Critical National Needs in New Technologies:

Efficiency & Renewables

National Academy of Sciences
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U.S. Department of Energy

Context

- **Energy-Linked Challenges**
  - Economy—economic development and growth; energy costs
  - Environment—local (particulates), regional (acid rain), global (GHGs)
  - Energy Security—foreign energy dependence, reliability, stability
  - Scale and Time Constants
- **Responses: EERE R&D Activities**

	FY06 App	FY07 App	FY08 App
– Energy Efficiency			
• Buildings	$ 68.3	$ 104.3	$108.9
• Industry	$ 55.8	$ 56.6	$ 64.4
• Vehicles	$ 178.4	$ 188.0	$213.0
• Hydrogen	$ 153.5	$ 193.5	$211.1
– Renewable Energy			
• Biomass	$ 89.7	$ 199.7	$198.2
• Wind	$ 38.8	$ 49.3	$ 49.5
• Solar	$ 81.8	$ 159.4	$156.1
• Geothermal	$ 22.8	$ 5.0	$ 19.8
Total Research	$ 689.1	$ 955.8	$1021
Total EERE	$1162.	$1457.	$1722

The Oil Problem

Nations that **HAVE** oil (% of Global Reserves)	
Saudi Arabia	26%
Iraq	11
Kuwait	10
Iran	9
UAE	8
Venezuela	6
Russia	5
Mexico	3
Libya	3
China	3
Nigeria	2
U.S.	**2**

Nations that **NEED** oil (% of Global Consumption)	
U.S.	**24.4%**
China	8.6
Japan	5.9
Russia	3.4
India	3.1
Germany	2.9
Canada	2.8
Brazil	2.6
S. Korea	2.6
Mexico	2.4
France	2.3
Italy	2.0

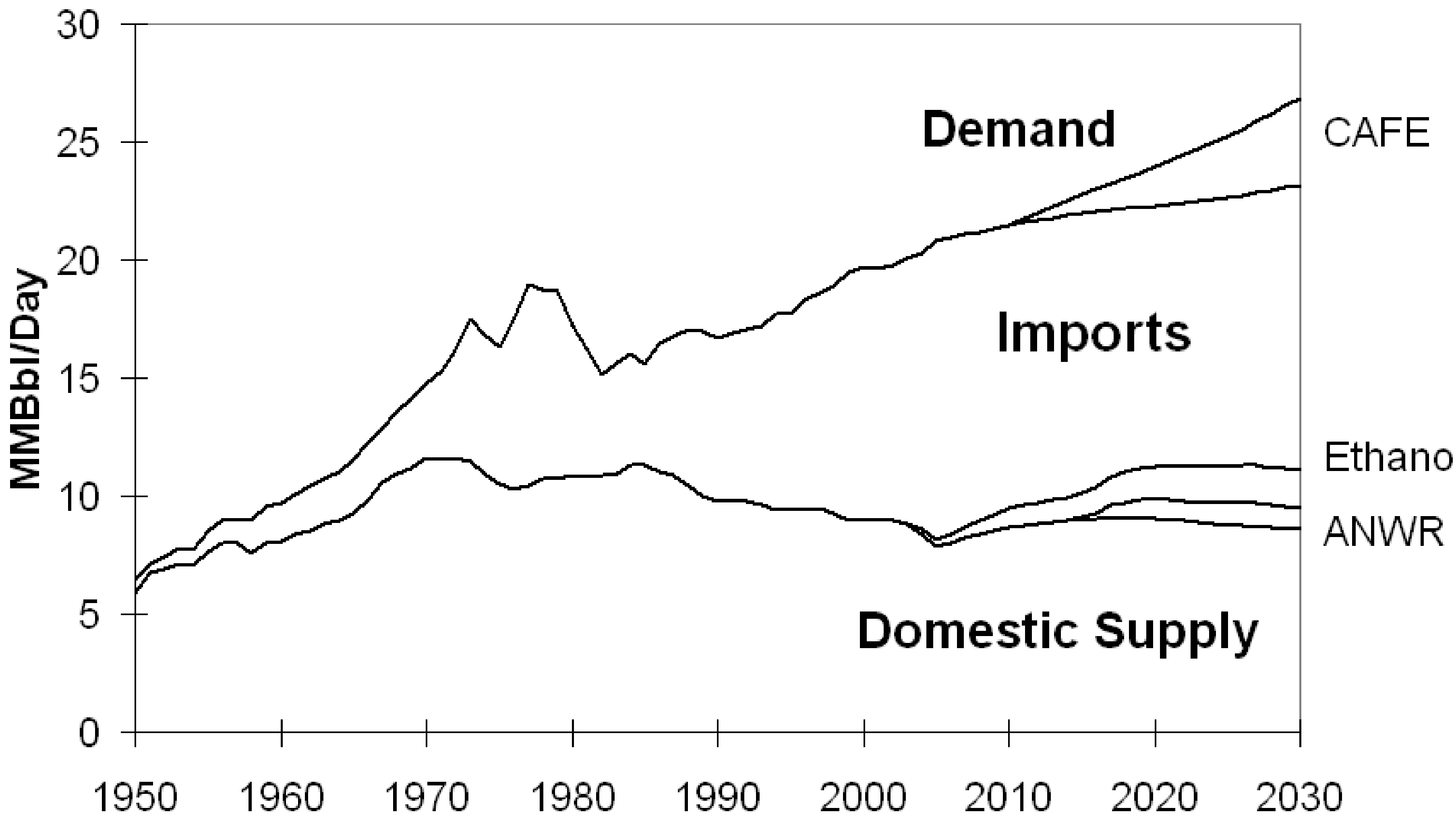
Source: EIA International Energy Annual

Impacts of Oil Dependence

- **Domestic Economic Impact**
- **Trade Deficit**: ~47% of $710B trade deficit in 2007
- **Foreign Policy Impacts**
  - Strategic competition for access to oil
  - Oil money supports undesirable regimes
  - Oil money finds its way to terrorist organizations
- **Vulnerabilities**
  - to system failures: tanker spills; pipeline corrosion; …
  - to natural disasters: Katrina; …
  - to political upheaval: Nigeria; …
  - to terrorist acts: Yemen; Saudi Arabia; …
- **Economic Development**
  - developing world growth stunted by high oil prices; increases instability

- **Natural Gas?**
  - Russia cut-off of natural gas to Ukraine
  - Russia provides 40% of European NG imports now; 70% by 2030.

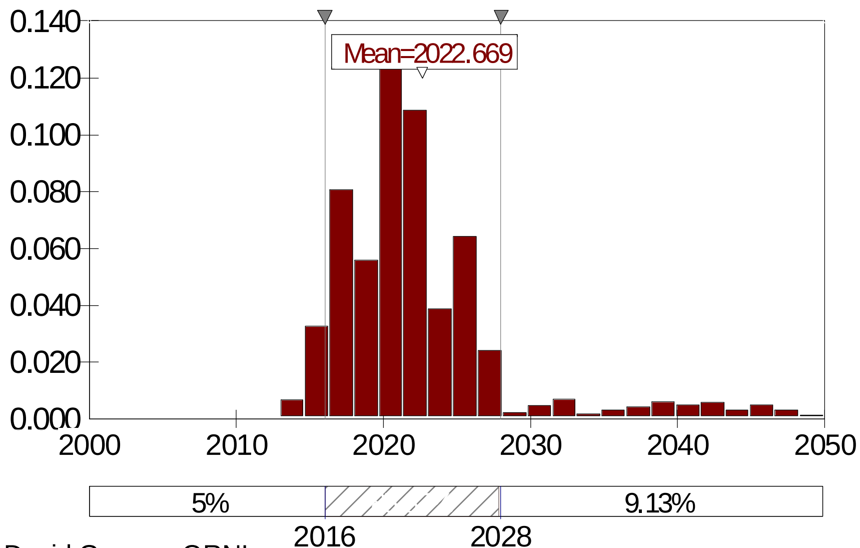
Oil Futures



MMBbl/Day
30
25
20
15
10
5
0
1950
1960
1970
1980
1990
2000
2010
2020
2030
Demand
CAFE
Imports
Ethanol
ANWR
Domestic Supply

Oil Sources

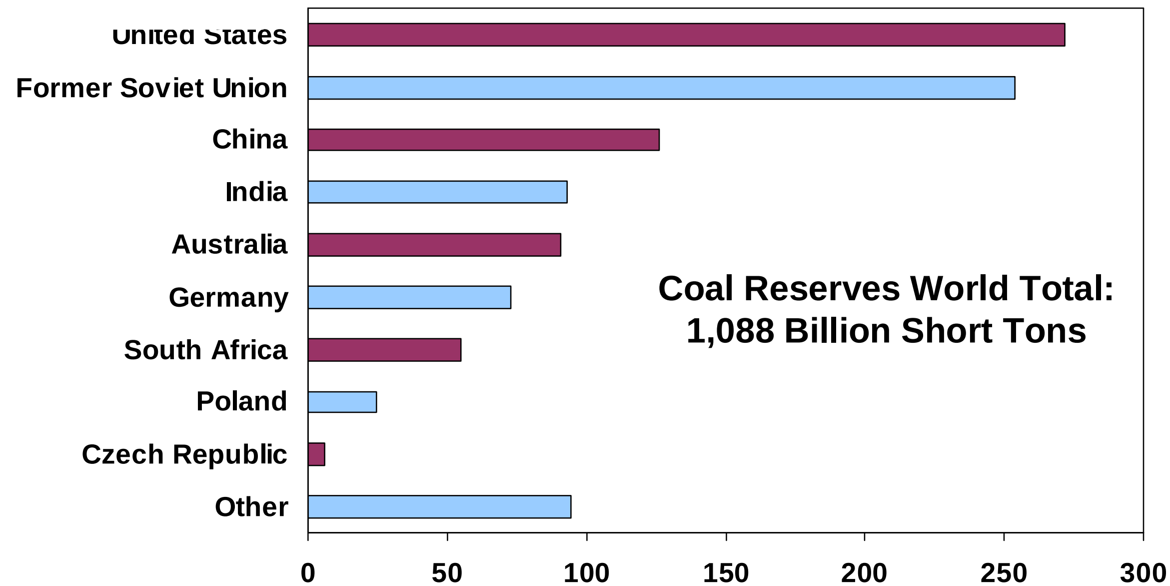
Peak Year of ROW Conventional Oil Production: Reference/USGS



Source: David Greene, ORNL

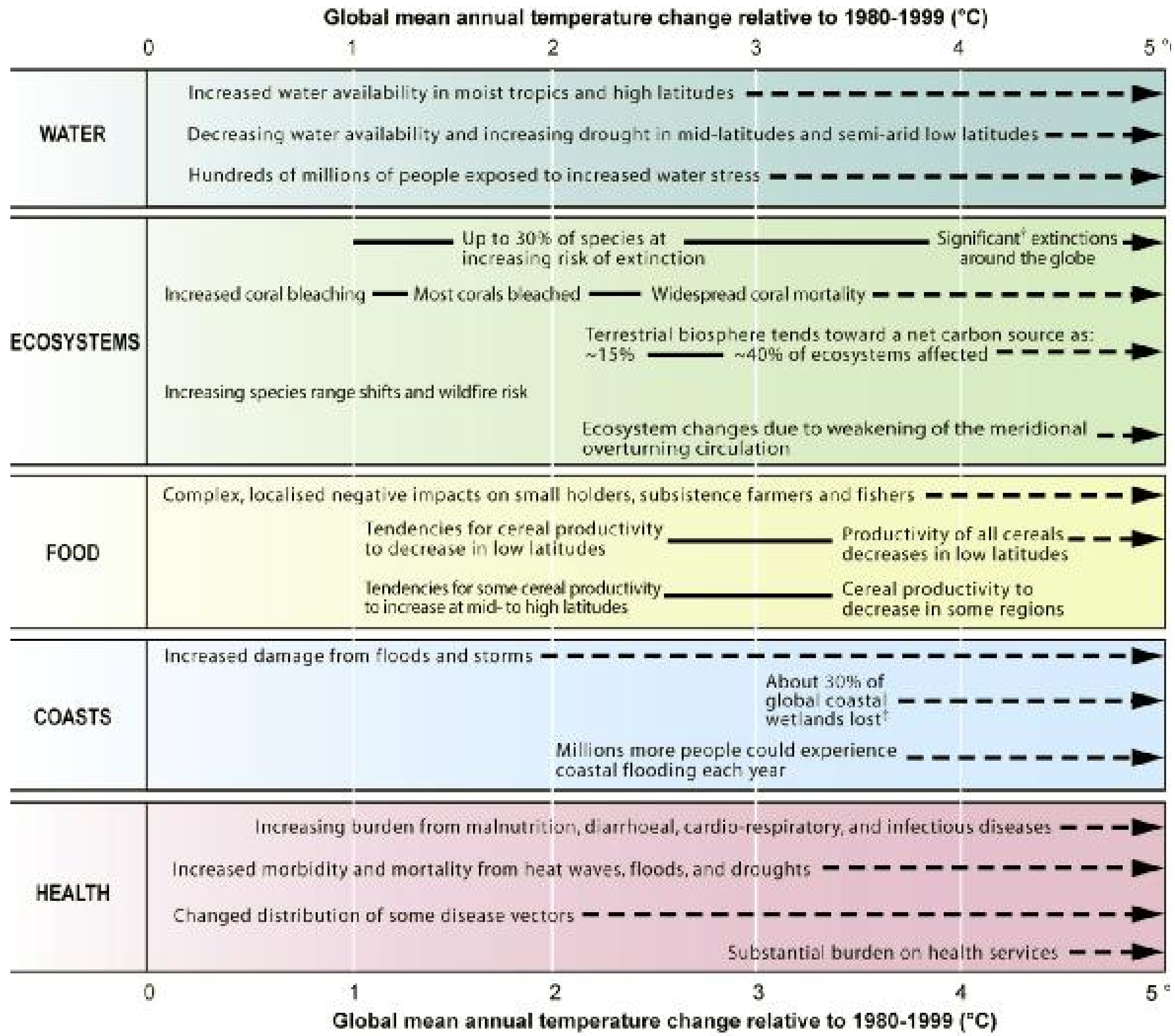
- **Resources**
  - **Oil Shale**
    - **U.S.—Over 1.2 trillion Bbls-equiv. in highest-grade deposits**
  - **Tar Sands**
    - **Canadian Athabasca Tar Sands—1.7 T Bbls-equivalent**
    - **Venezuelan Orinoco Tar Sands (Heavy Oil)—1.8 T Bbls-equiv.**
  - **Coal**
    - **Coal Liquefaction—4 Bbls/ton**

- **Constraints**
  - **Cost**
  - **Energy**
  - **Water**
  - **Atmosphere**



Potential Impacts of GHG Emissions

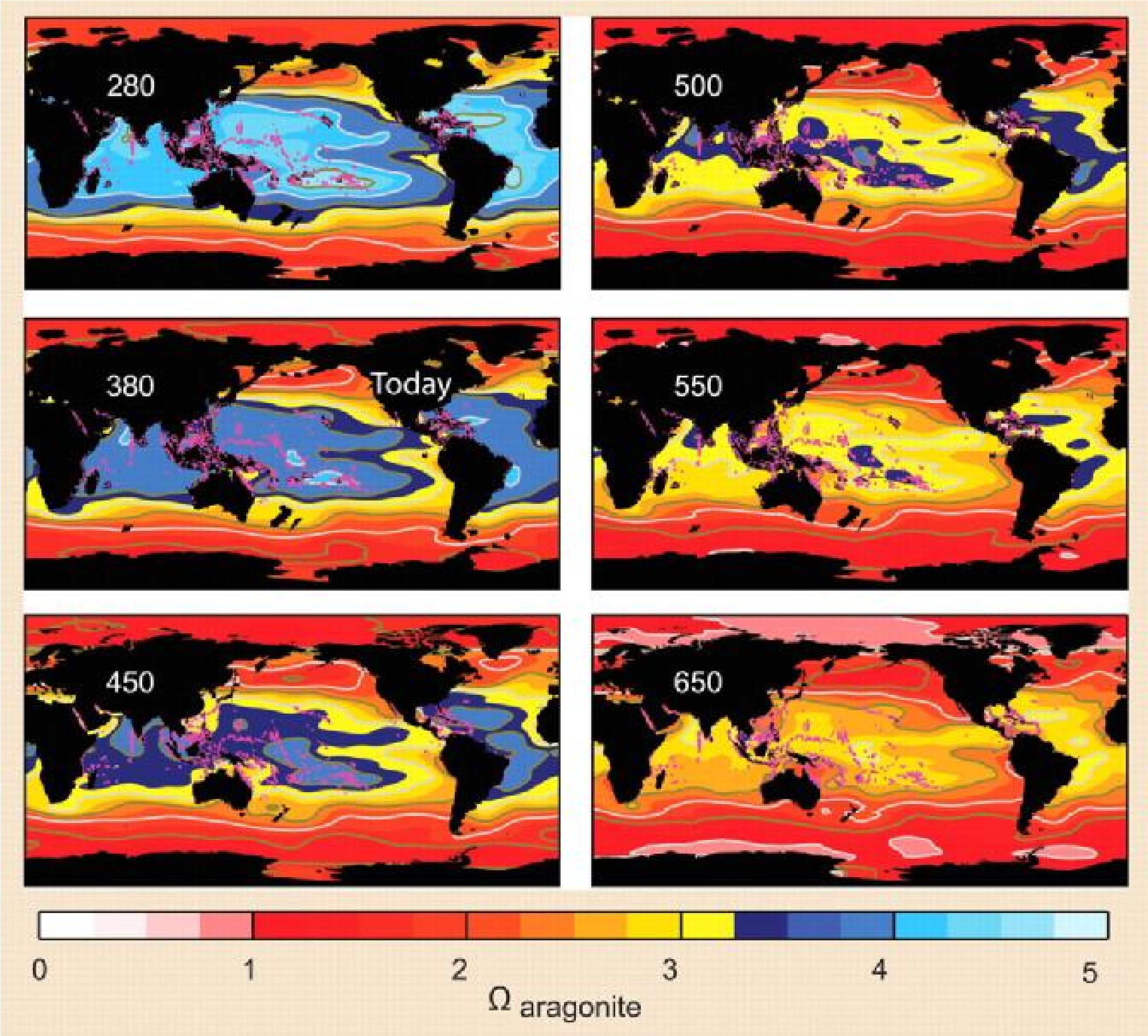
- Temperature Increases
- Precipitation Changes
- Glacier & Sea-Ice Loss
- Water Availability
- Wildfire Increases
- Ecological Zone Shifts
- Extinctions
- Agricultural Zone Shifts
- Agricultural Productivity
- Hurricane Intensity
- Sea Level Rise
- Ocean pH Decreases
- Human Health
- Feedback Effects



Source: Intergovernmental Panel on Climate Change, Fourth Assessment Report, Working Group 2, "Impacts Adaptation and Vulnerability".

