UT-BATTELLE

The Potential for Energy Efficiency in the Long Run

Presented to
"Energy Options for the Future"
Naval Research Laboratory

Marilyn A. Brown, PhD, CEM
Director, Energy Efficiency and Renewable Energy Program
Oak Ridge National Laboratory

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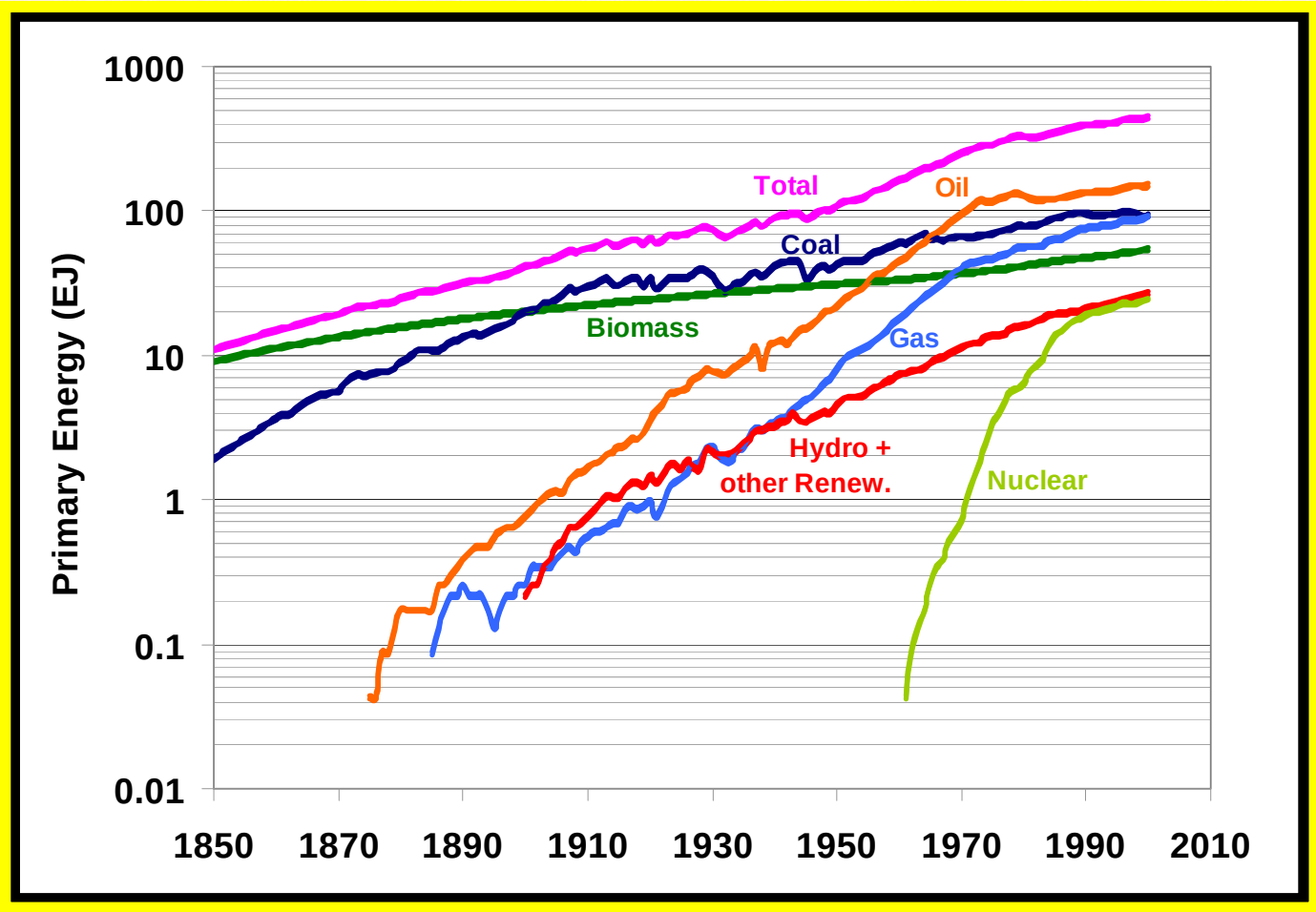
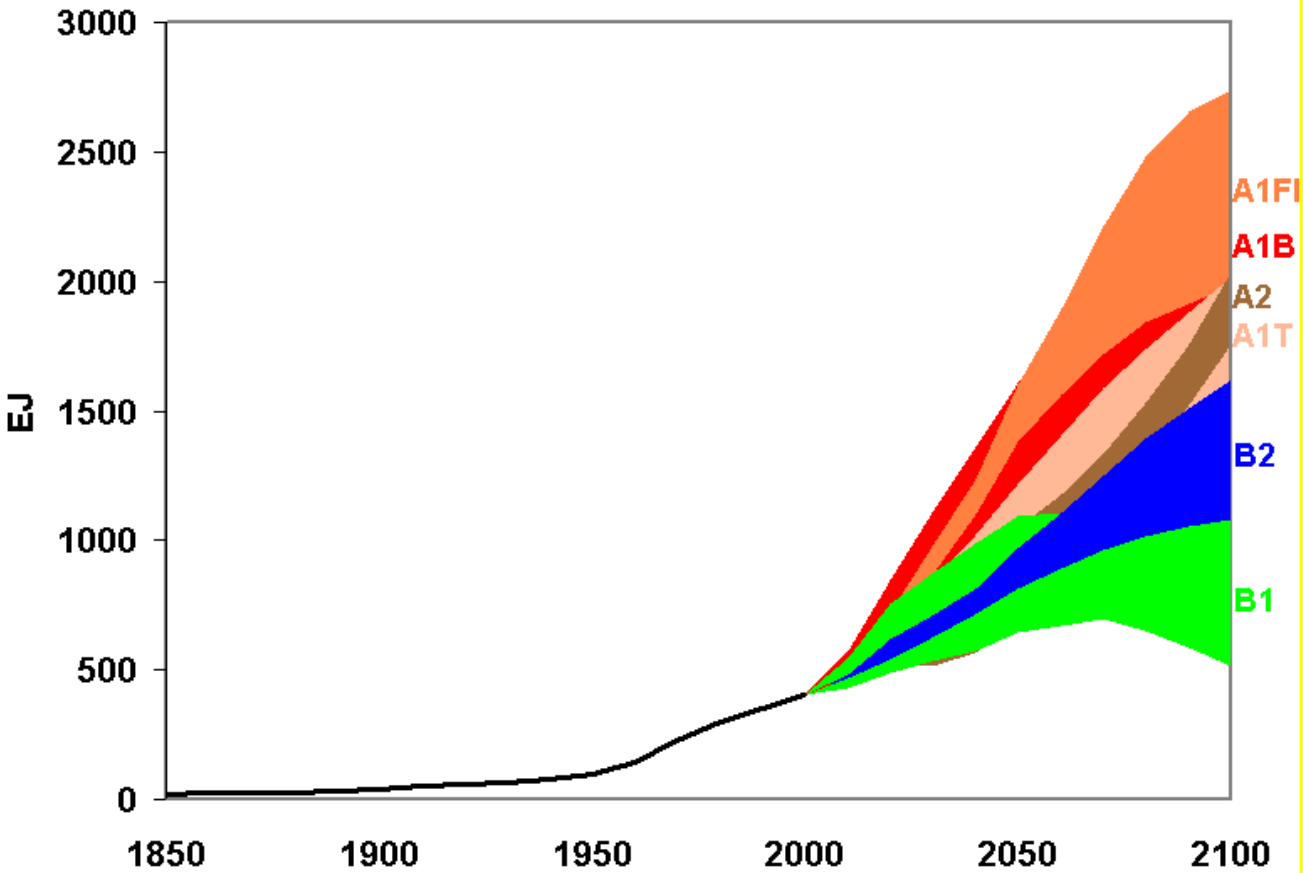
OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

World primary energy consumption is growing at a 2% annual rate



Nakicenovic, Joint IPP-DRDA-DOE Workshop, Garching, Germany, 12/10/2003

At a 2% annual growth rate, a 7-fold increase would occur by 2100



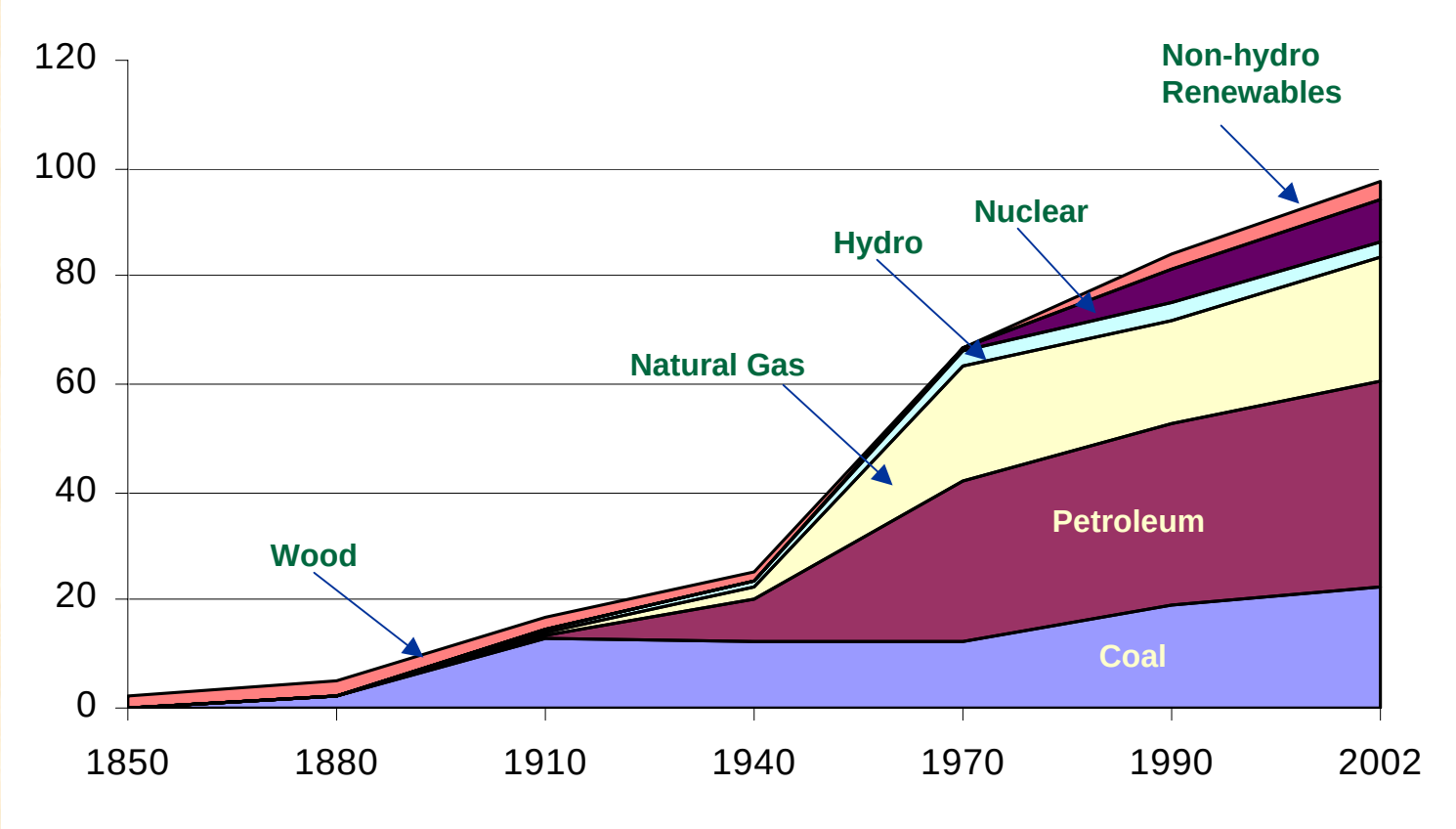
Where today's technologies would take us

