# Building Energy Efficiency: A Perspective from NSF

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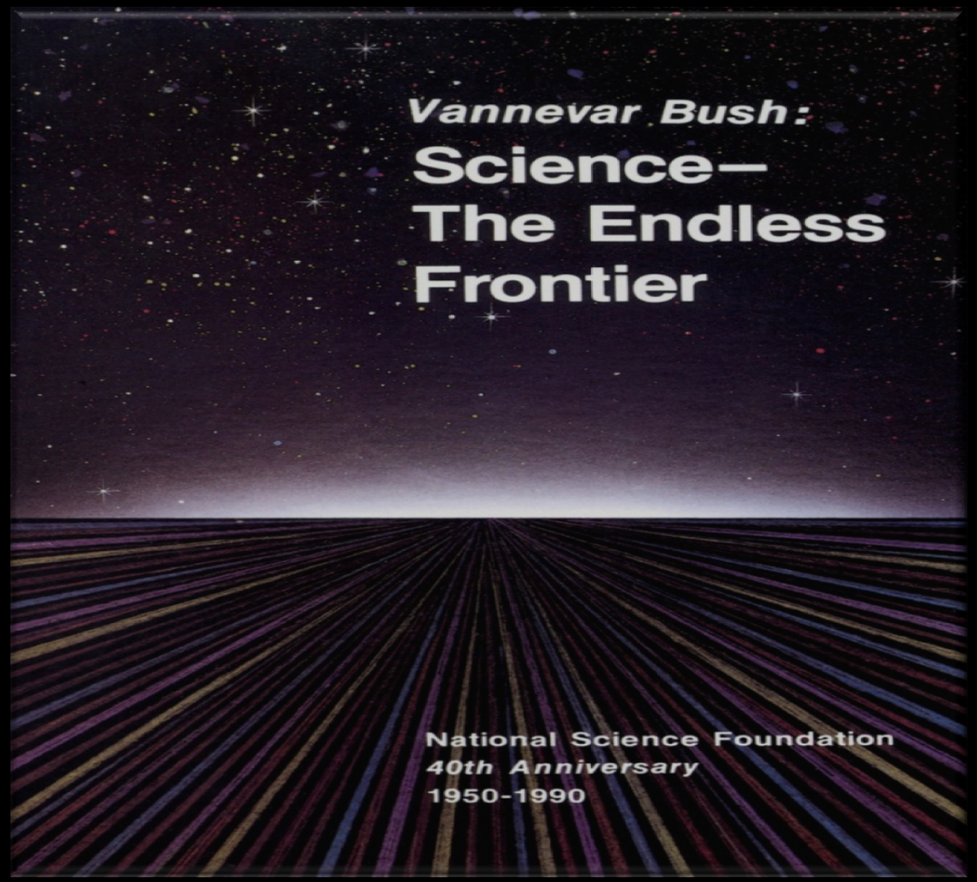
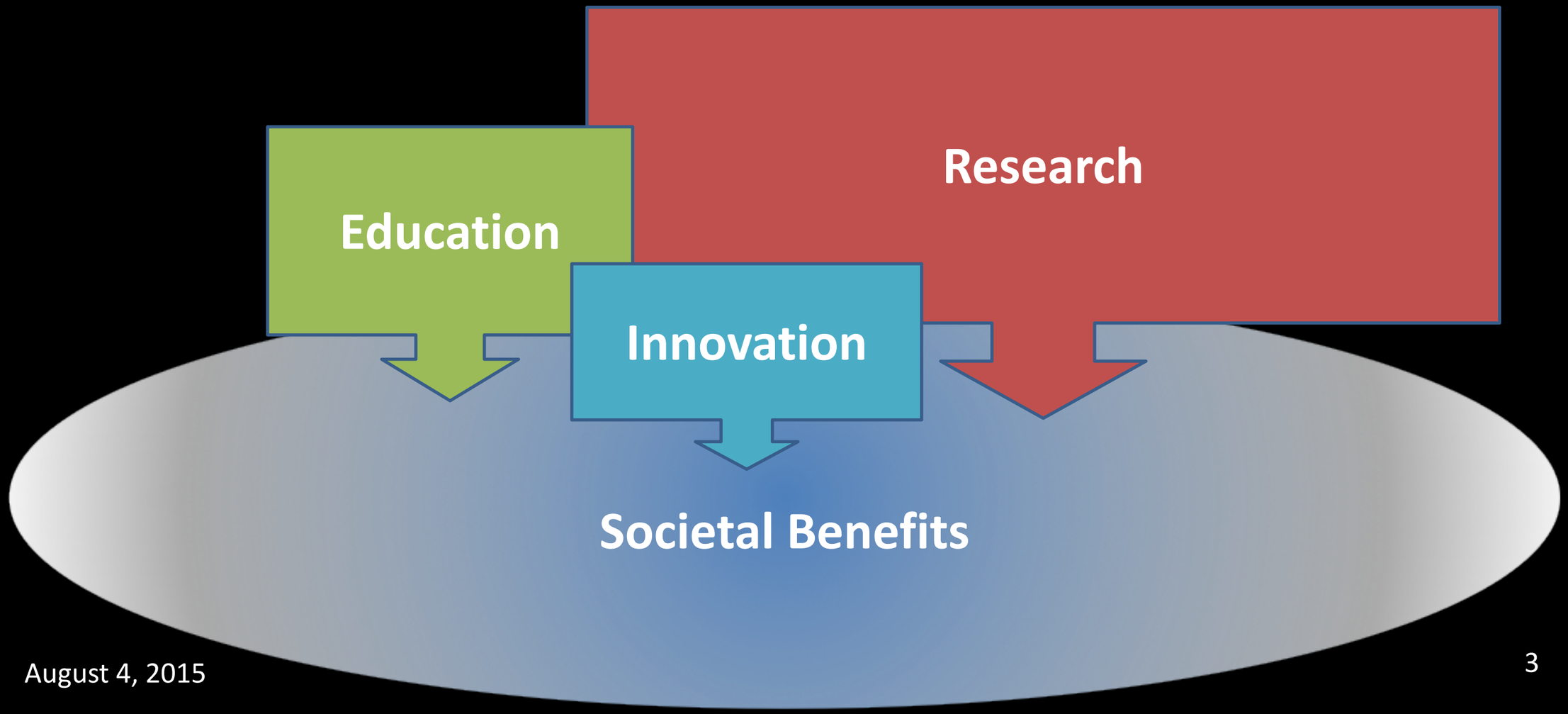
National Science Foundation
Assistant Director *for*
Engineering Directorate

SinBerBEST Mini Symposium, Singapore, 2015




"to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF Act, 1950

# NSF ENG: Investing in engineering research and education to foster innovations for benefit to society



# Directorate for Engineering

## Fundamental

### EFRI

### CBET

- Chemical & Biochemical Systems
- Bioengineering and Engineering Healthcare
- Environmental Engineering and Sustainability
- Transport, Thermal, & Fluid Phenomena

### CMMI

- Advanced Manufacturing
- Mechanics and Engineering Materials
- Resilient and Sustainable Infrastructure
- Operations Design and Dynamical Systems

### ECCS

- Electronics, Photonics, and Magnetic Devices
- Communications, Circuits, and Sensing Systems
- Energy, Power, Control and Networks

### EEC

- Engineering Research Centers
- Engineering Education
- Engineering Workforce

## Translational

### IIP

- Academic Partnerships
- Small Business Partnerships

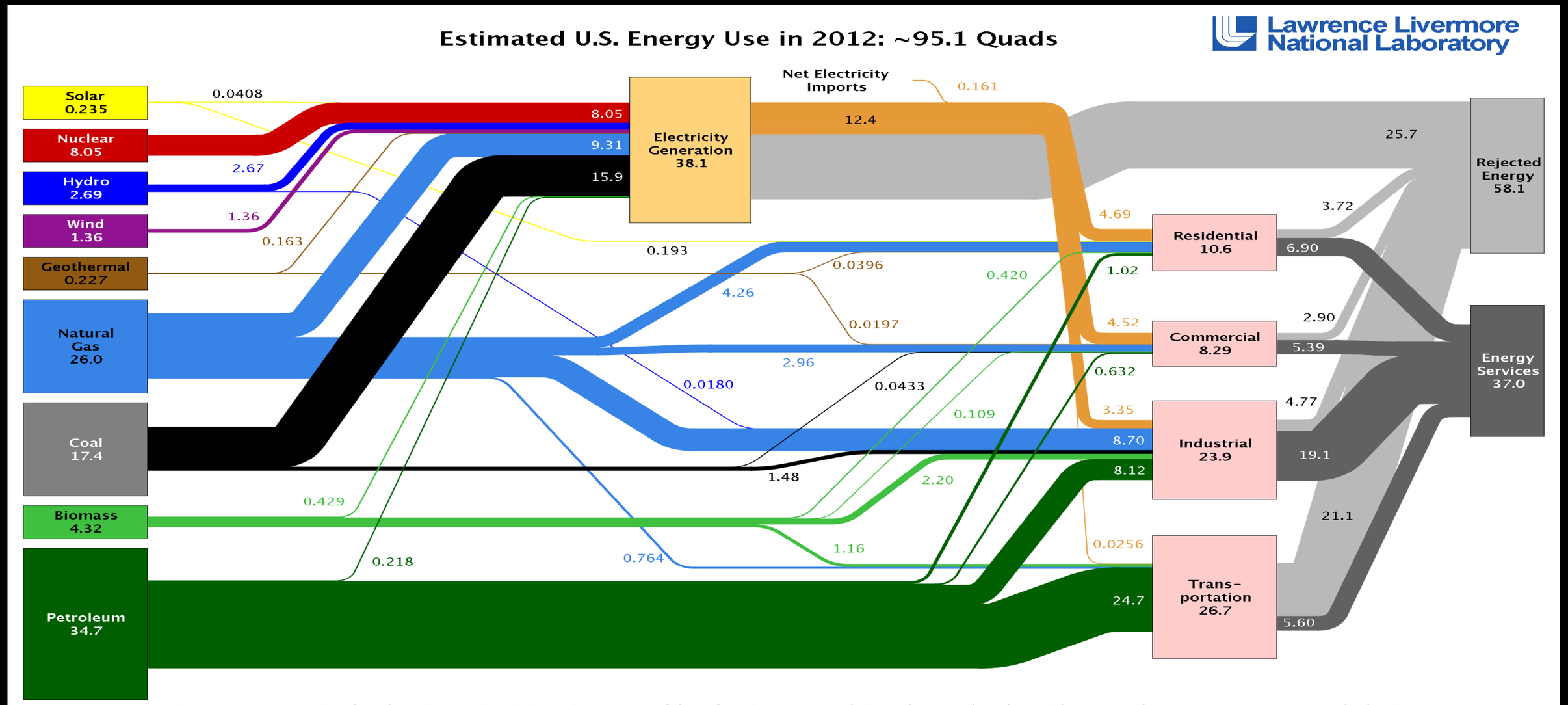
# ENG R&RA Budget ($M)

| | FY 2014 Actual* | FY 2015 Current Plan | FY 2016 Request | Change over FY 2015 Current Plan | |
|---|---|---|---|---|---|
| | | | | Amount | Percent |
| CBET | $167.76 | $177.82 | $192.26 | $14.44 | 8.1% |
| CMMI | 195.23 | 209.52 | 222.73 | 13.21 | 6.3% |
| ECCS | 100.37 | 110.43 | 119.24 | 8.81 | 8.0% |
| EEC | 119.50 | 117.49 | 110.39 | -7.10 | -6.0% |
| IIP | 205.99 | 226.98 | 248.11 | 21.13 | 9.3% |
| *SBIR/STTR* | *159.99* | *177.11* | *194.36* | *17.25* | *9.7%* |
| EFMA | 44.27 | 50.07 | 56.49 | 6.42 | 12.8% |
| ENG TOTAL | $833.12 | $892.31 | $949.22 | $56.91 | 6.4% |

# Federal R&D Support for Energy

- Department of Energy
  - Office of Energy Efficiency and Renewable Energy
- Department of Defense
- National Science Foundation
- Other agencies (EPA, USDA, …)

# US: 58 percent or 57 quads of energy rejected




Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Source: LLNL, EIA AEO 2012

# Residential Buildings

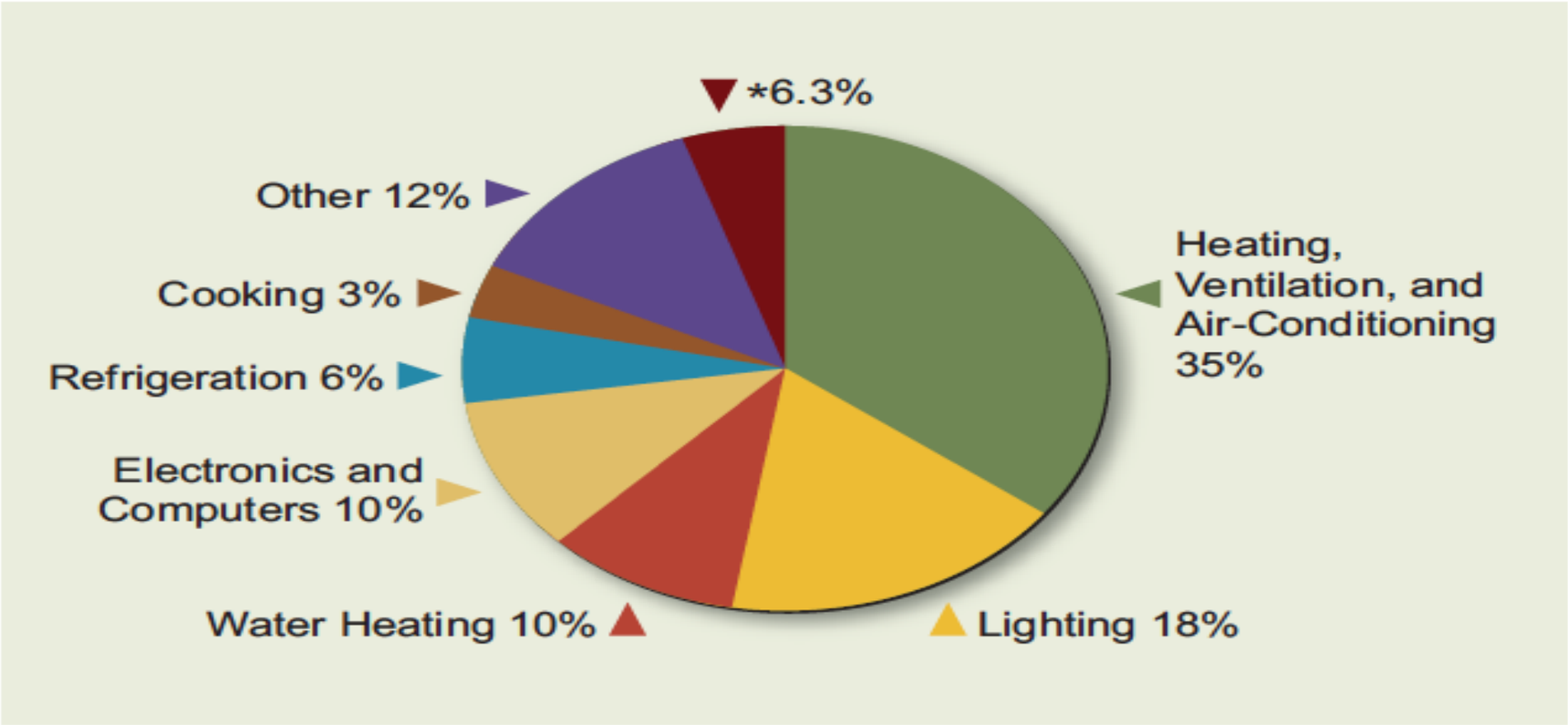



**FIGURE 2.1** *Energy use in U.S. residential buildings by end-use, 2006.*
*Note: *, Energy Information Administration (EIA) adjustment factor that accounts for incomplete data in EIA's sampling and survey methodology.*
*Source: Pew Center on Climate Change, based on data in DOE/EERE (2008), available at http://www.pewclimate.org/technology/overview/buildings.*



Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

# Commercial Buildings

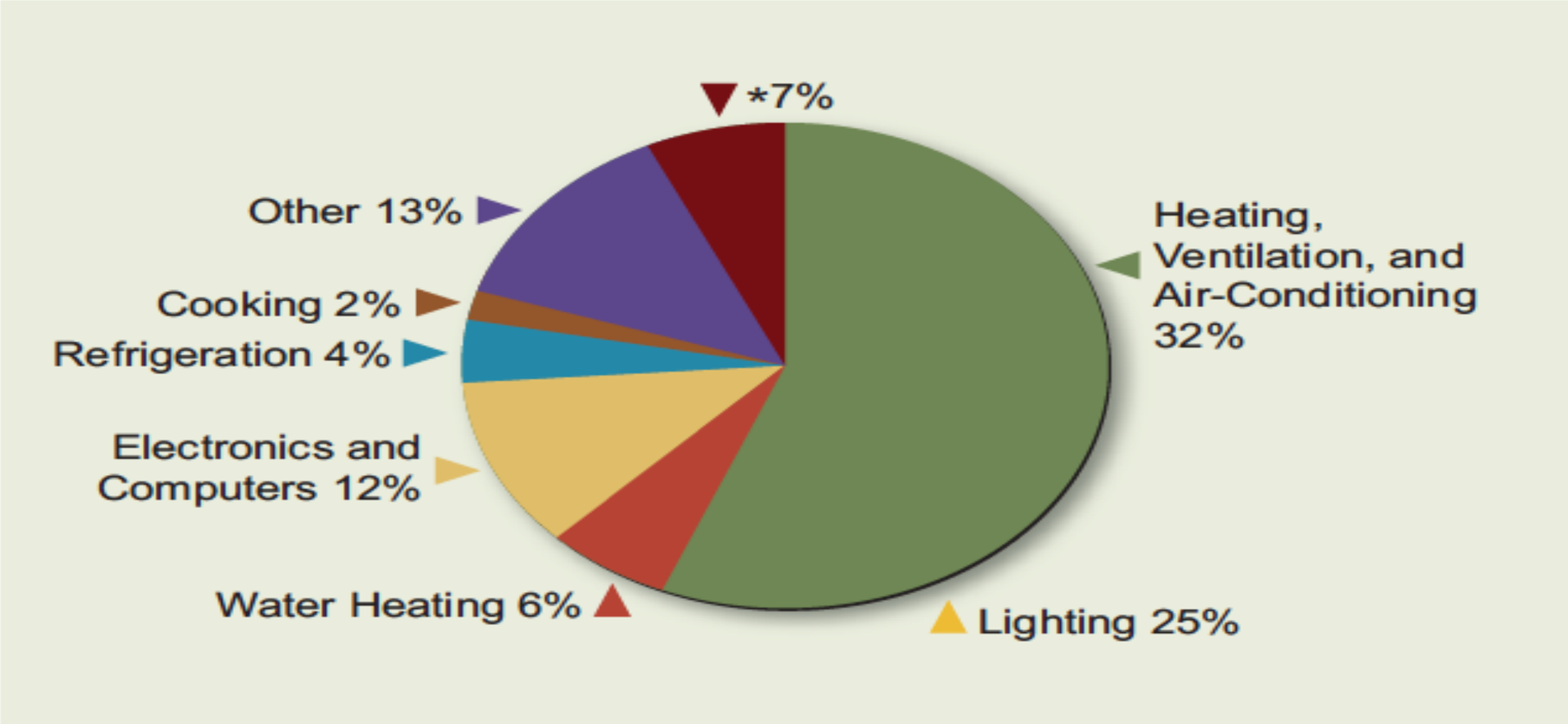



**FIGURE 2.2** *Energy use in U.S. commercial buildings by end-use, 2006.*
*Note: *, Energy Information Administration (EIA) adjustment factor that accounts for incomplete data in EIA's sampling and survey methodology.*
*Source: Pew Center on Climate Change, based on data in DOE/EERE (2008), available at http://www.pewclimate.org/technology/overview/buildings.*

Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

# Residential Buildings Trend

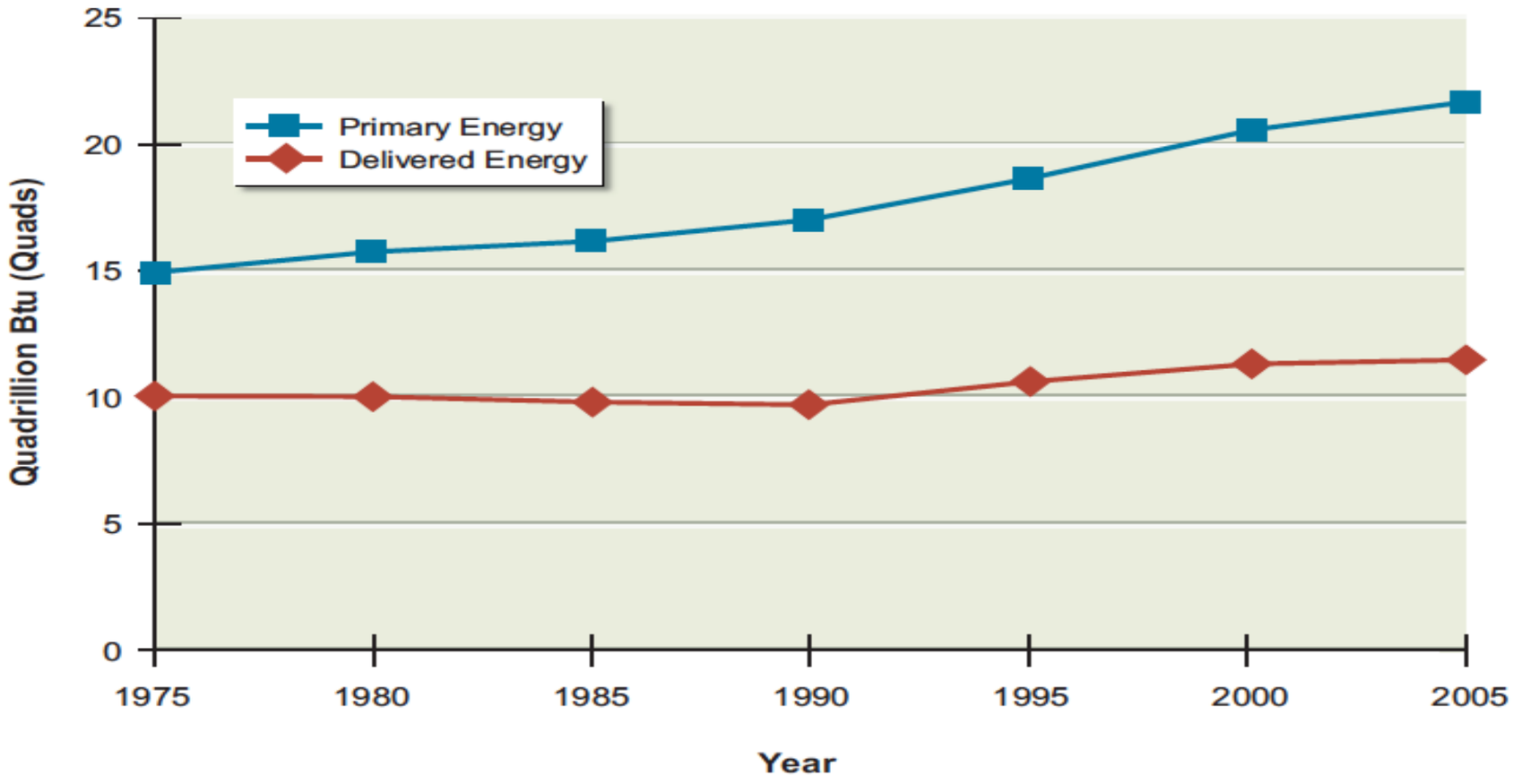



**FIGURE 2.3** *U.S. residential energy use trends. Primary energy use (accounting for losses in electricity generation and transmission and distribution, and for fuels, such as natural gas, used on-site) has increased faster than delivered energy use (which does not account for such losses, but does include fuels used on-site) because use of electricity has increased faster than use of other fuels.*
*Source: Data from EIA, 2007b.*

Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

# Commercial Buildings Trend

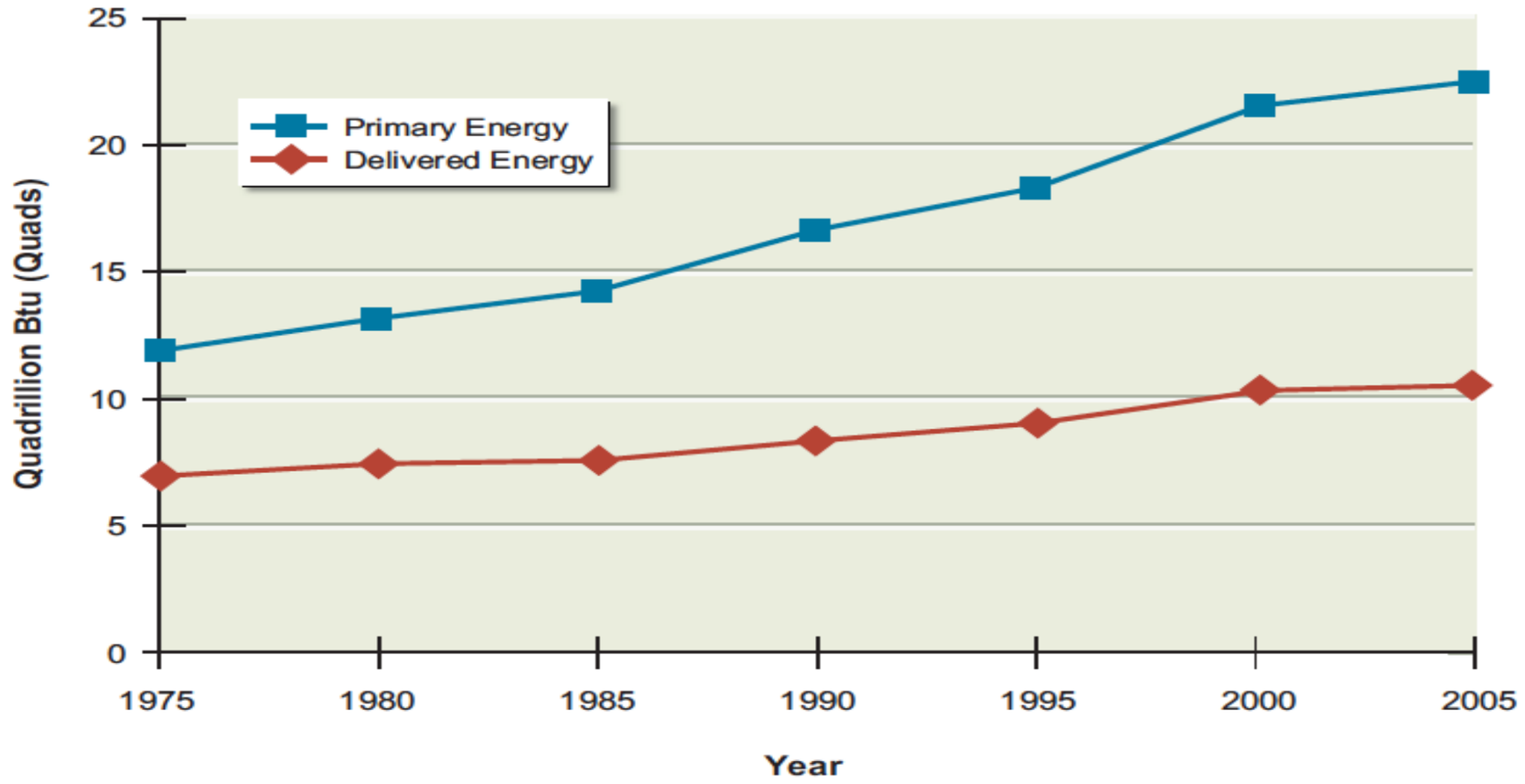



**FIGURE 2.5** *U.S. commercial energy-use trends. Primary energy use (accounting for losses in electricity generation and transmission and distribution and for fuels, such as natural gas, used on-site) has increased faster than delivered energy use (which does not account for such losses but does include fuels used on-site) because use of electricity has increased faster than use of other fuels.*
*Source: EIA, 2007b.*

Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

# National Academies Report on Energy Efficiency

TABLE S.1 Panel Estimate of the Potential for Cost-Effective Annual U.S. Energy Savings (in quads) Achievable with Energy Efficiency Technologies in 2020 and 2030

| | Conservative Estimate | | Optimistic Estimate | |
|---|---|---|---|---|
| | 2020 | 2030 | 2020 | 2030 |
| Buildings, primary (source) electricity | 9.4 | 14.4 | 9.4 | 14.4 |
| Residential | 4.4 | 6.4 | 4.4 | 6.4 |
| Commercial | 5.0 | 8.0 | 5.0 | 8.0 |
| Buildings, natural gas | 2.4 | 3.0 | 2.4 | 3.0 |
| Residential | 1.5 | 1.5 | 1.5 | 1.5 |
| Commercial | 0.9 | 1.5 | 0.9 | 1.5 |
| Transportation, light-duty vehicles | 2.0 | 8.2 | 2.6 | 10.7 |
| Industry, manufacturing | 4.9 | 4.9 | 7.7 | 7.7 |
| Total | 18.6 | 30.5 | 22.1 | 35.8 |

Note: Savings are relative to the reference scenario of the EIA's *Annual Energy Outlook 2008* (EIA, 2008a) or, for transportation, a similar scenario developed by the panel. See Table 1.2 for more information on the baselines used in the panel's analysis of the buildings, transportation, and industry sectors.



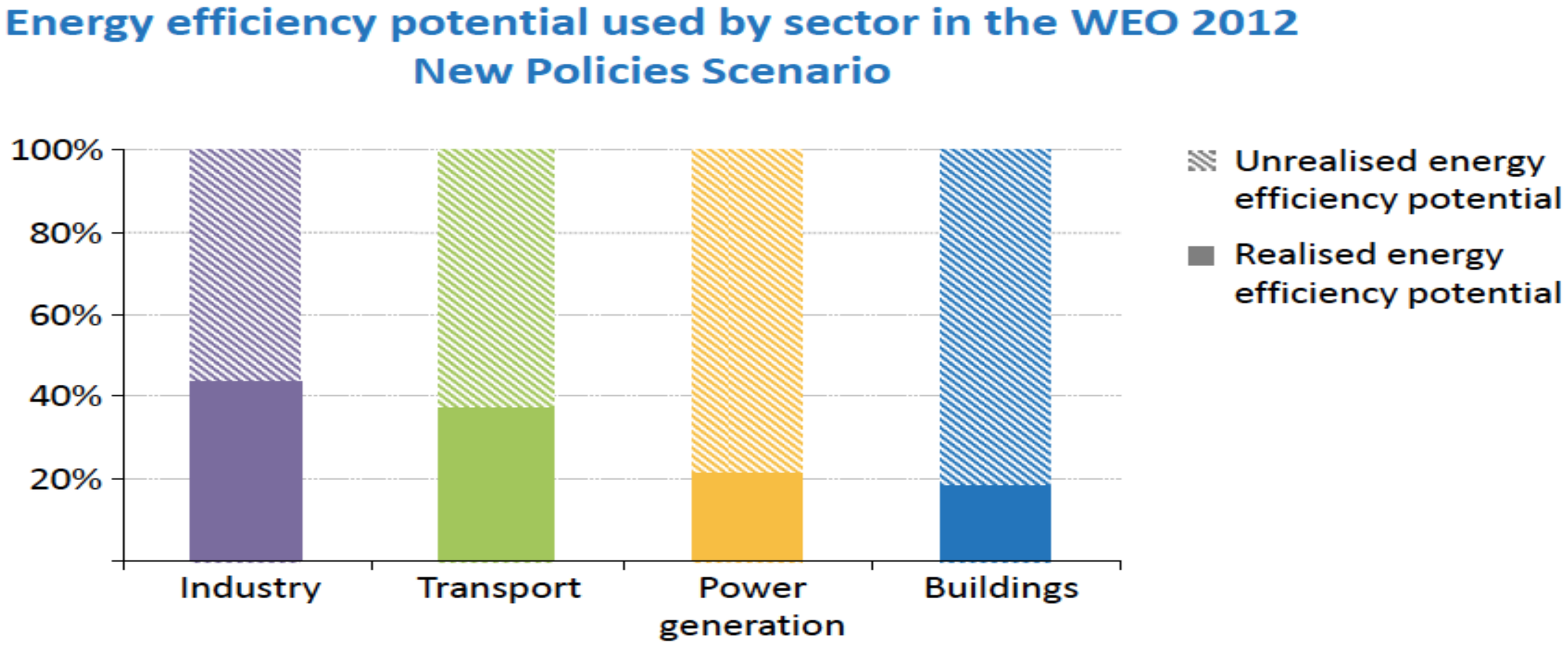
Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

TABLE 2.10 Summary of Commercial Building Energy Consumption, Savings Potential, and Efficiency Measure Costs in 2030, by End-Use

| Fuel and End-Use | Business as Usual (BAU) 2030 U.S. Consumption[a] | Technoeconomic Potential: % Savings Relative to BAU Case | Technoeconomic Potential: Consumption Savings | Cost of Conserved Energy |
|---|---|---|---|---|
| Electricity | *(TWh)* | | *(TWh)* | *(2007¢/kWh)* |
| Space heating[b] | 77 | 39 | 30 | 0.5 |
| Space cooling[b] | 238 | 48 | 115 | 2.8 |
| Water heating[b] | 59 | 11 | 6 | 1.2 |
| Ventilation[b] | 131 | 45 | 59 | 0.5 |
| Cooking[c] | 11 | 30 | 3 | 8.3 |
| Lighting[b] | 543 | 25 | 137 | 5.2 |
| Refrigeration[b] | 89 | 38 | 34 | 1.3 |
| Office equipment—PCs[c] | 120 | 60 | 71 | 3.9 |
| Office equipment—non-PCs[c] | 271 | 25 | 68 | 3.2 |
| Other uses[b] | 523 | 35 | 182 | 1.4 |
| Total electricity | 2062 | 34 | 705 | 2.7 |

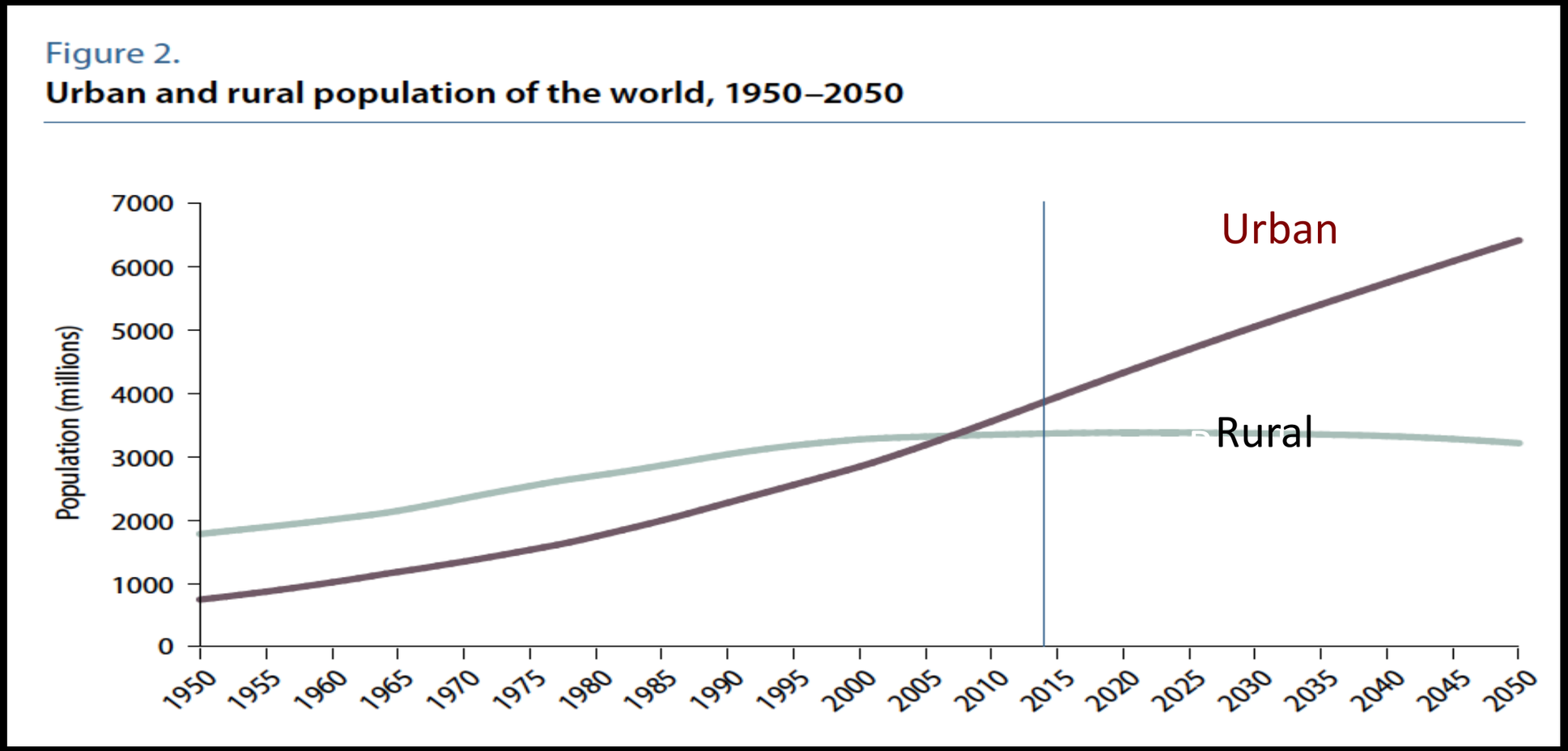
# Global Perspective

More than 2/3 of potential efficiency gains still unrealized




Source: IEA, WEO 2012

# Urbanization - Global Megatrend




Potential for large impact from energy and water efficiency in new residential and commercial buildings

Source: World Urbanization Prospects, 2014, UN

# NSF ENG Clean Energy Investments: 2012-2014

## Renewable Energy Production

**Alternative Fuels**
Biofuels (bio & chemical routes)
Solar Fuels ($CO_2$, water splitting)

**Electricity**
Solar Photovoltaics
Wind
Water (hydrokinetic/tidal/wave)
Solar Thermal
Geothermal

**$139,236,192 (64%)**

## Storage & Grid

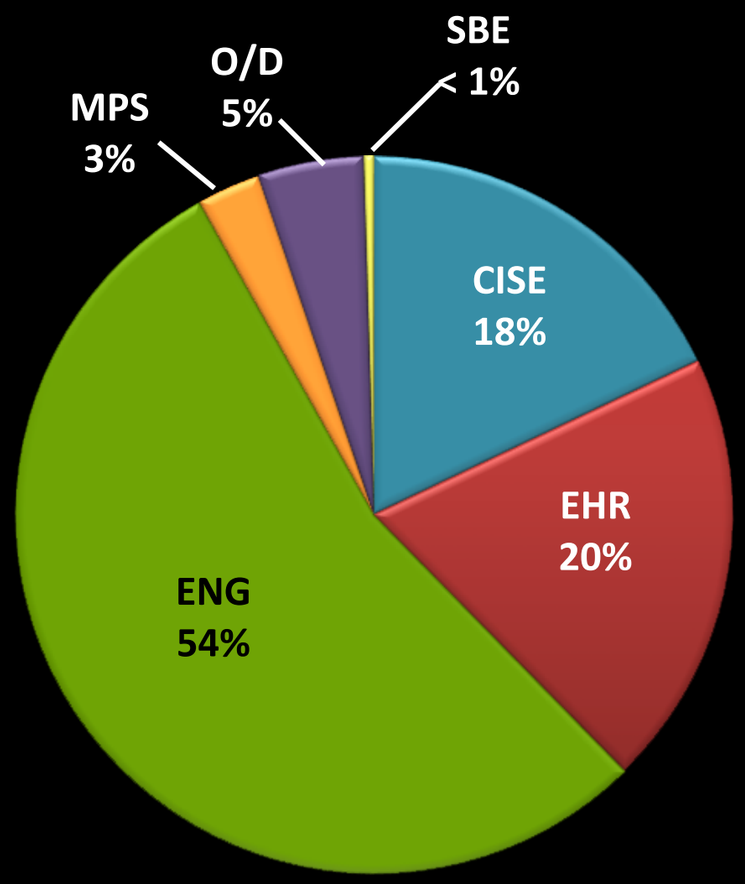
**Energy Storage**
Batteries & capacitors
Fuel Cells
Thermal Storage

**Other Topics**
Grid (micro, smart)
Energy Efficiency
Carbon Capture

**$71,653,915 (34%)**

# NSF Investments by Directorate in Energy Efficiency

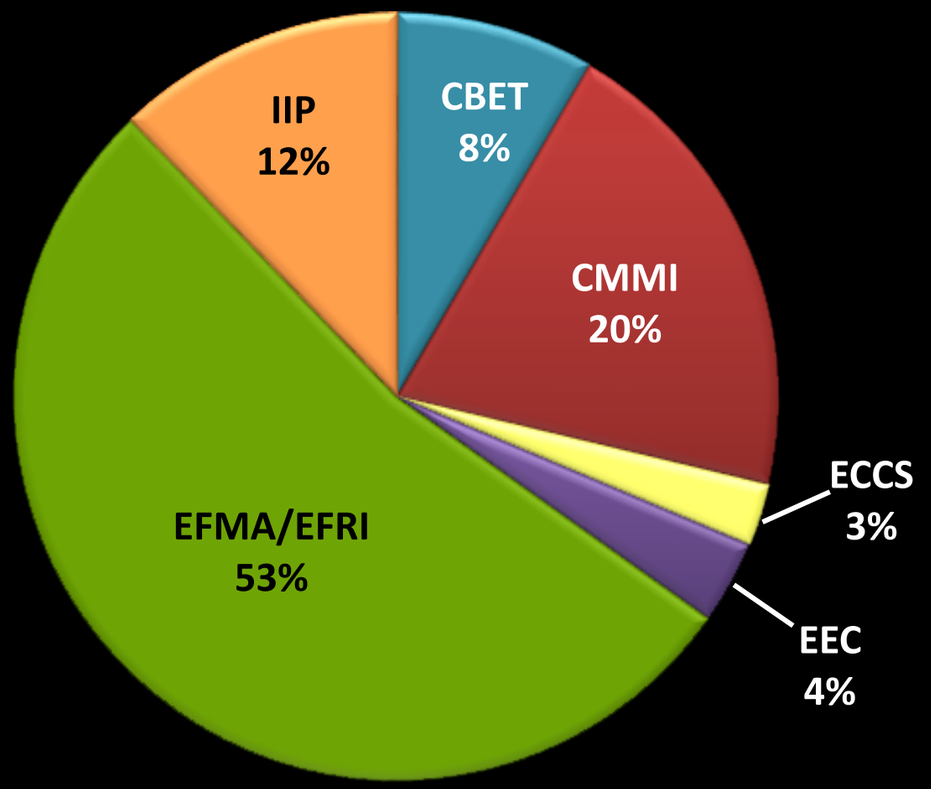
- Directorate for Computer & Information Science & Engineering (CISE): $ 11.6 million
- Directorate for Education & Human Resources (EHR): $ 12.8 million
- Directorate for Engineering (ENG): $ 35 million
- Directorate for Mathematical & Physical Sciences (MPS): $ 1.9 million
- Office of the Director (O/D): $ 3 million
- Social, Behavioral, & Economic Sciences (SBE): $ 300 k




**NSF Total: $ 64,590,168**

# ENG Investments by Division

- Chemical, Engineering, Environmental & Transport Systems (CBET): $ 2.9 million
- Civil, Mechanical & Manufacturing Innovation (CMMI): $ 7.1 million
- Electrical, Communications & Cyber Systems (ECCS): $ 916 k
- Engineering Education & Centers (EEC): $ 1.2 million
- Emerging Frontiers & Multidisciplinary Activities (EFMA) / Emerging Frontiers in Research and Innovation (EFRI): $ 18.6 million
- Industrial Innovation & Partnerships (IIP): $ 4.3 million