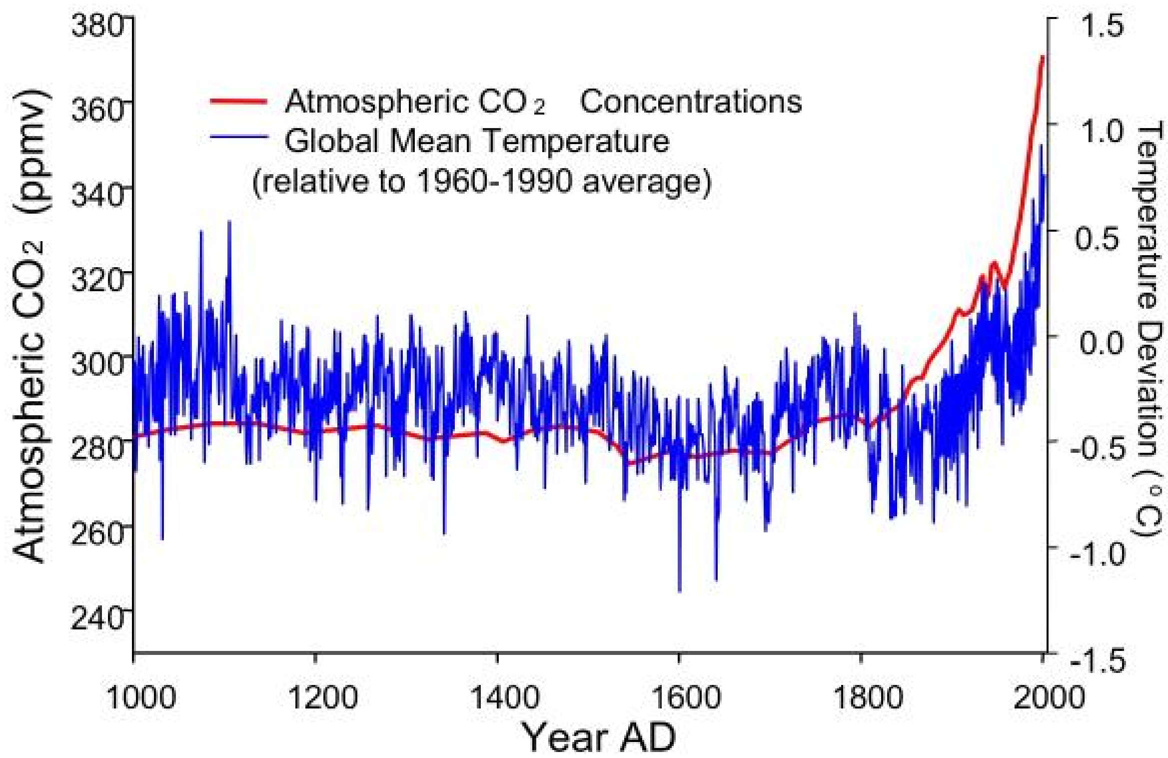
Carbon Emissions, Ocean pH, & Coral Reefs

Hoegh-Guldberg, et al., Science, V.318, pp.1737, 14 Dec. 2007

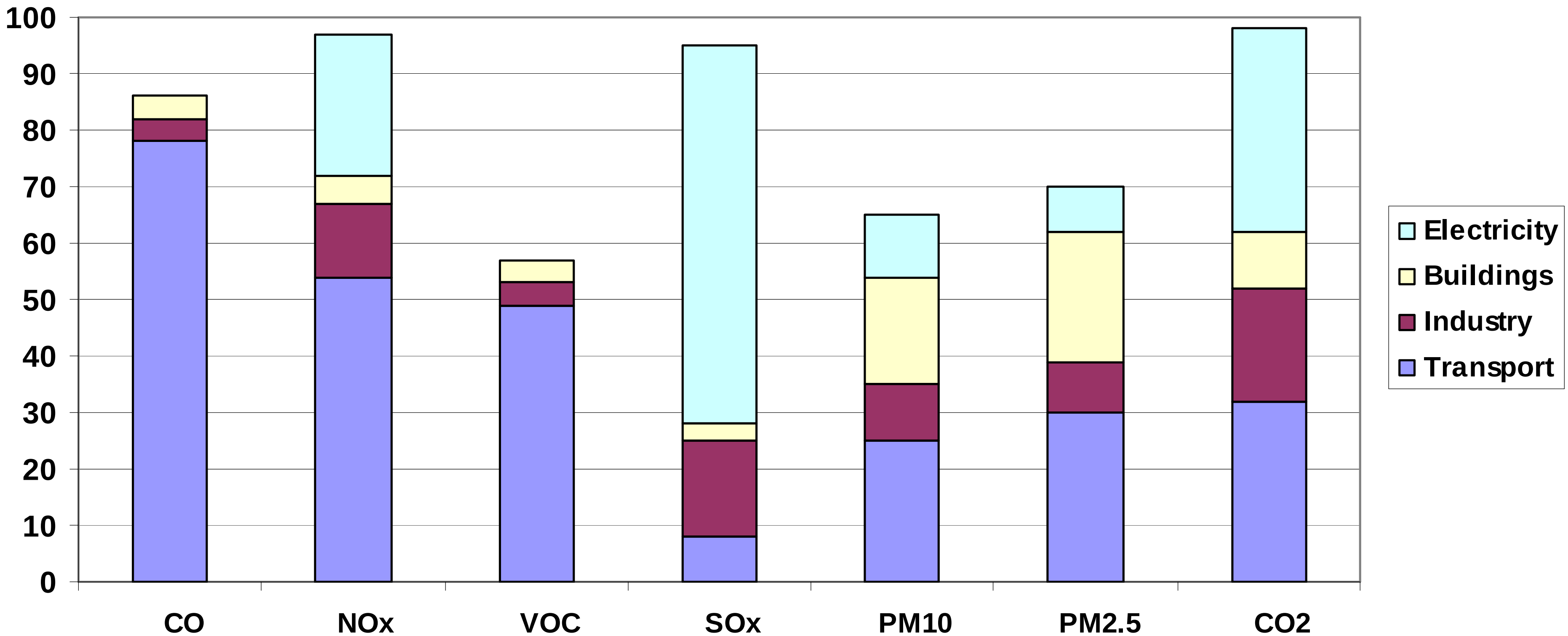


Climate Change

- **Joint Science Academies' Statement**:
  - "There is now strong evidence that significant global warming is occurring."
  - "…most of the warming in recent decades can be attributed to human activities."
  - "The scientific understanding of climate change is now sufficiently clear to justify nations taking prompt action."
  - "Long-term global efforts to create a more healthy, prosperous, and sustainable world may be severely hindered by changes in climate."
  - "We urge all nations … to take prompt action to reduce the causes of climate change …".
  - **Signed by National Academies' of Science: Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, United Kingdom, U.S.A., 2005.**



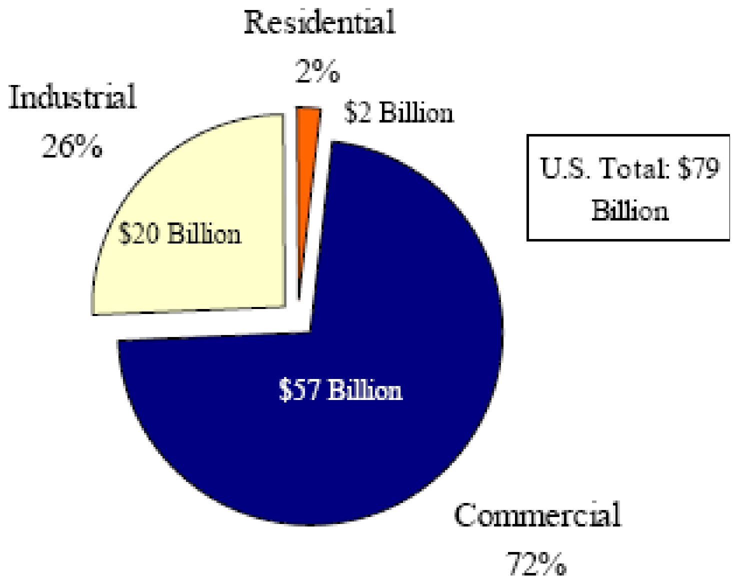
U.S. Energy-Linked Emissions as Percentage of Total Emissions

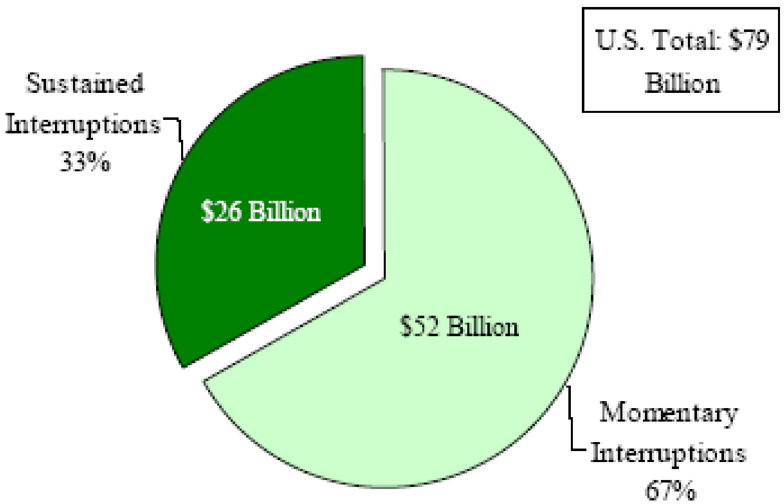


Costs of Power Interruptions

New York City during the August 2003 blackout

Chip East / Reuters file





Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

Time Constants

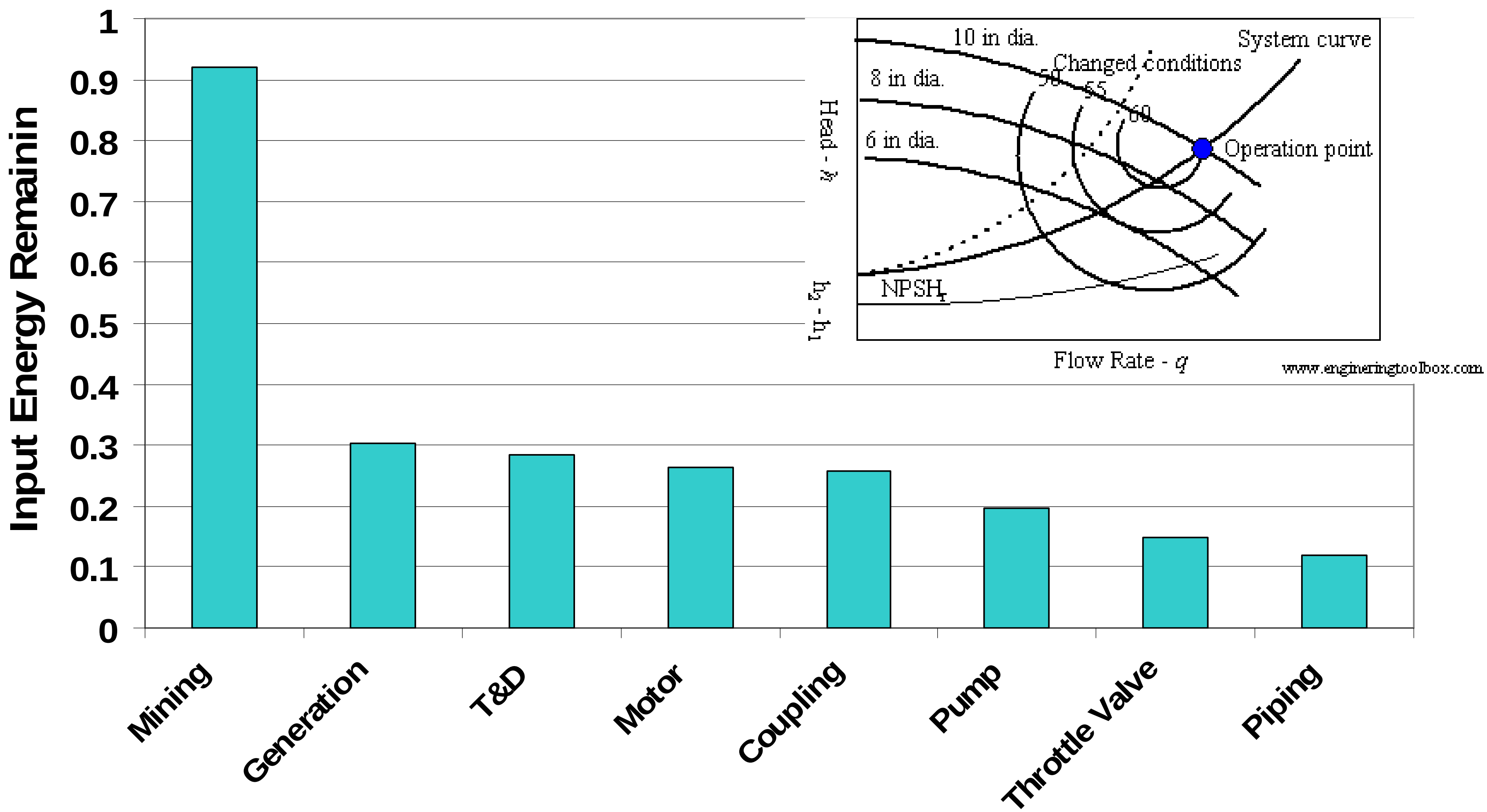
- Political consensus building ~ 3-30+ years
- Technical R&D ~10+
- Production model ~ 4+
- Financial ~ 2++
- Market penetration ~10++
- Capital stock turnover
  - Cars ~ 15
  - Appliances ~ 10-20
  - Industrial Equipment ~ 10-30/40+
  - Power plants ~ 40+
  - Buildings ~ 80
  - Urban form ~100's

- Lifetime of Greenhouse Gases ~10's-1000's
- Reversal of Land Use Change ~100's
- Reversal of Extinctions Never

- Time available for significant action ??

