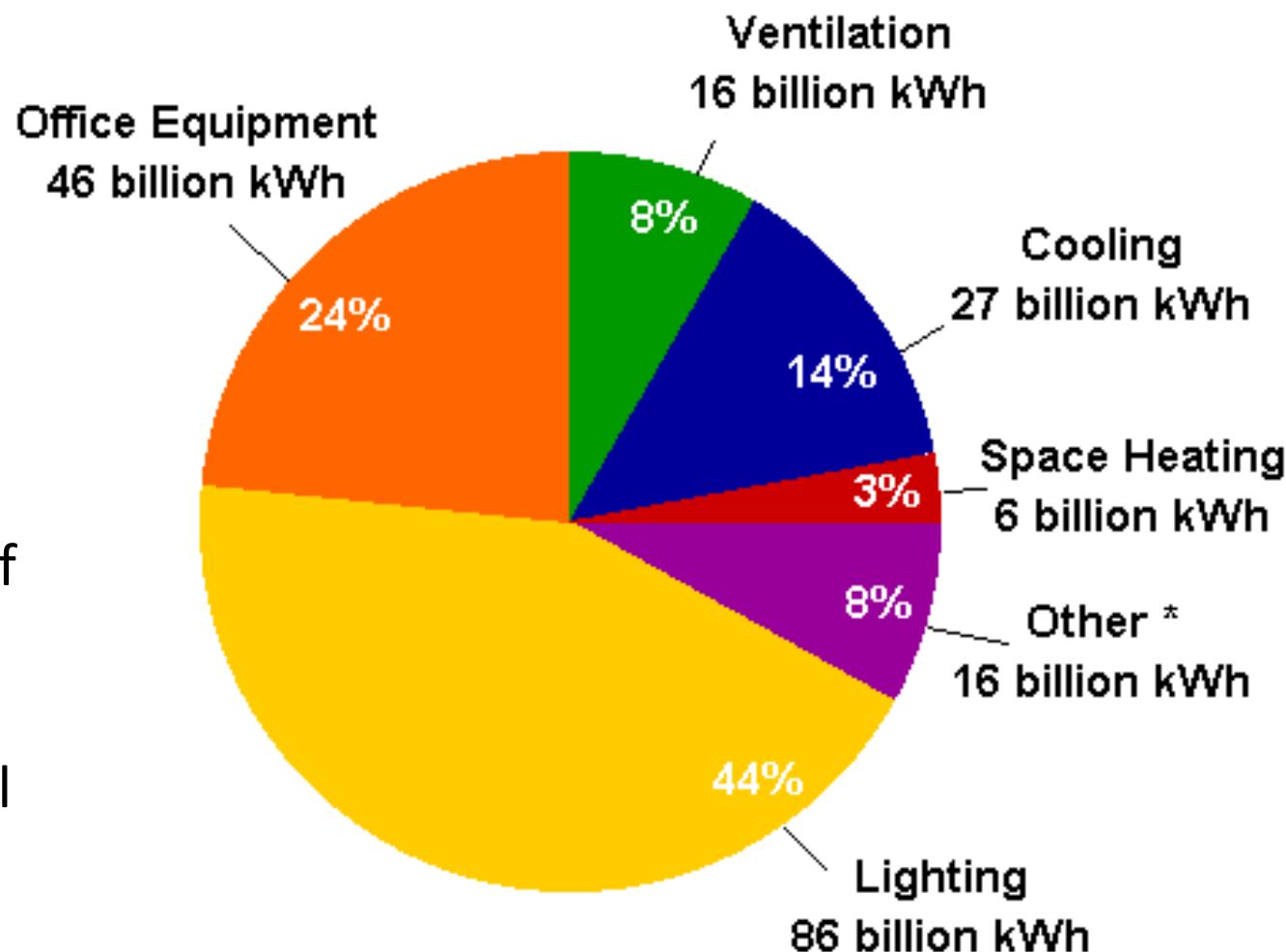
- From 1975 to 2005, despite increased energy efficiencies, an increase in the number of residences and the amount of commercial space led to substantial increases in total energy use—15 percent in residential buildings and 50 percent in commercial buildings
- The efficiency gains, which were made in refrigerators and lighting, as well as in air conditioners, building envelopes, and many appliances, were promoted by Energy Star labeling of appliances and even of buildings
- For example, the number of new residences that attained Energy Star status increased from 57,000 in 2001 to 189,000 in 2006. For buildings, the median cost-effective and achievable potential (taking barriers to implementation into account) are 24 percent for electricity and 9 percent for natural gas (sensitive to price, especially for natural gas)



## Electricity use in office buildings

# How do they use electricity?

- Office buildings use 198 billion kWh within the building) each year.
- An electricity intensity of 18.9 kWh per square foot, a bit higher than the average for all commercial buildings.



\* Other includes miscellaneous uses (13 billion kWh), water heating (2 billion kWh), refrigeration (1 billion kWh), and cooking (<1 billion kWh).

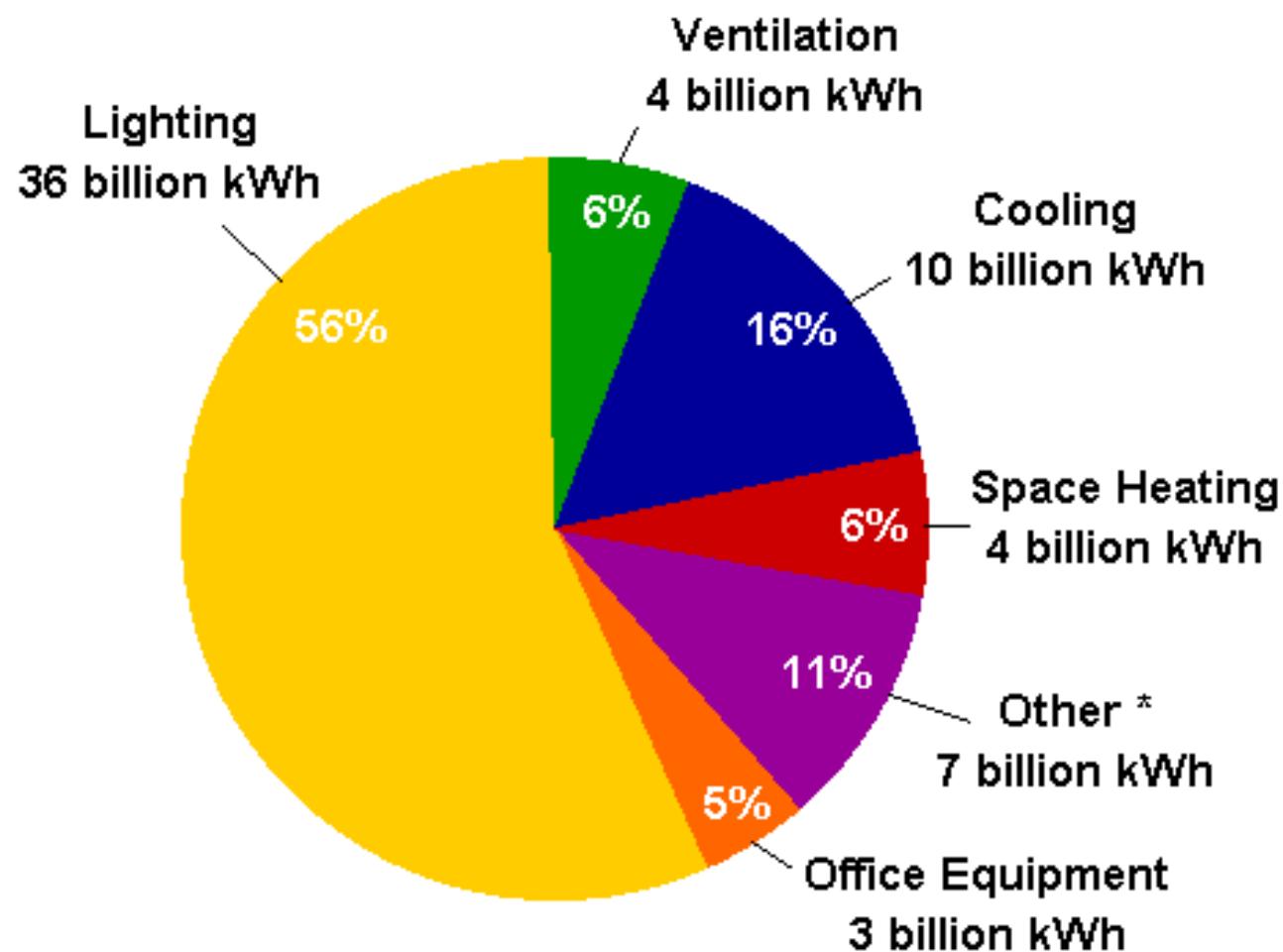
Source: U.S. DOE EIA



## Electricity use in education buildings

# How do they use electricity?

- 65 billion kWh electricity used within the building each year
- An electricity intensity of 8.4 kWh per square foot, lower than the average for all commercial buildings



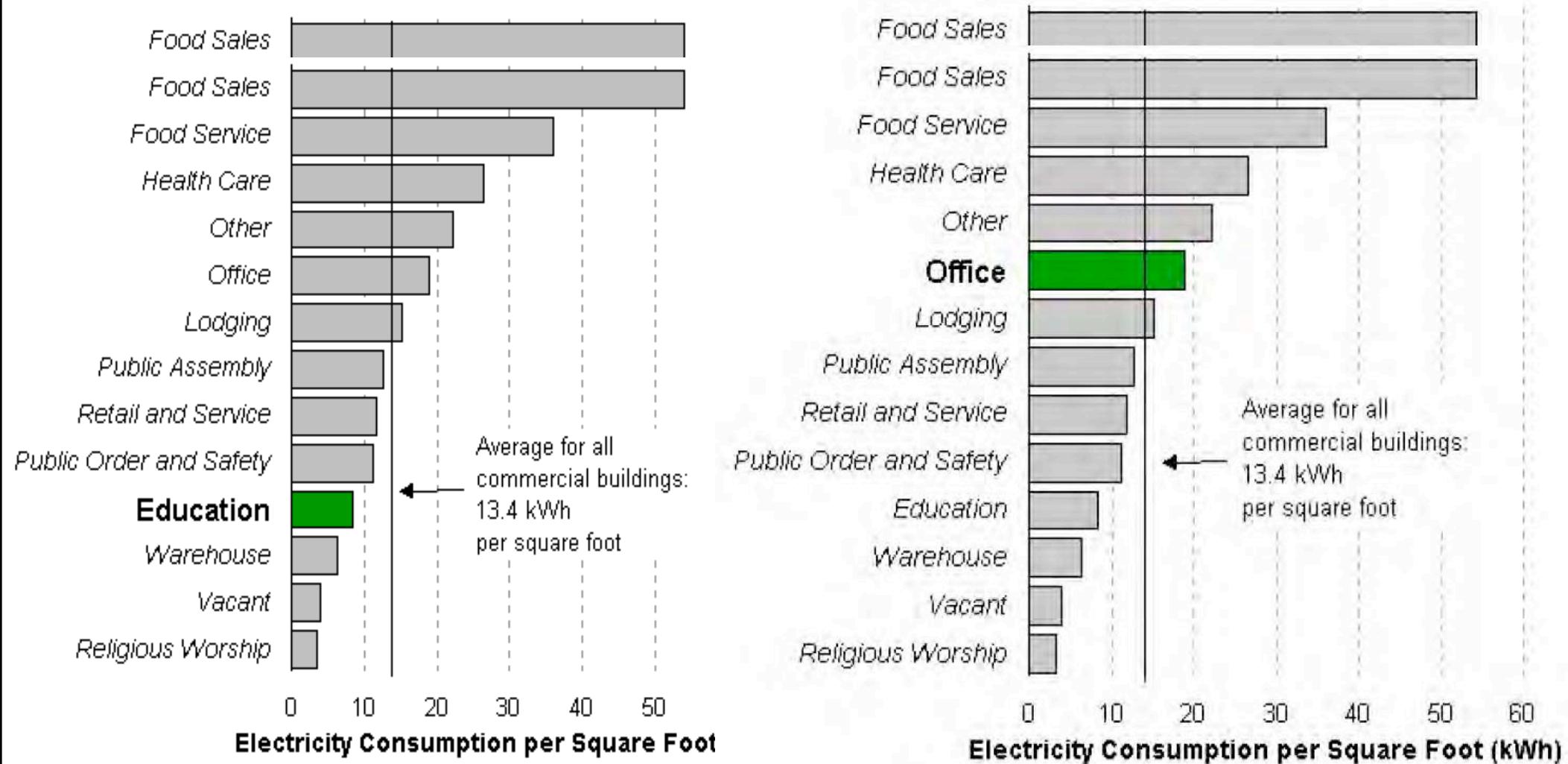
\* Other includes miscellaneous uses (2 billion kWh), water heating (2 billion kWh), refrigeration (2 billion kWh), and cooking (1 billion kWh).

Source: U.S. DOE EIA



## Electricity use in education and office buildings

# How do they use electricity?





## Trends in Electricity Use (2000-2010)

# Electronics and Continued Electrification Drive the Growth

2000 – 2010



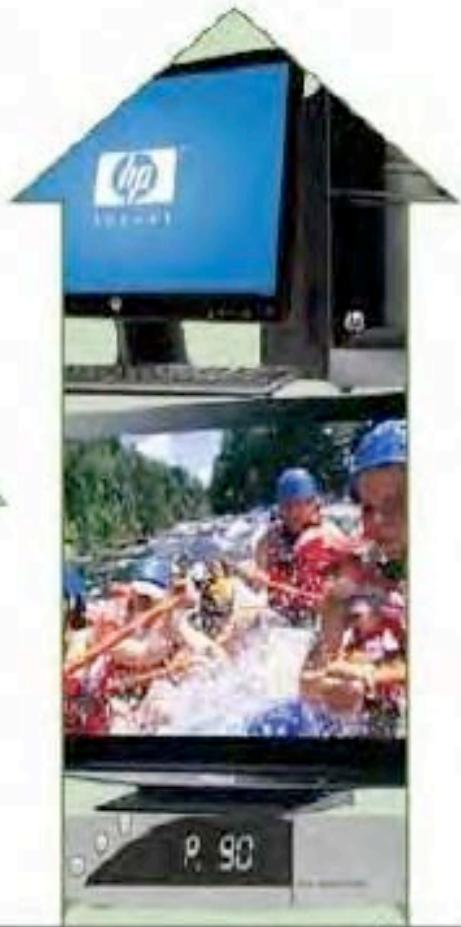
**Summer Peak Demand**  
790 GW  
(16% Growth)



**Electricity Use**  
3,750 TWh  
(10% Growth)



**Space Cooling**  
326 TWh  
(115% Growth)



**TV/PC**  
152 TWh  
(180% Growth)

## 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



Internet TV



Online Gaming



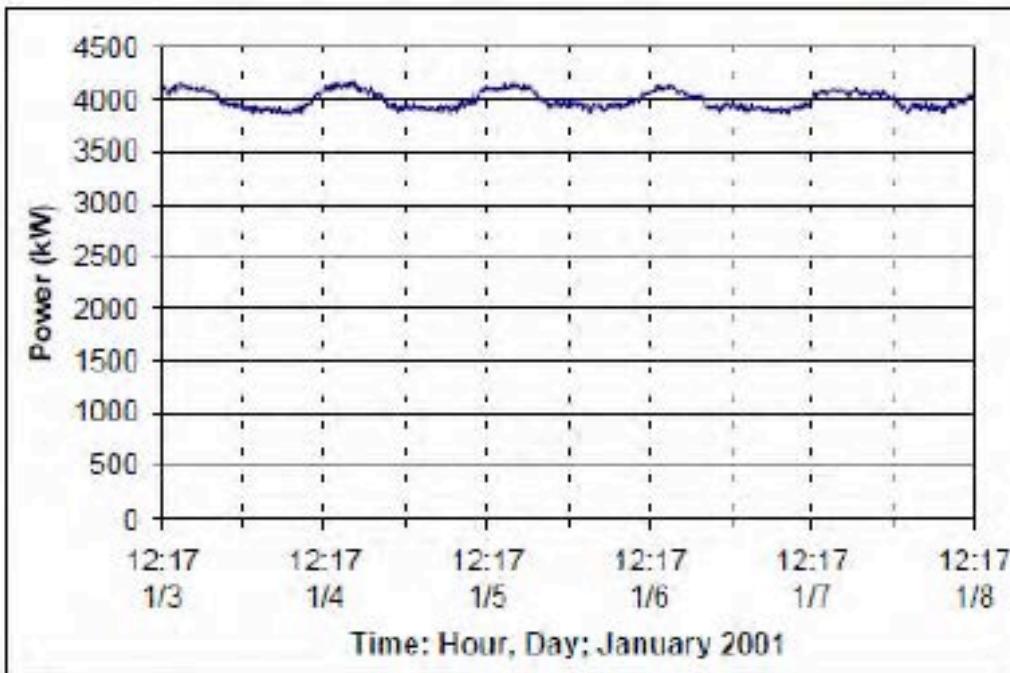
Digitization of Records

Digital Technologies... Store, Route, Stream data and video... like never before!