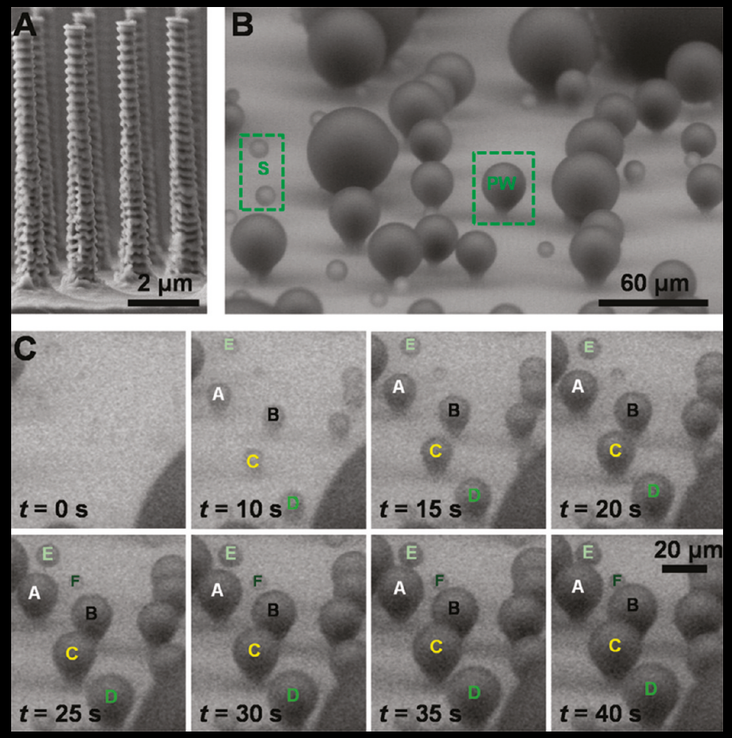



**ENG Total: $35,023,191**

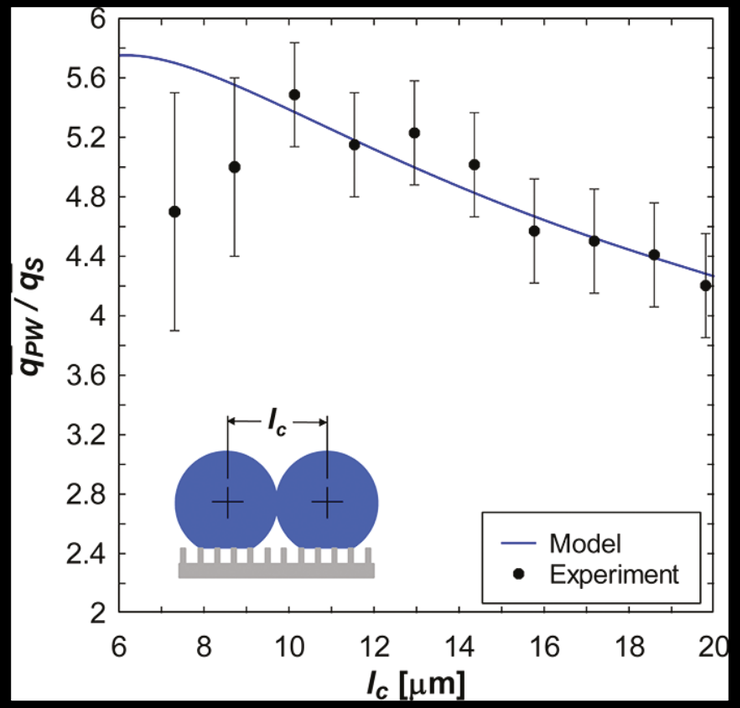
# Example Projects

# Efficient Heat Transfer

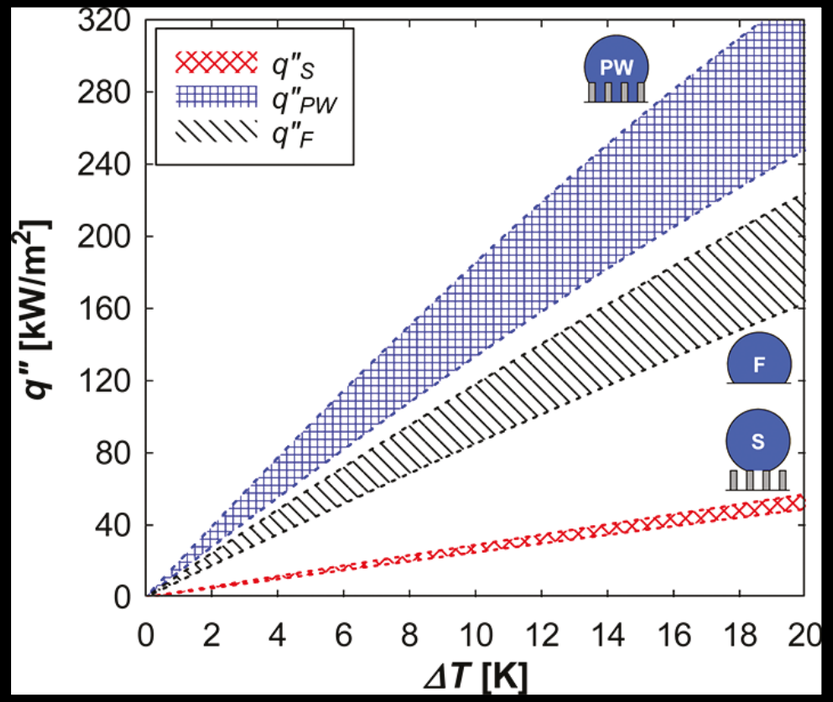
Wang et al. *ACS Nano*, **2012**, *6*. 1777.




**Time Lapse Images of condensation**




**Individual droplet heat transfer ratio of PW to S as a function of coalescence length ($l_c$)**



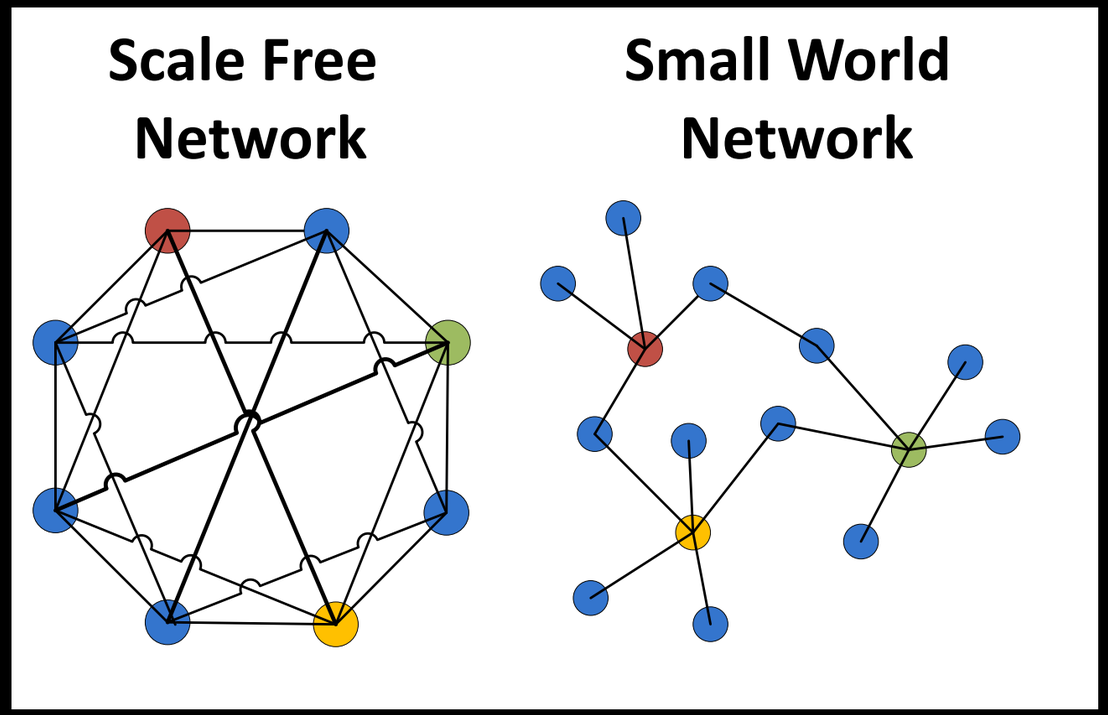

**Theoretical Steady State heat flux ($q''$) vs ΔT for surfaces having PW, S, and F droplets.**

NSF 0824328: BRIGE: Dynamically Tunable Nanostructured Surfaces for Multiphase Microfluidics
Current : NSF: ECS-0335765 (Center for Nanoscale Systems) + DOE BES

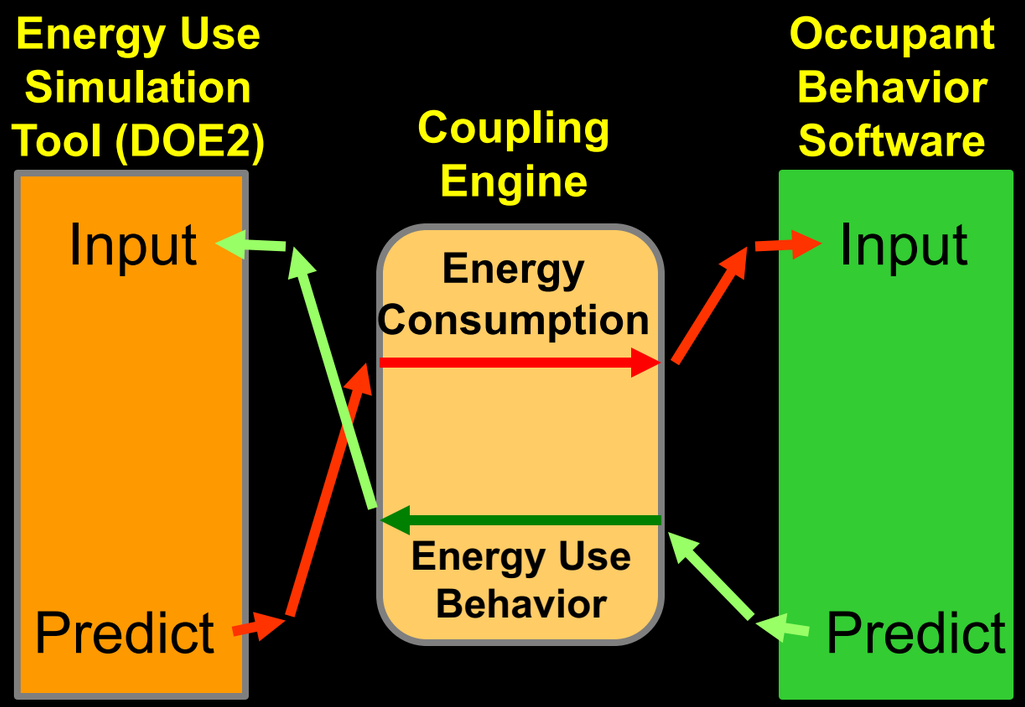
***Evelyn Wang, MIT***

# Understanding and Modeling the Impact of Occupant Energy Usage Characteristics in Building

## Agent Based Model of Occupancy Networks in Buildings

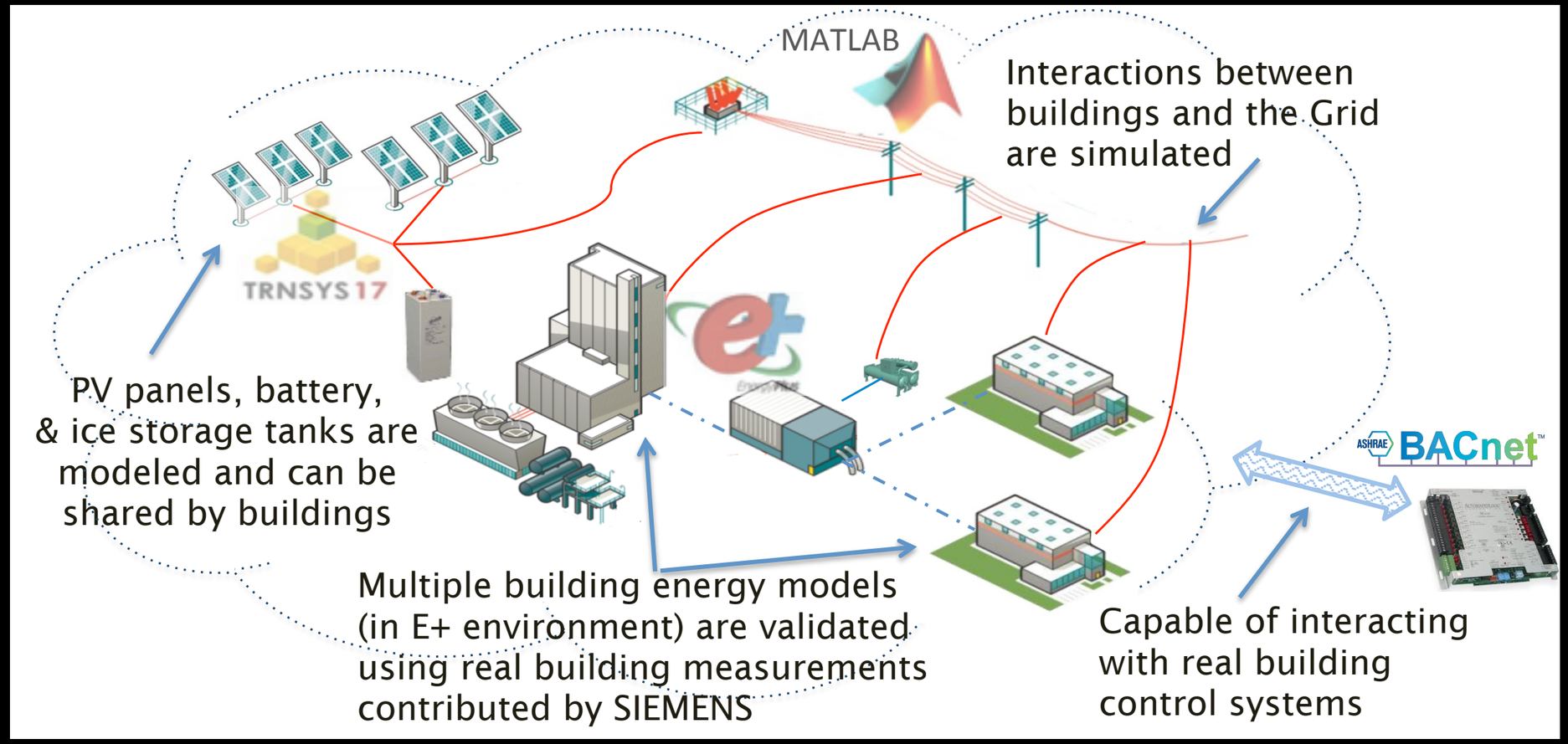



## Dynamic Energy Analysis




*Carol Menassa*
*University of Michigan*

# CPS: SMARTER - Smart Manager for Adaptive and Real-Time decisions in building clustERs



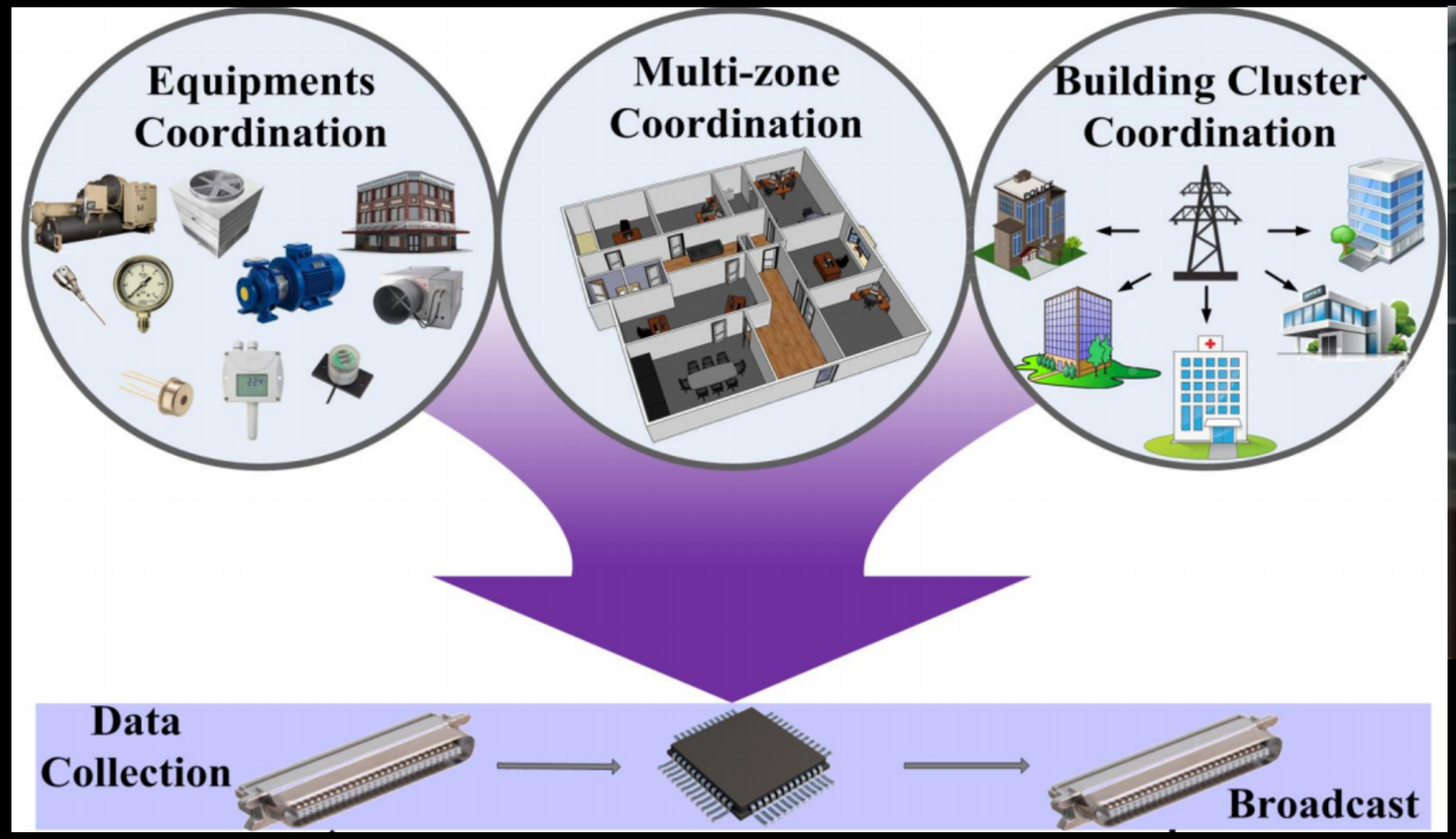

**Vision:** buildings freely form clusters to share and exchange site-generated energy

**Test Bed:** building clusters, high fidelity models, and operation strategies

*Jin Wen, Drexel University*

# CPS: Plug-and-Play Cyber-Physical Systems to Enable Intelligent Buildings

## Multi-Agent Control Architecture

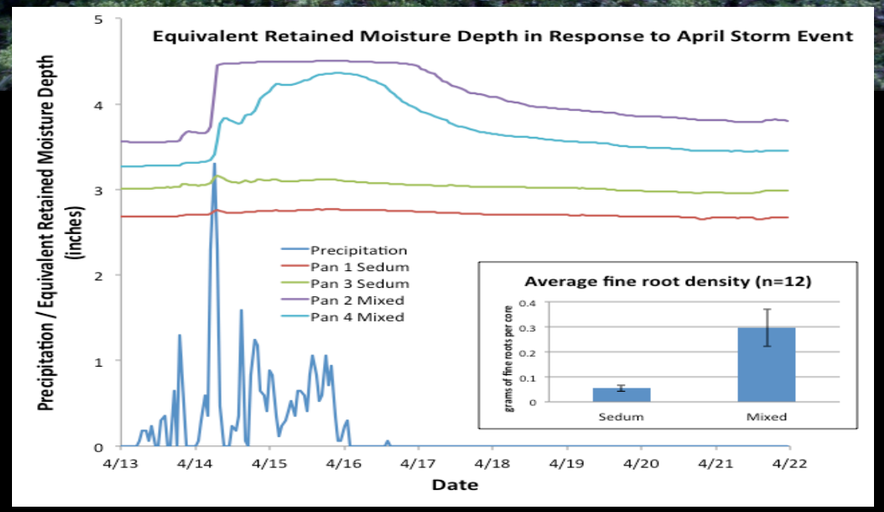



## Real Time Occupant Sensing

*Purdue University Living Lab*
*Center for High Performance Buildings*

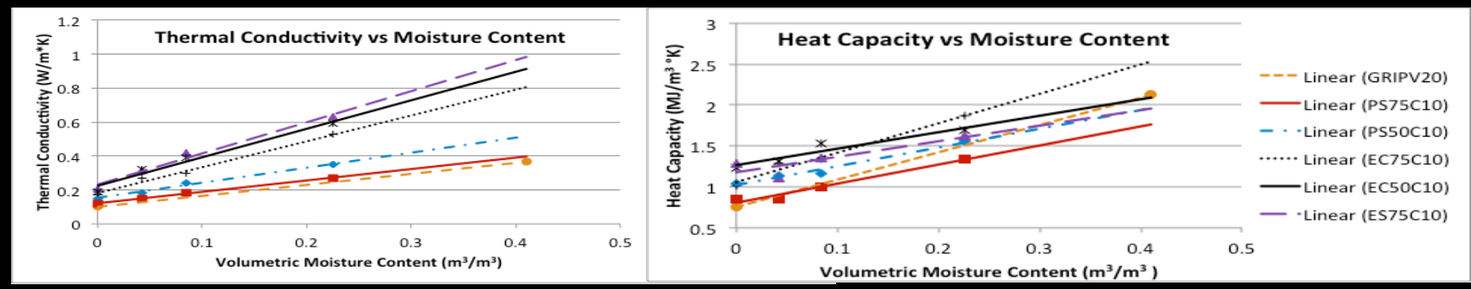
# Integrating Green Roofs and Photovoltaic Arrays


## Carl Wamser, David Sailor, Todd Rosenstiel
## Portland State University - CBET-0853933

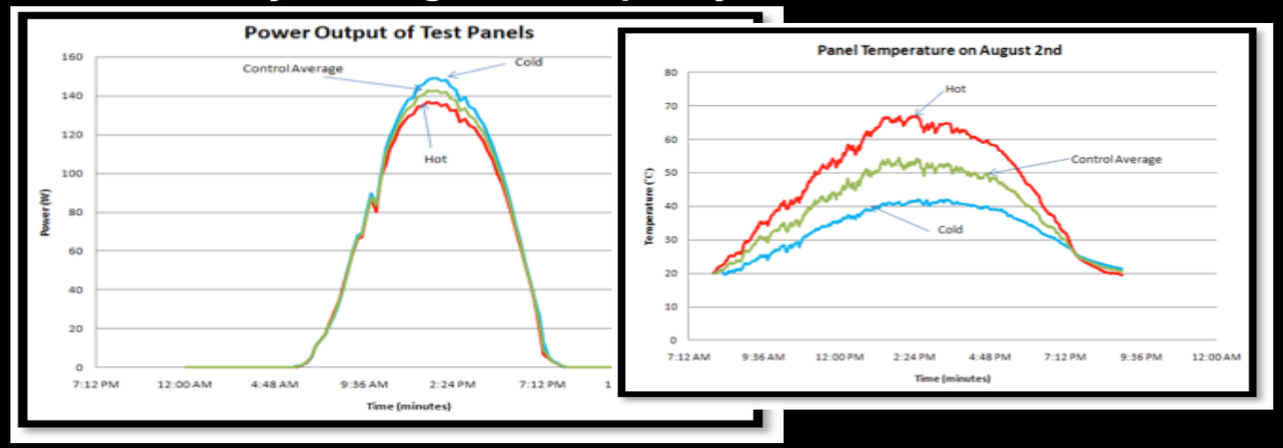




Green roof pans with mixed plant matter are much more effective than sedum in retaining moisture from storm events.