Where our current aspirations for technologies would take us

Where we may need to go to stabilize carbon

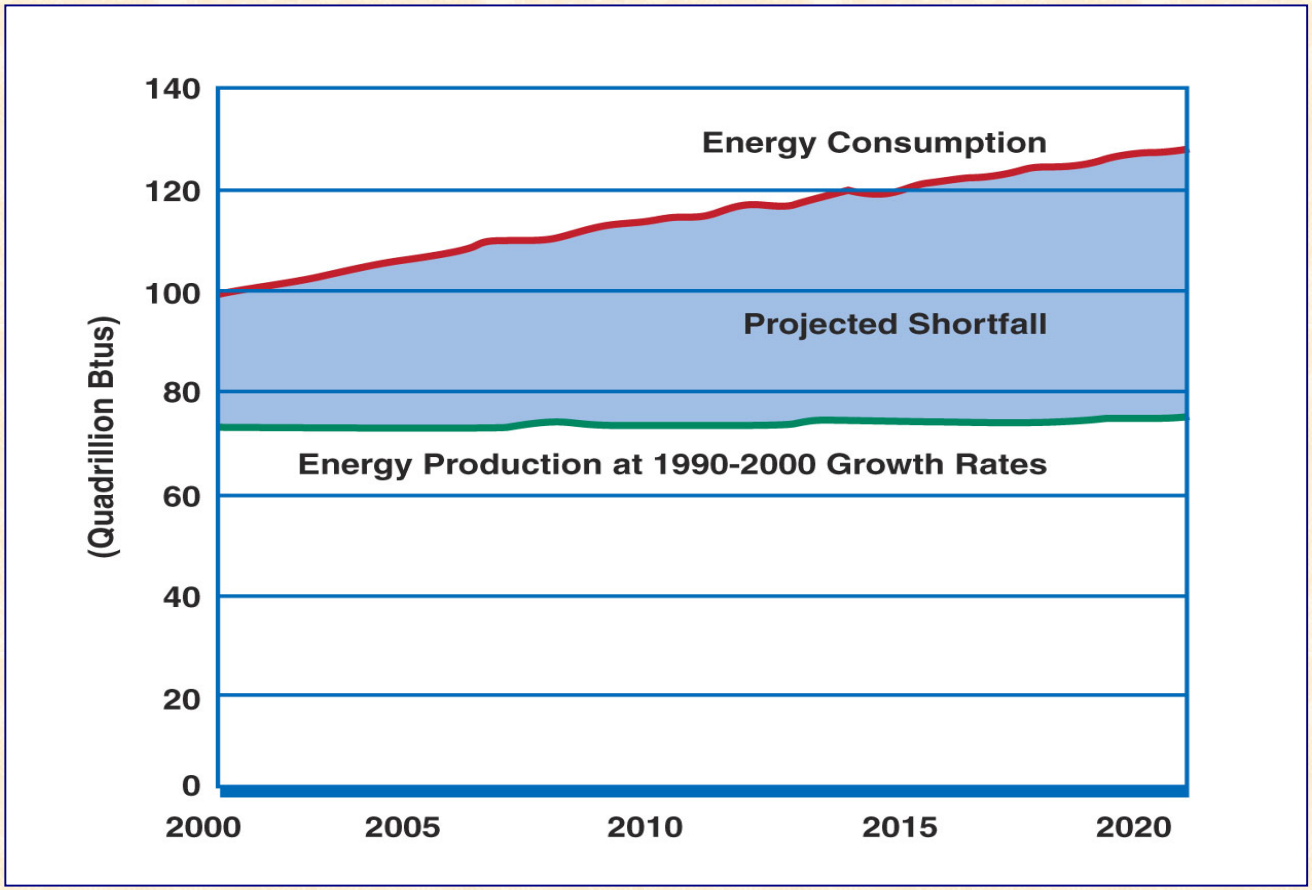
Nakicenovic, Joint IPP-DRDA-DOE Workshop, Garching, Germany, 12/10/2003

U.S. energy consumption is growing at a 1 - 1.5% annual rate



Source: ***EIA Annual Energy Review 2003*****, Table 1.3**

U.S. Energy Supplies are Inadequate to Meet the Nation's Future Needs



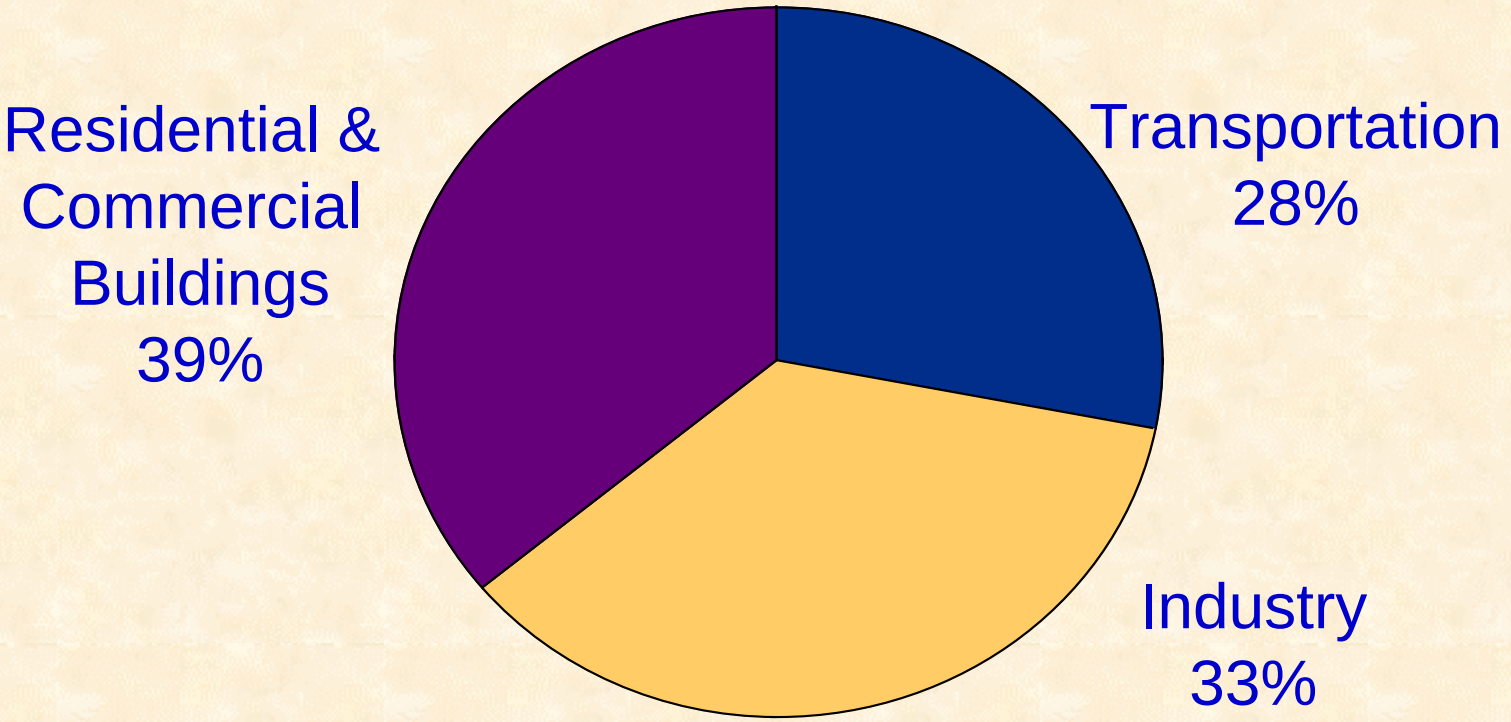
Assuming an annual growth rate of 1.5%:

~40% increase by 2025
~4.4X increase by 2100

With a 1% growth rate:

~28% increase by 2025
~2.7X increase by 2100

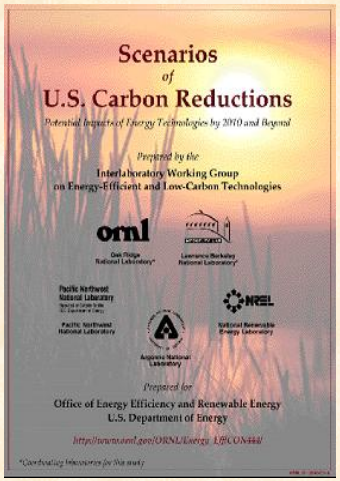
Energy Efficiency Improvements are Needed in Every Sector