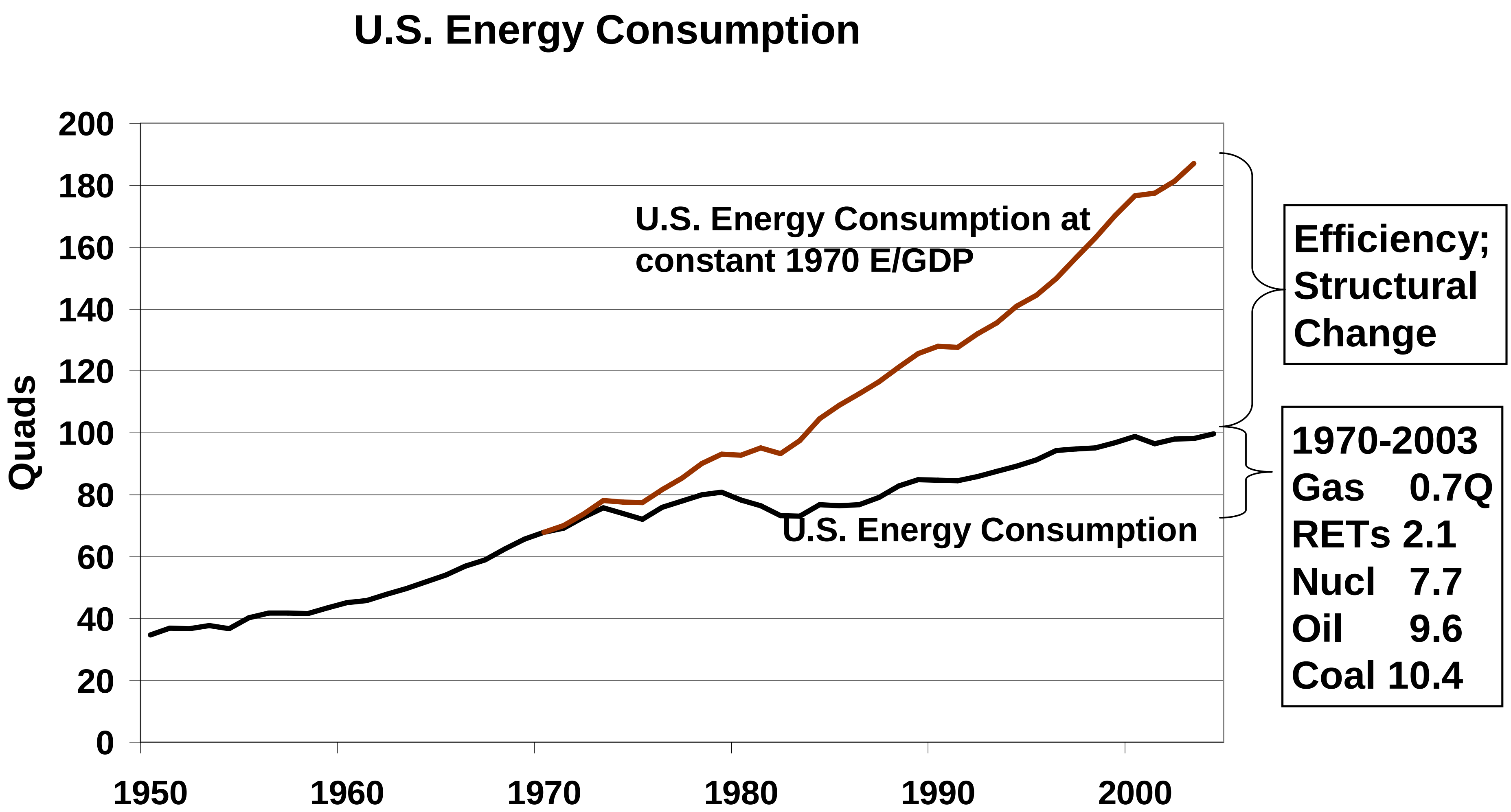
End-use Efficiency Upstream Leverage

Motor Drive System Efficiency



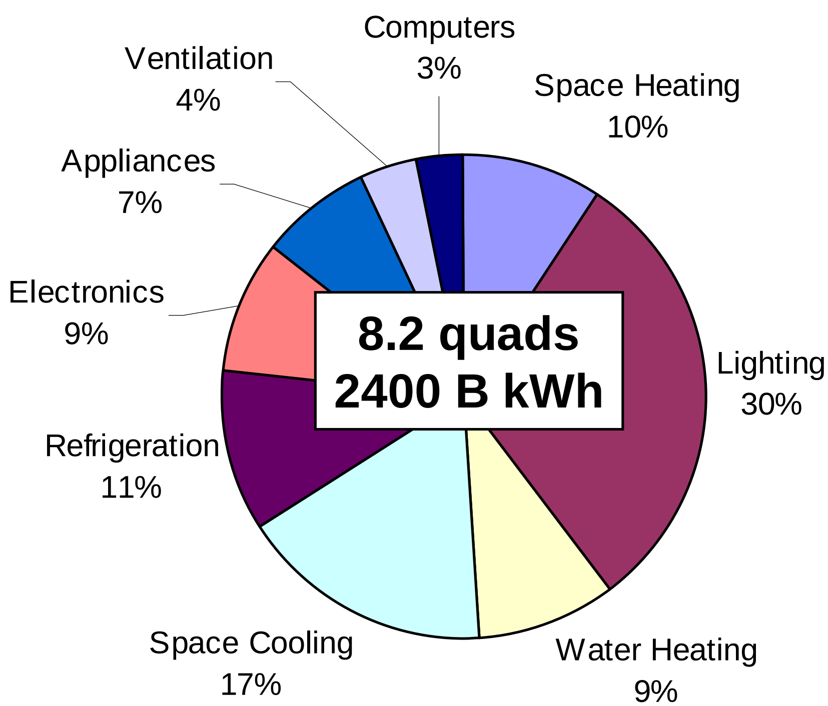
Reducing energy loss in end-use systems has large leverage upstream!

Energy Efficiency

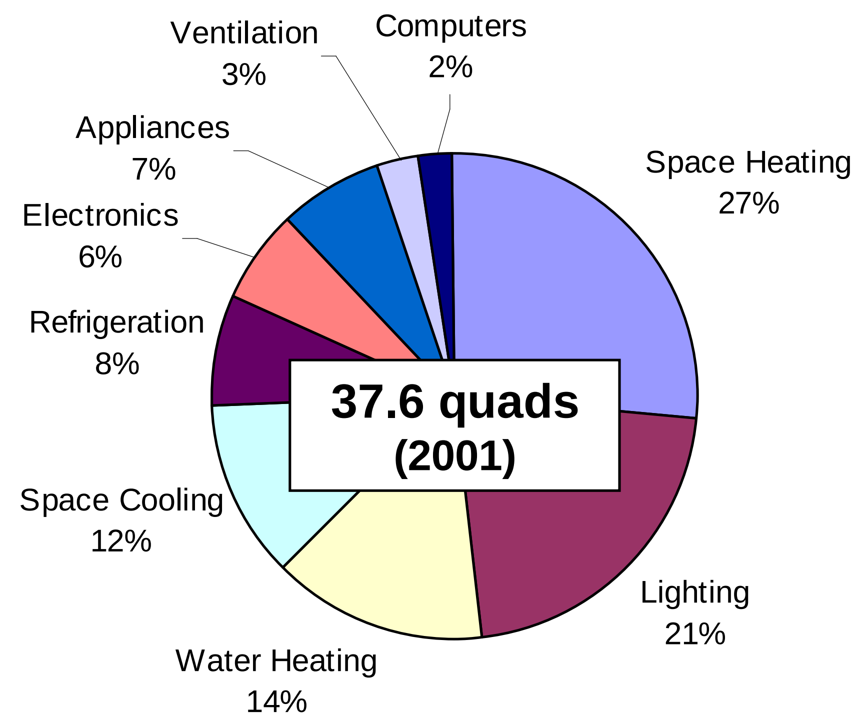


Buildings Energy Use

Site Electricity Consumption

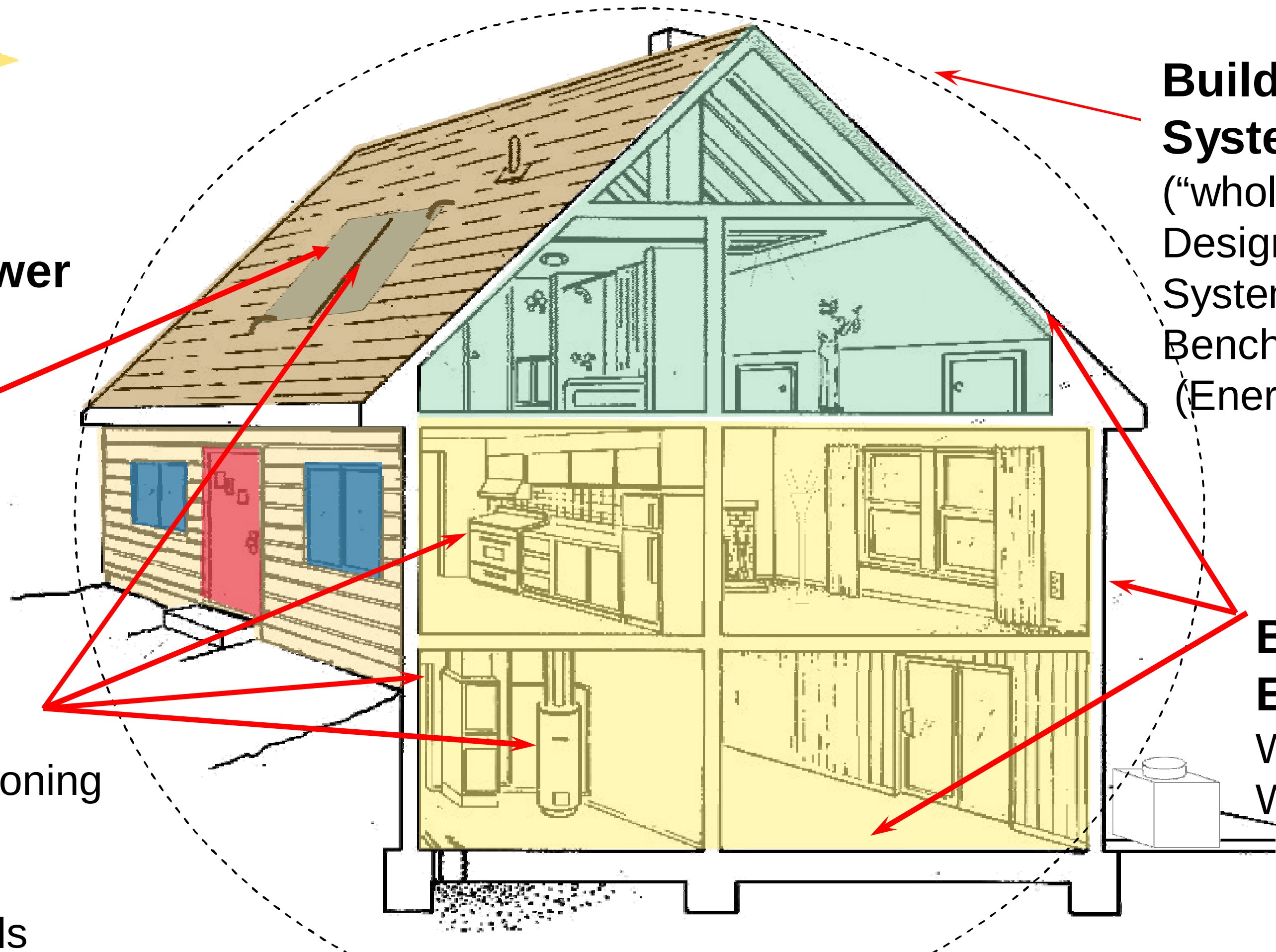


Total Primary Energy (all fuels)



Source: Building Technology Program Core Databook, August 2003. http://buildingsdatabook.eren.doe.gov/frame.asp?p=tableview.asp&TableID=509&t=xls

Net Zero Energy Buildings



On-Site Power Systems
Building Integrated Photovoltaics
Fuel Cells

Building Equipment
Space conditioning
Lights
Appliances
Smart Controls

Building Systems
("whole-systems")
Design tools
System Integration
Benchmarking
(EnergyStar, LEED)

Building Envelope
Windows, Walls, Floors

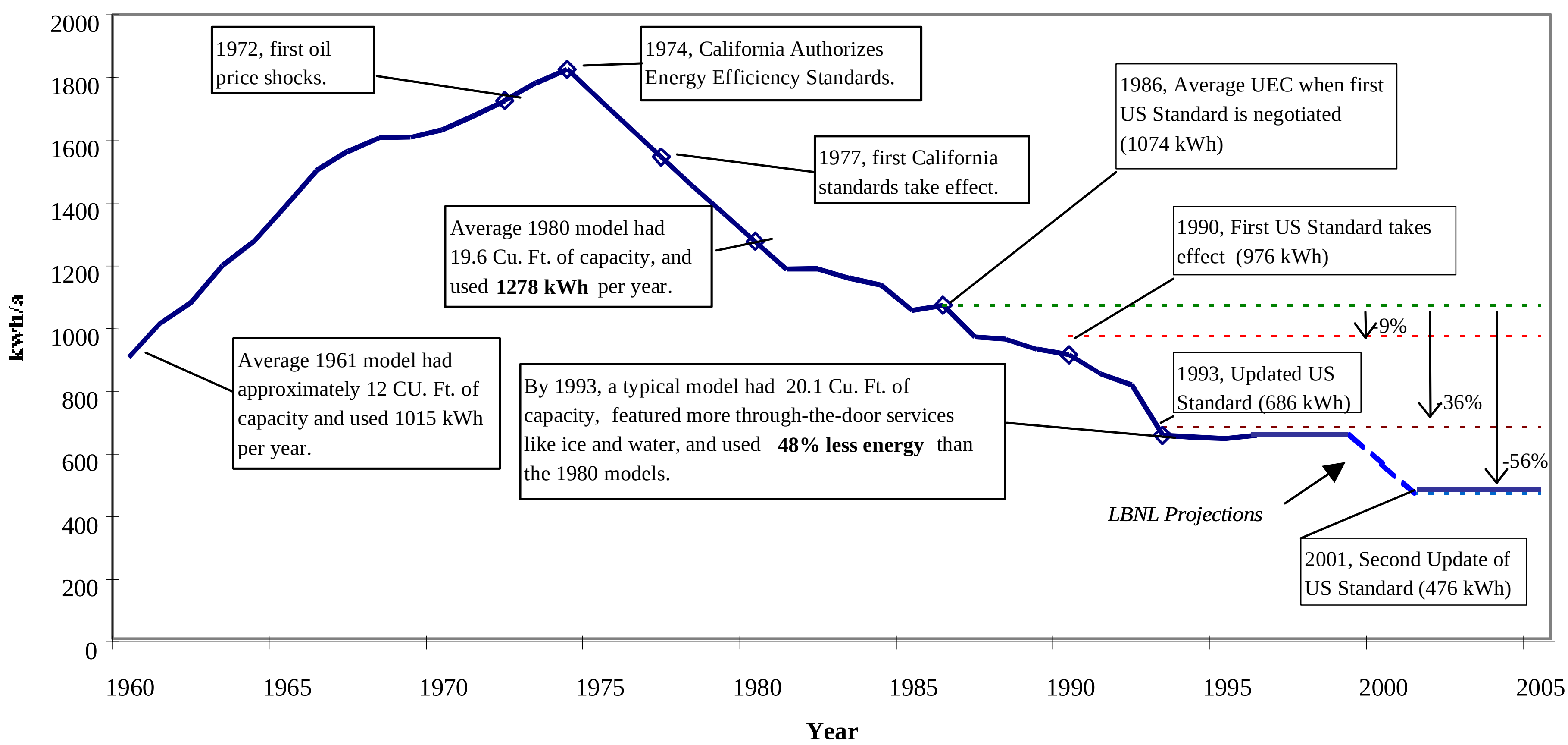
Reduce total building energy use by 60–70 percent

Highly efficient, cost-effective solid-state lighting technologies, advanced windows and space heating and cooling technologies.

Source: BTP

U.S. Refrigerator Energy Consumption

(Average energy consumption of new refrigerators sold in the U.S.)



Source: LBNL

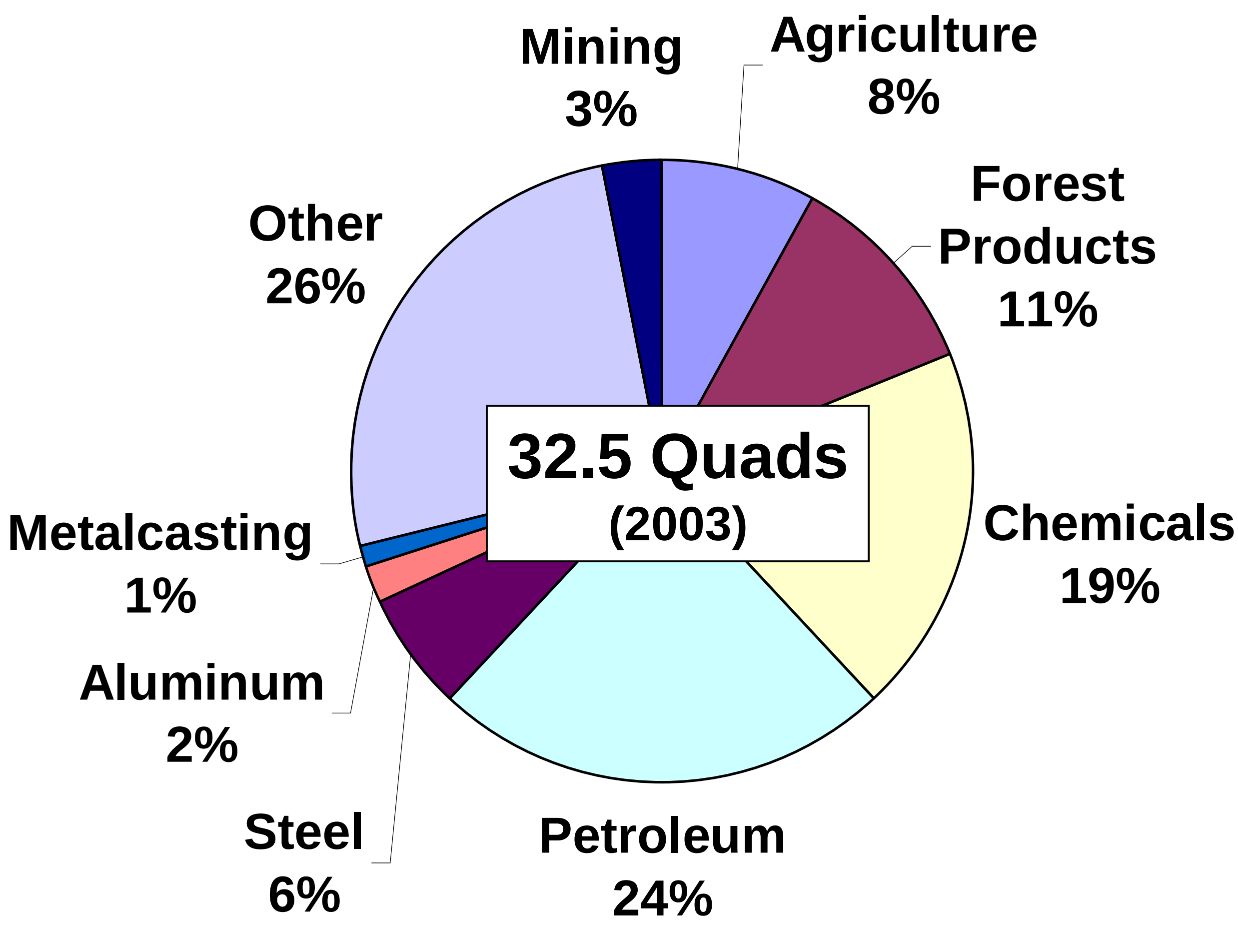
Buildings R&D Opportunities

- **Cooling Technologies**: Building A/C & Refrigeration (7.5Q—utility peak load); Industrial A/C & process cooling (~1.6Q); transportation A/C (1.0—vehicle load):
  - Thermoelectrics; Magnetic Cooling; Dehumidification materials; Heat pumps and heat exchangers
    - Avoiding HFC refrigerants also reduces GHGs
- **Lighting**:
  - LED lighting—additional materials, device structures, phosphors, encapsulants.
  - Conventional lighting—non-Hg fluorescent lamps; multi-photon phosphors, etc.
- **Water Heating**: Building water heating (3.6Q); industrial water heating:
  - Building-Integrated solar water heaters that are low-cost, long-life, freeze-tolerant, and operate at line pressure.
  - Low-cost, high reliability electric- or gas-powered heat pump water heaters.
- **Building Shells:**
  - Insulants; Phase-change materials for thermal storage
  - Windows: Electrochromics;
- **Others**:
  - Building Intelligence: building-integrated sensors and controls; advanced building controls; automated continuous commissioning;
  - Whole Building System Integration: Design tools; Component design/install;
  - Low-wattage standby devices; low-cost adjustable speed motor drives with integrated sensors/controllers; selective surfaces for cool roofs, paints; etc.

