# Renewable Energy

## Presentation to PCAST
## September 20, 2005

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Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

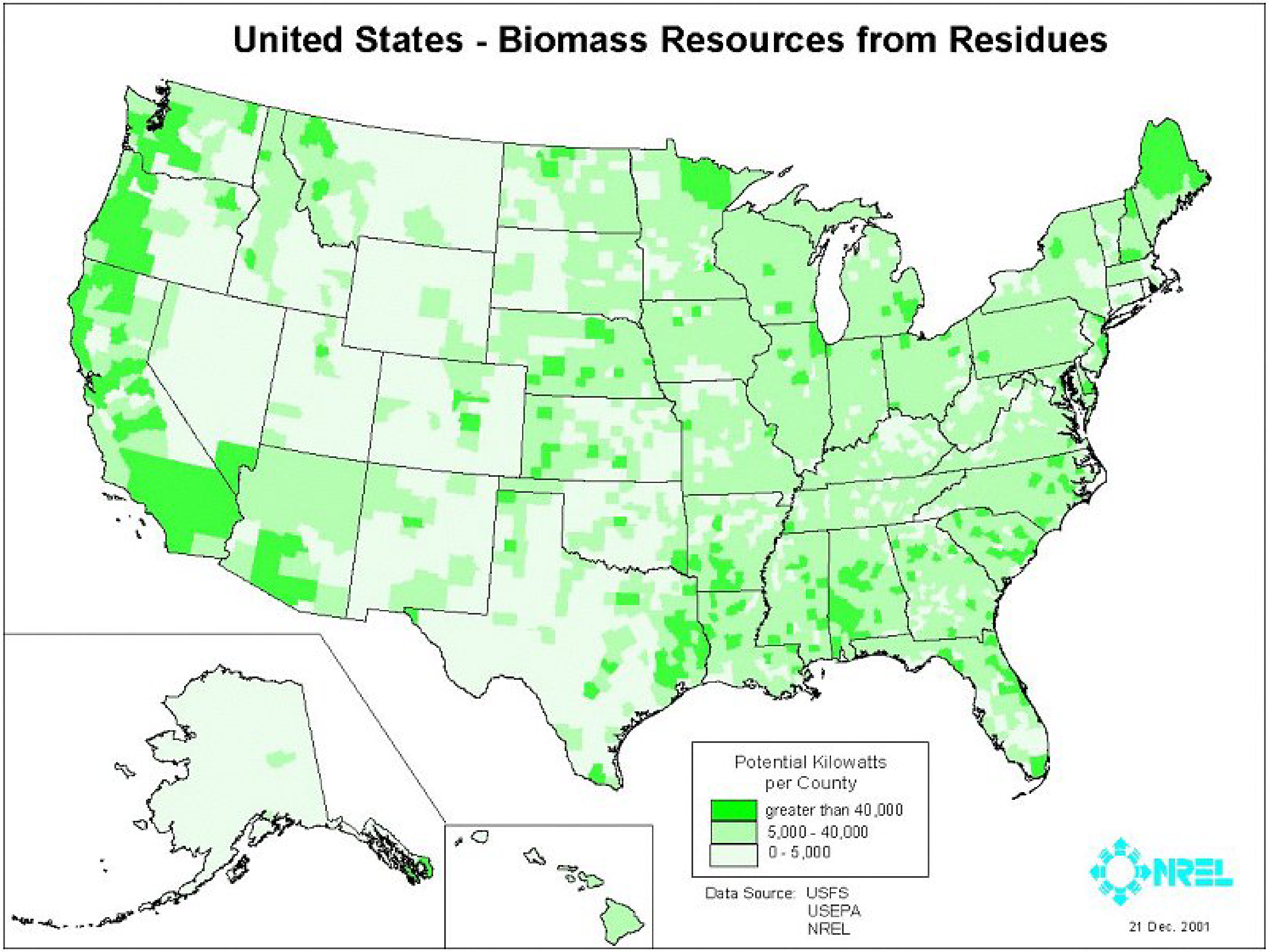
# Energy-Linked Challenges

- **Economy**
  - Economic development and growth.
  - Oil Imports cost and volatility.
- **Environment**
  - Local urban air quality—e.g., particulates.
  - Regional air quality—e.g., acid rain.
  - Global warming.
- **Energy Security**
  - Dependence on insecure supplies of foreign oil; natural gas.
  - Energy reliability.
  - Economic development/political stability.

