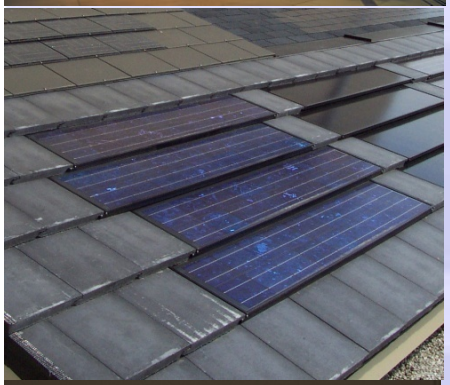
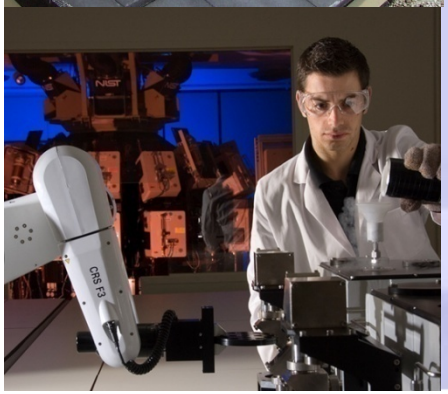




Building Energy Efficiency:

Net-Zero Energy, High-Performance Green Buildings

2010 GreenGov Symposium:
The Net-Zero Building

October 6, 2010

S. Shyam Sunder

Director, Engineering Laboratory

National Institute of Standards and Technology

U.S. Department of Commerce

Energy Statistics

Global energy-related CO_2 emissions

- 28,000 MMT in 2005 (40% oil, 40% coal, 20% NG)
- 43,000 MMT in 2030 (*business as usual* projection)

U.S. energy consumption and related CO_2 emissions

- About 20% of global energy consumption
- 20 mbpd oil, 60 bcf/day natural gas, 3 million tons/day coal
- 5900 MMT in 2005 (45% oil, 35% coal, 20% NG), 21% of global
- 6900 MMT in 2030 (*business as usual* projection), 16% of global

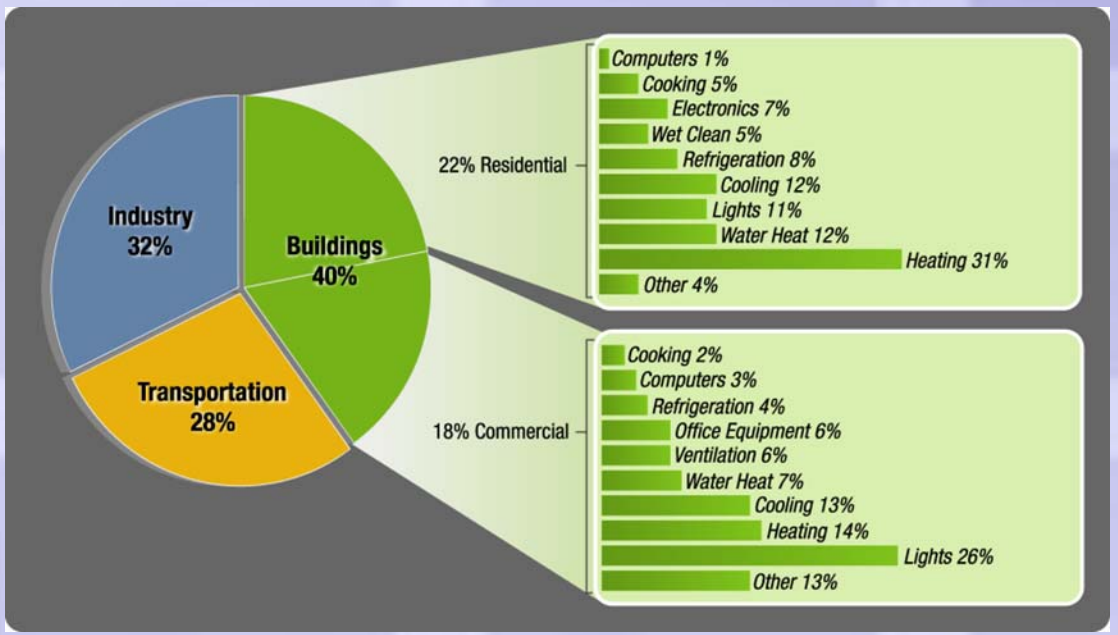
Regional *Business as Usual* CO_2 Projections

- 60% of the 25-year projected increase will be in China, India, and other developing nations in Asia
- 7% of the increase in the U.S.

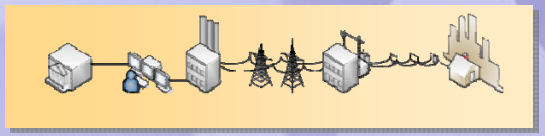
Why Buildings' Energy Use Is Important

The combined residential and commercial buildings sector is the largest energy consumer in the U.S.

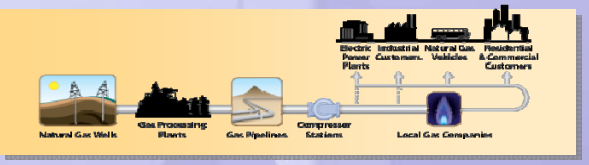
40% of U.S. Primary Energy Consumption



72% of U.S. Electricity



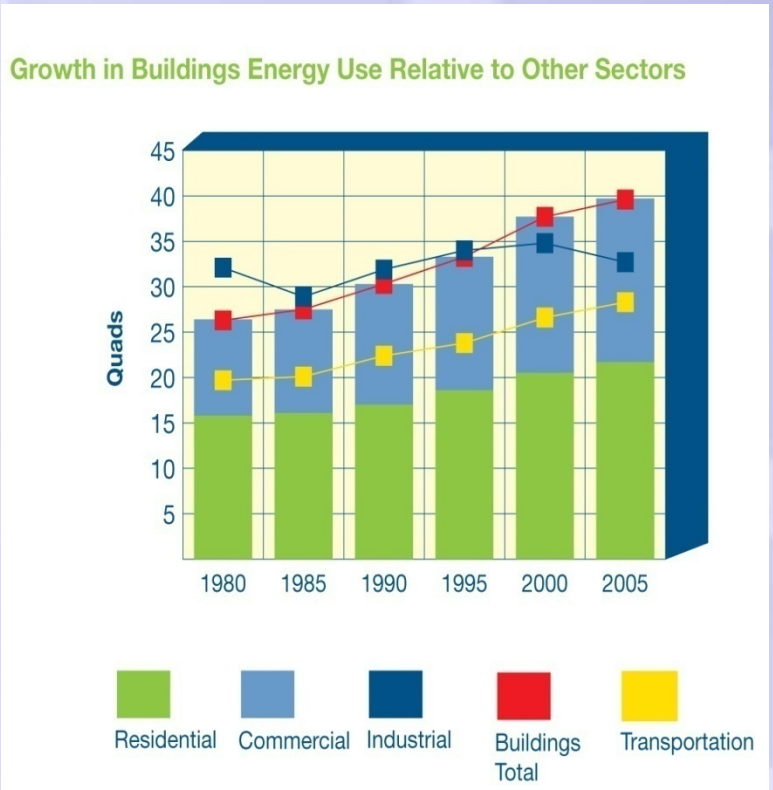
55% of U.S. Natural Gas



U.S. spends about $450 to 500 B/year in energy costs for operation and use of constructed facilities

