# Energy Efficiency: Progress and Opportunities

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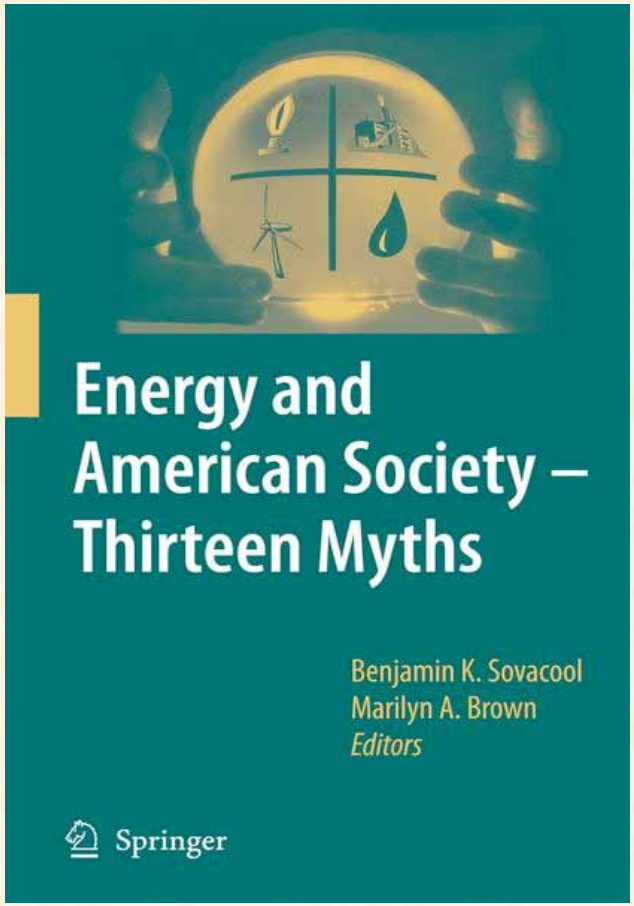


**Global Climate and Energy Project**
**Annual Symposium**

**Stanford University**

**October 1, 2007**

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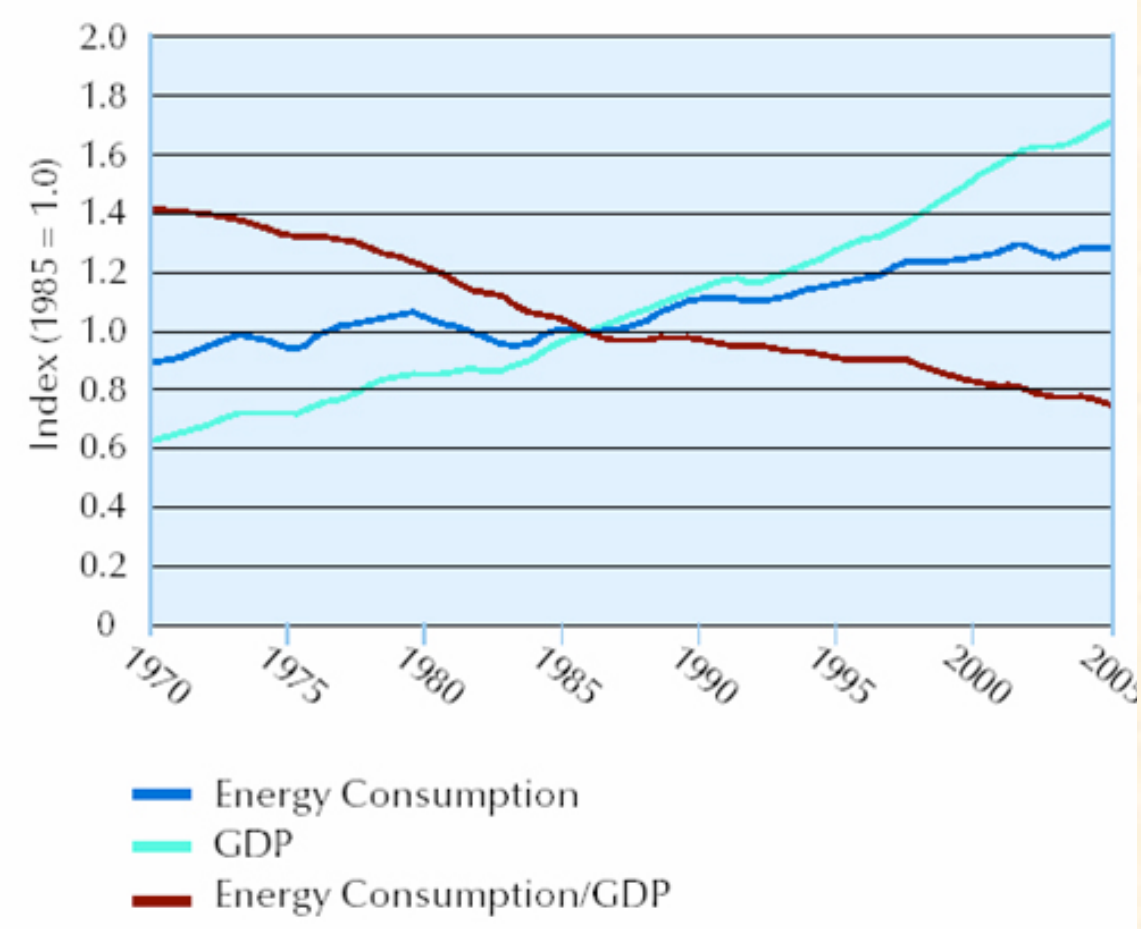
# The Good News:
# U.S. Energy Productivity is Improving




Source: Based on data from *EIA Annual Energy Review 2004*

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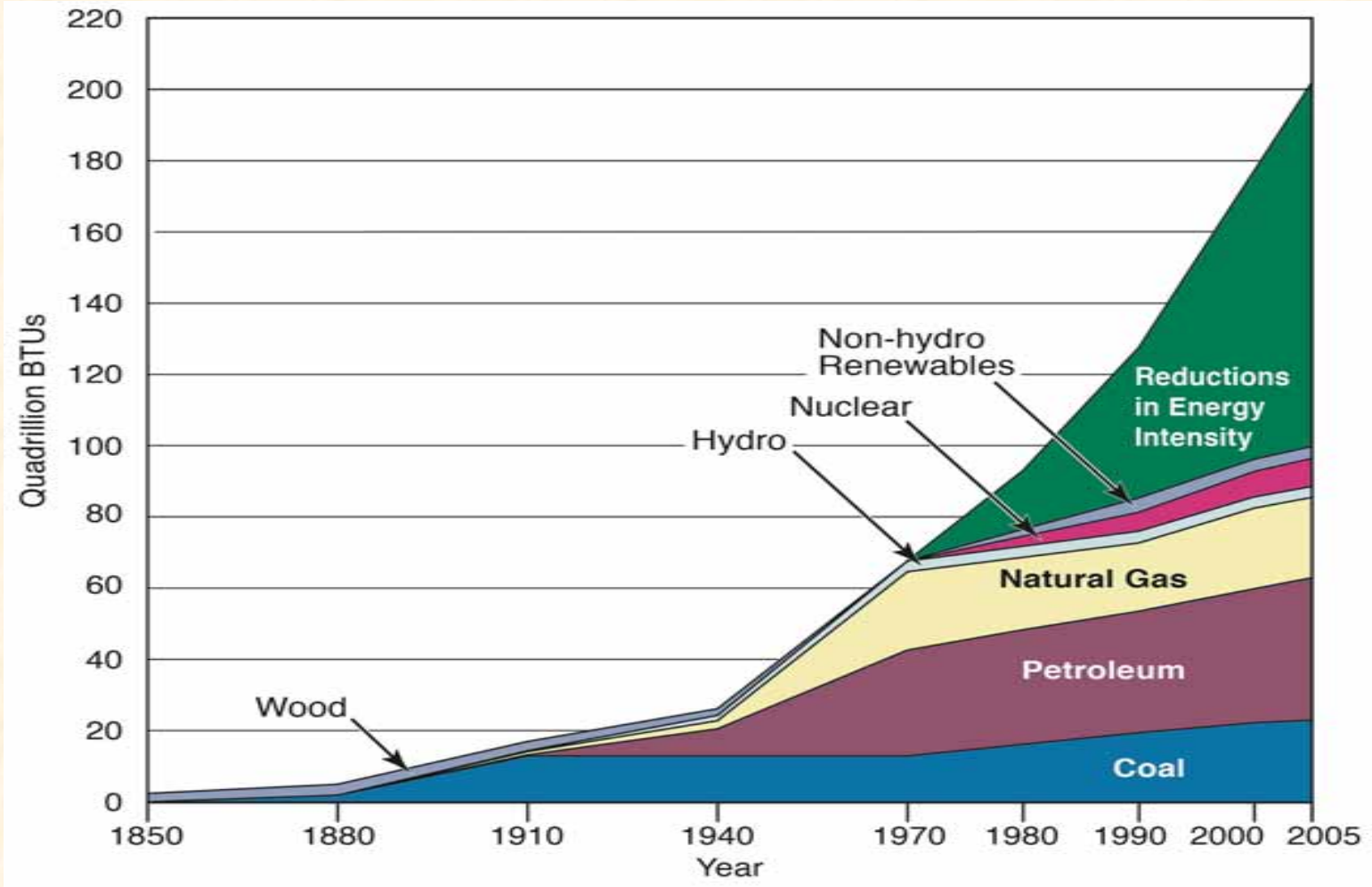
# For 30 years, energy efficiency has been the largest U.S. energy resource




Source: Updated from Brown, M. A. 2007. *Energy and American Society: Thirteen Myths*, Ch. 2.