Buildings Technology Barriers

- **Buildings sector faces a variety of market frictions/failures, including:**
  - **Consumer Perspective:**
    - **Split incentives**: owner of building may not pay utilities—paid instead by the tenants—so that owner has little or no incentive to invest in high efficiency equipment.
    - **Lack of information**: The energy performance of a building may not be known, limiting the ability of the purchaser or user to make an informed investment decision. There are a variety of other shortcomings in information, ranging from difficulty getting reliable, trusted information by the individual to
    - **Externalities**: such as environmental impacts or national security (oil) impacts are generally not fully captured, if at all, in the price/rent of the building and its equipment.
    - **Capital Cost**: consumers are generally more sensitive to first cost than operating cost.
    - **Bundled attributes**. Efficiency may be just one consideration among many attributes.
    - **Uncertainties** about the new technology may delay consumer adoption.
  - **Corporate Perspective:**
    - **Appropriability of R&D**. Corporations may not adequately invest in R&D because it is difficult to capture the full value of the knowledge gained.
    - **Externalities**. Many external costs are not included in the price of energy, limiting R&D value.
    - **Market Fragmentation** may limit the ability of new efficiency technologies to penetrate or for industry to gather critical mass for conducting the R&D or market development.
    - **Compartmentalization** of architects, developers, construction firms, others, fail to provide appropriate incentives for energy efficiency and limits technology adoption.
    - **Economies of scale/learning** may be difficult to develop for new efficiency technology
- **Appliance standards/building codes assist rapid deployment at low risk.**

Industrial Energy Use



ITP R&D Areas: Focus on Energy Efficiency

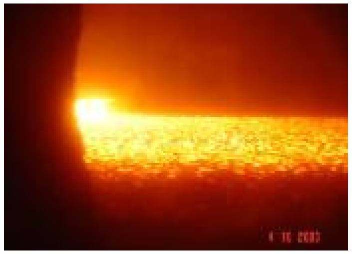
Industrial Reaction and Separation

Develop technologies for efficient reaction and separation processes

- Oxidation Processes
- Microchannel Reactors
- Hybrid Distillation
- Alternative Processes
- Advanced Water Removal

High Temperature Processes

Develop energy efficient high-temperature process technologies for producing metals and non-metallic minerals



- Advanced Metal Heating and Reheating
- Advanced Melting
- Efficient Heat Treating
- High Efficiency Calcining
- Next-Generation Steelmaking

Energy Conversion Systems

Develop high efficiency steam generation and combustion technologies and improved energy recovery technologies

- Thermal Transport Systems
- Super Boiler
- Ultra-High Efficiency Furnace
- Waste Heat Recovery

Fabrication and Infrastructure

Develop energy efficient technologies for making near net-shape finished products from basic materials

- Near Net Shape Casting and Forming
- Energy Efficient and Safe Extraction Operations
- Inferential Process Control for Product Quality
- Ultra-hard Materials
- Joining and Assembly

Source: ITP

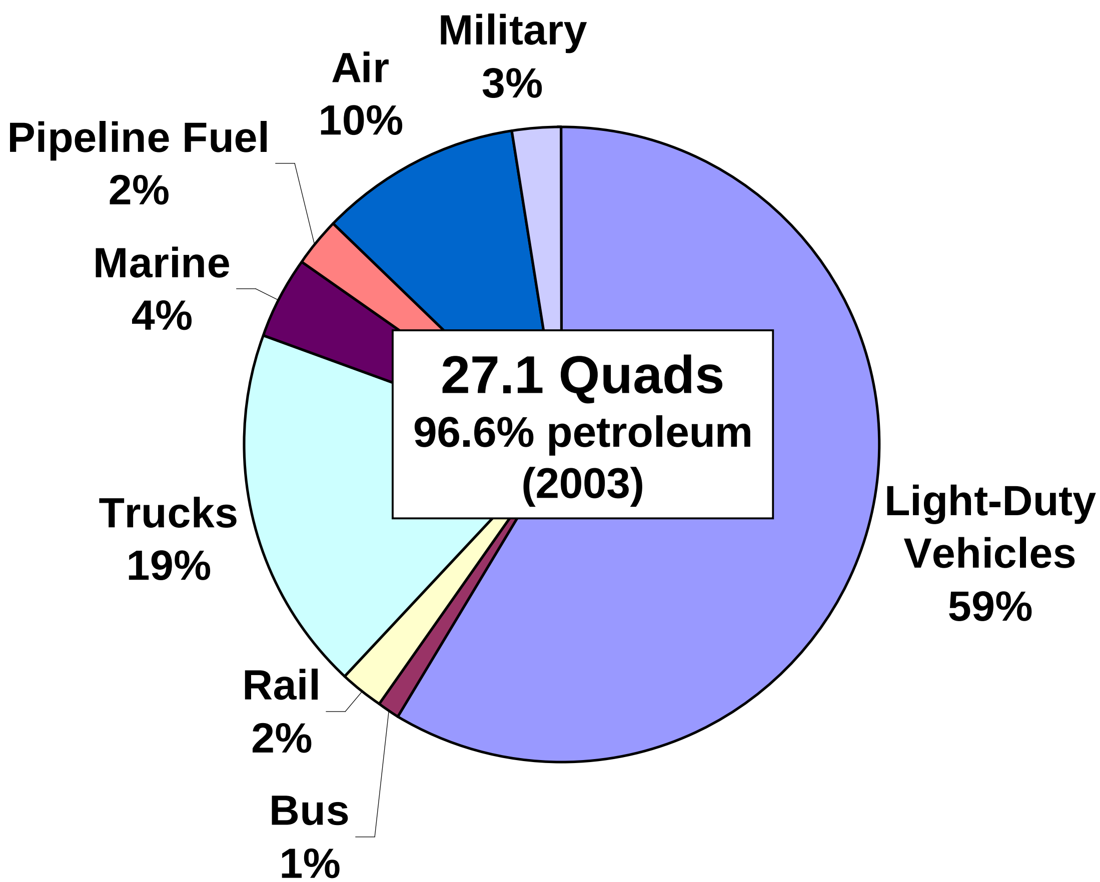
Industry R&D Opportunities

- **Advanced Materials:** Low-cost, high-strength materials; low-corrosion materials; micro-structural control of material properties; non-destructive testing of materials.
- **Advanced Fabrication and Forming Technologies**: Near-net shape forming; microstructure control.
- **Advanced Processing**: High-temperature processing (examples); microchannel reactors; synthetic biological processing; Agile manufacturing; System integration; Robotics;
- **Industrial Energy Flexibility**: Flexible multi-fuel industrial energy supply systems, using multiple energy resources—coal (with hot gas cleanup, etc.), biomass, etc.—for boilers, power, feedstocks.
- **Intelligent Processes:** Sensors and Controls, power electronics; Sensors for high temperature, reactive environments;
- **Motor Drive:** Low-cost adjustable speed drives for motors (also FCVT).
- **Reactions and Separations:** Energy-efficient; high temperature membranes; reactive membranes; filters; Separation mechanisms in multicomponent systems, heterogeneous/homogenous catalysis;
- **Computational Fluid Dynamics:** Analysis of multi-phase systems and flows.
- **Advanced Combustion**: Emissions controls;
- **Super Boilers:** high-efficiency and low-emission boiler systems.
- **Waste Heat Recovery:** Thermoelectrics (from FCVT); Heat exchangers; nanostructured heat-exchanger fluids;
- **Lighting, Cooling, Water Heating, etc**.—(from BTS)**.**

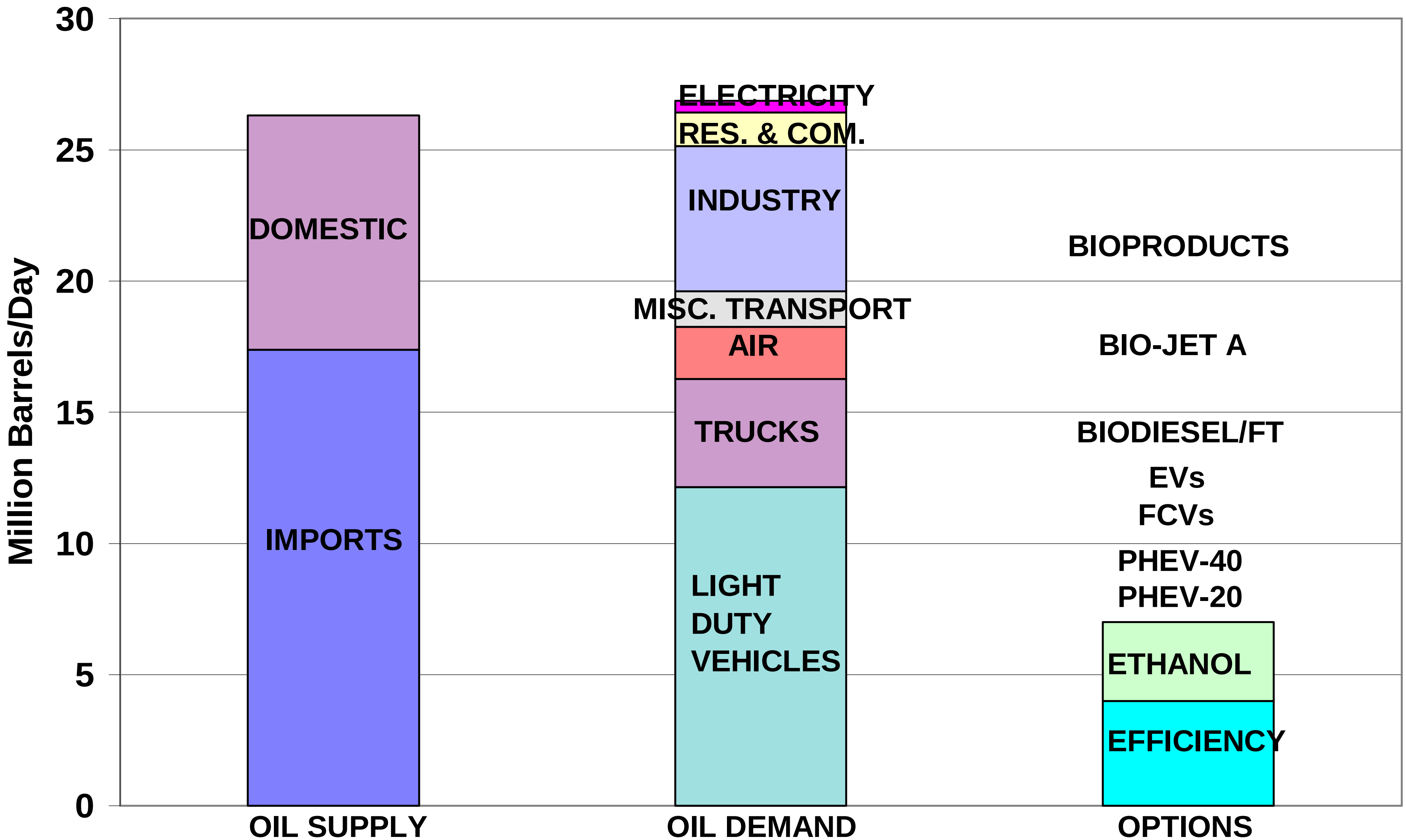
Industry Technology Barriers

- **The Industrial sector, and especially the heavy materials arena, faces a variety of market challenges, frictions, and failures, including:**
  - **1) Mandatory investments; 2) Capacity expansion; 3) Product Development; 4) Cost Reduction—and all face Capital Constraints**
  - **Severe International Competition** by low-wage, low-cost, low environmental compliance countries limit U.S. profit margins and ability to invest in product and process R&D improvements. Some industries carry a high retiree and health overhead, further reducing available capital for R&D investment. Underlying financial health is poor with industry profit margins of 1-2%(?), credit ratings downgraded, resulting in higher cost of capital.
  - **Product Differentiation** is more difficult for basic commodity materials, reducing the incentive for product R&D, and focusing R&D instead on process improvements.
  - **Process R&D.** It can be difficult to fully appropriate the benefits from process R&D. Implementing process changes are high risk for operating lines—shutting down production and risking future production in order to save a relatively small cost for energy. Companies prefer to be the 2^{nd} or 3^{rd} to invest, not the leader, to reduce risk and save capital.
  - **Overall, R&D Investments are low**, averaging 0.8% for energy-intensive industries, compared to 4.3% of sales for all industry (update numbers).
  - **Applications are specialized,** often requiring special development for particular industries.
  - **Scales and capital intensity are large** for greenfield development, thus sharply limiting opportunities for next generation systems. Turnover of existing capital stock is very slow.
  - **Offshoring of consumer product manufacturing** reduces geographical benefit for U.S.-based materials industries.
  - **Research base is eroding**, with few grad students in key areas (metallurgy, motors, etc.)

Transport Energy Use

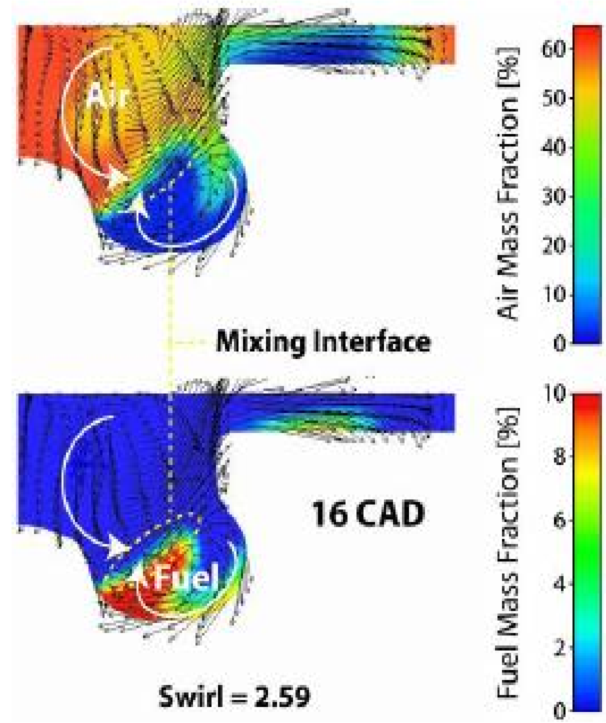


Oil Supply, Demand, Options in 2030



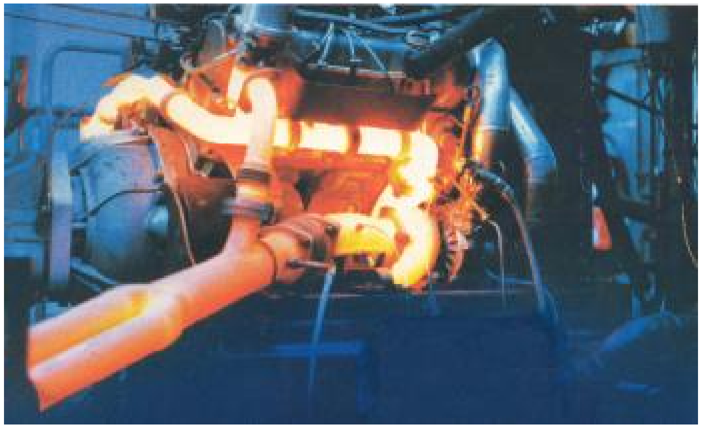
Vehicle R&D Needs

- **High Performance Engines:**
  - Combustion modeling
  - Soot formation and evolution
  - Lean NOx catalyst modeling
  - Low speed multiphase flows; turbulence
- **Battery Storage: HEV/PHEV**
  - High Power/High Energy
  - Abuse Tolerance; Stability
- **Thermoelectrics:**
  - Waste heat recovery
  - Air conditioning
- **Lightweight Frames:**
  - Material deformation in crashes
    - Composites; lightweight alloys.
- **Aerodynamic Drag:**
  - Low speed flow; turbulence
- **Heat Exchangers:**
  - Nanostructured Heat Exchange Fluids
  - Microchannel Heat Exchangers
- **Advanced Motors:**
  - NdFeB temperature sensitivity
- **Power Electronics:**
  - Reliability; Temperature sensitivity



Simulation of Fuel-Air Mixing and Combustion. R.D. Weitz, U Wisconsin, in "Basic Research Needs for Clean and Efficient Combustion of 21st Century Transportation Fuels."

Hot exhaust system suitable for thermoelectrics.

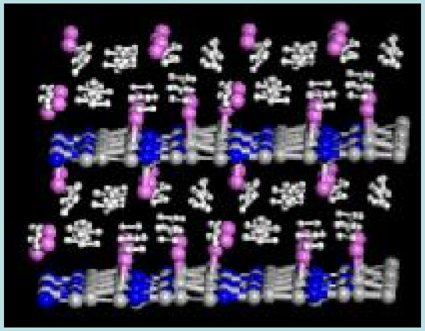


Transport Fuels

- **Advanced Fossil Fuels**
- **Biofuels:** Ethanol; Fischer-Tropsch Liquids; Biodiesel; others.
- **Hydrogen:**
  - **Production:** Fossil or biomass reformers; Fossil-, nuclear-, or renewable-powered electrolysis; Nuclear- or solar-heated thermochemical cycles; Photoelectrochemistry; others
  - **Storage:** Chemical hydrides, alanates, chemical carriers, carbon nanostructures, liquid or compressed gas, etc.
  - **Use:** Fuel cell cathode design and platinum loading; polymer electrolytes; fuel processing catalysis
  - "Summary Report from Theory Focus Session on Hydrogen Storage Materials", http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_theory_focus.html
- **Electricity:** Fossil, Nuclear, Renewables.

Air Products and Chemicals, Inc.