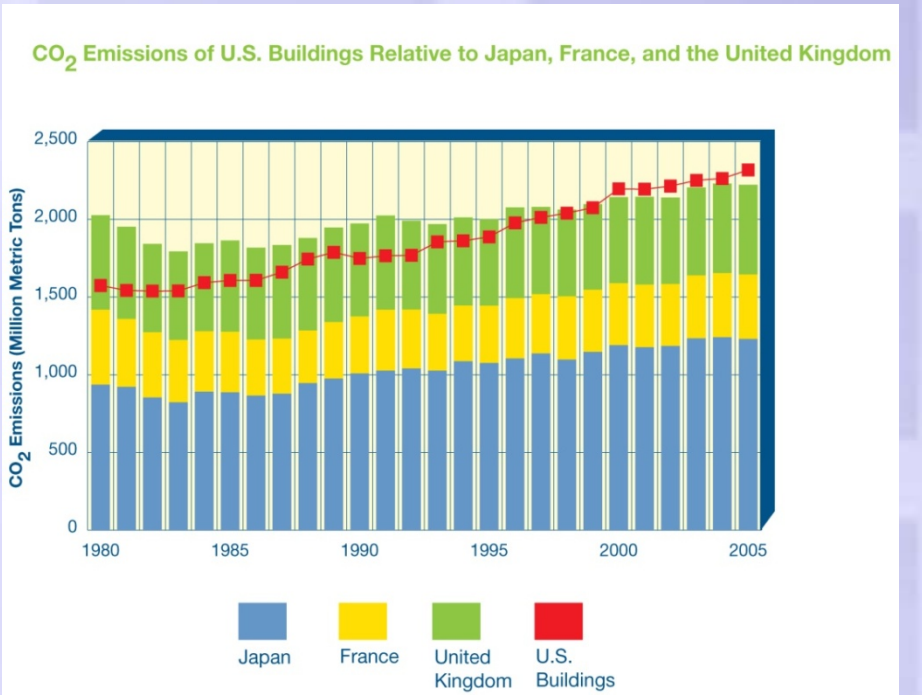
Fastest-Growing Energy Sector

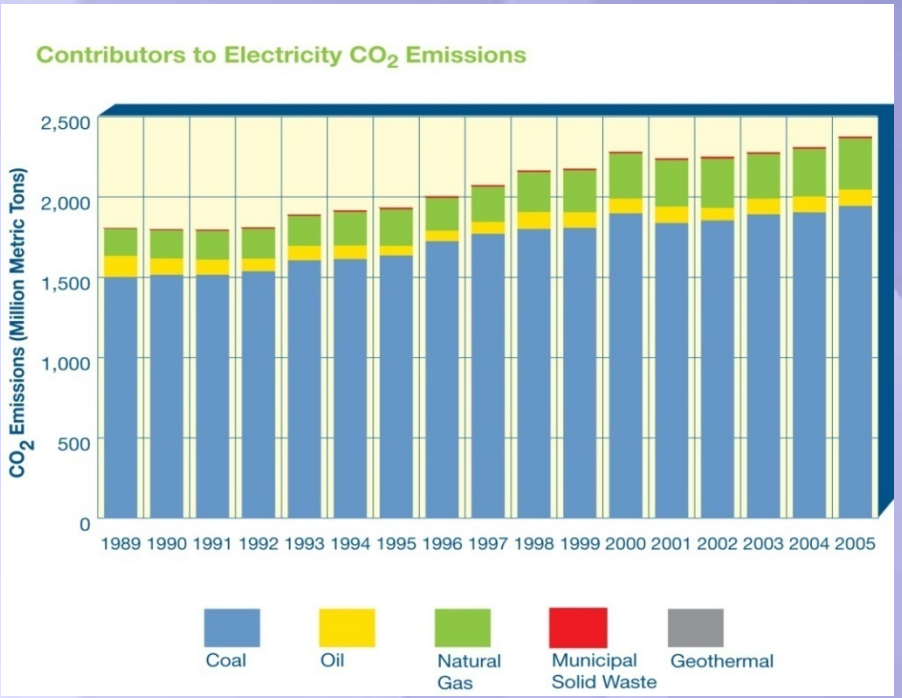
Energy consumption by commercial buildings sector rose 70% between 1980 and 2005



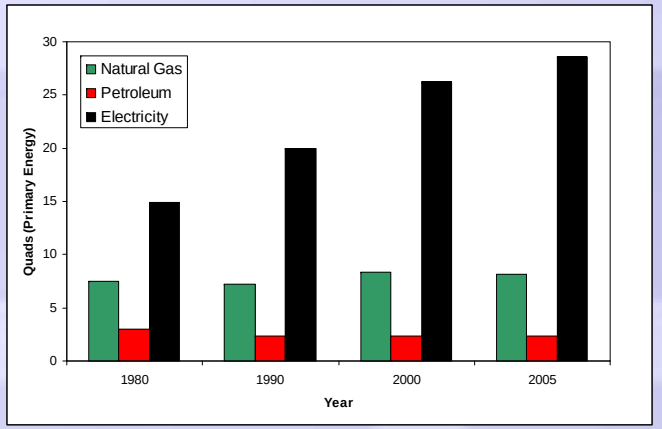
Buildings' Environmental Footprint Is Large

U.S. buildings contribute 9% of world's carbon dioxide emissions (double the emissions of India)