August 4, 2015




**Thermal properties of the green roofs (GRIPV) show low thermal conductivity and high heat capacity versus different models.**




Photovoltaic power output is very sensitive to temperature effects, as expected for silicon photovoltaic materials.

- Ongoing work is aimed at understanding interactions between green roof functions and photovoltaic functions.
- The working hypothesis is that each system will function at least as well even when the two are integrated.

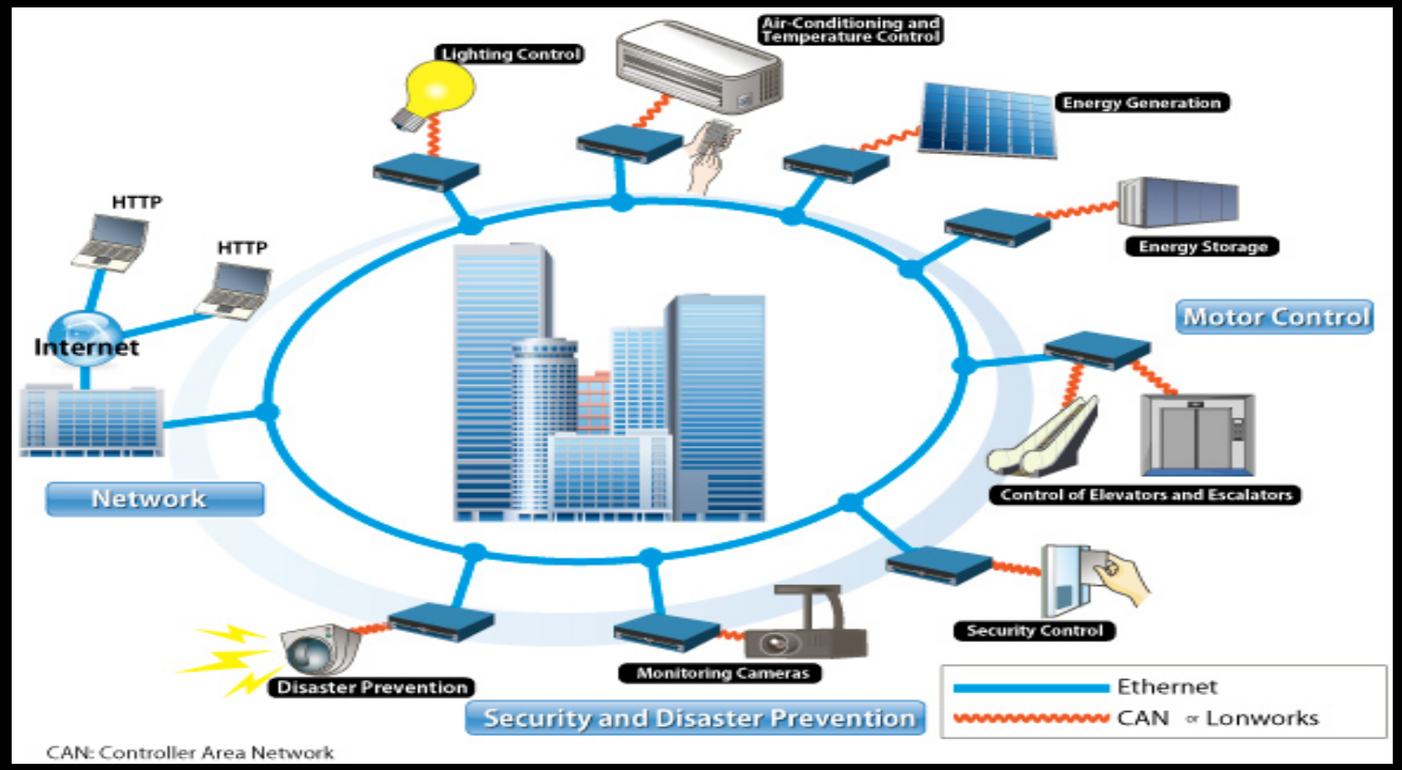
# Science in Energy and Environmental Design (SEED) – An EFRI Program

- Integrated multidisciplinary science, engineering and systems research for innovative, transformative buildings research
- Program launched in 2010
- $18.6M total funding
- 10 awards focused on buildings

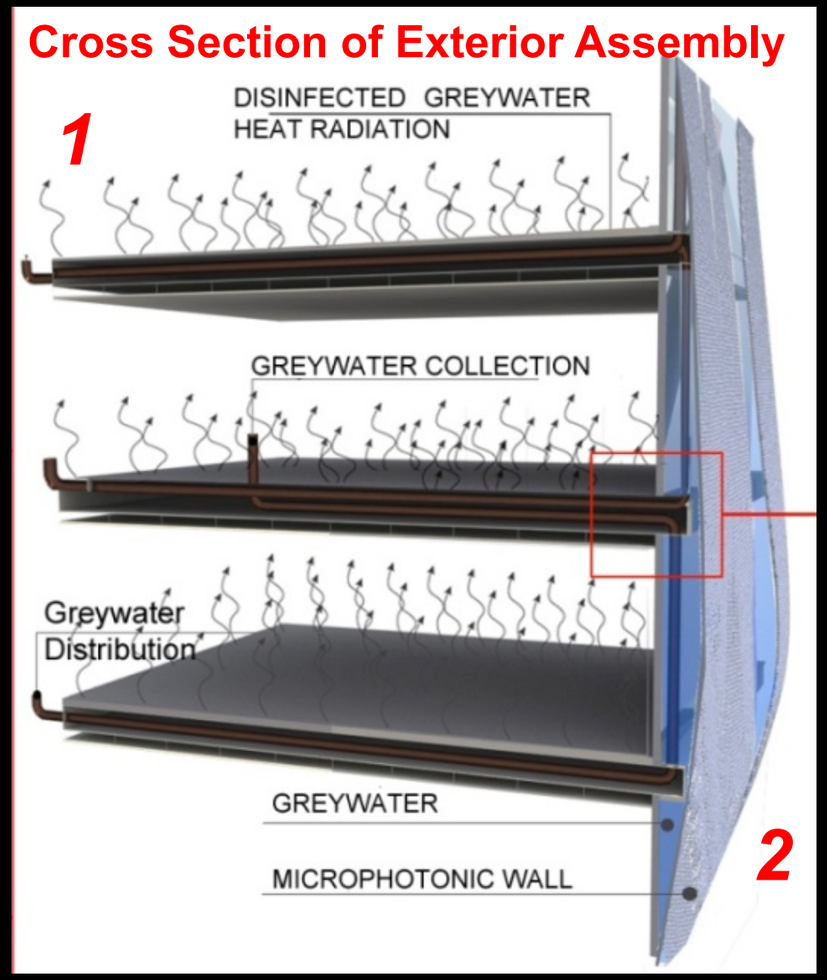
# EFRI SEED: Interactive building intelligence

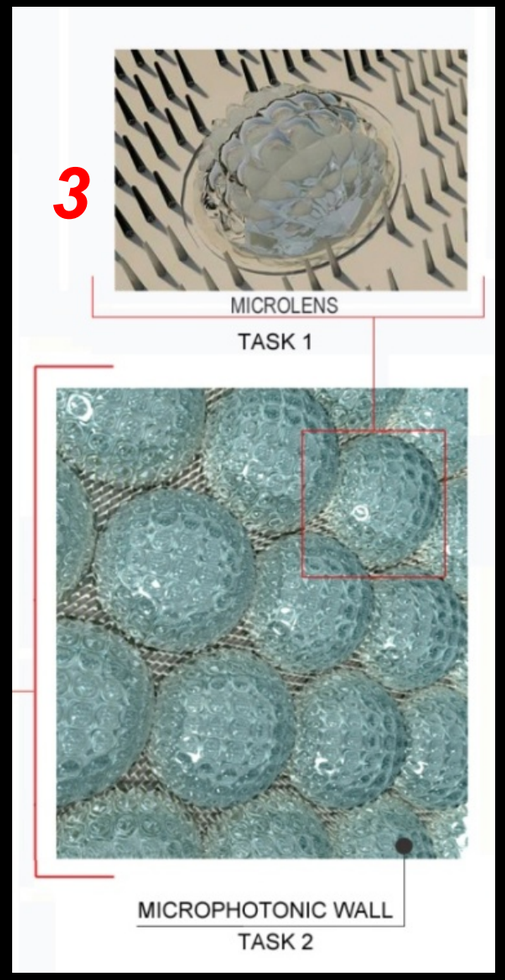
Smart Control Protocols of Distributed Energy Resources (DERs) – HVAC, Storage, EV, VHP… – can Transcend Local Efficiency Gains by Responding to System Marginal Costs.

- Optimal Power Scheduling in multi-period Day-Ahead Markets => 5-20% decrease in System Energy Cost.
- Efficient Provision of Reserves may enable Massive Penetration of Clean Renewable, albeit Volatile, Generation.
- Regulation Service Provision => 10-40% decrease of Wholesale market Priced Energy Consumption.
- Control of DER Volt/Var Control Devices – Roof top PV inverters, EV battery Chargers, HVAC and CHP variable Speed Drives – can reduce line losses by 50%, relieve distribution feeder congestion, enhance Distribution Net. Asset Life and Increase Distribution Infrastructure Resilience.



# EFRI SEED: Solar Optics-based Active Panels (SOAP) for Greywater Reuse and Integrated Thermal Building Control



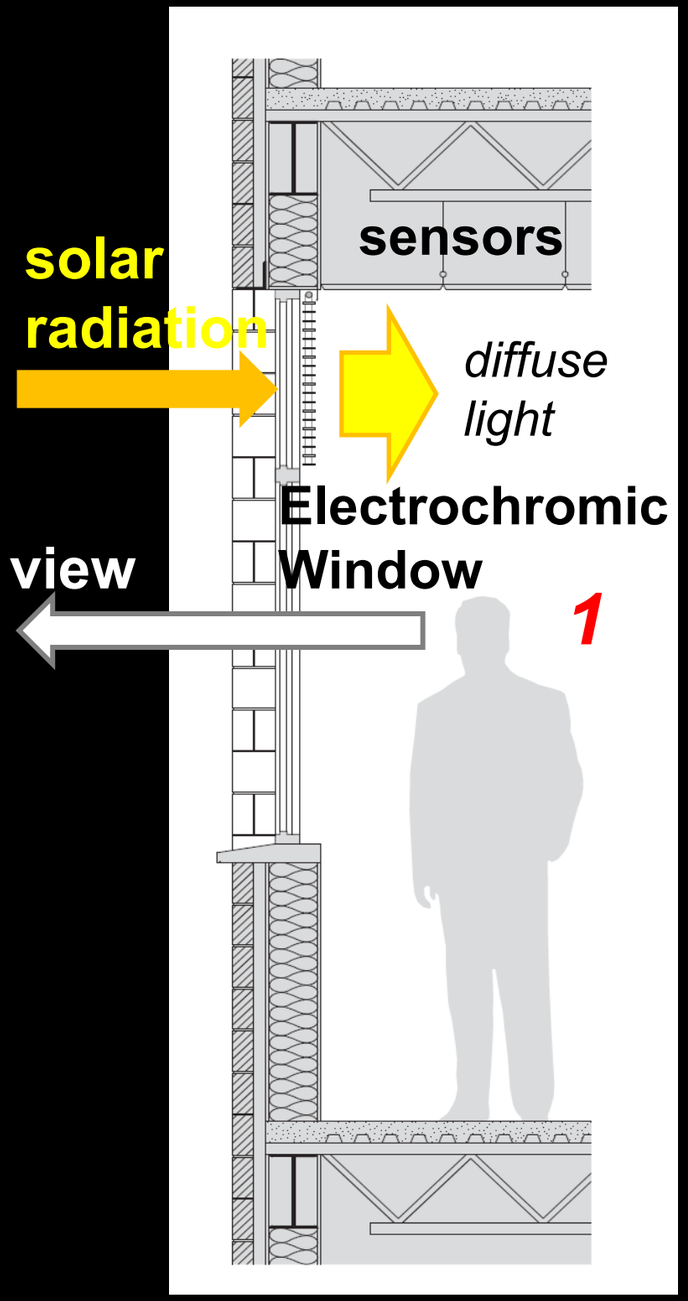




## Innovative Features of SOAP:

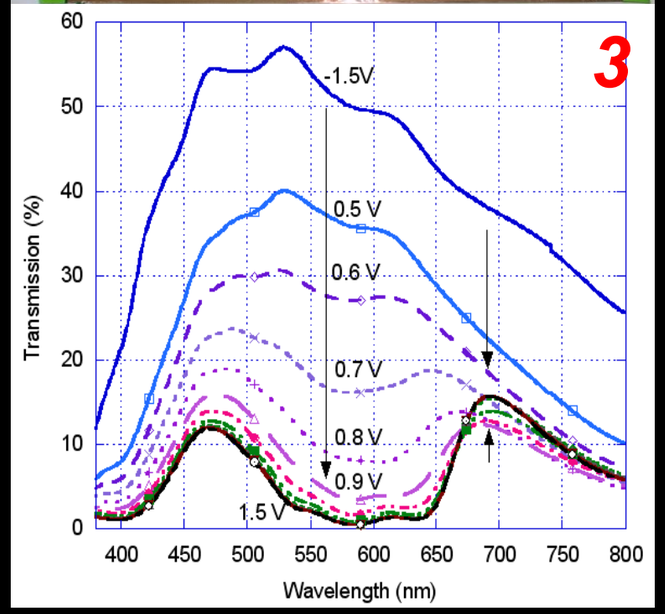
- Greywater collection and disinfection by solar thermal radiation
- Solar optics based exterior panel for solar thermal energy collection and storage
- Microphotonic membrane for solar light concentration


*Maria Paz Gutierrez et al.*
*University of California - Berkeley*

# EFRI-SEED: Toward Zero-Energy Building Based on Electrochromic Windows (ECW) and Energy Harvesting



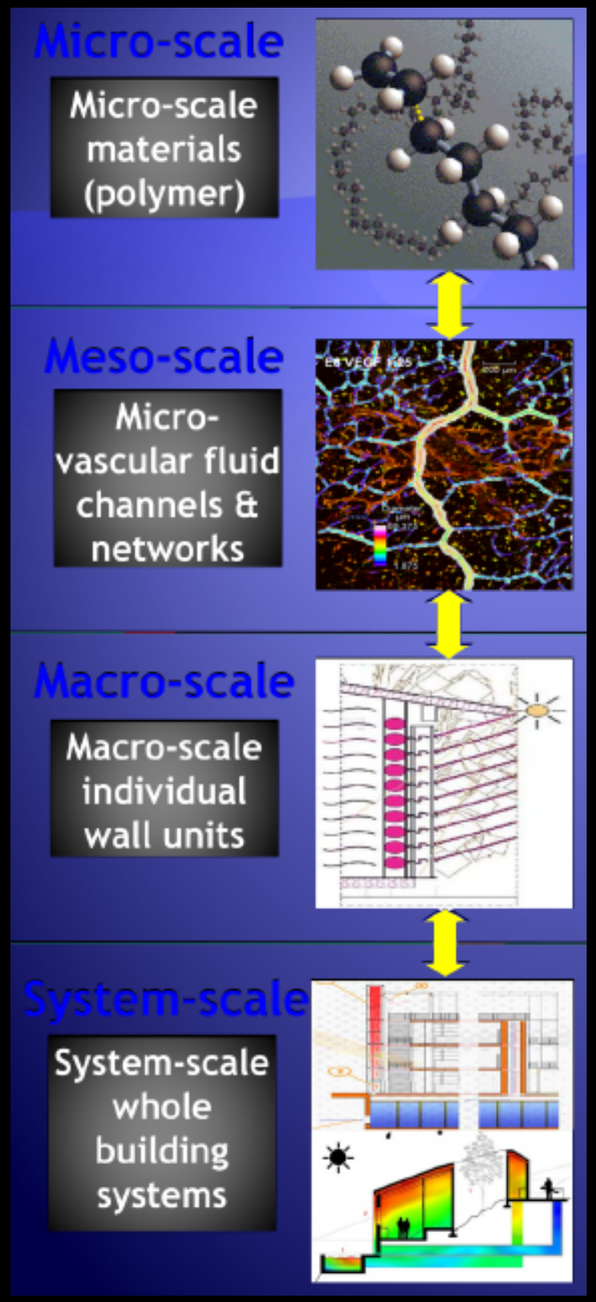





## Innovative Features of ECW:

- Organic Electrochromic Window senses and "adjusts" to lighting needs and reduces solar heating load
- Can have aesthetic elements
- Applied voltage sets solar transmittance

*Minoru Taya et al, University of Washington*

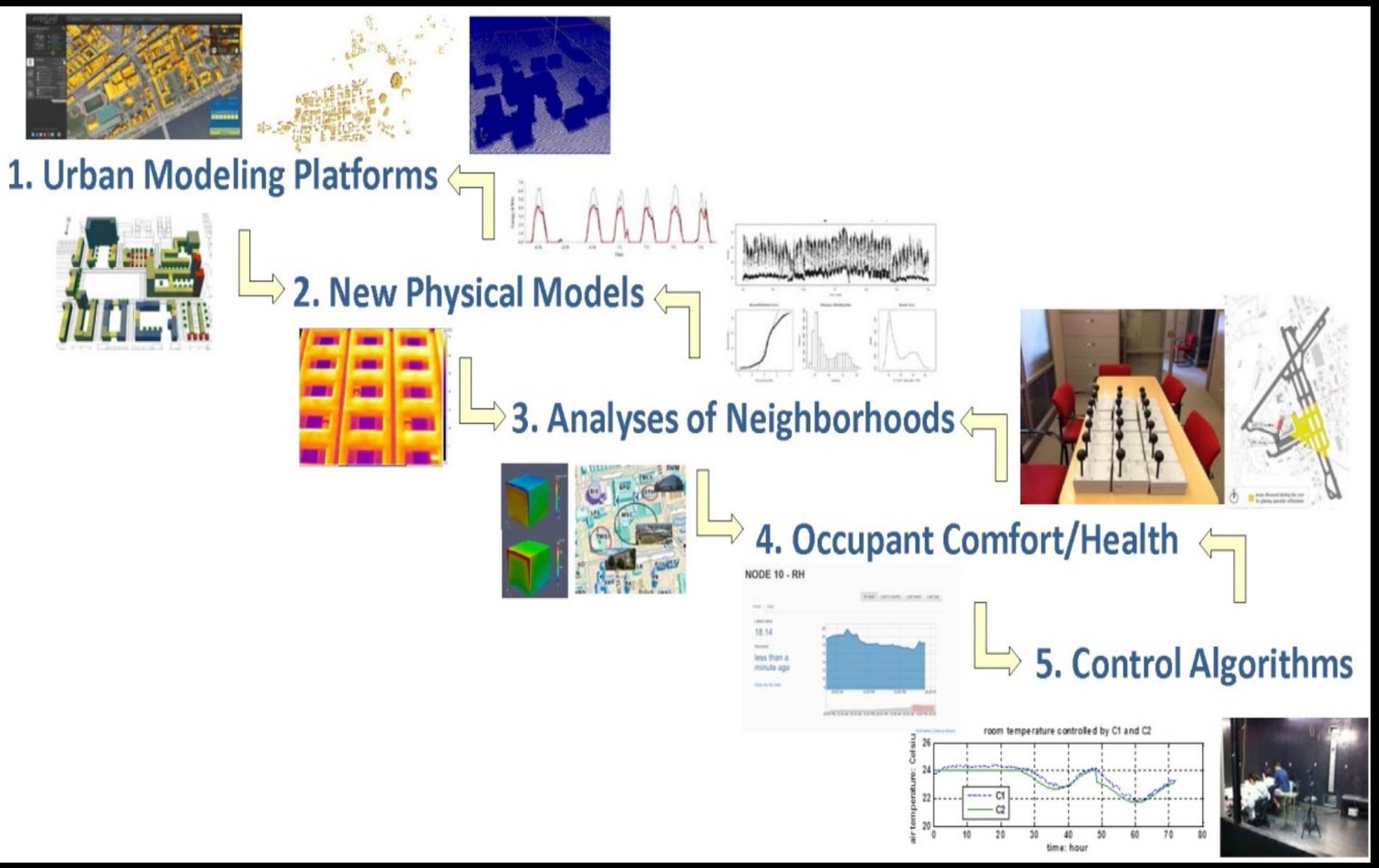


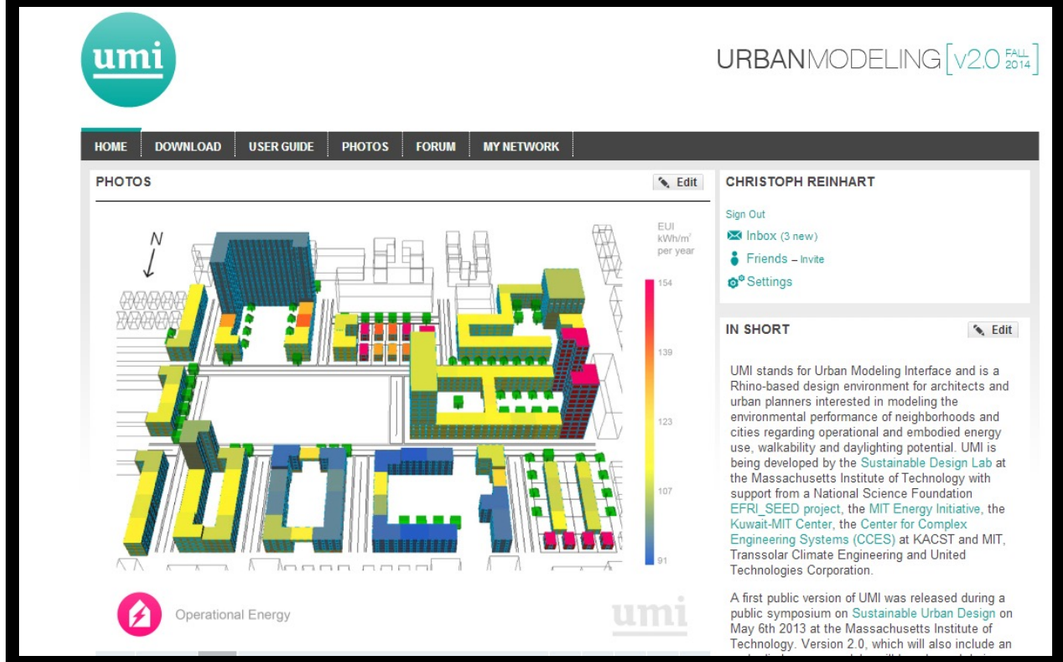

# EFRI-SEED: Living Wall Materials and Systems for Automatic Building Thermo-Regulation

## Innovative Features:

- Bioinspired micro-vascular networks and distributed phase change medium (PCM) embedded into an polymer-based wall unit
- Autonomous movement of air and liquid and charge/ discharge of PCM to dynamically regulate the thermal behaviors of building envelope and entire dwelling