7.4 wt% H_2 in $(C_6N_2)_n^{2n+}$ $2nF^-$ @ 300K



- MD shows lattice expansion upon H_2 adsorption
- Calculated average H_2 adsorption energy of -20.2 kJ/mol H_2 at 7.4 wt% H_2 loading.

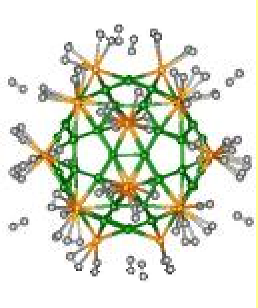
Cheng et al., DOE 2007 Hydrogen Program Review

NREL

TM boride (no-carbon) nanostructures

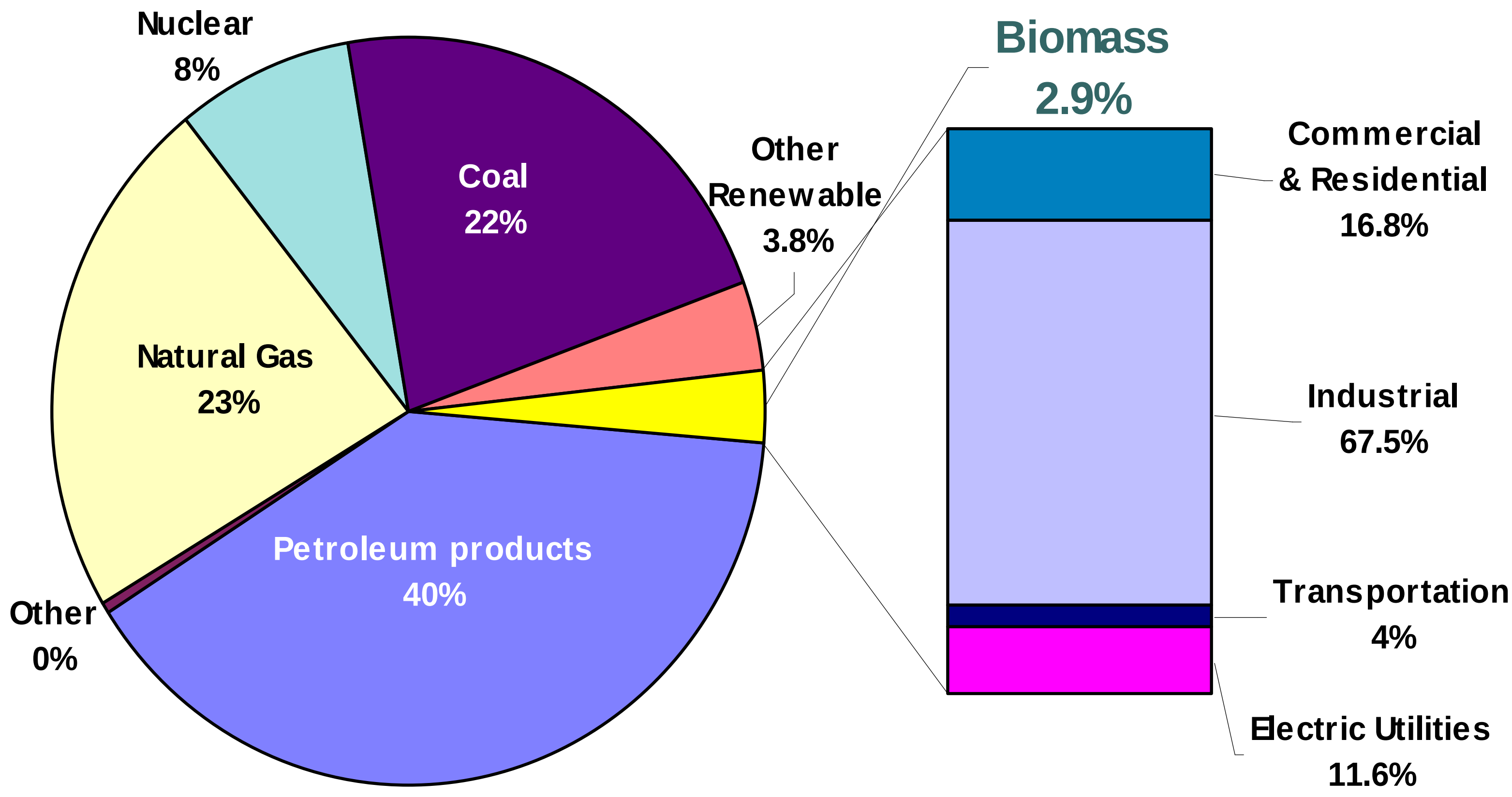
$B_{60}M_{20} + 72\ H_2 \Longleftrightarrow B_{60}M_{20}H_{144}$

- Concepts developed for carbon can be extended to other elements
- Reversible capacity: 8.6 wt%
- Binding energies range: 15 - 35 kJ/mol



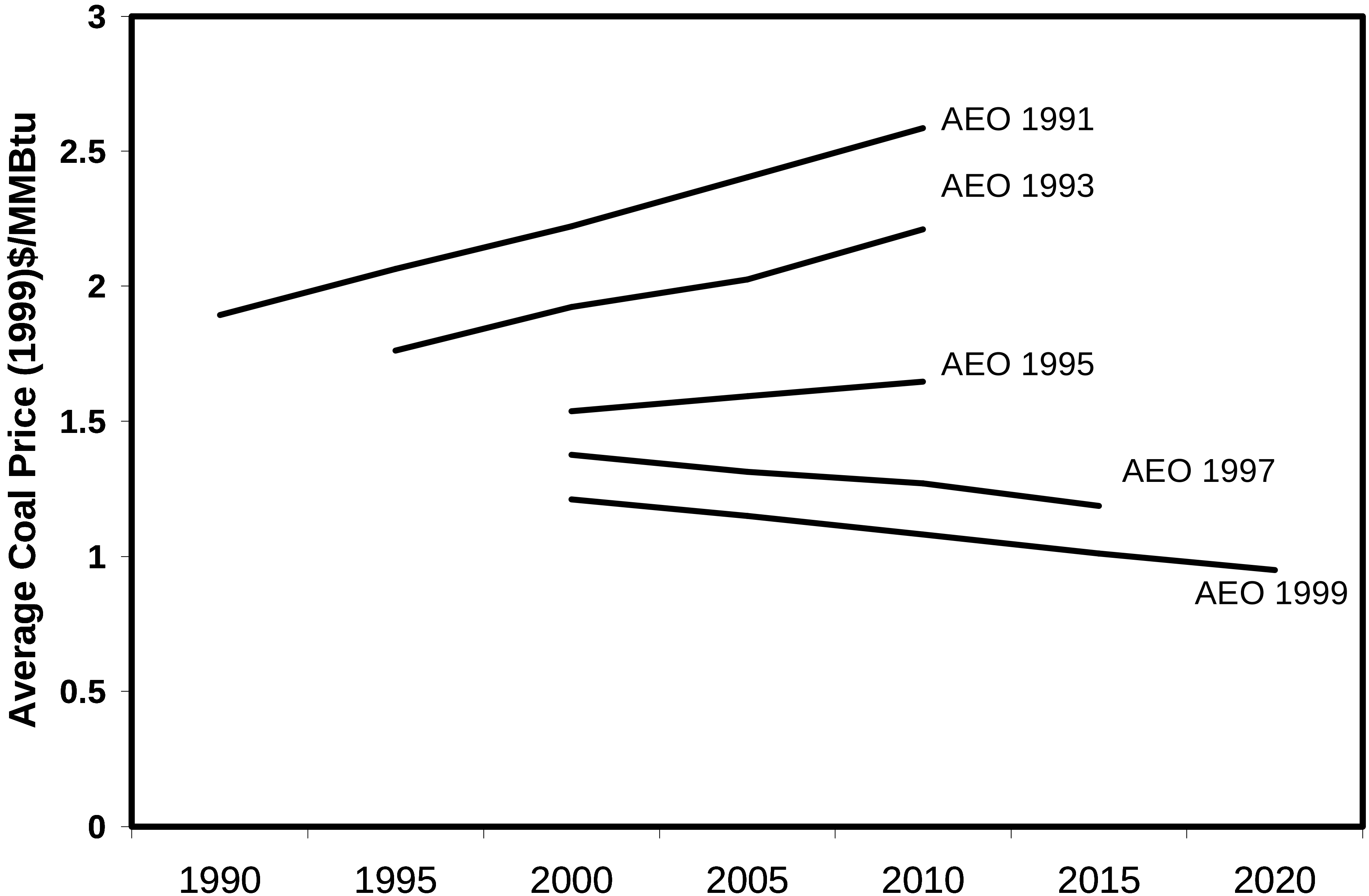
Zhao et al., DOE 2007 Hydrogen Program Review

Bioenergy



Nuclear
8%
Coal
22%
Other
Renewable
3.8%
Natural Gas
23%
Petroleum products
40%
Other
0%
Biomass
2.9%
Commercial
& Residential
16.8%
Industrial
67.5%
Transportation
4%
Electric Utilities
11.6%

EIA Coal Price Projections



Ultimate Biorefinery Goal: From any Feedstock to any Product

Feedstock production, collection, handling & preparation

- Hydrolysis / Acids, enzymes → Sugars and Lignin
- Gasification / High heat, low oxygen → Synthesis Gas
- Digestion / Bacteria → Bio-gas
- Pyrolysis / Catalysis, heat, pressure → Bio-Oil
- Extraction / Mechanical, chemical → Carbon-Rich Chains
- Separation / Mechanical, chemical → Plant Products

USES

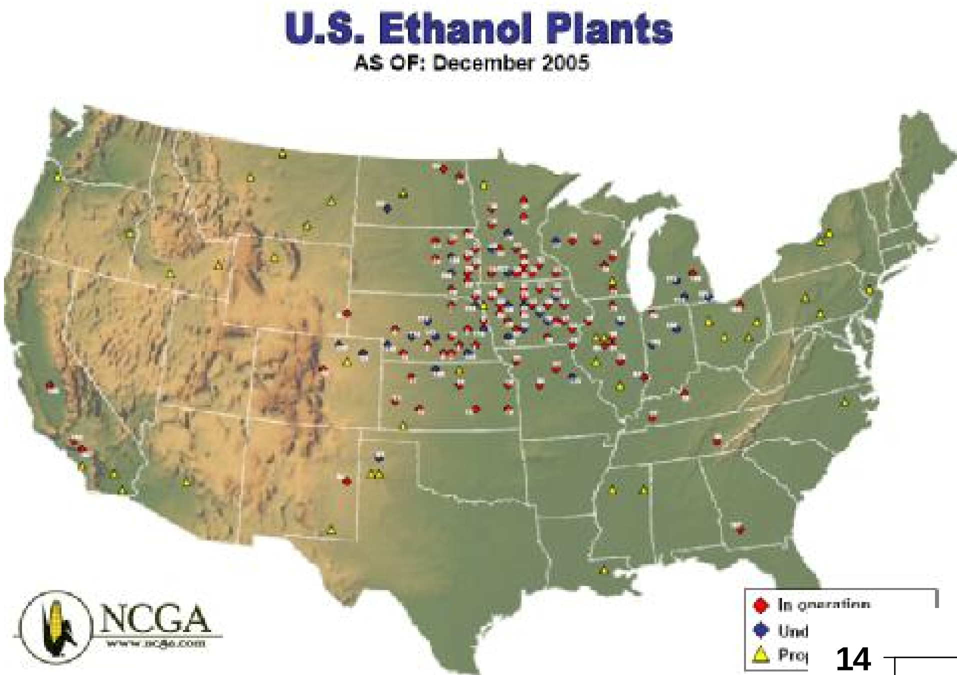
Fuels:
- Ethanol
- Renewable Diesel
- Hydrogen

Power:
- Electricity
- Heat

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

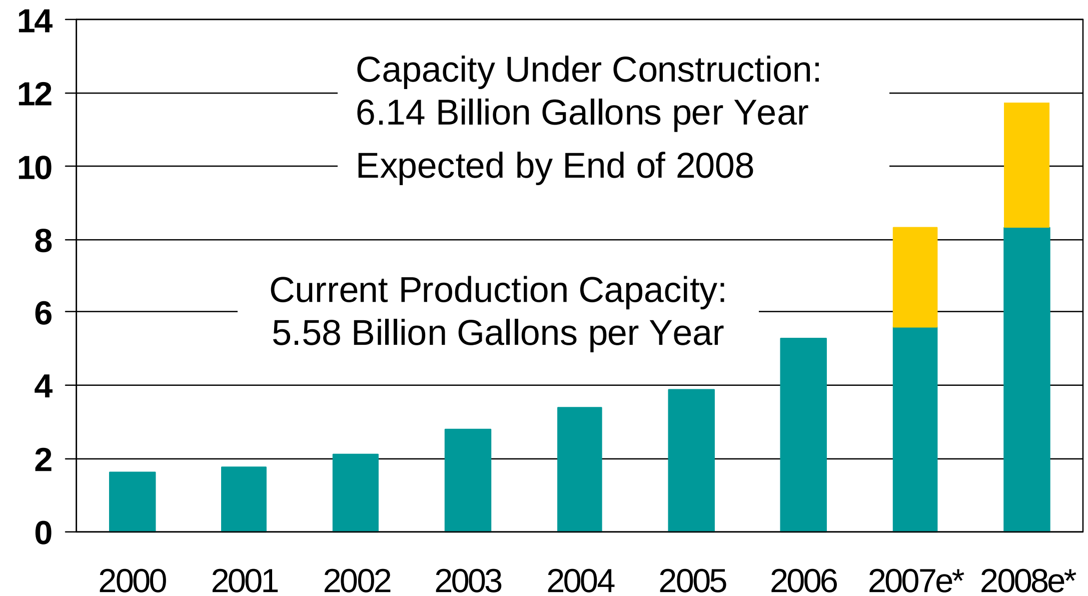
Food and Feed

BioFuels

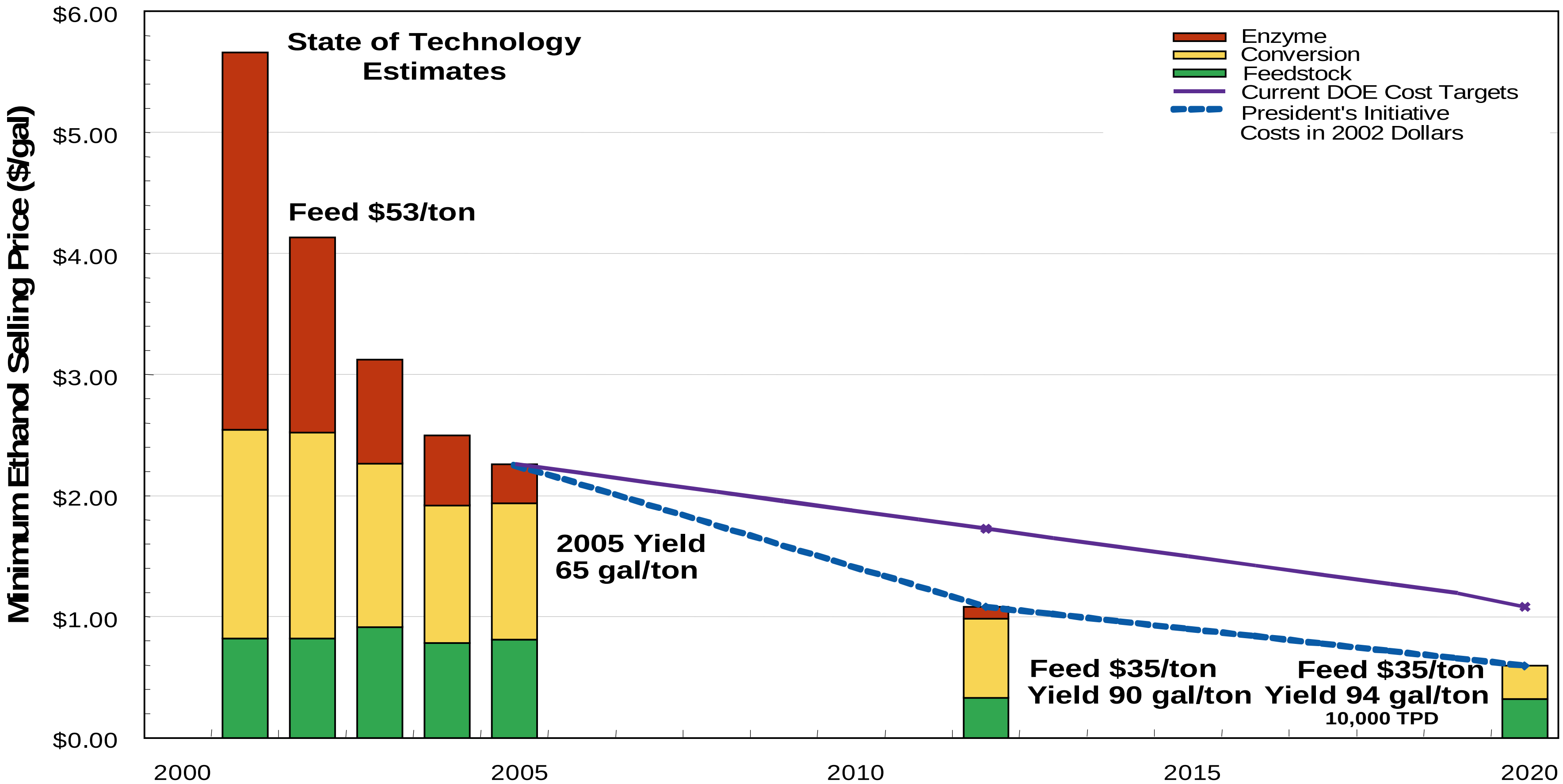


- US near-term potential of 1.3 billion dry tons biomass for energy, with minimal impact to ag/forests; could displace up to 30% oil use as fuel.
- Corn ethanol net energy ~25%; cellulosic ethanol net ~85-90%
- Cargill (-Dow) has 150,000 tons capacity of polylactide polymer/yr.
- Toyota projects global bioplastics market of >$50B by 2020

- Novozyme, Genencor, NREL received 2004 R&D100 award for improving the cellulase enzyme, reducing its cost by ~30-fold to ~$0.18/gallon-ethanol; with corresponding reduction of ethanol cost from $5+/gal to ~$2.25/gal. at present.