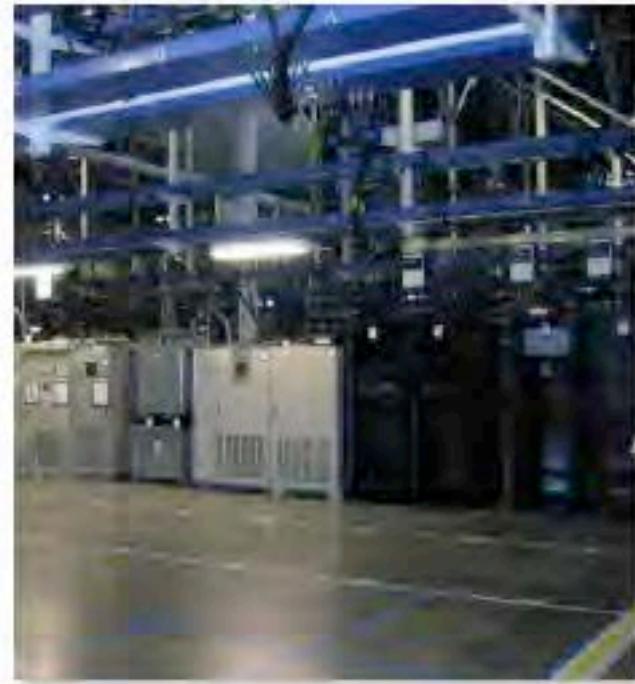


## The Next “Industrial Revolution”...Data Centers

# Expected to Double Every 5 Years...



**Flat Load Profile of Data Centers**



**Data Center Server Room**

## By 2030 Could Reach 20% of Total U.S. Electricity Use

- How many watts used per iPhone, Smart Phone and Blackberry device?
- What infrastructure quality of service and security do we expect?

Source: EPRI

Smarter and Stronger Grid

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

Recommendations for moving to energy systems to meet demand of tomorrow

- **Build a stronger and smarter electrical energy infrastructure**

- Transform the Network into a Smart Grid
- Develop an Expanded Transmission System
- Develop Massive Electricity Storage Systems

- **Break our addiction to oil by transforming transportation**

- Electrify Transportation: Plug-In Hybrid Electric Vehicles
- Develop and Use Alternative Transportation Fuels

- **Green the electric power supply**

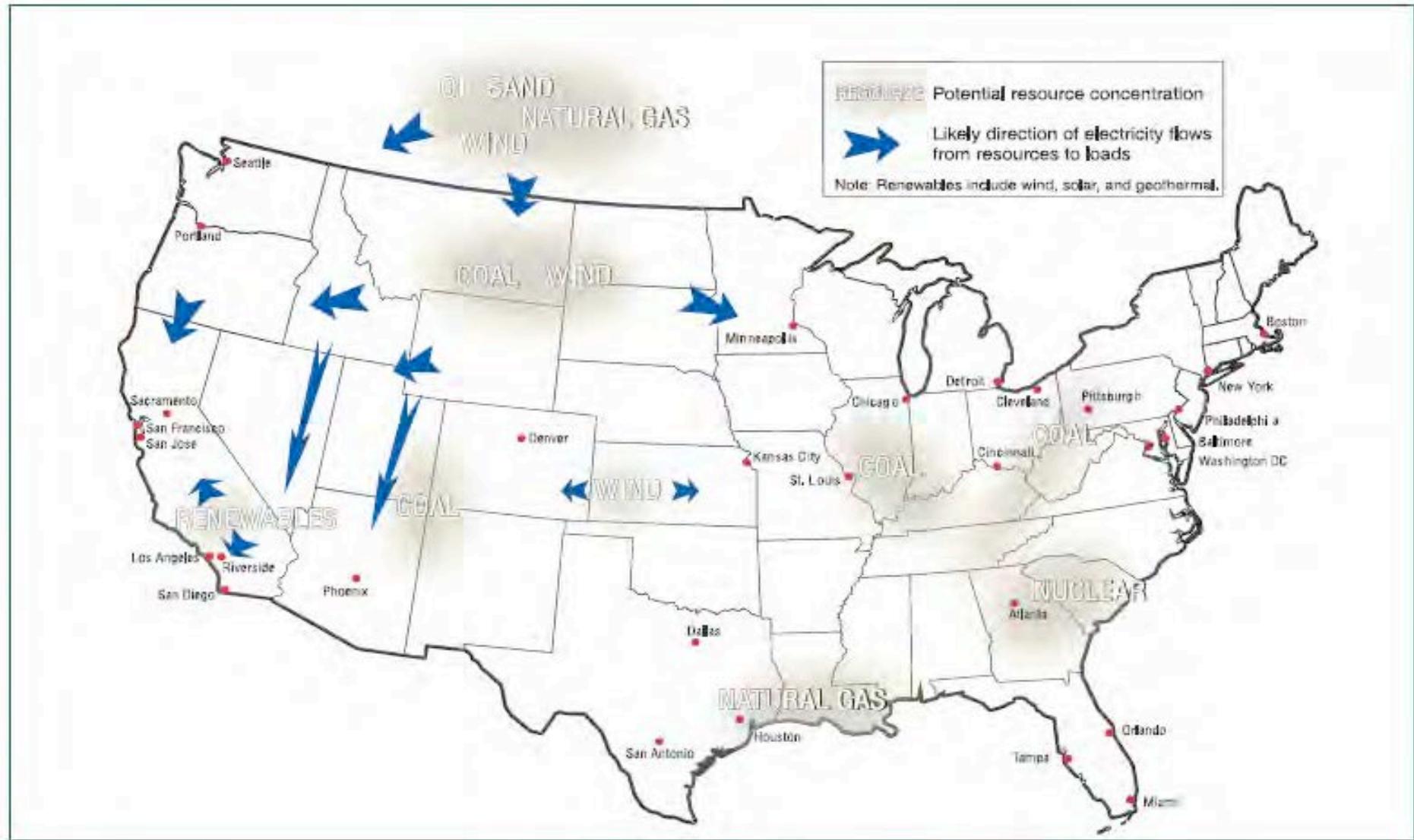
- Expand the Use of Renewable Electric Generation
- Expand Nuclear Power Generation
- Capture Carbon Emissions from Fossil Power Plants

- **Increase energy efficiency**



## Stronger Grid

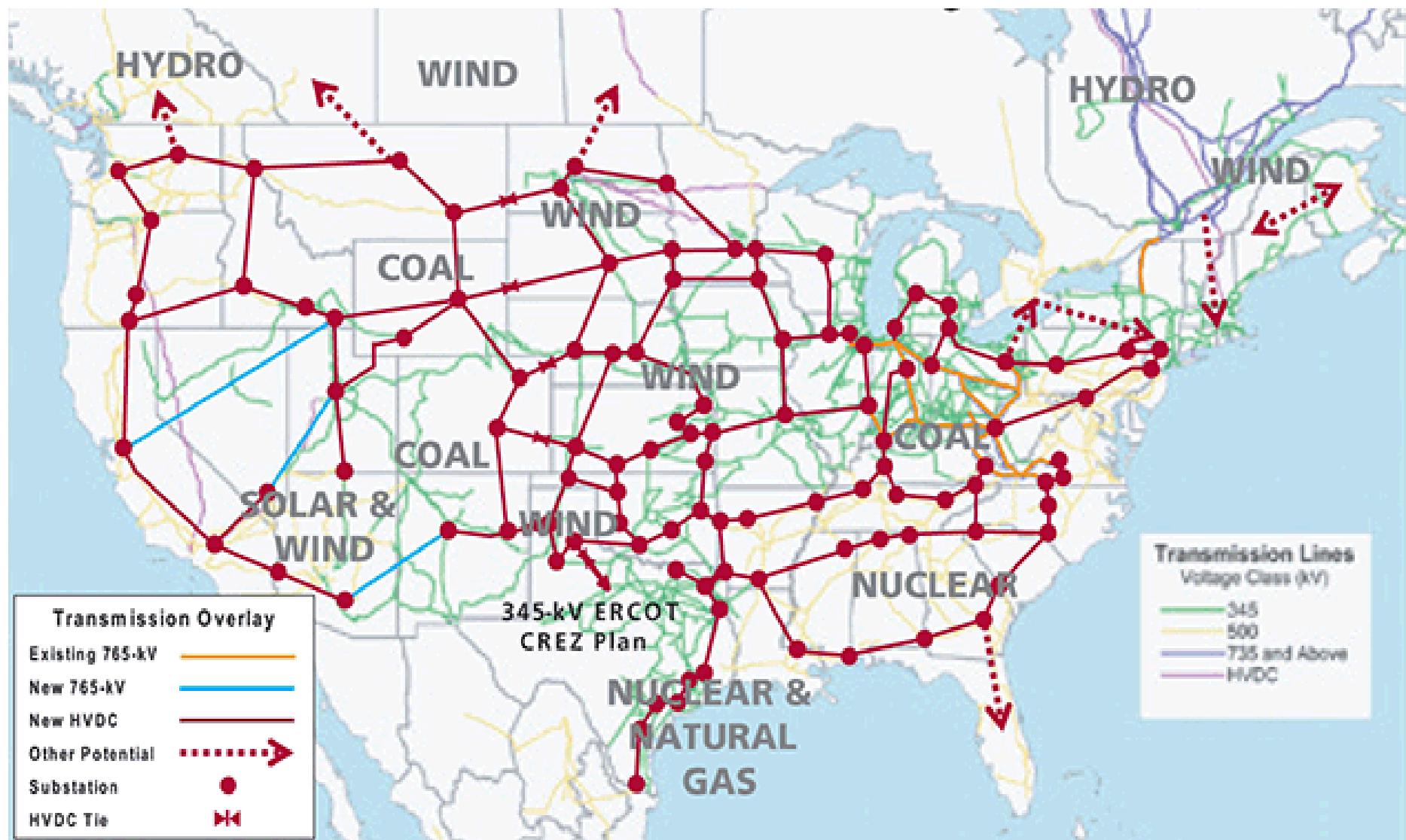
# Emerging Supply and Demand Patterns





## Stronger Grid

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



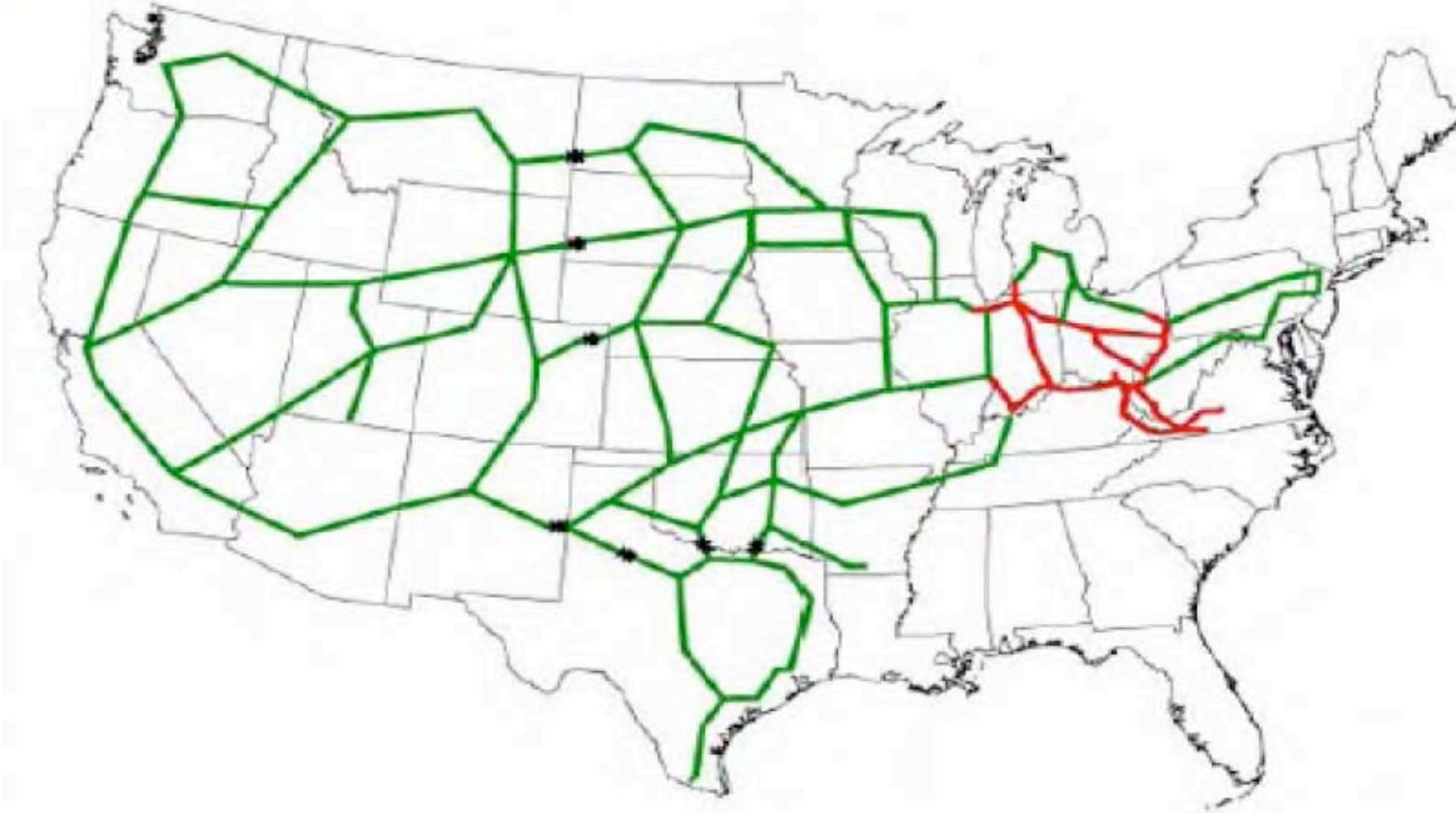
Map adapted from the U.S. DOE National Electric Transmission Congestion Study

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Stronger Grid

# Transmission System Upgrade Assessments



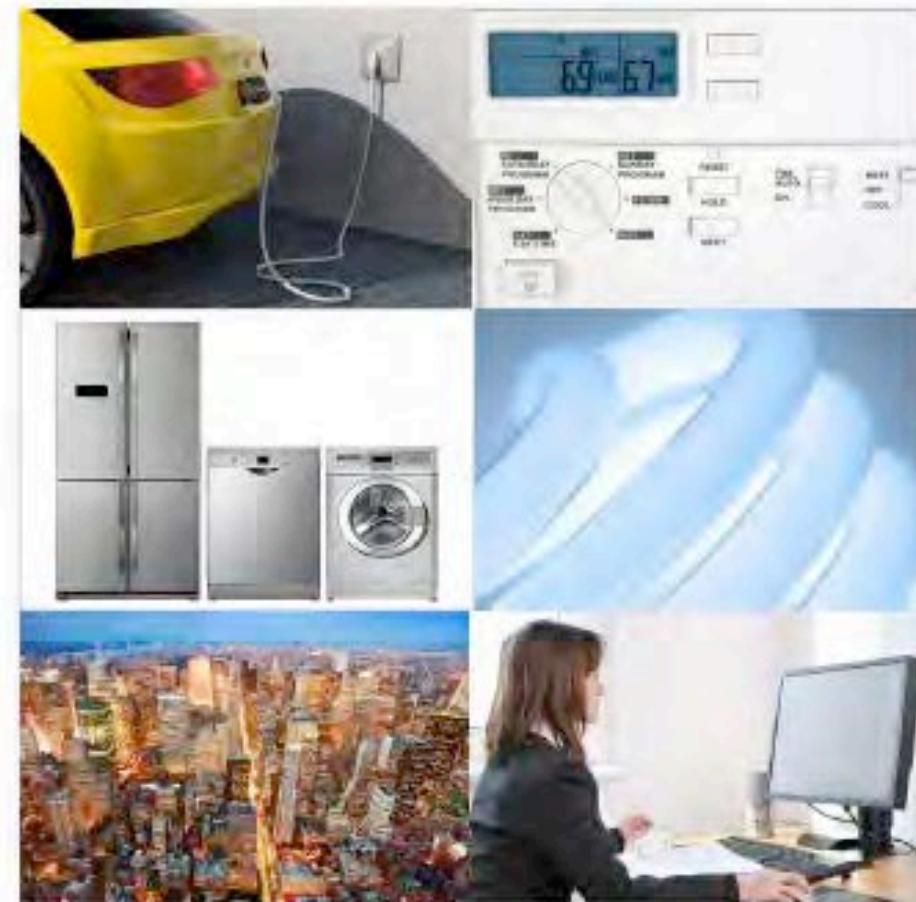
New 765-kV lines are shown in green and new interties in black, complementing the existing 765-kV system shown in red, to facilitate deployment of up to 400 GW of additional wind capacity.