# EFRI-SEED: PULSE - Population in Urban Landscape for Sustainable Built Environment

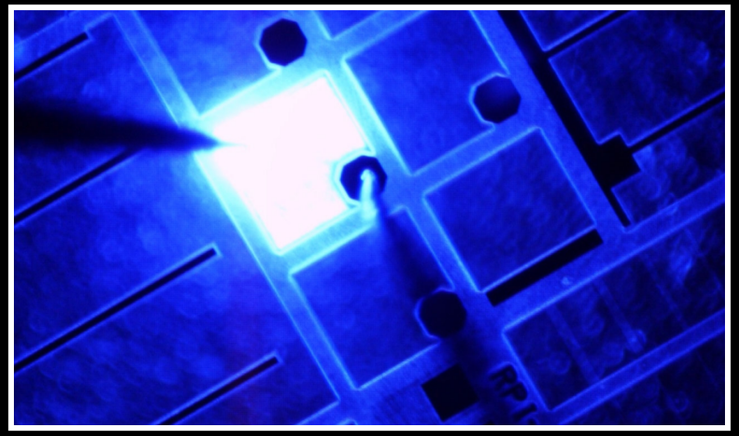


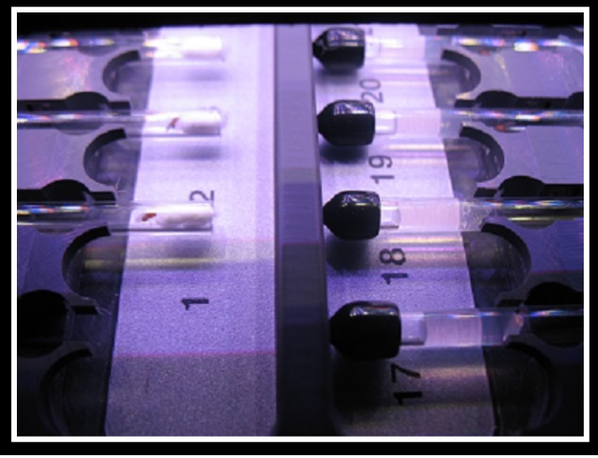



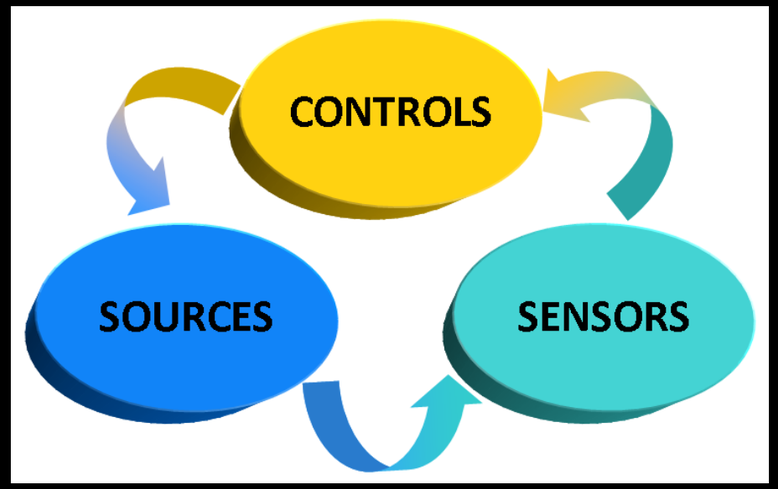

C. Reinhardt, MIT, J. Spengler, Harvard, J. Srebrik, UMD

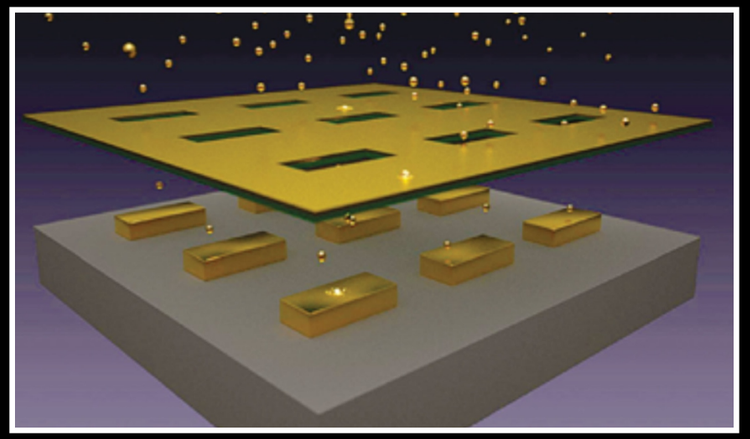
# SMART LIGHTING ENGINEERING RESEARCH CENTER

*The right light where and when you need it*







https://smartlighting.rpi.edu/index.php/leadership/

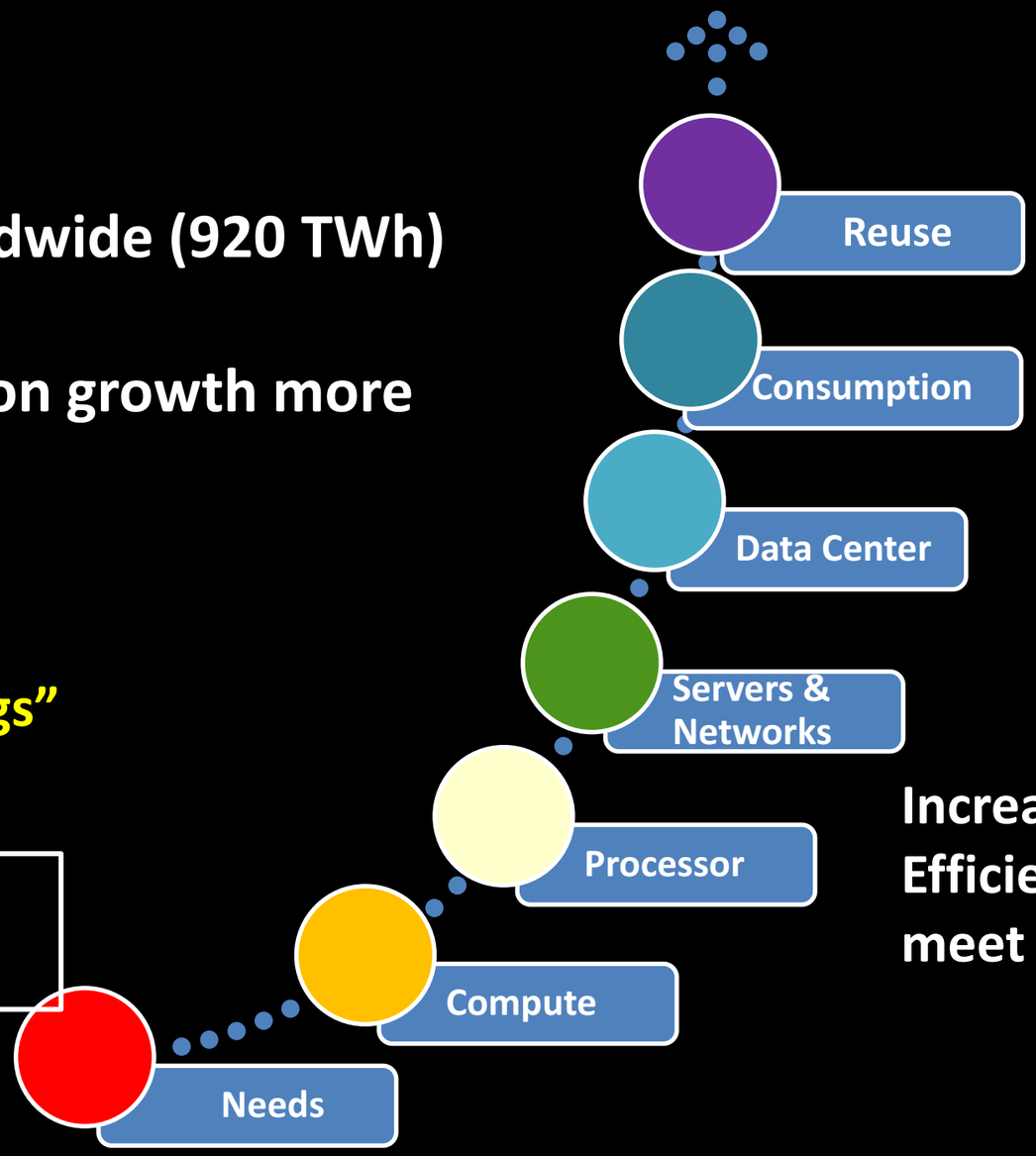
# The Energy Use in Information & Communication Technologies

**2012: ICT consumed 4.7 % of electricity worldwide (920 TWh)**

**ICT sector growing but electricity consumption growth more moderate**

**Large unknown-the effect of the "Internet of Things"**

**Significant and growing NSF portfolio in energy efficient electronics and computing**

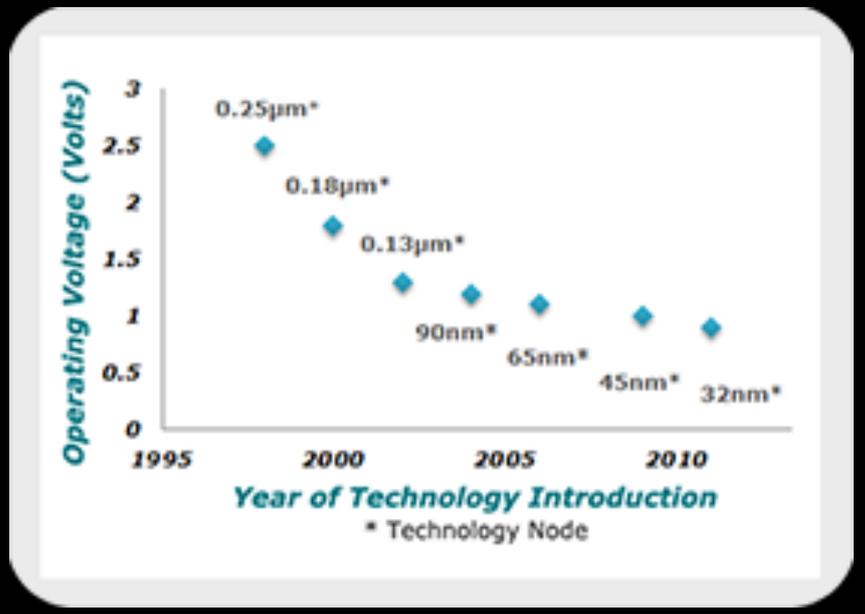



**Increases in Efficiency to meet <u>Needs</u>**

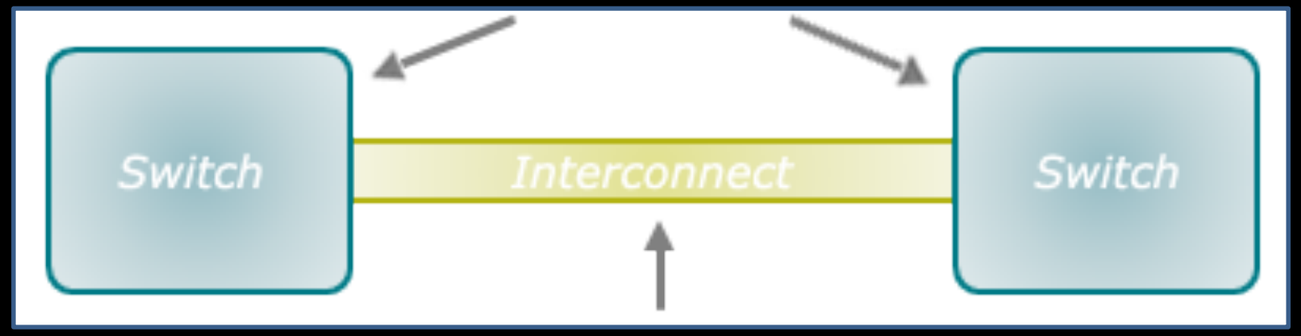
E. Gelenbe and Y. Caseu, Information Technology Impact on Energy Consumption and Carbon Emissions, *Ubiquity*, June 2015.

# Center for Energy Efficient Electronics Science

Size of ICs vs. power consumption

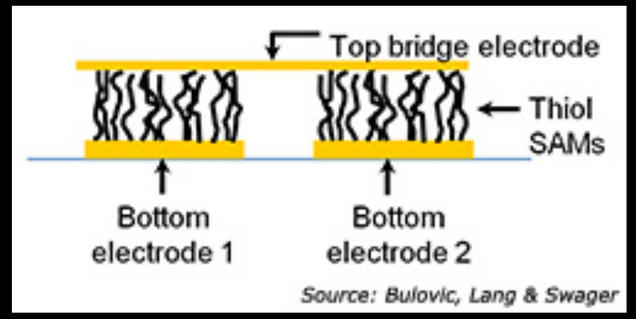



Theme 1: Nanoelectronics
Theme 2: Nanomechanics
Theme 4: Nanomagnetics




Theme 3: Nanophotonics

Example from Theme 2




**NSF 0939514: Center for Energy Efficient Electronics Science (Center for E3S) at UC Berkeley - $44 million**

http://www.e3s-center.org/

# Energy Efficiency Gap

- Net present value of energy efficiency gains far exceeds the required investment
- Yet, actual investments in energy efficiency are much lower than economically justifiable levels
- Energy efficiency gap or paradox
- What are the causes of this gap?

# Barriers and Impediments

- Three types of barriers: structural, behavioral, and availability
- Specific barriers:
  - Regulatory barriers
  - Upfront capital investments needed
  - Energy efficiency not a critical or primary objective
  - Fragmented diffused opportunity
  - Incentives split and not aligned
  - Ownership transfer before capturing full benefit
  - Lack of awareness and education
  - Investment of time and effort
  - Adverse bundling

# Rebound Effects

- Jevons Paradox
- 3 Channels for Rebound Effect
  - Direct effects
  - Indirect effects
  - Macro-economic effects
- Analysis and understanding of rebound effects is difficult and controversial
- Wide variations in estimates of rebound effects – 9% to 60% or more

# Conclusions

- Energy efficiency has large potential to positively impact energy and climate change
  - Urbanization in the developing world offers unprecedented opportunities
- Existing and emerging technologies
- It is a socio-technical problem

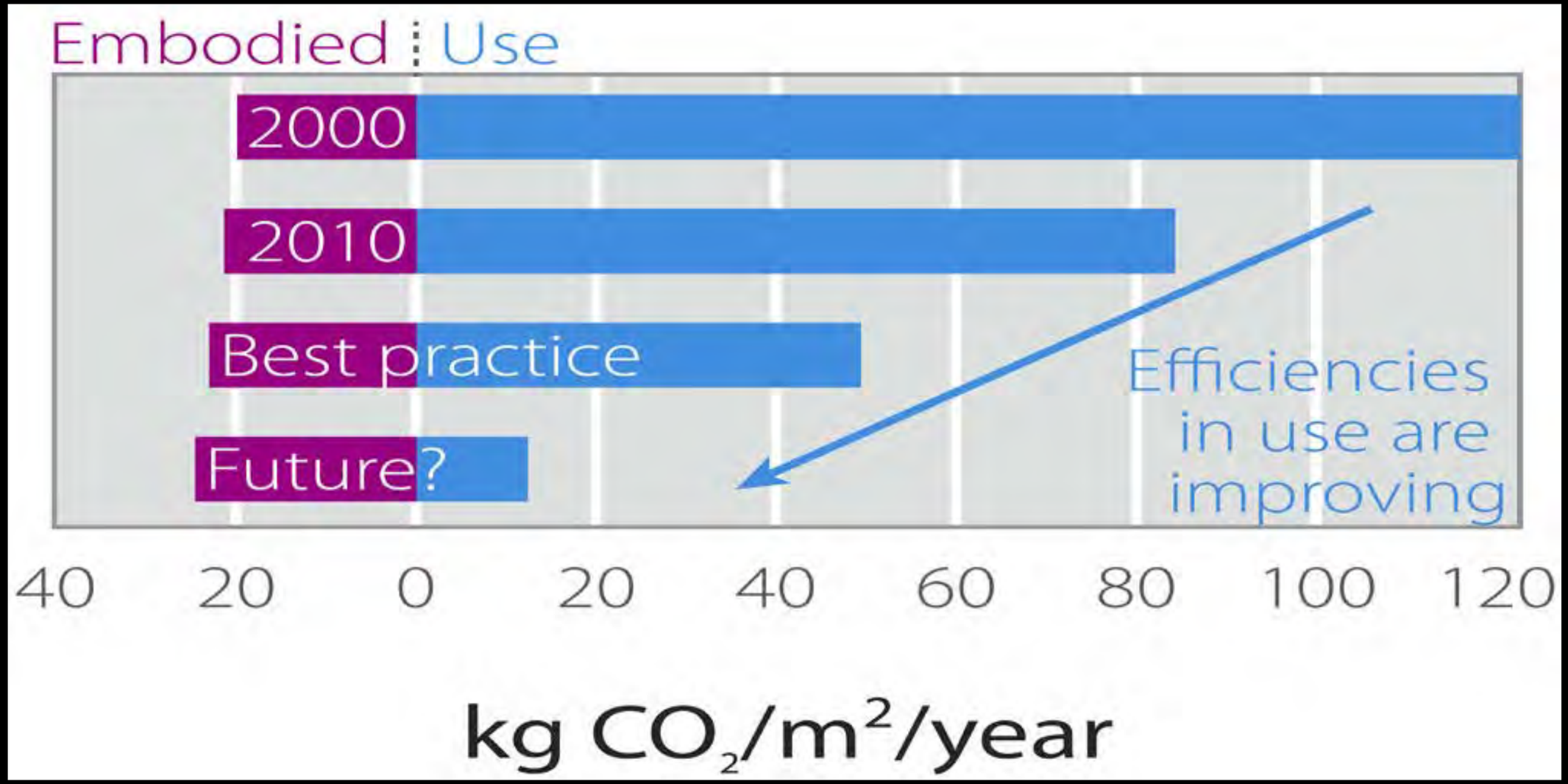
# Thank you!