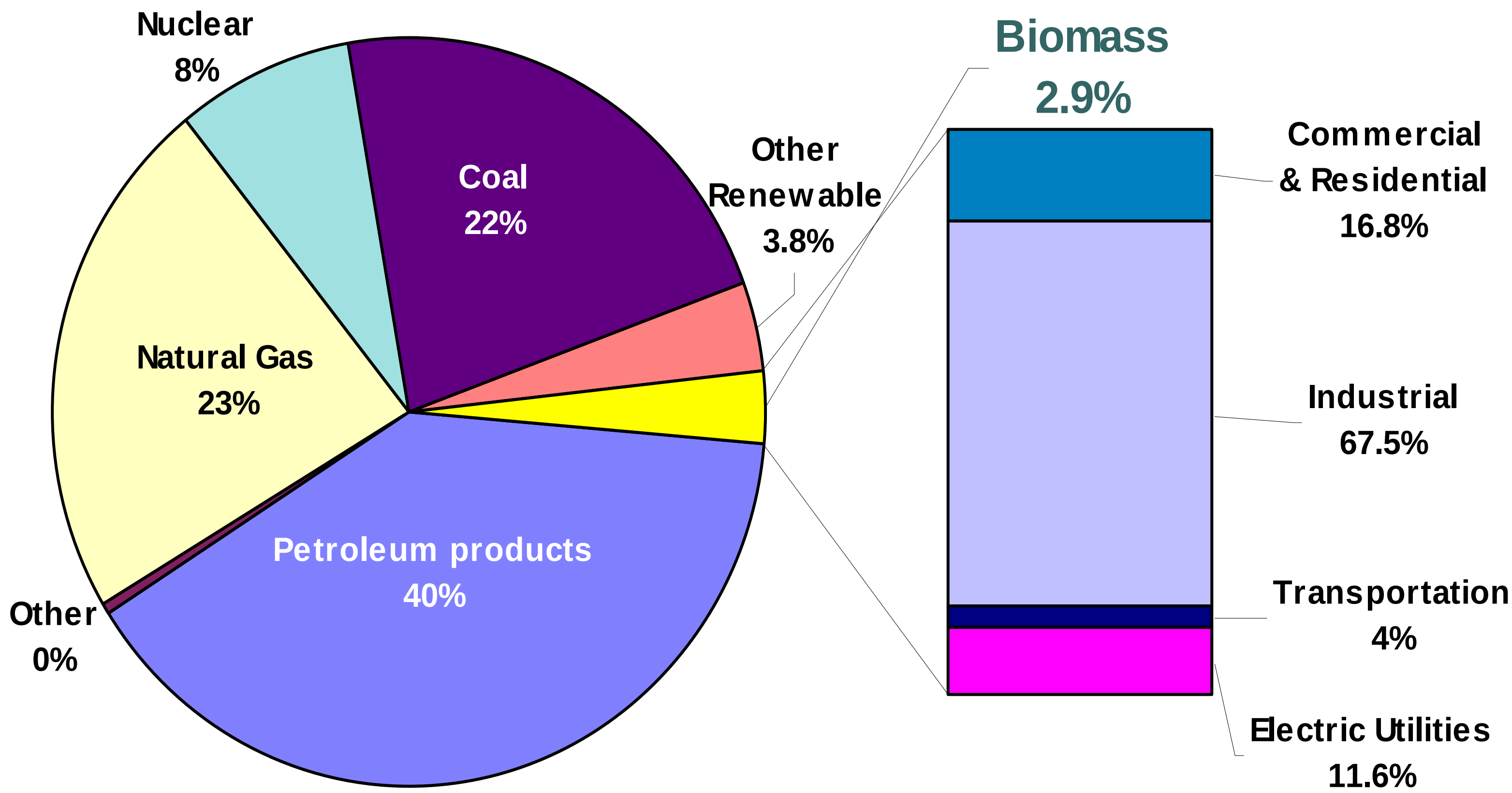
# EERE FY05 Funding

| EERE Programs | FY05 Approp | FY06 Request |
|---|---|---|
| | Millions of Current Dollars | |
| • Biomass | $ 88.1 | $ 72.2 |
| • Building Techs | $ 65.5 | $ 58.0 |
| • DER | $ 60.4 | $ 56.6 |
| • FEMP | $ 19.9 | $ 19.2 |
| • FreedomCAR & VT | $ 165.4 | $ 165.9 |
| • Geothermal | $ 25.3 | $ 23.3 |
| • Hydrogen, FC&IT | $ 168.9 | $ 182.7 |
| • Industrial Techs | $ 74.8 | $ 56.5 |
| • Solar | $ 85.1 | $ 84.0 |
| • Weatherization & IP | $ 325.8 | $ 310.1 |
| • Wind & Hydropower | $ 45.7 | $ 44.7 |
| TOTAL | $1,248.6 | $1,200.4 |

