Energy Efficiency & Renewable Energy: Challenges and Opportunities

Florida Energy Systems Consortium
University of Florida
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Sam Baldwin

Chief Technology Officer and Member, Board of Directors
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Challenges

- **Economy—**economic development and growth; energy costs
- **Security—**foreign energy dependence, reliability, stability
- **Environment—**local (particulates), regional (acid rain), global (GHGs)
- **Scale**
- **Time to Respond**

Can EE & RE meet these Challenges?

- **Efficiency: Buildings, Industry, Transport**
- **Oil and Electricity**
- **Renewable Energy Technologies**
- **Constraints**
- **Price Points**

The EE & RE Opportunity

- **Administration Support**
- **Budgets**
- **Legislation**

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**

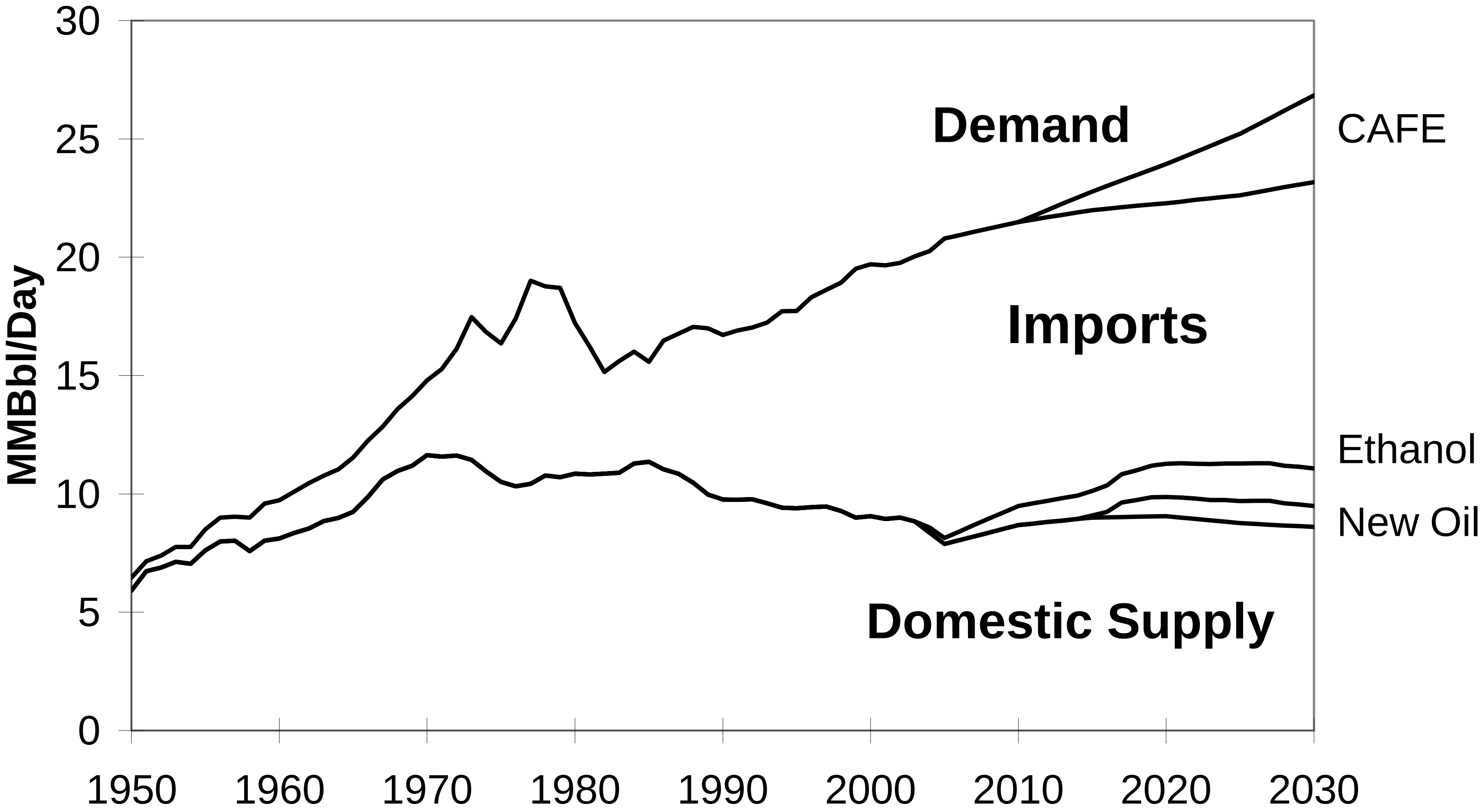
Nations that **NEED** oil (% of Global Consumption)	
U.S.	**24.4%**
China	8.6
Japan	5.9
Russia	3.4
India	3.1
Germany	2.9
Canada	2.8
Brazil	2.6
S. Korea	2.6
Mexico	2.4
France	2.3
Italy	2.0
Total	85 MM Bbl/day

Source: EIA International Energy Annual

Impacts of Oil Dependence

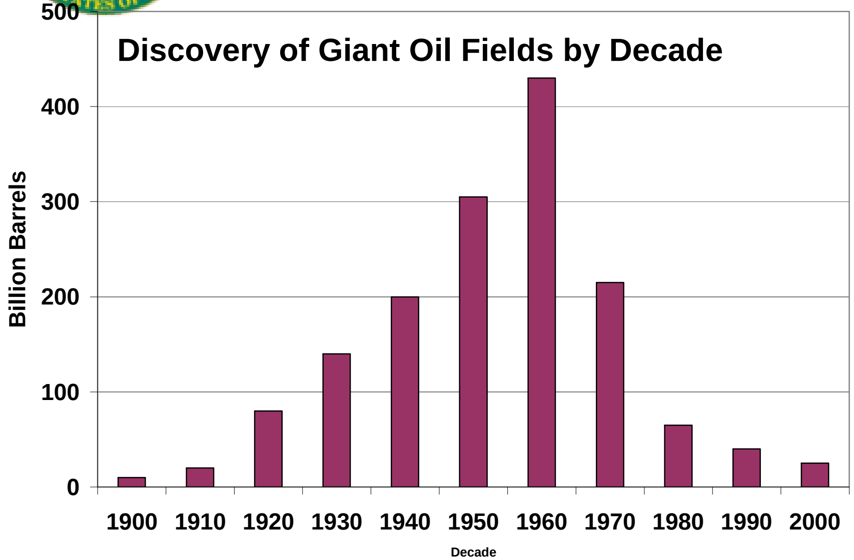
- **Domestic Economic Impact**
- **Trade Deficit**: **Oil ~57% of $677B trade deficit in 2008**
- **Foreign Policy Impacts**
  - Strategic competition for access to oil
  - Oil money supports undesirable regimes
  - Oil money finds its way to terrorist organizations
- **Vulnerabilities**
  - to system failures: tanker spills; pipeline corrosion; …
  - to natural disasters: Katrina; …
  - to political upheaval: Nigeria; …
  - to terrorist acts: Yemen; Saudi Arabia; …
- **Economic Development**
  - Developing country growth stunted by high oil prices; increases instability
- **Natural Gas?**
  - Largest producers: Algeria, Iran, Qatar, Russia, Venezuela
  - Russia provides 40% of European NG imports now; 70% by 2030.
  - Russia cut-off of natural gas to Ukraine

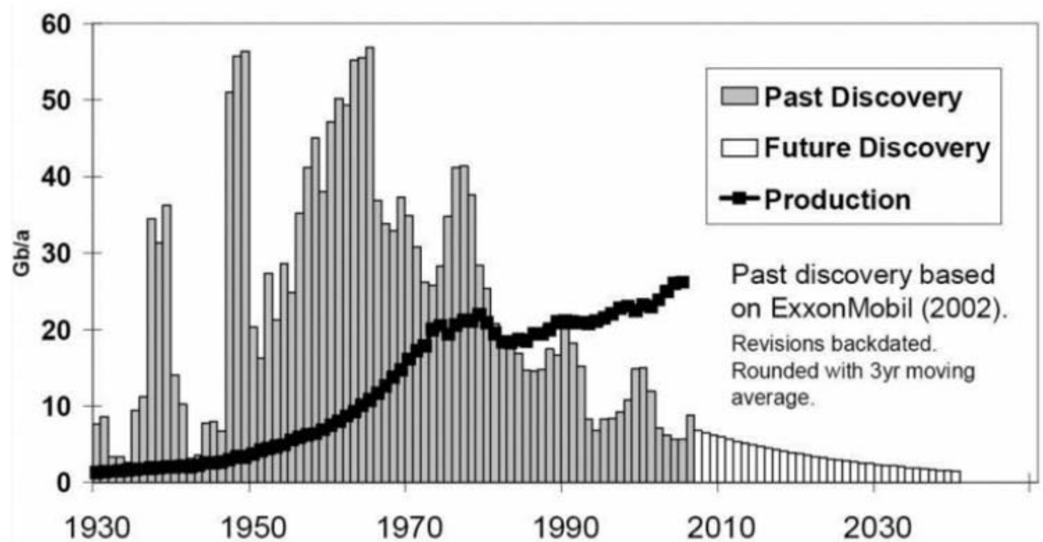
Oil Futures



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

Conventional Oil

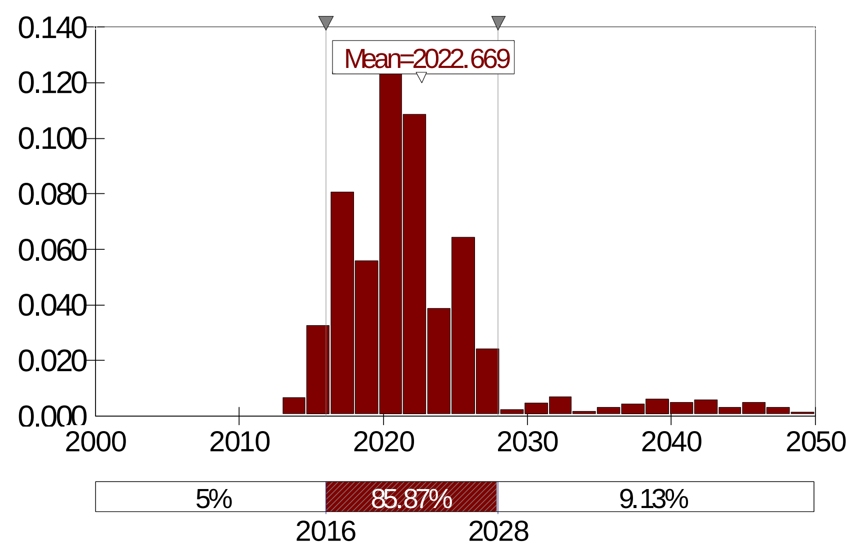




International Energy Agency, 2008

- Across 798 of world's largest oil fields, average production decline of 6.7%/year.
- Of 798 fields, 580 had passed peak.
- To meet growth & replace exhausted resources, will have to add 64 MB/d by 2030, or 6X Saudi Arabia.

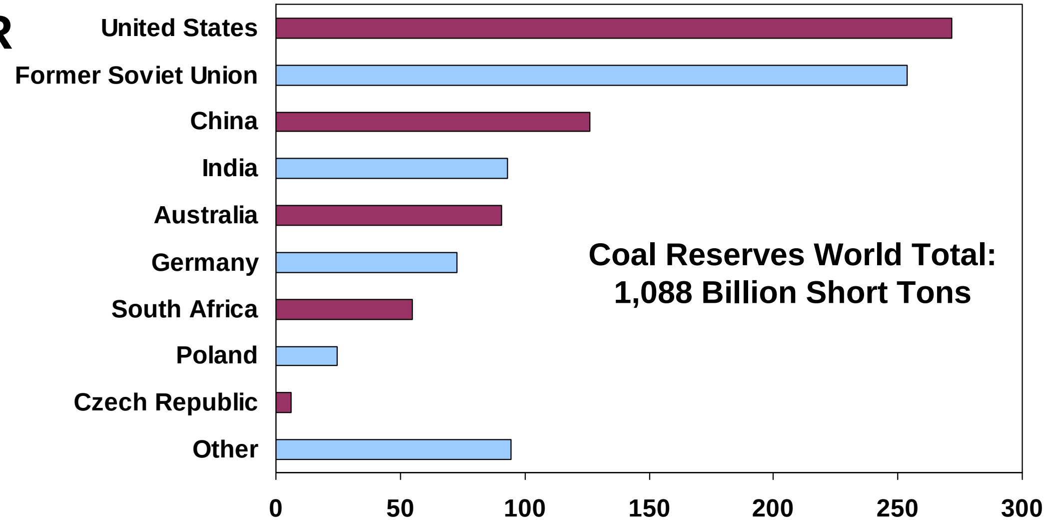
Peak Year of ROW Conventional Oil Production: Reference/USGS



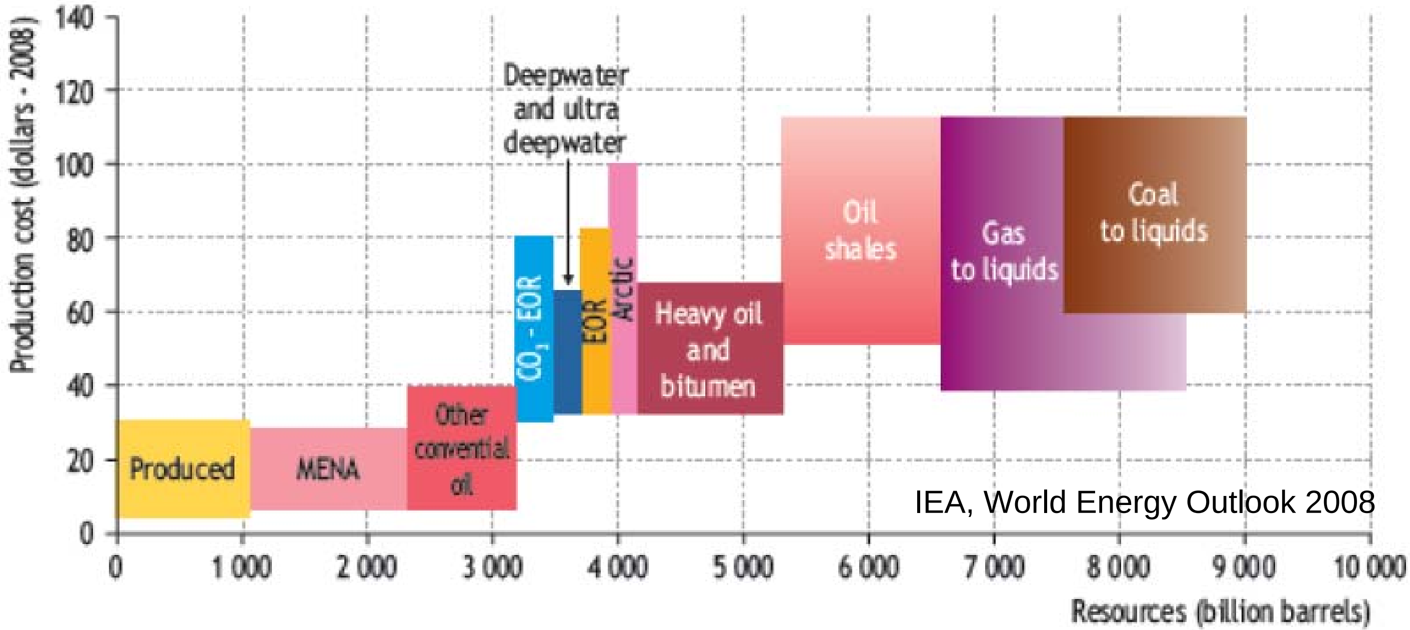
- Sources: (Figure 1) Fredrik Robelius, Uppsala Universitet; (Figure 2) Association for the Study of Peak Oil; (Figure 3) David Greene, ORNL.

Oil Sources

- Resources
  - Oil: Infill wells, Flooding, EOR
  - 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)



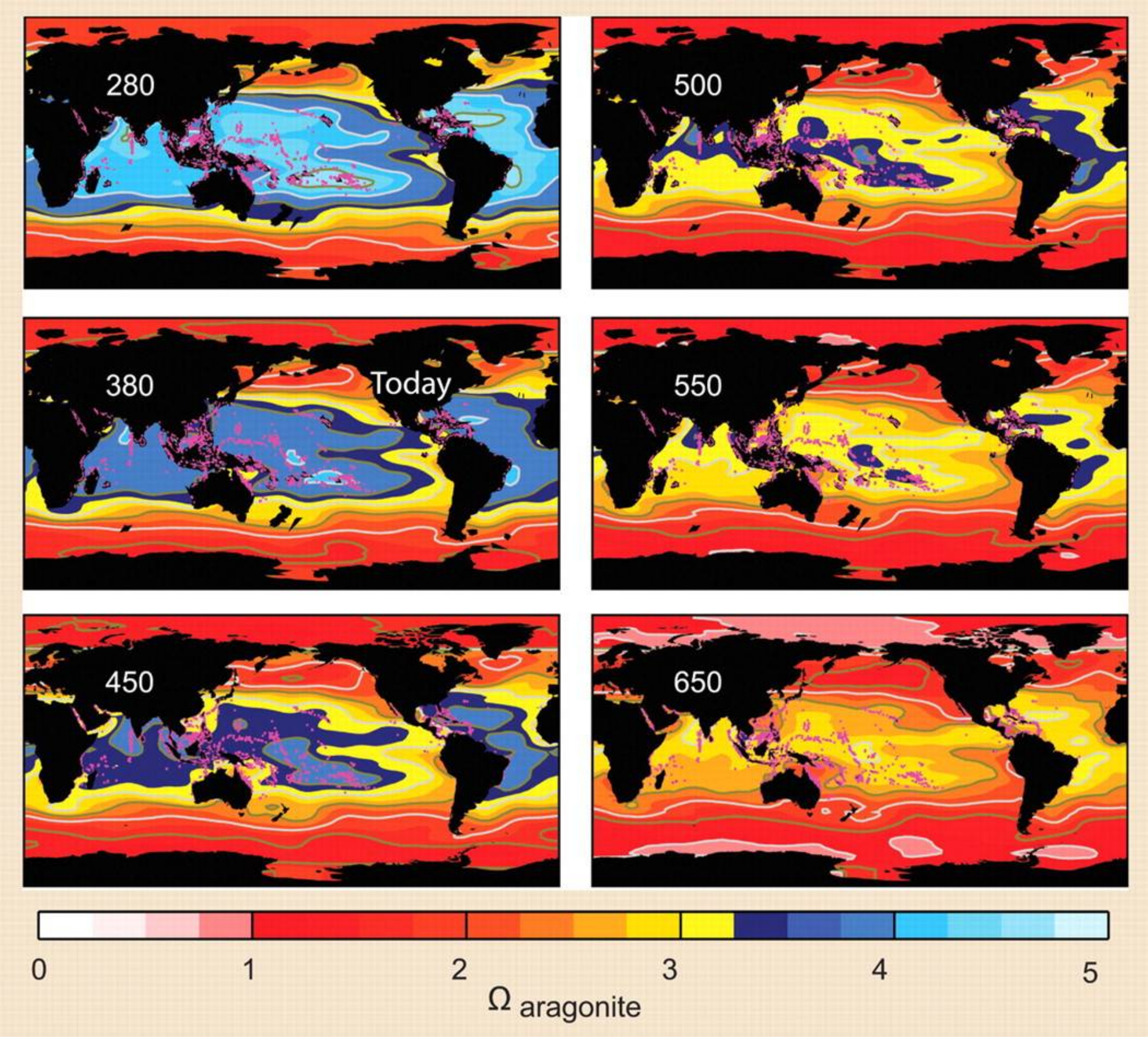
- Constraints
  - Cost
  - Energy
  - Water
  - Atmosphere