Questions? *Comments?*

pkhargon@nsf.gov

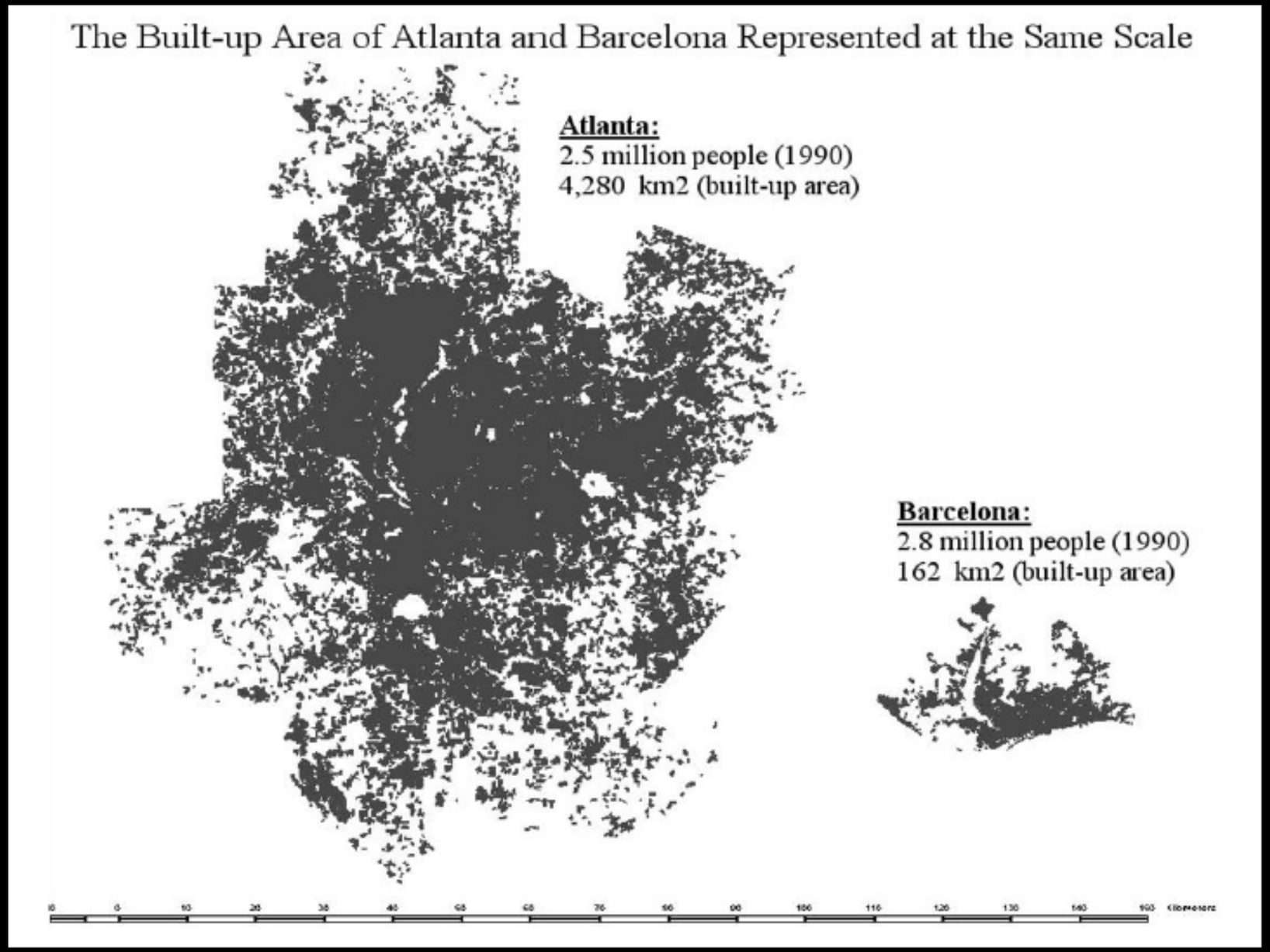
# Backup Slides

# Balance is shifting toward embodied energy




Allwood and Cullen, 2011

# Design Choices have Large Impacts




*Bertaud and Richardson, 2004*

# Potential Impact of Advanced Cooling

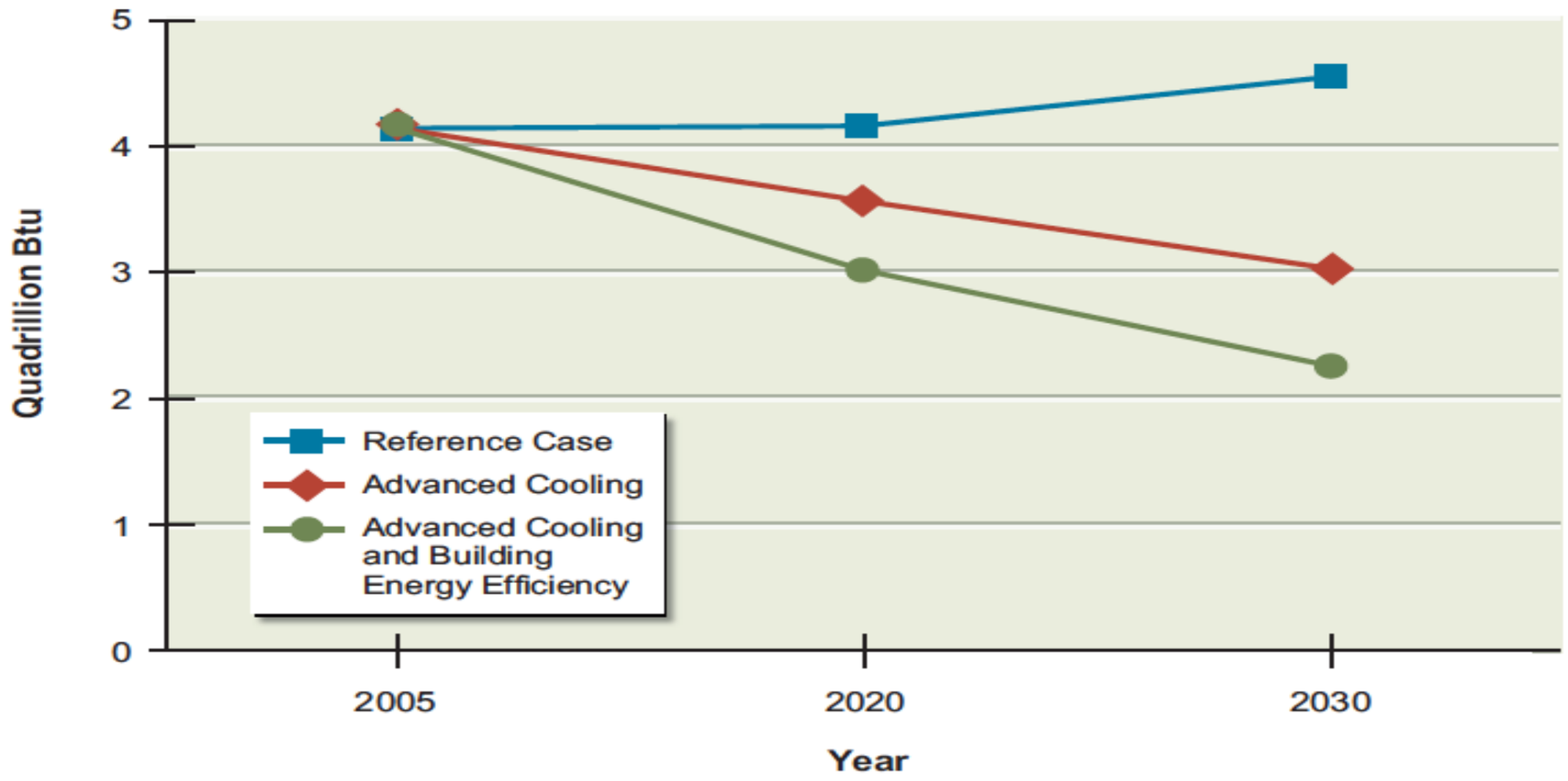



**FIGURE 2.11** *Potential reduction in cooling demand in U.S. buildings using advanced technologies.*
*Source: Courtesy of S. Dunn, Southwest Energy Efficiency Project, Boulder, Colo., November 2007; based on data from the Annual Energy Outlook 2007 (EIA, 2007a) and the Buildings Energy Data Book 2007 (DOE/EERE, 2007).*

Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

# Transportation

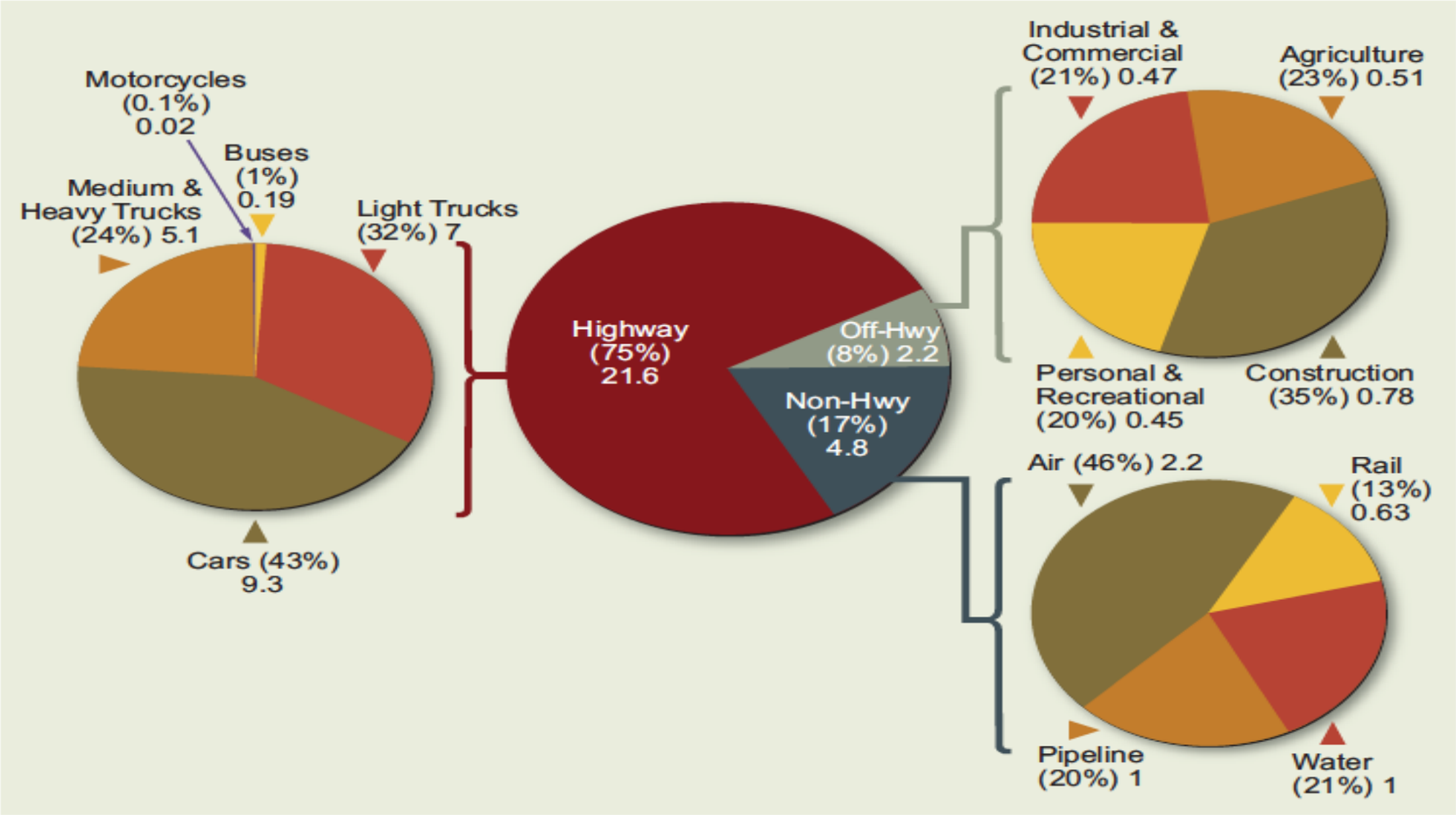



**FIGURE 3.1** *U.S. transportation energy consumption (quads) by mode and vehicle in 2003.*
*Note: Total U.S. energy consumption = 98.2 quads.*

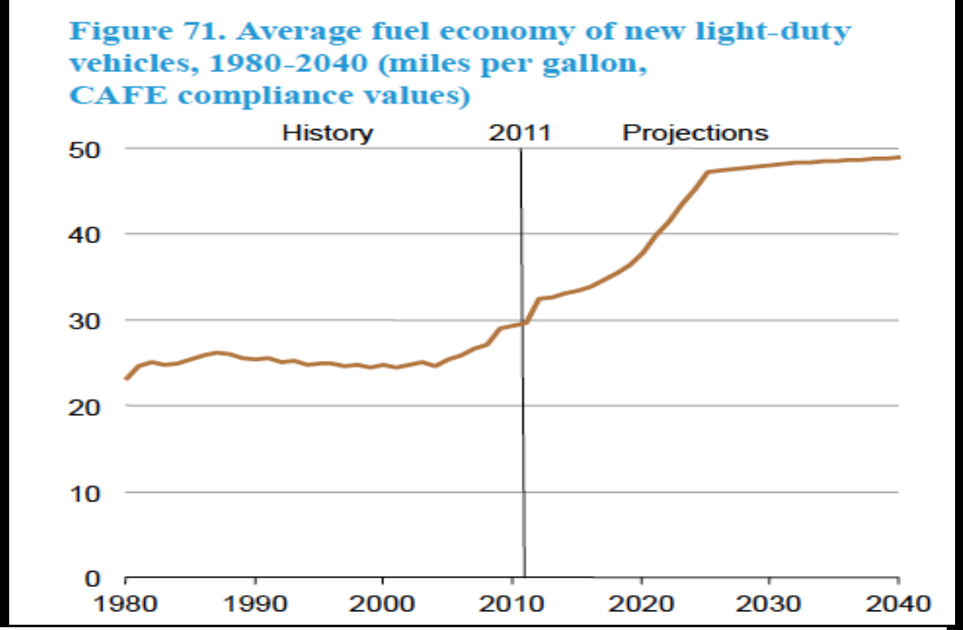
# Transportation

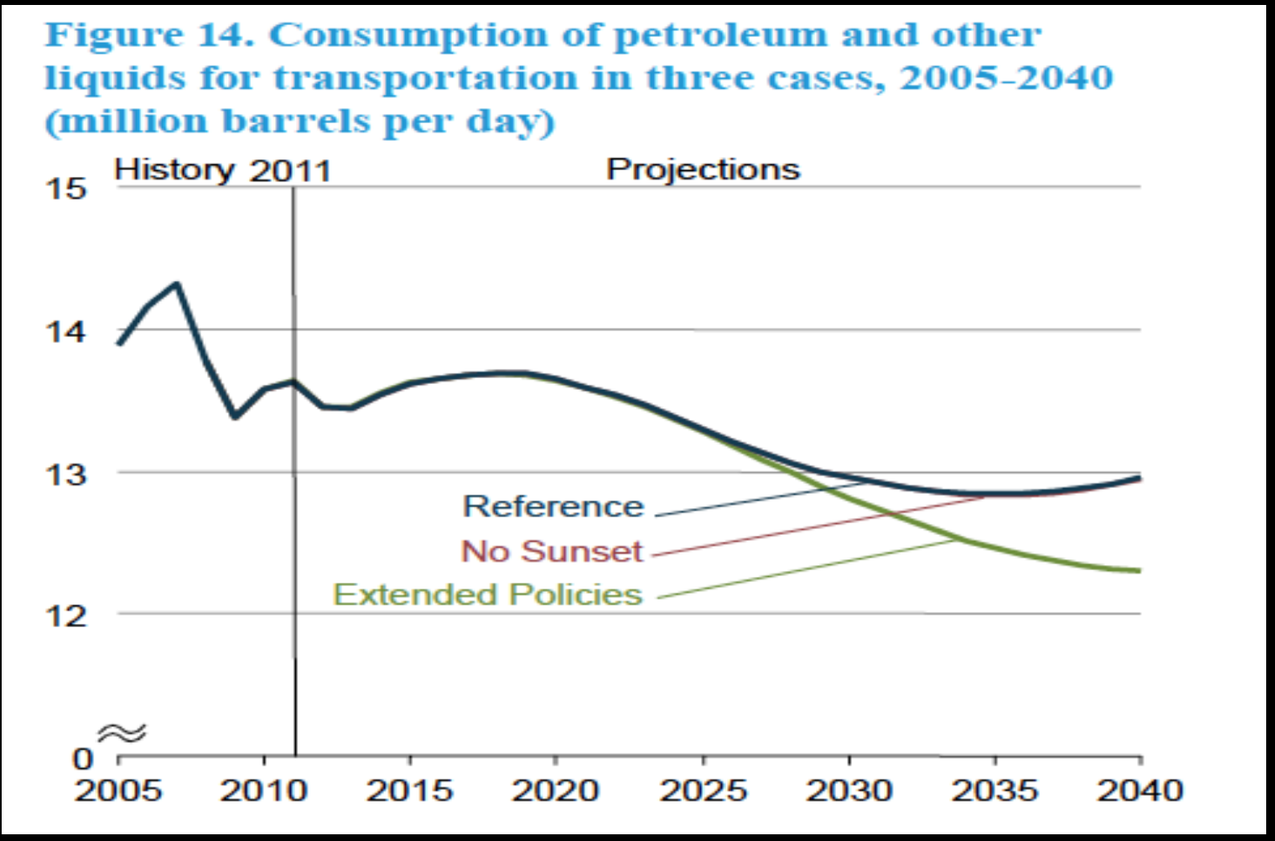
TABLE S.3 Potential Relative Vehicle Petroleum Use and Greenhouse Gas Emissions from Vehicle Efficiency Improvements Through 2035

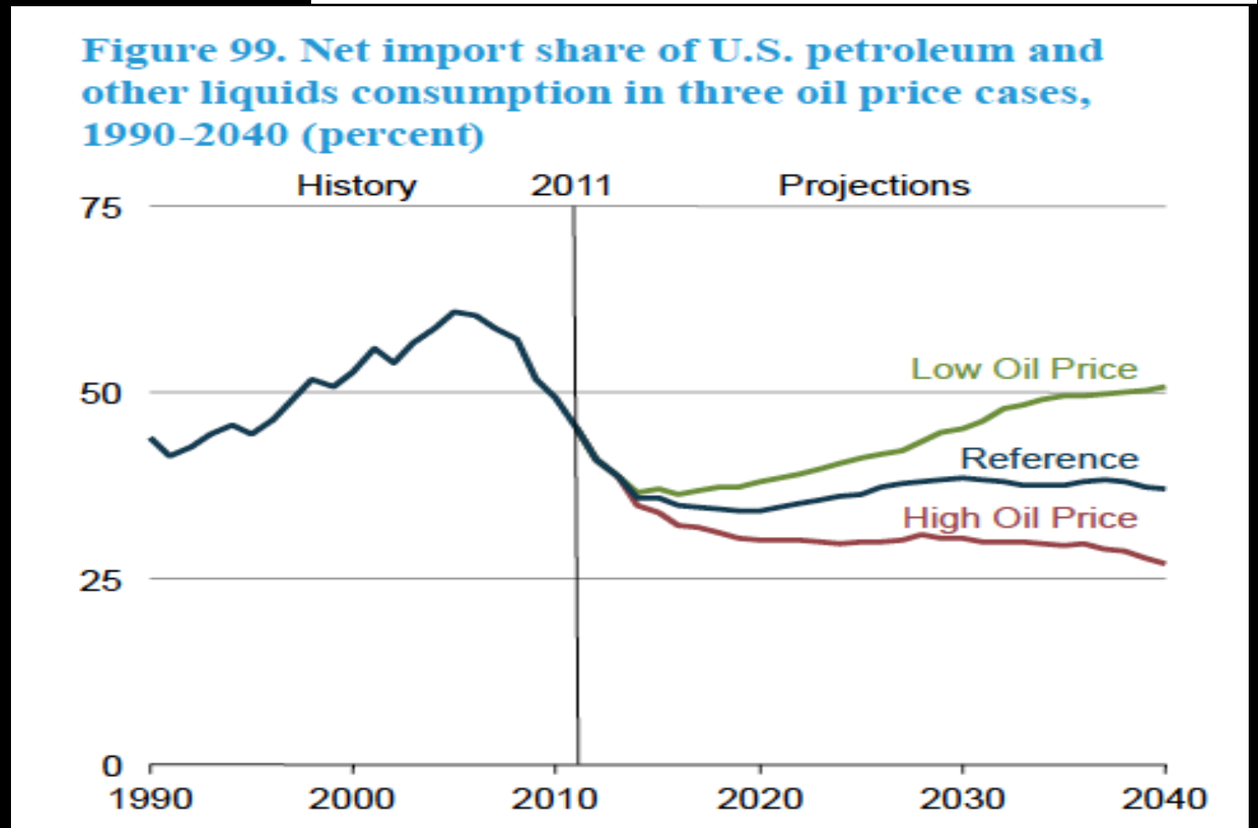
| | Petroleum Consumption (gasoline equivalent) | | Greenhouse Gas Emissions[a] | |
|---|---|---|---|---|
| Propulsion System | Relative to Current Gasoline ICE | Relative to 2035 Gasoline ICE | Relative to Current Gasoline ICE | Relative to 2035 Gasoline ICE |
| Current gasoline | 1.00 | | 1.00 | |
| Current turbocharged gasoline | 0.90 | | 0.90 | |
| Current diesel | 0.80 | | 0.80 | |
| Current hybrid | 0.75 | | 0.75 | |
| 2035 gasoline | 0.65 | 1.00 | 0.65 | 1 |
| 2035 turbocharged gasoline | 0.60 | 0.90 | 0.60 | 0.90 |
| 2035 diesel | 0.55 | 0.85 | 0.55 | 0.85 |
| 2035 HEV | 0.40 | 0.60 | 0.40 | 0.60 |
| 2035 PHEV | 0.20 | 0.30 | 0.35–0.45 | 0.55–0.70 |
| 2035 BEV | None | | 0.35–0.50 | 0.55–0.80 |
| 2035 HFCV | None | | 0.30–0.40 | 0.45–0.60 |

# Fuel Consumption Projections

Source: EIA, Aeo 2013



# Industry

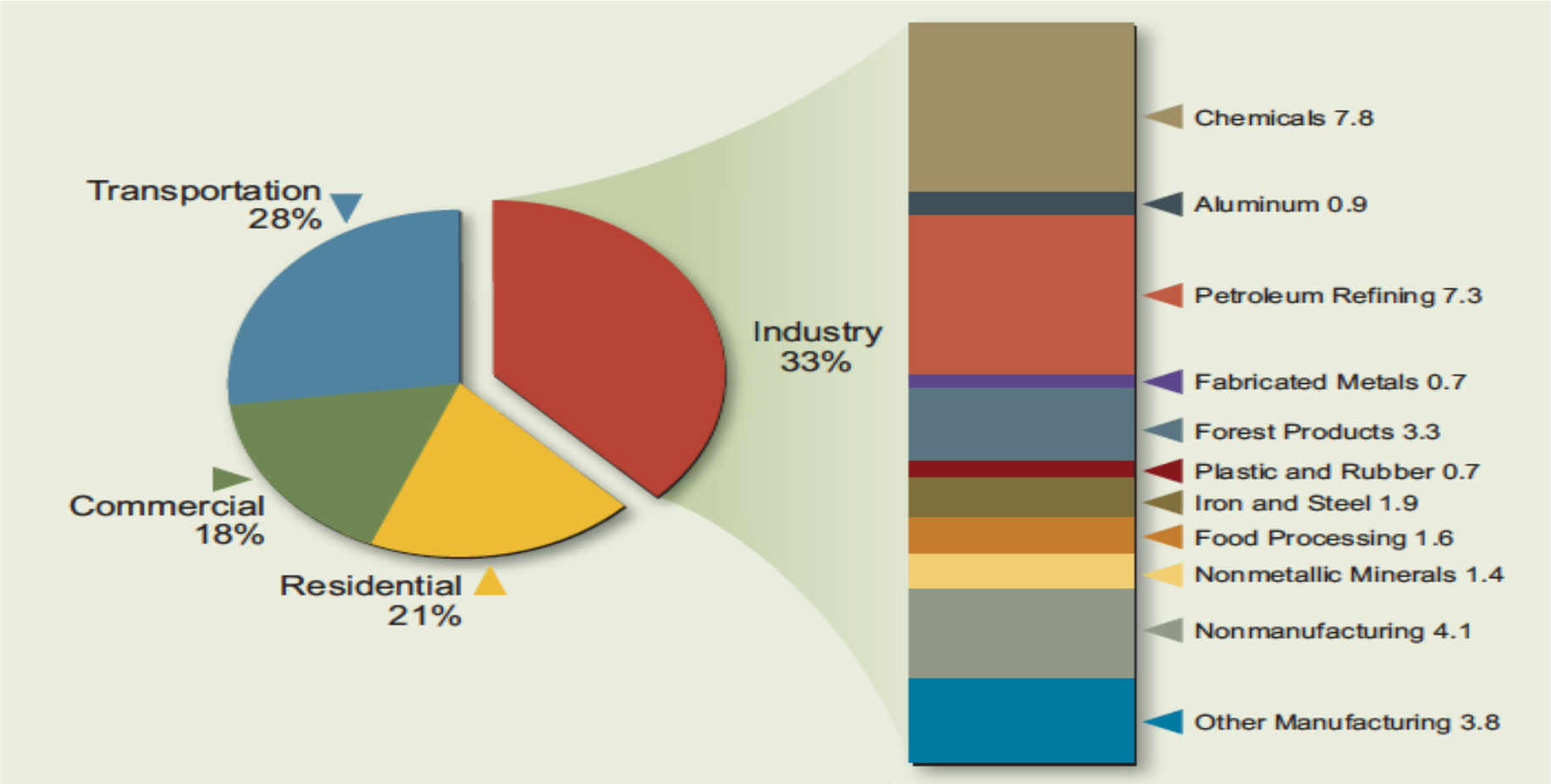



**FIGURE 4.1** *Total energy use in the U.S. industrial sector in 2004, quadrillion Btu (quads). Values include electricity-related losses. Total U.S. energy use in 2004 was 100.4 quads; total U.S. industrial energy use in 2004 was 33.6 quads.*
*Source: Craig Blue, Oak Ridge National Laboratory, based on EIA (2004) (preliminary) and estimates extrapolated from EIA (2002).*

# Forecasts

TABLE 4.3 "Business as Usual" Forecast of U.S. Industrial Energy Consumption (quadrillion Btu, or quads)

| Industry | 2006 | 2020 | 2030 |
|---|---|---|---|
| Refining | 3.94 | 6.07 | 7.27 |
| Aluminum | 0.39 | 0.36 | 0.33 |
| Iron and steel | 1.44 | 1.36 | 1.29 |
| Cement | 0.45 | 0.43 | 0.41 |
| Bulk chemical | 6.83 | 6.08 | 5.60 |
| Paper | 2.18 | 2.31 | 2.49 |
| Total | 32.6 | 34.3 | 35 |

Source: EIA, 2008a.