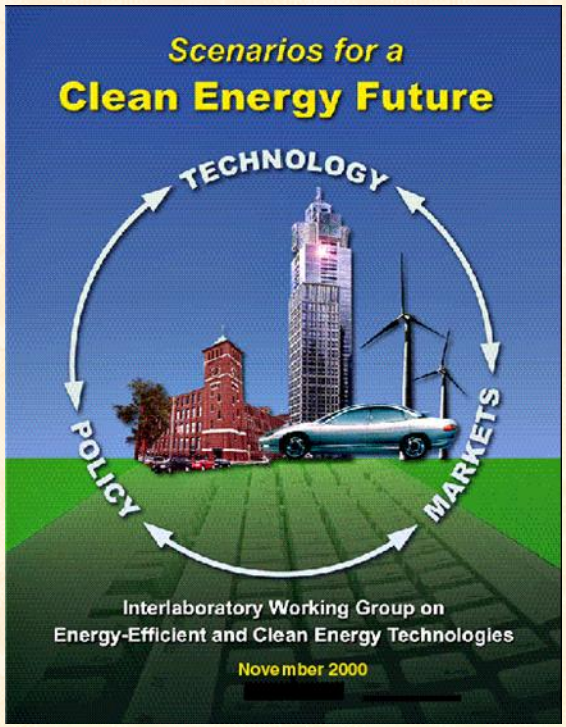
U.S. Energy Consumption by Sector: 2002

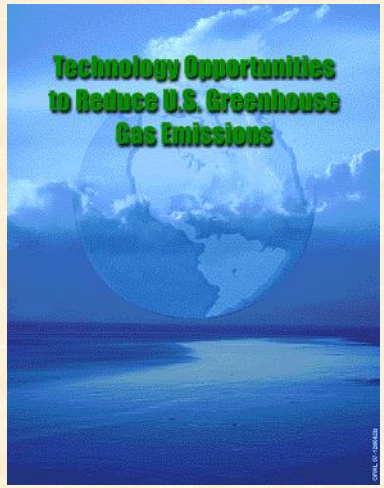
Source: EIA, *Annual Energy Outlook 2004,* Table A2

Several Multi-Lab Studies have Detailed the Potential for Improved Energy Efficiency



Scenarios of U.S. Carbon Reduction (1997)
www.ornl.gov/Energy_Eff





Technology Opportunities to Reduce
U.S. Greenhouse Gas Emissions (1998)
www.ornl.gov/climate_change/climate.htm

Scenarios for a Clean Energy Future (2000)
www.ornl.gov/ORNL/Energy_Eff/CEF.htm

Energy Efficiency Concepts

- **Conservation refers to behavioral changes that reduce energy use**
- **Energy efficiency refers to permanent changes in equipment that result in increased energy services per unit of energy consumed**
- **Economic potential for energy efficiency refers to technically feasible energy efficiency measures that are cost-effective**

  --they exist because of market failures and barriers
- **Energy efficiency increases can be achieved by:**

  --implementing current technology

  --inventing & implementing new technology

Implementing Current Technology

- ***California's Secret Energy Surplus: The Potential for Energy Efficiency*** **by Michael Rufo and Fred Coito (2002) (www.Hewlett.org)**

  -- estimates that CA has an economic energy potential of:

  13% of total base electricity usage in 2011

  15% of total base demand in 2011

- ***Natural Gas Price Effects of Energy Efficiency and Renewable Energy Practices and Policies*** **by Neal Elliott, et al., Am. Council for an Energy Efficient Economy (2003) (http://aceee.org)**

  -- by 2008 the U.S. could reduce:

  electricity consumption by 3.2%

  natural gas consumption by 4.1%

Inventing and Implementing New Technology

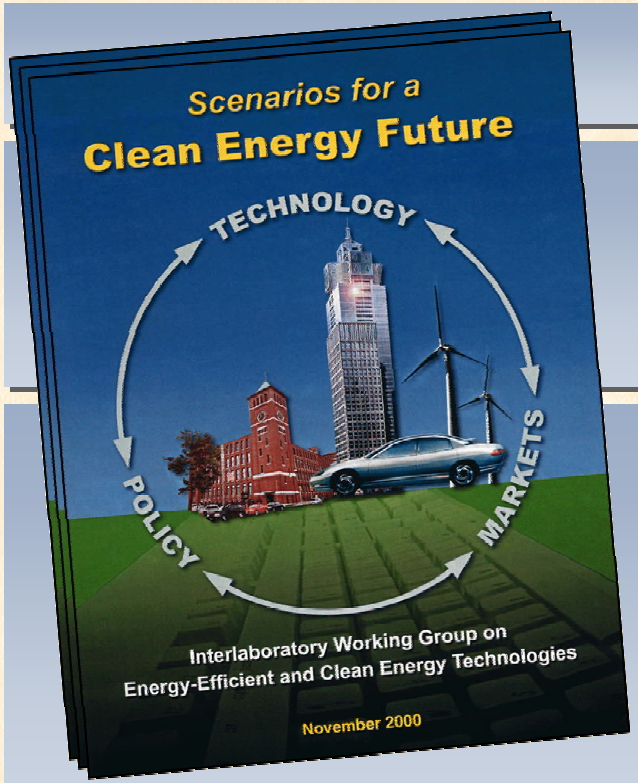
- ***Technology Options for the Near and Long Term*** **(2003) (www.climatetechnology.gov)**
- ***Energy intensity decline implications for stabilization of atmospheric CO_2 content*** **by H. Douglas Lightfoot and Christopher Green (2002) (www.mcgill.ca/ccgcr/)**

  --Upper limits on attainable energy efficiency for non-electric uses, by 2100:

  232% for residential energy consumption

  119% for industry

Scenarios for a Clean Energy Future



Funded by DOE and EPA

Undertaken by researchers
at 5 DOE national laboratories
with input from experts groups

Goal: to identify and analyze policies that promote efficient and clean energy technologies to reduce CO_2 emissions and improve energy security and air quality