IEA, World Energy Outlook 2008

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
- Ocean Acidification
- Ocean Oxygen Levels
- Sea Level Rise
- Human Health Impacts
- Feedback Effects



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

U.S.: 5.9 GT CO_2/yr energy-related
World: 28.3 GT CO_2/yr

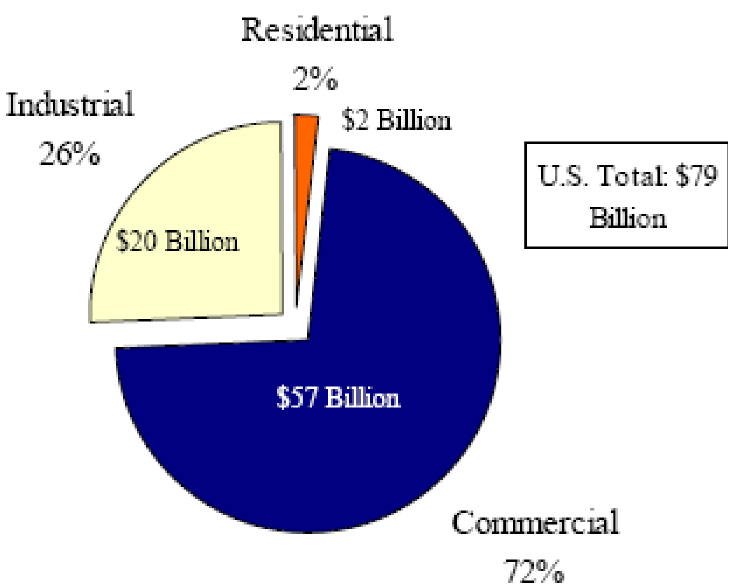
InterAcademy Panel Statement On Ocean Acidification, 1 June 2009

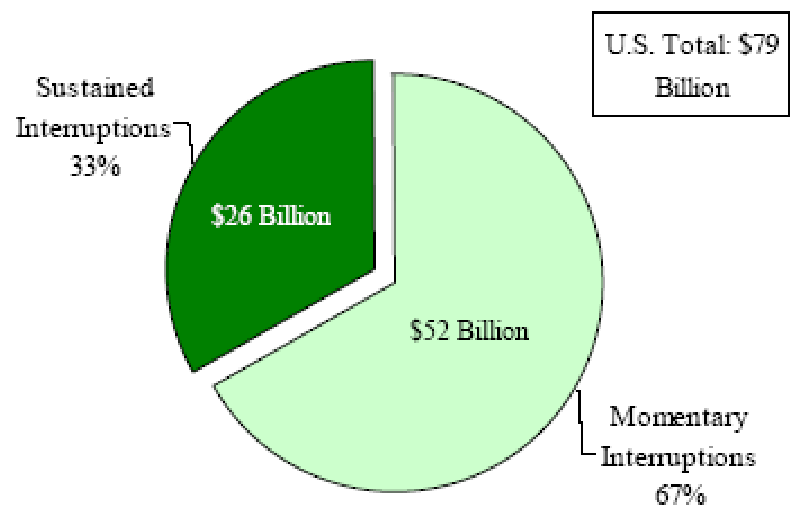
- **Signed by the National Academies of Science of 70 nations:**
  - Argentina, Australia, Bangladesh, Brazil, Canada, China, France, Denmark, Greece, India, Japan, Germany, Mexico, Pakistan, Spain, Taiwan, U.K., U.S…..
- **“The rapid increase in CO2 emissions since the industrial revolution has increased the acidity of the world’s oceans with potentially profound consequences for marine plants and animals, especially those that require calcium carbonate to grow and survive, and other species that rely on these for food.”**
  - Change to date of pH decreasing by 0.1, a 30% increase in hydrogen ion activity.
- **“At current emission rates, models suggest that all coral reefs and polar ecosystems will be severely affected by 2050 or potentially even earlier.”**
  - At 450 ppm, only 8% of existing tropical and subtropical coral reefs in water favorable to growth; at 550 ppm, coral reefs may be dissolving globally.
- **“Marine food supplies are likely to be reduced with significant implications for food production and security in regions dependent on fish protein, and human health and well-being.”**
  - Many coral, shellfish, phytoplankton, zooplankton, & the food webs they support
- **Ocean acidification is irreversible on timescales of at least tens of thousands of years.**

Costs of Power Interruptions

New York City during the August 2003 blackout

Chip East / Reuters file



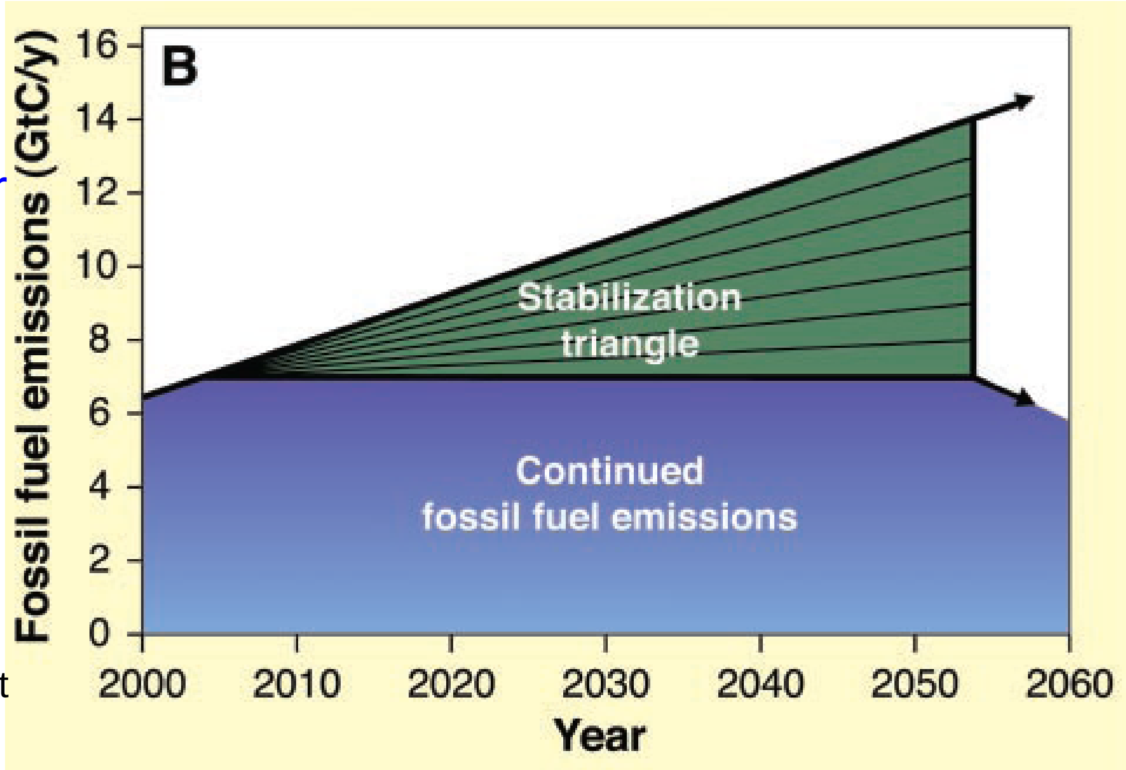


Kristina Hamachi LaCommare, and Joseph H. Eto, LBNL

Scale of the Challenge

- Increase fuel economy of 2 billion cars from 30 to 60 mpg.
- Cut carbon emissions from buildings by one-fourth by 2050—on top of projected improvements.
- With today's coal power output doubled, operate it at 60% instead of 40% efficiency (compared with 32% today).
- Introduce Carbon Capture and Storage at 800 GW of coal-fired power.
- Install 1 million 2-MW wind turbines.
- Install 3000 GW-peak of Solar power.
- Apply conservation tillage to all cropland (10X today).
- Install 700 GW of nuclear power.

Source: S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technology", Science 13 August 2004, pp.968-972.



Time Constants

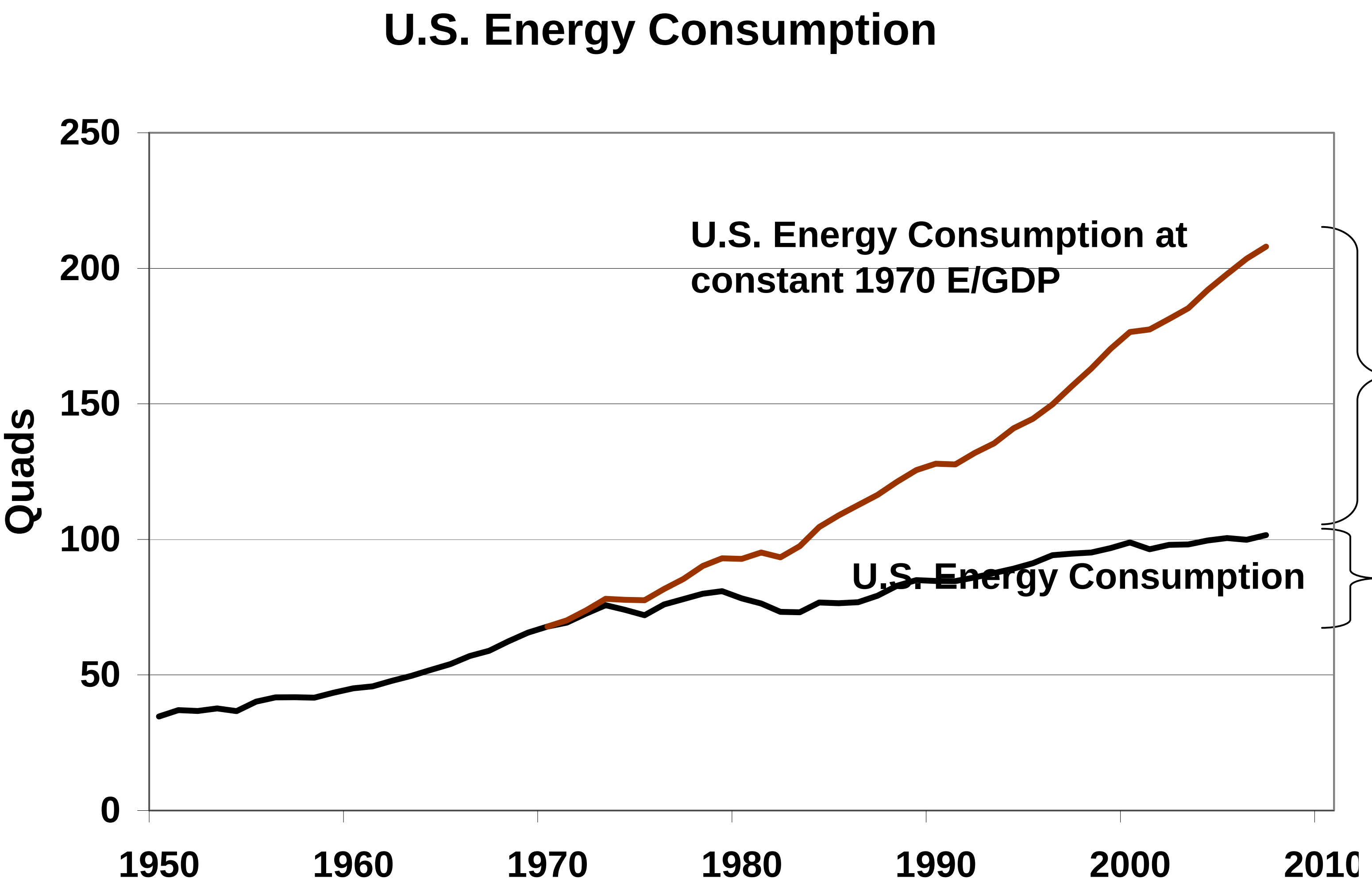
• Political consensus building	~ 3-30+ years
• Technical R&D	~10+
• Production model	~ 4+
• Financial	~ 2++
• Market penetration	~10++
• Capital stock turnover	
– Cars	~ 15
– Appliances	~ 10-20
– Industrial Equipment	~ 10-30/40+
– Power plants	~ 40+
– Buildings	~ 80
– Urban form	~100's
• Lifetime of Greenhouse Gases	~10's-1000's
• Reversal of Land Use Change	~100's
• Reversal of Extinctions	Never
• Time available for significant action	Must Act Now!

Can EE & RE Meet These Challenges?

- **Extending Current Options**
  - Fossil/CCS
  - Nuclear
- **Efficiency**
  - Buildings
  - Industry
  - Transportation
  - Smart End-Use Equipment (dispatched w/ PV)
  - Plug-In Hybrids/Smart Charging Stations
- **Renewable Energy & Energy Storage**
  - Biomass
  - Geothermal
  - Hydropower
  - Ocean Energy
  - Solar Photovoltaics / Smart Grid / Battery Storage
  - Solar Thermal / Thermal Storage / Natural Gas
  - Wind / Compressed Air Energy Storage / Natural Gas
- **Transmission Infrastructure**
  - Smart Grid

HOW FAR?
HOW FAST?
HOW WELL?
AT WHAT COST?
BEST PATHWAYS?

Energy Efficiency: 1970-2007

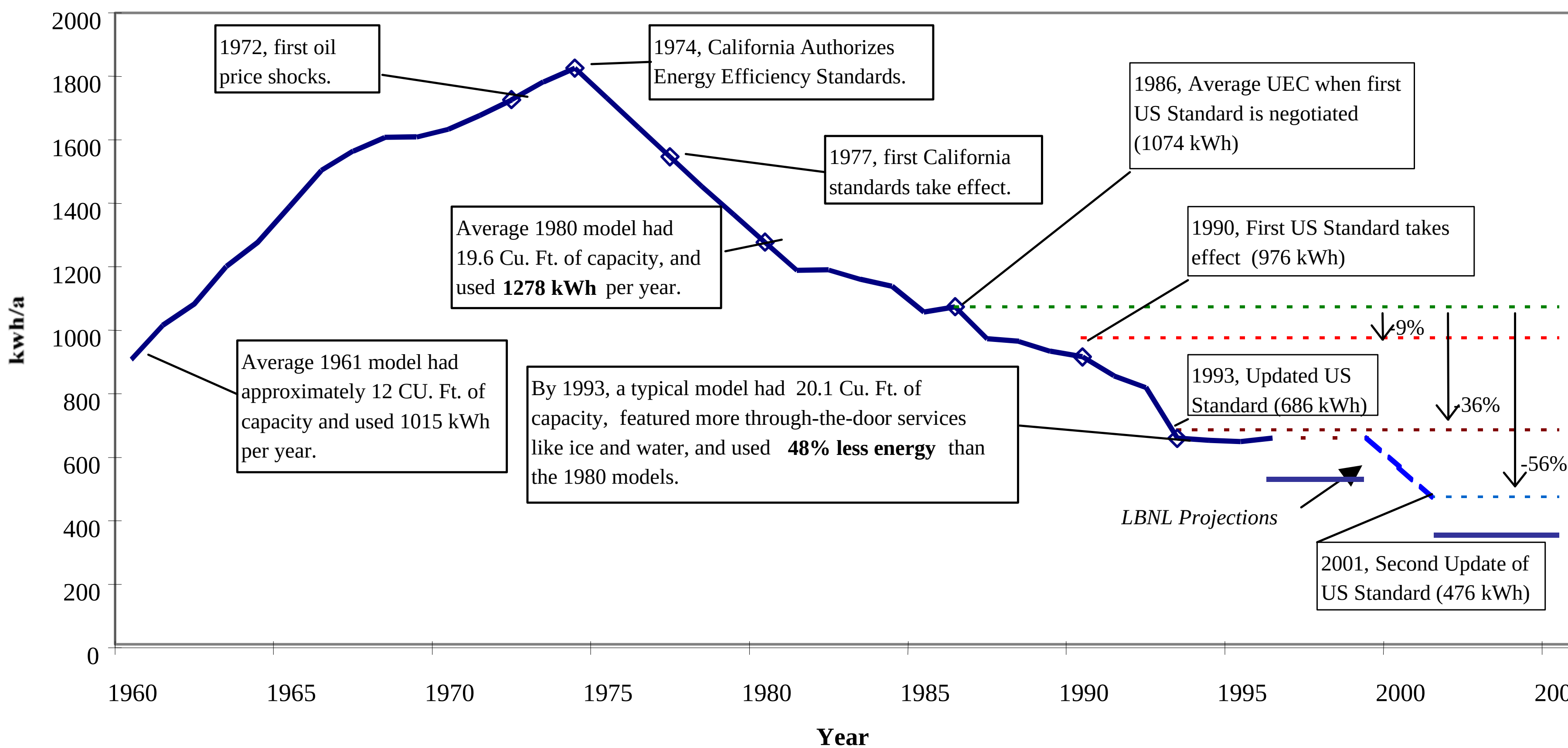


Efficiency; Structural Change: Total 106.8

New Supply	
Gas	1.8Q
RE	2.8
Nucl	8.2
Oil	10.3
Coal	10.5
Total	33.8

Refrigerator Energy Consumption

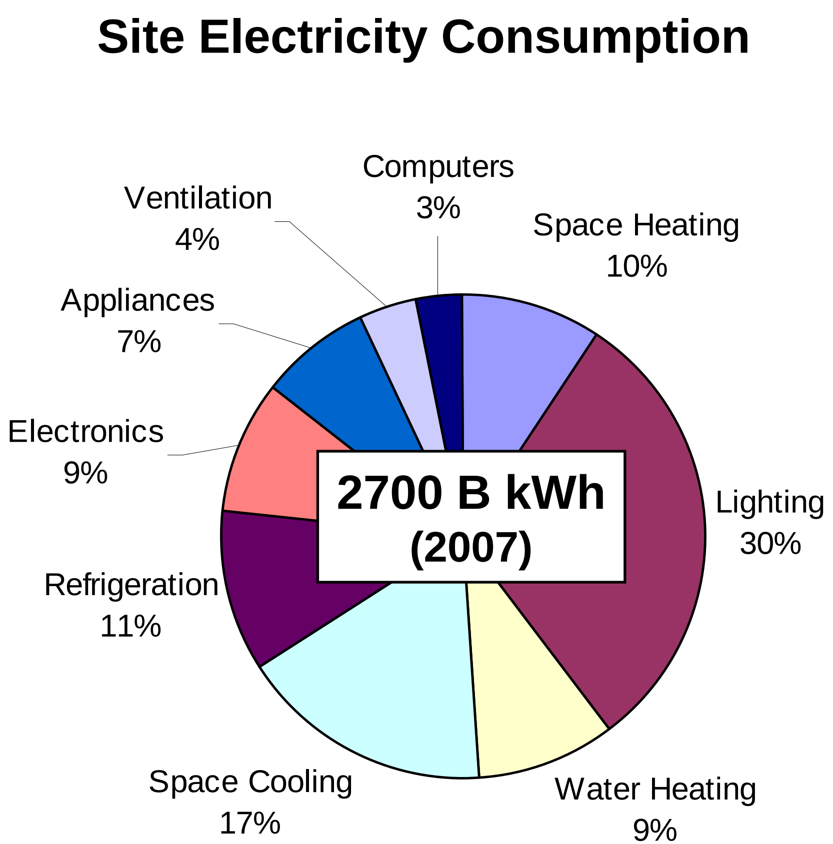
(Average energy consumption of new refrigerators sold in the U.S.)