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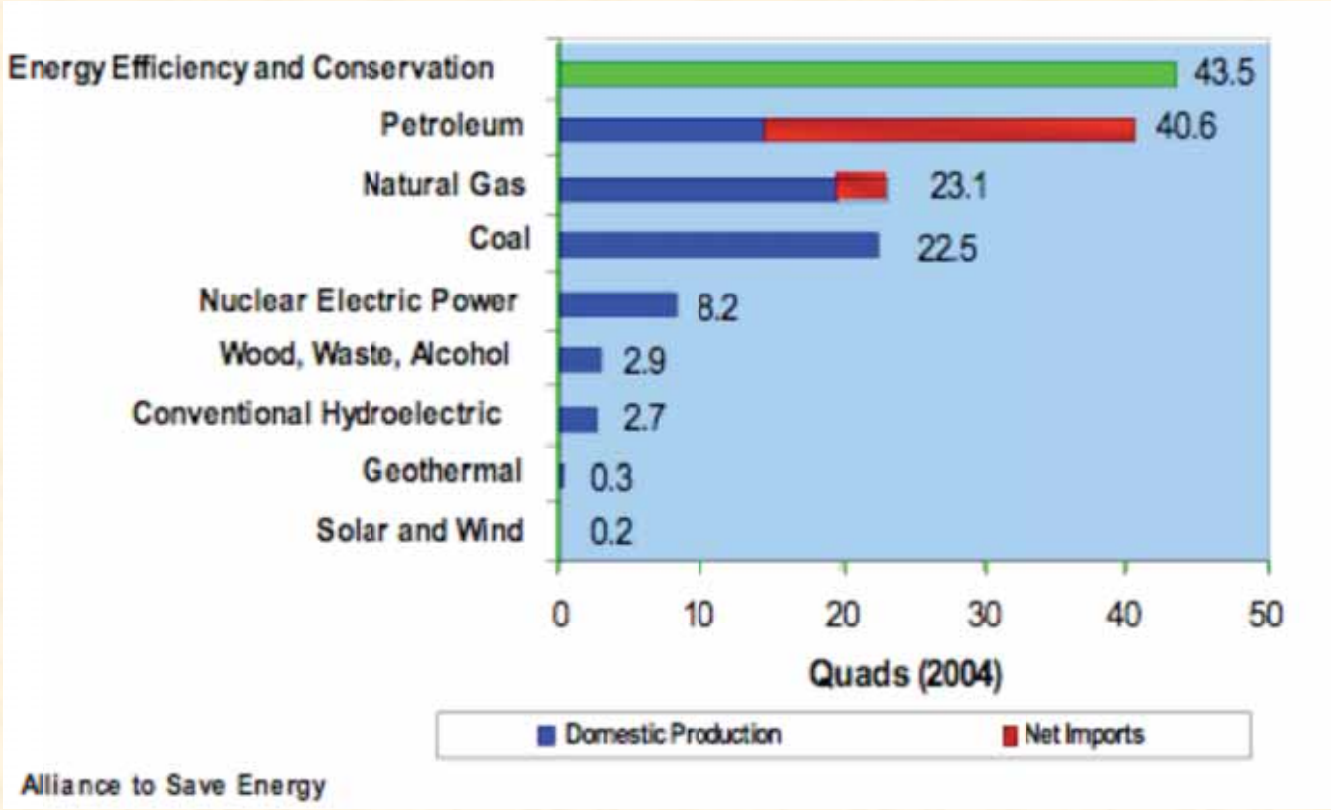
# Energy efficiency and conservation improvements since 1973 have reduced annual energy consumption by 40+ quads




Roughly $400 billion energy savings per year.

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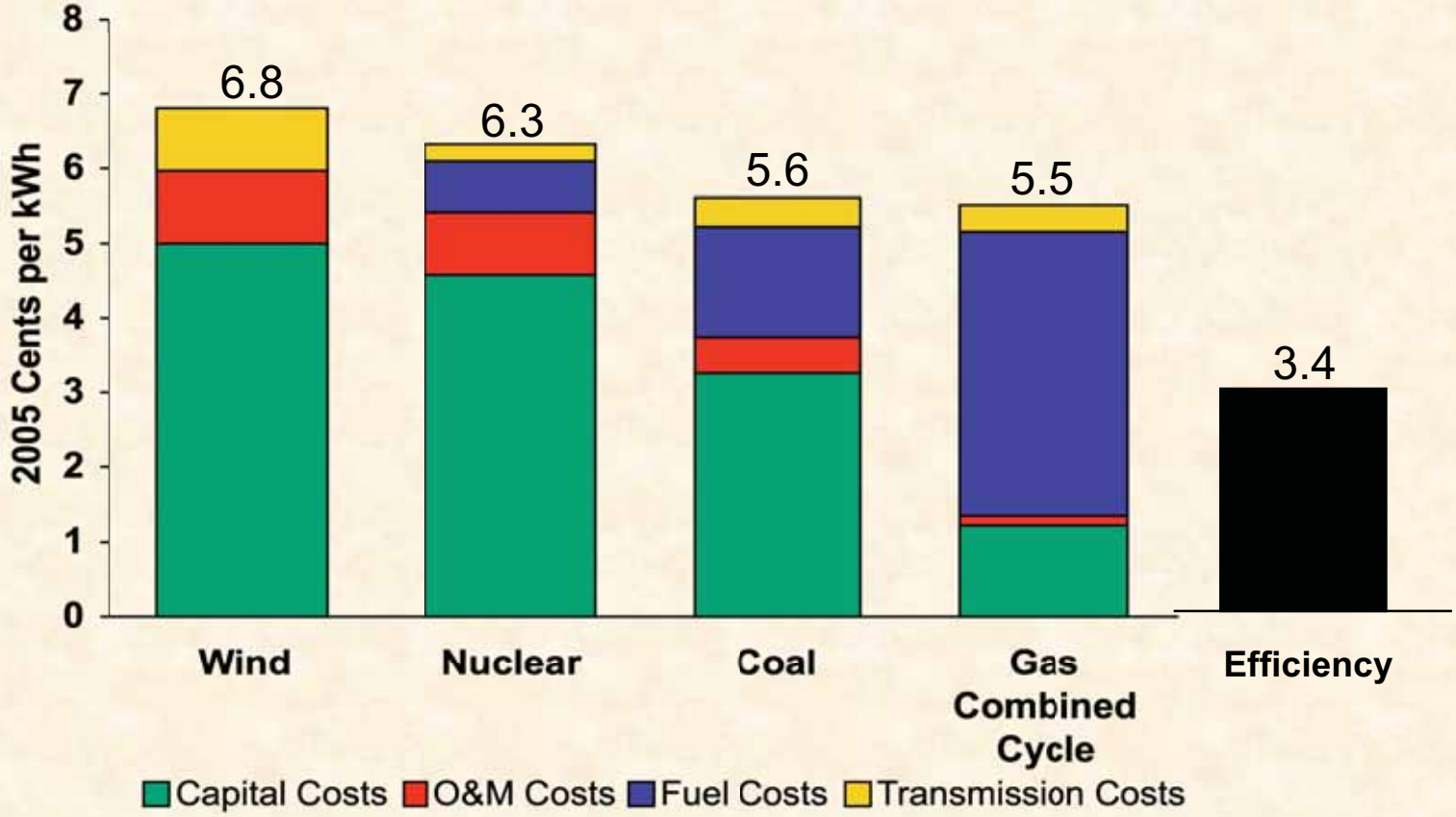
# Projected Cost of New Generation vs. Energy Efficiency Improvement–the Fastest, Cheapest, Cleanest Energy Resource




Sources: *Annual Energy Outlook 2007* (EIA), Figure 56, and "Five Years In: An Examination of the First Half-Decade of Public Benefits Energy Efficiency Policies" (ACEEE, 2004), Table 5.

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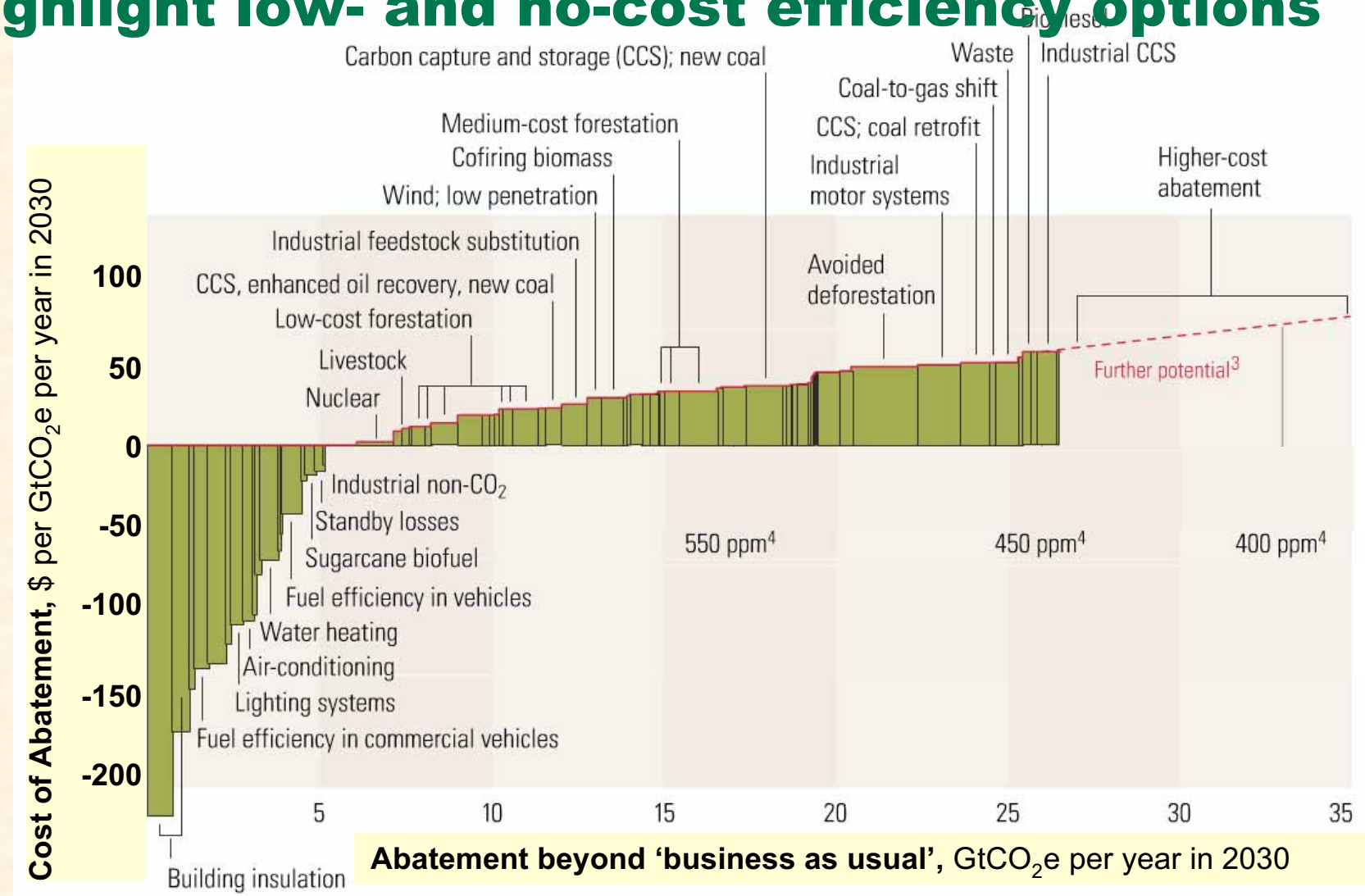
# Global supply curves for $CO_2$ reductions highlight low- and no-cost efficiency options




Source: Based on P. Enkvist, T. Nauclér, J. Rosander. "A Cost Curve for Greenhouse Gas Reduction." *The McKinsey Quarterly*. 2007.