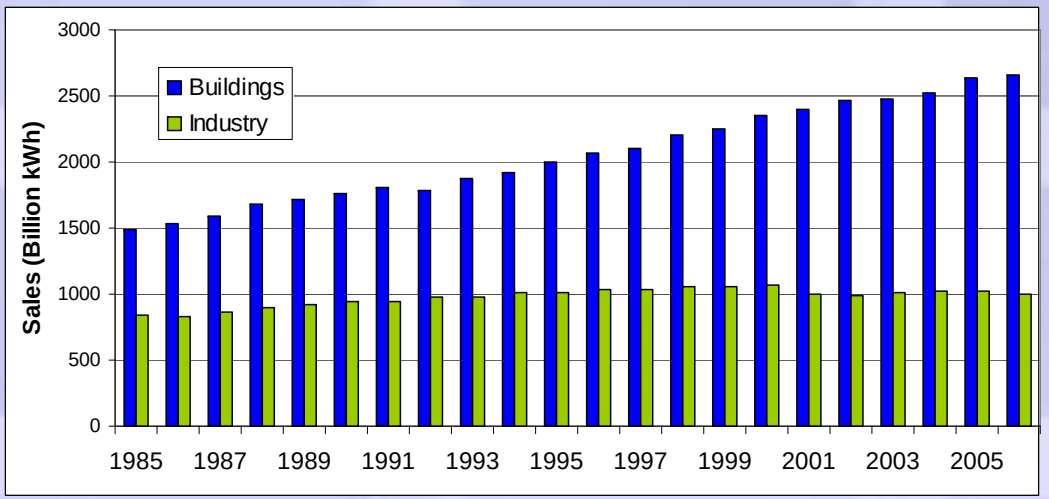


Electricity: A Dominant and Growing Source of Building Energy



Source: 2007 BED, Tables 1.1.1

Electricity increased from 56% of overall primary energy use in buildings in 1980 to 72% in 2005



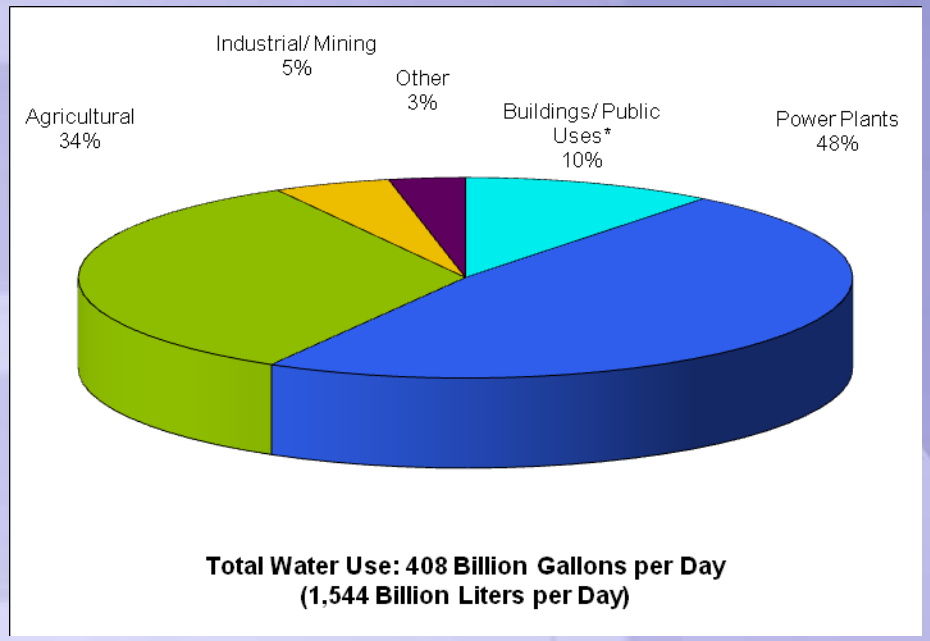
Source: EIA Annual Energy Review, Table 8.9, June 2007

Buildings' electricity demand is driving need for electricity infrastructure

Buildings' Water Use Is Significant

Including electric generation, buildings account for 45 percent of U.S. water use:

- Not including electricity, U.S. per capita domestic water use is 100 gal/day (378 liters/day)
- Approximately 140 billion gal/day (530 billion liters/day)), is used to produce electricity for buildings or an estimated 470 gal/person/day (1,779 liters/person/day)