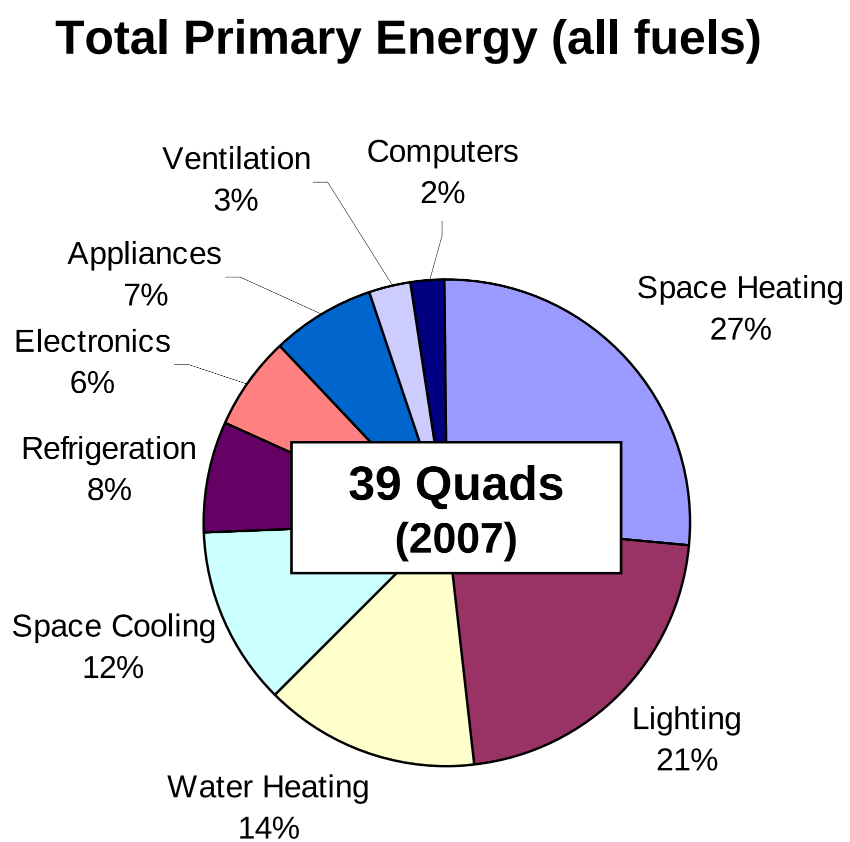


Savings: ~1400 kWh/year * $0.10/kWh = $140/yr per household
***100 M households = $14 B/year**

Source: LBNL

Buildings Energy Use



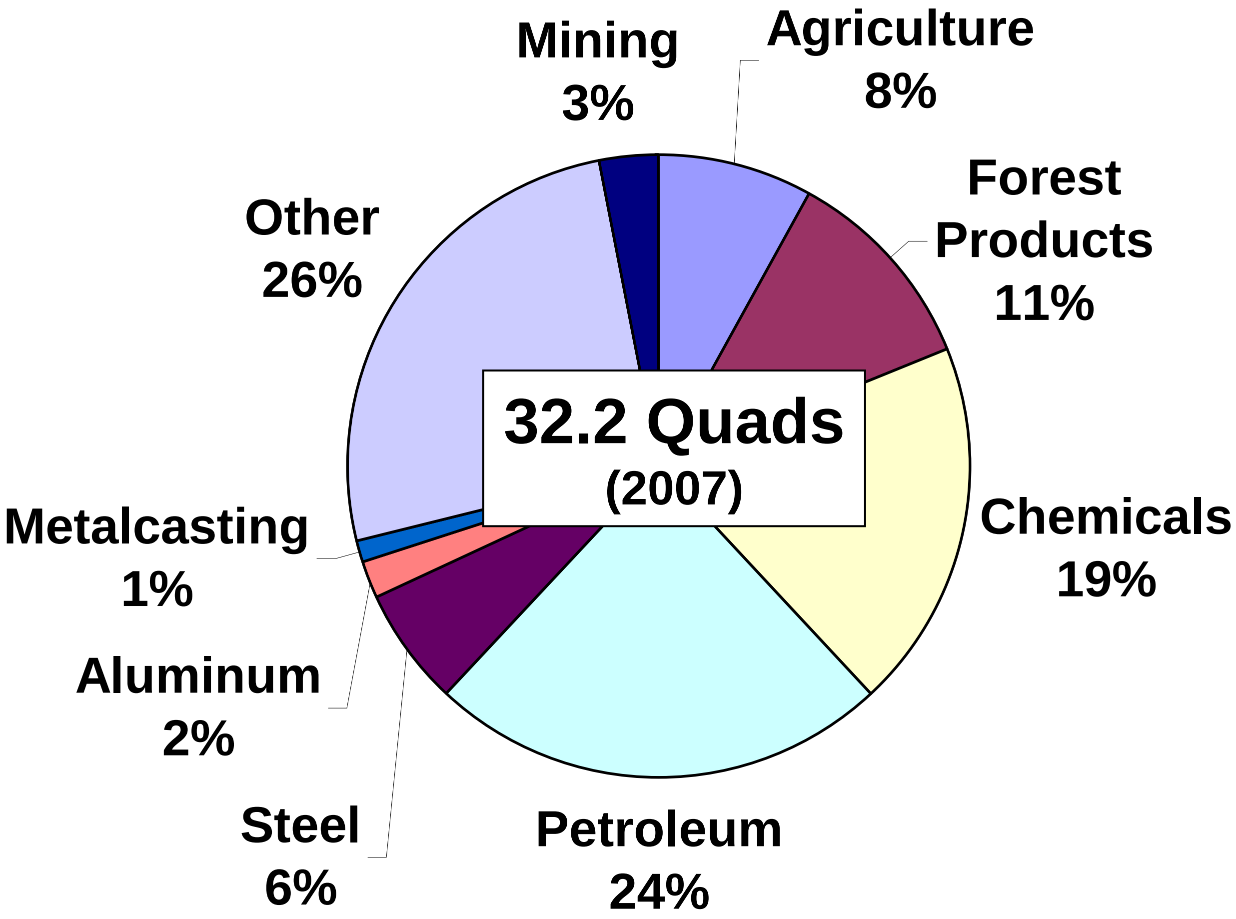


Source: Building Technology Program Core Databook, August 2003. http://buildingsdatabook.eren.doe.gov/frame.asp?p=tableview.asp&TableID=509&t=xls

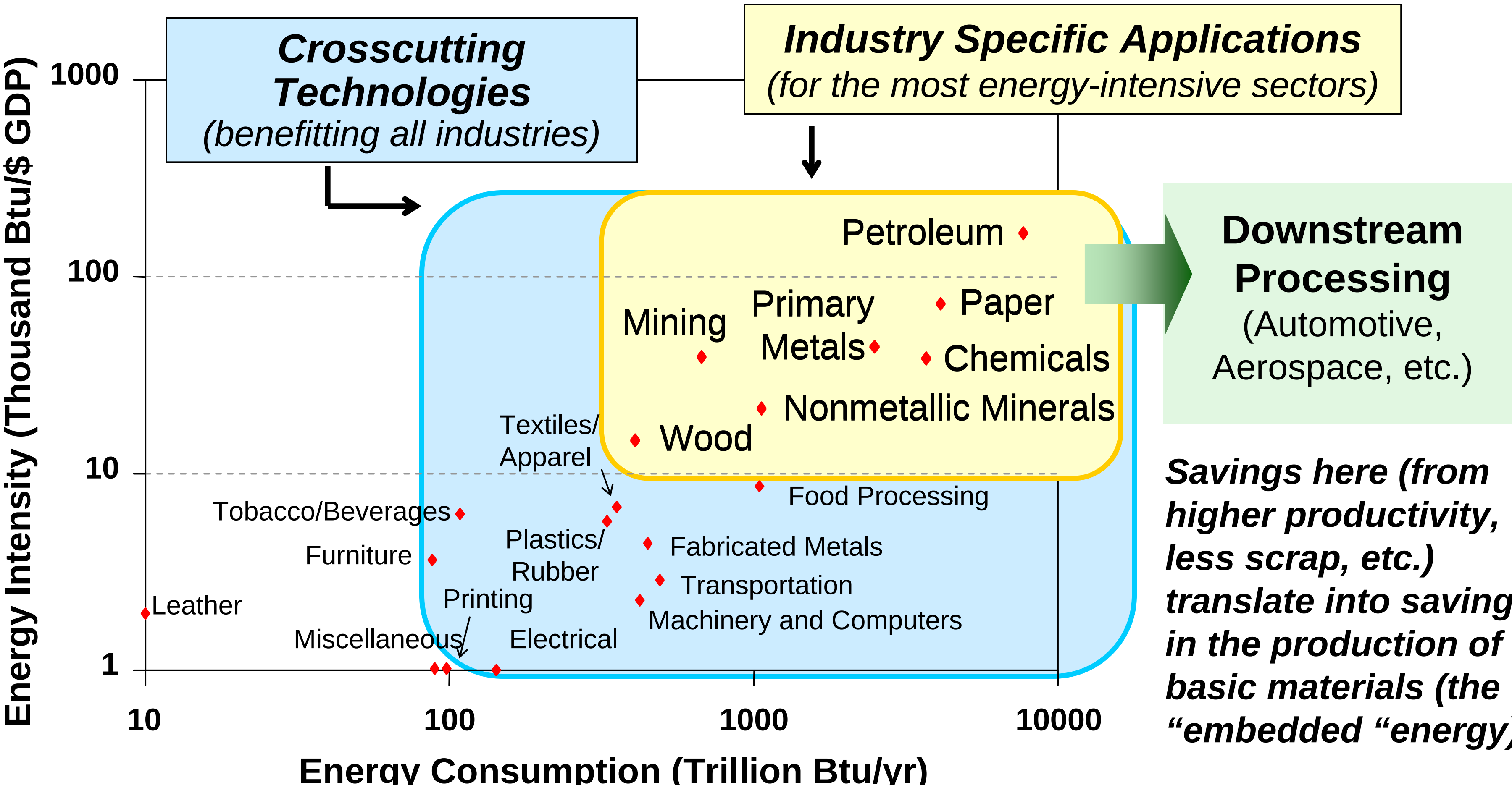
Buildings R&D Issues

- **Lighting**:
  - LED lighting—materials, device structures, phosphors, encapsulants.
  - Conventional lighting—non-Hg fluorescent lamps; multi-photon phosphors, etc.
- **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); Eliminate use of HFC refrigerants
  - Thermoelectrics; Magnetocalorics; Electrocalorics; Thermionics; New Vapor Compression Cycles; Absorption Cycles; Dehumidification materials; Heat Pumps; Heat Exchangers; Phase-Change Materials for Thermal Load Shifting
- **Building Shells:**
  - Insulants; Phase-change materials for thermal storage; Advanced Membranes
  - Windows: Electrochromics; High Insulation
  - Spectrally-selective paints and roof coatings
- **Building Design Tools, Construction, Intelligent Operation:**
  - Building-Integrated Sensor Networks/Controls; System Integration; Passive Design; Cradle-to-Cradle Materials Design/Use
- **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.
- **Others**:
  - Low-wattage standby devices; low-cost adjustable speed motor drives with integrated sensors/controllers

Industrial Energy Use



Industry Opportunities



Savings here (from higher productivity, less scrap, etc.) translate into savings in the production of basic materials (the "embedded "energy)

Industry R&D Issues

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

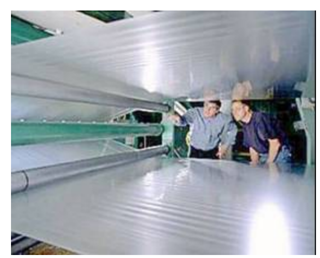
Energy Conversion Systems

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

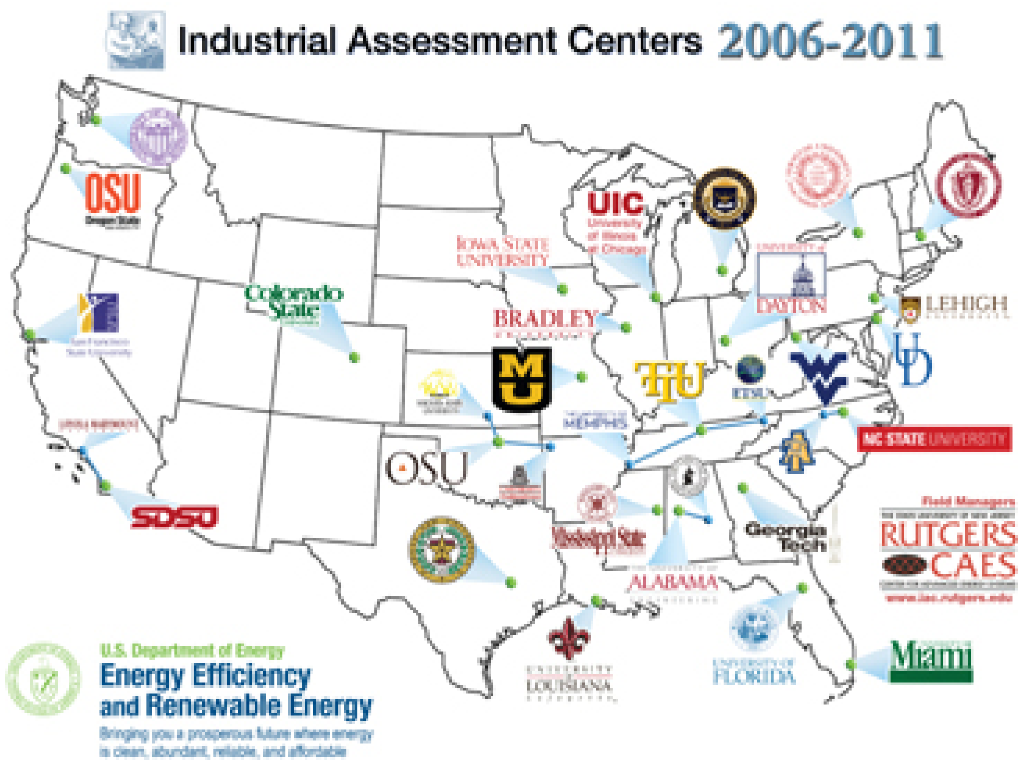


- Near Net Shape Casting/Forming
- Energy Efficient and Safe Extraction Operations
- Inferential Process Control for Product Quality
- Ultra-hard Materials
- Joining and Assembly

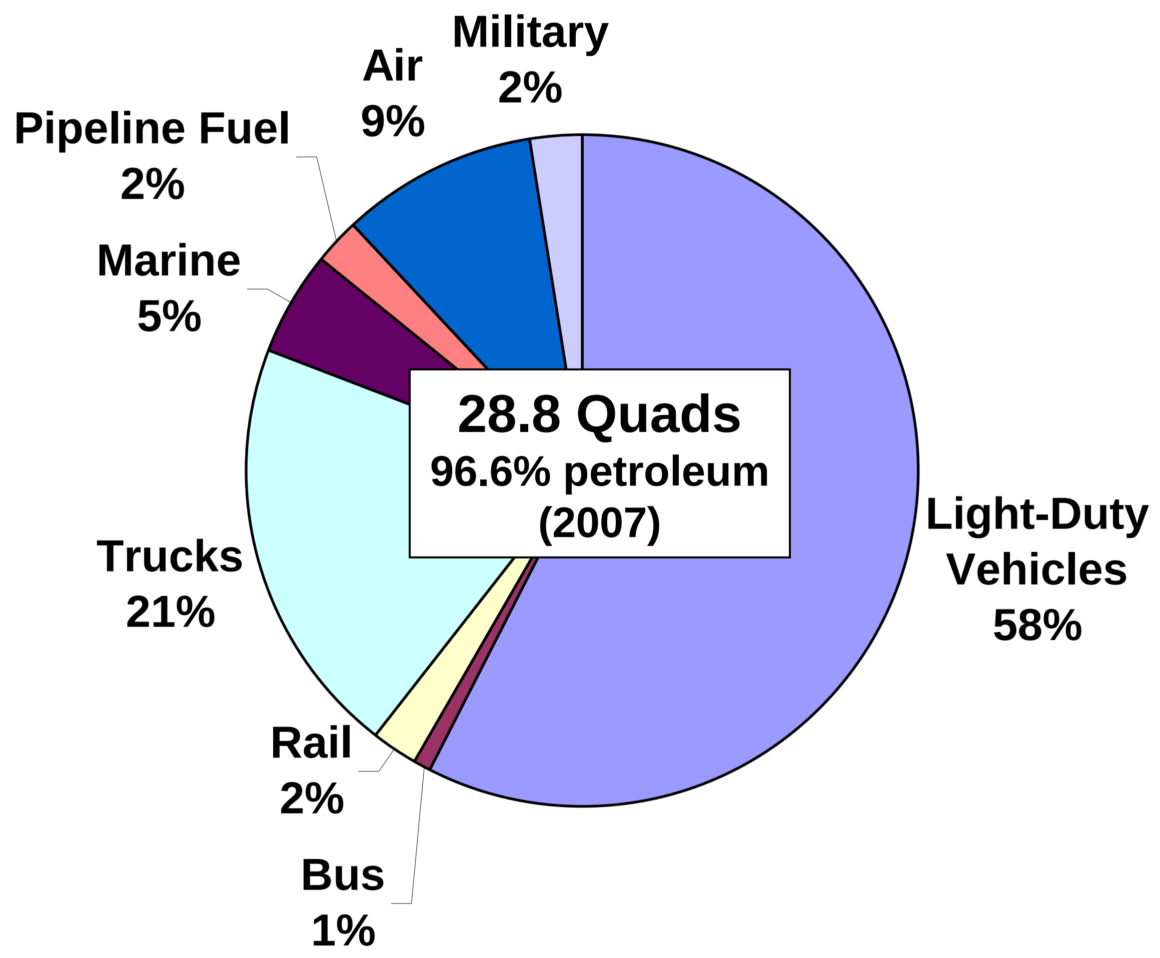
Source: ITP

Industrial Assessment Centers

- DOE's 26 university-based Industrial Assessment Centers (IACs) train engineering students for careers in industrial energy efficiency
- IACs serve 300+ plants per year (under 1 TBtu/yr) and typically identify savings of 8%-10% or $115,000/plant
- Database of 13,500 assessment results: http://iac.rutgers.edu/database