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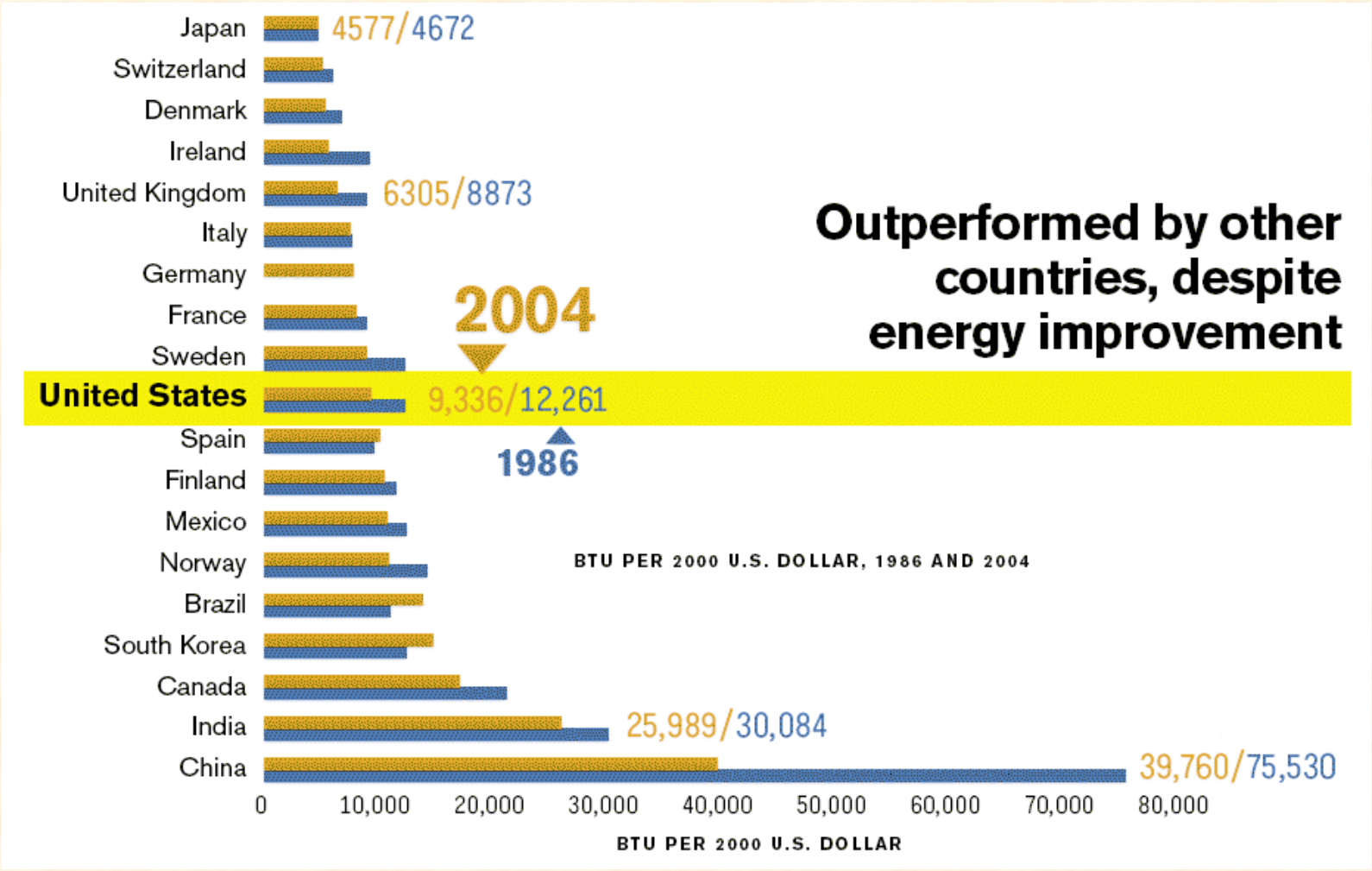
# U.S. energy productivity is outperformed by many countries




Source: Council on Competitiveness. 2007. *Competitiveness Index: Where America Stands.* Figure 4.32, p. 103.

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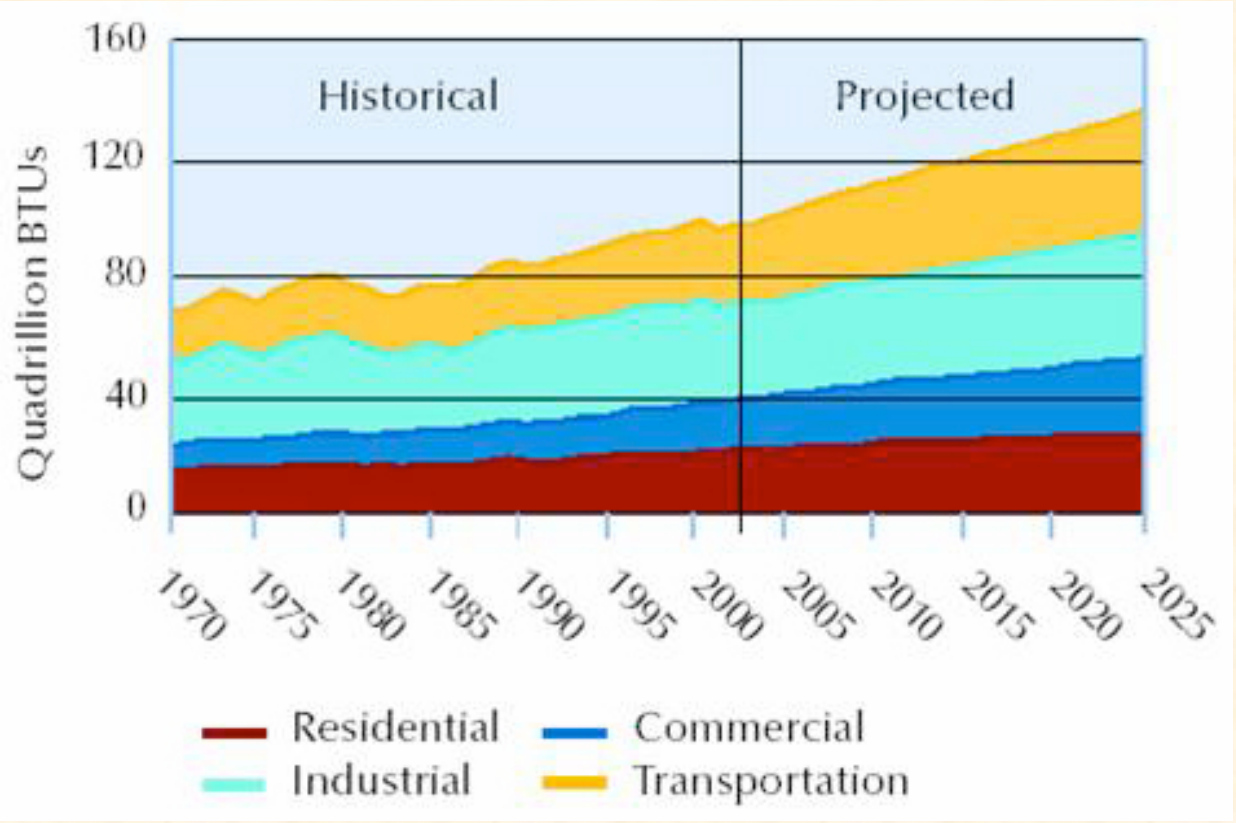
# Energy efficiency must help the U.S. and Georgia meet its future needs

U.S. Energy Consumption:




**Continuing to grow our energy use by 1.1% annually would require:**

**~31% increase by 2030**
**~183% increase by 2100**
**(850 more 300 MW plants…)**

**Cutting the growth rate in half (0.55%) would result in a more viable pace of resource expansion:**

**~15% increase by 2030**
**~68% increase by 2100**

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# How Much More Energy Efficiency is Available and Worth Buying?

# A lot, based on 3 assessments.

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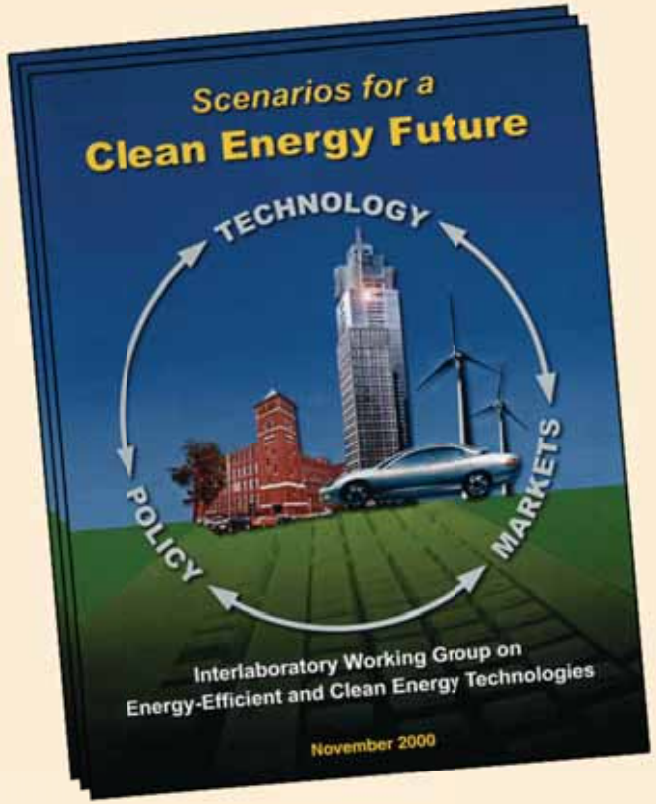
# (1) Scenarios for a Clean Energy Future

- **Advanced policies implemented in 2000 could cut U.S. electricity consumption in 2020 by 24%, with no net cost to the economy.**
  - Funded by DOE and EPA
  - Undertaken by researchers at 5 DOE national laboratories with input from experts groups
  - Published in November 2000




http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm
"Special Issue" of ***Energy Policy***, Vol. 29, No. 14, Nov. 2001