Published in November 2000

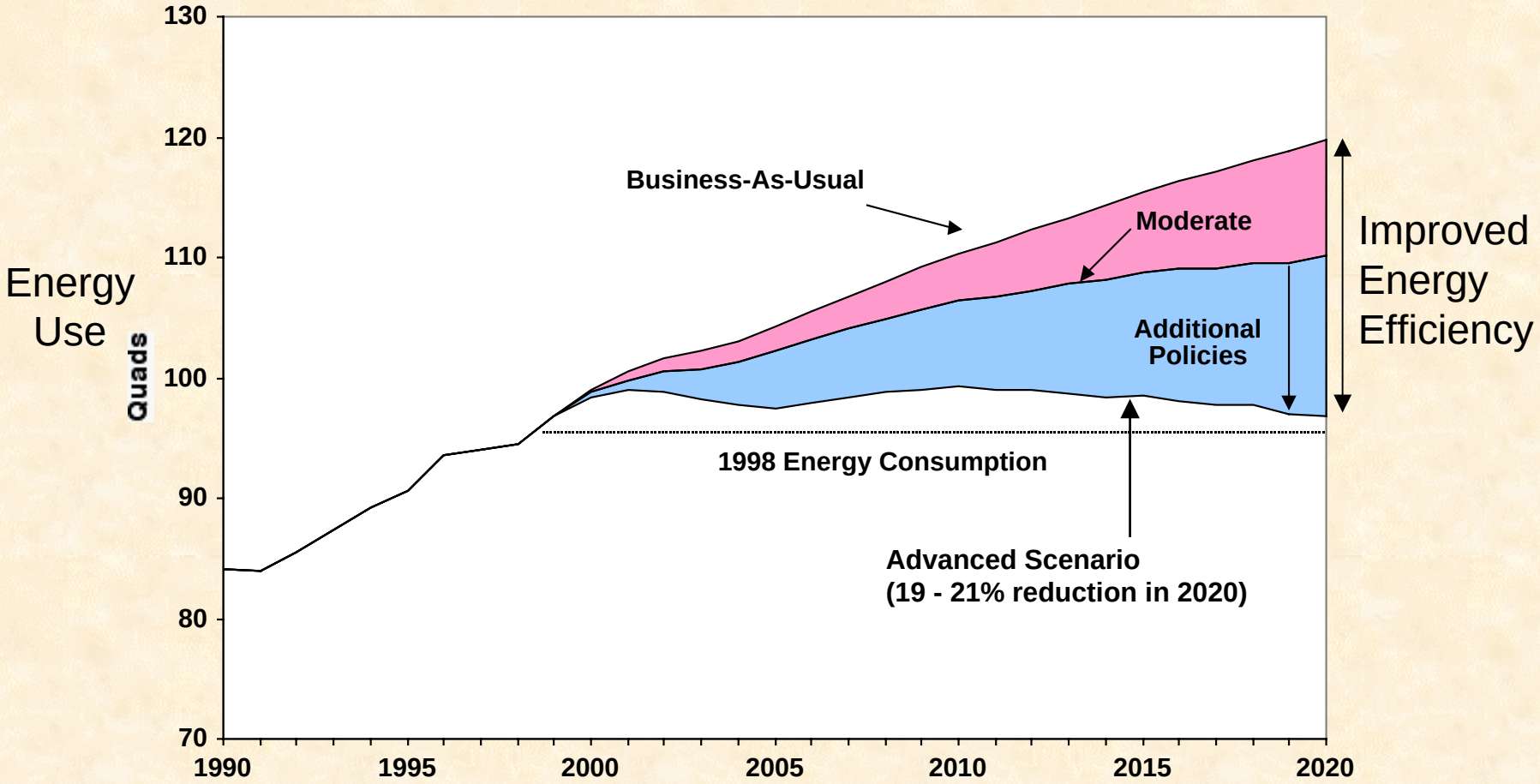
http://www.ornl.gov/eere/cef/index.htm

"Special Issue" of ***Energy Policy***, Vol. 29, No. 14, Nov. 2001

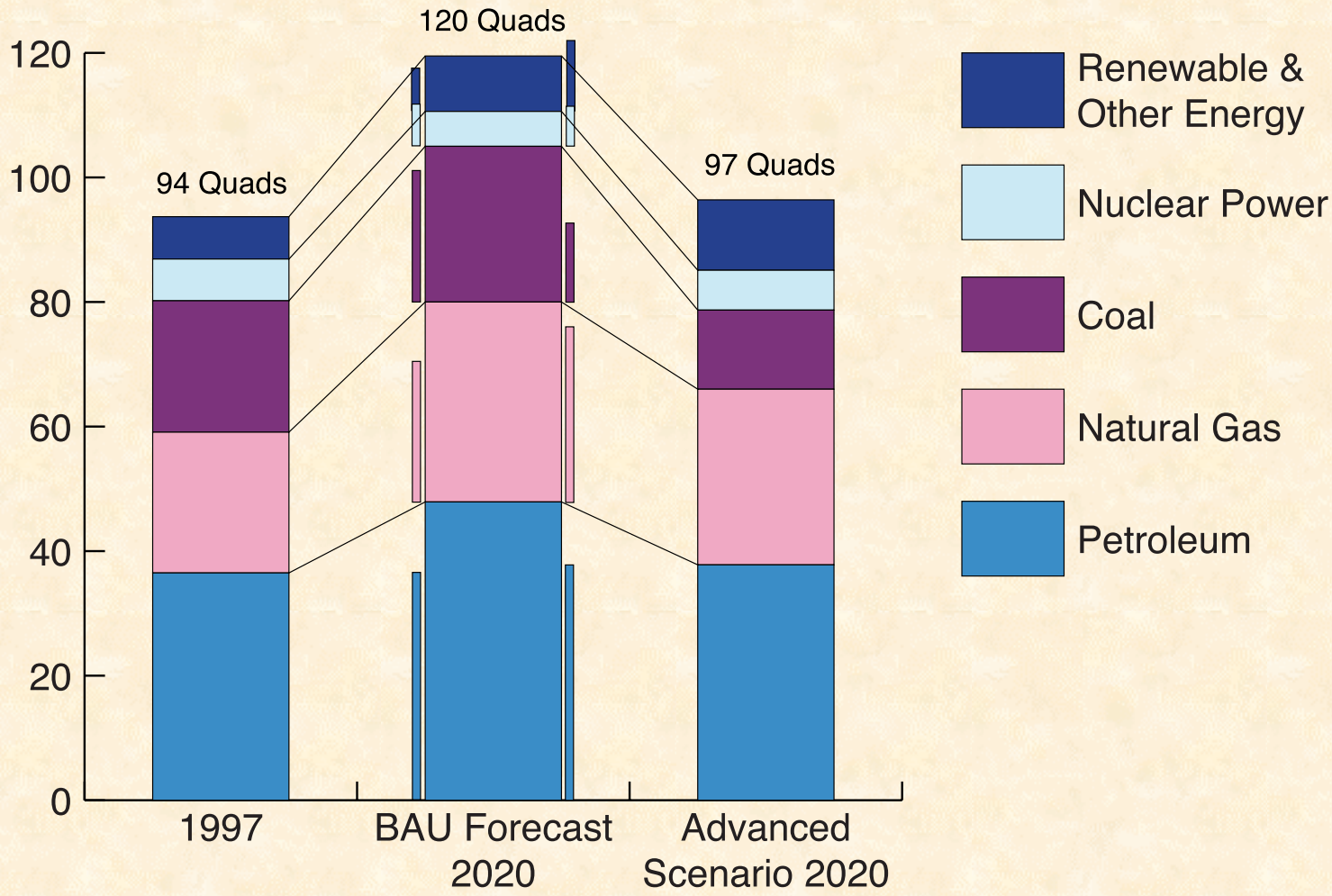
The "advanced scenario" modeled the following U.S. energy policies

Buildings	• Efficiency standards for equipment • Voluntary labeling and deployment programs
Industry	• Voluntary programs to increase energy efficiency • Voluntary agreements with individual industries
Transportation	• Voluntary fuel economy agreements with auto manufacturers • "Pay-at-the-pump" auto insurance
Electric Utilities	• Renewable energy portfolio standards • Production tax credits for renewable energy
Cross-Sector Policies	• Doubled federal R&D • Domestic carbon trading system

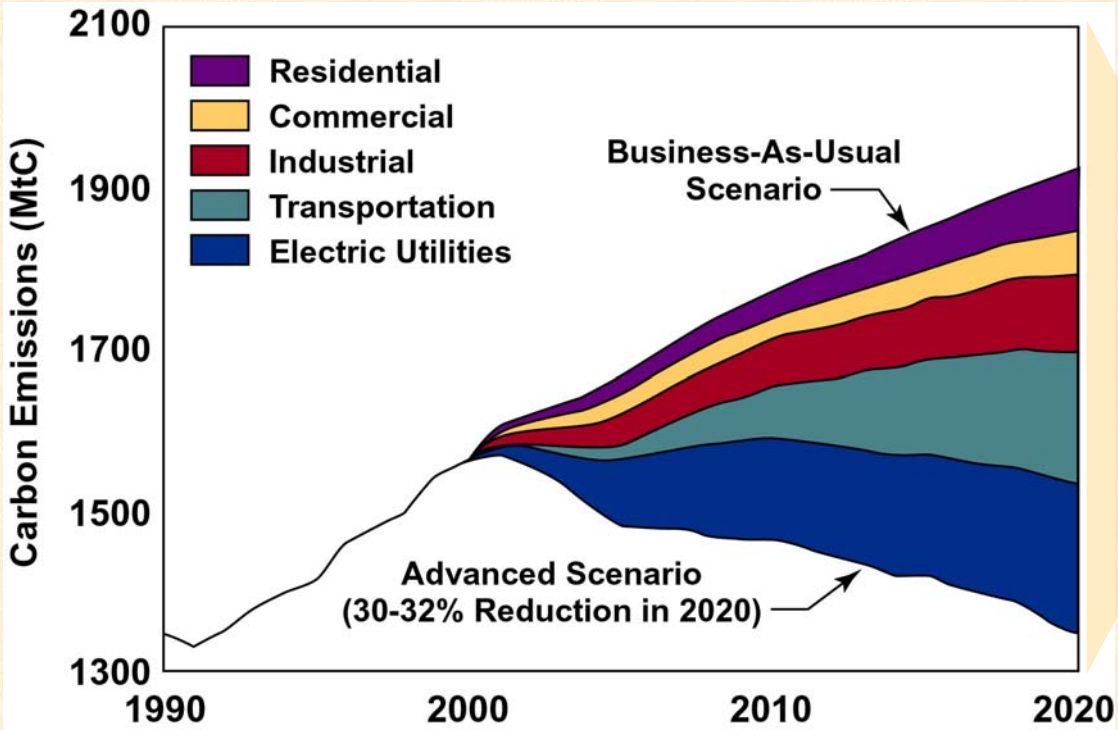
The CEF study documents a large "economic potential" for energy efficiency



SOURCES OF ENERGY



CEF documents a large potential for "low cost" carbon reductions



1990 carbon emissions level was restored by 2020, with continued economic growth

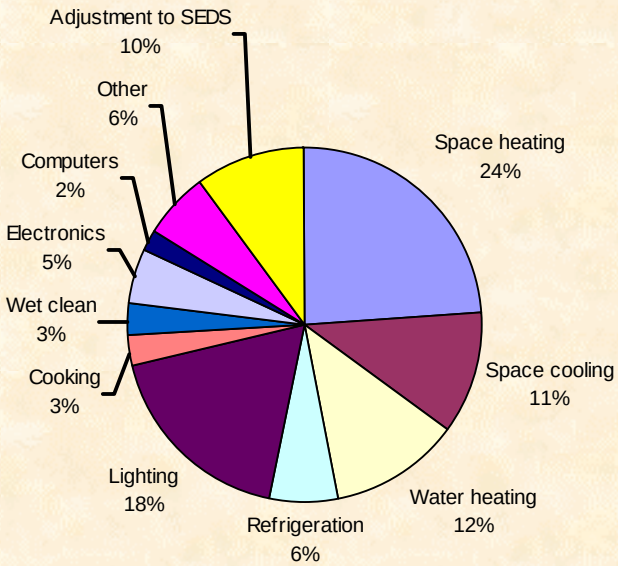
- By 2020 emission reductions from transportation could be large
- Electric sector policies account for a third of the carbon reductions in the Advanced Scenario

Buildings Sector

Residential Buildings

- **Efficiency standards and voluntary programs are the key policy mechanisms.**
- **End uses with the greatest energy savings are space cooling, space heating, water heating, and lighting.**

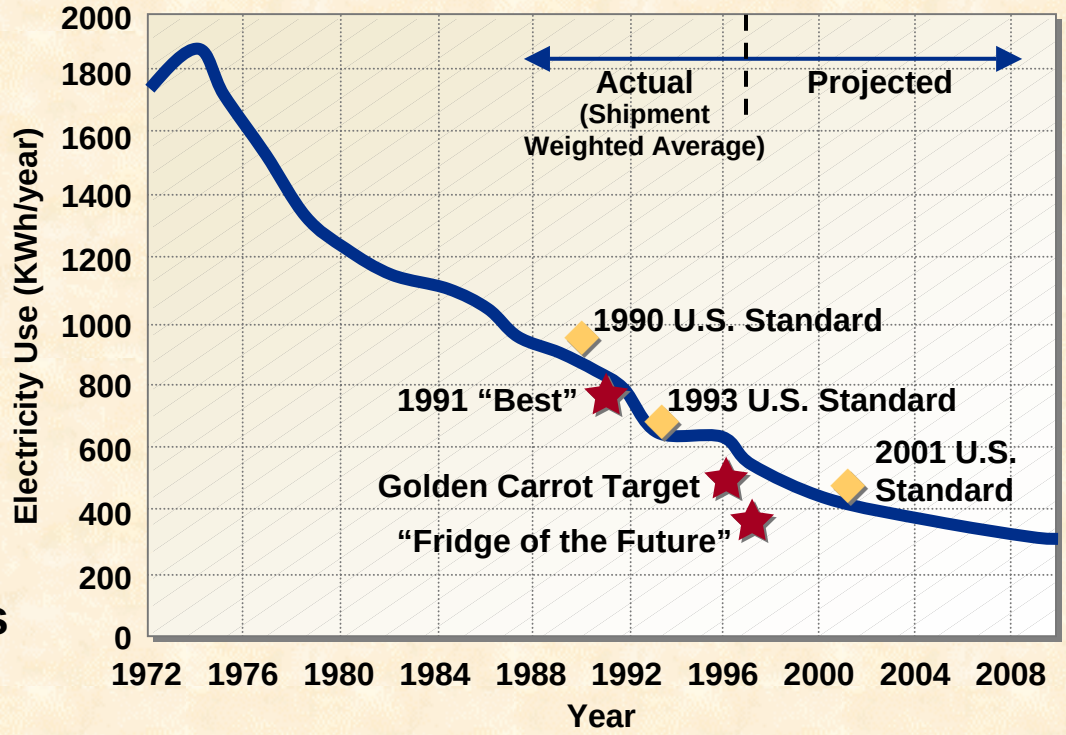
Primary Energy Consumption, 2001



Source: 2003 Buildings Energy Databook 1.1.4, www.buildingsdatabook.eere.energy.gov