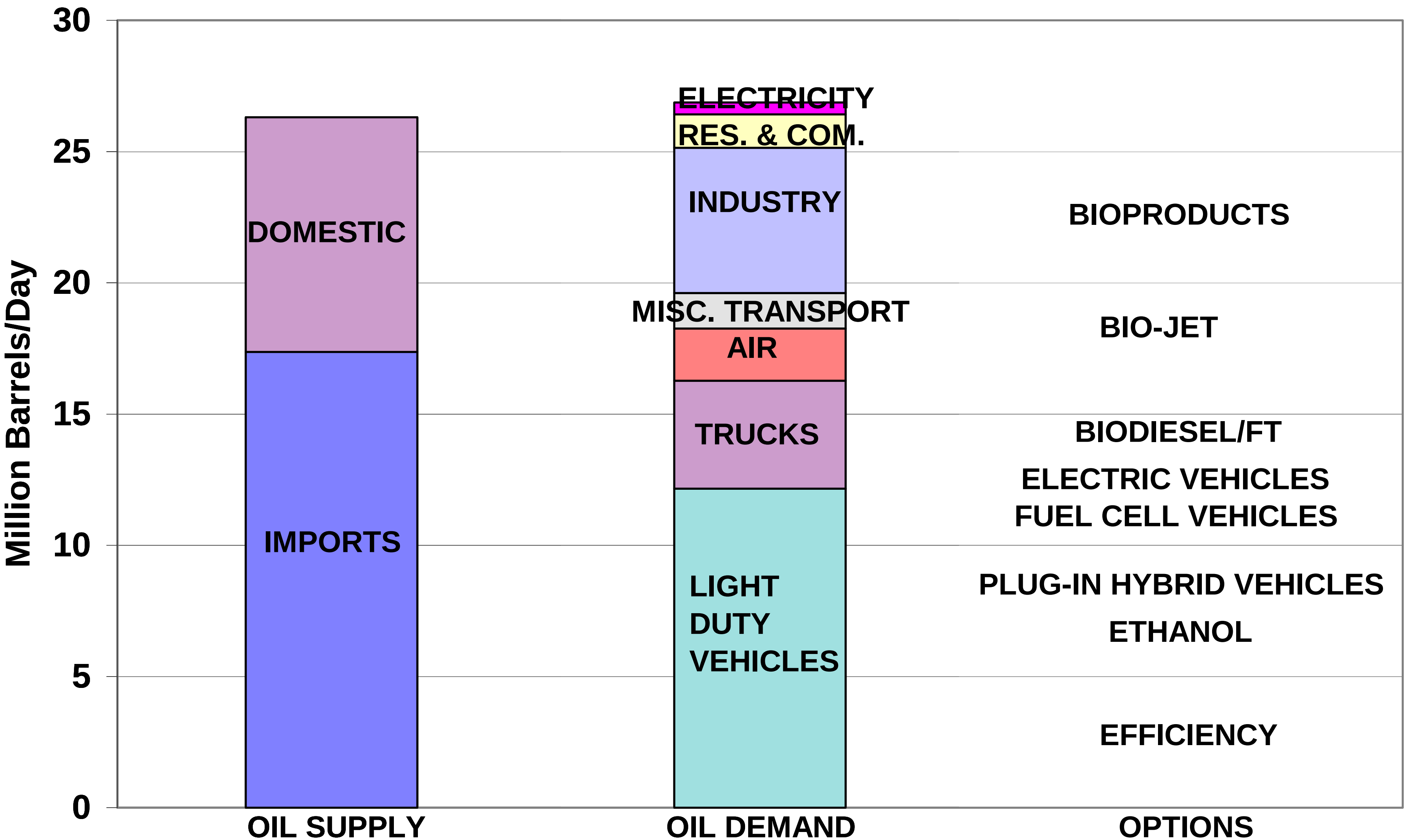


Transport Energy Use



Can We Meet the Oil Challenge?

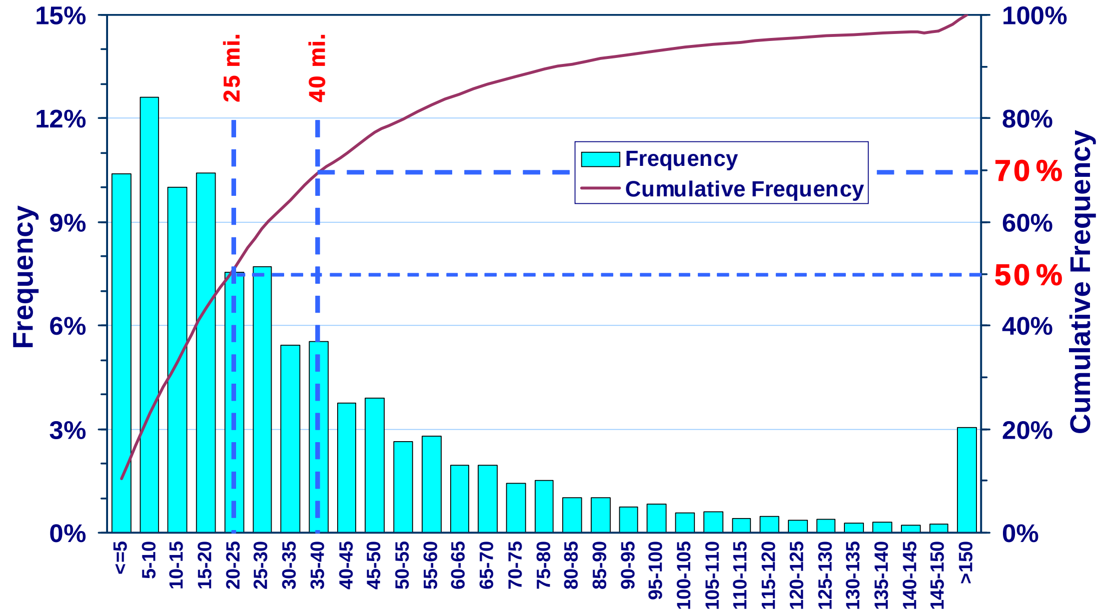
Oil Supply, Demand, Options in 2030



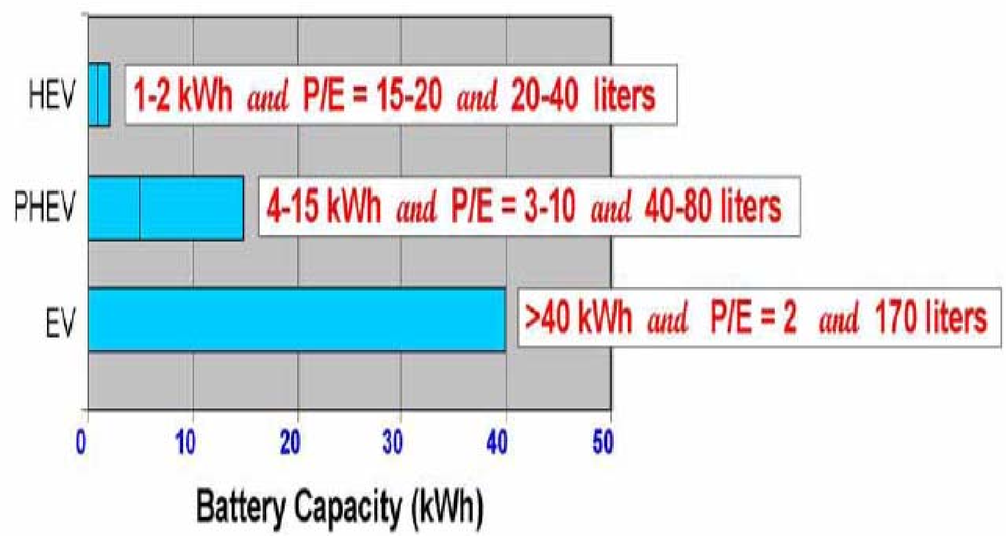
Plug-In Hybrids

- Battery Storage, Power Electronics, System Int.
- A123 -- Nano-Structured Iron-Phosphide Cathode.
- **Wind 200 GW→450 GW**

50% Travel ≤25 mi./day; 70% ≤40 mi./day

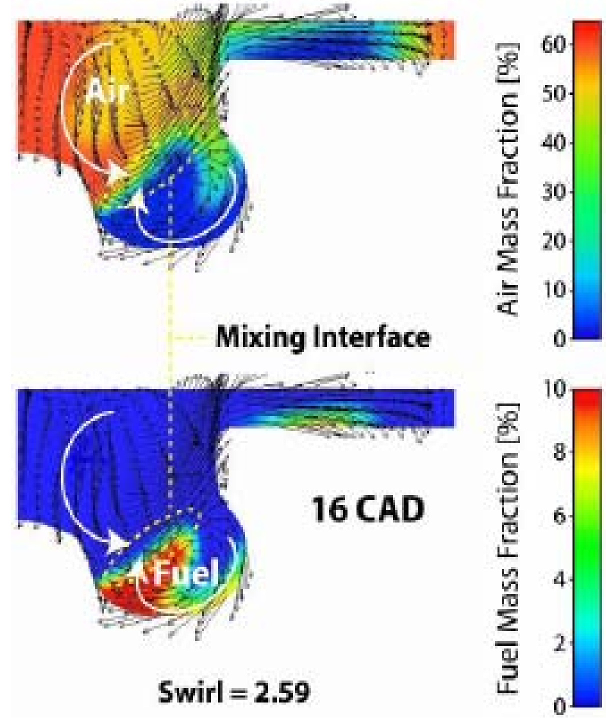


Source: 2001 National Household Travel Survey



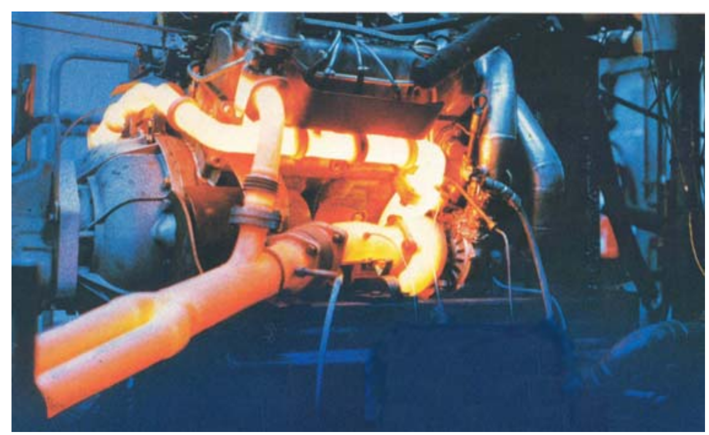
Vehicle R&D Issues

- **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 and Components:**
  - Material deformation in crashes
    - Composites; lightweight alloys.
- **Aerodynamic Drag:**
  - Low speed flow; turbulence
- **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.



Ultimate Biorefinery Goal:
From any Feedstock to any Product

Feedstock production, collection, handling & preparation

Hydrolysis
Acids, enzymes

Gasification
High heat, low oxygen

Digestion
Bacteria

Pyrolysis
Catalysis, heat, pressure

Extraction
Mechanical, chemical

Separation
Mechanical, chemical

Sugars and Lignin

Synthesis Gas

Bio-gas

Bio-Oil

Carbon-Rich Chains

Plant Products

USES

Fuels:
- Ethanol
- Renewable Diesel
- Hydrogen

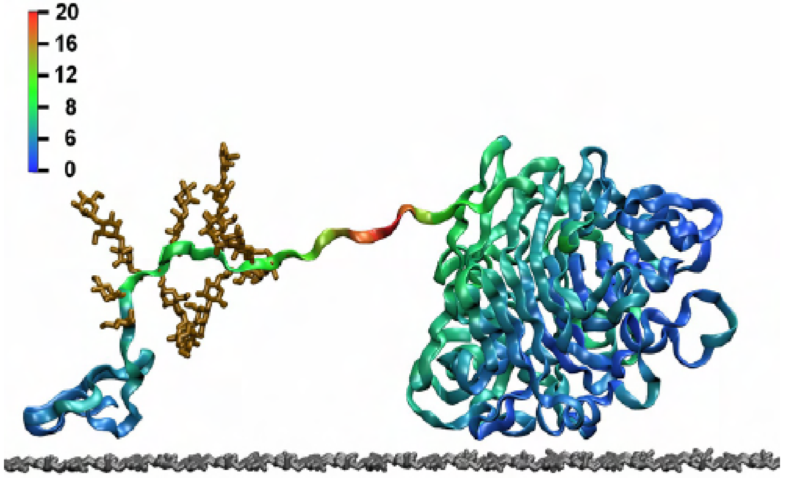
Power:
- Electricity
- Heat

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

Food and Feed

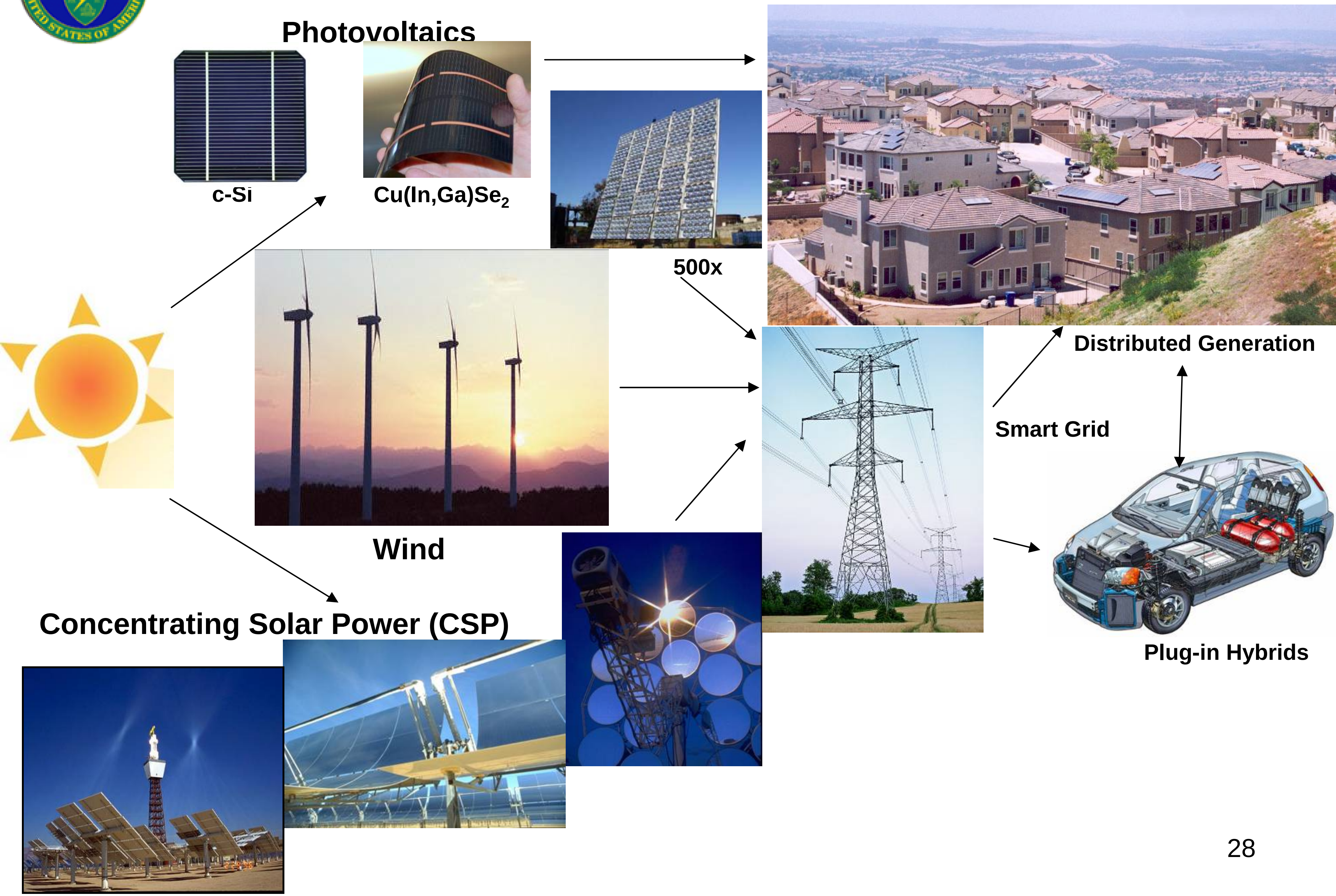
BioEnergy R&D Issues

- **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”

Renewable Electricity Systems



Can RETs Meet the Electricity Challenge?