## Smart Grid: Technological Innovations

### Customer

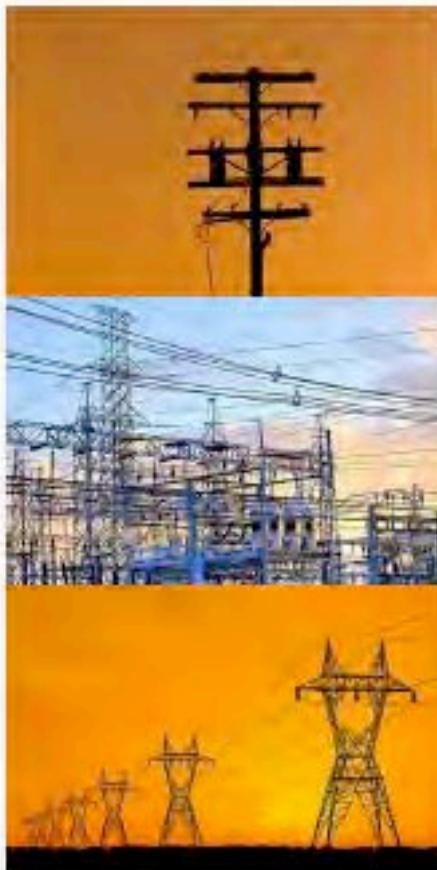
- Smart Appliances
- Electric Vehicles
- Energy Efficiency
- Demand Response
- Distributed Energy Resources





## Smart Grid: Technological Innovations

# Smart Grid and Power Delivery



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

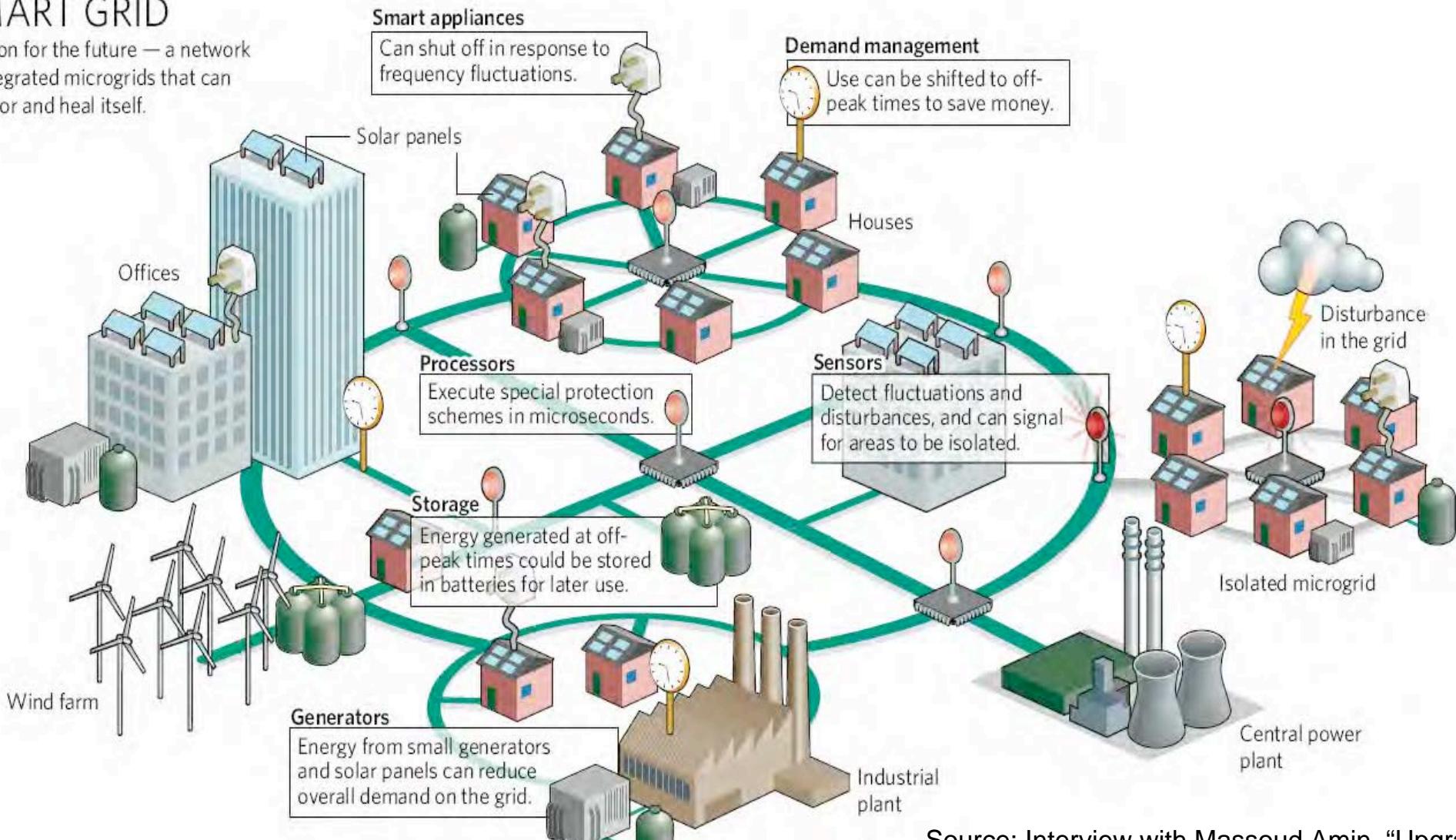


## Smart Grids

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

### SMART GRID

A vision for the future — a network of integrated microgrids that can monitor and heal itself.

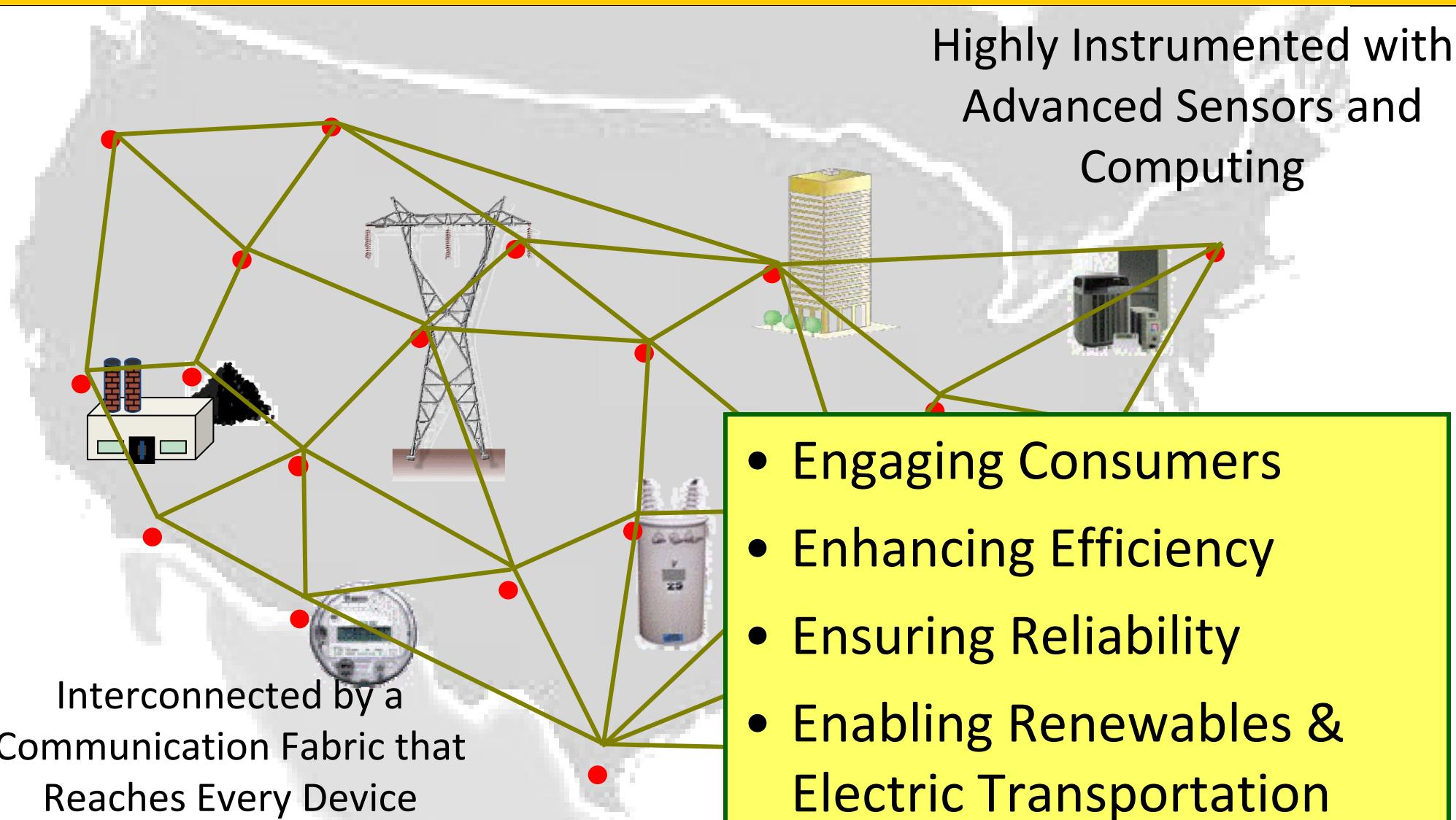


Source: Interview with Massoud Amin, "Upgrading the grid," *Nature*, vol. 454, 570–573, 30 July 2008



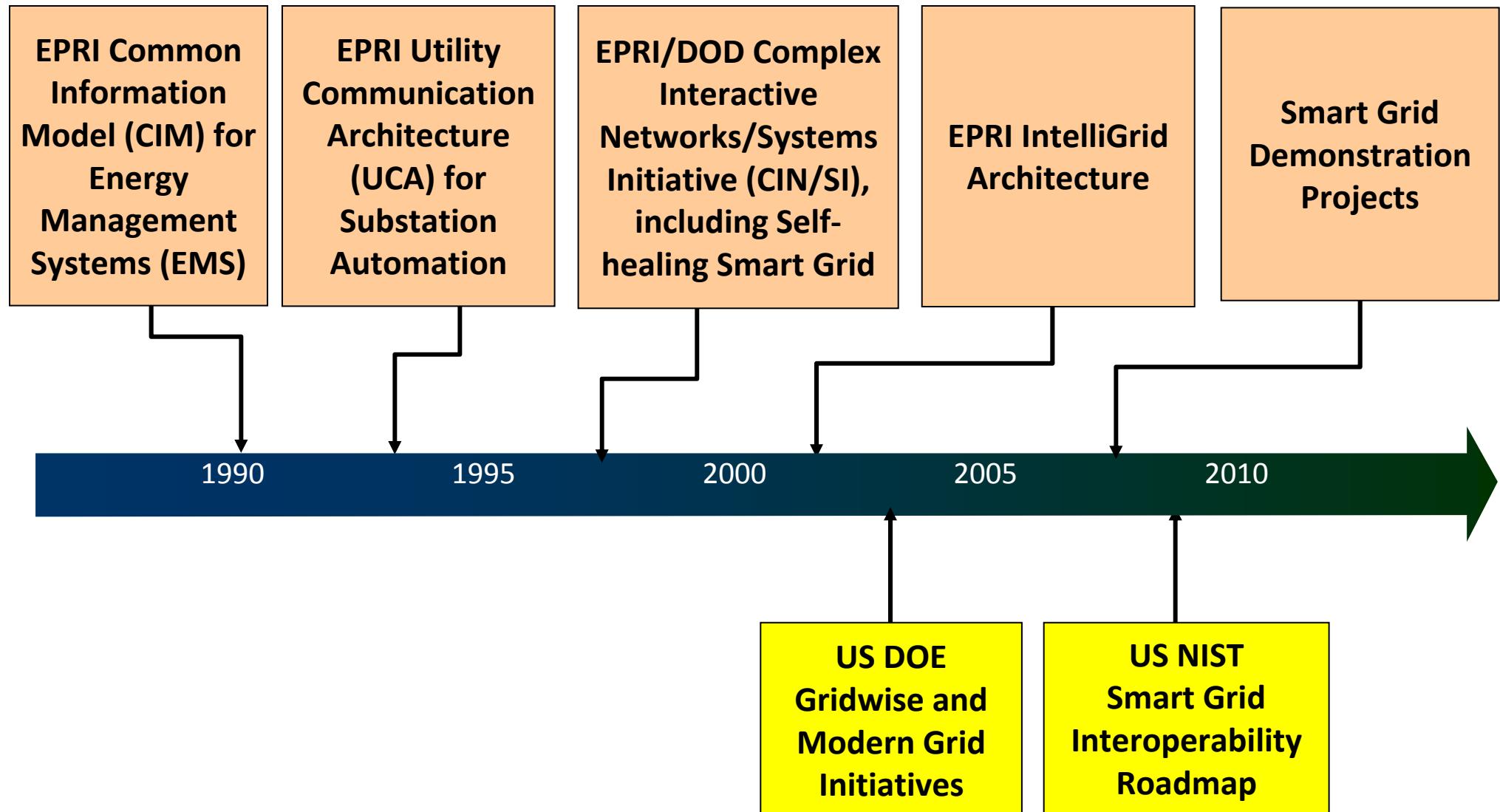
## Many Definitions – But One VISION

# Visualizing the Smart Grid



## Smart Grids

# Evolution of Smart Grid Programs at DOE and EPRI



## Smart Grids

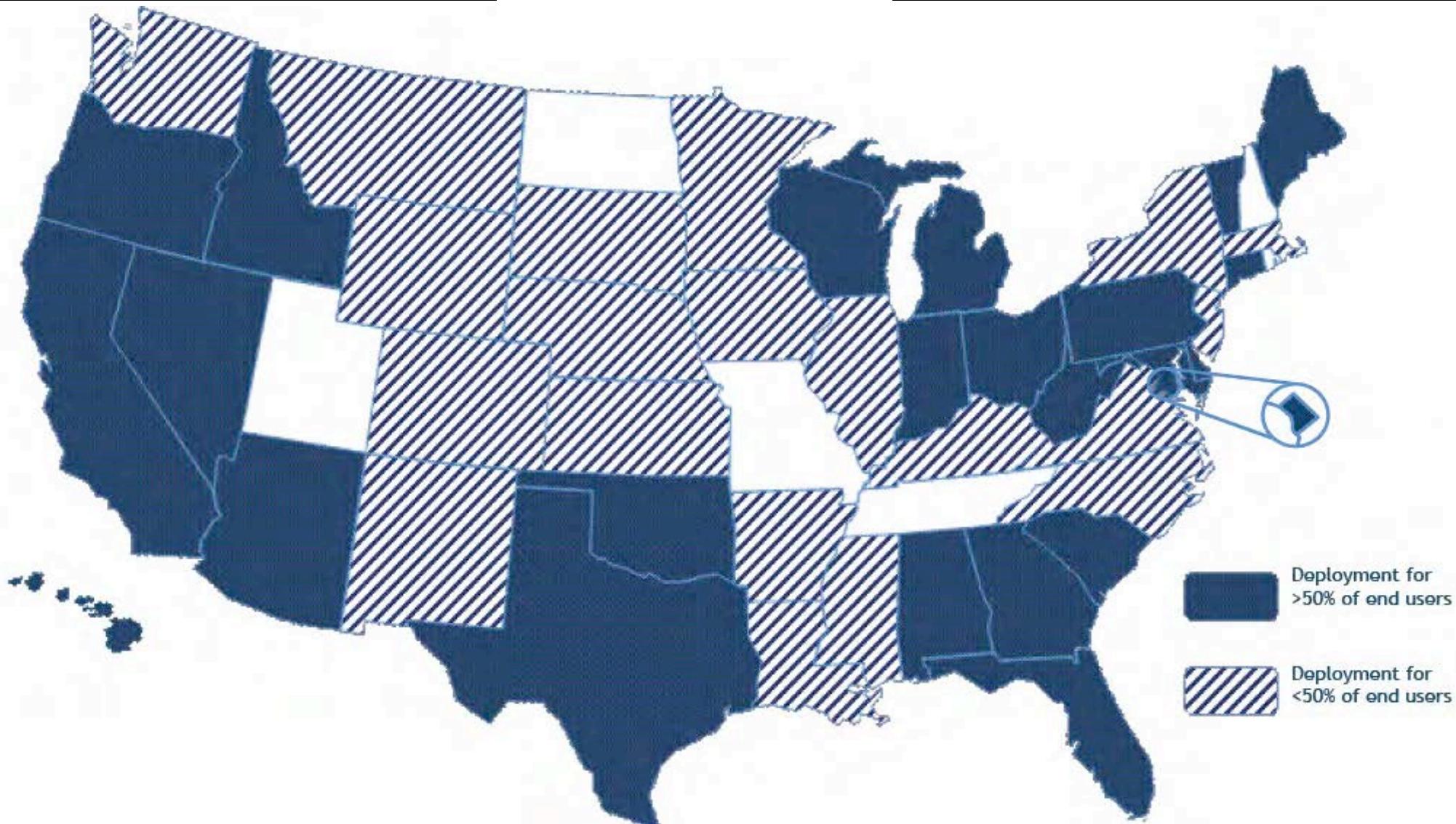
# 14 Years in the Making

- Self-Healing Grid (May 1998- Dec. 2002)
  - 1998-2002: EPRI/DOD Complex Interactive Networks/Systems Initiative (CIN/SI):
  - 108 professors and over 240 graduate students in 28 U.S. universities funded, including Carnegie Mellon, Minnesota, Illinois, Arizona St., Iowa St., Purdue, Harvard, MIT, Cornell, UC-Berkeley, Wisconsin, RPI, UTAM, Cal Tech, UCLA, and Stanford.
  - 52 utilities and ISO (including TVA, ComEd/Exelon, CA-ISO, ISO-NE, etc.) provided feedback; 24 resultant technologies extracted.
- Intelligrid (2001-present): EPRI trademarked
- Smart Grid: Final name adopted at EPRI and DOE