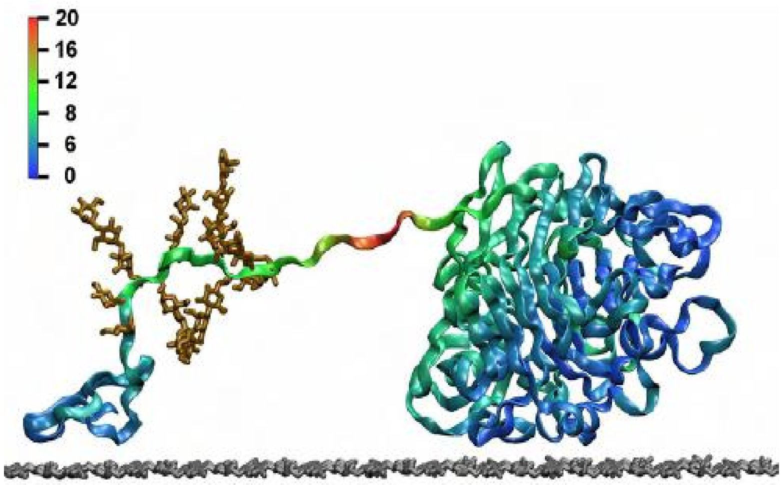
Fermentation Platform Cost Reduction



Source: NREL

BioEnergy R&D

- **Feedstock production and collection**
  - Functional genomics; respiration; metabolism; nutrient use; water use; cellular control mechanisms; physiology; disease response;
  - Plant growth, response to stress/marginal lands; higher productivity at lower input (water, fertilizer)
  - Production of specified components
- **Biochemical platform**
  - Biocatalysis: enzyme function/regulation; enzyme engineering for reaction rates/specificity
- **Thermochemical platform**
  - Product-selective thermal cracking. Modeling catalyst-syngas conversion to mixed alcohols, FTs—predicting selectivity, reaction rates, controlling deactivation due to sulfur (e.g. role of Ru in improving S tolerance of Ni).
  - CFD modeling of physical and chemical processes in a gasification/pyrolysis reactor
- **Bioproducts**
  - New and novel monomers and polymers;
  - Biomass composites; adhesion/surface science
- **Combustion**
  - NOx chemistry, hot gas cleanup

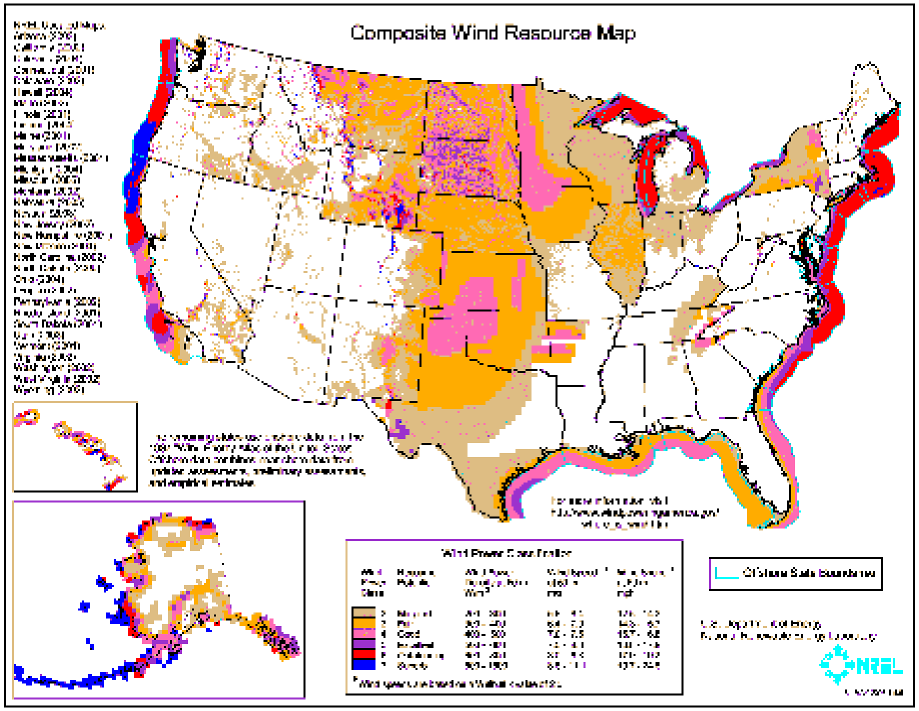


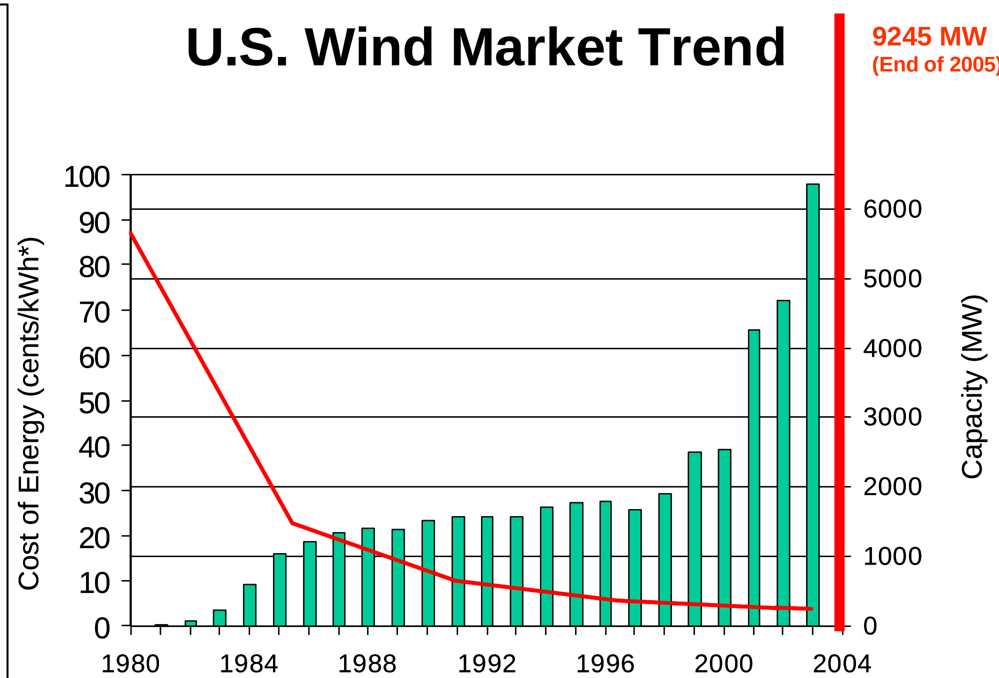
Cellulase Enzyme interacting with Cellulose. Source, Linghao Zhong, et al., “Interactions of the Complete Cellobiohydrolase I from *Trichodera reesei* with Microcrystalline Cellulose I”

Wind Energy

>16,800
2007

11,600
2006

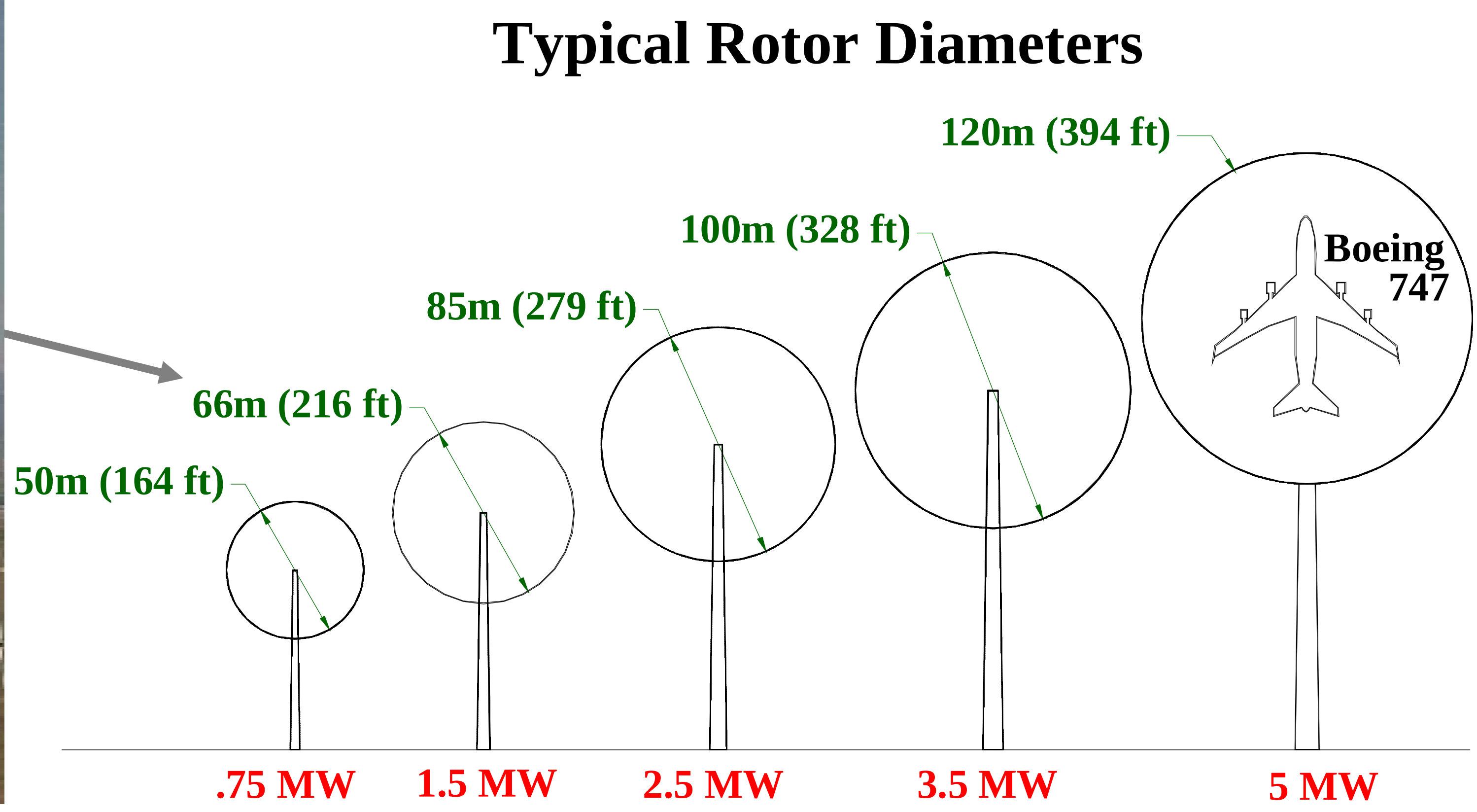




- R&D has reduced cost of wind power from 80 cents per kilowatt-hour in 1979 to a current range of ~5+ cents per kWh (Class 5-6), moving towards 3 c/kWh.
- Low wind speed technology: x20 resource; x5 proximity
- Offshore Resources

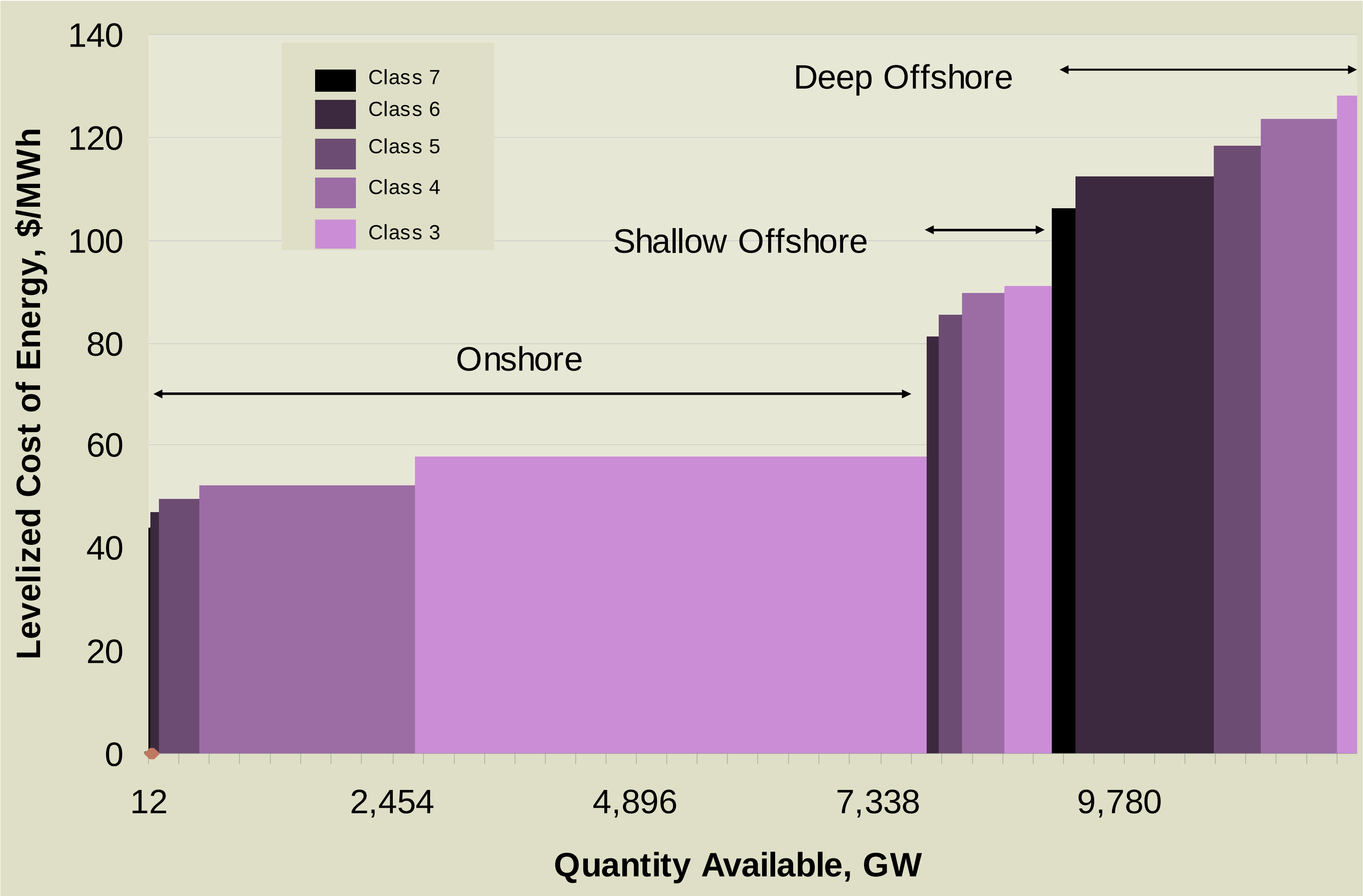
Big Machines, and Growing…

GE Wind 1.5 MW



Source: WTP

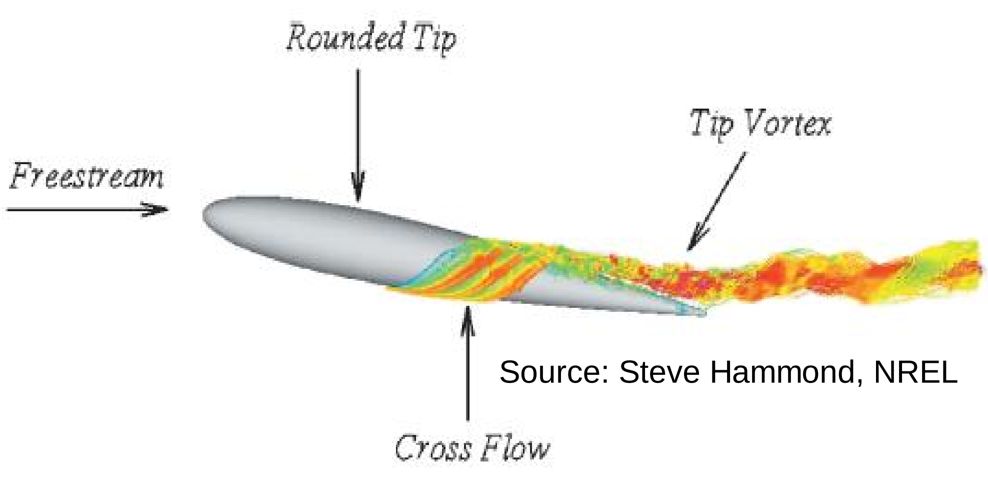
U.S. Wind Supply Curve



Busbar Cost, No Transmission Cost, Today's Cost/Performance, with PTC (2006$)