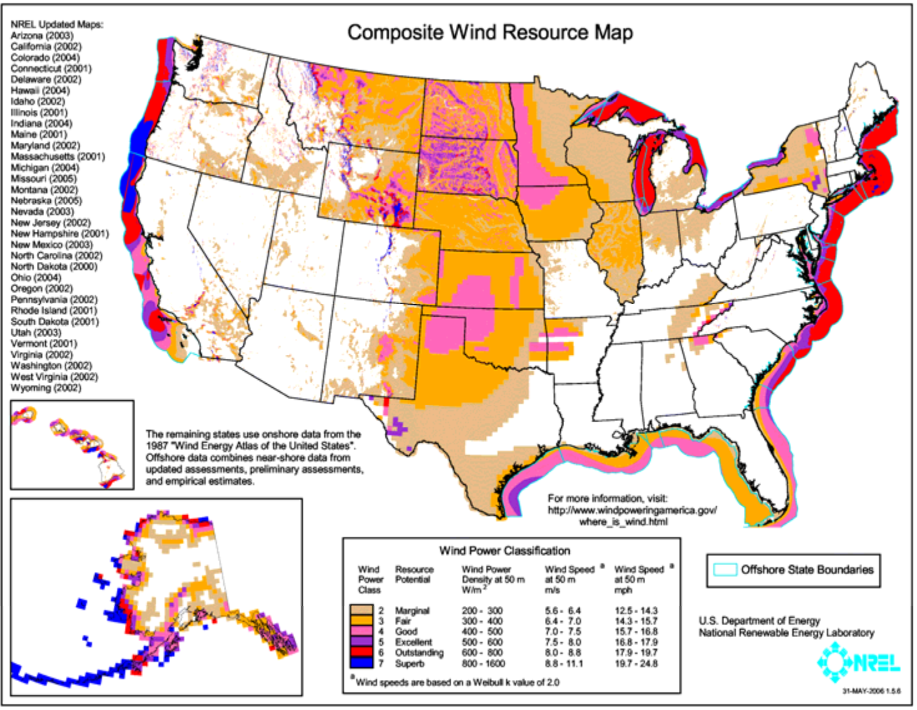
- **Power:** (Energy Information Administration)
  - 2007: Total: 3900 TWh. Wind: 26 TWh Solar: 0.5 TWh
  - 2030: Total: 4900 TWh. Wind: 130 TWh Solar: 3.0 TWh
  - 2050: Total: ~6000 TWh? (with efficiency➔4500?)
    PHEVs: 1500 TWh/y?
    (5000 Bmiles/ 3 miles/kWh * 90% of Fleet)
- **End-Use Systems**
  - Additional efficiency
  - Smart End-Use Equipment
- **Renewable Energy 2050** (notional numbers)
  - Biomass Power?
  - Geothermal: 100 GW ➔ 800 TWh/y?
  - Hydropower?
  - Ocean Energy?
  - Solar Photovoltaics / Battery Storage
    Solar Thermal / Thermal Storage / Natural Gas
    ➔ Solar: 2000 TWh/y ➔ 1500 GW ➔ ~35-40 GW/y?
  - Wind / CAES / Natural Gas
    ➔ Wind: 2000 TWh/y ➔ 600 GW ➔ ~15 GW/y?

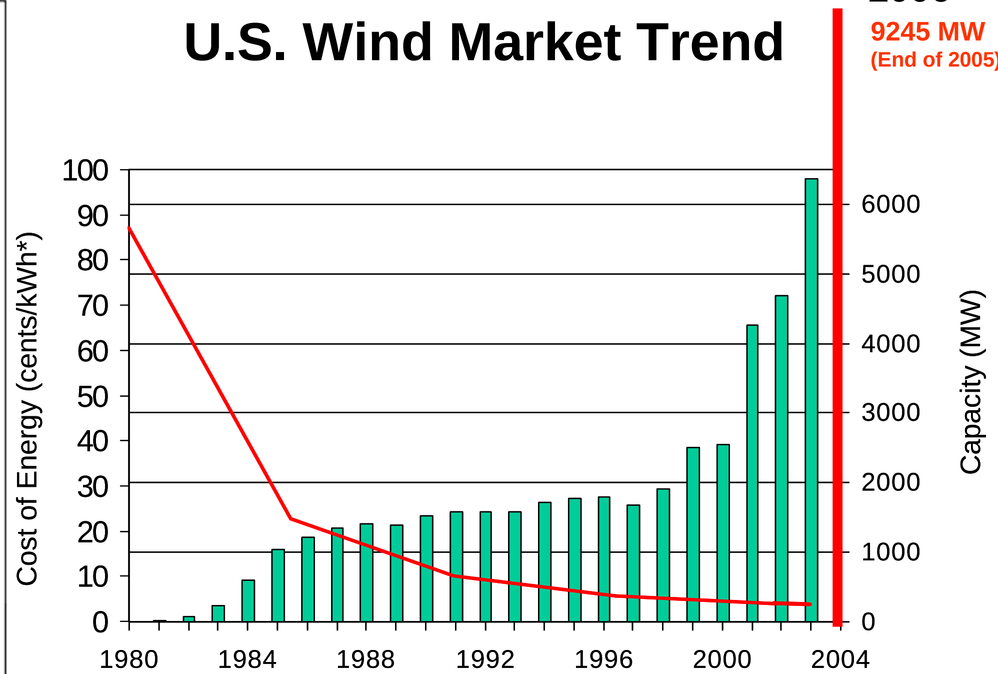
CHALLENGES

- Efficiency
- Supply R&D
- Storage R&D
- Materials Supply
- Grid Integration
- Manufacturing
- Policy
- Training

Can Wind Energy Meet the Challenge?

~25,500
2008
~16,800
2007
11,600
2006

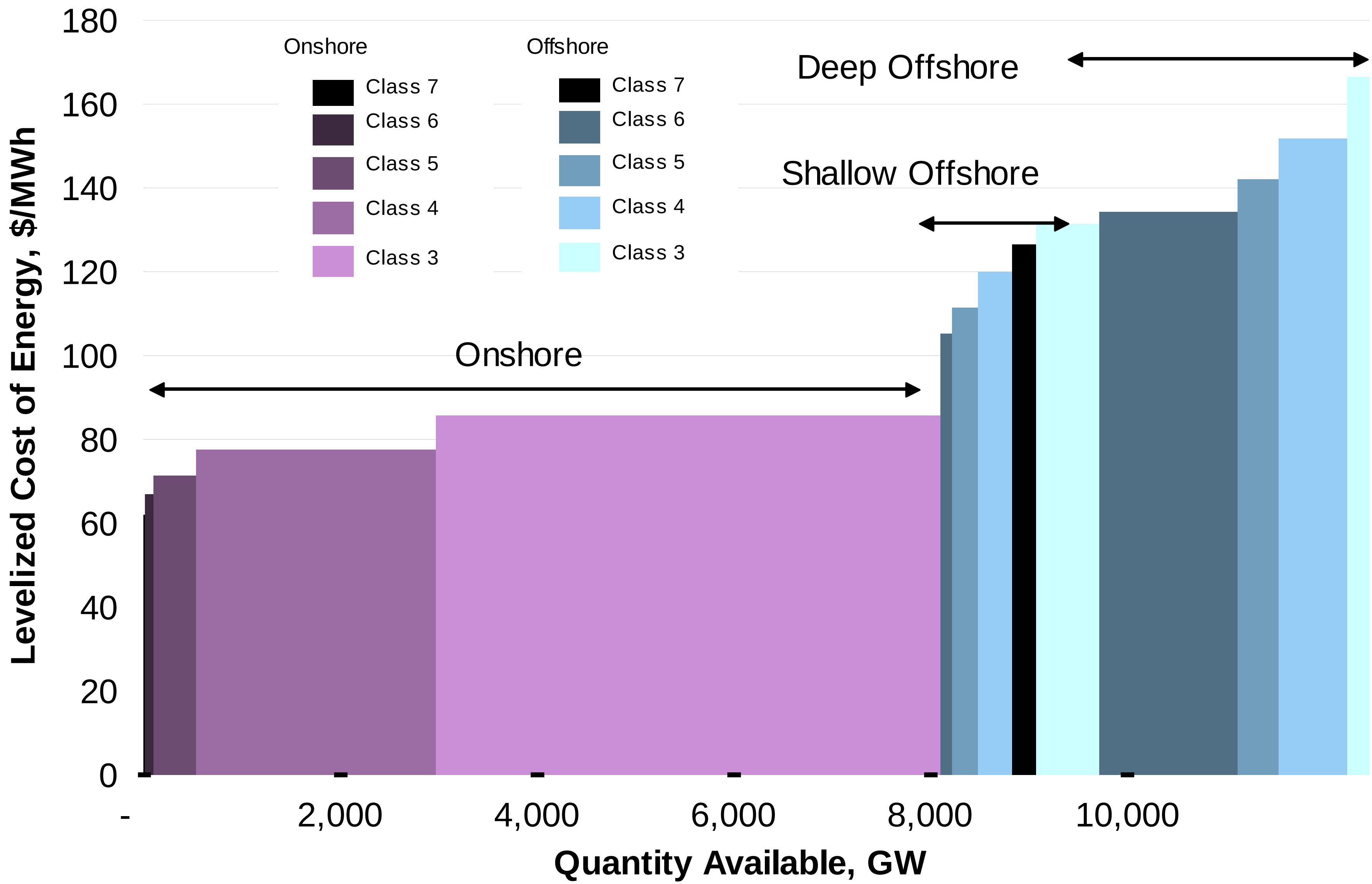




- Cost of wind power from 80 cents per kilowatt-hour in 1979 to a current range of ~$0.05/kWh (Class 5-6).
- Low wind speed technology: x20 resource; x5 proximity
- >8000 GW of available land-based wind resources
- Offshore Resources.
- Directly Employs 85,000 people in the U.S.

Source: EERE/WTP

Resource Potential Exceeds Electricity Demand

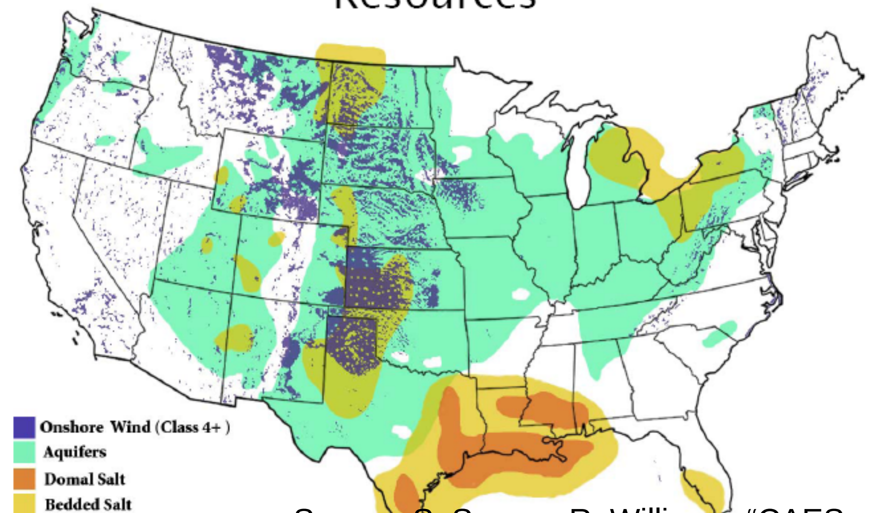


2010 Costs w/o PTC, w/o Transmission or Integration costs

Wind Energy and Storage

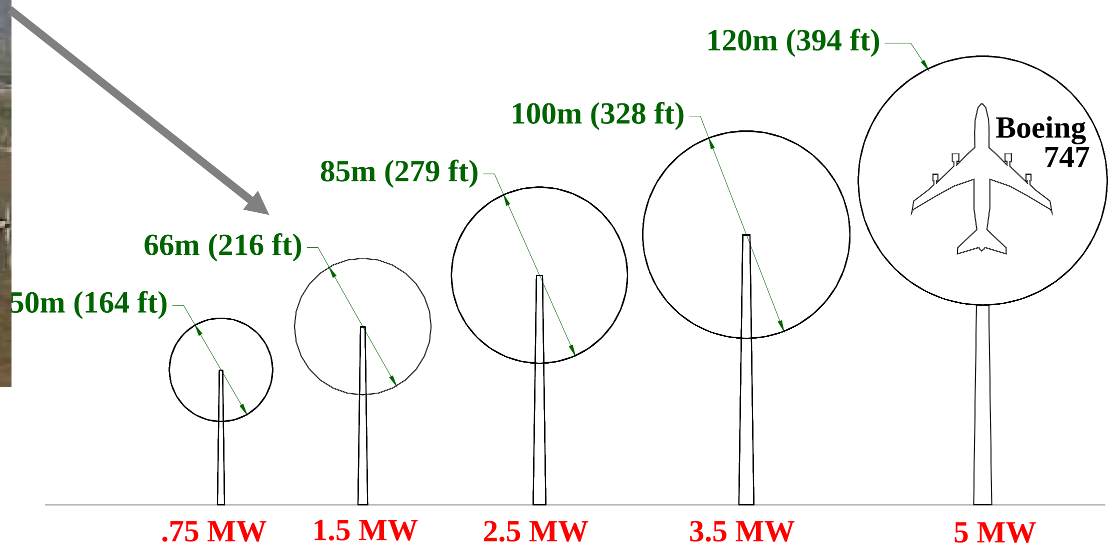
GE Wind 1.5 MW

Geology Suitable for CAES & Class 4+ Wind Resources



Source: S. Succar, R. Williams, "CAES: Theory, Resources, Applications…" 4/08

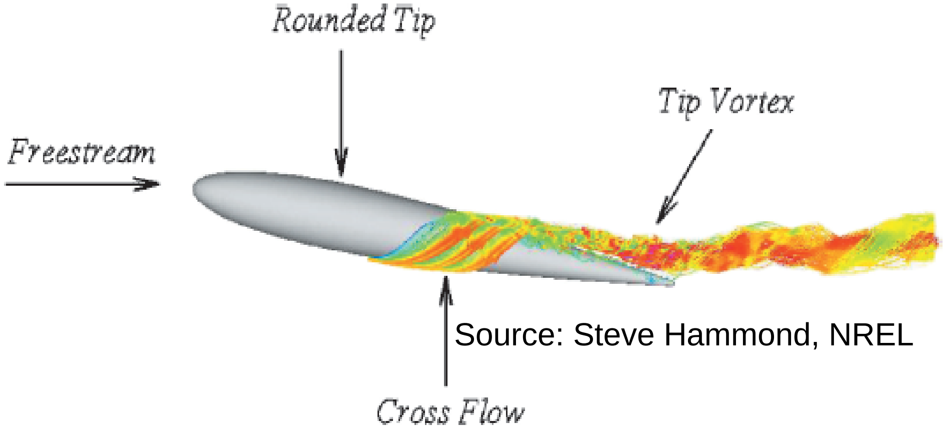
Typical Rotor Diameters



Source: EERE/WTP

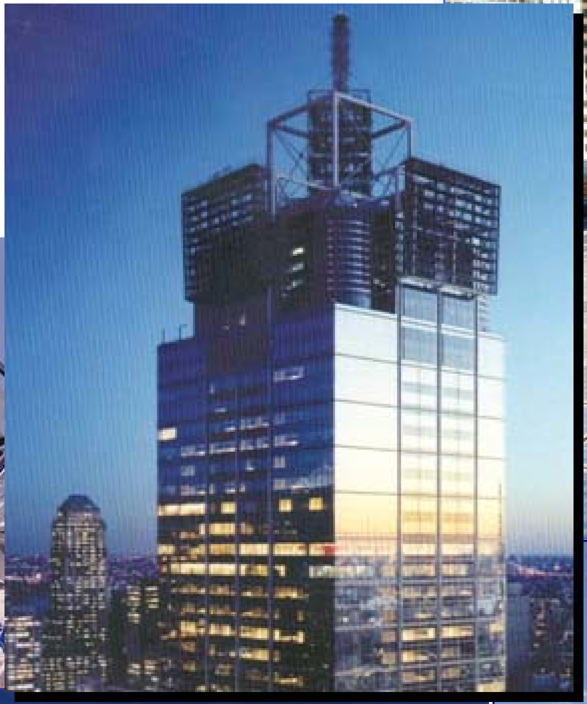
Wind Energy R&D Issues

- **Reliability:** Testing and validation of blades, hubs, gear boxes, etc**.**
- **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 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 Off-Shore:**
  - Wave loading; marine environment



Source: Steve Hammond, NREL

Can PV Meet the Challenge?