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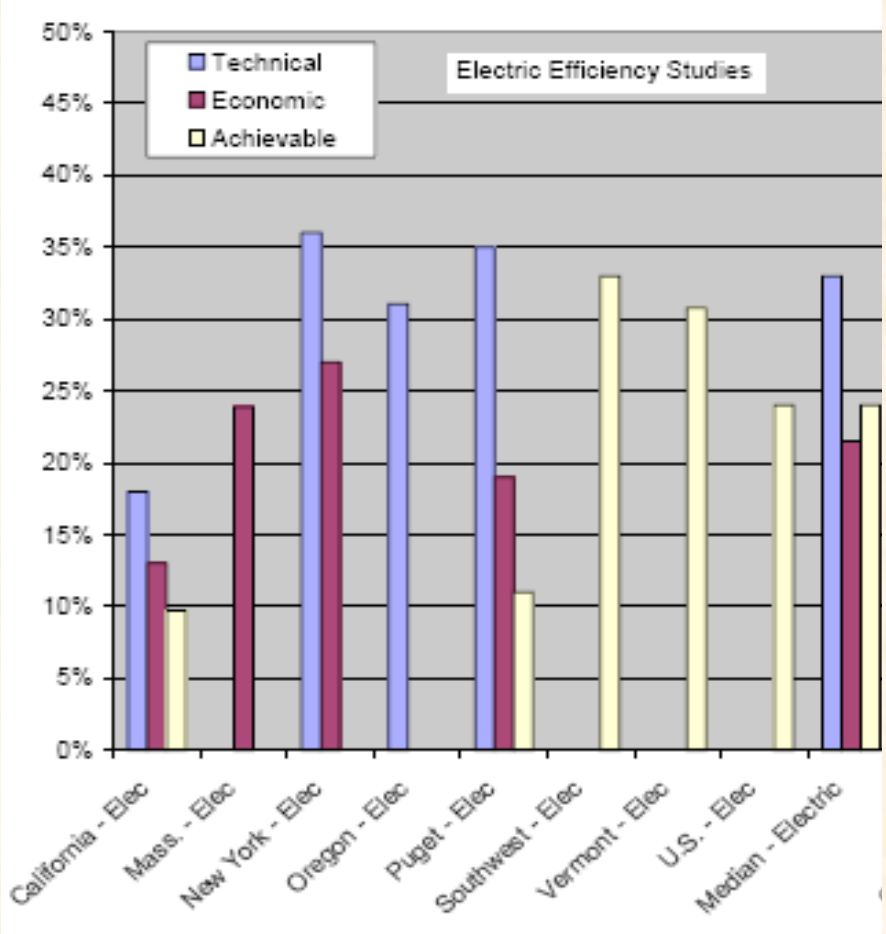
# (2) Meta-Analysis of Recent Studies

- **10 - 33% reductions in electricity use are "achievable," depending on timeframe and state/region**
  - Conducted by the American Council for an Energy Efficient Economy in 2004
  - Update: FL, GA, & NC estimates range from 9 to 14% (2017 vs 2023)



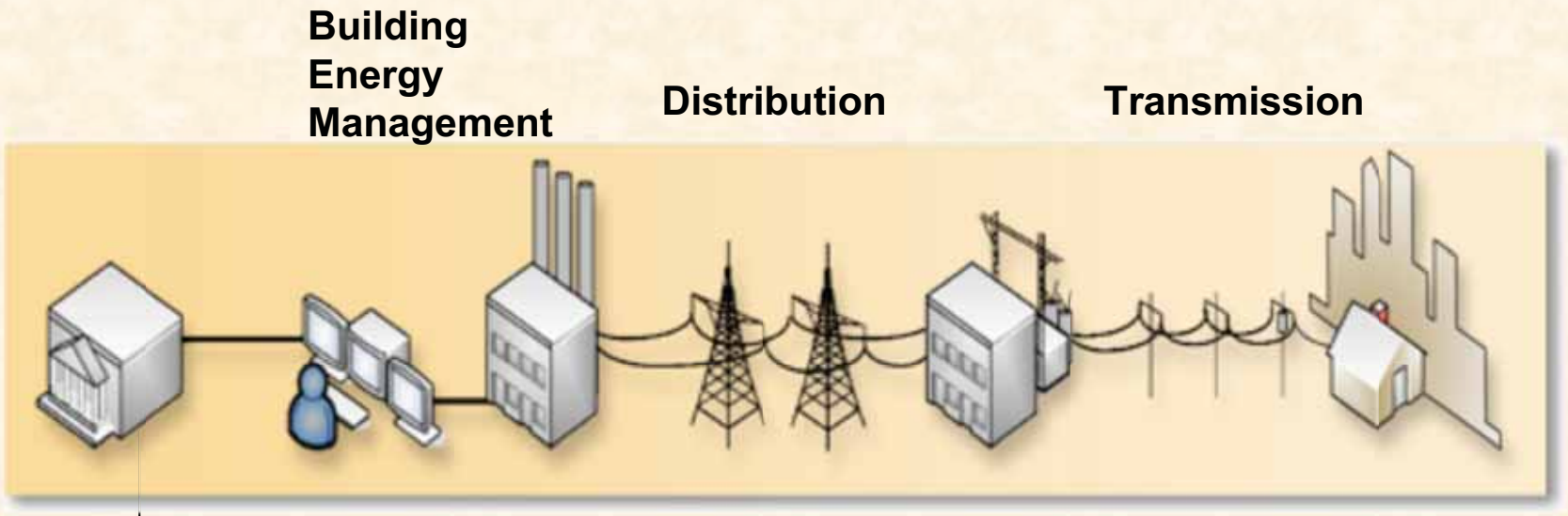

<http://www.aceee.org/conf/04ss/rnemeta.pdf> Steven Nadel, et al., "The Technical, Economic and Achievable Potential for Energy-Efficiency in the U.S. – A Meta-Analysis of Recent Studies" (August 2004) and Jess Chandler, "SEEA States Electric Efficiency Potential Study" (Draft, 2007)

# (3) National Action Plan for Energy Efficiency

- **More than half of expected growth in demand for electricity and natural gas can be avoided over the next 15 years**
  - This can be done by extending energy efficiency "Best Practice" programs to the entire country
  - Save nearly $20 billion annually on energy bills
  - Avoid 30,000 MW -- 60 new 500 MW power plants
  - Avoid more than 400 million tons of $CO_2$ annually
  - NAPEE Leadership Group included 27 electric and gas utilities, 16 state agencies, and 13 other organizations (+ EPA and DOE)

www.epa.gov/eeactionplan Leadership Group. 2006. *National Action Plan for Energy Efficiency*. Washington, DC: U.S. Department of Energy and U.S. Environmental Protection Agency

# Layers of Inefficiency Exist




**3% efficient!**

Source of the 3% efficiency estimate: Lovins, A. B., 2005, "More Profit With Less Carbon," *Scientific American* (September), pp. 74–82, www.sciam.com/media/pdf/Lovinsforweb.pdf.

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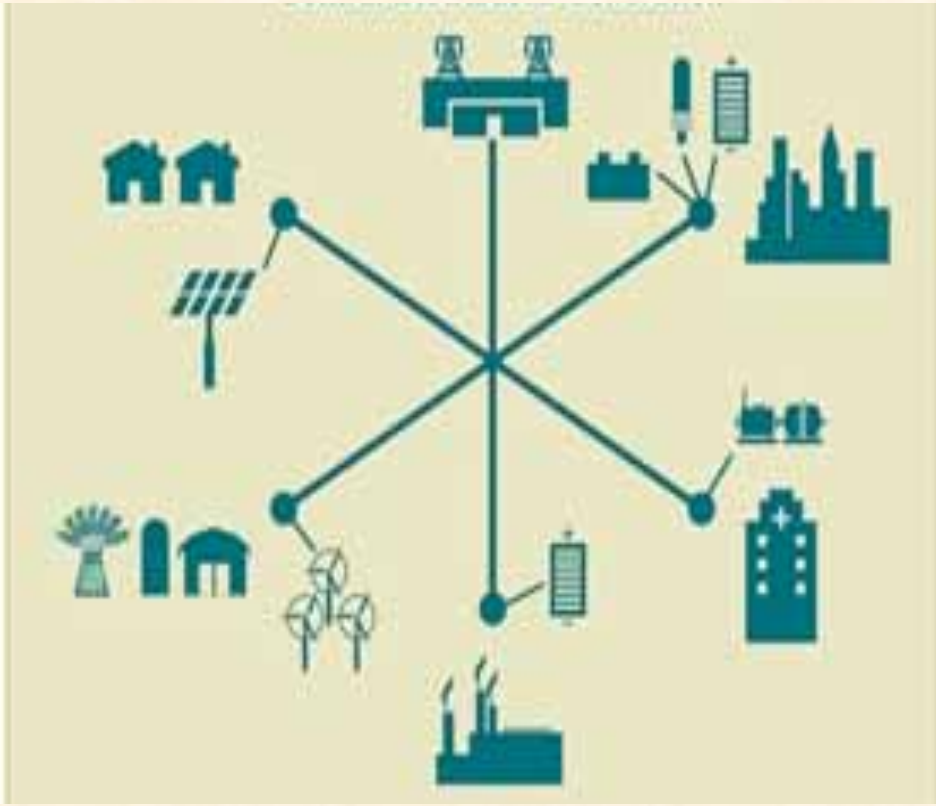
# New “Systems” are Needed: Distributed Generation