Wind Energy Challenges

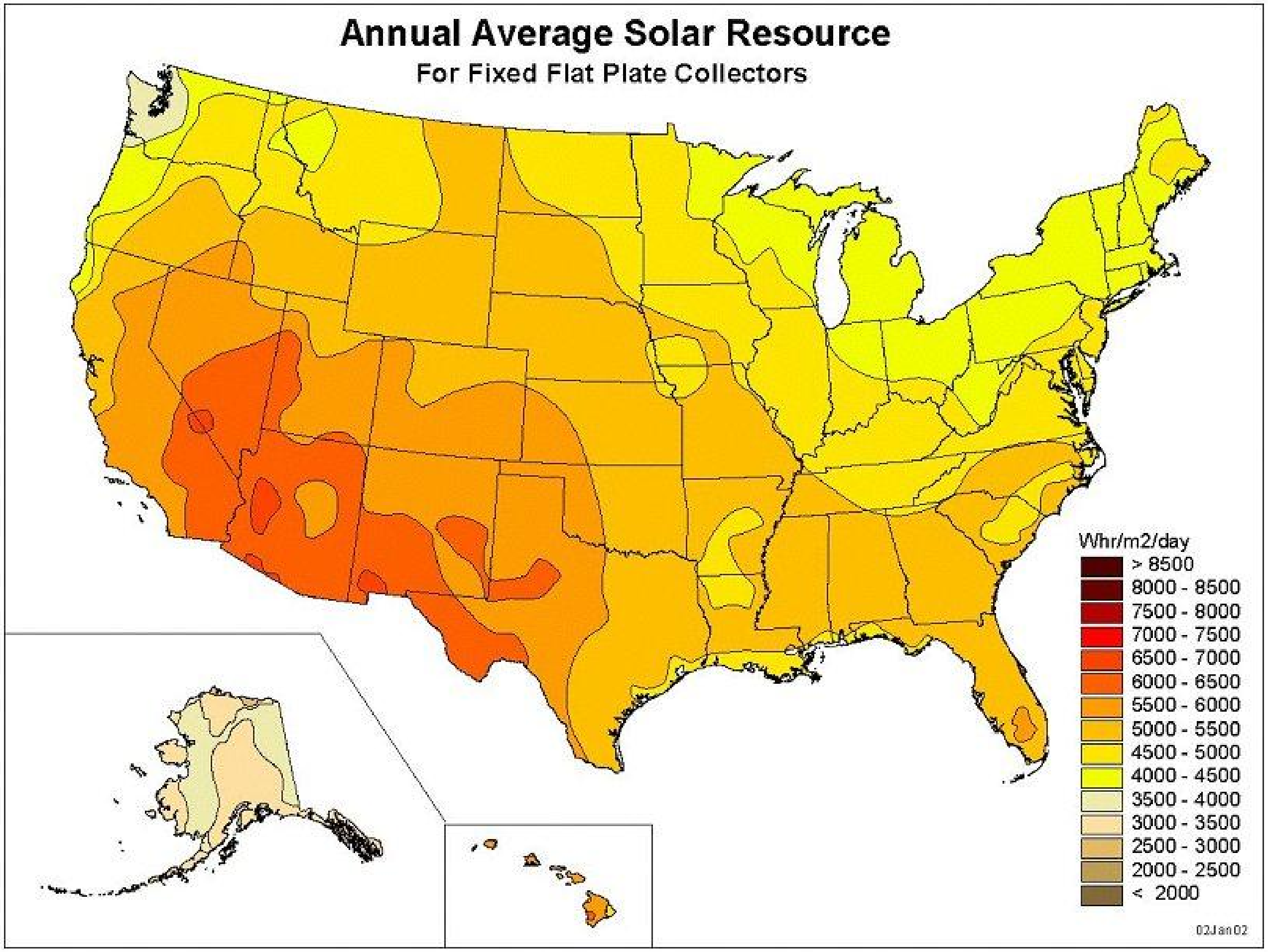
- **Wind Energy Systems:**
  - Stiff, heavy machines that resist cyclic and extreme loads—Versus—Lightweight, flexible machines that bend and absorb or shed loads.
  - Need 30 year life in fatigue driven environment with minimal maintenance/no major component replacement.
  - Improve models of turbulence and flow separation; Improve analysis of aeroacoustics, aeroelastics, structural dynamics, etc.
- **Wind Turbine Design Methods:**
  - Replace full-scale testing with computational models to prove the efficacy of blade and turbine design.
- **Wind Farm Design:**
  - Model turbine interactions with each other and with complex terrain to improve farm layout.
- **Composite Materials:**
  - Model material strength, fatigue (progressive loss of strength and stiffness), and failure (fiber failure, bond failure, wall collapse, buckling, etc.)
- **Grid Integration:**
  - Understand impact of system on the utility grid—to better accommodate intermittent wind.
- **Atmospheric Modeling:**
  - Improve modeling for wind forecasting; turbine interactions.
- **Optimize Turbines for Ocean:**
  - Wave loading; marine environment



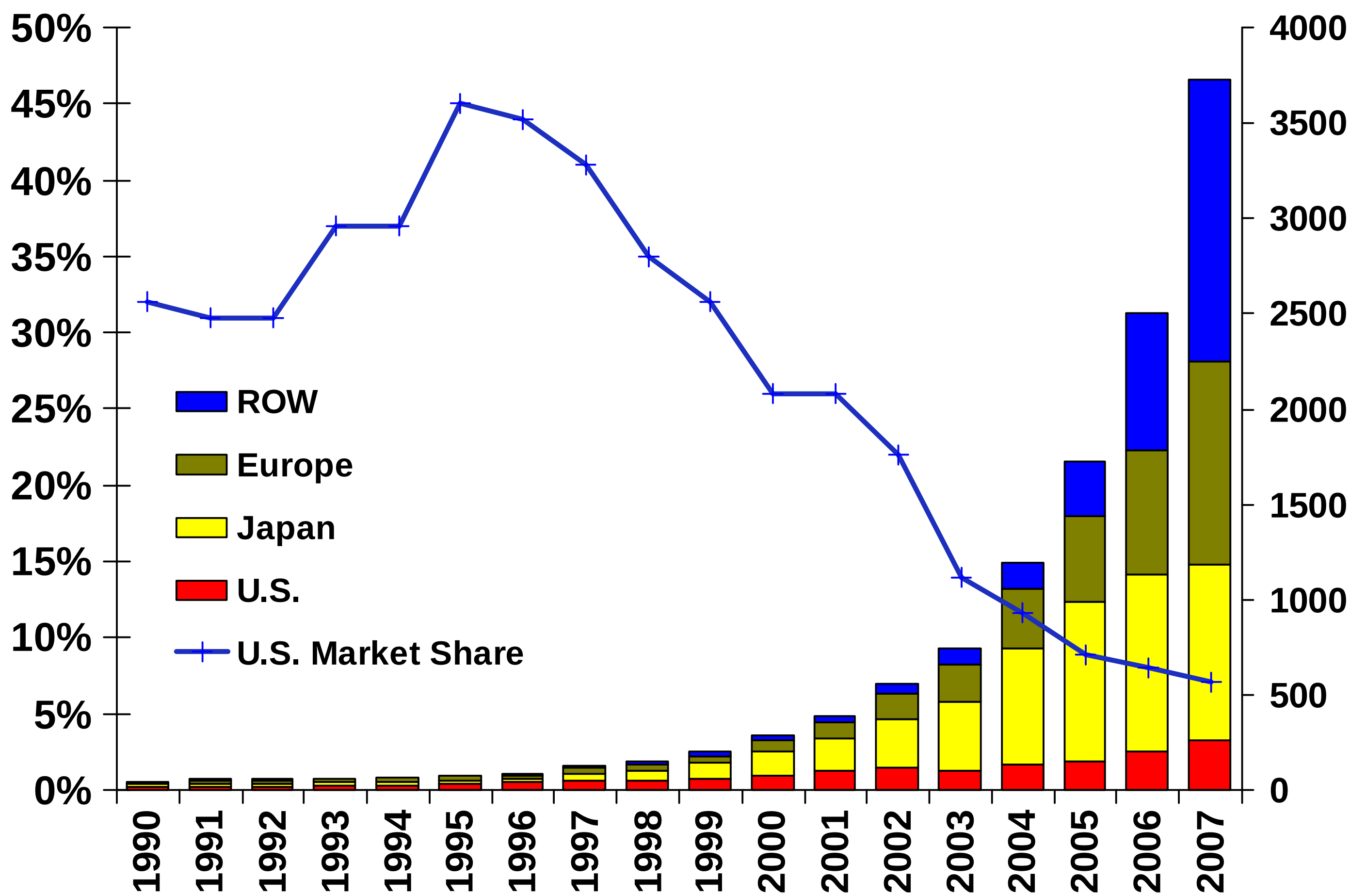
Source: Steve Hammond, NREL

Solar Energy

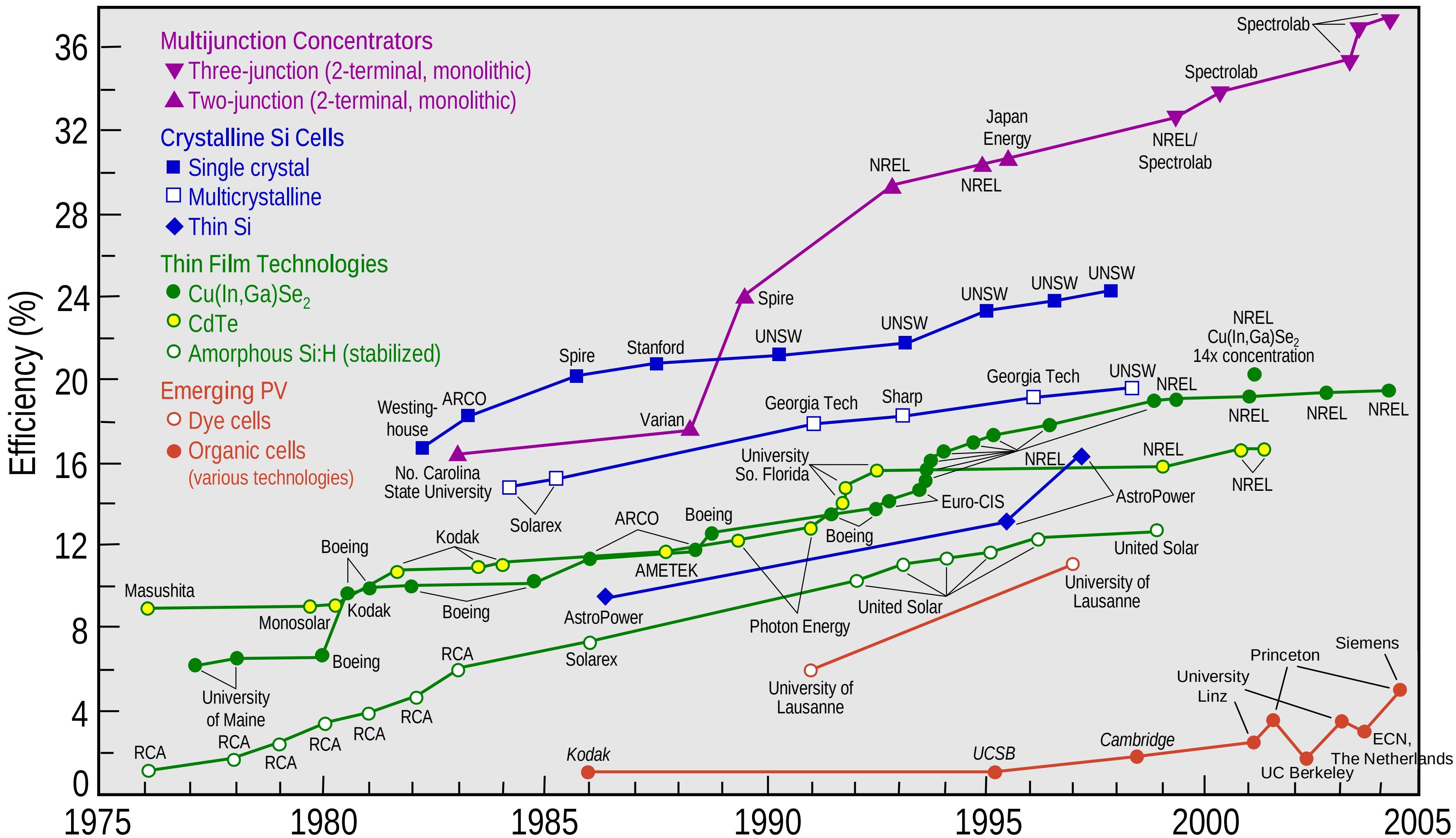
- Price of electricity from grid-connected PV systems are ~20¢/kWh. (Down from ~$2.00/kWh in 1980)
- Nine parabolic trough plants with a total rated capacity of 354 MW have operated since 1985, with demonstrated system costs of 12 to 14¢/kWh.



PV Shipments and U.S. Market Share



Best Research-Cell Efficiencies



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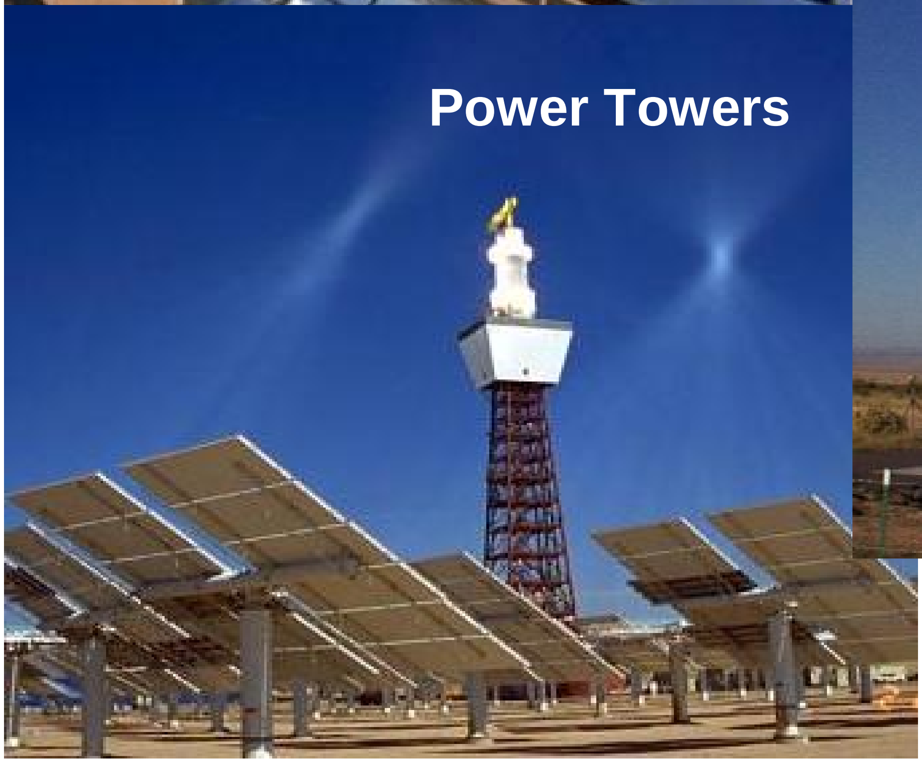
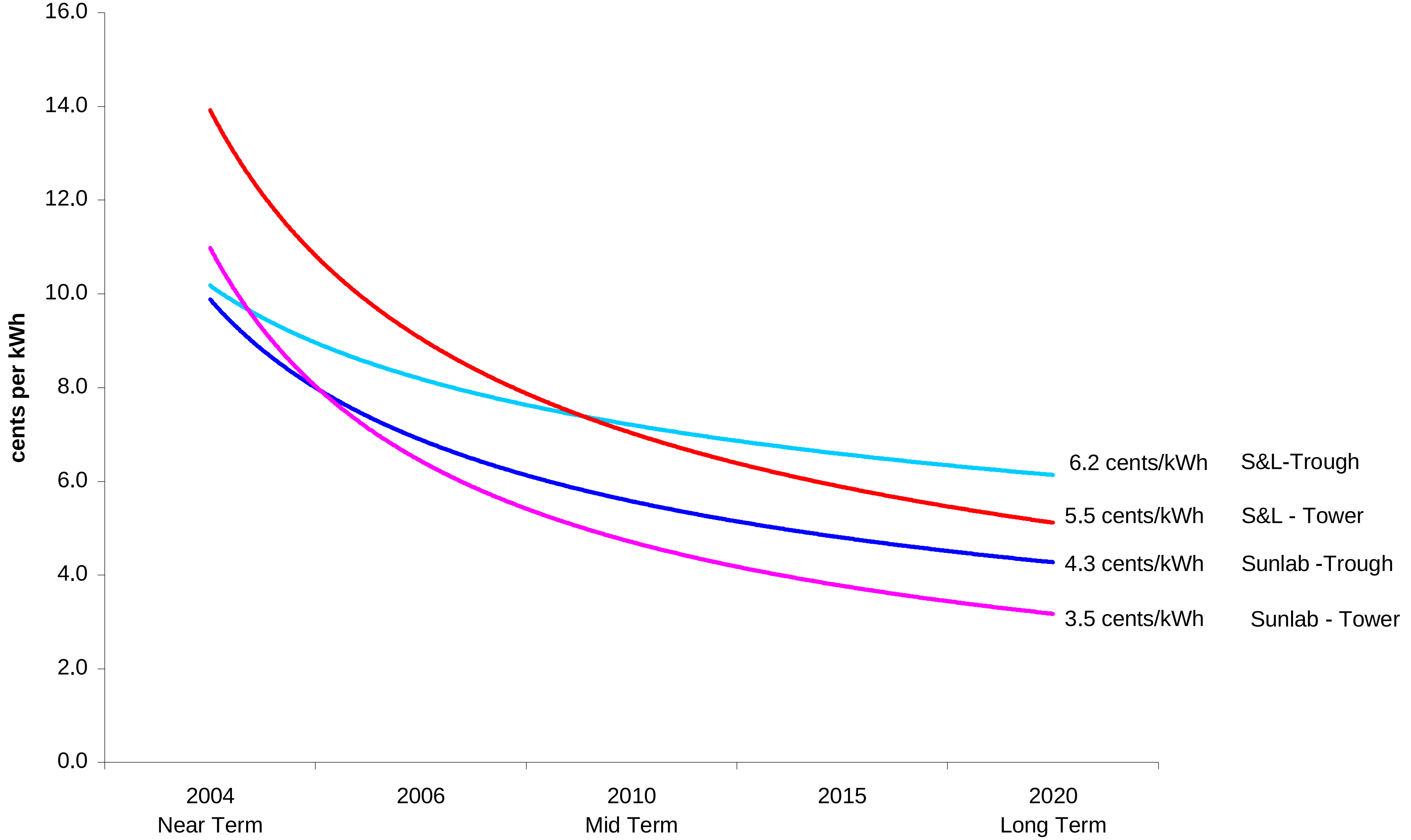
Source: NREL