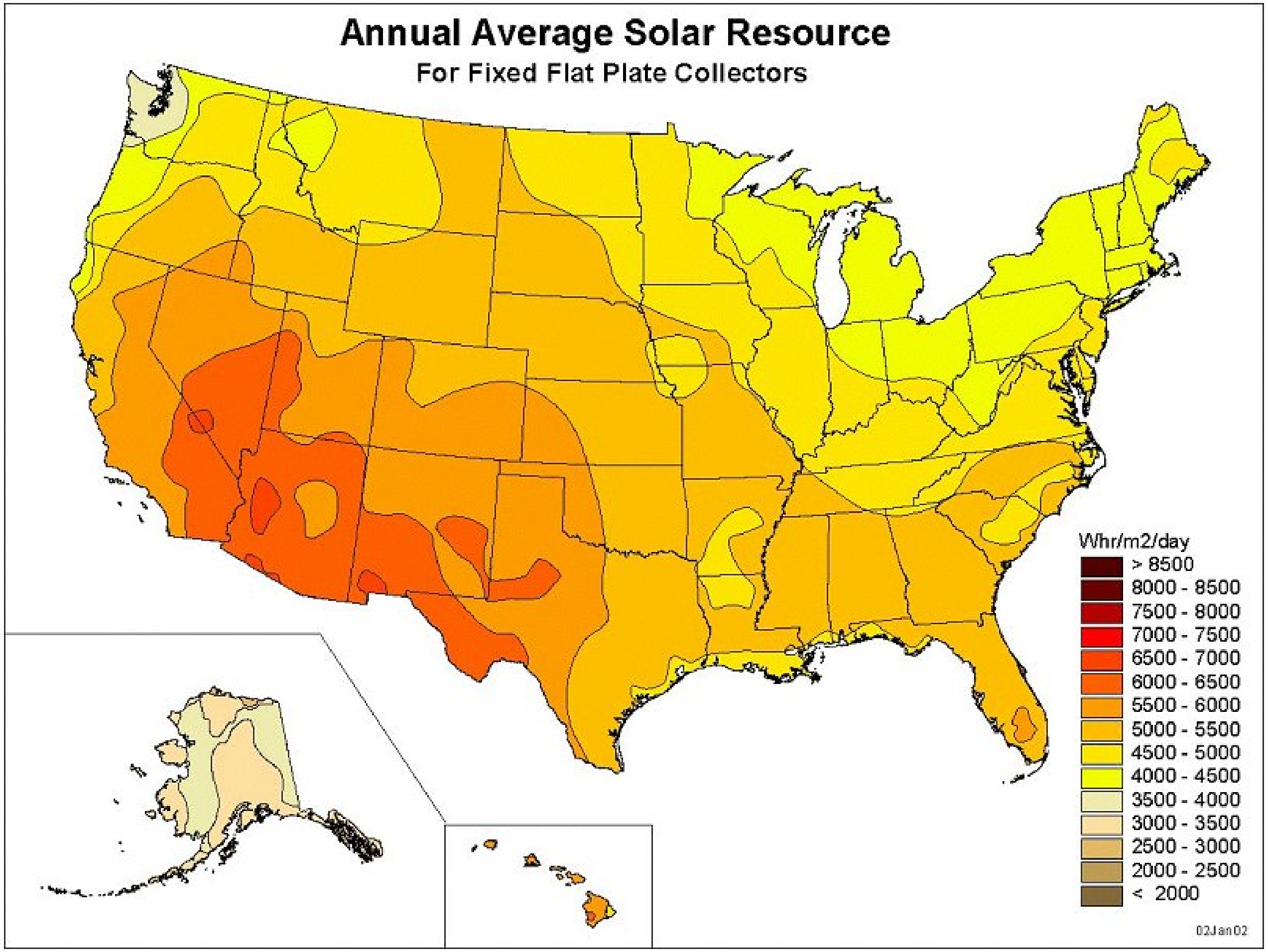


Source: EERE/STP

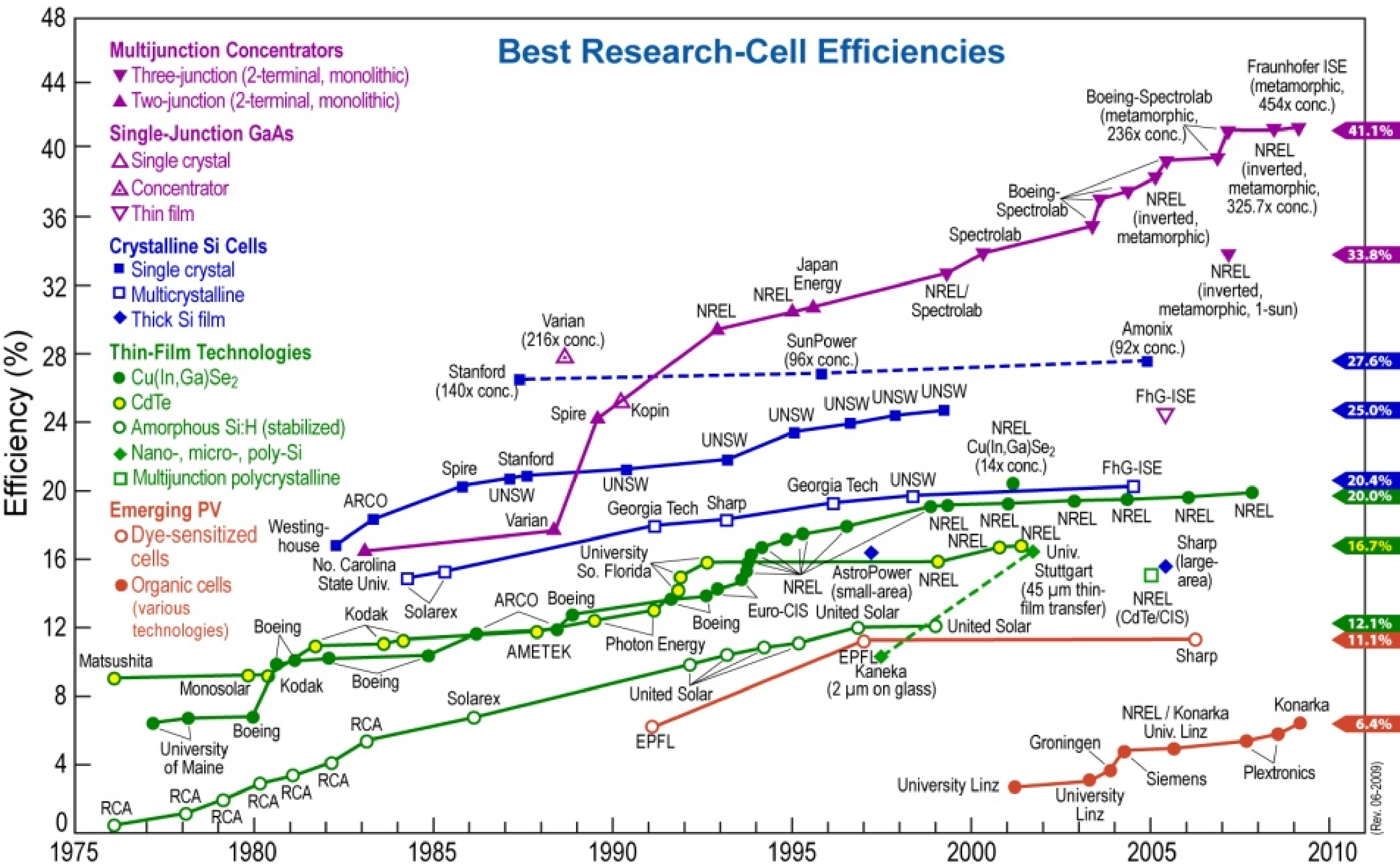
Solar Energy

- Price of electricity from grid-connected PV systems are ~20¢/kWh. (Down from ~$2.00/kWh in 1980)

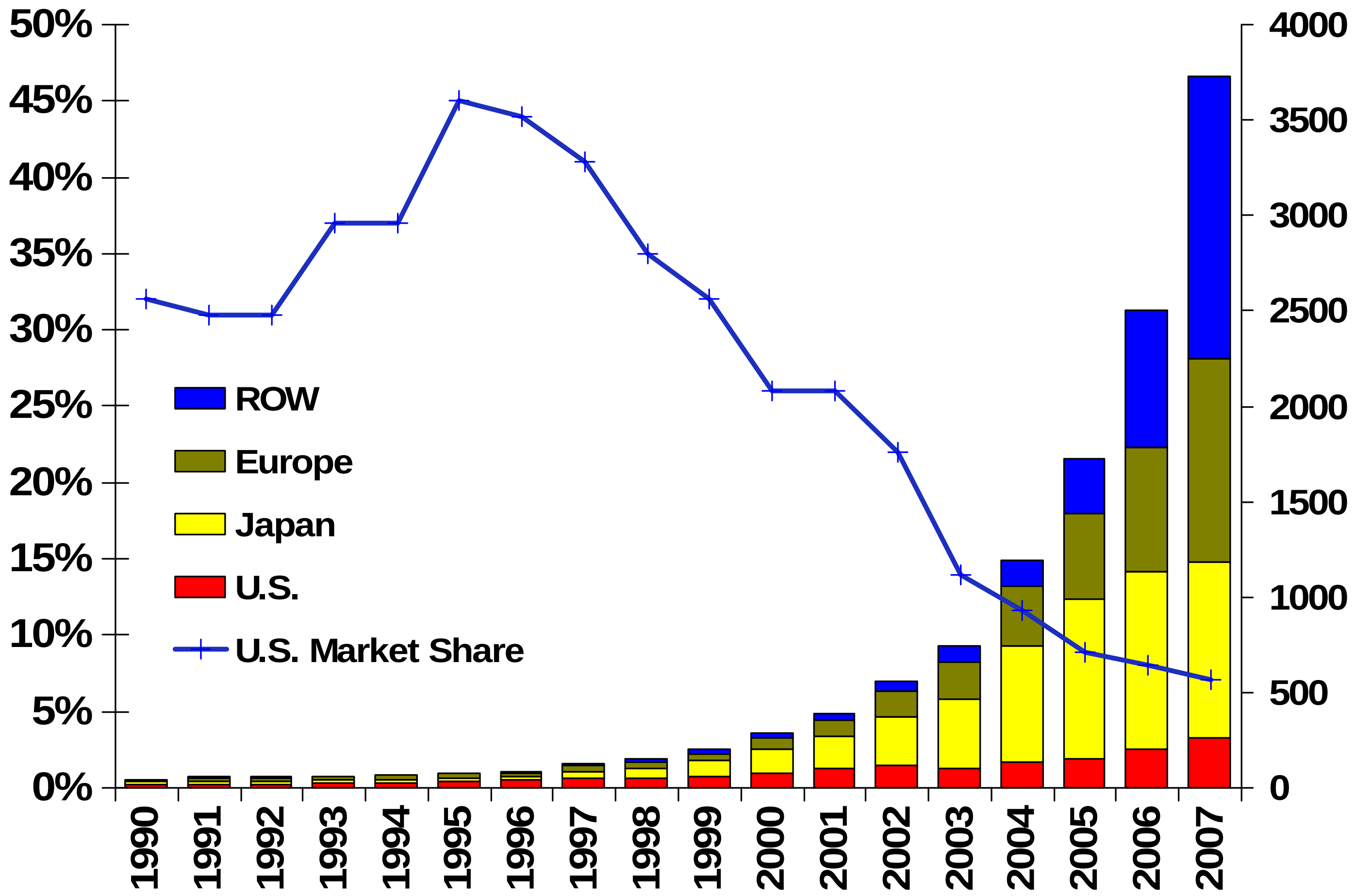
- Nine parabolic trough plants with a total rated capacity of 354 MW have operated since 1985, with demonstrated system costs of ~14¢/kWh.



Best Research-Cell Efficiencies

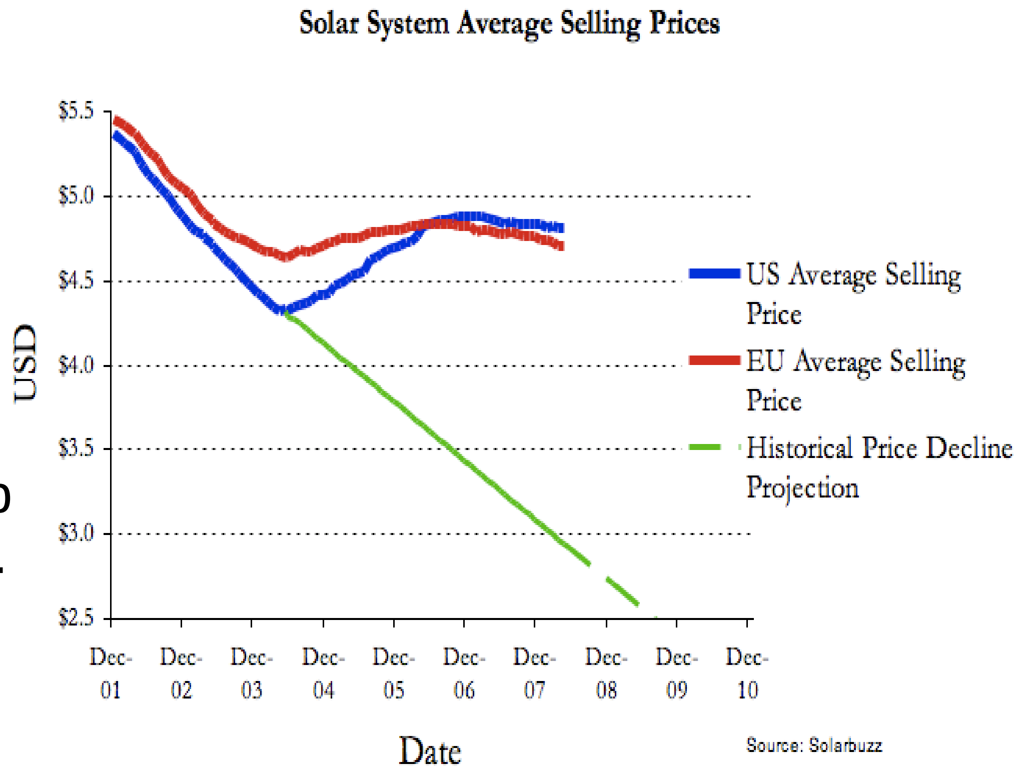


PV Shipments and U.S. Market Share



Materials

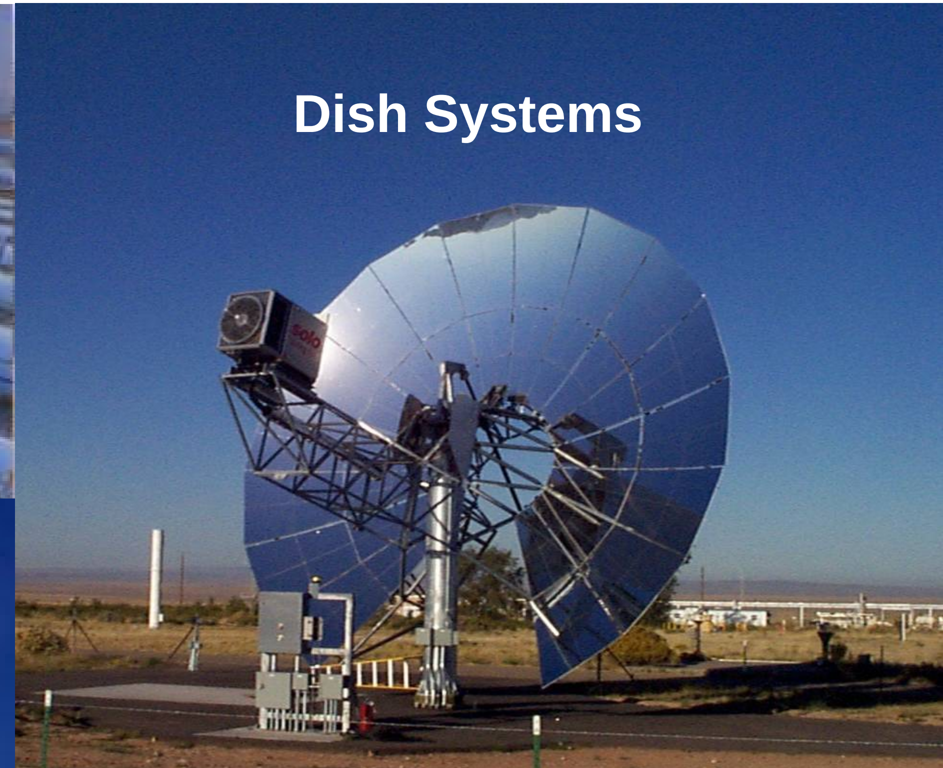
- **Commodity Materials**
  - Steel, Cement, Glass, Copper
  - Silicon
- **Specialty Materials**
  - CIGS, CdTe, others.
  - Lithium; Cobalt; Ruthenium; Tb
  - National Controls: China, etc…
- **Responses**
  - New Sources of Supply
  - More efficient use
  - Substitution ($LiFePO_4$)
  - Recycling

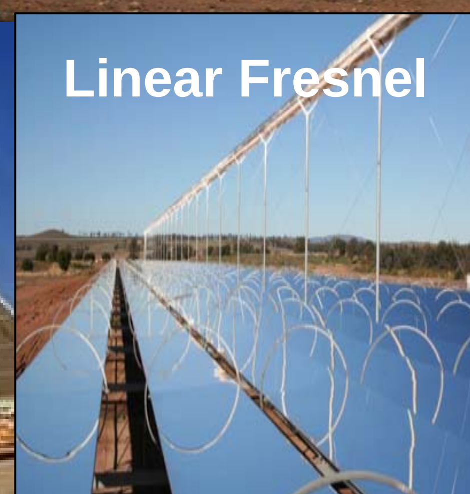


Material	World Production	Material at 20 GW/y	% Current Production
Indium	250 MT/y	400 MT/y	160%
Selenium	2,200 MT/y	800 MT/y	36%
Gallium	150 MT/y	70 MT/y	47%
Tellurium	450 MT/y (2000 MT/y unused)	930 MT/y	38% (of total)
Cadmium	26,000 MT/y	800 MT/y	3%

- **X 5+ Globally**

Concentrating Solar Thermal Power





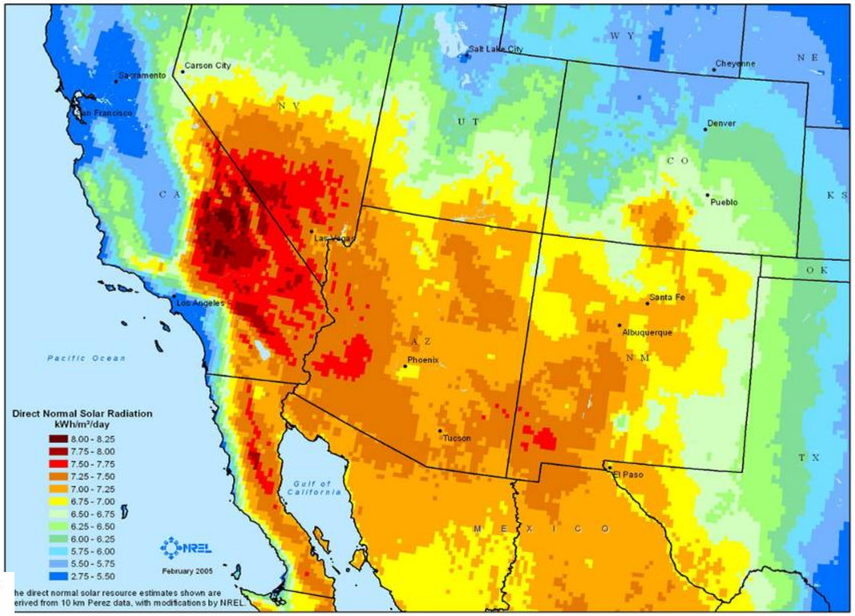
Source: EERE/STP

Can CSP Meet the Challenge?