Today’s Central Generation

Tomorrow’s System with Distributed Generation



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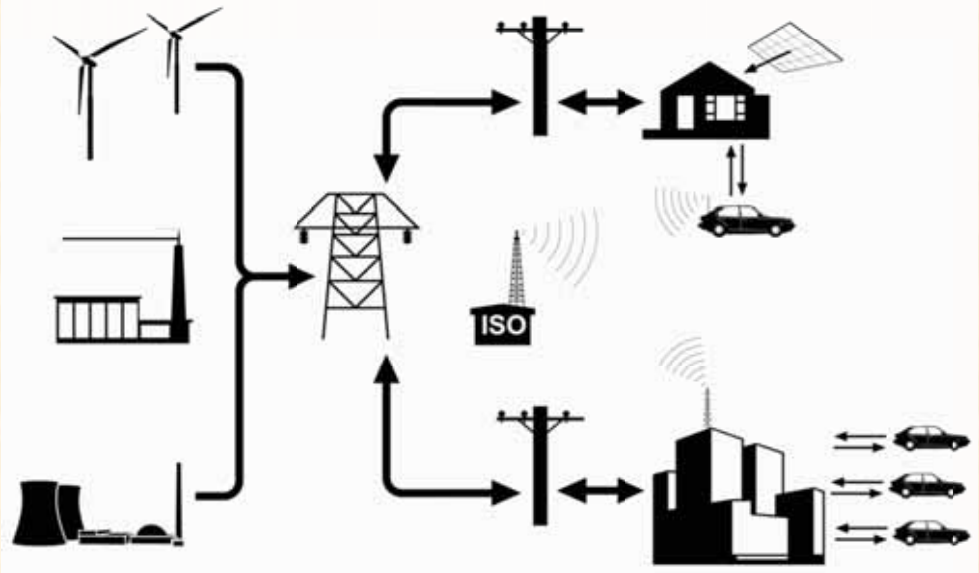
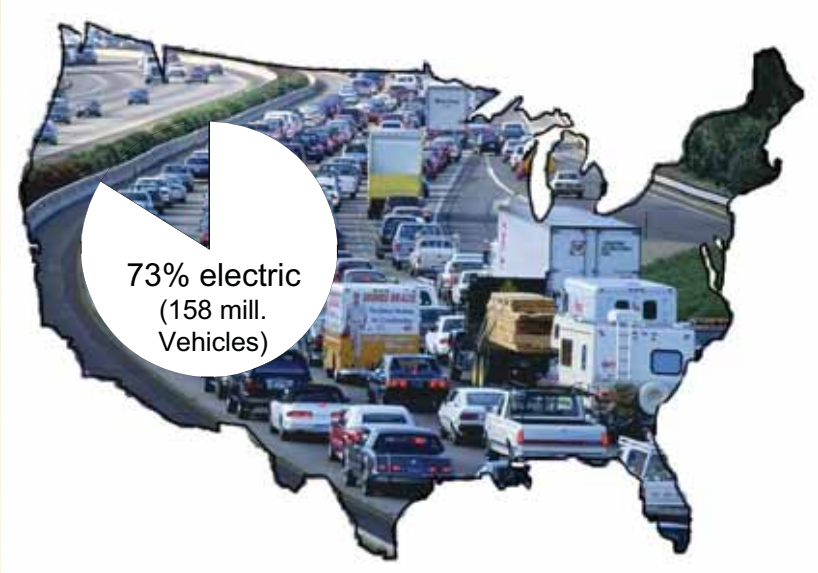
# Another Promising New System: Plug-in Hybrid Electric Vehicles




The direction of power flows with plug-in hybrid electric vehicles

Source: Joe Romm in *Energy and American Society – Thirteen Myths* (2007)




Idle capacity of today's grid could support 73% of light duty fleet

Source: Michael Kintner-Meyer, et al., 2007. "Impact Assessment of Plug-in Hybrid Vehicles on Electric Utilities" LERDWG Meeting, Washington, DC, February 7.

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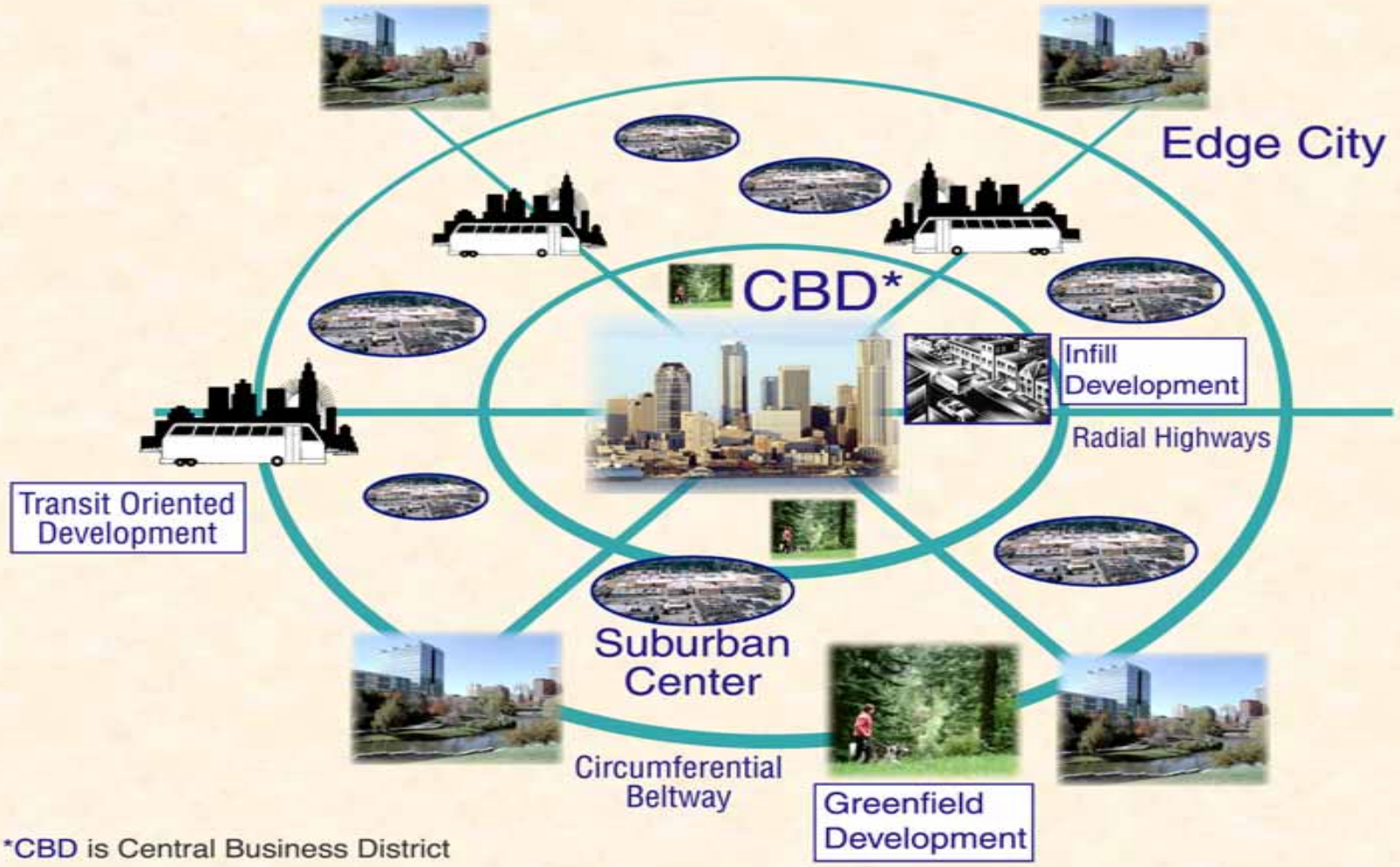
# “Smart growth” could benefit from “systems” engineering

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# Nano-info-bio discoveries will lead to highly efficient technologies

- **Illustrative Opportunities:**
  - Integrated heat pump technologies
  - Phase change materials in insulation
  - Self-optimizing sensor systems
  - Pulse thermal processing
  - Super-durable materials for aggressive environments
  - Energy-efficient distillation through supercomputing
  - Novel energy-efficient separations

**New technologies could have broad impact in daily life.**

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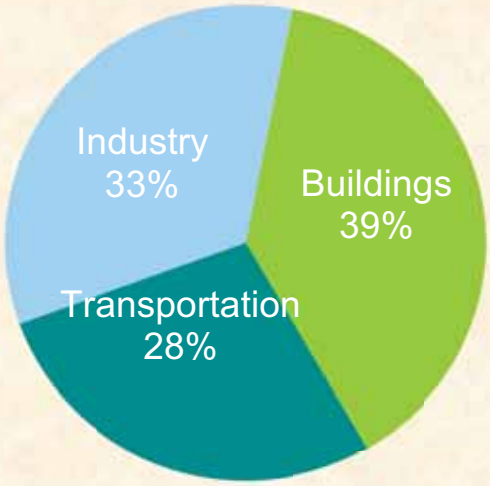
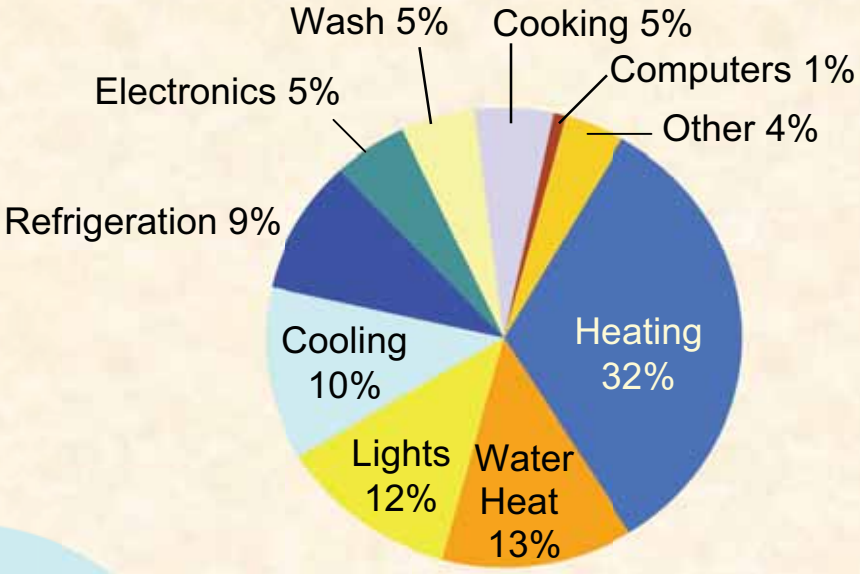
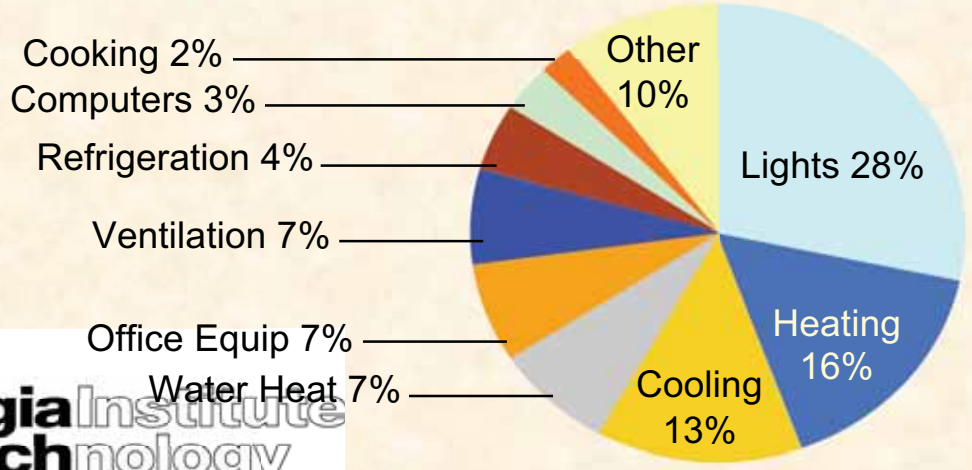
# Buildings Use 72% or U.S. Electricity & 54% of Natural Gas