# McKinsey Estimates

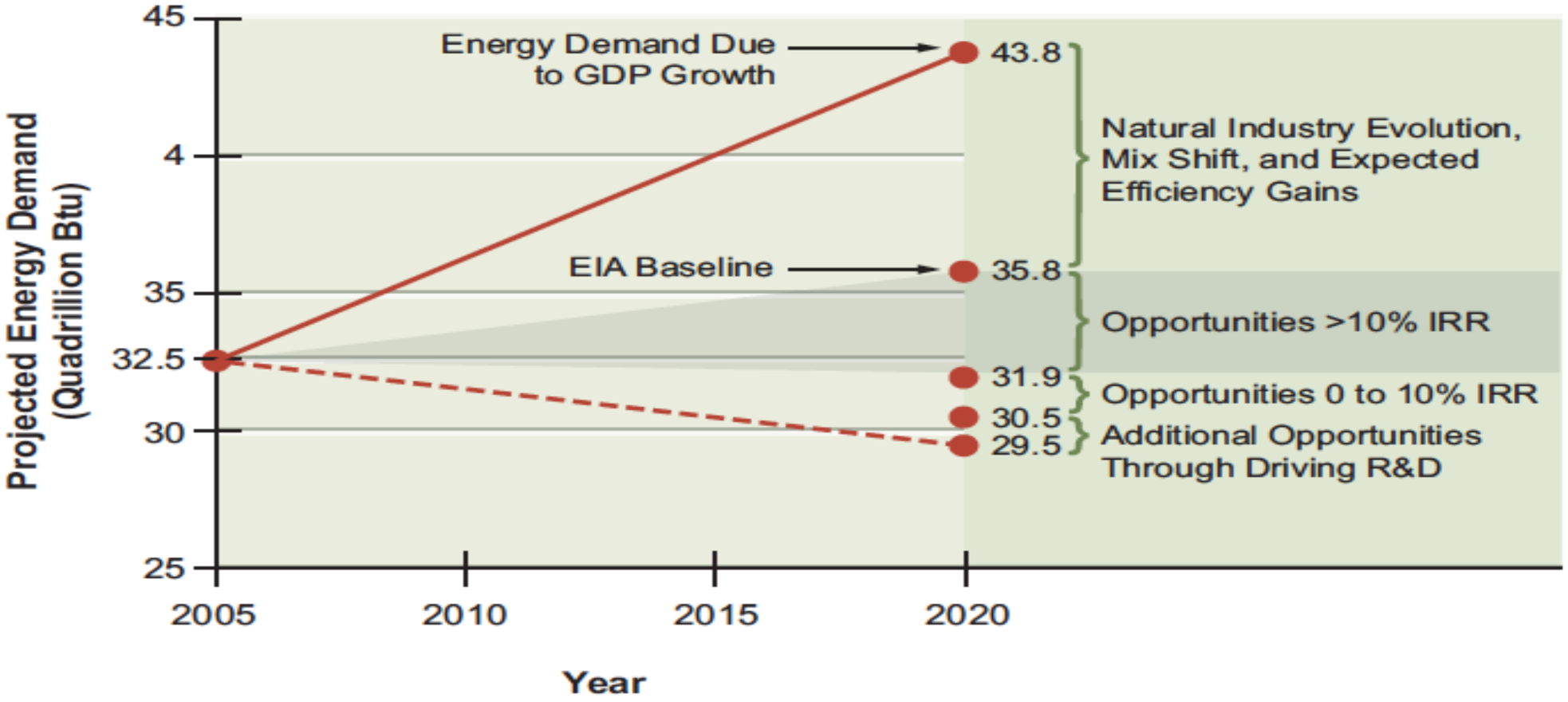



**FIGURE 4.3** *Summary of industrial energy efficiency opportunities through 2020 identified by McKinsey and Company.*
*Note: GDP = gross domestic product; IRR = internal rate of return; R&D = research and development.*
*Source: McKinsey and Company, 2007.*

# Cross-Cutting Technologies

- Combined Heat and Power (CHP)
- High Temperature and Separations Processes
- Materials
  - Nanocoating
  - Nanoceramics
  - Novel refractory materials
  - Fiber-reinforced aerogel-based pipe insulation systems
- CPS: Sensors, Communications and Controls
- Electric Motors and Drives

# Policy Impacts

TABLE 5.2 Estimates of Annual Energy Savings from Major Energy Efficiency Policies and Programs

| Policy or Program | Electricity Savings (TWh/yr) | Primary Energy Savings (Quads/yr) | Year | Source |
|---|---|---|---|---|
| CAFE vehicle efficiency standards | — | 4.80 | 2006 | NRC, 2002[a] |
| Appliance efficiency standards | 196 | 2.58 | 2006 | Nadel et al., 2006[b] |
| PURPA and other CHP initiatives | — | 1.62 | 2006 | Shipley et al., 2008[c] |
| ENERGY STAR® labeling and promotion | 132 | 1.52 | 2006 | EPA, 2007b[d] |
| Building energy codes | — | 1.08 | 2006 | Nadel, 2004[e] |
| Utility and state end-use efficiency programs | 90 | 1.06 | 2006 | York and Kushler, 2006[f] |
| DOE industrial efficiency programs | — | 0.40 | 2005 | DOE, 2007[b] |
| Weatherization assistance program | — | 0.14 | 2006 | DOE, 2006[g] |
| Federal energy management program | — | 0.11 | 2005 | FEMP, 2006[h] |
| Total | — | 13.32 | — | — |

# California Experience

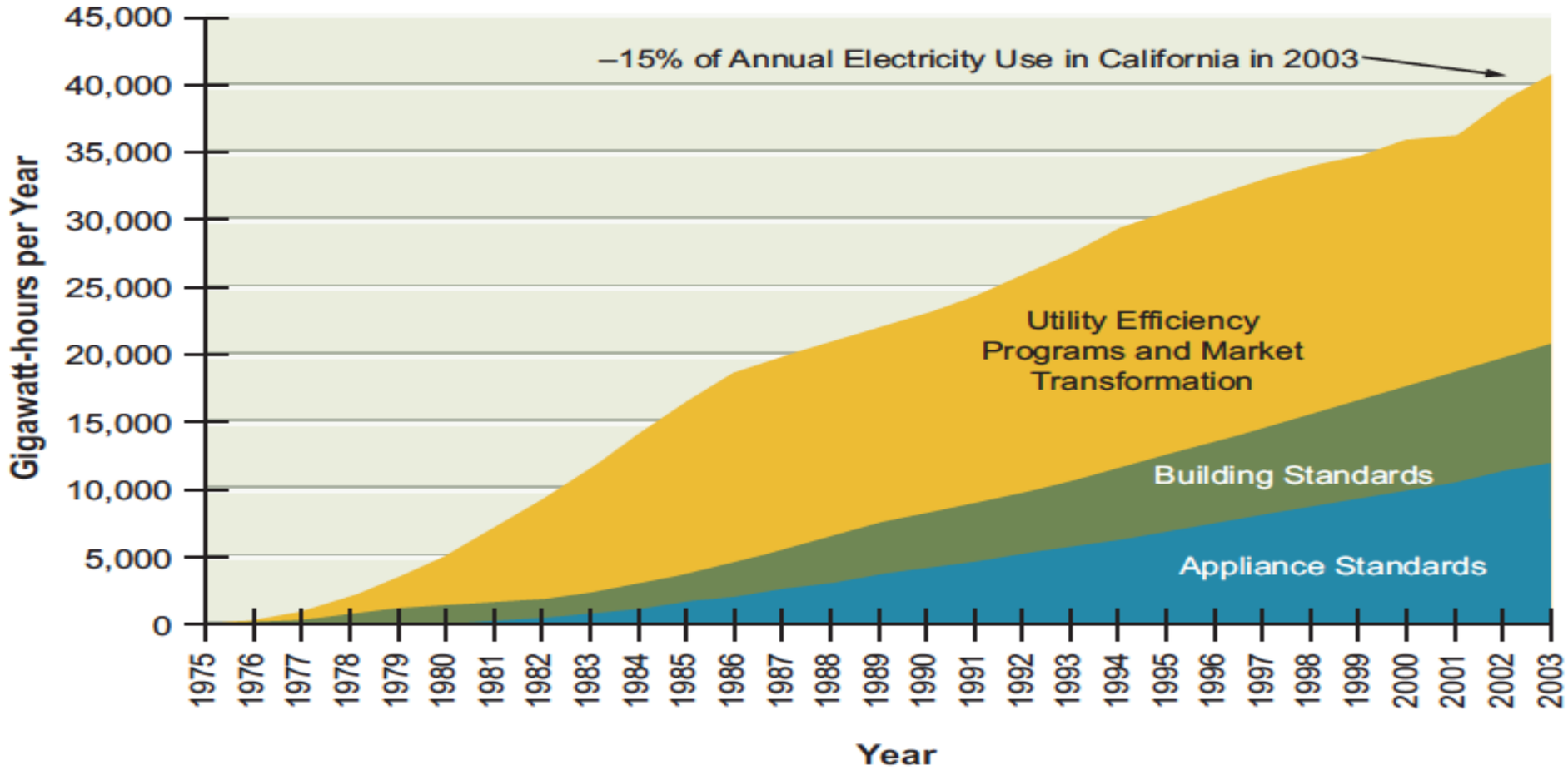
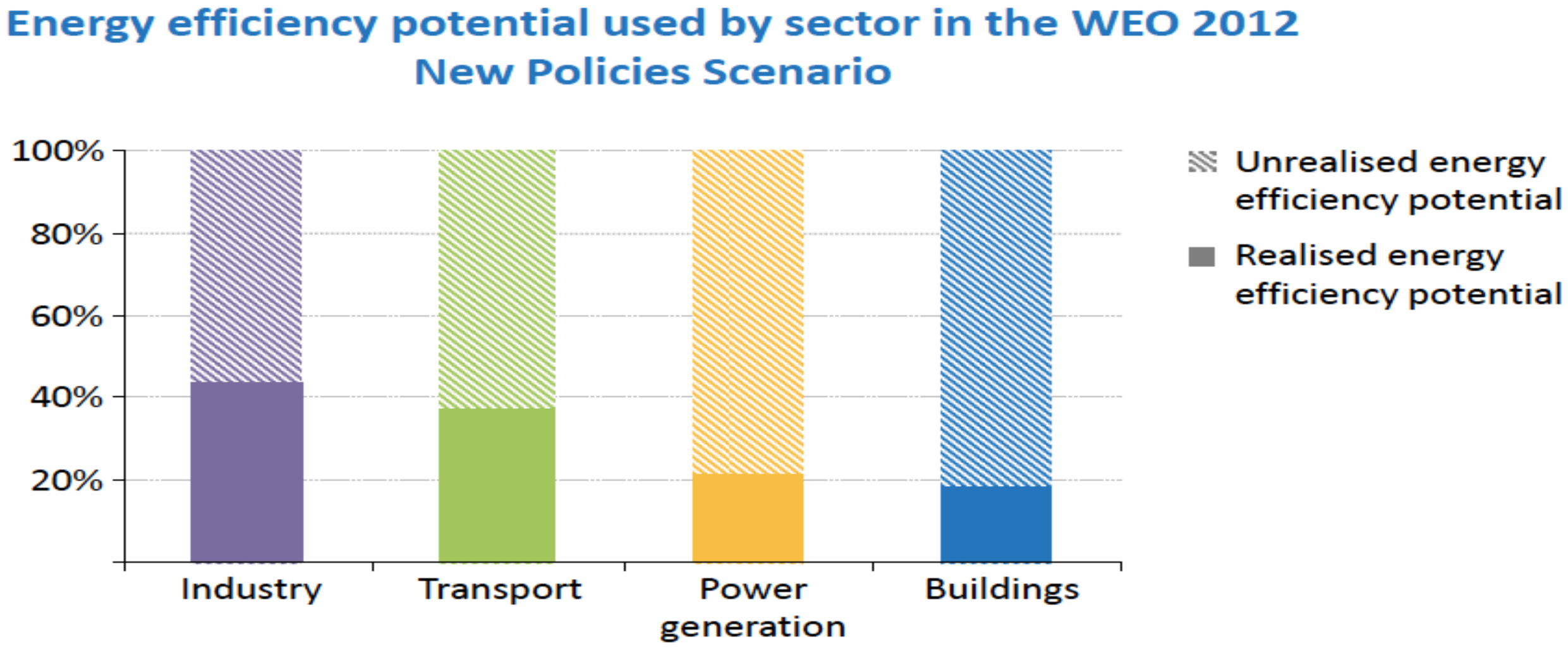



**FIGURE 5.7** *Annual electricity savings from key energy efficiency policies and programs implemented in California, 1975–2003.*
*Source: CEC, 2007.*

Source: NAE, NAS, NRC, Real Prospects for Energy Efficiency in the United States, 2009

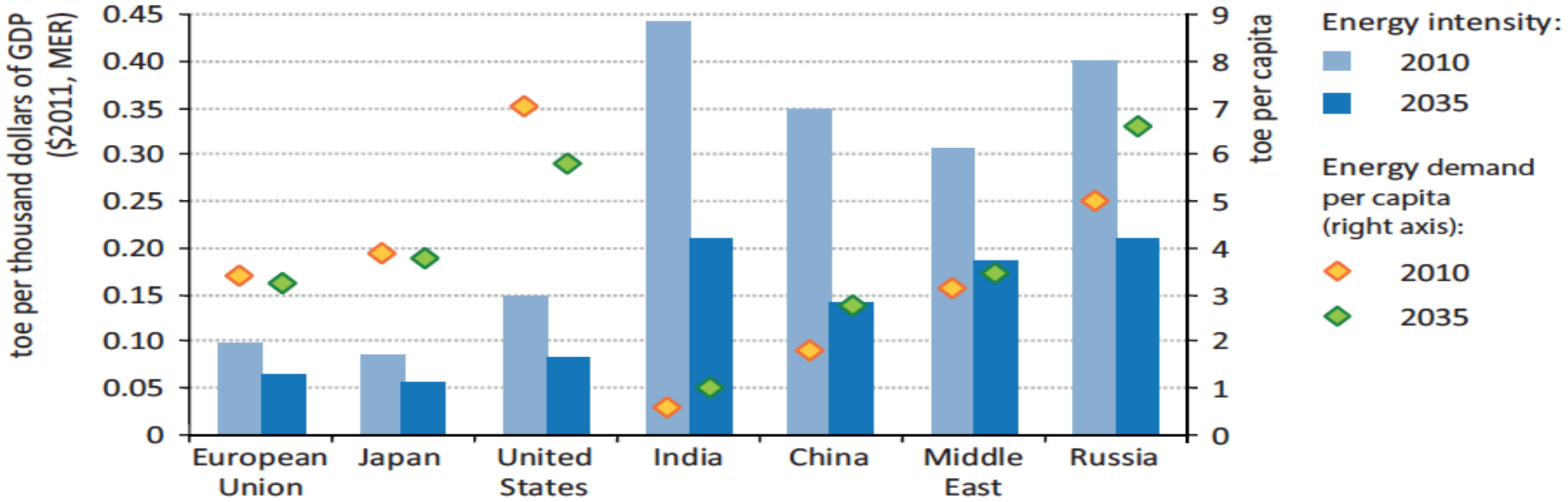
# Global Perspective




More than 2/3 of potential efficiency gains still unrealized

Source: IEA, WEO 2012

**Figure 2.4 ▷ World primary energy demand per unit of GDP and per capita in the New Policies Scenario in selected regions and countries**




Source: IEA, WEO, 2012

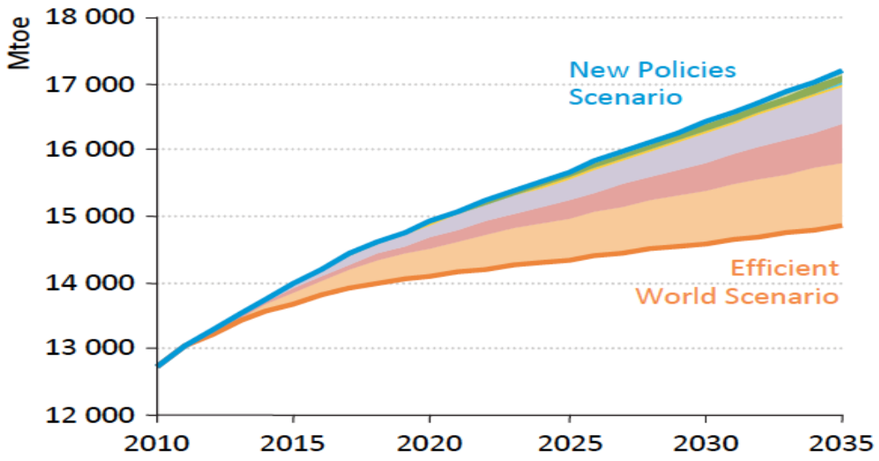
# Estimates can Vary Widely

Table 5 Energy demand reductions from recent state and regional studies [a]

| Region | Source | Years | Total savings (%) | | |
|---|---|---|---|---|---|
| | | | TP [d] | EP [d] | MP [d] |
| *Electricity:* | | | | | |
| California | Rufo and Coito 2002 | 10 | 19% | 14% | 10% |
| Georgia | ICF 2005 | 5 | 29% | 20% | 6% |
| Iowa | Eng Cent Wisc 2009 | 11 | | 22% | 13% |
| Mass | RLW 2007 | 5 | | 19% | |
| New Mex | Itron 2006 | 10 | | | 8% |
| North Carolina | GDS 2006 | 11 | 33% | 20% | 14% |
| Texas | OEI 2007 | 15 | | | 20% |
| Utah | Tellus 2001 | 6 | | | 9% |
| Vermont | GDS 2006 | 6 | 35% | 19% | |
| Wisconsin | Eng Cent Wisc 2009 | 7 | | 18% | 11% |

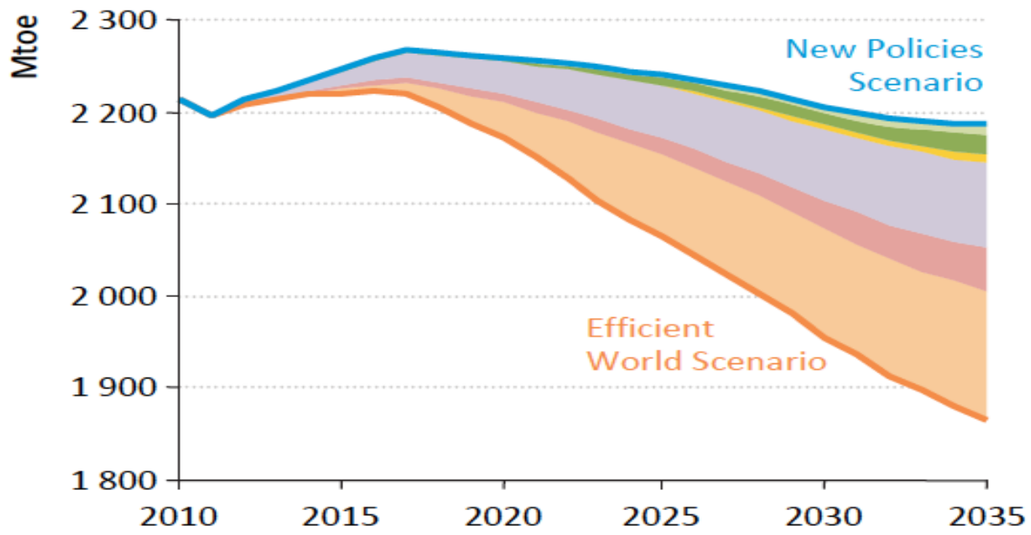
# Future Prospects

**Figure 12.1a ▷ Global primary energy demand by scenario**




| EWS total primary energy demand | Mtoe | |
|---|---|---|
| | 2010 | 2035 |
| Other renewables | 112 | 650 |
| Bioenergy | 1 277 | 1 749 |
| Hydro | 295 | 476 |
| Nuclear | 719 | 1 094 |
| Gas | 2 740 | 3 541 |
| Oil | 4 113 | 4 061 |
| Coal | 3 474 | 3 274 |

**Figure 12.2a ▷ United States primary energy demand by scenario**




| EWS total primary energy demand | Mtoe | |
|---|---|---|
| | 2010 | 2035 |
| Other renewables | 18 | 89 |
| Bioenergy | 90 | 188 |
| Hydro | 23 | 28 |
| Nuclear | 219 | 239 |
| Gas | 556 | 534 |
| Oil | 805 | 513 |
| Coal | 503 | 276 |

**Table 9** Direct, macroeconomic and total rebound effect of energy-efficiency policies (%), % difference between policy case and reference case

| World | Direct | | | Macroeconomic | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Energy supply industries | 0 | 0 | 0 | 0 | 20.8 | 43.7 | 0 | 20.8 | 43.7 |
| Transport | 0 | 9.1 | 9.1 | 0 | 26.9 | 43.1 | 0 | 36.0 | 52.2 |
| residential/services buildings | 0 | 20.0 | 20.0 | 0 | 24.3 | 40.6 | 0 | 44.3 | 60.6 |
| Industry | 0 | 5 | 5 | 0 | 18.3 | 40.8 | 0 | 23.3 | 45.8 |
| Agriculture | 0 | 5 | 5 | 0 | 11.8 | 36.1 | 0 | 16.8 | 41.1 |
| Total | 0 | 9.4 | 9.7 | 0 | 22.1 | 41.6 | 0 | 31.5 | 51.3 |

Figures are total rebound effects, assumed direct rebound plus projected macroeconomic rebound effects