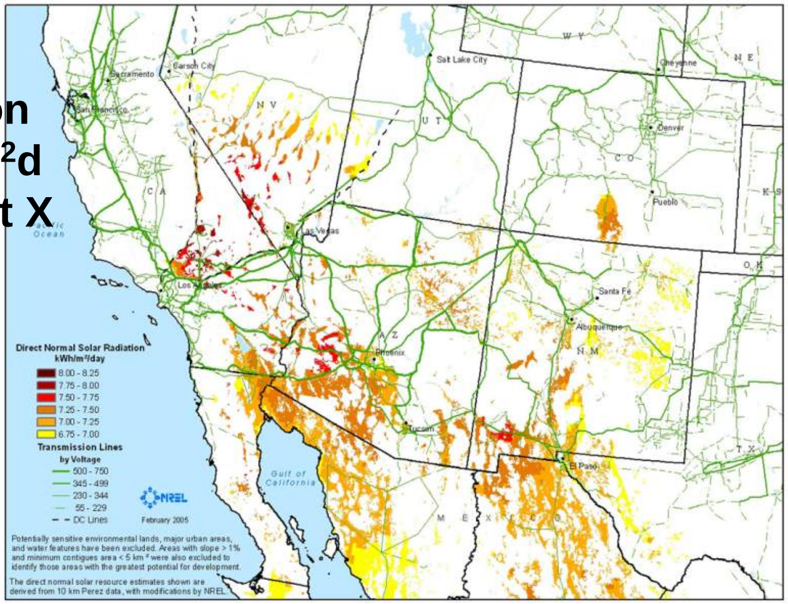
Systems in place
- 354 MW Trough, 1984-1990, ~14¢/kWh
- 1 MW Trough, Arizona, 2006
- 64 MW Trough, Nevada, 2007
- 5 MW Kimberlina Linear Fresnel, CA 2008

Cost Reduction Potential
- Sargent & Lundy, WGA Solar Task Force: CSP costs <6 cents/kWh w RD&D.
  - Scale-up ~37%
  - Volume Production ~21%
  - Technology Development ~42%

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



Filters:
Transmission
>6.75kWh/m²d
Environment X
Land Use X
Slope < 1%



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

CSP Systems

50 MW AndaSol Parabolic Trough Plants w/ 7-hr Storage, Andalucía

CSP Projects Under Development

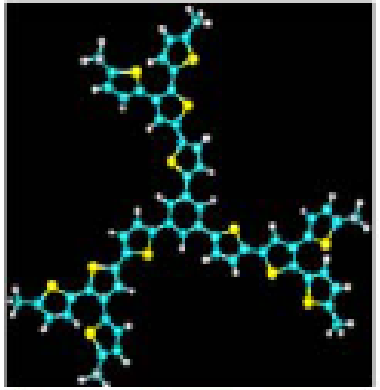
- Abu Dhabi 100 MW
- Algeria 20
- China 1000
- Egypt 20
- Israel 240
- Mexico 30
- Morocco 20
- South Africa 150
- Spain 2200
- U.S. 4500
- TOTAL 8280

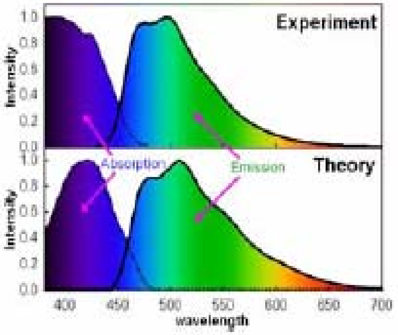
Abengoa PS10, PS 20; Spain

Photos courtesy of Mark Mehos, NREL

Solar Energy R&D Opportunities

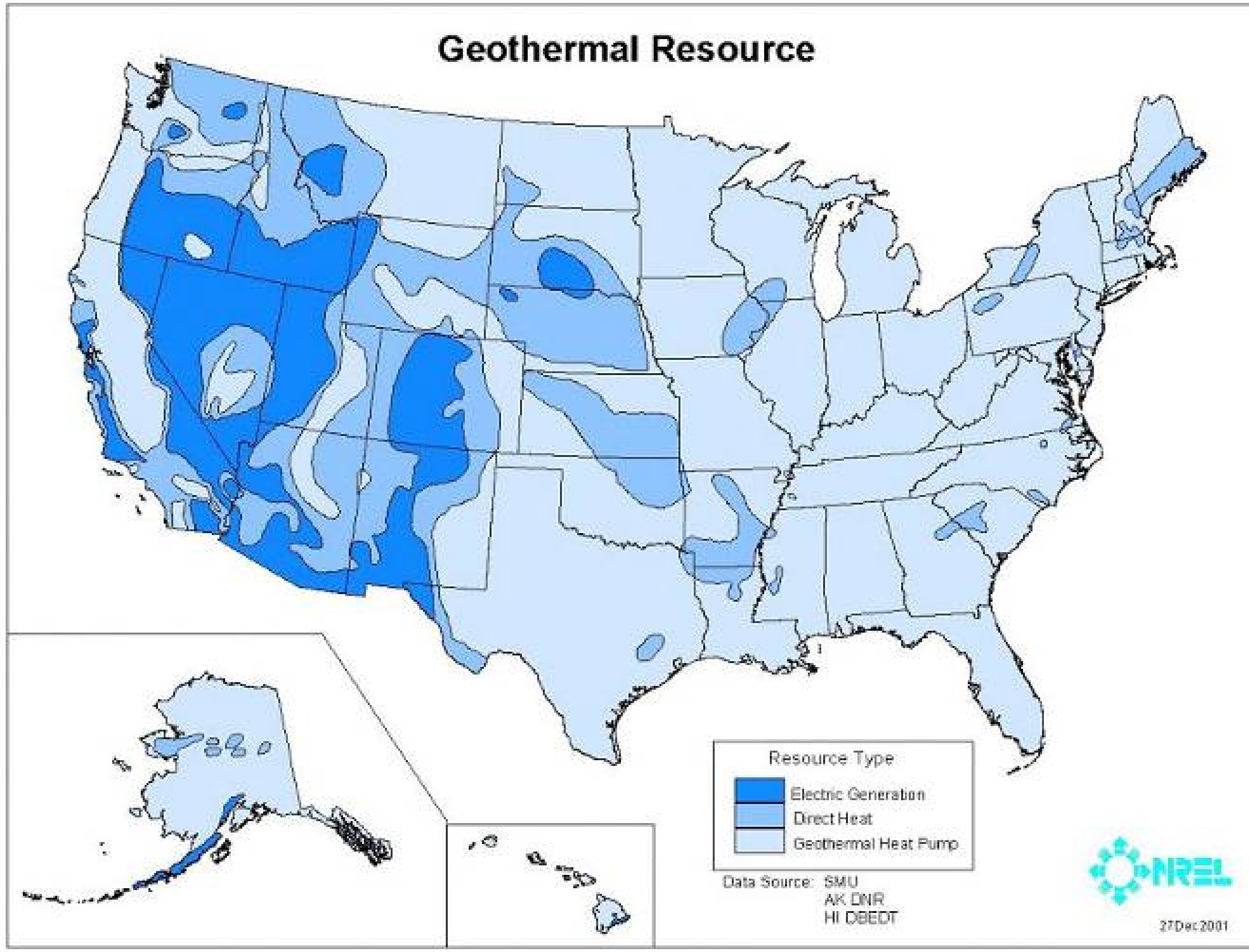
- **Photovoltaics**:
  - Improve materials/growth/characterization/devices, esp.CIGS, CdTe, Multi-junction thin films, reduce thickness of active layers, increase production rates
  - Develop new/improved Transparent Conducting Oxides
  - Improve module and interconnect designs and performance
  - Improve packaging: encapsulants cure time/hermiticity/UV-resistance/etc
  - 3rd Generation intermediate-band cells, Quantum Dot cells, etc.
  - Improve inverter performance/reliability/cost/surge prot.; plug & play; etc.
  - Improve BOS; Improve concentrator secondary optics for T>70 C, x100s
- **Concentrating Solar Power**:
  - Stable, high temperature heat transfer and thermal storage materials to 600C (1200 C), with low vapor pressure, low freezing points, low cost
  - Stable, high temperature, high performance selective surfaces
  - High performance reflectors; self-cleaning coatings; improved optics/aim
- **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
  - 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

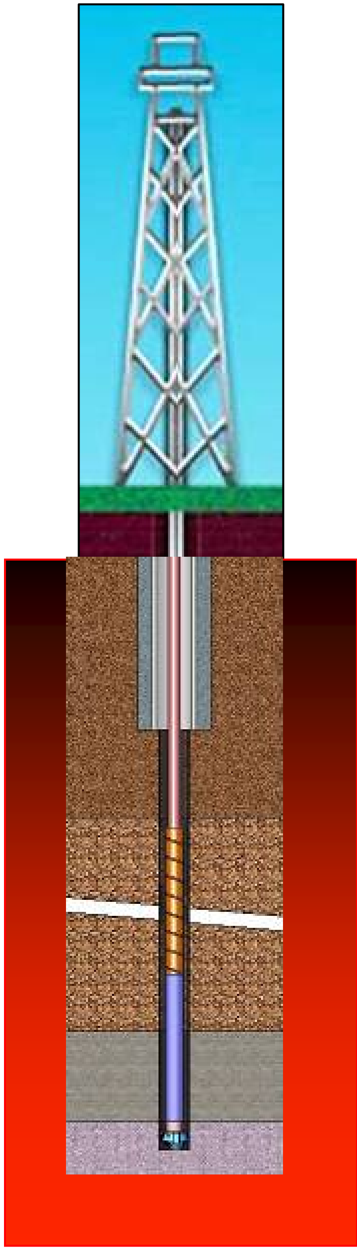
Geothermal Technologies



- 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 Issues

- **Exploration:**
  - Remote sensing
- **Reservoir Development:**
  - Well stimulation techniques; proppants; Enhanced Geo Systems
- **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.



Water Technology Types & Barriers

Program Focuses on the Following Technologies:

5 wave technology types

- Attenuator, Point Absorber, Oscillating Water Column, Oscillating Wave Surge Converter, Overtopping

3 hydrokinetic technology types

- Horizontal Axis Turbine, Vertical Axis Turbine, Oscillating Hydrofoil

3 types of ocean thermal energy conversion (OTEC)

- Closed-cycle, Open-cycle, Hybrid

R&D Necessary to Reduce Implementation Barriers:

Technologies are in very early stage of development, with few full-scale demonstrations

- Lack of cost and performance data
- No standardized basis for technology assessments and comparisons
- Prototype deployment is costly and time-consuming

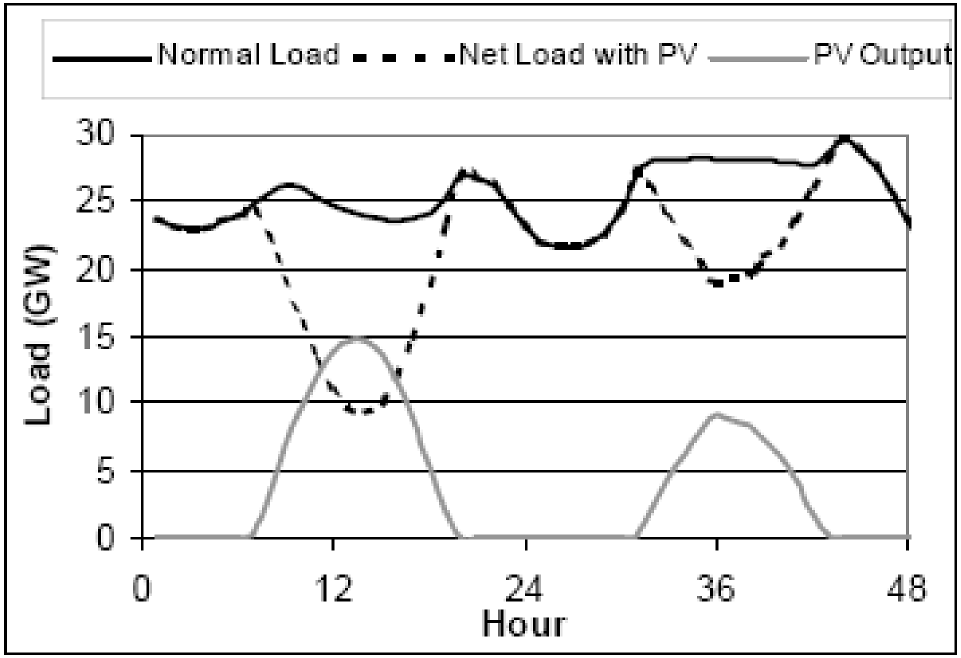
Lack of water resource assessment data for rivers, ocean and tidal currents, and wave states/regimes

Uncertain environmental impacts

- More data necessary on the environmental, navigational, and competing use impacts

Grid Integration

- **Barriers:** Variable output; Low capacity factor; Located on weak circuits; Lack of utility experience; Economics of transmission work against wind/solar.



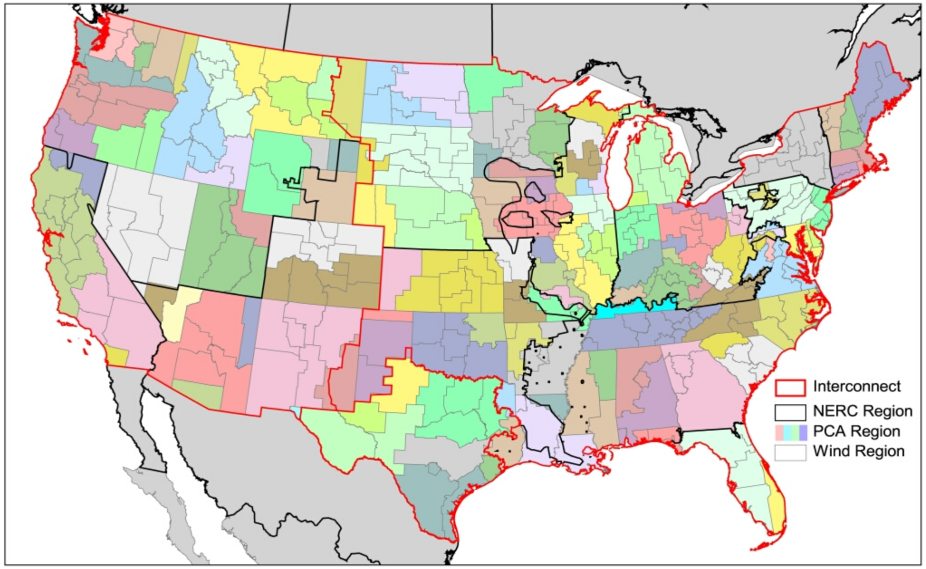
ISSUES

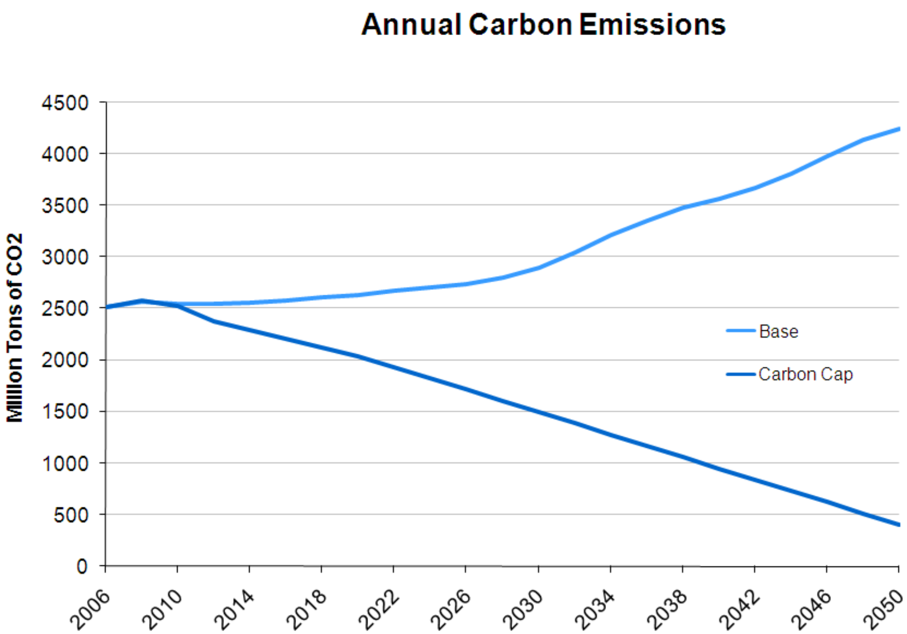
-Geographic Diversity
-Resource Forecasting
-Ramp Times
-Islanding
-System Interactions
-Storage
-Load Shifting
-2-Way Power Flow
-Stability
-Dynamic Models
-Communications, Control, Data Management

- **Assess** potential effects of large-scale Wind/Solar deployment on grid operations and reliability:
  - Behavior of solar/wind systems and impacts on existing grid
  - Effects on central generation maintenance and operation costs, including peaking power plants
- **Engage** with utilities to mitigate barriers to technology adoption
  - Prevent grid impacts from becoming basis for market barriers, e.g. caps on net metering and denied interconnections to "preserve" grid
  - Provide utilities with needed simulations, controls, and field demos
- **Develop** technologies for integration:
  - Smart Grid/Dispatch.

ReEDS Model

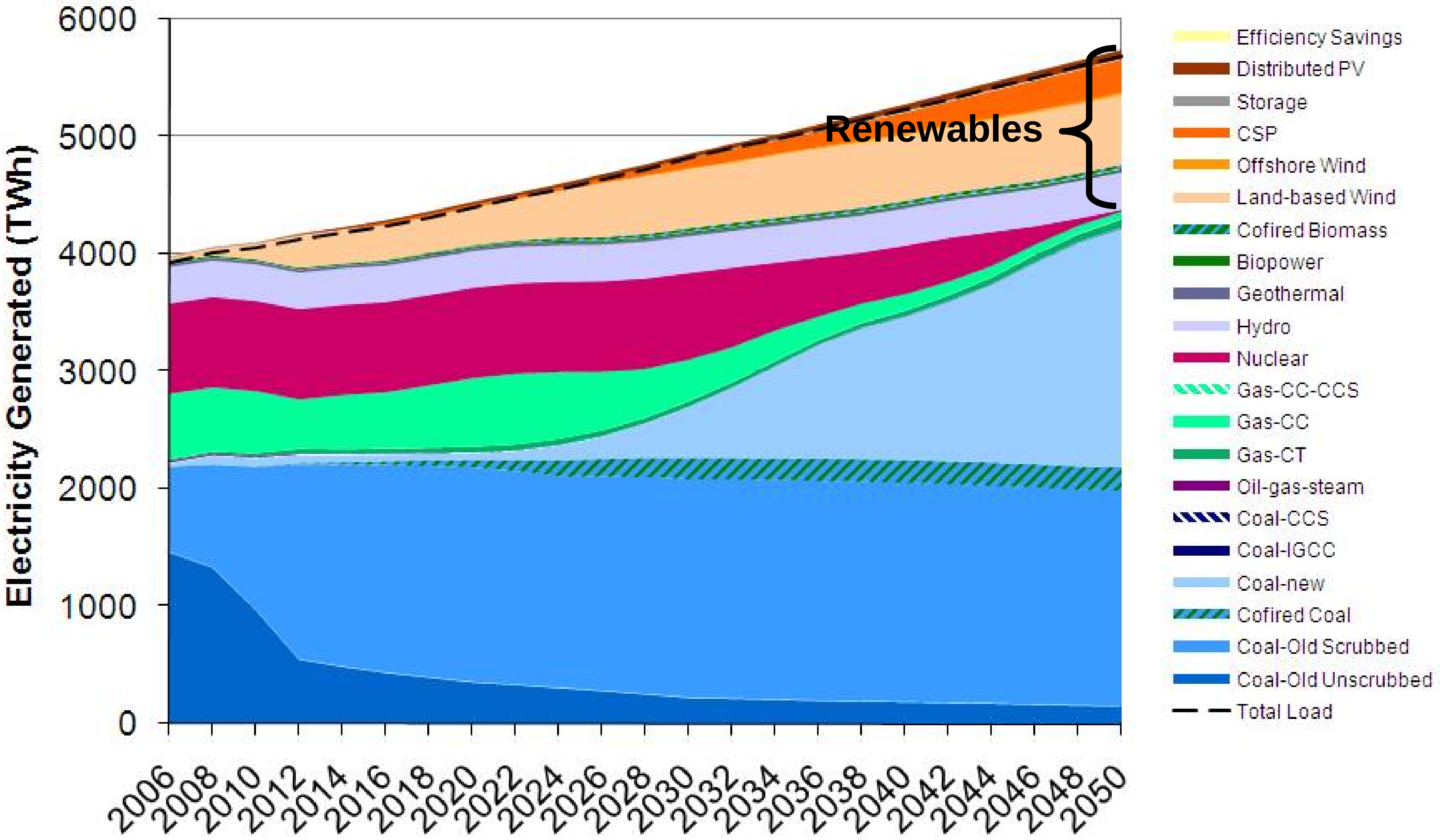
- **356 regions in Continental U.S.**
- **Linear program cost minimization**: 23 two-year periods from 2006-2050.
- **All major power technologies**–hydro, gas CT, gas CC, 4 coal (w/wo CCS), gas/oil steam, nuclear, wind, CSP, biopower (wo *CCS*), geothermal, 3 storage technologies.
- **Sixteen time slices in each year**: 4 daily x 4 seasons (+one super-peak).
- **Input future electric demands and fuel prices by region.**
- Simple elasticities provide *demand* and fossil fuel price response.
- **6 levels of regions** – RE supply, power control areas, RTOs, states, NERC areas, Interconnection areas.
- **Existing/new transmission lines.**
- **State-level incentives.**
- **Stochastic treatment of resources.**
- **Does not yet directly include PV or distributed benefits;** PV a placeholder
- **Policy: 80% emissions reduction from 2005 by 2050.**