## Smart Meters: Utility-Scale Smart Meter Deployments, Plans & Proposals (Sept. 2010)

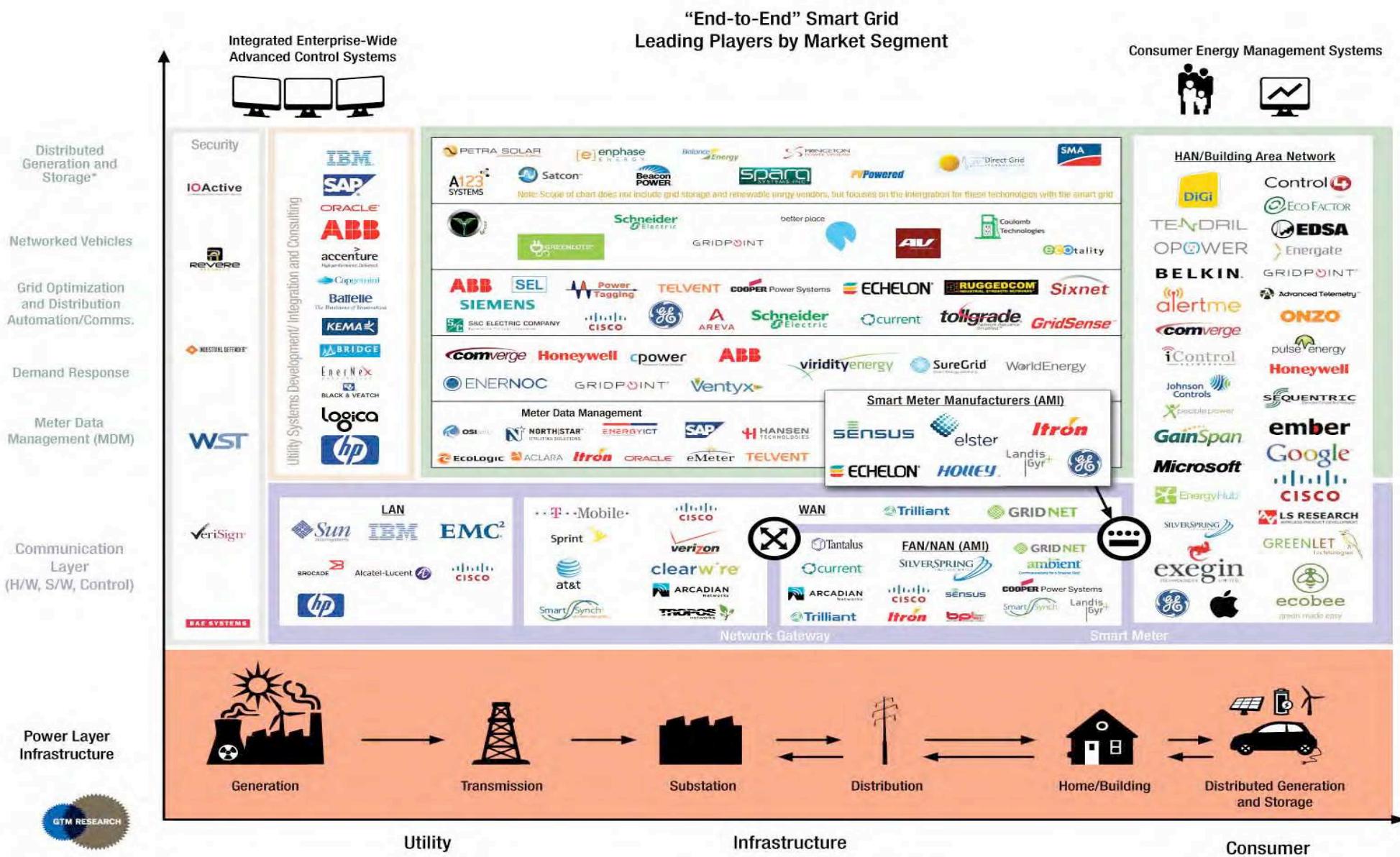
# Leaders & Laggards





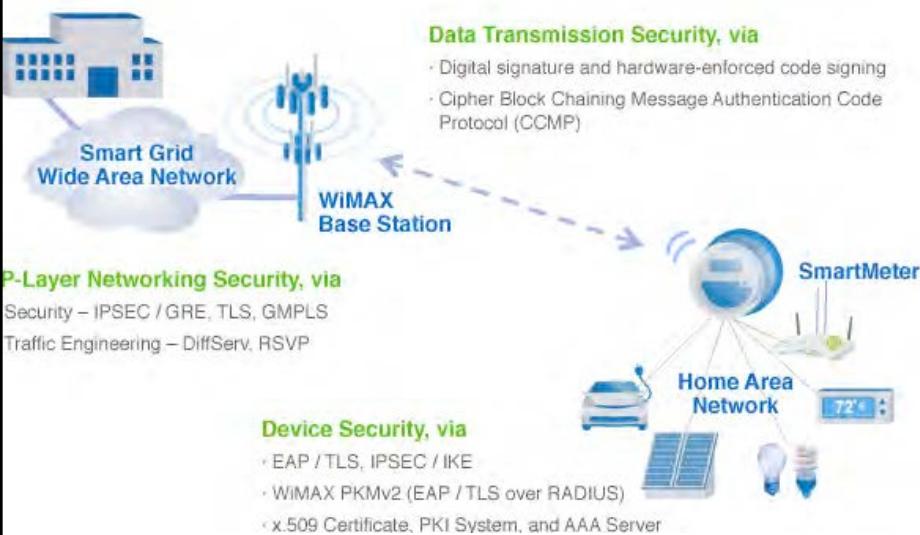
## Smart Grids

# End-to-End Smart Grid Players/Opportunities



## Smart Grids

# Sample “Smart Grid” Components & Devices



Secure Smart Grids are architected with standards (source: Gridnet)



Smart Meters



Google Power Meter



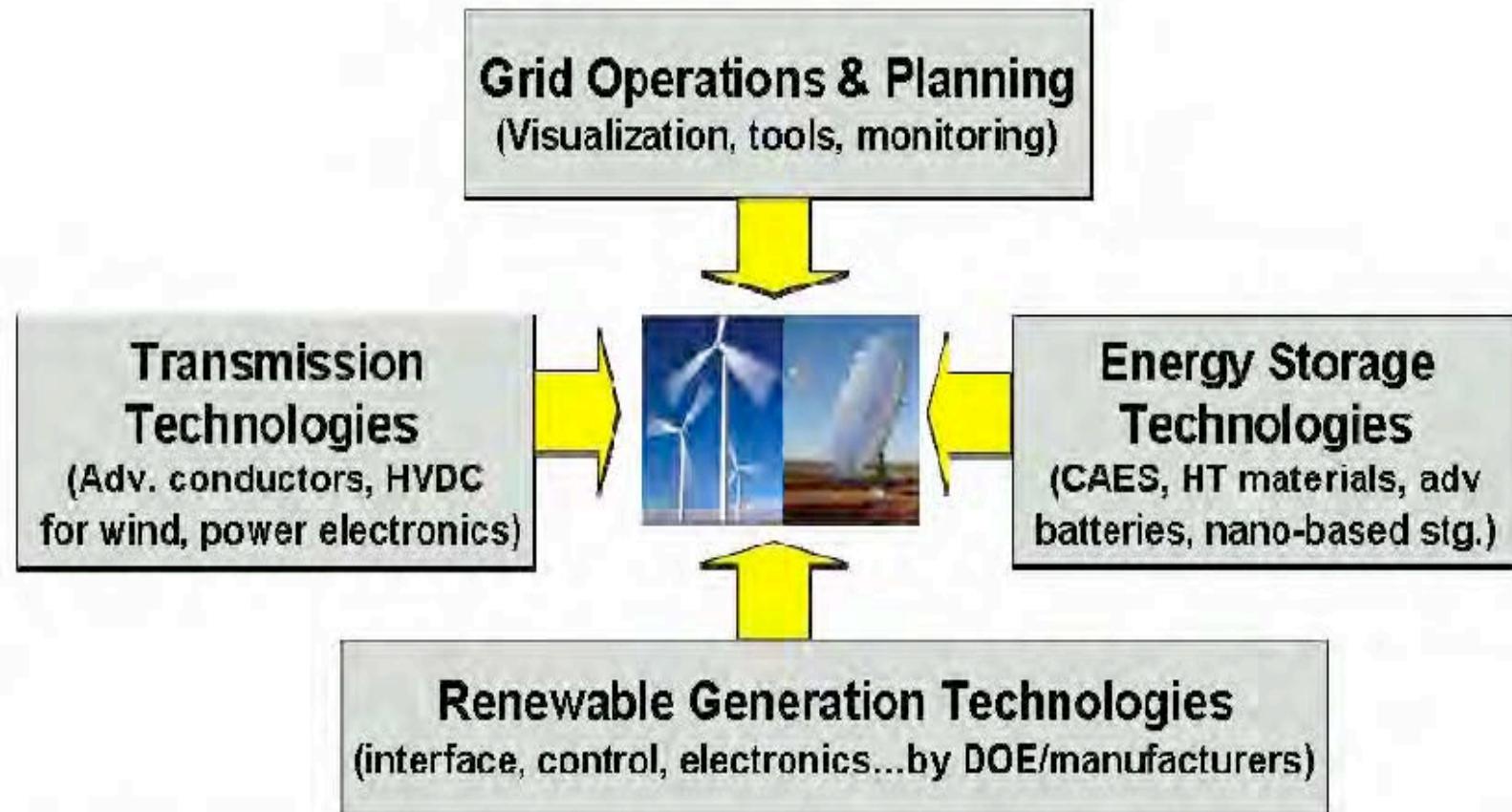
Source: IBM Smart Grid

Control4's EMS-100



## Smart Grid: Technologies

# Foresight: Integration Technologies



**Figure 4-10**

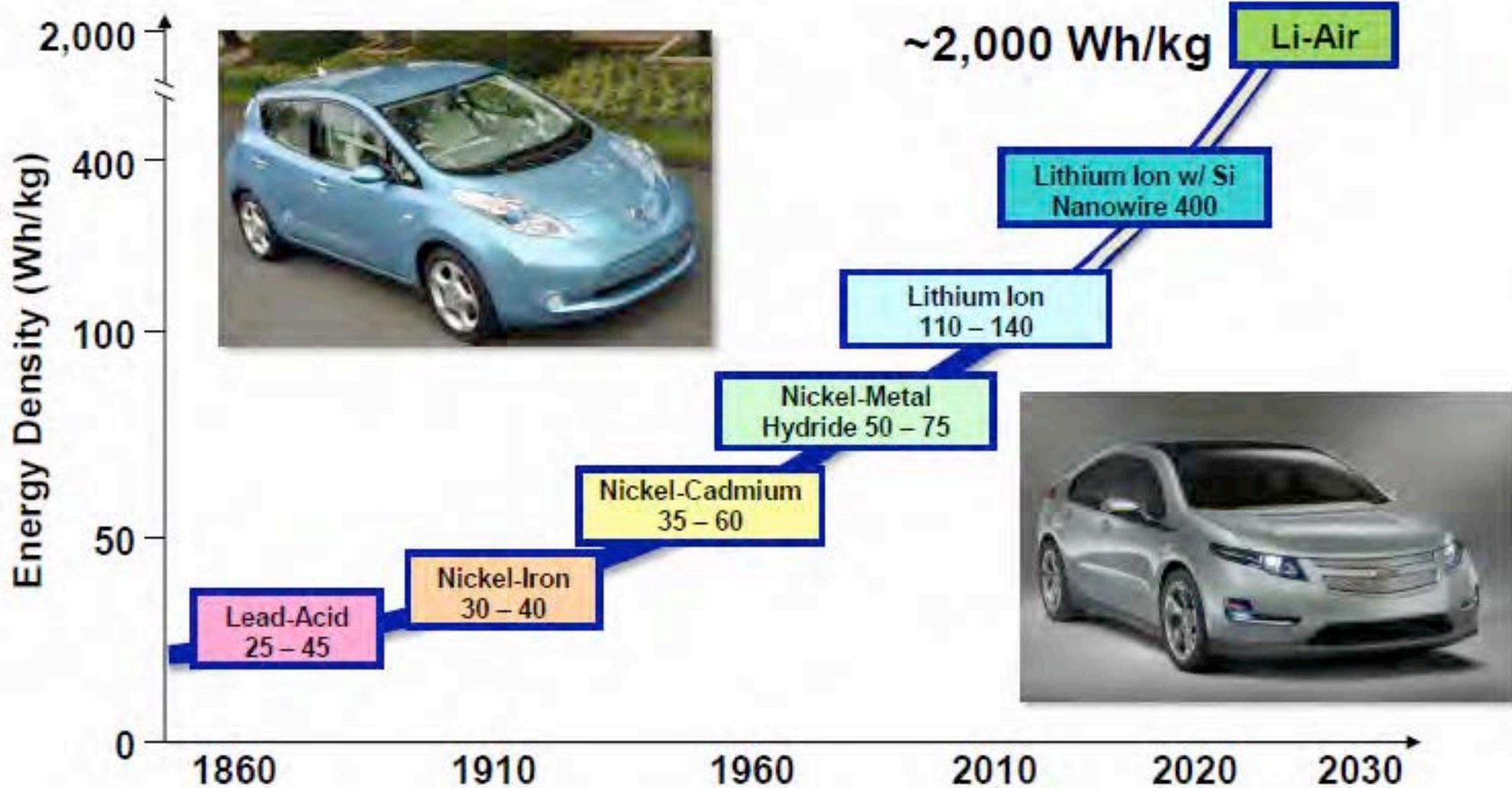
**Several Different Integration Technologies Will Combine to Ease Integration of Renewable Energy Resources**

*Renewable Energy Technical Assessment: Edf Annual Update 2008: Solar Photovoltaics, Solar Thermal, and Grid Integration Technologies and Greenhouse Gas Emissions Control.* EPRI, Palo Alto, CA: 2009. 1018492.