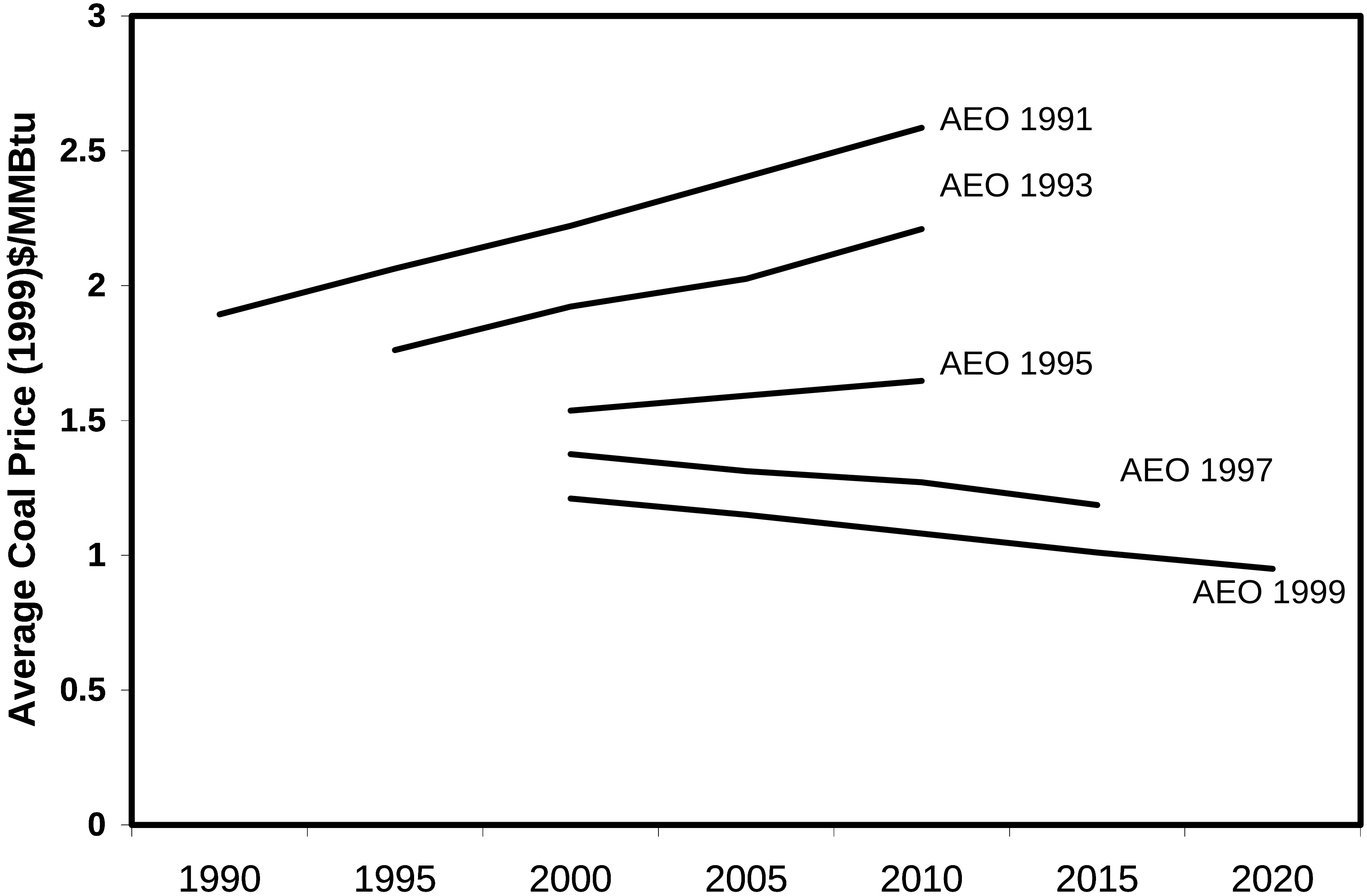
# Biomass Resources



# 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**

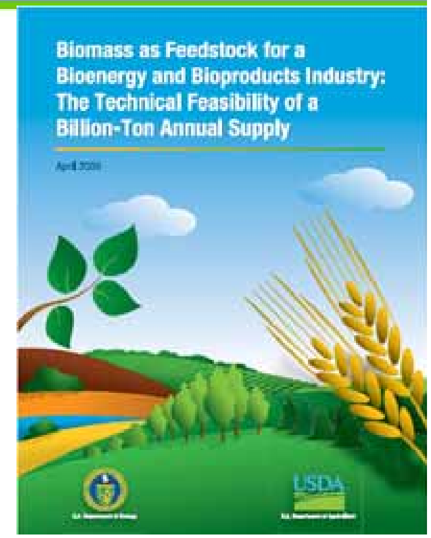
**Fuels:**
- Ethanol
- Renewable Diesel
- Hydrogen

**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**

# Biomass




- **Biomass Potential**:
  - The US currently has near-term potential of 1.3 billion dry tons of biomass for energy production, without significant impact to agricultural and forest land uses. This is enough to displace up to 30% of current petroleum fuel use with biobased fuels, and would be a 7-fold increase in current biomass production.
- **Biomass Markets:**
  - Cargill-Dow has 150,000 tons capacity of polylactide polymer production/year, Blair, Nebraska.
  - Toyota has projected a global bioplastics market of ~$38B by 2020
- **Biomass Progress**
  - Novozyme, Genencor, NREL received 2004 R&D100 award for improving the cellulase enzyme (catalytic activity, yields, etc.), 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.
- **Biomass Net Energy**:
  - Corn ethanol net of 26%; cellulosic ethanol net ~90%; biodiesel 69%.

# BioEnergy—S&T Challenges

- **Feedstock production and collection**
  - Plant growth and response to stress (and on marginal lands)**;**
  - Higher productivity at lower input (water, fertilizer, etc.)
  - Production of certain components and/or new components
  - Functional genomics; biochemistry; physiology; cellular control mechanisms; respiration; photosynthesis, metabolism, nutrient use, disease response
- **Biochemical pathways**
  - Biocatalysis: enzyme function and regulation; enzyme engineering; catalyst reaction rates and specificity
- **Thermochemical pathways**
  - Product-selective thermal cracking of biomass; CFD modeling
- **Bioproducts**
  - New and novel monomers and polymers;
  - Biomass composites; adhesion/surface science
- **Combustion**
  - NOx chemistry; CFD modeling