Refrigerator energy efficiency improvement

- **Research and standards have cut refrigerator energy use by two-thirds**
- **DOE investment of $5M from 1977–82 enabled improvements that saved consumers $9B in the 1980s**
- **R&D:**
  - **Improved compressor, motors, insulation, controls**
  - **Testing and input to national standards**
- **Projected savings of 0.7 quad/year by 2010 based on research in the 1990s**



SPONSOR:

BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS
OFFICE OF
U.S. DEPARTMENT OF ENERGY

PARTNERS:

Columbus Products Co., Appliance Research Consortium

AHAM
association of home appliance manufacturers

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ORNL and Partners Building Village of "Zero Energy" Houses

- **The "Zero Energy" goal is for houses to produce as much energy as they use**
- **Advanced energy technologies being researched with Habitat for Humanity**
  - **HPWH**
  - **High velocity ducts**
  - **Photovoltaics**
  - **Structural insulated panels**
- **Up to 90% more efficient than typical Habitat for Humanity (HFH) homes**

Solar panels on the roof will generate electrical power for the home.

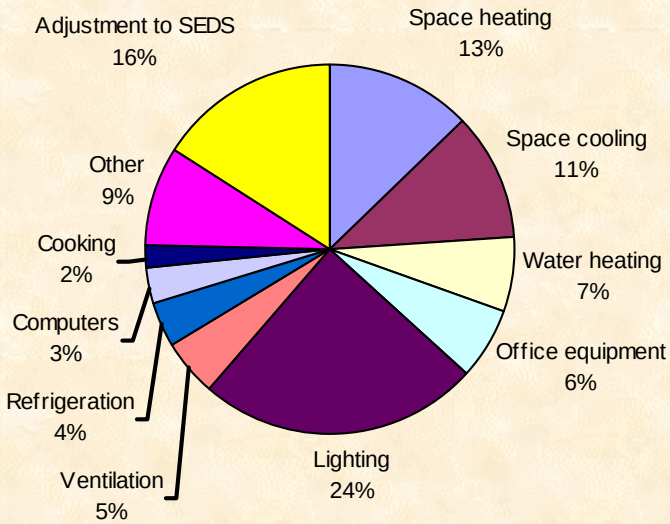
Sponsor: Building Technologies
Partners: Habitat for Humanity, Tennessee Valley Authority, building materials manufacturers

Commercial Buildings

- **Voluntary programs and equipment standards are the key policy mechanisms.**
- **End uses with the greatest energy are lighting and office equipment.**

High-efficiency office lighting

Primary Energy Consumption, 2001

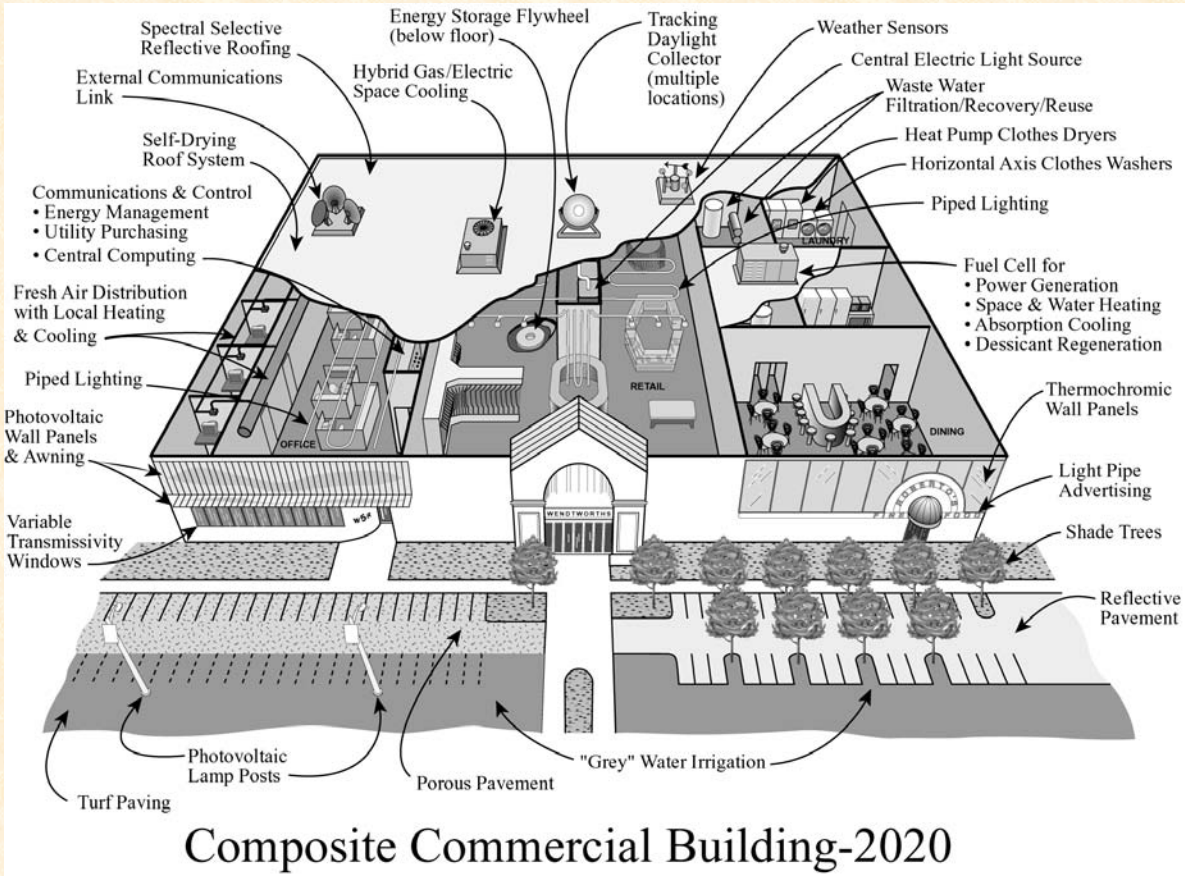


Absorption -based chillers and heat pumps

Source: 2003 Buildings Energy Databook 1.3.3, www.buildingsdatabook.eere.energy.gov

Composite Commercial Building in 2002

- **Solid state lighting integrated into hybrid solar daylighting systems**
- **Smart windows**
- **Photovoltaic roof shingles, walls, and awnings**
- **Solar heating and superinsulation**
- **Combined heat and power–gas turbines and fuel cells**
- **Intelligent building systems**



Composite Commercial Building-2020

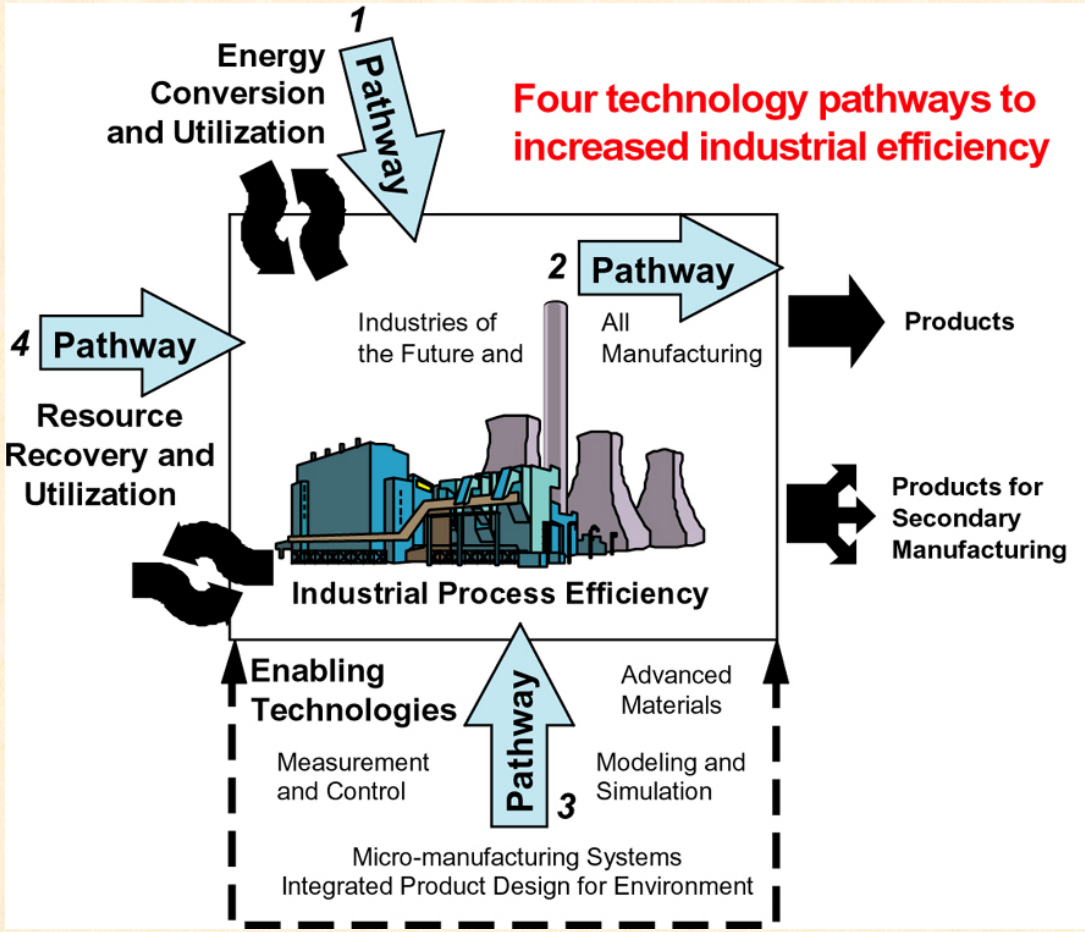
Industry sector

Industry

- **Key Policies: Voluntary programs (technology demonstrations, energy audits, financial incentives), voluntary agreements between government and industry, and doubling cost-shared federal R&D.**
- **Key Crosscutting Technologies: Combined heat and power, preventive maintenance, pollution prevention, waste recycling, process control, stream distribution, motor and drive system improvements.**
- **Numerous subsector-specific technologies play a role.**