## Smart Grid: Technological Innovations

# Energy Storage

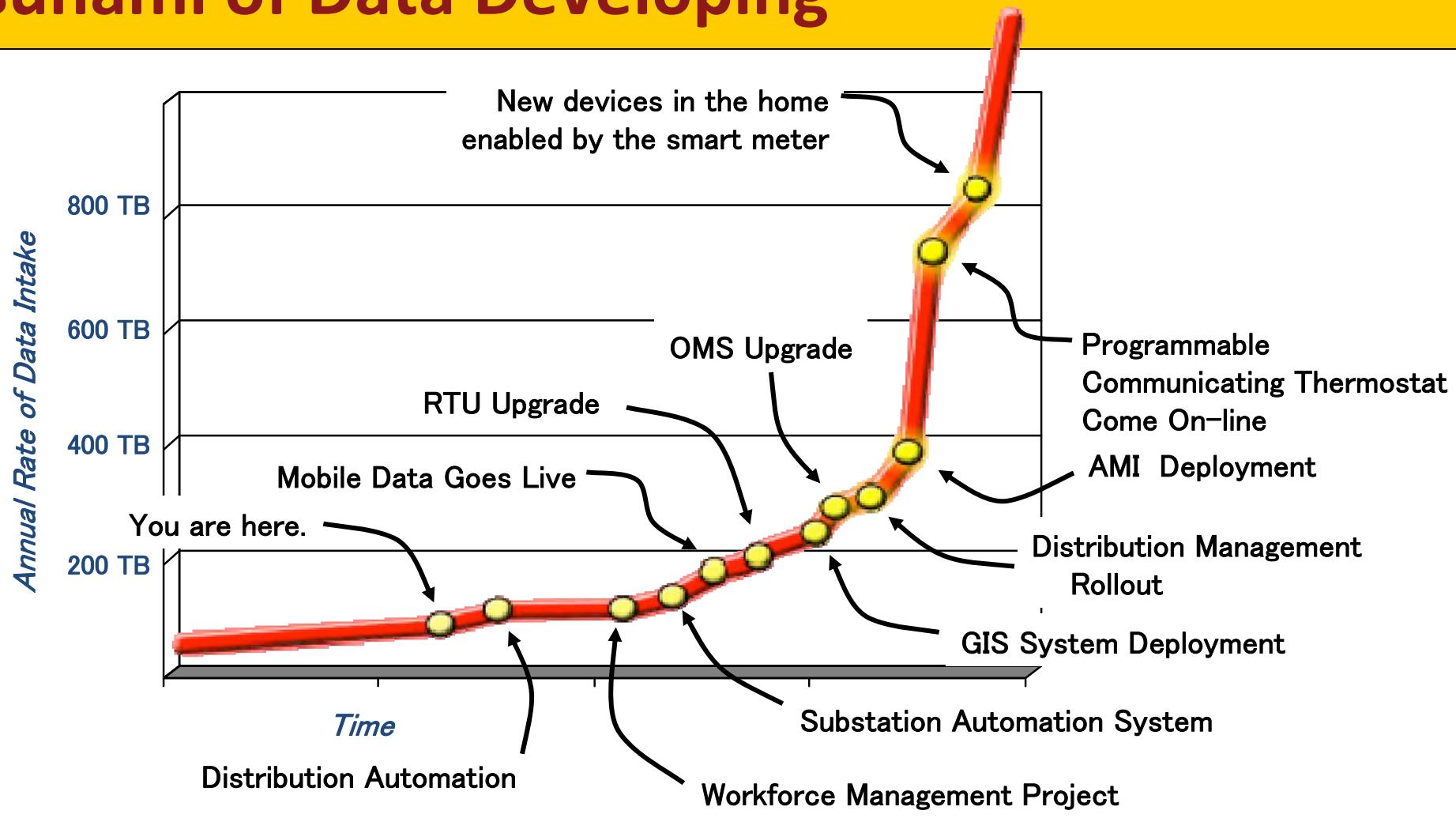


Sources: EPRI



## Smart Grid: Applications and Data

# Tsunami of Data Developing



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



**Connecting Everywhere – the wireless revolution**

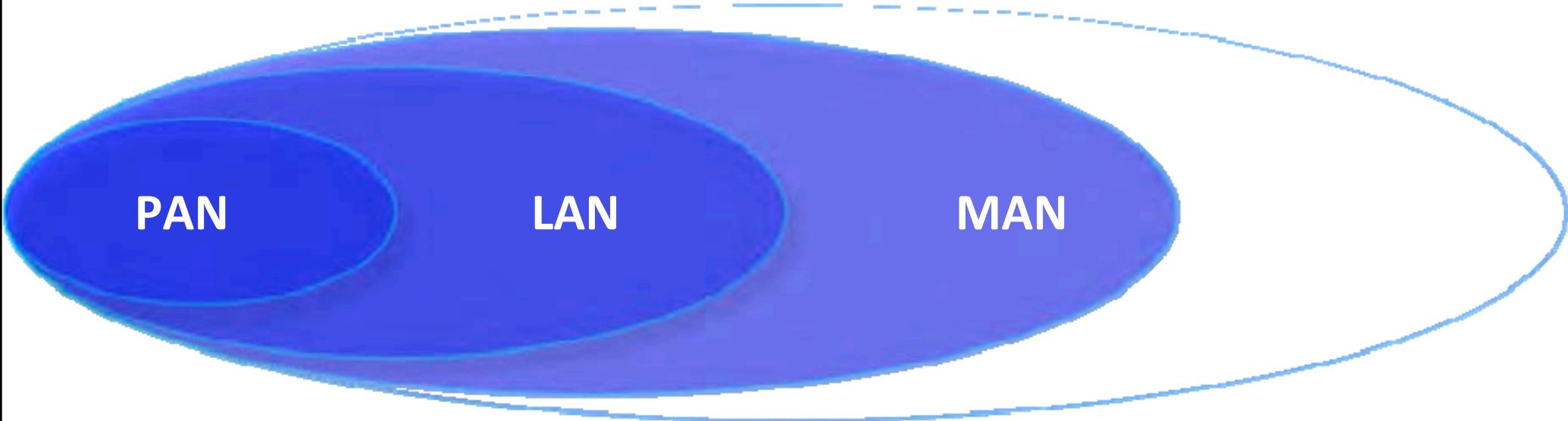
# Interface of Smart Grid and Buildings

Personal Space

On-Campus / Public

City, Community

Cellular/ PCS /Satellites



PAN

LAN

MAN

Bluetooth, Zigbee  
(Feet to 10's of feet)

WLAN 802.11X  
(10's, 100's of feet)

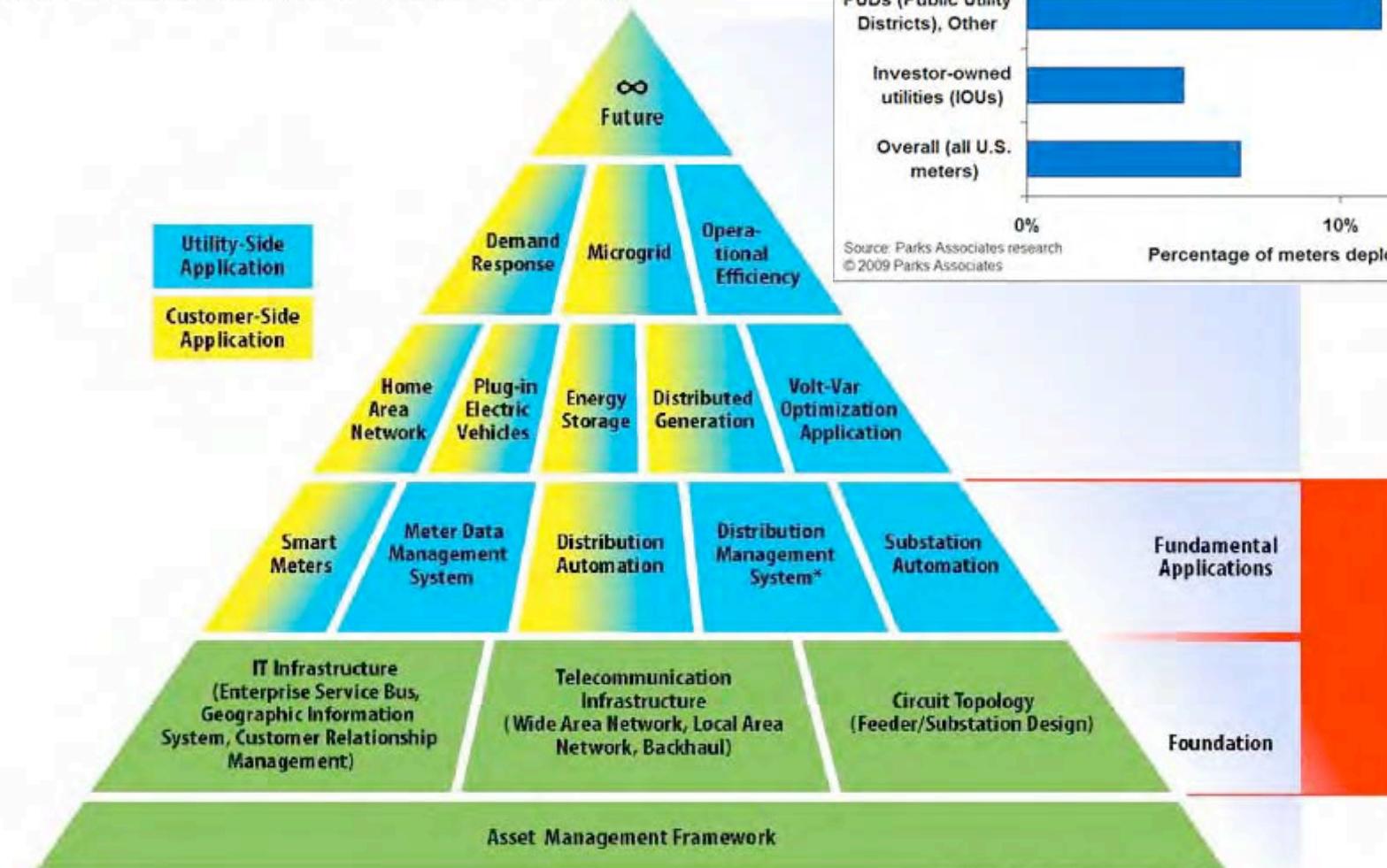
WMAN 802.16, 802.20,  
Ad-hoc, Beam Forming

Cellular/Satellite



## End-to-End Smart Grid Opportunities

# Smart Grid framework



# What is Smart Grid and why consider it?

- 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.**



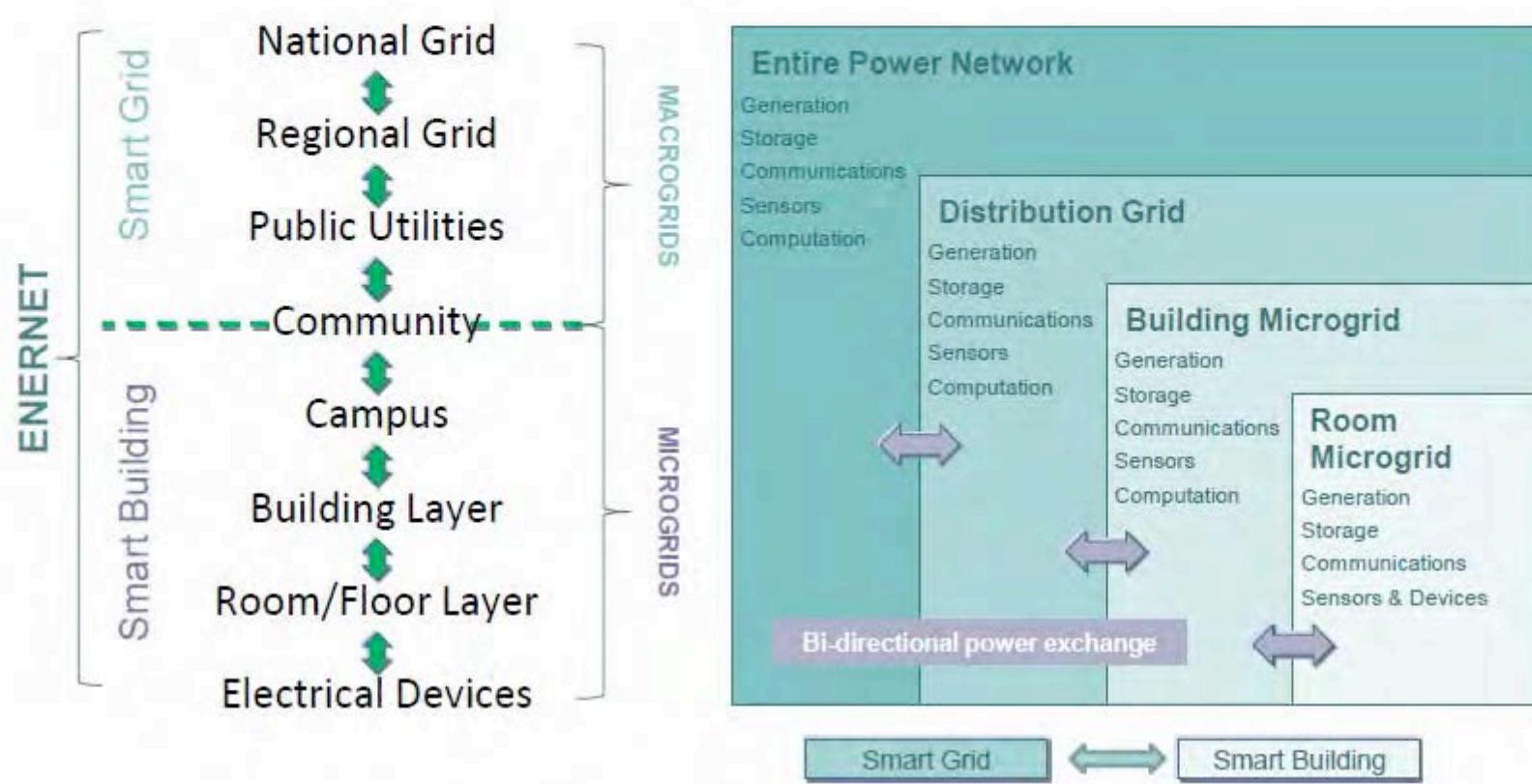
## Smart Grid: Options, Costs and Benefits

# Interface of Smart Grid and Buildings



## Zero Energy Buildings (ZEB)

A ZEB driven network will look much like the Internet





## Smart Grid: Options, Costs and Benefits



### Zero Energy Buildings (ZEB)

Drive need to create an integrated microgrid energy network

#### Proactive Technology Solutions



Distributed Grid Architecture



## Smart Grid: Options, Costs and Benefits

# Interface of Smart Grid and Buildings



Optimize and balance

**Energy Supply = Energy Demand**

- **Microgrids**
- **Local Energy Networks**
- **Energy Efficiency**
  - AC source to AC loads
  - DC source to DC loads
  - Intelligent switching in between
  - Eliminate conversions
  - Use energy how and where it is generated

Transforming Transportation

- Electrifying Transportation
- Alternative Fuels

**Breaking the Addiction to Oil**

**Mitigating Environmental Impacts**

Energy Efficiency

- All Can Participate

Greening the Power Supply

- Expanding Use of Renewables
- Expanding Nuclear Power
- Capturing Carbon Emissions

Smarter & Stronger Electrical Infrastructure

- Smart Grid
- Expanded Transmission System
- Energy Storage

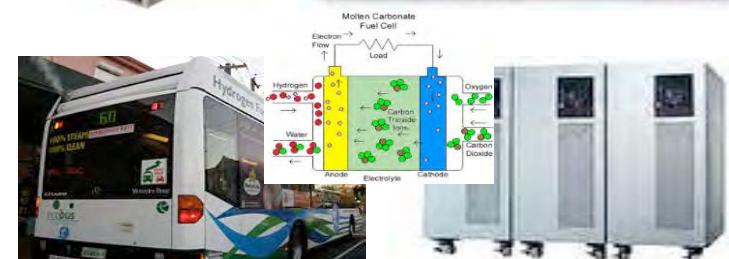
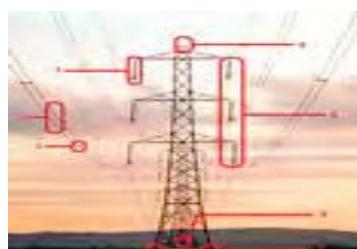
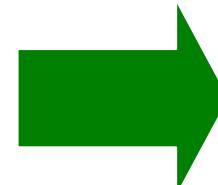


## Smart Grid: Options, Costs and Benefits

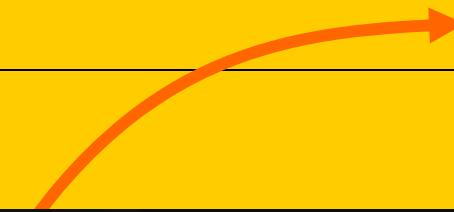
# Interface of Smart Grid and Buildings

- Fossil Fuel
- Long Distance Central Station
- An Aging Infrastructure
- Out of Capacity

- Renewable Power
- On-site
- Zero Energy Building
- Smart Grid



## Smart Grid: Options, Costs and Benefits



# Building's CO<sub>2</sub> emission

New York City: **Reality**

400' S.F of office space<sup>6</sup>

50 lbs CO<sub>2</sub> / year/S.F.

Total: 10 million tons CO<sub>2</sub> / year



**Long time ago**

How it started?