**Residential (21%)**




**Commercial (18%)**

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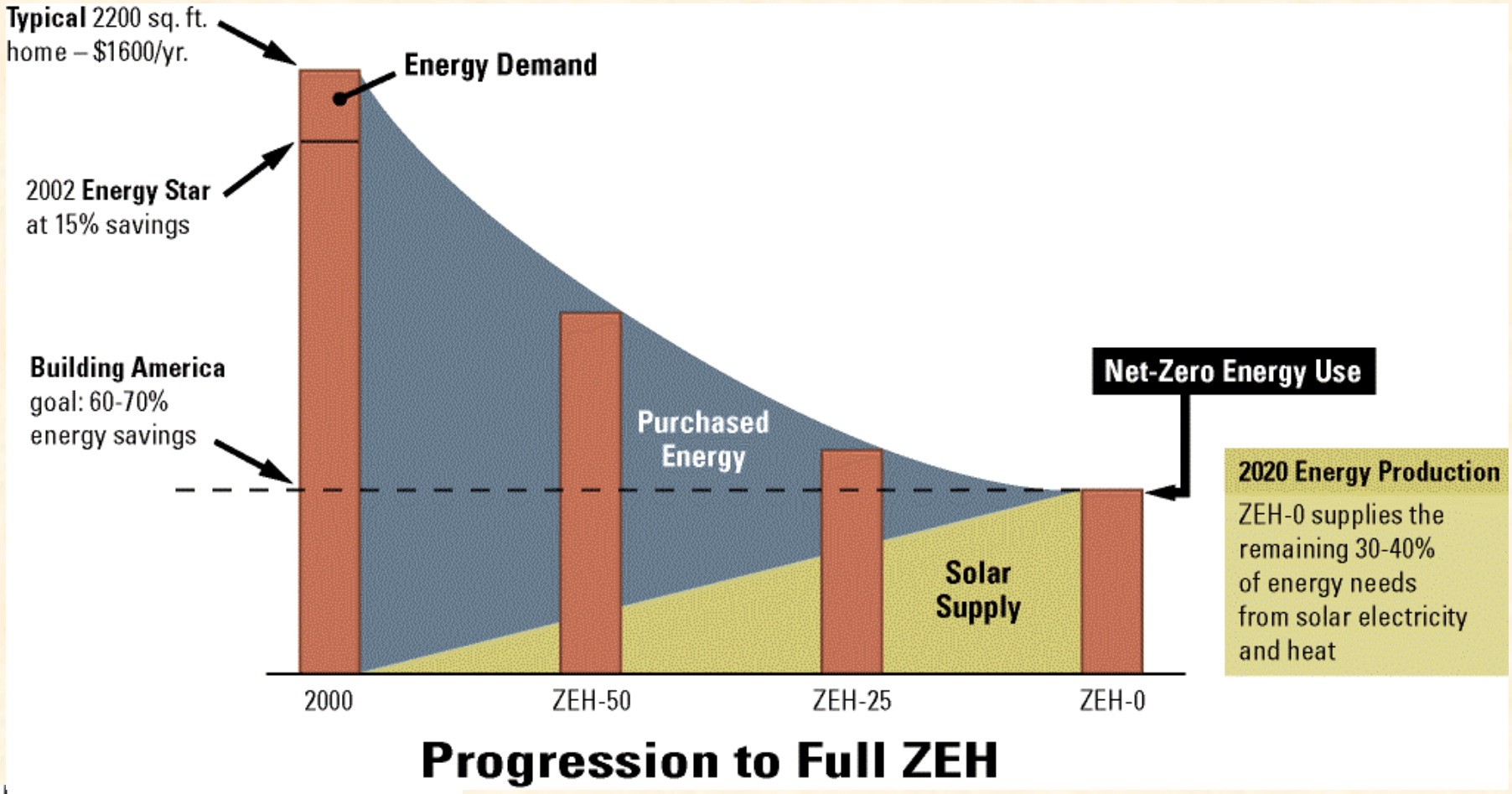
Source: 2004 Buildings Energy Data Book

# DOE Goal: Cost-Competitive Net-Zero Energy Home (ZEH)

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# Near Zero-Net Energy Homes are Being Built

- Advanced energy technologies being researched with Habitat for Humanity
  - Integrated heat pump water heaters
  - High velocity ducts
  - Structural insulated panels
  - Photovoltaics
  - Geothermal heat pumps
- Annual heating cost = $92, cooling cost = $74 with air-source heat pump, and hot water cost = $90
- 82 cents per day for total energy including plug loads

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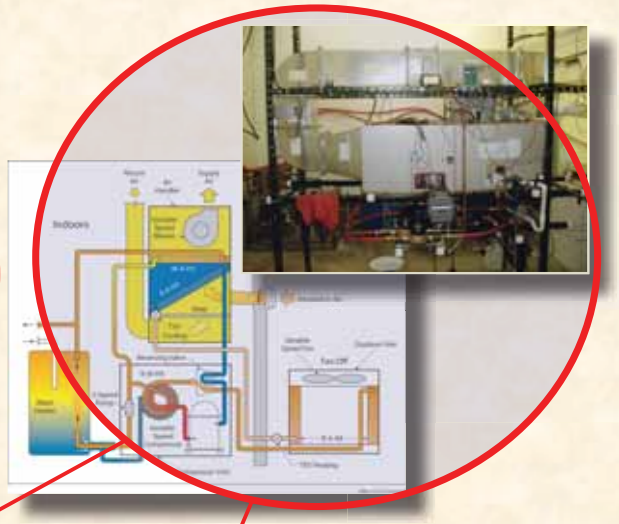
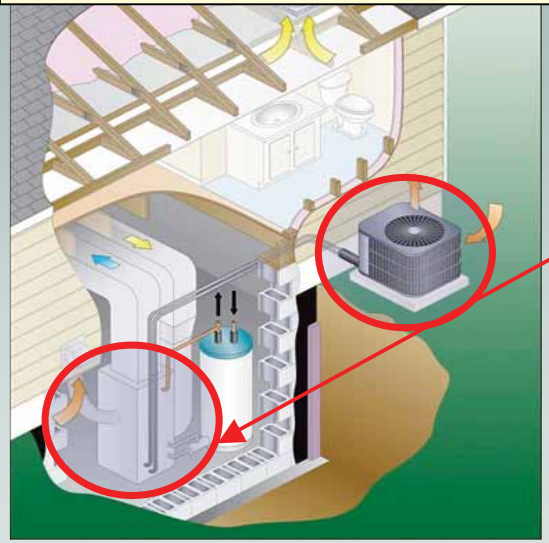
# Several Heat Pump Technologies are Emerging as 50% Energy Savers

## Heat Pump Water Heater

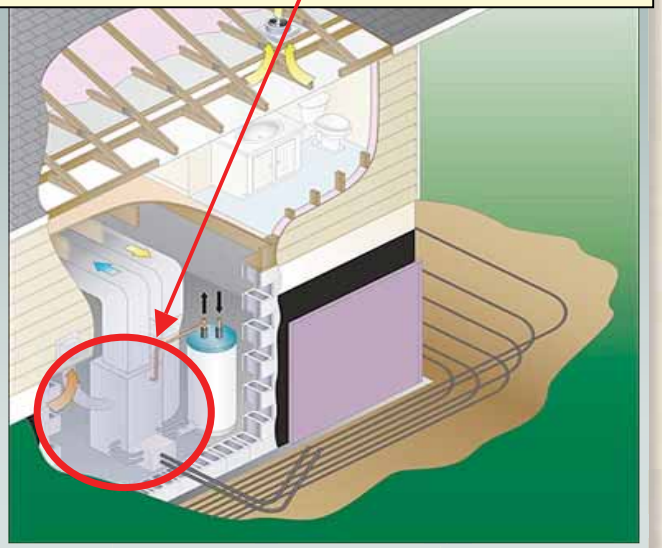
50% saver for the electric water heating mass market

## Air-Source | Integrated Heat Pump (IHP) | Ground-Source



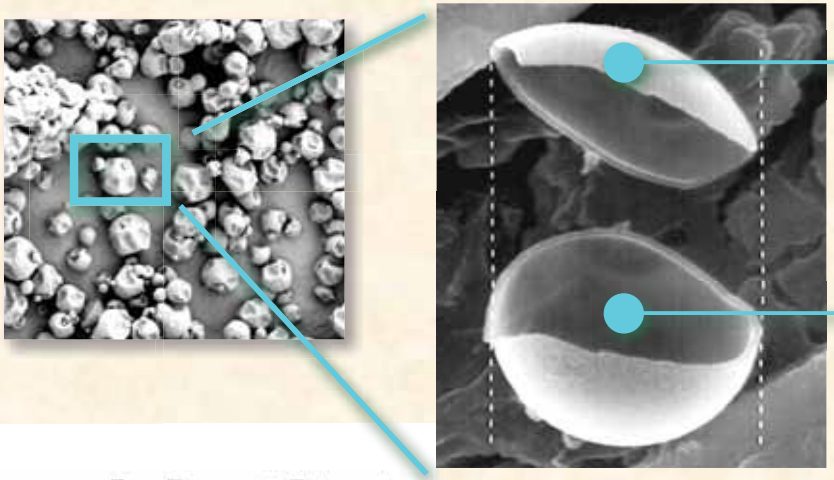
H, C, WH, V & demand dehumidification in all-electric homes.