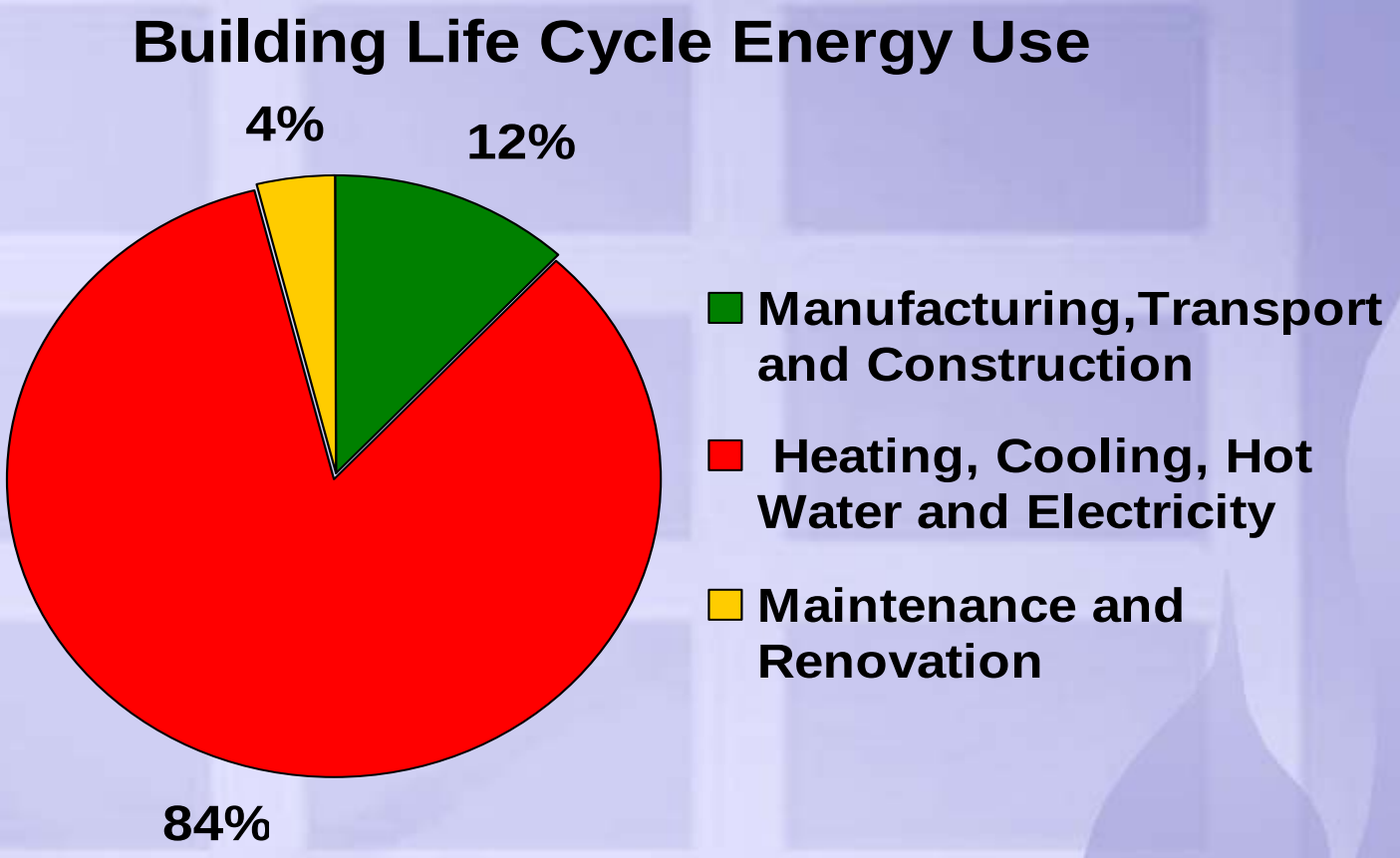


*Does not include self-supplied water of approximately 15 billion liters/day.

Source: Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004, Estimated use of water in the United States in 2000: Reston, Va., U.S. Geological Survey Circular 1268; http://www.epa.gov/WaterSense/water/save/use.htm

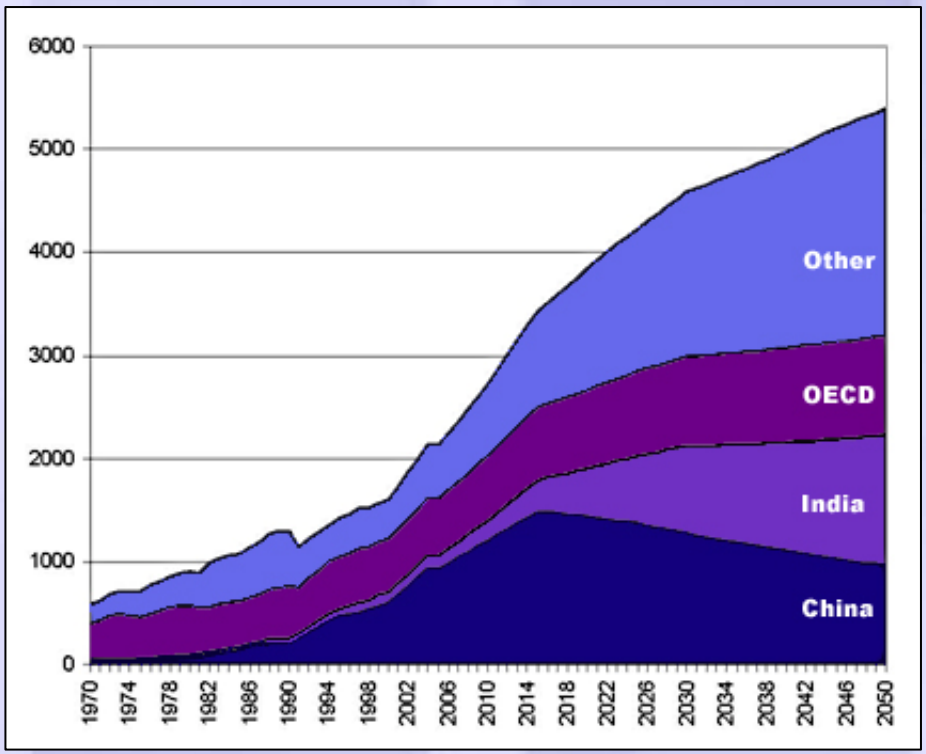
A recent U.S. study shows 36 states will have local, regional or statewide water shortages by 2013.

Operational Vs. Embodied Energy



Carbon Footprint of Materials

Global Cement Demand by Region and Country (1970-2050)



Source: USGS and IEA

An additional 5-8% of CO_2 emissions are attributable to cement production

- 1 ton of cement produces about 1 ton of CO_2
- 130 million tons/year of cement used in U.S.
- 2.3 billion tons/year of cement used globally

Indoor Environmental Quality is a Significant Concern

Combustion
- Environmental Tobacco Smoke (ETS)
- Other Combustion Products
- Carbon Monoxide (CO)
- Nitrogen Dioxide and Sulfur dioxide

Biological
- Dander, Molds, Dust Mites
- Other Biologicals

Mycotoxins

Volatile Organic Compounds (VOCs)

Pesticides

Heavy Metals
- Airborne Lead
- Mercury Vapor

Asbestos

Radon

Airborne Disease
- Tuberculosis
- Legionnaires Disease

Occupant Sensitivity
- Allergic Reactions
- Hypersensitivity Pneumonitis
- Humidifer Fever

Sick Building Syndrome (SBS)

Protection from Airborne Chemical, Biological, or Radiological Attacks
- Physical security
- Ventilation and filtration
- Maintenance, administration, and training

New Versus Existing Buildings

Greatest potential in retrofitting and renovating existing buildings

- Replacement rate of existing building stock roughly 1% per year
- Most retrofit or energy service companies only address large commercial buildings or residential buildings. Yet 95% of the U.S. building stock is small to mid-sized buildings that consume 44% of total energy use (or the largest 5% consume 56%).

New buildings also extremely important

- 34 million new homes projected 2005-2030
- 48% increase in commercial building floor space projected (from 73 to 108 billion sq. ft.)

U.S. Energy Goals & Mandates

Obama-Biden comprehensive *New Energy for America* plan and *Livability of Cities* urban policy (www.change.gov)

- **Reduce our greenhouse gas emissions 80% by 2050**
- Build more livable and sustainable communities
- Use innovative measures to dramatically improve efficiency of buildings
- Weatherize one million homes annually
- Make the U.S. a leader on climate change

New mandates in the Energy Independence and Security Act of 2007

- Vehicle efficiency: 40% increase in fuel economy standards by 2020
- Renewable fuels: 36 billion gal/yr of biofuels (21 billion advanced) by 2022
- Improved lighting efficiency
- Appliances: Significantly increased efficiency standards in 9 categories
- Federal buildings: 35% reduction in energy use by 2015

State and local mandates

- Building codes
- Renewable power standards

National Science and Technology Council

Buildings Technology R&D Subcommittee

U.S. Department of Agriculture
U.S. Department of Commerce (co-chair)
U.S. Department of Defense
U.S. Department of Energy (co-chair)
U.S. Department of Health and Human Services
U.S. Department of Homeland Security
U.S. Department of Housing and Urban Development
U.S. Department of the Interior
U.S. Department of Labor
U.S. Department of State
U.S. Department of Veterans Affairs
U.S. Environmental Protection Agency
U.S. General Services Administration
National Aeronautics and Space Administration
National Science Foundation
Executive Office of the President
Office of the Architect of the Capital
Smithsonian Institution
U.S. Postal Service