Systems Approach to Plant Design

- **Resource recovery and recycling**
- **Advanced sensors, measurement and control**
- **Catalysts, advanced membrane separations, green chemistry**
- **High temperature superconducting motors, transformers, power lines, …**
- **Advanced materials for high temperature processing**
- **Gasification of wastes into fuels, power, and bioproducts**



Advanced materials can cut energy use in energy-intensive industries

- **New crack-resistant alloys for Kraft recovery boiler tubes**
  - **5-10% improvement in energy efficiency of boiler operations**

- **Nickel aluminide alloys improve energy efficiency in steel, heat treating industries**
  - **Energy efficiency improvements range from 10–25%**

The New Industrial Biorefinery

Biomass Feedstock

– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

Conversion Processes

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Combustion
- Co-firing

USES

Fuels:
– **Ethanol/Methanol**
– **Renewable Diesel**

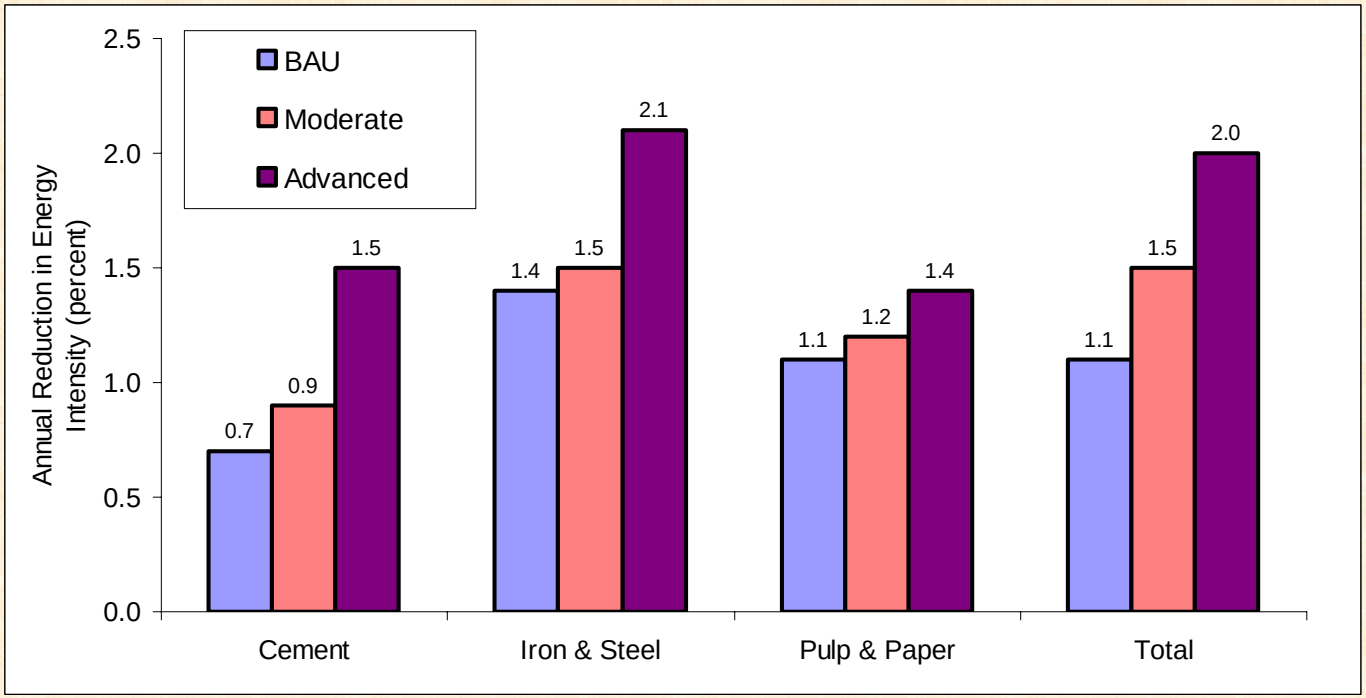
Power:
– **Electricity**
– **Heat**

Chemicals
– **Plastics**
– **Solvents**
– **Chemical Intermediates**
– **Phenolics**
– **Adhesives**
– **Furfural**
– **Fatty acids**
– **Acetic Acid**
– **Carbon black**
– **Paints**
– **Dyes, Pigments, and Ink**
– **Detergents**
– **Etc.**

Food and Feed

Energy Intensity Reductions

- **Cement, iron & steel, and other energy-intensive industries save the most energy.**
- **Pulp and paper industry reduces its carbon emissions by 41% in the Advanced scenario.**



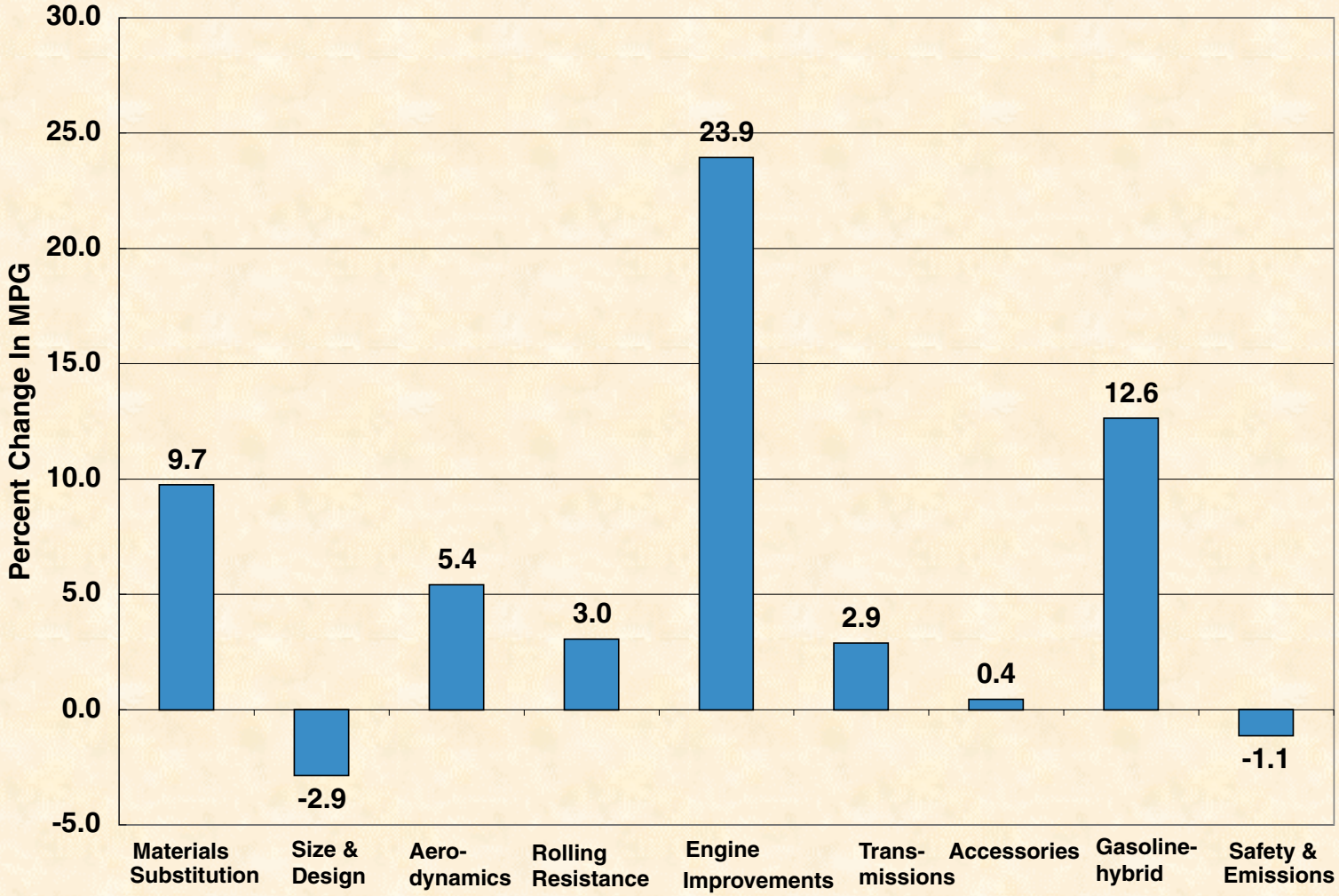
Transportation Sector

Transportation

KEY POLICIES:

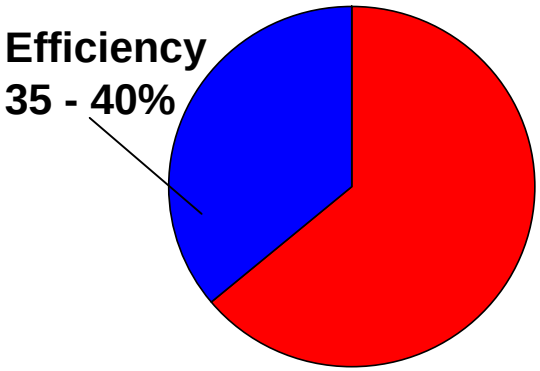
- **Doubling cost-shared federal R&D is critical to achieving a greater degree of technological success**
- **Voluntary commitments by vehicle manufacturers to fuel economy goals**
- **Pay-at-the-pump insurance fees**
- **Domestic carbon trading system**

Passenger Car MPG Improvements: 28 to 44 MPG in the Advanced Scenario



Improving engine efficiency to enable the transition to a hydrogen economy

Today's Engines



Losses:

