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**

- **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

**Translational**

- **EEC**
  - Engineering Research Centers
  - Engineering Education
  - Engineering Workforce

- **IIP**
  - Academic Partnerships
  - Small Business Partnerships

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## ENG R&RA Budget ($M)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Amount</td>
</tr>
<tr>
<td>CBET</td>
<td>$167.76</td>
<td>$177.82</td>
<td>$192.26</td>
<td>$14.44</td>
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<td>CMMI</td>
<td>195.23</td>
<td>209.52</td>
<td>222.73</td>
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<td>ECCS</td>
<td>100.37</td>
<td>110.43</td>
<td>119.24</td>
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<td>EEC</td>
<td>119.50</td>
<td>117.49</td>
<td>110.39</td>
<td>-7.10</td>
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<tr>
<td>IIP</td>
<td>205.99</td>
<td>226.98</td>
<td>248.11</td>
<td>21.13</td>
</tr>
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<td>SBIR/STTR</td>
<td>159.99</td>
<td>177.11</td>
<td>194.36</td>
<td>17.25</td>
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<tr>
<td>EFMA</td>
<td>44.27</td>
<td>50.07</td>
<td>56.49</td>
<td>6.42</td>
</tr>
<tr>
<td>ENG TOTAL</td>
<td>$833.12</td>
<td>$892.31</td>
<td>$949.22</td>
<td>$56.91</td>
</tr>
</tbody>
</table>
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, EIA AEO 2012
Residential Buildings


August 4, 2015

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

<table>
<thead>
<tr>
<th></th>
<th>Conservative Estimate</th>
<th>Optimistic Estimate</th>
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<tbody>
<tr>
<td></td>
<td>2020</td>
<td>2030</td>
</tr>
<tr>
<td>Buildings, primary (source) electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>4.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Commercial</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Buildings, natural gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>2.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Commercial</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Transportation, light-duty vehicles</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Industry, manufacturing</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Total</td>
<td>18.6</td>
<td>30.5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(TWh)</td>
<td>% Savings Relative to BAU Case</td>
<td>Consumption Savings</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td>(TWh)</td>
</tr>
<tr>
<td>Space heating[^b]</td>
<td>77</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>Space cooling[^b]</td>
<td>238</td>
<td>48</td>
<td>115</td>
</tr>
<tr>
<td>Water heating[^b]</td>
<td>59</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Ventilation[^b]</td>
<td>131</td>
<td>45</td>
<td>59</td>
</tr>
<tr>
<td>Cooking[^c]</td>
<td>11</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Lighting[^b]</td>
<td>543</td>
<td>25</td>
<td>137</td>
</tr>
<tr>
<td>Refrigeration[^b]</td>
<td>89</td>
<td>38</td>
<td>34</td>
</tr>
<tr>
<td>Office equipment—PCs[^c]</td>
<td>120</td>
<td>60</td>
<td>71</td>
</tr>
<tr>
<td>Office equipment—non-PCs[^c]</td>
<td>271</td>
<td>25</td>
<td>68</td>
</tr>
<tr>
<td>Other uses[^b]</td>
<td>523</td>
<td>35</td>
<td>182</td>
</tr>
<tr>
<td>Total electricity</td>
<td>2062</td>
<td>34</td>
<td>705</td>
</tr>
</tbody>
</table>

[^a]: 2030 Business as Usual is used as a reference point for savings potential.

[^b]: Base year 1985.

More than 2/3 of potential efficiency gains still unrealized.
Urbanization - Global Megatrend

Figure 2.
Urban and rural population of the world, 1950–2050

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

Source: World Urbanization Prospects, 2014, UN
Renewable Energy Production

Alternative Fuels
Biofuels (bio & chemical routes)
Solar Fuels (CO₂, 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 ENG Clean Energy Investments: 2012-2014

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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

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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

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Example Projects
Efficient Heat Transfer


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 $\Delta T$ 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

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Understanding and Modeling the Impact of Occupant Energy Usage Characteristics in Buildings

Agent Based Model of Occupancy Networks in Buildings

Scale Free Network

Small World Network

Dynamic Energy Analysis

Energy Use Simulation Tool (DOE2)

Coupling Engine

Occupant Behavior Software

Energy Consumption

Energy Use Behavior

Input

Predict

Predict

Input

Carol Menassa

University of Michigan

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PV panels, battery, & ice storage tanks are modeled and can be shared by buildings

MATLAB

Interactions between buildings and the Grid are simulated

MATLAB

Multiple building energy models (in E+ environment) are validated using real building measurements contributed by SIEMENS

Capable of interacting with real building control systems

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

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

Multi-Agent Control Architecture

Real Time Occupant Sensing

Jianghai Hu, Purdue University

Purdue University Living Lab
Center for High Performance Buildings

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Integrating Green Roofs and Photovoltaic Arrays
Carl Wamser, David Sailor, Todd Rosenstiel
Portland State University - CBET-0853933

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.