1 Kg of wood

=1.8 kg of CO<sub>2</sub>



30 ton CO<sub>2</sub> / year

**Today**



**When life was simple**

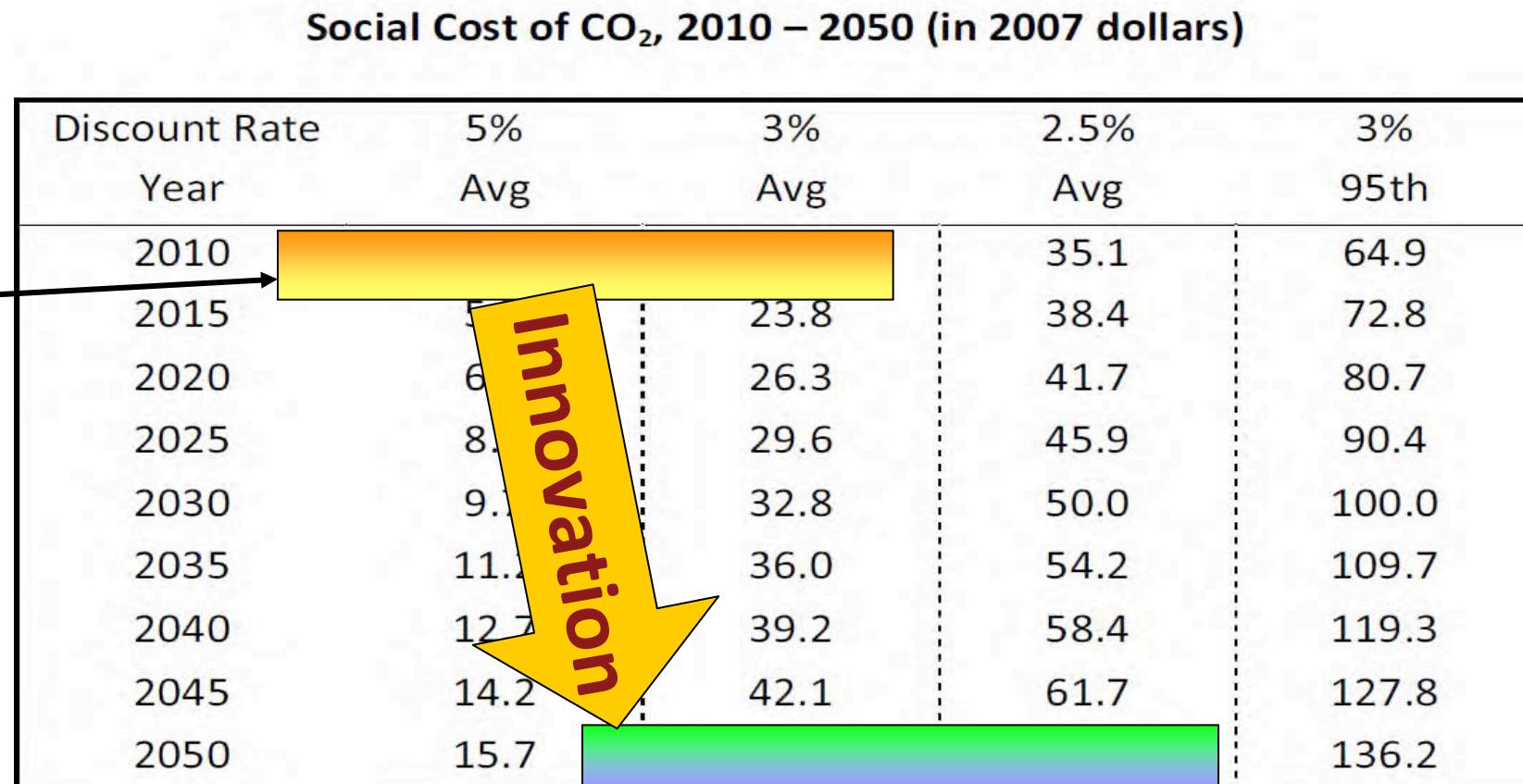
0.1-1 ton CO<sub>2</sub> / year



# Smart Grid: Options, Costs and Benefits

# Interface of Smart Grid and Buildings

# Current Market Value



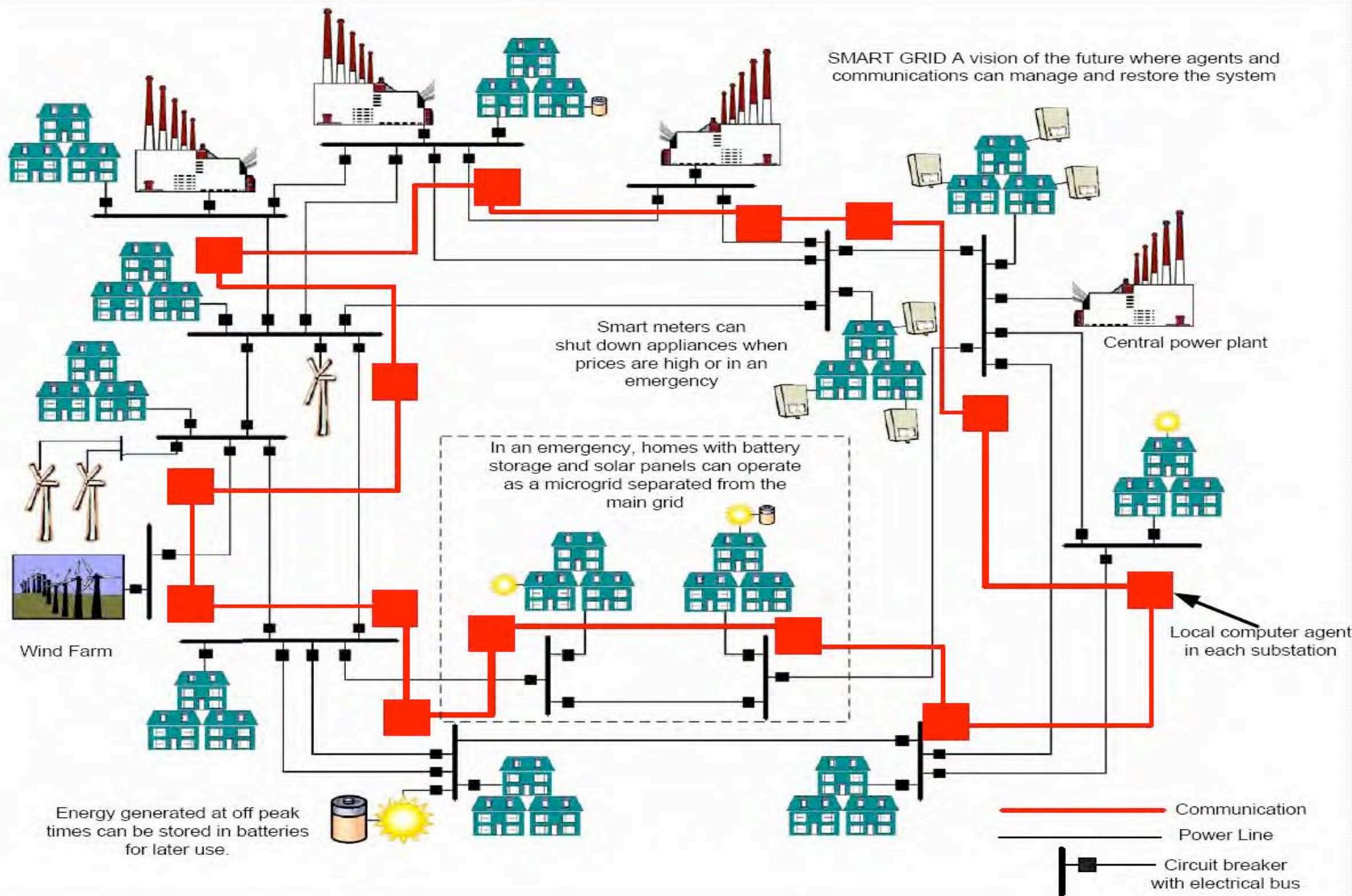
# Future Market Value

## Smart Grid: Technologies

# Key Technology Areas

Technology Area	Description
<b>Integrated Communications</b>	High-speed, fully integrated, two-way communication technologies will make the modern grid a dynamic, interactive “mega-infrastructure” for real-time information and power exchange. Open architecture will create a plug-and-play environment that securely networks grid components to talk, listen and interact.
<b>Sensing and Measurement</b>	These technologies will enhance power system measurements and enable the transformation of data into information. They evaluate the health of equipment and the integrity of the grid and support advanced protective relaying; they eliminate meter estimations and prevent energy theft. They enable consumer choice and demand response, and help relieve congestion.
<b>Advanced Control Methods</b>	New methods will be applied to monitor essential components, enabling rapid diagnosis and timely, appropriate response to any event. They will also support market pricing and enhance asset management and efficient operations.
<b>Improved Interfaces and Decision Support</b>	In many situations, the time available for operators to make decisions has shortened to seconds. Thus, the modern grid will require wide, seamless, real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Decision support with improved interfaces will amplify human decision making at all levels of the grid.

# Our team's Smart Grid Research

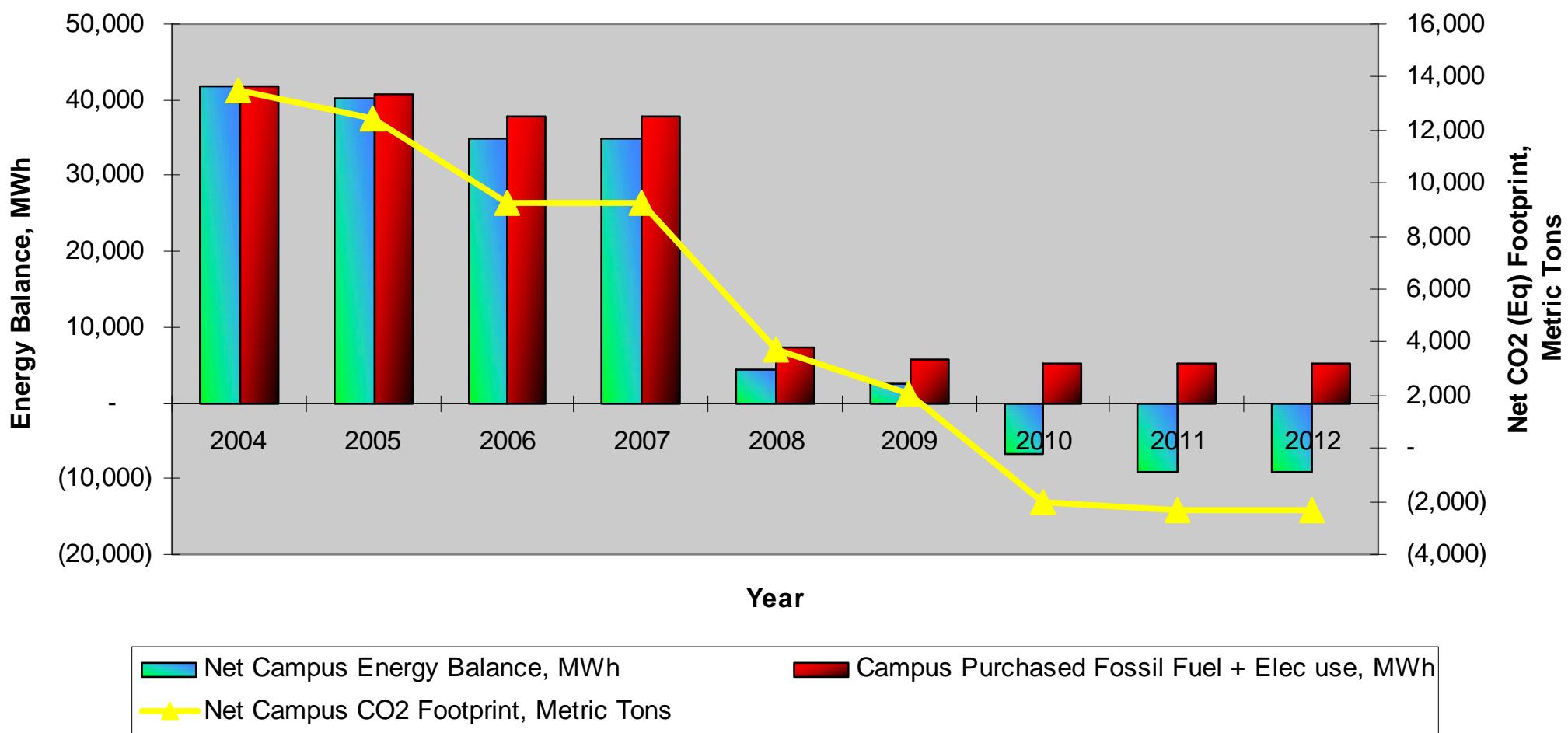




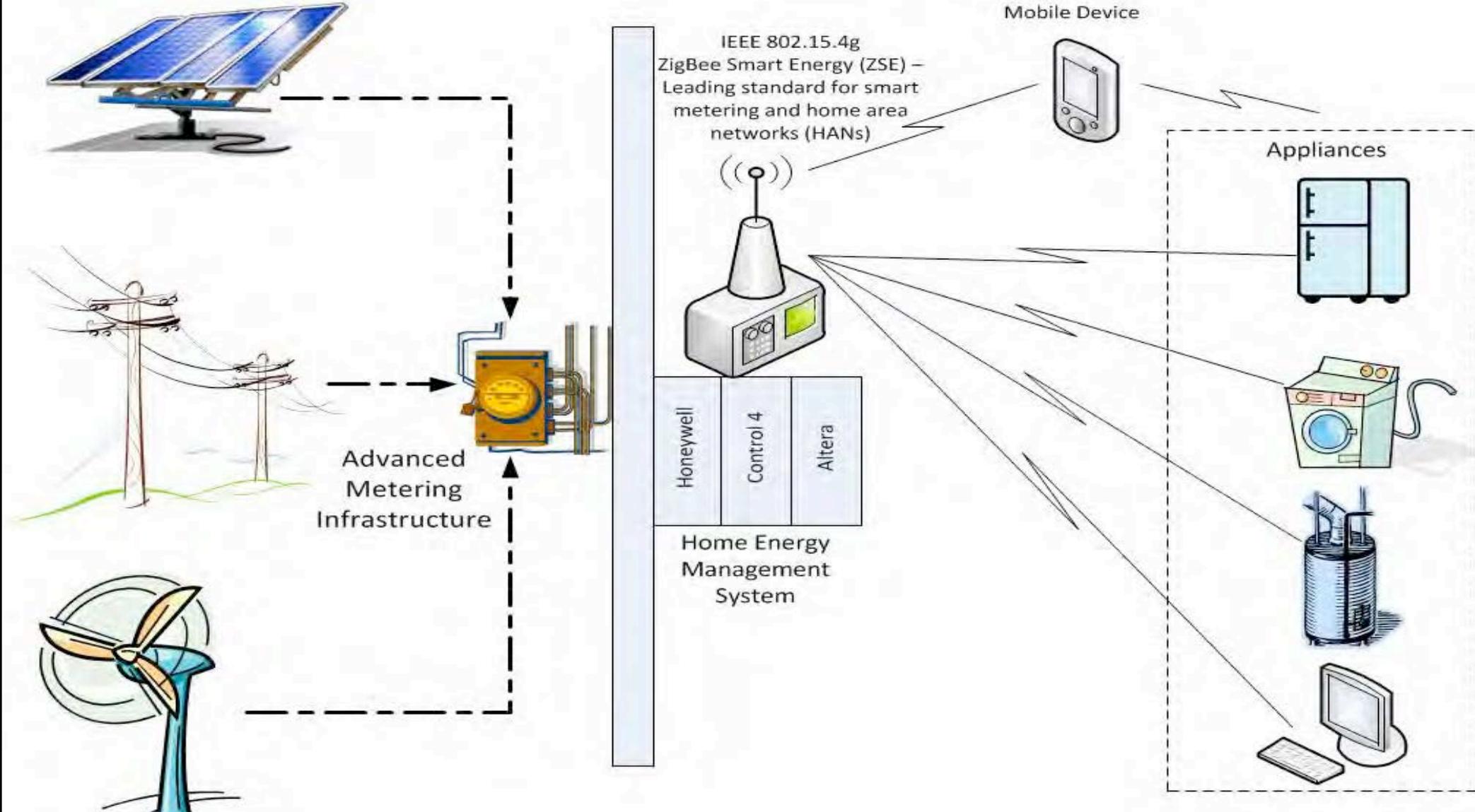
## Smart Grid: Options, Costs and Benefits