Sources: E3MG 2.4 and 4CMR

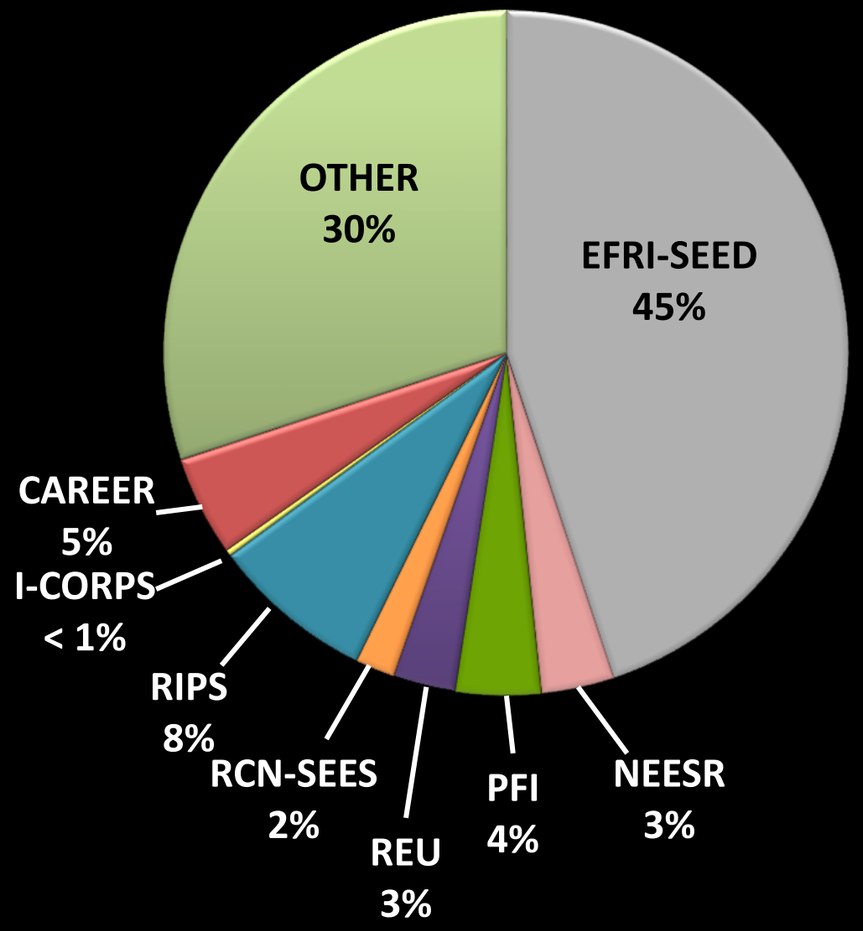
# Energy Efficiency and Energy Security

- Energy security enhanced by reducing the need for unreliable sources of energy
- Energy efficiency measures can reduce risks (ex. FOB)
- Collective action problem - payoff from increased energy security often cannot be harnessed to motivate and incentivize energy efficiency
- Policy tools needed to connect energy security and energy efficiency

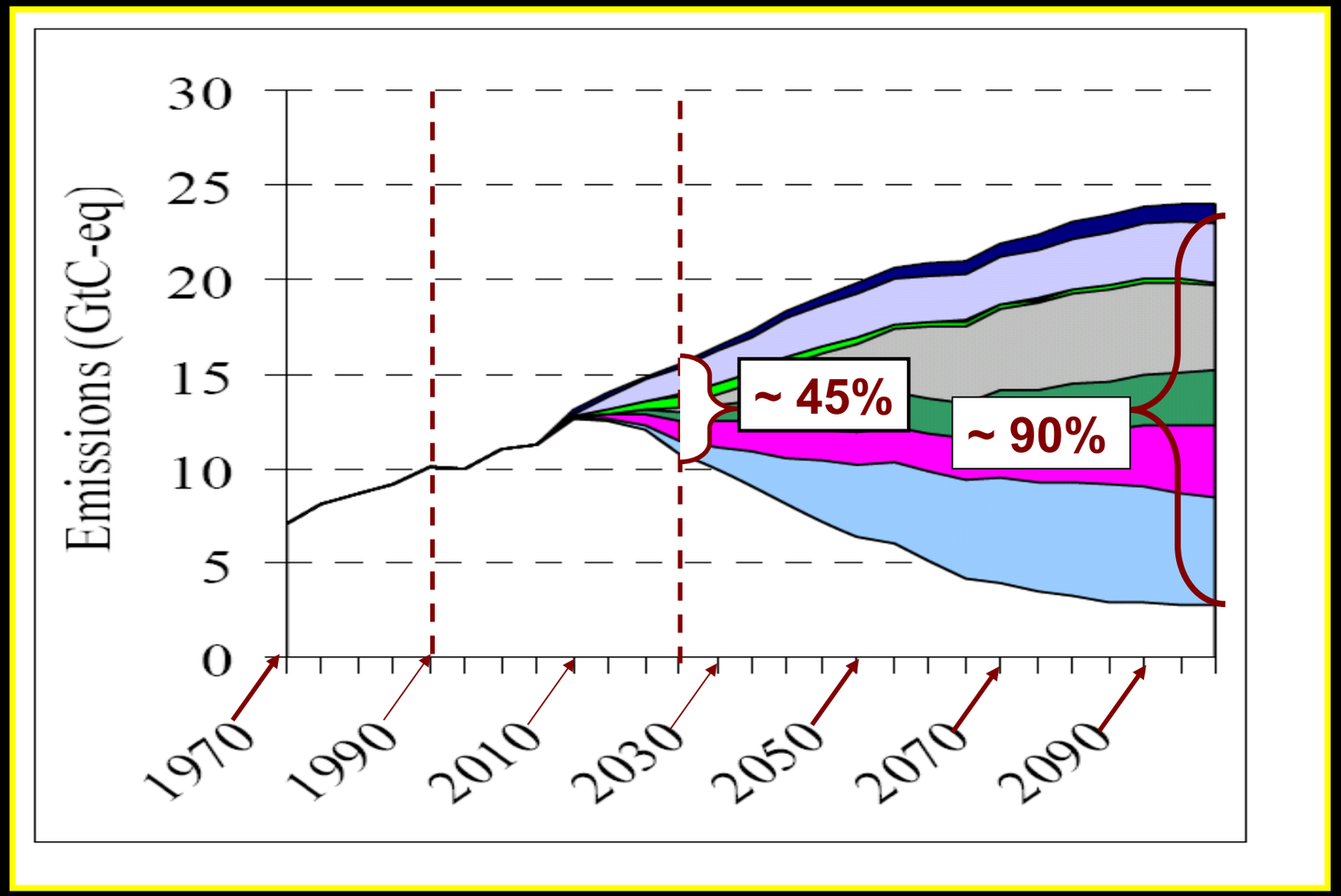
# ENG Investments by Award Type

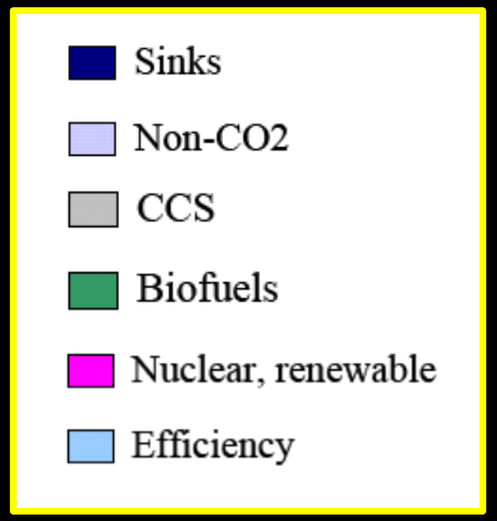
- EFRI-SEED: $ 15.7 million
- RIPS: $ 2.7 million
- CAREER: $ 1.7 million
- PFI: $ 1.4 million
- REU: $ 1 million
- NSEER: $ 1.2 million
- RCN-SEES: $ 652 k
- I-CORPS: $ 100 k
- OTHER: $ 10.5 million

ENG Total: $35,023,191



# Scenario for reducing global emissions of greenhouse gases to stabilize $CO_2$ at 450 ppm (van Vuuren et al,2006)



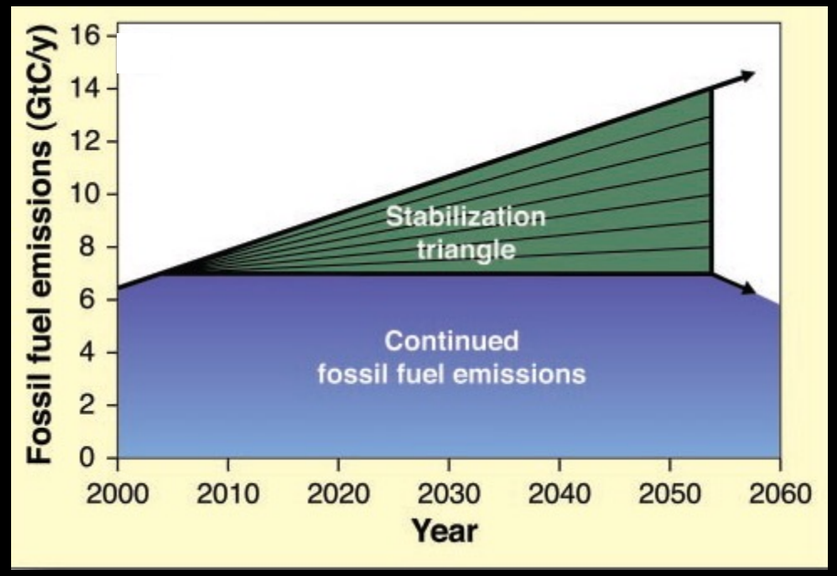




1 t C = 3.67t $CO_2$

1 t C-eq ≅ 0.49 t $CO_2$

# $CO_2$ Reduction - Stabilization Wedges

Pacala and Socolow, *Science*, Vol. 305 (2004)




**Transportation**

- Efficient vehicles
  - 2 billion cars average 10,000 miles per year, 60 vs. 30 mpg
- Reduced use of vehicles
  - 2 billion cars went 5,000 vs. 10,000 miles

**Efficient Buildings**

- Cut emissions for buildings and appliances

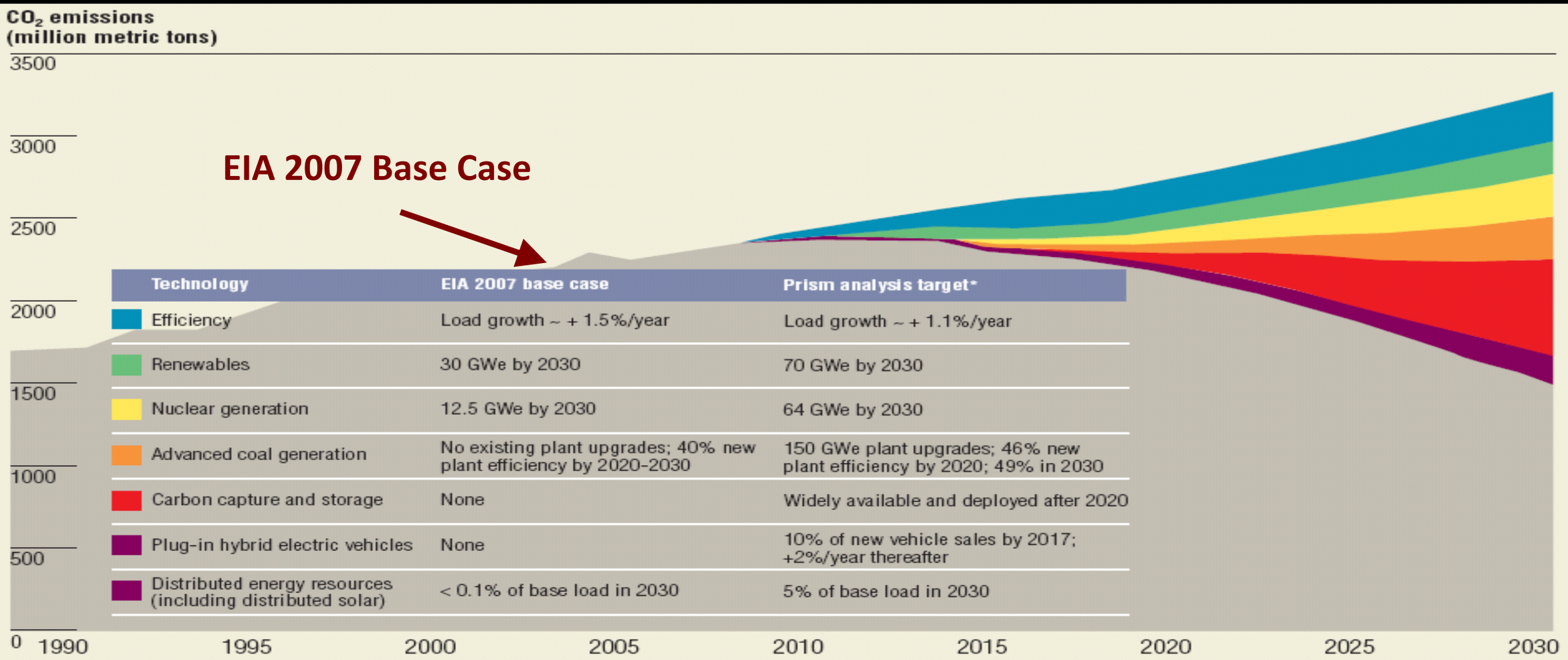
**Efficient Coal Plants**

- 60% vs 40%

**Forests & Ag soils**

- Reduce deforestation plus reforestation, new plantations
- Conservation tillage

# Scenario for Reducing $CO_2$ from U.S. Electric Sector by 45% over IEA 2030 Projections (EPRI, Prism, 2007)




| Technology | EIA 2007 base case | Prism analysis target* |
|---|---|---|
| Efficiency | Load growth ~ + 1.5%/year | Load growth ~ + 1.1%/year |
| Renewables | 30 GWe by 2030 | 70 GWe by 2030 |
| Nuclear generation | 12.5 GWe by 2030 | 64 GWe by 2030 |
| Advanced coal generation | No existing plant upgrades; 40% new plant efficiency by 2020–2030 | 150 GWe plant upgrades; 46% new plant efficiency by 2020; 49% in 2030 |
| Carbon capture and storage | None | Widely available and deployed after 2020 |
| Plug-in hybrid electric vehicles | None | 10% of new vehicle sales by 2017; +2%/year thereafter |
| Distributed energy resources (including distributed solar) | < 0.1% of base load in 2030 | 5% of base load in 2030 |

* Prism analysis targets do not reflect economic or potential regulatory and siting constraints.

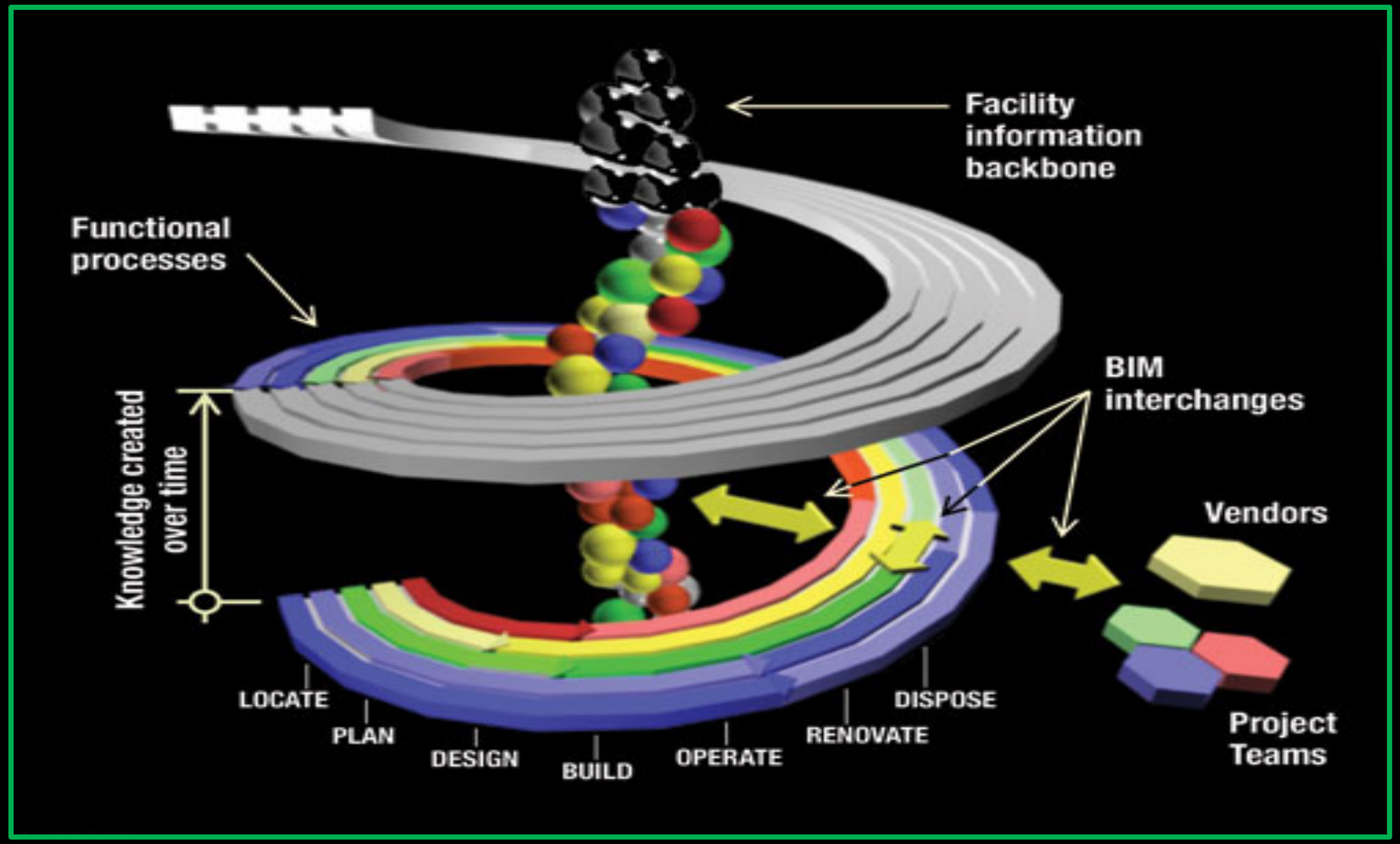
# Motivation – Critical National Need

1. Commercial and residential building construction constitutes $805 billion of our GDP (6.1% of $13.2 trillion).

2. According to the US Green Building Council/EPA, in the United States, buildings account for:

- 72% of electricity consumption,
- 39% of energy use,
- 38% of all carbon dioxide ($CO_2$) emissions,
- 40% of raw materials use,
- 30% of waste output (136 million tons annually),
- 14% of potable water consumption.

# Transformative Characteristics




Facility Lifecycle Helix

# Transformative Characteristics

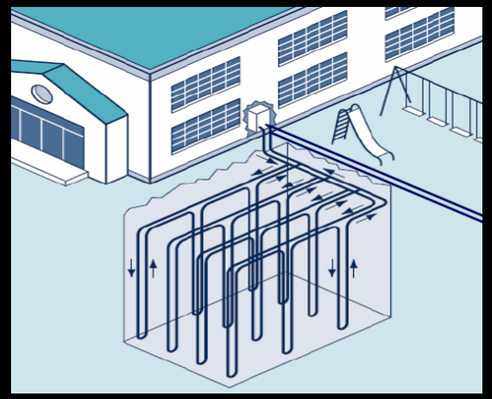
The **three interrelated research thrusts** **for integrated** multidisciplinary science, engineering and systems research for innovative, transformative buildings research are:

- **Materials and Sensing**
- **Modeling and Simulation**
- **Concepts for Autonomy and Interdependence**

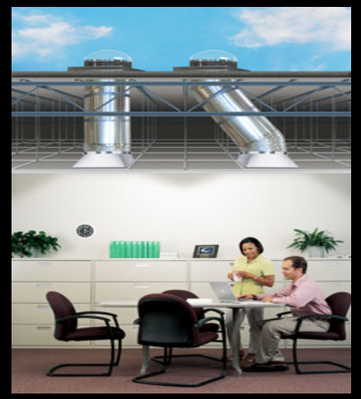
# Transformative Research

Materials and controls used today in building systems (envelope, MEP, HVAC) are not sophisticated, not well-understood, not robust and will not be able to meet the needs of the future.

Materials, devices and control systems used today to produce, store and distribute alternative energy for buildings are in their infancy.



Geothermal



Solar light

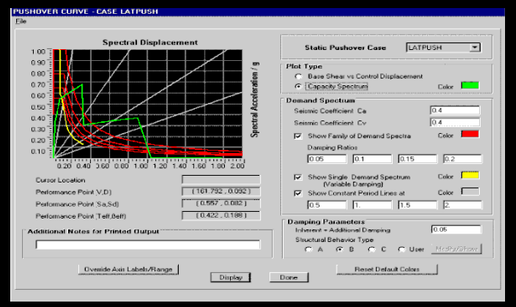
Small wind

Solar electric and solar thermal

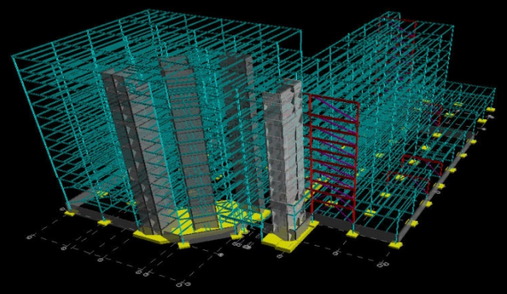
# Transformative Research

Building system analysis and design software is currently at the level that structural analysis software was 30 years ago.

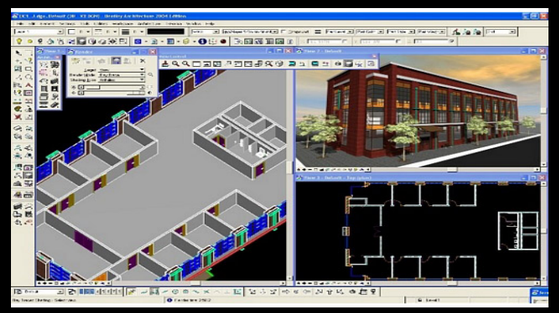
At present, building systems software tries to solve complex interacting-system problems with simplistic non-interoperable, unintegrated, and non-user friendly computational tools.



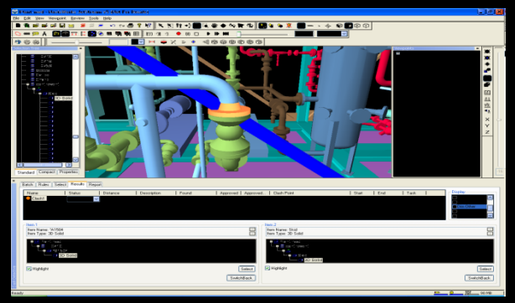

Nonlinear Analysis



Structural Design



Building Information Model



Interference Detection

# Advanced Technologies

- Solid State Lighting – Light Emitting Diodes
- Advanced Cooling
  - Indirect-Direct Evaporative Cooling (IDEC)
  - Solar Thermal Cooling (STC)
  - Low Lift Cooling (LLC)
  - Dessicants
- Advanced Windows
- Energy efficiency in computing and electronics