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

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

- 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 – Rooftop 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.

M. Carmanis et al, BU-MIT
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
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

1. Urban Modeling Platforms
2. New Physical Models
3. Analyses of Neighborhoods
4. Occupant Comfort/Health
5. Control Algorithms

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

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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

Center for Energy Efficient Electronics Science

Size of ICs vs. power consumption

Theme 1: Nanoelectronics
Theme 2: Nanomechanics
Theme 3: Nanophotonics
Theme 4: Nanomagnetics

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/

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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

Embodied : Use

2000

2010

Best practice

Future?

Efficiencies in use are improving

kg CO₂/m²/year

Allwood and Cullen, 2011
Design Choices have Large Impacts

The Built-up Area of Atlanta and Barcelona Represented at the Same Scale

**Atlanta:**
- 2.5 million people (1990)
- 4,280 km² (built-up area)

**Barcelona:**
- 2.8 million people (1990)
- 162 km² (built-up area)

Bertaud and Richardson, 2004
Potential Impact of Advanced Cooling


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

<table>
<thead>
<tr>
<th>Propulsion System</th>
<th>Petroleum Consumption (gasoline equivalent)</th>
<th>Greenhouse Gas Emissions*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative to Current Gasoline ICE</td>
<td>Relative to 2035 Gasoline ICE</td>
</tr>
<tr>
<td>Current gasoline</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Current turbocharged gasoline</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>Current diesel</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Current hybrid</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>2035 gasoline</td>
<td>0.65</td>
<td>1.00</td>
</tr>
<tr>
<td>2035 turbocharged gasoline</td>
<td>0.60</td>
<td>0.90</td>
</tr>
<tr>
<td>2035 diesel</td>
<td>0.55</td>
<td>0.85</td>
</tr>
<tr>
<td>2035 HEV</td>
<td>0.40</td>
<td>0.60</td>
</tr>
<tr>
<td>2035 PHEV</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>2035 BEV</td>
<td>None</td>
<td></td>
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<tr>
<td>2035 HFCV</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
Figure 14. Consumption of petroleum and other liquids for transportation in three cases, 2005-2040 (million barrels per day)

Source: EIA, AEO 2013
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)**

<table>
<thead>
<tr>
<th>Industry</th>
<th>2006</th>
<th>2020</th>
<th>2030</th>
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<tbody>
<tr>
<td>Refining</td>
<td>3.94</td>
<td>6.07</td>
<td>7.27</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.39</td>
<td>0.36</td>
<td>0.33</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>1.44</td>
<td>1.36</td>
<td>1.29</td>
</tr>
<tr>
<td>Cement</td>
<td>0.45</td>
<td>0.43</td>
<td>0.41</td>
</tr>
<tr>
<td>Bulk chemical</td>
<td>6.83</td>
<td>6.08</td>
<td>5.60</td>
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<tr>
<td>Paper</td>
<td>2.18</td>
<td>2.31</td>
<td>2.49</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>32.6</strong></td>
<td><strong>34.3</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

Source: EIA, 2008a.
**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.*

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

<table>
<thead>
<tr>
<th>Policy or Program</th>
<th>Electricity Savings (TWh/yr)</th>
<th>Primary Energy Savings (Quads/yr)</th>
<th>Year</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>CAFE vehicle efficiency standards</td>
<td>—</td>
<td>4.80</td>
<td>2006</td>
<td>NRC, 2002&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Appliance efficiency standards</td>
<td>196</td>
<td>2.58</td>
<td>2006</td>
<td>Nadel et al., 2006&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>PURPA and other CHP initiatives</td>
<td>—</td>
<td>1.62</td>
<td>2006</td>
<td>Shipley et al., 2008&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>ENERGY STAR&lt;sup&gt;®&lt;/sup&gt; labeling and promotion</td>
<td>132</td>
<td>1.52</td>
<td>2006</td>
<td>EPA, 2007&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Building energy codes</td>
<td>—</td>
<td>1.08</td>
<td>2006</td>
<td>Nadel, 2004&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Utility and state end-use efficiency programs</td>
<td>90</td>
<td>1.06</td>
<td>2006</td>
<td>York and Kushler, 2006&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>DOE industrial efficiency programs</td>
<td>—</td>
<td>0.40</td>
<td>2005</td>
<td>DOE, 2007&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Weatherization assistance program</td>
<td>—</td>
<td>0.14</td>
<td>2006</td>
<td>DOE, 2006&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>Federal energy management program</td>
<td>—</td>
<td>0.11</td>
<td>2005</td>
<td>FEMP, 2006&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>—</td>
<td><strong>13.32</strong></td>
<td></td>
<td></td>
</tr>
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</table>
FIGURE 5.7 Annual electricity savings from key energy efficiency policies and programs implemented in California, 1975–2003.
Energy efficiency potential used by sector in the WEO 2012
New Policies Scenario