# Going Carbon Negative...

**UM Morris Net Energy Balance**

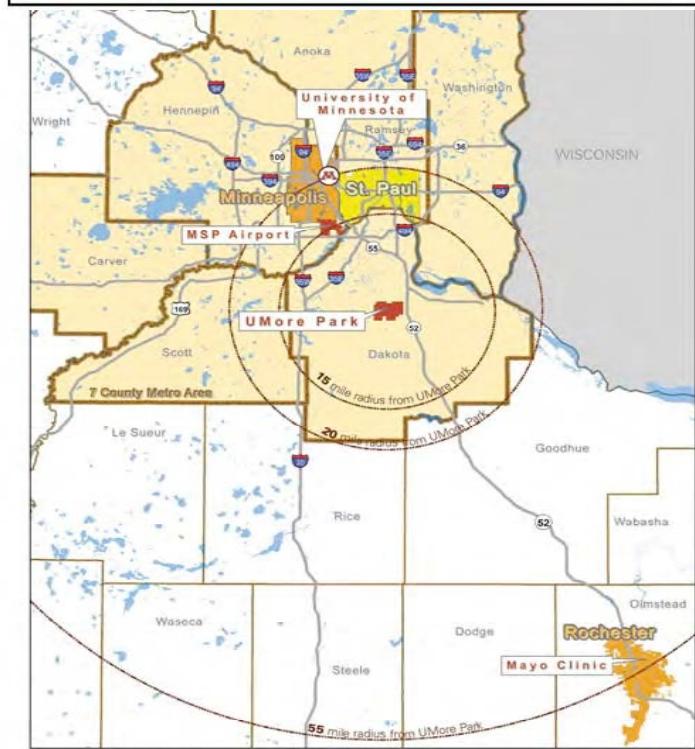


# Local System Communication Overlay

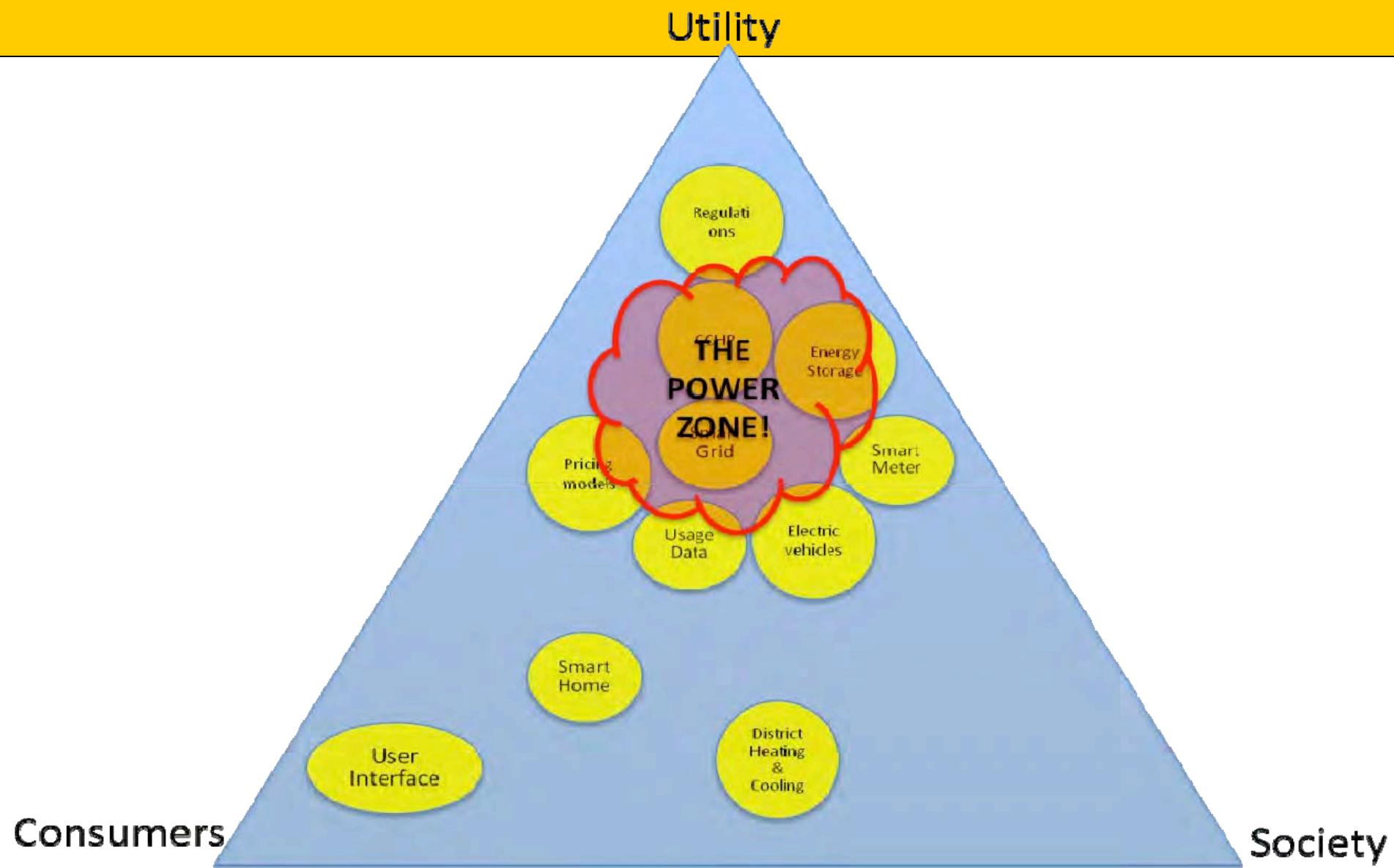


# Smart Grid assessment for UMore Park

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



# Analysis - Technology Space Map



# 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

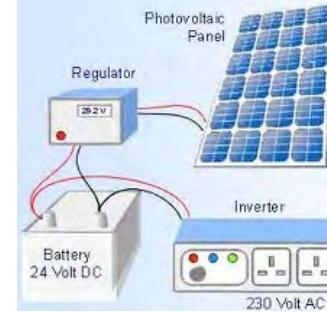
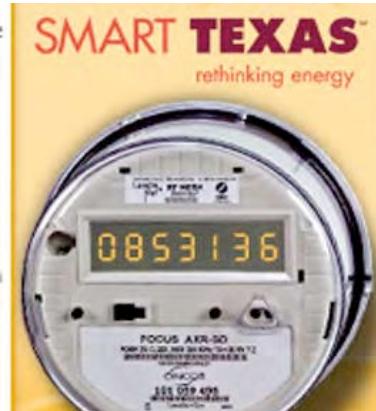
- Incorporating new technologies
- Scanning renewable technology



## Smart Grid: Options, Costs and Benefits

# 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



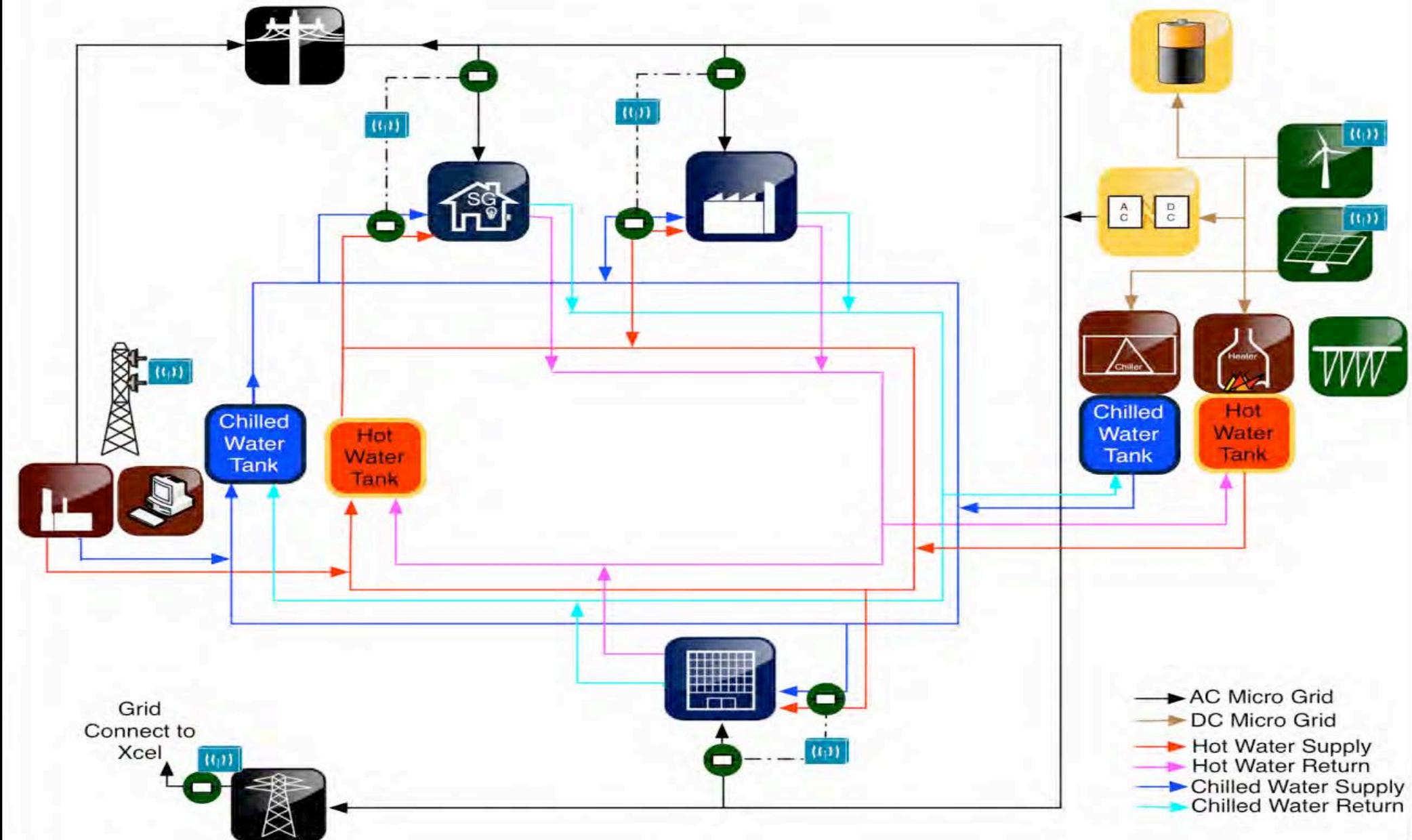
# Estimated Prices for Energy-Efficient, Smart Grid Ready Homes in UMore Park

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
<b>Small Lot</b>	1,600	2,500	2,050	\$225,000	\$350,000	\$287,500
<b>Traditional</b>	1,800	2,800	2,300	\$225,000	\$410,000	\$317,500
<b>Large Lot</b>	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
<b>Small Lot</b>	\$244,920	\$379,920	\$312,420	\$19,920	\$29,920	\$24,920
<b>Traditional</b>	\$244,920	\$444,720	\$344,820	\$19,920	\$34,720	\$27,320
<b>Large Lot</b>	\$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: Options, Costs and Benefits

# Interface of Smart Grid and Buildings

# Energy Savings Opportunities for Building Owners

<b>Building Applications (in priority timing of EMerge Alliance)</b>	<b>Ave % of Building Energy Used</b>	<b>Potential Energy Savings by Going DC</b>	<b>Keys to Maximizing Efficiency in Going DC</b>
Interiors (Lighting)*	28%*	Up to 15%	LED, Renewables
Data/Telecom	17%	Up to 30%	Higher voltage conversions, Renewables
Service/Utility (HVAC)	36%	Up to 10%	Renewables
Outdoor	6%	Up to 10%	LED, Renewables
Other (misc equip loads)	13%	Up to 5%	Different voltage conversions

\*Higher energy use in office buildings, up to 40%

# Smart Grid U™

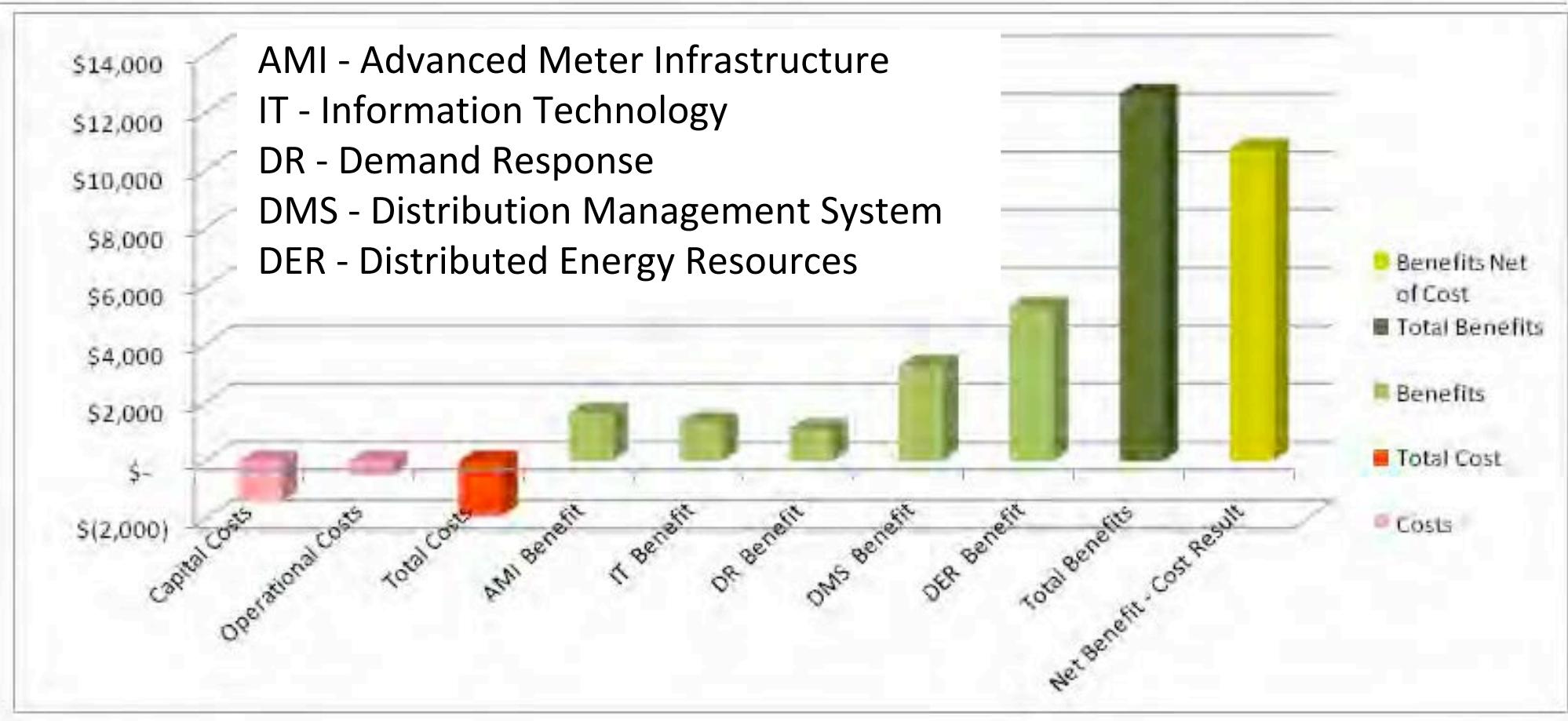
## Lessons learned and key messages

- 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.**
  - **What are the range of new services enabled by smart grids?**
  - **“Smart Grid as a Means to an End—Not an End Unto Itself”**



## Smart Grid: Options, Costs and Benefits

# West Virginia Business Case



Source: National Energy Technology Laboratory



## Smart Grid: Options, Costs and Benefits

# Awareness, Costs and Benefits

### Awareness:

- ~68% of consumers in the U.S. don't know what "Smart Grid" is...
  - what is the "Smart Grid"?
  - what are the range of new consumer-centered services enabled by smart grids?
  - what are the smart grid's potential to drive economic growth?

### Costs/Benefits:

- EPRI report, "Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid":
  - The new report finds that the estimated net investment needed to realize the envisioned power delivery system of the future is between \$338 and \$476 billion.
  - Previous EPRI assessments (2004) had put the estimated costs at about \$165 billion over 20 years (\$8 to \$10 billion per year).
- Energy consulting firm Brattle Group: \$1.5 trillion spread over 20 years (~\$75 billion per year) for an overhaul of the entire electricity infrastructure.
- My work, 1998-present: \$160 to \$170 billion (\$10 to \$17 billion per year for 10-20 years).



## Smart Grid: Options, Costs and Benefits

# ... Awareness, Costs and Benefits

### Smart grid 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%
- Increases overall energy security, and can spur economic growth.
  - Benefits which could be as high as \$2.3 trillion for the U.S. —and if the definition were even wider, the long-term benefits would be even greater.
- Our \$14 trillion economy depends on reliable, disturbance-free access to electricity.