R&D Vision

R&D Vision: Enable design of new buildings and retrofit of existing buildings that over the life cycle:

- consume as much energy as they use from renewable sources (i.e., net-zero energy) while significantly reducing greenhouse gas emissions
- double service life of building materials, products, and systems while minimizing life cycle impacts
- halve use of domestic water (e.g., to 50 gal/day/person or less) while maximizing water recycling and rainwater harvesting and minimizing stormwater runoff
- achieve breakthrough improvements in indoor occupant health, productivity, and comfort

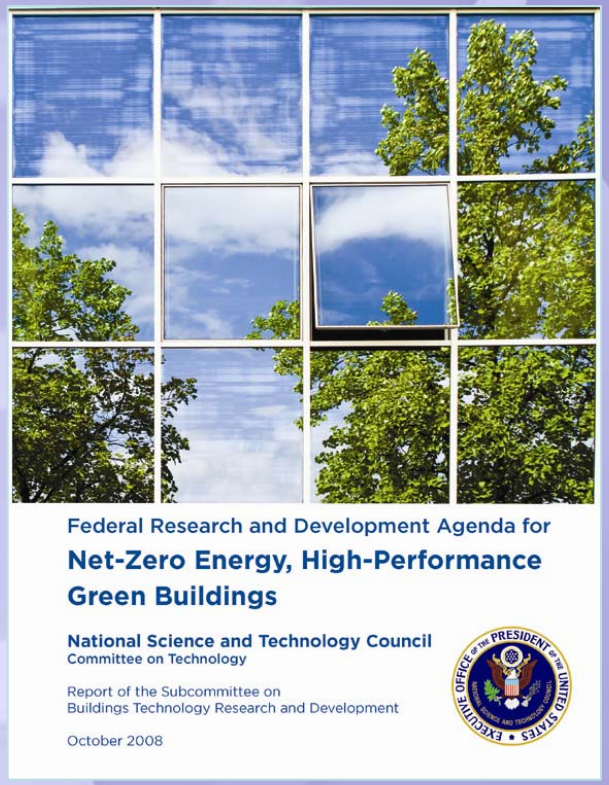
R&D vision can be achieved only

- through use-inspired basic research that enables innovative building technologies, practices, and standards
- by overcoming technical barriers to technology adoption and implementation
- by mitigating unintended health, environment, and other consequences of technology solutions that are implemented

R&D Goals

- Integrated, Performance-Based Design and Operation
- Net-Zero Energy Building Technologies and Strategies
- Water Use and Rainwater Retention
- Material Utilization, Waste, and Life Cycle Environmental Impacts
- Occupant Health and Performance
- Overcoming Barriers to Implementation

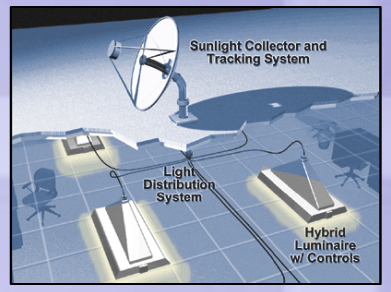
The scope of the above R&D goals is limited to new technologies, protocols, and practices at the building site, unless they apply as well to groups of buildings or communities.



Advanced Energy Technologies

Lighting Systems

- Solid State Lighting
- Intelligent natural daylighting distribution systems

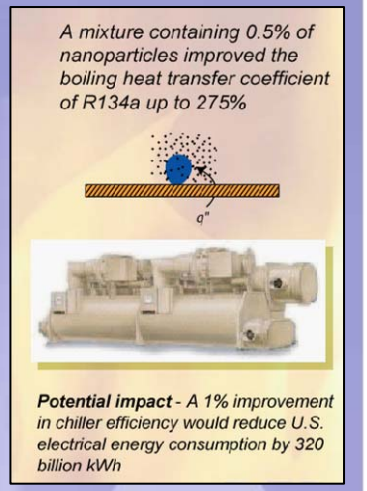


Hybrid Solar Lighting

Building Envelope Systems

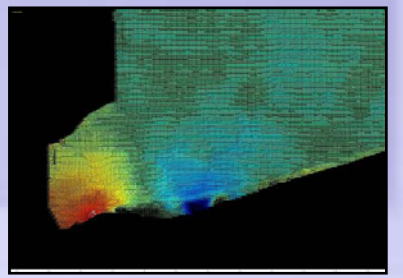
- Dynamic response (shades and electrochromic windows)
- Highly insulating façade systems
- Natural lighting technologies/designs (Green)

Solar Tracking Facility to Characterize Performance of Photovoltaic Cell Technologies



Intelligent Systems and Controls

- Diagnostic and real-time monitoring tools
- Sensors for improved building monitoring
- Grid/consumer supply/demand integration



Particle Image Velocimetry Image of Air Flow Distribution through Heat Exchanger

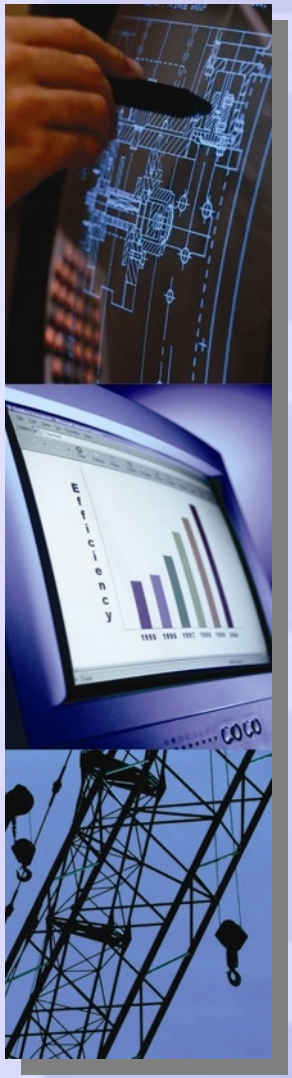
NIST's 0.5 meter Guarded Hot Plate Capable of Providing Measurements of Thermal Insulation from 90 to 900 K

Heating, Cooling, and Refrigeration

Boric Acid Nano Lubricant

- Nano-fluids and lubricants
- Thermally-activated heat pumps
- Distributed refrigeration/water-source heat pump
- Thermoelectric cooling
- Frostless heat pump
- Improved residential HVAC air distribution systems