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Source</th>
<th>Years</th>
<th>Total savings (%)</th>
<th>TP d</th>
<th>EP d</th>
<th>MP d</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>Rufo and Coito 2002</td>
<td>10</td>
<td></td>
<td>19%</td>
<td>14%</td>
<td>10%</td>
</tr>
<tr>
<td>Georgia</td>
<td>ICF 2005</td>
<td>5</td>
<td></td>
<td>29%</td>
<td>20%</td>
<td>6%</td>
</tr>
<tr>
<td>Iowa</td>
<td>Eng Cent Wisc 2009</td>
<td>11</td>
<td></td>
<td>22%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>RLW 2007</td>
<td>5</td>
<td></td>
<td>19%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Mex</td>
<td>Itron 2006</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>8%</td>
</tr>
<tr>
<td>North Carolina</td>
<td>GDS 2006</td>
<td>11</td>
<td></td>
<td>33%</td>
<td>20%</td>
<td>14%</td>
</tr>
<tr>
<td>Texas</td>
<td>OEI 2007</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>Utah</td>
<td>Tellus 2001</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>9%</td>
</tr>
<tr>
<td>Vermont</td>
<td>GDS 2006</td>
<td>6</td>
<td></td>
<td>35%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Eng Cent Wisc 2009</td>
<td>7</td>
<td></td>
<td>18%</td>
<td></td>
<td>11%</td>
</tr>
</tbody>
</table>
### Table 9: Direct, macroeconomic and total rebound effect of energy-efficiency policies (%), % difference between policy case and reference case

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply industries</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20.8</td>
<td>43.7</td>
<td>0</td>
<td>20.8</td>
<td>43.7</td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>9.1</td>
<td>9.1</td>
<td>0</td>
<td>26.9</td>
<td>43.1</td>
<td>0</td>
<td>36.0</td>
<td>52.2</td>
</tr>
<tr>
<td>residential/services buildings</td>
<td>0</td>
<td>20.0</td>
<td>20.0</td>
<td>0</td>
<td>24.3</td>
<td>40.6</td>
<td>0</td>
<td>44.3</td>
<td>60.6</td>
</tr>
<tr>
<td>Industry</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>18.3</td>
<td>40.8</td>
<td>0</td>
<td>23.3</td>
<td>45.8</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>11.8</td>
<td>36.1</td>
<td>0</td>
<td>16.8</td>
<td>41.1</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>9.4</td>
<td>9.7</td>
<td>0</td>
<td>22.1</td>
<td>41.6</td>
<td>0</td>
<td>31.5</td>
<td>51.3</td>
</tr>
</tbody>
</table>

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 CO₂ at 450 ppm (van Vuuren et al, 2006)

1 t C = 3.67 t CO₂
1 t C-eq ≈ 0.49 t CO₂
CO₂ Reduction - Stabilization Wedges

- **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)

### EIA 2007 Base Case

<table>
<thead>
<tr>
<th>Technology</th>
<th>EIA 2007 base case</th>
<th>Prism analysis target*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Load growth ~ + 1.5%/year</td>
<td>Load growth ~ + 1.1%/year</td>
</tr>
<tr>
<td>Renewables</td>
<td>30 GW$_e$ by 2030</td>
<td>70 GW$_e$ by 2030</td>
</tr>
<tr>
<td>Nuclear generation</td>
<td>12.5 GW$_e$ by 2030</td>
<td>64 GW$_e$ by 2030</td>
</tr>
<tr>
<td>Advanced coal generation</td>
<td>No existing plant upgrades; 40% new plant efficiency by 2020-2030</td>
<td>150 GW$_e$ plant upgrades; 46% new plant efficiency by 2020; 49% in 2030</td>
</tr>
<tr>
<td>Carbon capture and storage</td>
<td>None</td>
<td>Widely available and deployed after 2020</td>
</tr>
<tr>
<td>Plug-in hybrid electric vehicles</td>
<td>None</td>
<td>10% of new vehicle sales by 2017; +2%/year thereafter</td>
</tr>
<tr>
<td>Distributed energy resources</td>
<td>&lt; 0.1% of base load in 2030</td>
<td>5% of base load in 2030</td>
</tr>
</tbody>
</table>

* 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

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
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.
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