Concentrating Solar Thermal Power



Source: NREL

CSP Cost Projections



Sargent & Lundy

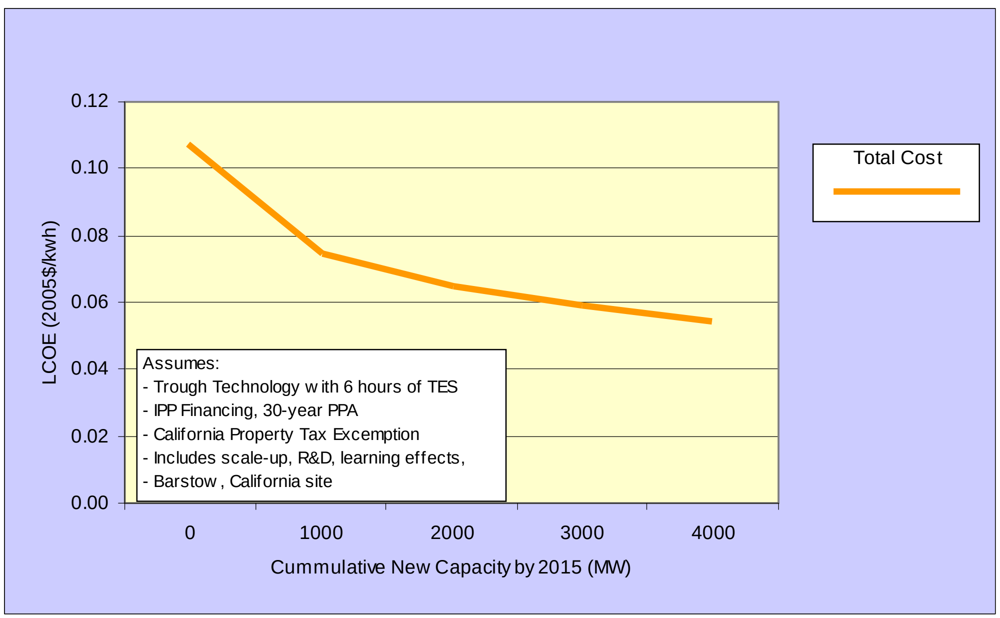
Concentrating Solar Power
U.S. Southwest – Significant Opportunity for CSP

Untapped Electricity Generation Potential

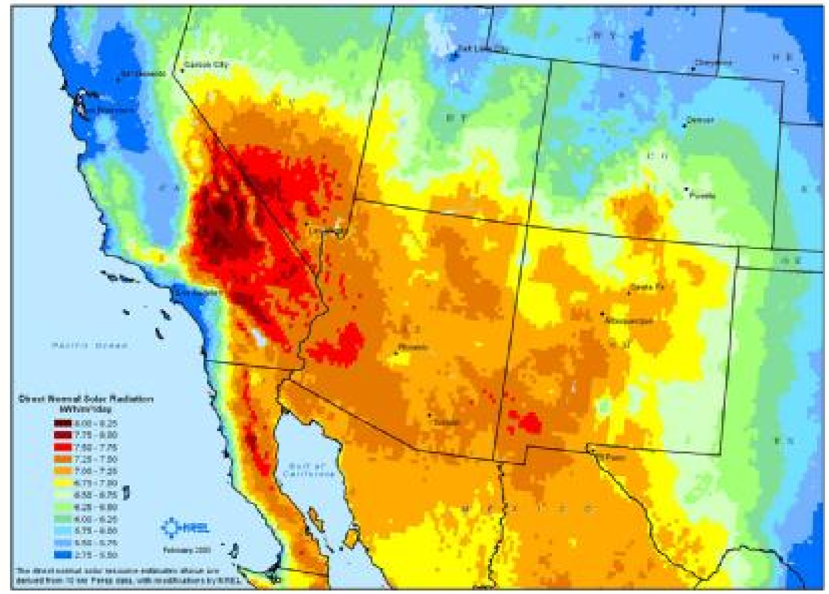
– Solar energy in southwestern states could generate 6,800 GW of electricity. (Current U.S. generating capacity is approximately 1,000 GW.)

Cost Reduction Potential

– Estimates from Sargent & Lundy and WGA Solar Task Force indicate costs can go below 6 cents/kWh assuming R&D and deployment.



Direct-Normal Solar Resource for the Southwest U.S.



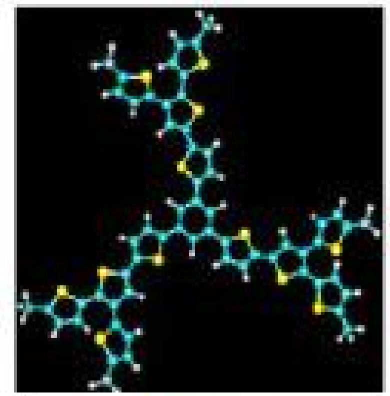
Potential Generation Capacity by State

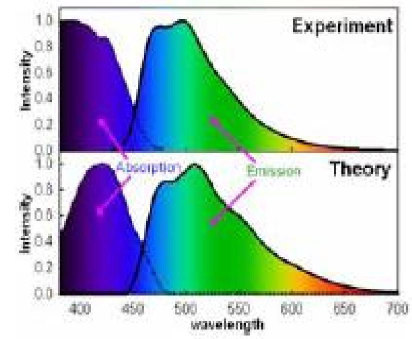
State	Land Area (mi²)	Solar Capacity (GW)	Solar Generation Capacity (GWh)
AZ	19,279	2,468	5,836,517
CA	6,853	877	2,074,763
CO	2,124	272	643,105
NV	5,589	715	1,692,154
NM	15,156	1,940	4,588,417
TX	1,162	149	351,774
UT	3,564	456	1,078,879
Total	53,727	6,877	16,265,611

Map and table courtesy of NREL

Solar Energy R&D Opportunities

- **Photovoltaics**:
  - Improve understanding of materials/growth/characterization and devices, esp. of CIGS, CdTe and Multi-junction thin films—interface chemistry, physics, defects, etc.
  - Improve efficiency of photon use with intermediate-band cells, Quantum Dot cells, etc.
  - Transparent conducting oxides
  - Innovative encapsulants.
- **Concentrating Solar Power**:
  - Stable, high temperature heat transfer and thermal storage materials, with low vapor pressure, low freezing points
  - Stable, high temperature, high performance selective surfaces
  - High performance reflectors
- **Fuels:**
  - High-temperature thermochemical cycles for CSP production—353 found & scored; 12 under further study; Develop falling particle receiver and heat transfer system for up to 1000 C cycles. Develop reactor/receiver designs and materials for up to 1800 C cycles.
  - Improved catalysts
  - Photoelectrochemical: good band-edge matching, durable in solution, manufacturable
  - Photobiological—unleashing hydrogenase pathway;
  - Electrolysis, including thermally boosted solid-oxide electrochemical cells
- **Cross-cutting Areas**:
  - Power electronics—wide-band gap materials; Reliable capacitors
  - Energy Storage





Source: *Muhammet E. Köse, et al.* "Theoretical Studies on Conjugated Phenyl-Cored Thiophene Dendrimers for Photovoltaic Applications", NREL

Solar Decathlon: *"Energy We Can Live With"*; Oct.12–Oct. 20

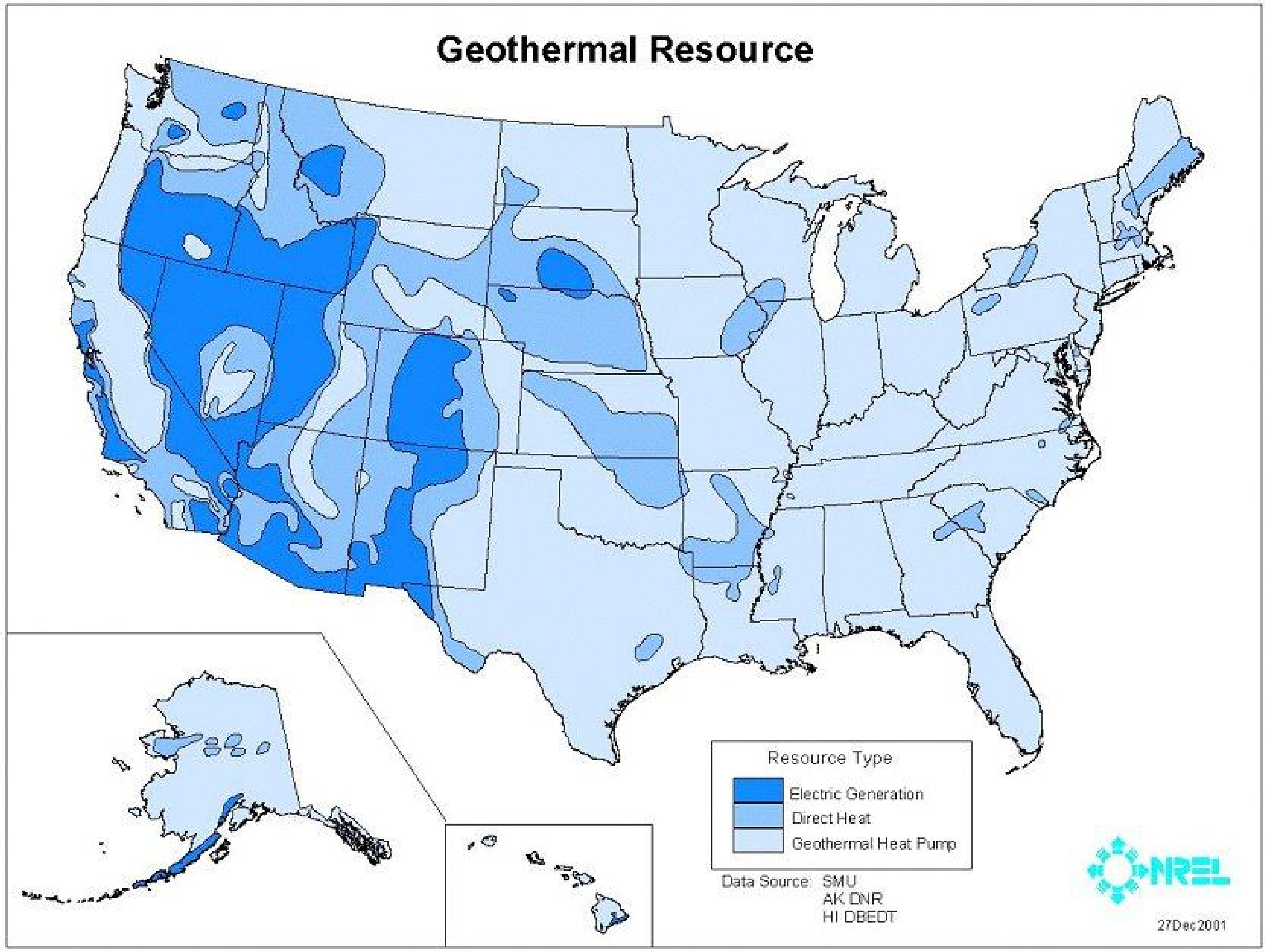
Architecture
Engineering
Market Viability
Communications
Comfort

Appliances
Hot Water
Lighting
Energy Balance
Getting Around

Carnegie Mellon; Cornell; Georgia Tech; Kansas State; Lawrence Technological University; MIT; New York Institute of Technology; Pennsylvania State; Santa Clara University; Team Montreal (École de Technologie Supérieure, Université de Montréal, McGill University); Technische Universität Darmstadt; Texas A&M; Universidad Politécnica de Madrid; Universidad de Puerto Rico; University of Colorado – Boulder; University of Cincinnati; University of Illinois; University of Maryland; University of Missouri, Rolla; University of Texas, Austin.

Source: STP

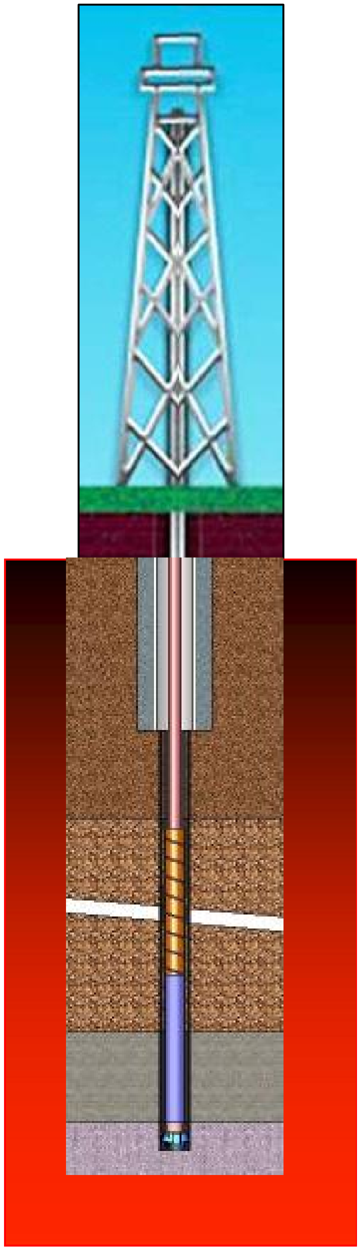
Geothermal Technologies



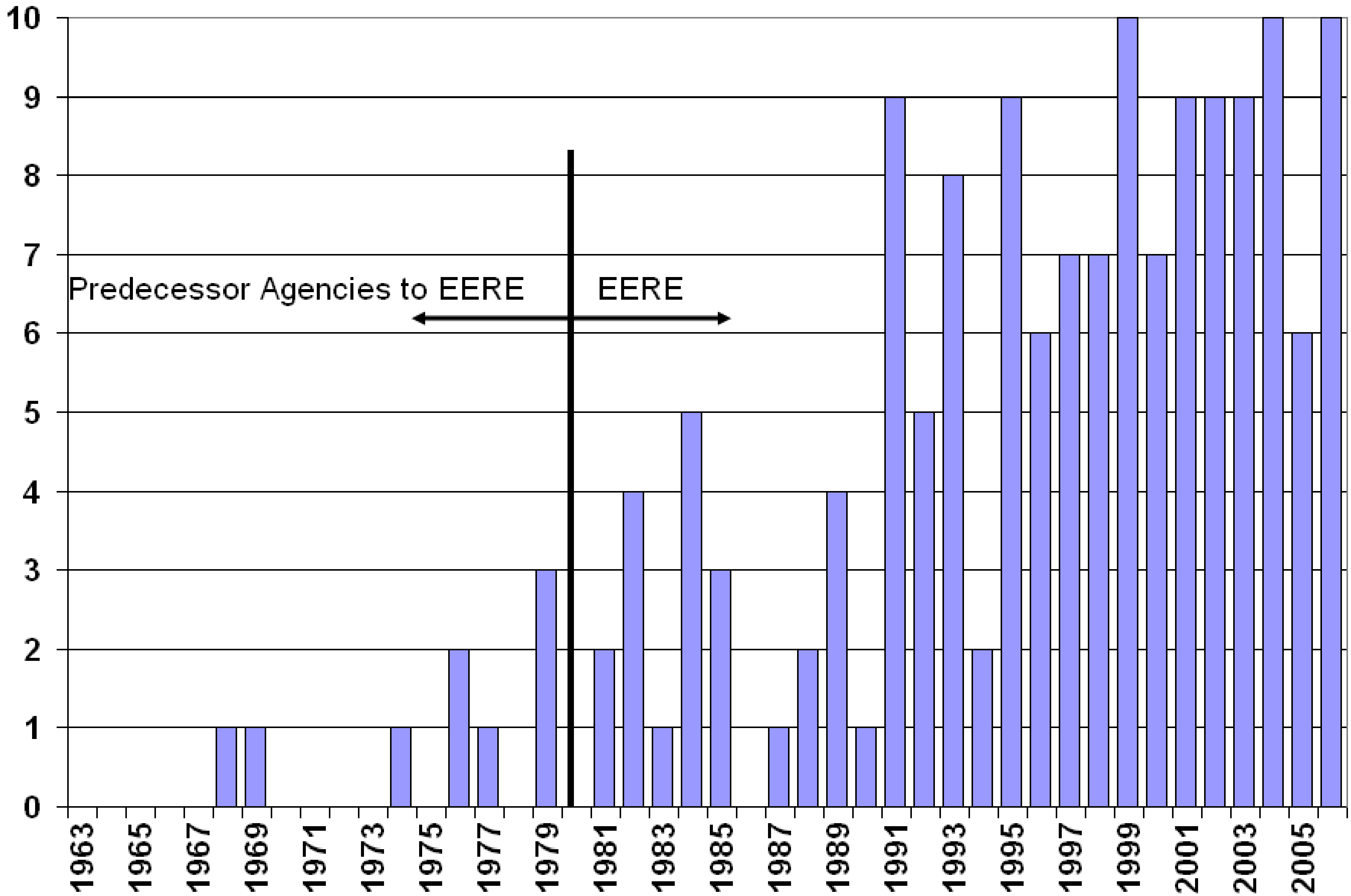
- Current U.S. capacity is ~2,800 MW; 8,000 MW worldwide.
- Current cost is 5 to 8¢/kWh; Down from 15¢/kWh in 1985
- 2010 goal: 3-5¢/kWh.

Geothermal R&D Opportunities

- **Exploration:**
  - Remote sensing
- **Reservoir Development:**
  - Well stimulation techniques; proppants
- **Drilling and Field Development**:
  - Bits--advanced materials, controls, mechanisms; (PDC Bits)
  - High-temp systems; diagnostics while drilling; telemetry
  - Lost circulation or short circuit control materials/techniques
  - Liners; casings; cements
- **Conversion**:
  - Mixed working fluids in binary plants;
  - Variable Phase Turbines;
  - Enhanced Heat Rejection
- **Oil & Gas**:
  - Coproduction of geothermal energy using binary systems
- **Sequestration**: CO_2 as a working (supercritical) fluid for EGS
  - Reduced power consumption in flow circulation; Reduced viscosity/higher flow rates than water, but lower heat capacity
  - CO_2 uptake/mineralization/sequestration at elevated temp.



EERE-Supported R&D100 Awards



For more information

http://www.eere.energy.gov