Sustainable Materials



- Advanced materials to enable *prefabrication, preassembly, modularization, and off-site fabrication* and processes
- Sustainable materials for *disaster-resilient structures*
  - Low-carbon, ultra-durable cementitious materials
  - Cost-effective, ultra-durable polymer composites
- *High thermal-efficiency, durable building envelope* materials and systems (i.e., walls, roofing, windows)
- *High-performance paints, coatings, and sealants* with predictable service life for building applications
- *Cost-effective, ultra-durable, fire-safe photovoltaic systems* for construction of new buildings and retrofit of existing buildings
- *Sustainable flame retardants* for building contents and furnishings to overcome environmental and health concerns
- *Low-cost, ultra-durable sensing and control* technologies (i.e., condition assessment, health monitoring, structural control)

Energy Efficient, Smart Buildings Critical to Smart Grid Success

NIST Measurement Science for Net-Zero Energy, High-Performance Green Buildings

High Efficiency HVAC Systems and Controls

Fuel Cell Test Facility

- **Enable building energy-use reduction through in-situ performance measurements**
  - In-situ measurement technologies to quantify thermal integrity, ventilation rates, indoor air contaminants
  - Measurement science to capture life-cycle performance of space conditioning equipment
- **Enable energy-use reduction through embedded intelligence in building controls**
  - Minimal energy consumption through real-time control
  - Utility/building interactions to minimize CO_2 emissions
- **Provide measurement science for emerging building energy technologies**
  - Renewable power sources (photovoltaic and fuel cell systems)
  - High performance HVAC systems (nanofluids, thermoelectric cooling)
  - Solid-state lighting for building applications
  - High-performance building insulation (e.g., vacuum panel insulation)
- **Enable development of sustainable materials, components, and systems**
  - Structural/envelope materials with longer service life, lower embodied energy, and reduced environmental impact
  - Life cycle performance and degradability of bio-based building materials
  - Increase use of industrial waste-stream materials (e.g., fly ash) as cement substitutes
  - New, environmentally benign fire suppressants
- **Develop carbon footprint metrics and tools for building sustainability performance evaluation**
  - Integration of life-cycle cost analysis with assessment of economic/environmental impacts
  - Sustainability performance metrics for building products and systems

NIST Net-Zero Energy Residential Test Facility (ARRA)

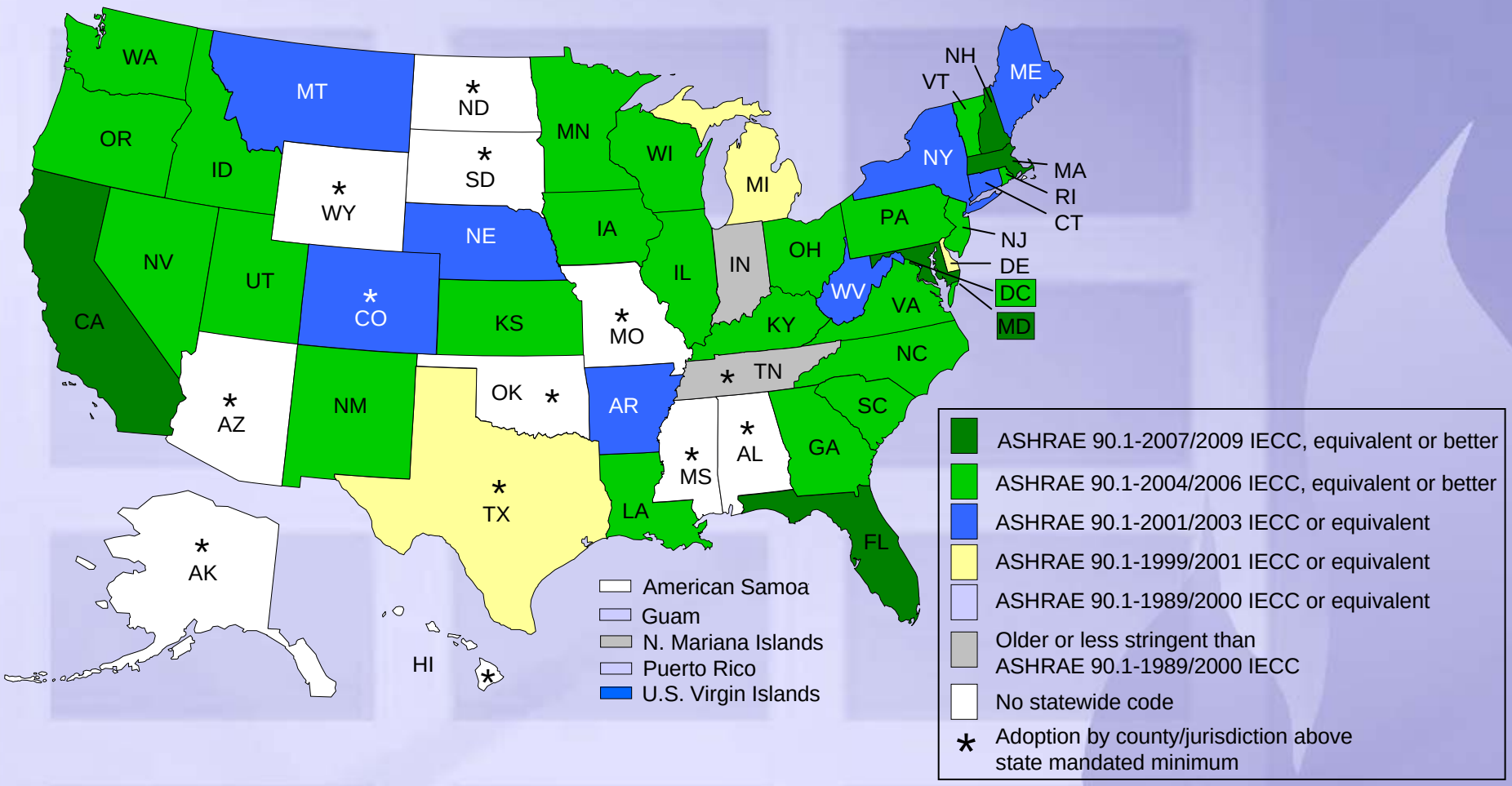
Objectives

- Demonstrate net-zero energy for residence similar in appearance to homes found in surrounding communities
- Provide a test bed for in-situ measurements of various components and systems
- Quantify energy use reductions through embedded intelligence in building control systems
- Compare actual installed performance to controlled laboratory measurements for components/systems

Planned Schedule

- Design Complete – March 2010
- Construction Start – October 2010
- Construction Complete – June 2011