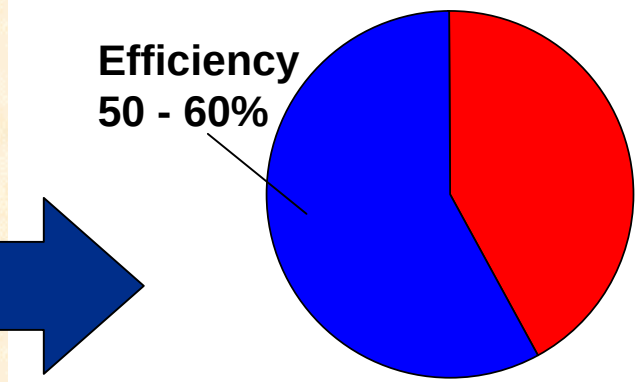
- Emission Controls 3 – 8%
- Exhaust 12%
- Thermodynamic Combustion 16 – 19%
- Heat Transfer 14%
- Mechanical Pumping 6%
- Friction 5%

Potential Paths

- Advanced Combustion Regimes
- Advanced Control Strategies
- Waste Heat Recovery
- Reduced Friction Coatings
- Reduced Injection Pressure
- Thermo-electrics
- Engine Electrification
- Enabling Fuels

R&D

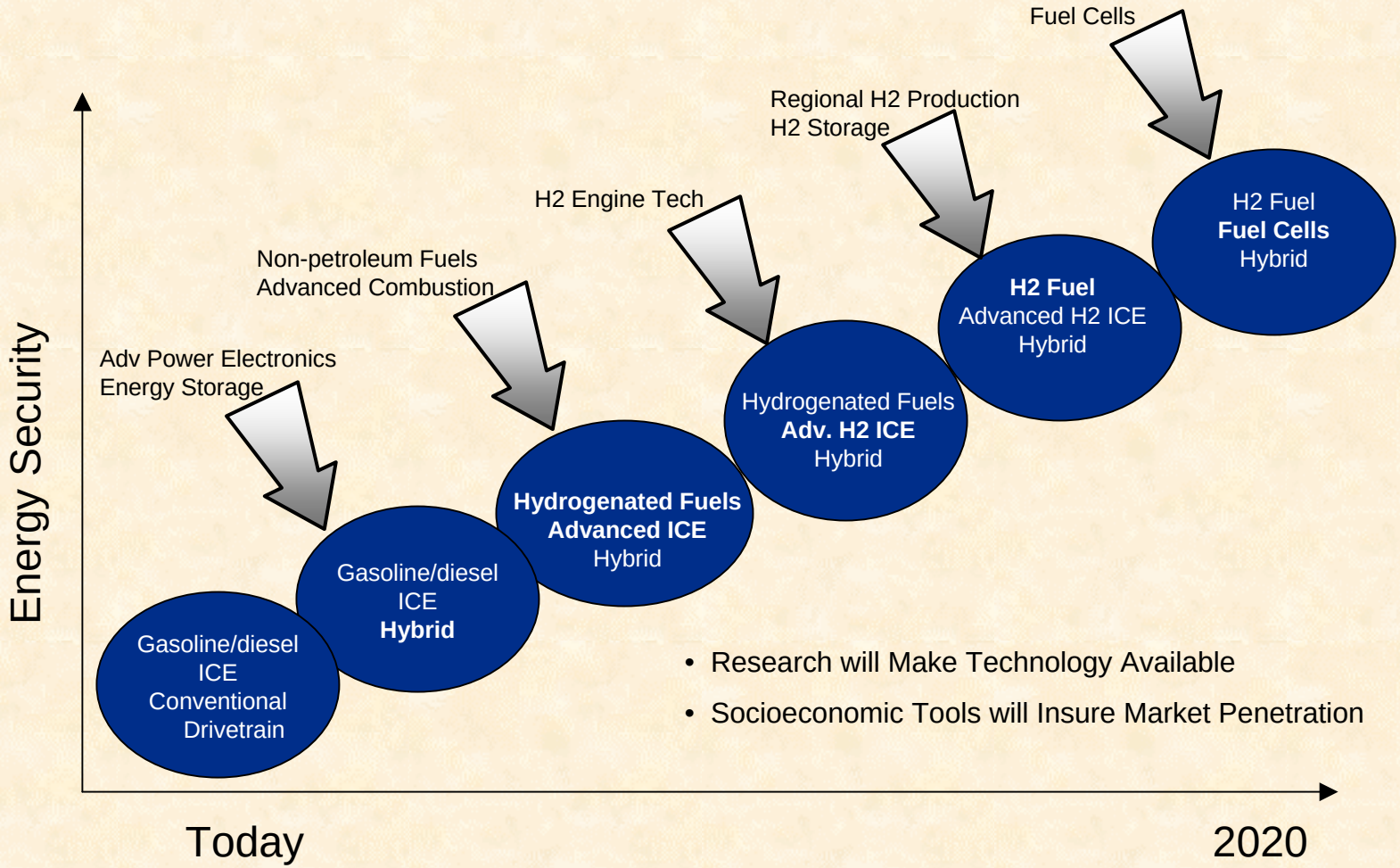
Advanced Combustion Engines



Losses:

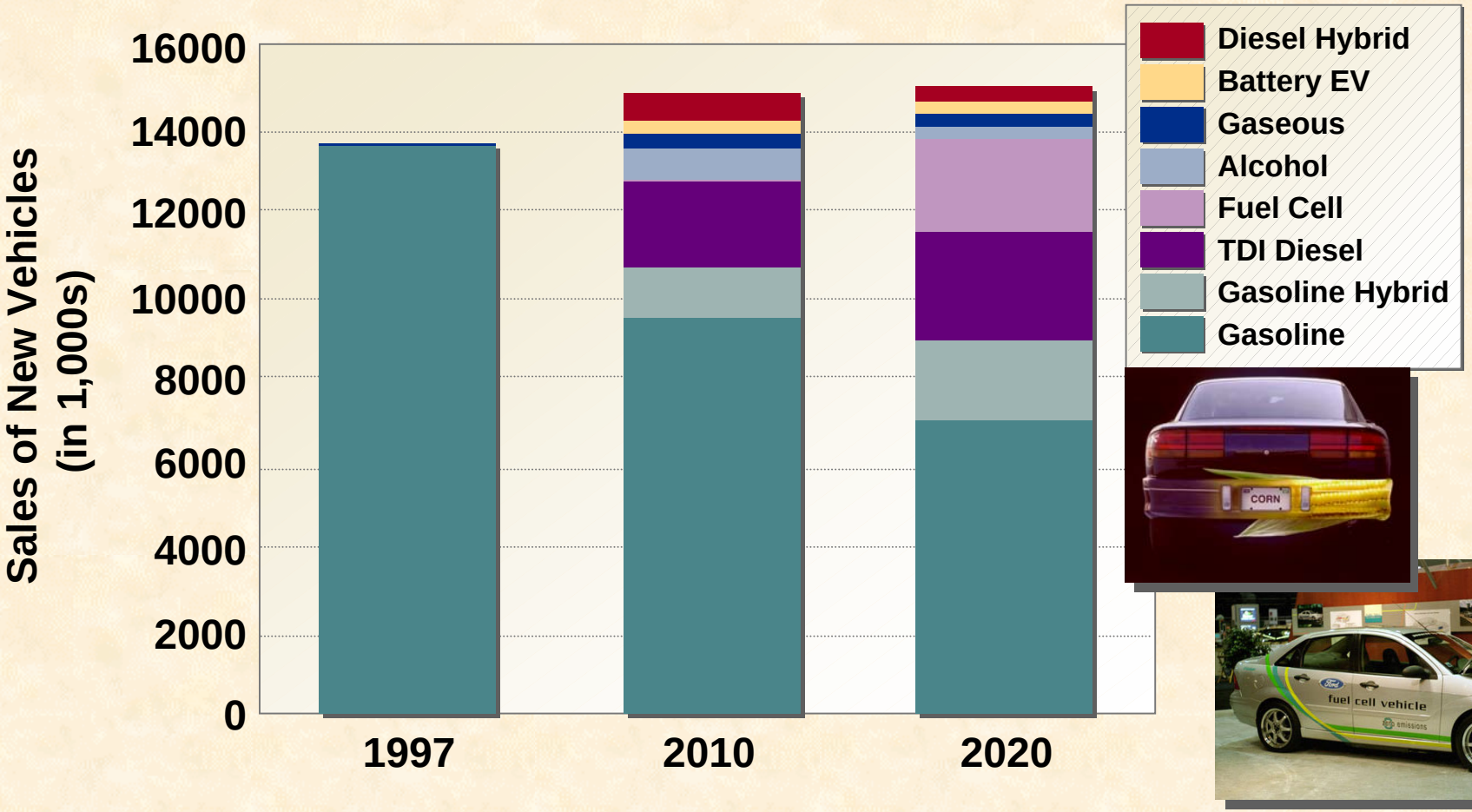
- Emission Controls 1 – 2%
- Exhaust 8%
- Thermodynamic Combustion 14%
- Heat Transfer 10%
- Mechanical Pumping 4%
- Friction 4%