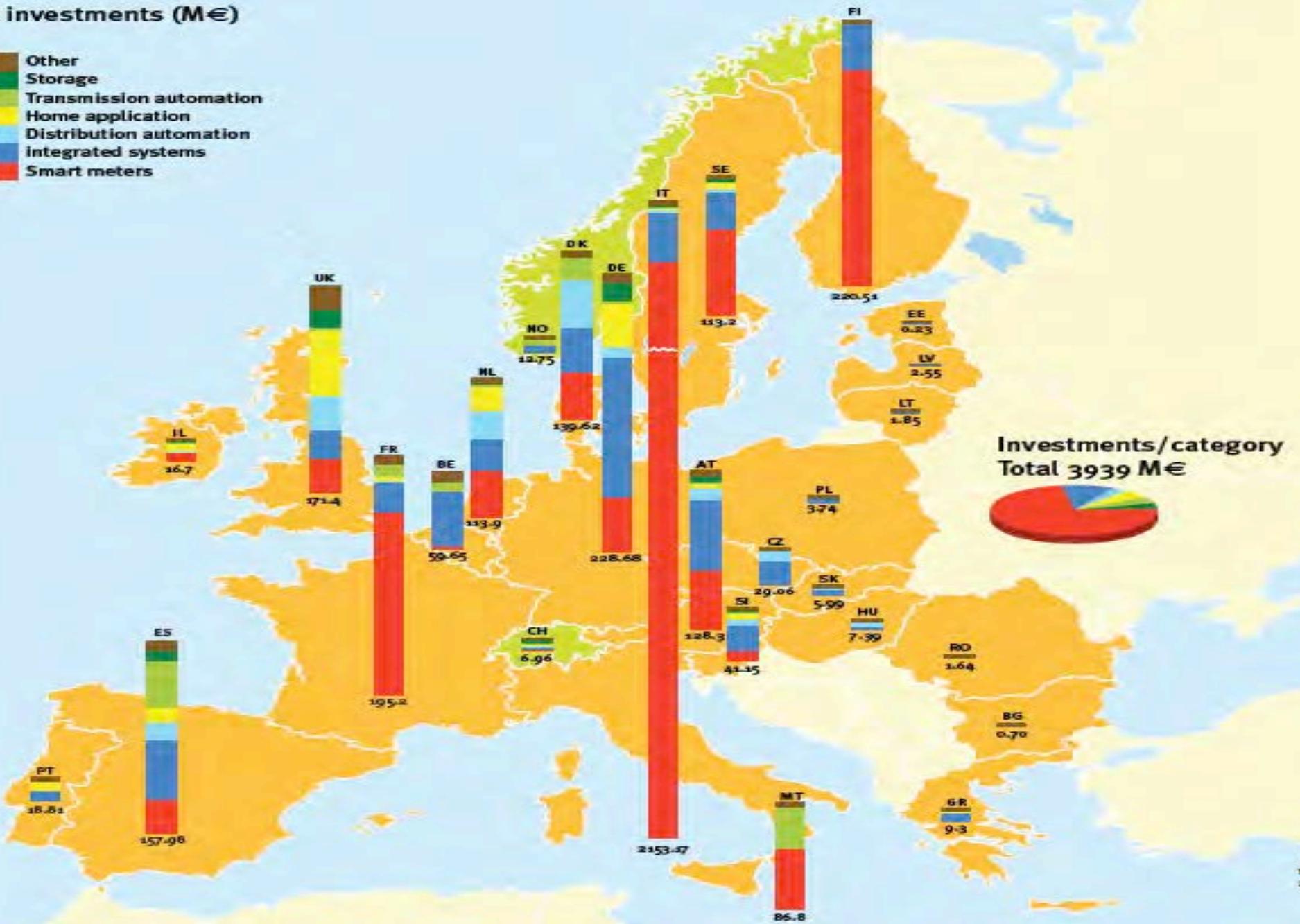
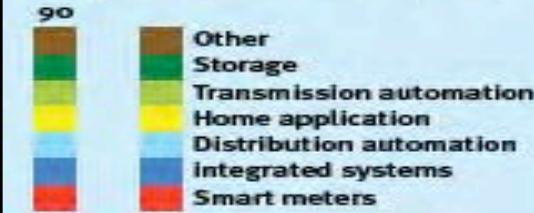
## Smart Grid: Options, Costs and Benefits

# Investments in Smart Grid Technologies

- Factors that boost smart grid 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.
- Nations/regions/cities that best implement new strategies and infrastructure may reshuffle the world pecking order. 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

Project investments (M€)



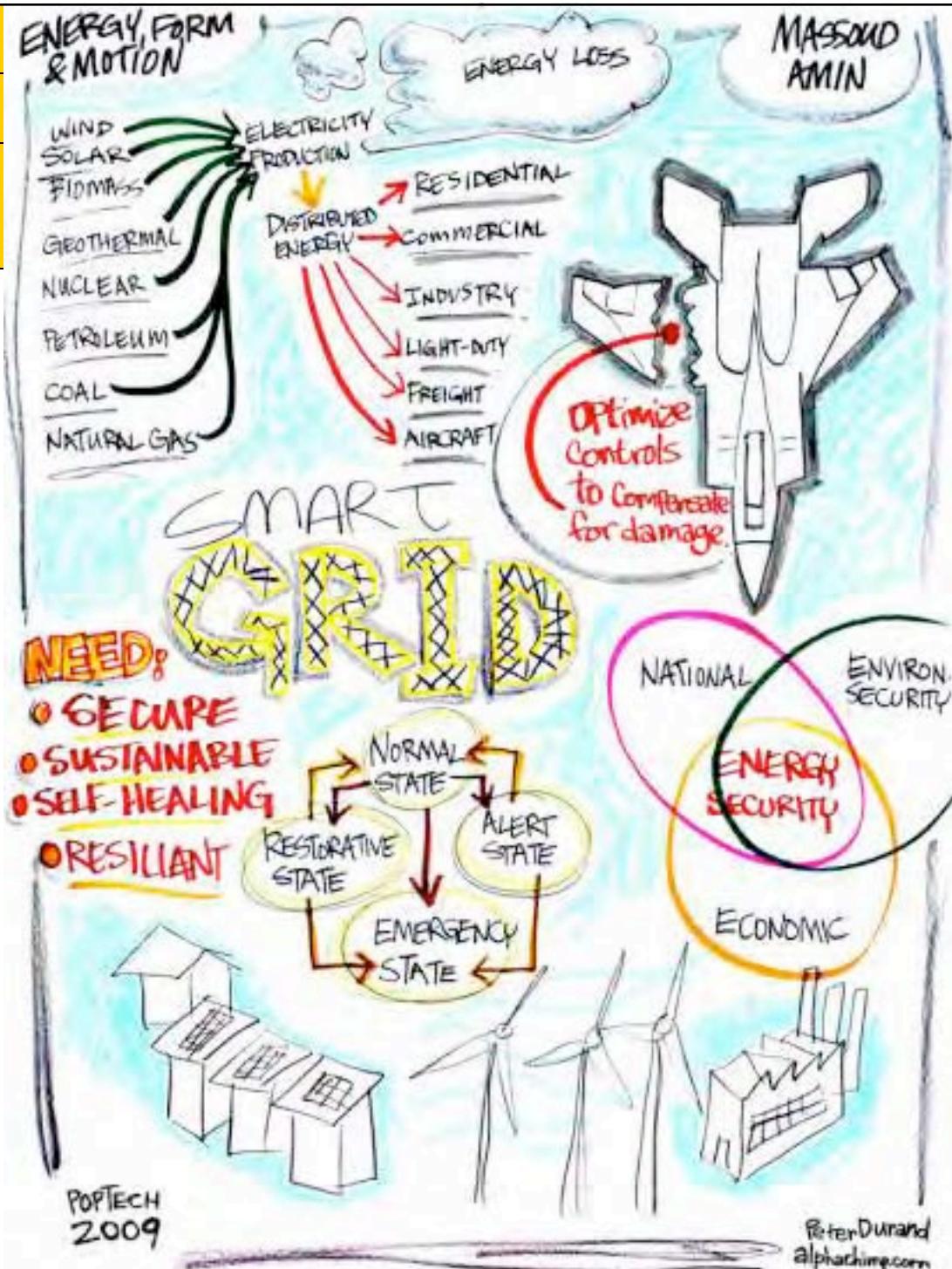
# The Emerging Smart Grid or Energy Web: A Complex Adaptive Infrastructure System

“... 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>





## Options, Costs and Benefits

“Computers are incredibly fast, accurate, and stupid; humans are incredibly slow, inaccurate and brilliant; together they are powerful beyond imagination.”

Albert Einstein



## Options, Costs and Benefits

# I-35W bridge: Stronger and Smarter

Just after 6:00 p.m. on Aug. 1, Prof. Massoud Amin was at work in his office on the University of Minnesota's West Bank, where he heard and watched the unthinkable happen—the collapse of the I-35W bridge about 100 yards away.

"As an individual, it was shocking and very painful to witness it from our offices here in Minneapolis," says Amin, director of the Center for the Development of Technological Leadership (CDTL) and the H.W. Sweatt Chair in Technological Leadership. Amin also viewed the tragedy from a broader perspective as a result of his ongoing work to advance the security and health of the nation's infrastructure.

In the days and weeks that followed, he responded to media inquiries from the BBC, Reuters, and the CBC, keeping his comments focused on the critical nature of the infrastructure. He referred reporters with questions about bridge design, conditions, and inspections to several professional colleagues, including Professors Roberto Ballarini, Ted Galambos, Vaughan Voller, and John Gulliver in the Department of Civil Engineering and the National Academy of Engineering Board on Infrastructure and Constructed Environment.

For Amin, Voller, and many others, the bridge collapse puts into focus the importance of two key issues—the tremendous value of infrastructure and infrastructure systems that help make possible indispensable activities such as transportation, waste disposal, water, telecommunications, and electricity and power, among many others, and the search for positive and innovative ways to strengthen the infrastructure.



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

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



Terry Ward



Heidi Hamilton



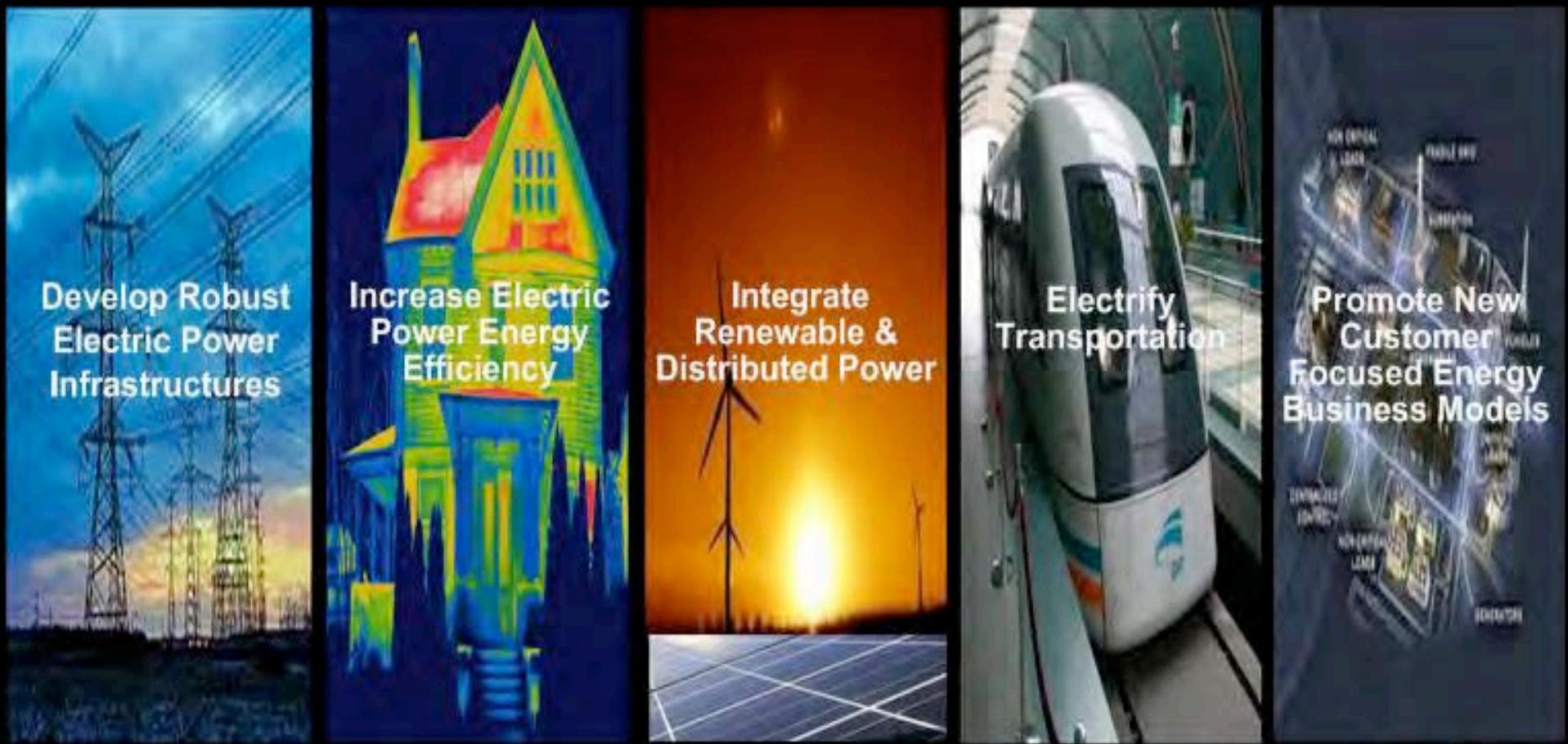
Val Svensson



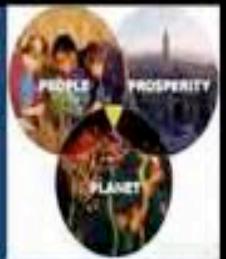
Joe Nietfeld



# Smart Grid Goals

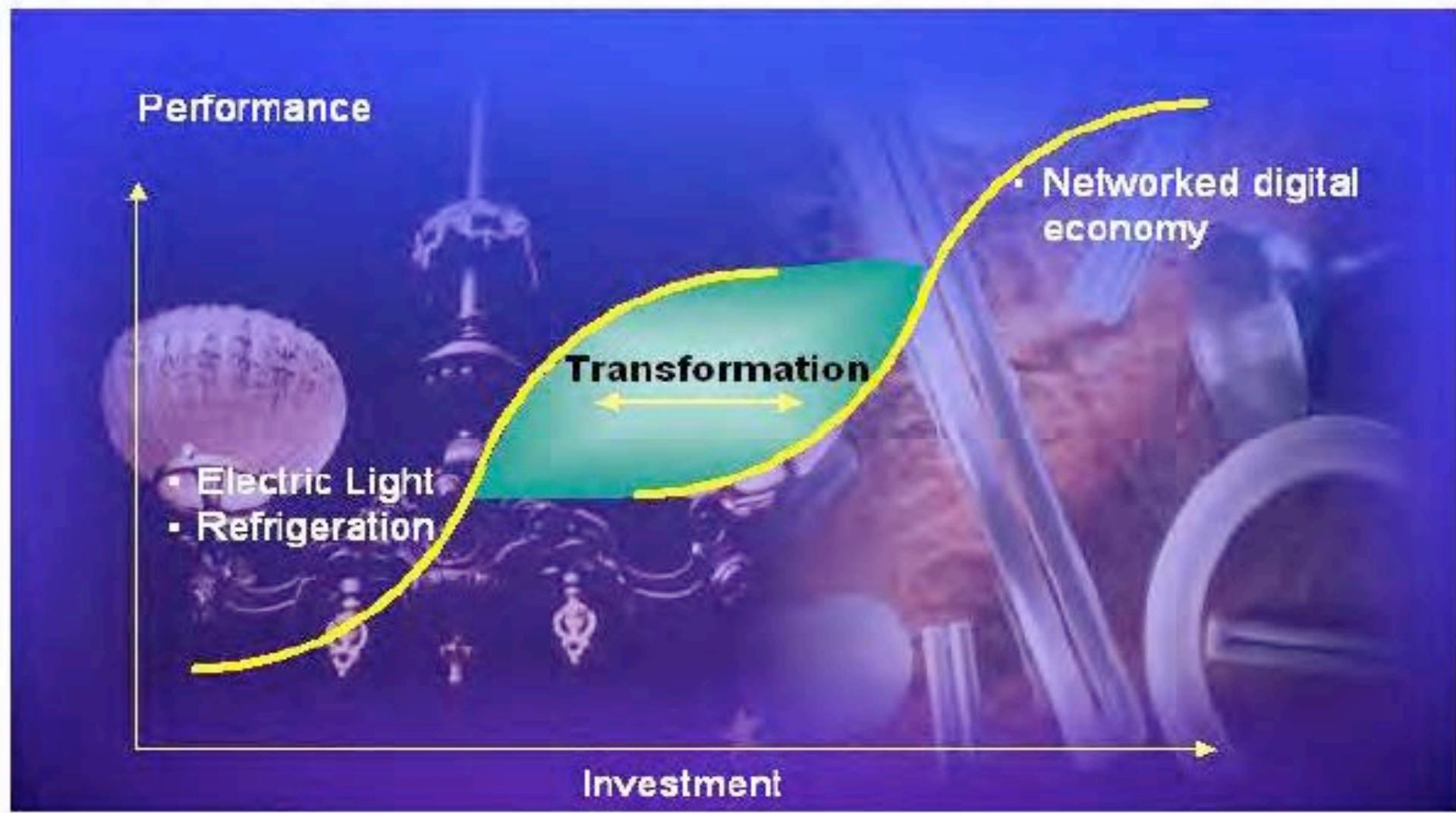


Sustainable Electrical Power





# Breaking the Limits on Electricity Value





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THANK YOU