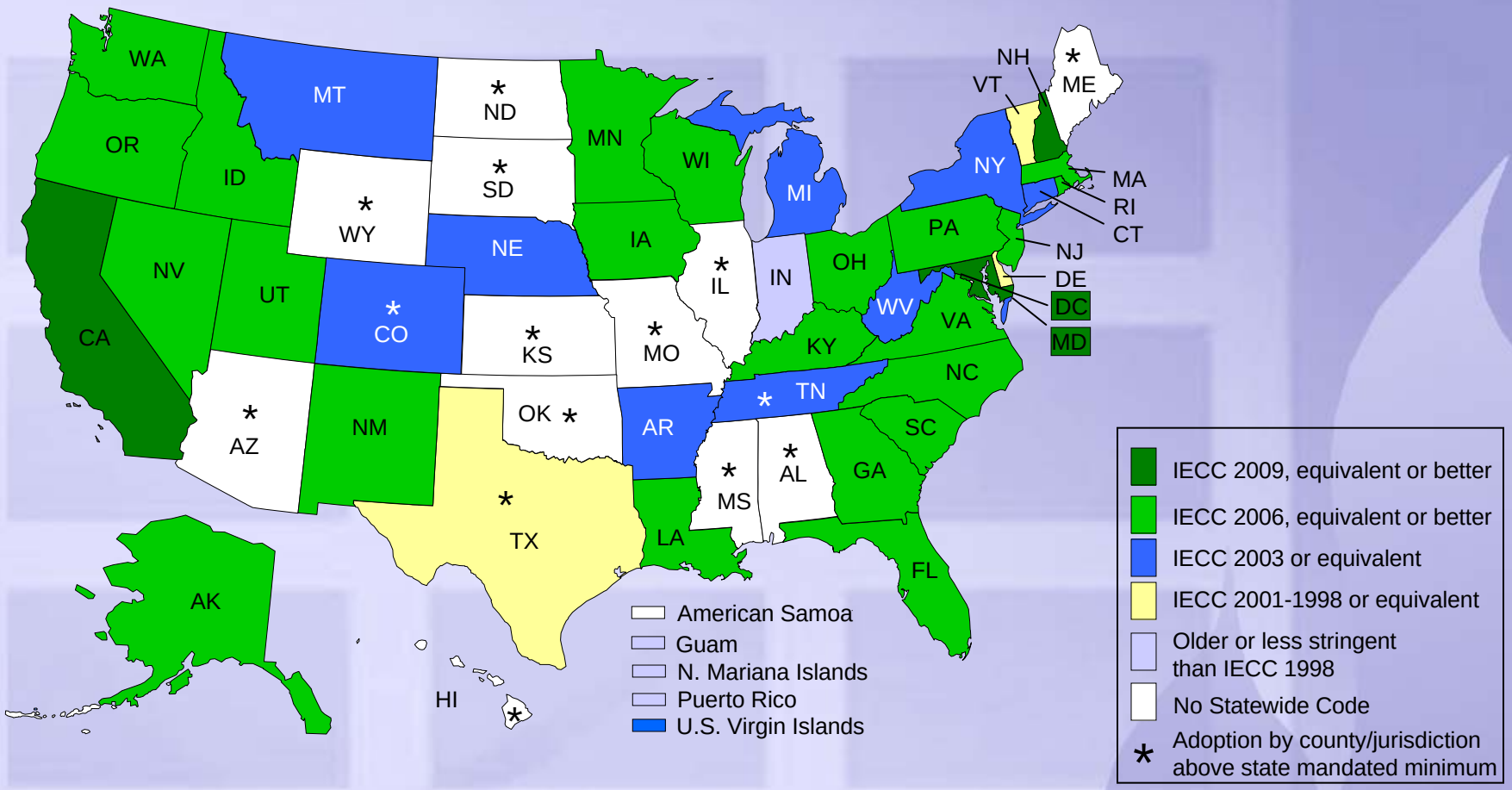
Need for Adoption and Enforcement of Commercial Energy Codes



Source: BECP's Status of State Codes
http://www.energycodes.gov/implement/state_codes/index.stm

as of 10/1/09

Need for Adoption and Enforcement of Residential Energy Codes



Source: BECP's Status of State Codes
http://www.energycodes.gov/implement/state_codes/index.stm

as of 10/1/09

Executive Order 13514

"This Executive Order builds on the momentum of the Recovery Act to help create a clean energy economy and demonstrates the Federal government's commitment, over and above what is already being done, to reducing emissions and saving money."

President Barack Obama signs in the CEQ Executive Order signing in the Oval Office, Oct. 5, 2009. (Official White House Photo by Pete Souza)

Federal Footprint

The Federal government:

- occupies nearly 500,000 buildings;
- operates more than 600,000 vehicles;
- employs more than 1.8 million civilians; and
- purchases more than $500 billion per year in goods and services.

Greenhouse Gas Reduction

- On January 29, 2010, the Federal Government announced a **28% emissions reduction target for Scope 1 & 2 GHG emissions by FY 2020**