# Phase Change Materials in Insulation

- PCM microcapsules could enable a new generation of building insulation
- First dynamic hotbox test of a wood-framed wall containing PCM-enhanced cellulose insulation – showed *40% reduction of cooling load*

*Installation of PCM-enhanced cellulose insulation in a test wall*

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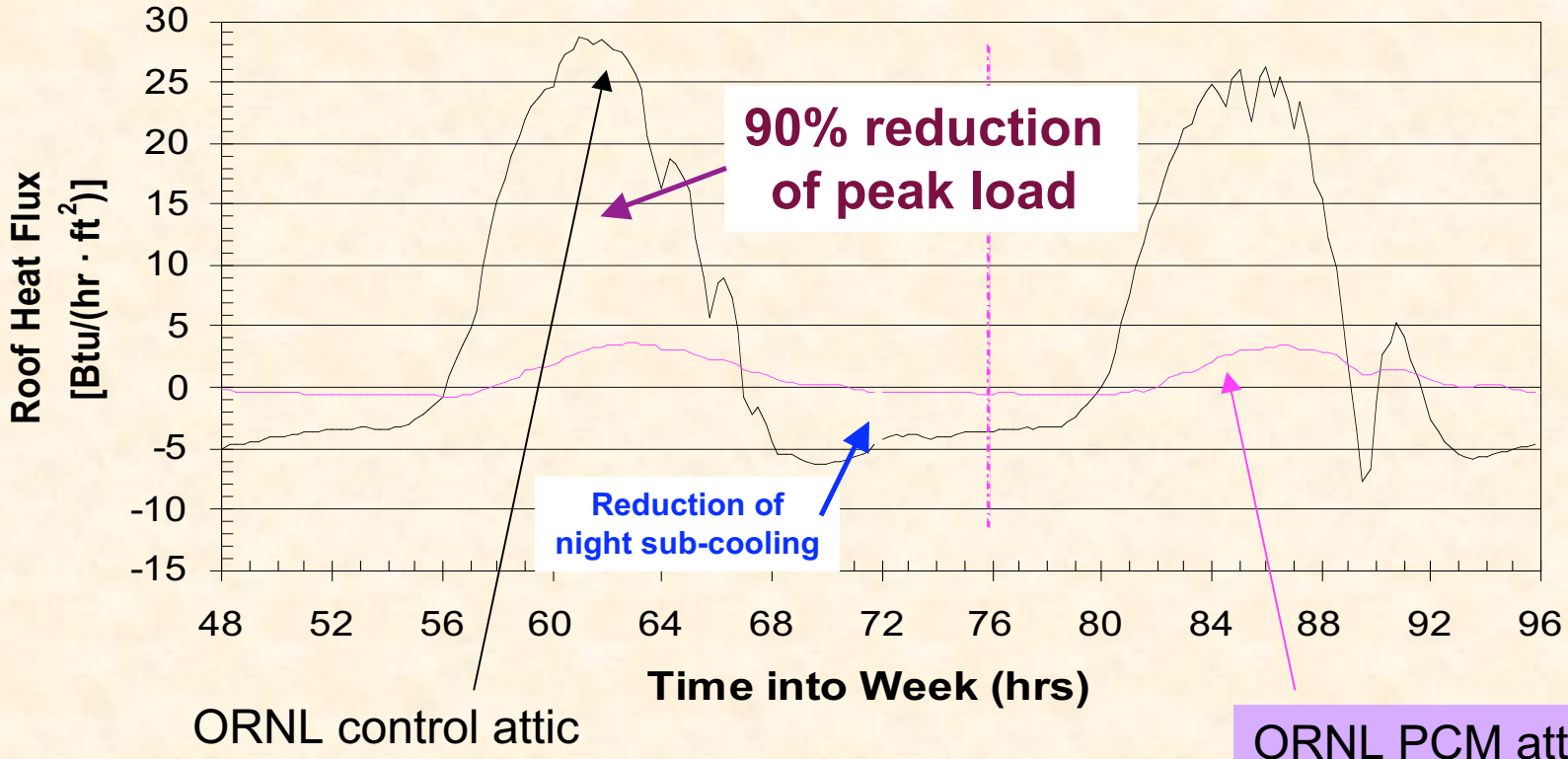


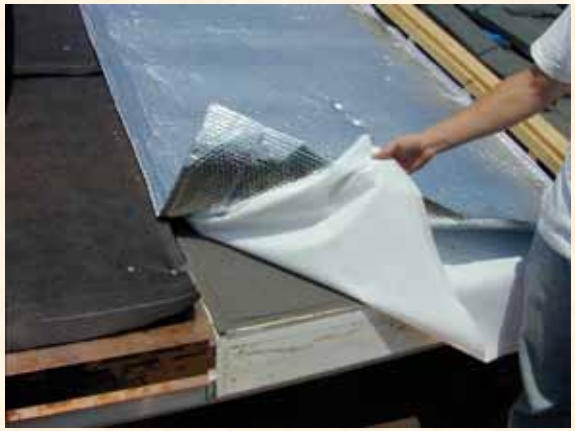

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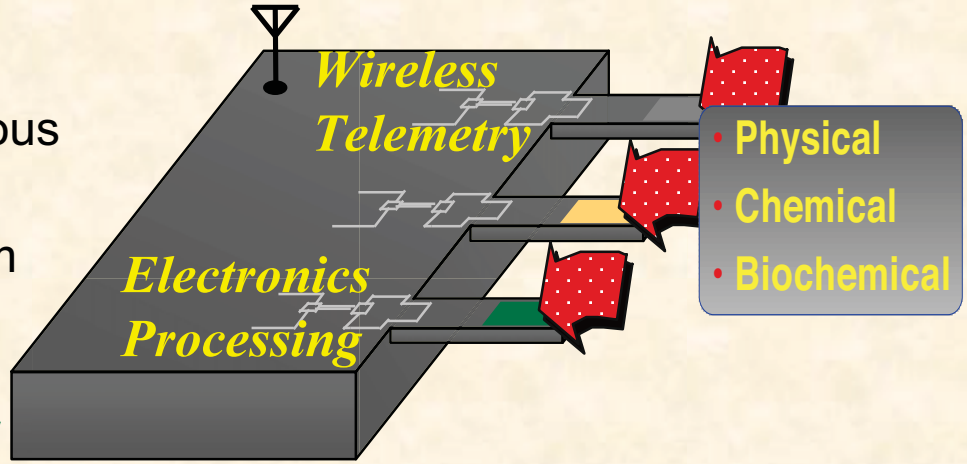
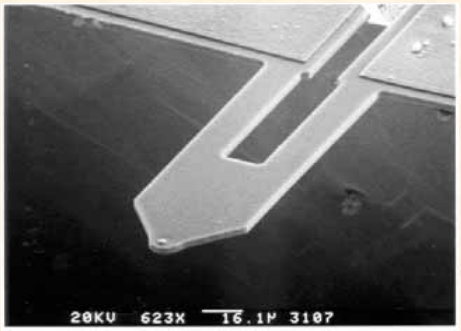
# Self-optimizing sensor systems

- Low-cost ubiquitously distributed micro-sensors that are self-calibrating and self-diagnosing
- Intelligence distributed to the sensor with wireless telemetry
- Anticipatory prognostics to allow continuous optimization
- Ultra-low power electronics operated from power scavenging




- **Potential Opportunities and Annual Energy Savings:**
  - Small motors: ~0.3 quads
  - Industrial buildings EMS: ~0.75 quads
  - Industrial energy systems:
    - Petroleum refining ~0.1 quad
    - Chemicals ~0.13 quad
    - Forest products ~0.15 quad
    - Food & beverage ~0.05 quad
  - Manufacturing: ~0.65 quad

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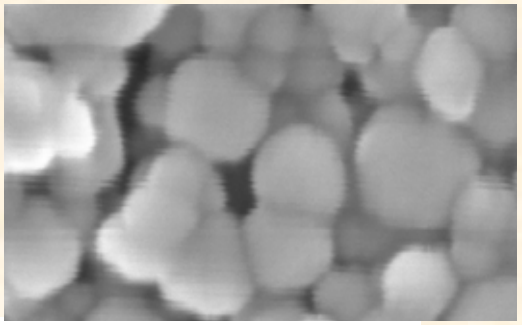
# Pulse Thermal Processing (PTP) - An Enabling Tool for Broad Area Nanoscale Processing

- PTP allows high temperature processing (3.5 - 20 kW/cm$^{2)}$ to achieve functionalization of nanomaterials on polymer substrates
- Uses a high density infrared radiant arc lamp (1 millisecond pulse capacity of 0.7 - 12 MW)
- Approaching power densities of a laser with processing area of 300 cm$^2$

Flexible solar module



$TiO_2$ nanoparticles (approx. 35 nm) sintered on a polymer substrate for a photovoltaic application. (ORNL data with 0.7 seconds of processing)

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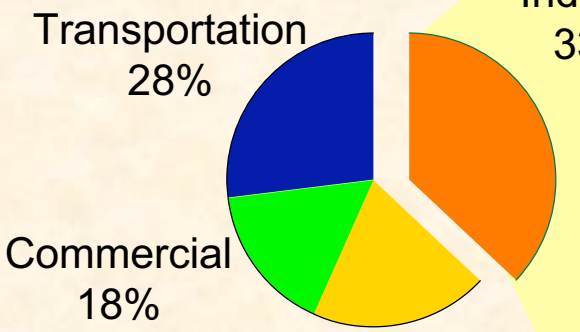
# Industry: Critical to National Energy Picture

***Industry is the largest energy using sector***

- 37% of U.S. natural gas demand
- 29% of U.S. electricity demand
- 30% of U.S. greenhouse gas emissions
- Uses more energy than any one of the other G8 nations

**2004 Energy Use*
100.3 Quads**




*Includes electricity losses

**(Quadrillion Btu)**


Source: DOE/EIA Monthly Energy Review 2004 (preliminary) and estimates extrapolated from MECS

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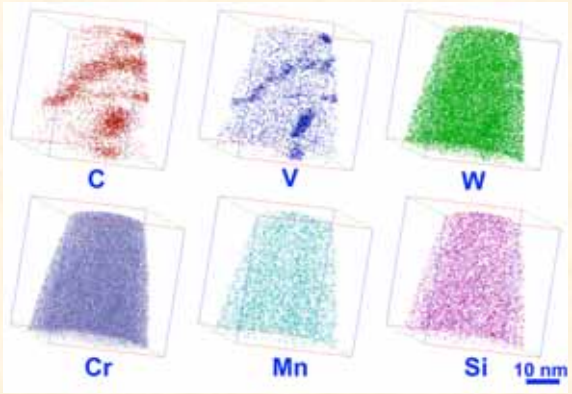
# Super-durable materials for aggressive environments

- Nano structures and phases enable new properties at the macroscale:
  - Enhanced mechanical strength
  - Improved high temperature tolerance
- Uses computational microstructure design methodology
- Result: higher temperature, stronger and more degradation resistant materials for industrial processes
- **Potential Opportunities and Annual Energy Savings:**
  - A 10% impact on industrial boilers, chemical reaction vessels, and furnaces can lead to energy savings of ~1.5 quad.