Energy Security Pathway to Fuel Cell Vehicles and Hydrogen Economy



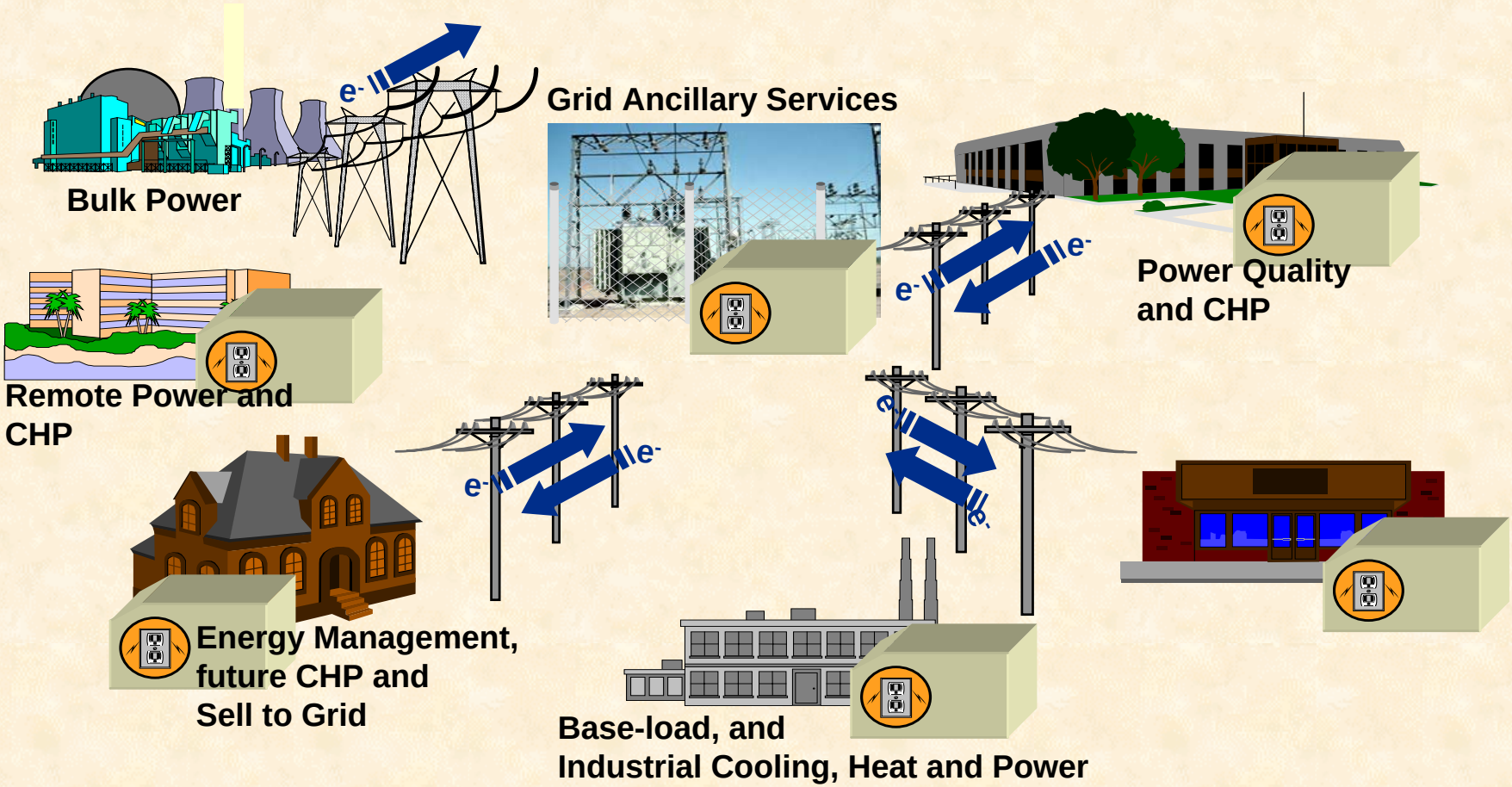
- Research will Make Technology Available
- Socioeconomic Tools will Insure Market Penetration

By 2020, alternative fuels and propulsion systems could have a large share of new U.S. car sales



Power Sector

A Distributed Energy Future



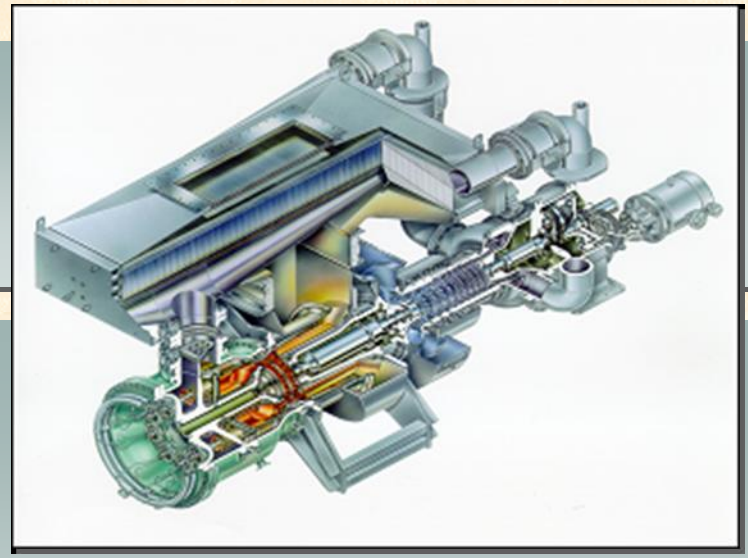
Improved industrial gas turbine technologies have advanced combined heat and power

1992

- 29% efficiency
- +2 pounds/MWhr No_x
- $600/kW

2001

- 38% efficiency
- Greater than 80% efficiency (CHP)
- 0.15 pounds/MWhr No_x
- $400/kW



Solar Turbines' Mercury 50

- Advanced designs
- Lower cost operations

Similar improvements are envisioned for microturbines

2000

First generation microturbines:

- 17-30% efficiency
- .35 pounds/MWhr NO_X
- $900-$1,200 / kW

2010

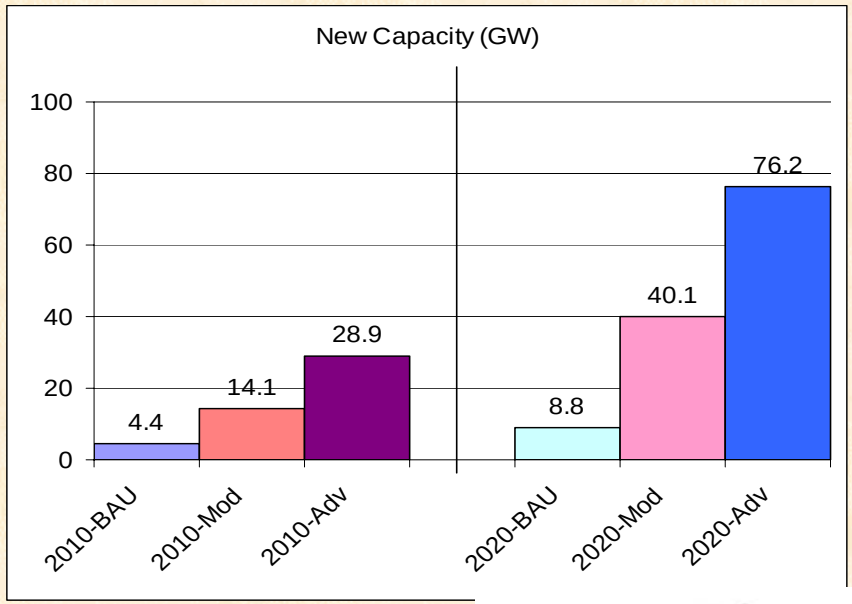
Advanced microturbines:

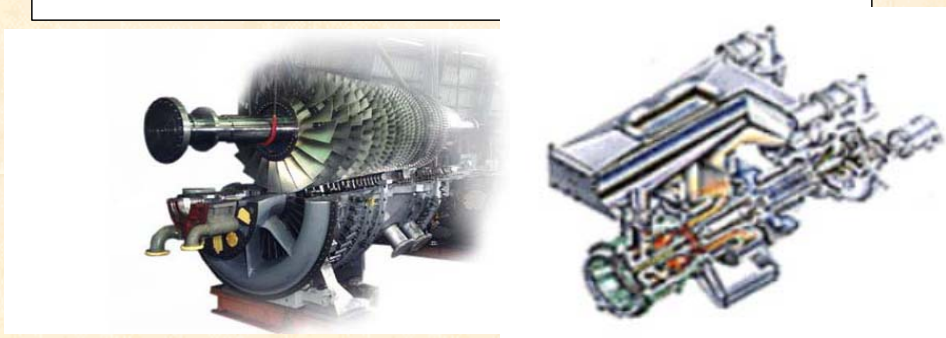
- 40% efficient
- Greater than 80% efficient (combined with chillers and desiccant systems)
- .15 pounds/MWhr NO_X
- $500 / kW

- Advanced designs
- Lower cost operations

Combined Heat and Power

- **BAU New Capacity:**
  - ⇨ **4 GW by 2010**
  - ⇨ **9 GW by 2020**
- **Advanced Scenario New Capacity:**
  - ⇨ **29 GW by 2010**
  - ⇨ **76 GW by 2020**
- **In 2020, this saves:**
  - ⇨ **2.4 quads of energy**
  - ⇨ **40 MtC of emissions**

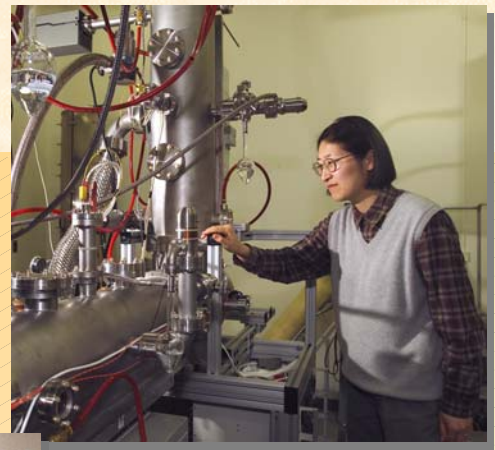




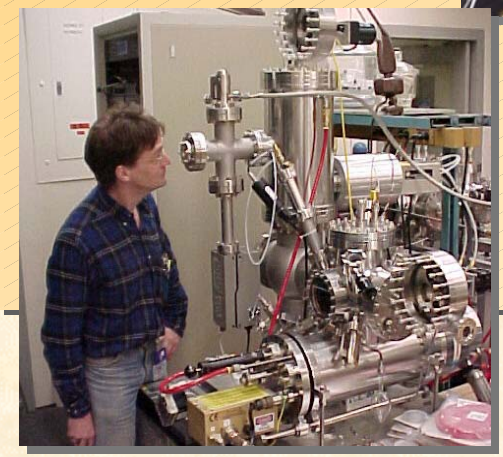
2010-2020: Broad product lines of cost- reduced advanced gas turbines

High-temperature super-conducting materials offer "transmission without friction"

- **"Rolling-assisted, biaxially textured substrates" (RABiTS) invention**
- **Substrates require near single-crystal-like performance in kilometer lengths**
- **Possible applications**
  - **Transmission cables**
  - **Transformers**
  - **Motors**
  - **Generators**



Reel-to-Reel annealing and buffer layer deposition for scale-up research and development



RF sputtering is used to deposit oxide multilayers on 10-m long biaxially textured nickel tapes

Conclusions

1. **A large economic potential for energy efficiency exists using current technologies**

2. **Technology advances will further expand this potential**

3. **Energy efficiency can moderate the need for new energy supplies and:**
   - Reduce greenhouse gas emissions
   - Improve air quality
   - Strengthen electric reliability and energy security