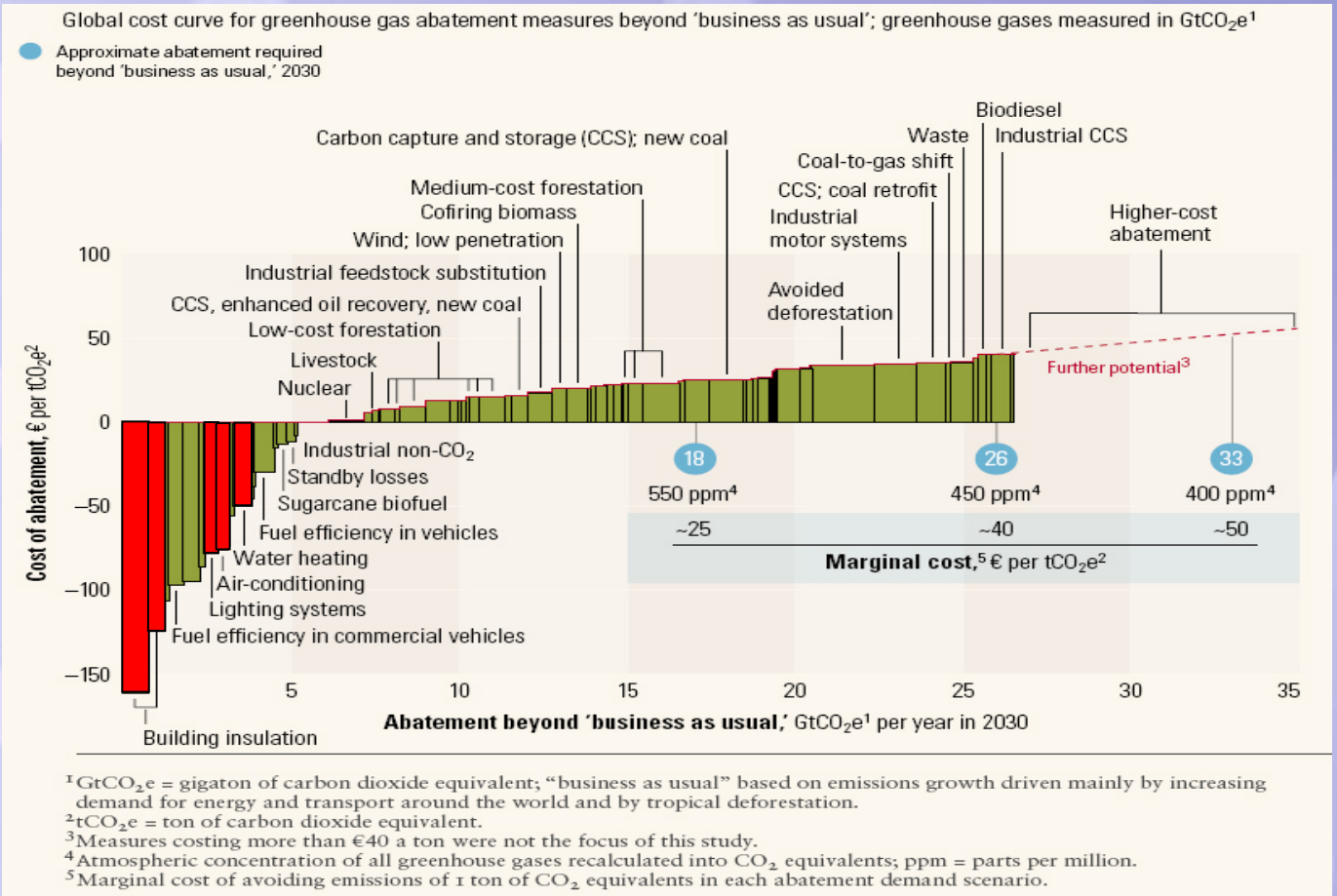
  Scope 1: *Direct GHG emissions from sources owned or controlled by the Federal agency;*
  Scope 2: *Direct GHG emissions resulting from the generation of electricity, heat, or steam purchased by a Federal agency;*

- The Federal target reflects the goals established by 35 Federal agencies and primarily covers Federal buildings and Federal fleet vehicles

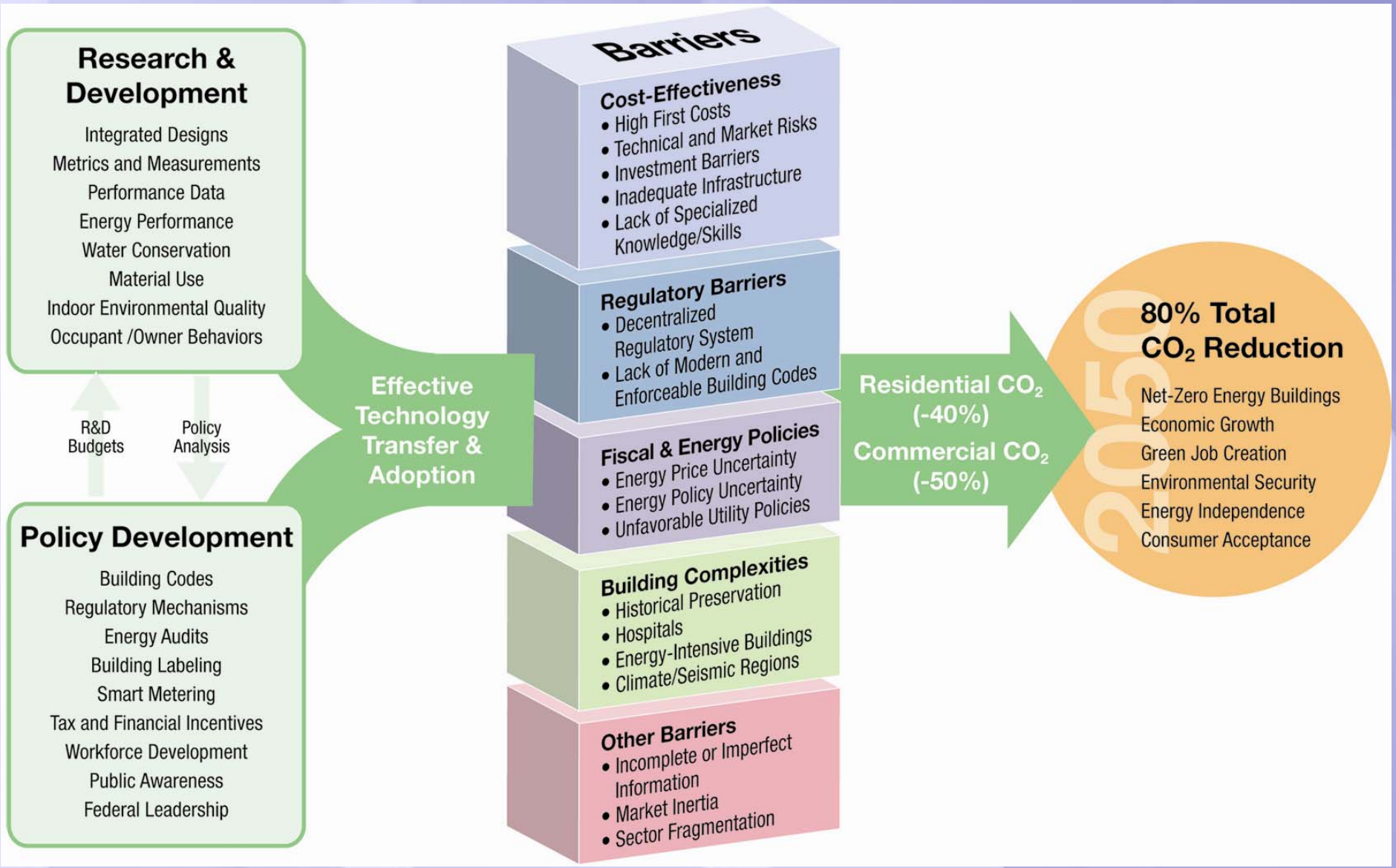
"As the largest energy consumer in the United States, we have a responsibility to American citizens to reduce our energy use and become more efficient."

President Obama

Low/No-Cost Carbon Reduction Options



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

Source: McKinsey Global Institute, 2007

Policy Framework