Process heating uses over 15 Quadrillion Btu/yr in the US (~15% of annual U.S. energy use)


**New alloys possess stable nanostructures of ~10nm**

**Atom Probe Analyses**

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# Enhanced nickel aluminide ($Ni_3AL$) for rolls in steel reheat furnaces


ORNL R&D on new $Ni_3AL$ alloys is successfully applied in industry

- Development of new alloys and manufacturing procedures enabled production of 115 rolls for installation and testing
- Materials successfully reached 32 month milestone – over 300,000 tons of steel processed (~4.3X steel in Empire State Building)
- Eliminated over 85 furnace shut downs (~260 days; over 25% increase in up-time)
- Higher yield, no rework and increased product quality due to *no roll-related downgrading of steel*
- 35% increase in furnace energy efficiency (natural gas).

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# Energy-efficient distillation through supercomputing

- **Advanced modeling and simulation of complex industrial processes can lead to significantly improved design and operation**
- **Modeling of counterflows through structured packings can improve distillation hydrodynamics**
  - Empirically characterizing the hydrodynamics of a packing element requires a high-end supercomputing cluster capability
  - Terascale computers will be needed to perform an integrated hydrodynamic calculation for an entire distillation column
- **Potential Opportunities and Annual Energy Savings:**
  - Distillation accounts for ~3 quads of energy usage annually, about half in petroleum refineries
  - 10-20% reductions are possible with improved geometries of packing elements
  - Comparable savings possible through steam system engineering

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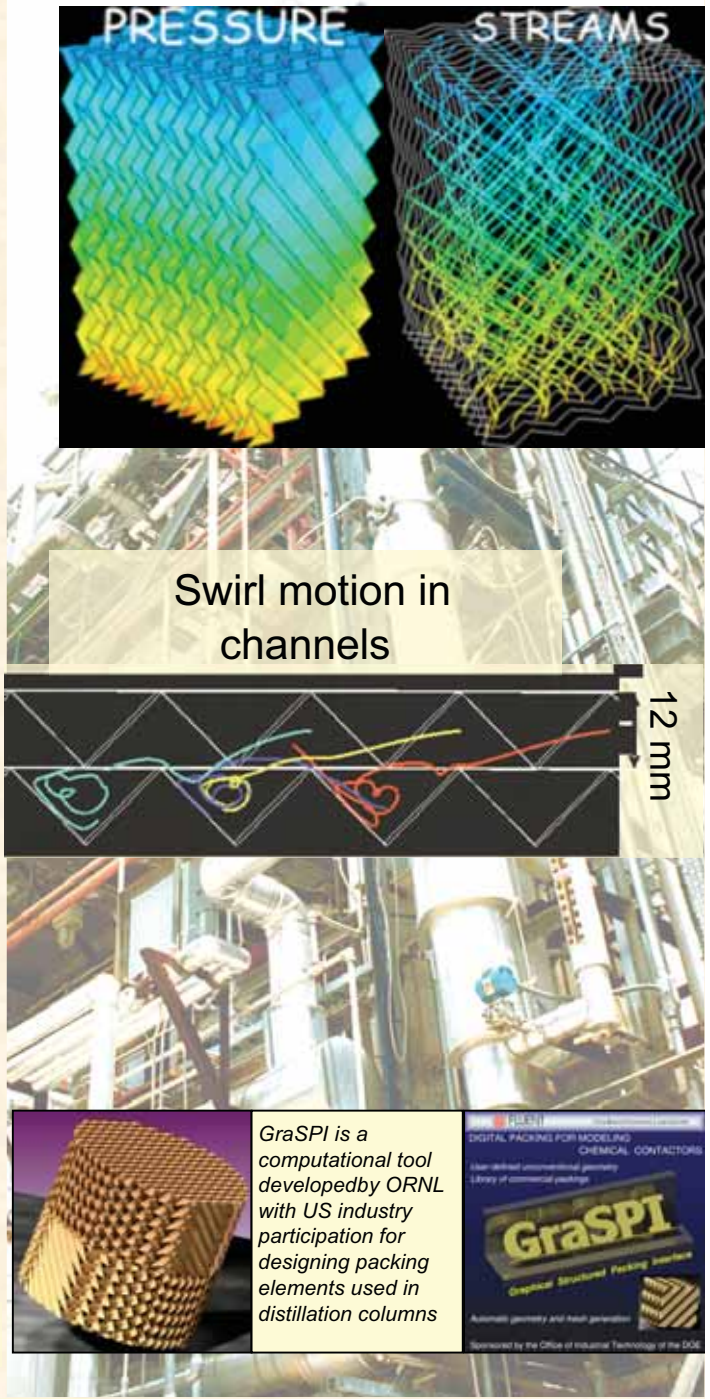
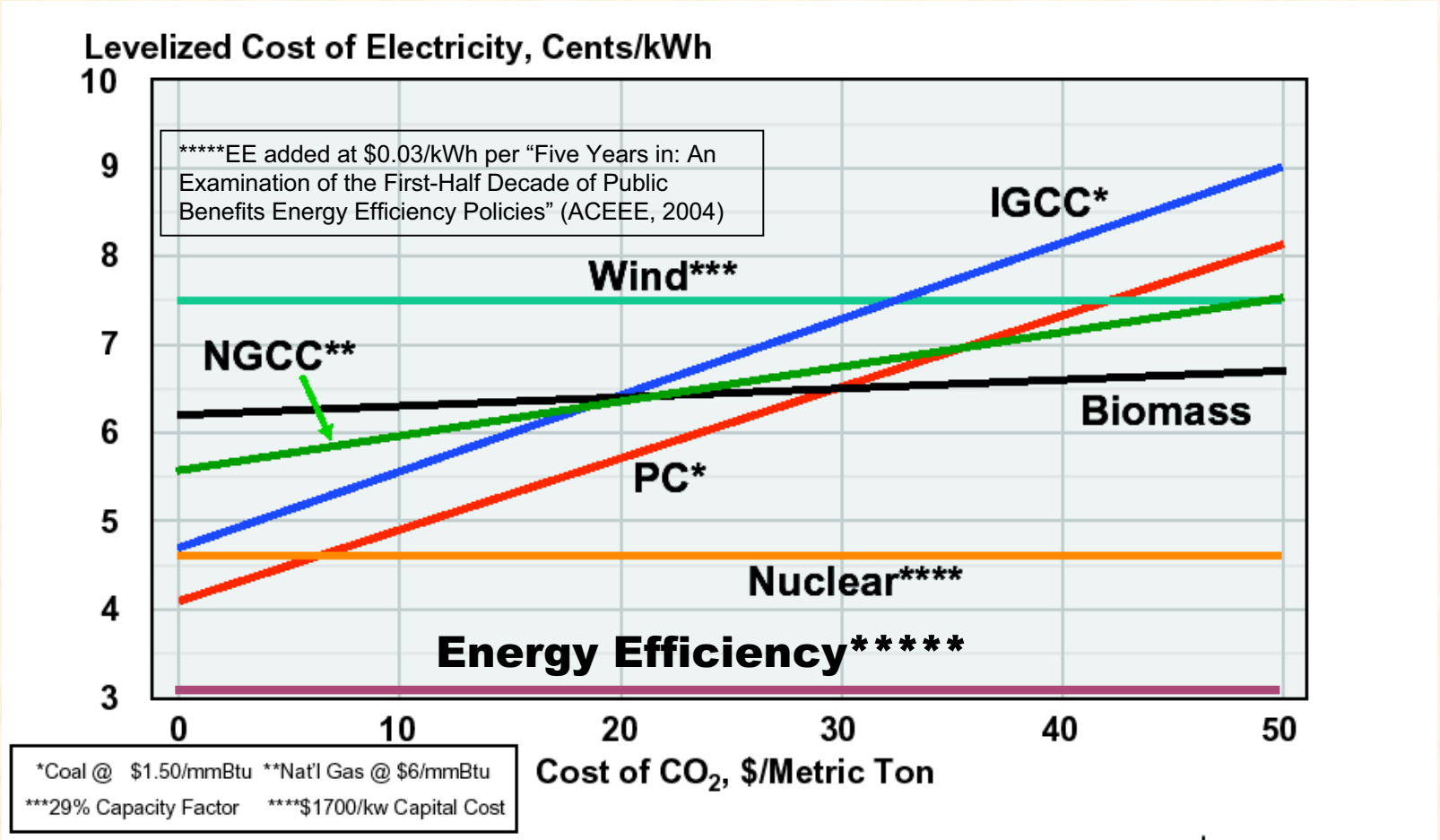
Source: http://distillation.ornl.gov



# The Future for Energy Efficiency Is Bright

Comparative Cost of 2010 Generating Options (and Energy Efficiency) under Different Carbon Prices





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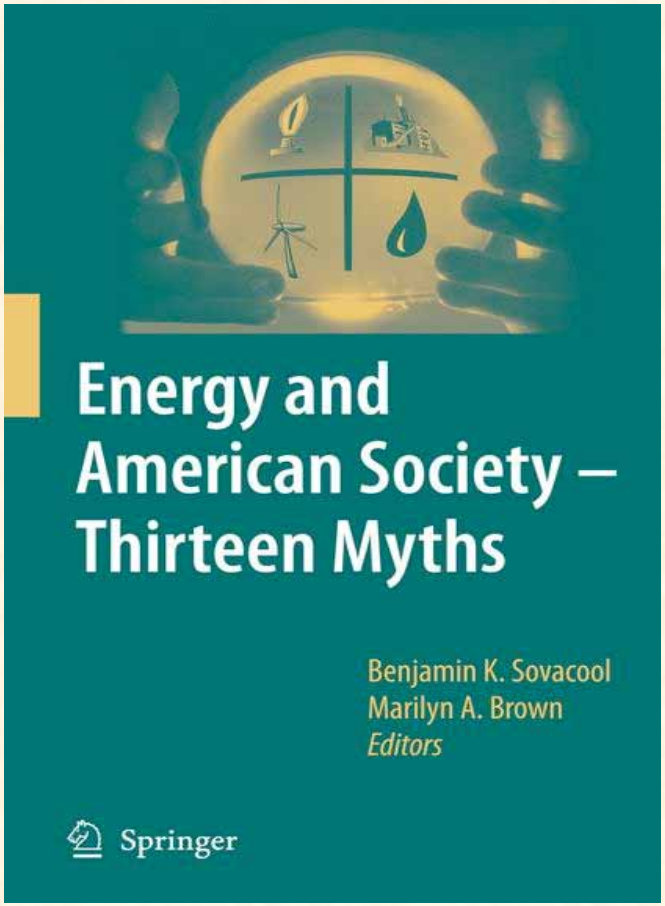
# Concluding Remarks

- Targeting energy efficiency is a no regrets strategy for mitigating climate change
- Technology advances are needed to sustain the pipeline of new options
- New and reformed policies are needed to overcome market and government failures*

*See: Brown and Chandler. "Governing Confusion…." *Stanford Law and Policy Review,* forthcoming.

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