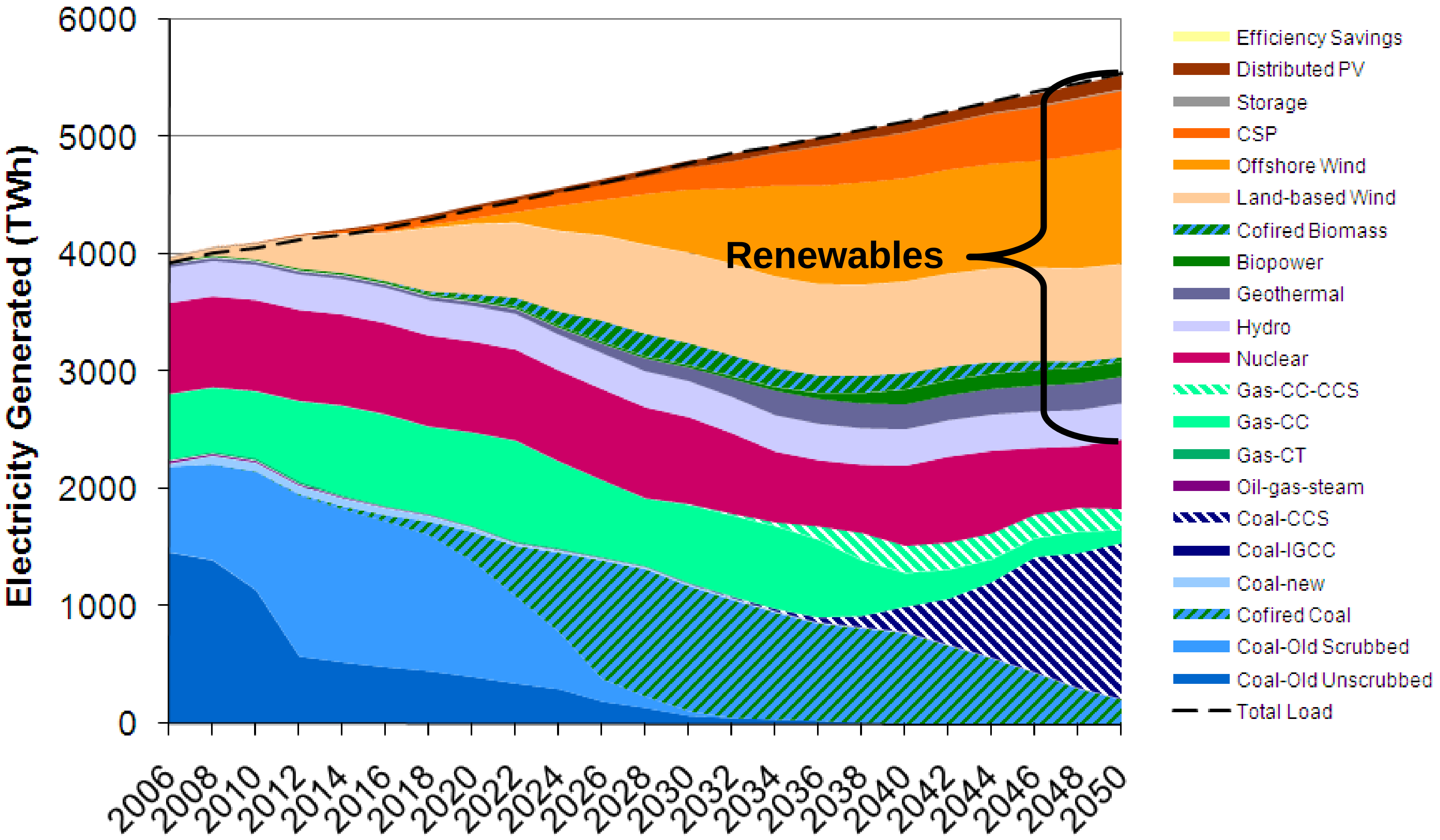
Source: Walter Short, NREL

Base Case Generation



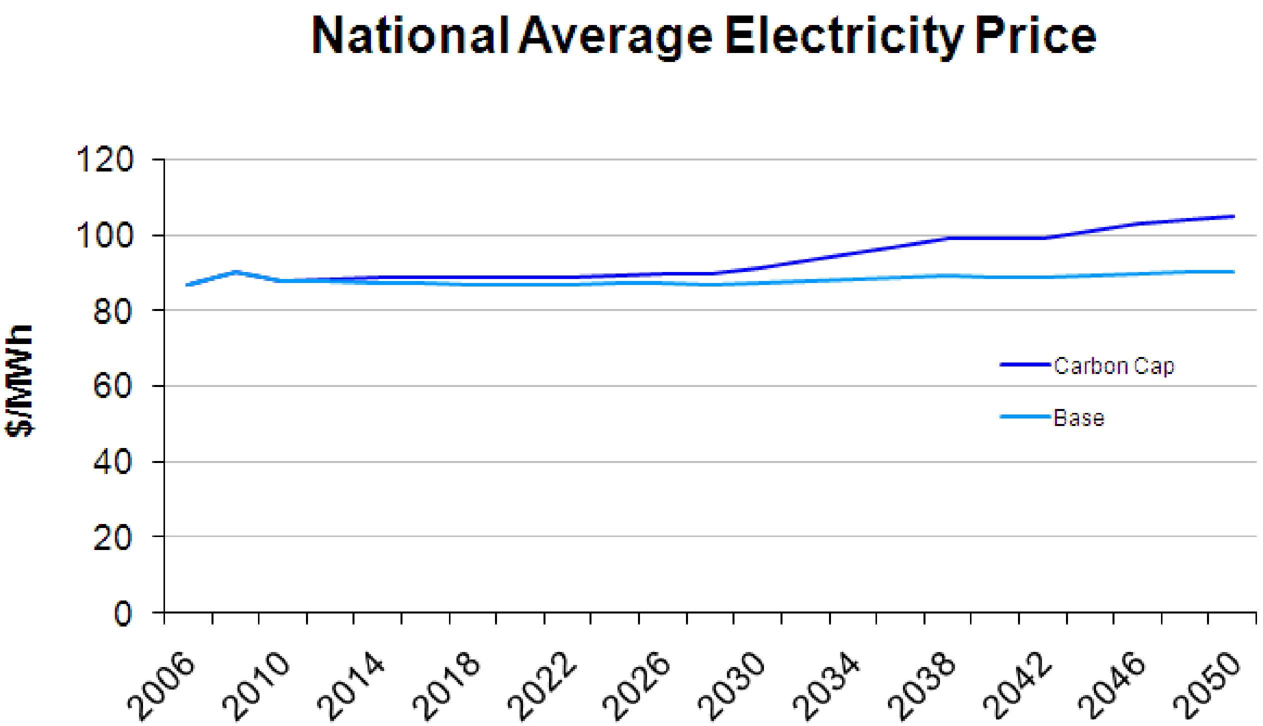
Source: Walter Short, NREL

Carbon Cap: Generation

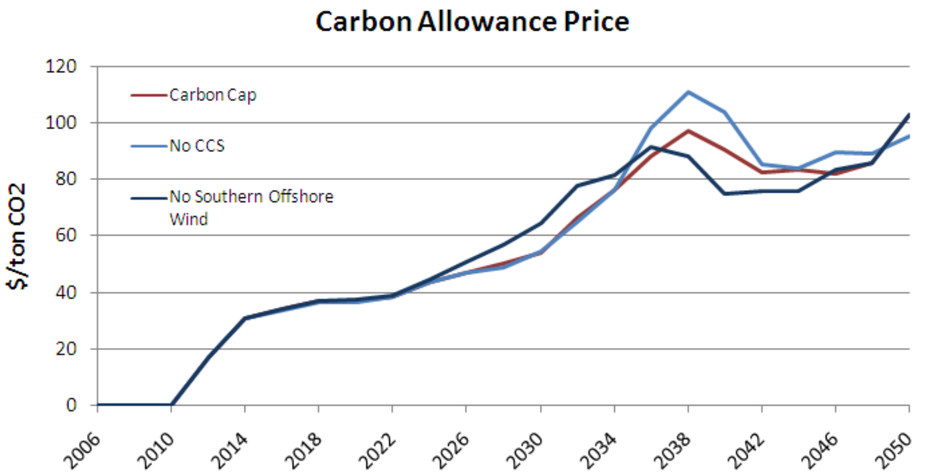


Source: Walter Short, NREL

Carbon Cap: Electricity Prices



➔ Price targets for PV systems, not including distributed benefits.



Source: Walter Short, NREL

Clean Energy to Secure America's Future

"For everywhere we look, there is work to be done. The state of our economy calls for action: bold and swift. And we will act not only to create new jobs but to lay a new foundation for growth... We will restore science to its rightful place... We will harness the sun and the winds and the soil to fuel our cars and run our factories. All this we can do. All this we will do."

President Obama 1/20/09

"We have a choice. We can remain the world's leading importer of oil, or we can become the world's leading exporter of clean energy. We can hand over the jobs of the future to our competitors, or we can confront what they have already recognized as the great opportunity of our time: the nation that leads the world in creating new sources of clean energy will be the nation that leads the 21st century global economy. That's the nation I want America to be."

– **President Obama,** Nellis Air Force Base, Nevada, 5/27/09

EERE R&D Activities

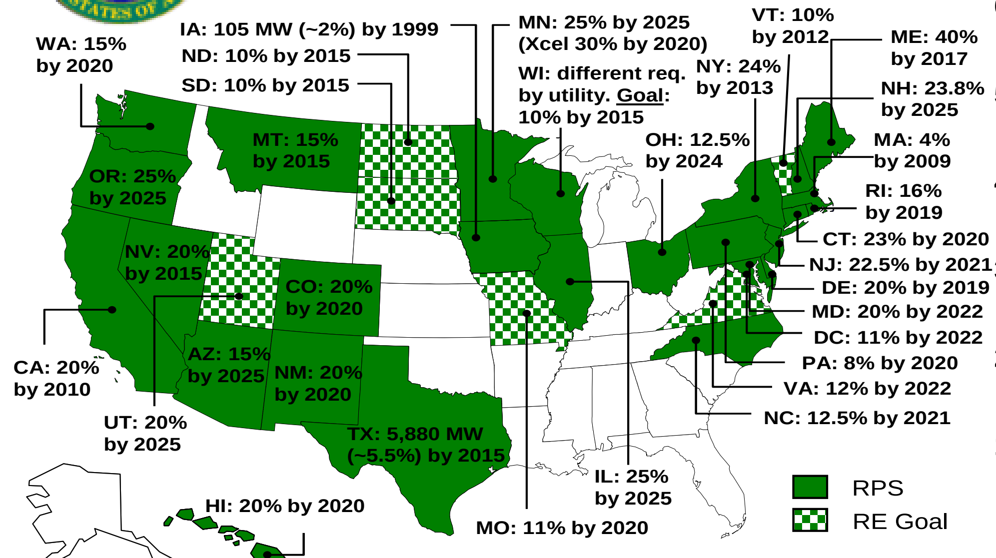
($Millions)

	FY06Ap	FY08Ap	FY09Ap	ARRA	FY10Req	10/9
• **Efficiency**						
– Buildings	$ 68.3	$ 107.4	$ 140.0	$ 346	$ 237.7	70%
– Industry	$ 55.8	$ 63.2	$ 90.0	$ 216	$ 100.0	11%
– Vehicles	$ 178.4	$ 208.4	$ 273.2	$ 415	$ 333.3	22%
– Hydrogen	$ 153.5	$ 206.2	$ 168.9	$ 43	$ 68.2	-60%
• **Renewables**						
– Biomass	$ 89.7	$ 195.6	$ 217.0	$ 786	$ 235.0	8%
– Wind/Water	$ 38.8	$ 49/9.6	$ 55/40	$ 108/32	$ 75/30	36/-25
– Solar	$ 81.8	$ 166.3	$ 175.0	$ 117	$ 320.0	83%
– Geothermal	$ 22.8	$ 19.3	$ 44.0	$ 400	$ 50.0	14%
Total R&D	$ 689	$1025	$1203	$2463	$1449	20%
(PHEVs)				($2400)		
Total EERE	$1162	$1704	$2178	$16800	$2318	6%

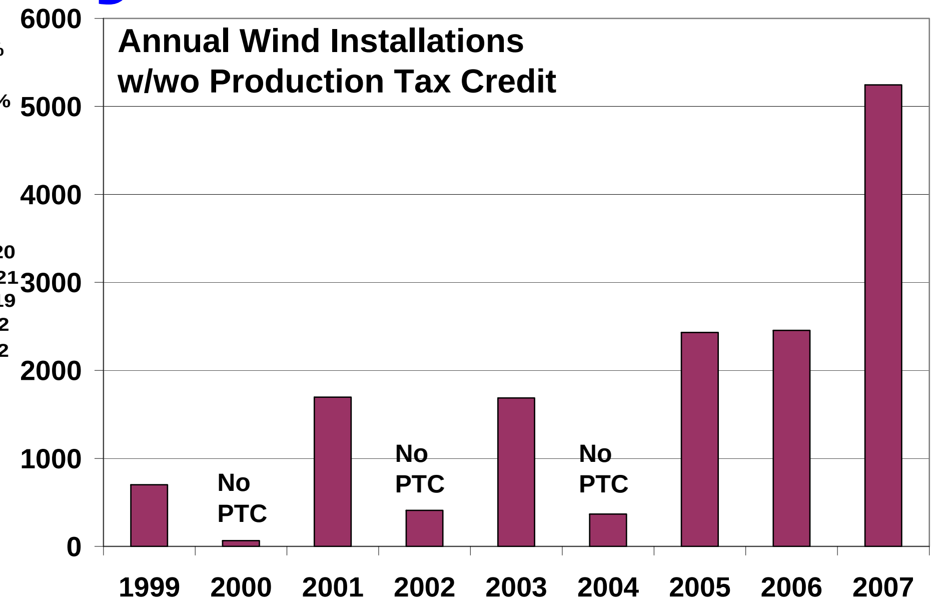
Office of Science, Energy Frontier Research Centers

- **18 Centers that include solar-related research.**
- **46 Centers Total, with $777M of Support over 5 years.**

Policy



Sources: Union of Concerned Scientists and NREL



- **House: American Clean Energy and Security Act: HR 2454** (31 to 25, 5/21)
  - Carbon Cap & Trade: reduce 17% by 2020, 80% by 2050, compared to 2005
    - Allocations: Consumers; Industry; State Programs; University R&D; other
  - Renewable Electricity Standard of 20%, 15% Renewables, 5% Efficiency

- **Senate: America Clean Energy Leadership Act of 2009**
  - Clean Energy Financing
  - Improved Transmission Siting
  - Renewable Electricity Standard
    - June 4 (33 amendments, 21 passed): 15% RES, of which up to 4% Efficiency.
  - Renewables on Public Lands: June 9.

Drivers of R&D Change & Challenges

- **Increasing global competition**
  - Trade issues: currency manipulation; implicit/explicit supports
- **Rapid technological change; Shorter development cycles; Increasing complexity of emerging technologies**
  - Multidisciplinary teams (ITIF: R&D100: 1971-2006: Sole private ~80%➔30%; mixed private and/or public: ~15%➔60+%)
- **Embedded value in manufacturing**
  - Consumer Electronics ➔ Batteries
- **Changes in corporate structure**
  - Deregulation; Outsourcing of corporate R&D
- **Markets**
  - High-value market niches and learning curves for commodity energy
  - Market Drivers: Standards; Incentives; Taxes; Feebates; etc.
- **New Models for Energy R&D: ARPA-E**
  - Avoiding new stovepipes; standing up new system; controlling external pressures
- **U.S. Manufacturing (Batteries)**
  - Maintaining/strengthening market competitiveness: manufacturing R&D?
  - Catalyzing market demand, infrastructure development, manufacturing ramp-up
  - Achieving/maintaining the public-private scale of activity required over time
- **How to better align R&D and Policy**

Human Resources: Solar Decathlon

8-18 October 2009

Architecture
Engineering
Market Viability
Communications
Comfort

Appliances
Hot Water
Lighting
Energy Balance
Getting Around

Cornell; Iowa State; Penn State; Rice; Team Alberta (U. Calgary, SAIT Polytechnic, Alberta College, Mount Royal College); Team Boston (Boston Architectural College, Tufts); Team California (Santa Clara U., California College of Arts); Team Missouri (Missouri S&T, U. Missouri); Team Ontario/BC (U. Waterloo, Ryerson, Simon Fraser); Technische Universitat Darmstadt; Universidad Politecnica de Madrid; Ohio State; U. Arizona; U. Puerto Rico; U. Illinois-Urbana; U. Kentucky; U. Louisiana-Lafayette; U. Minnesota; U. Wisconsin-Milwaukee; Virginia Tech.

For more information

http://www.eere.energy.gov

Sam.Baldwin@ee.doe.gov