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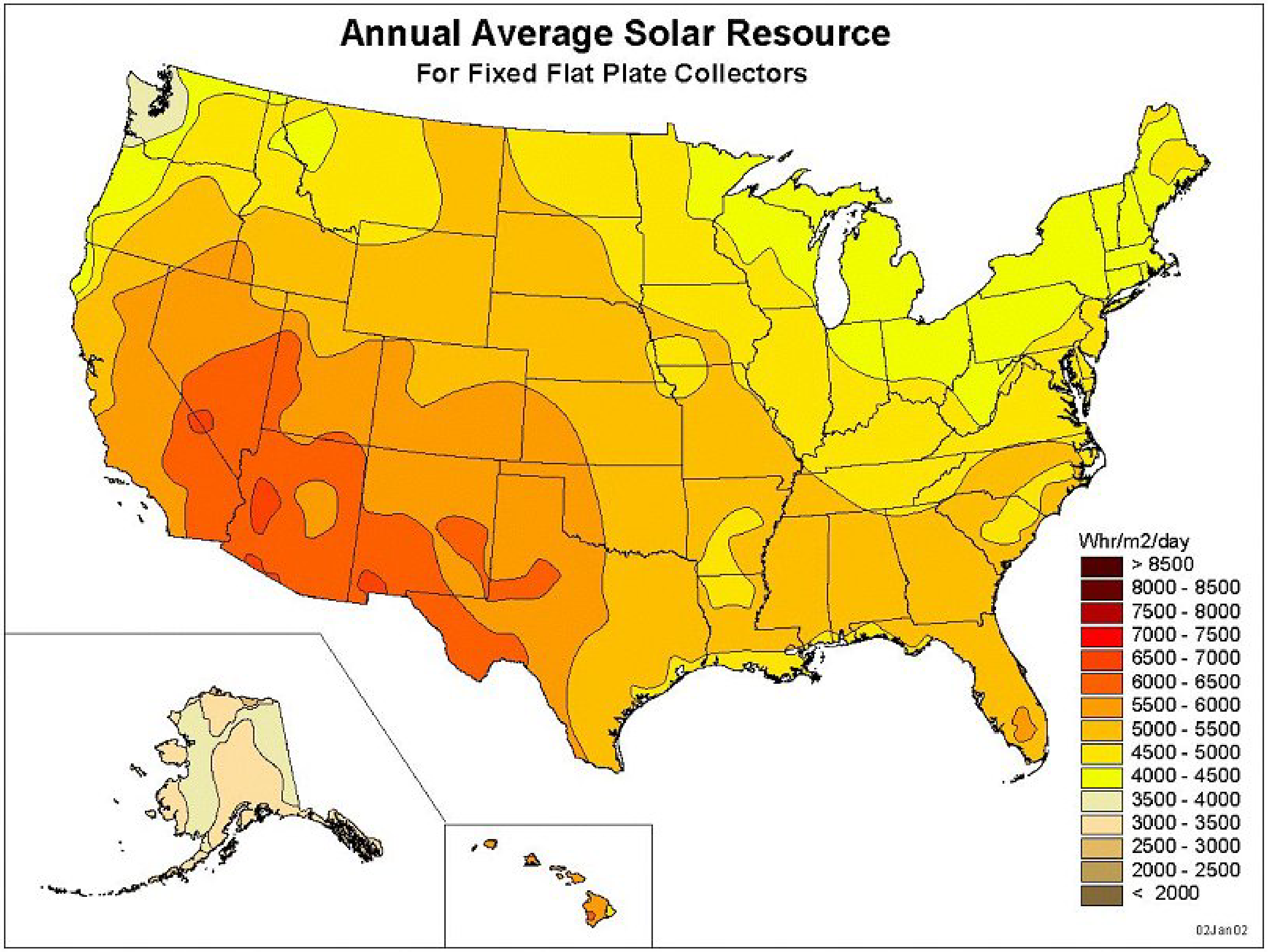
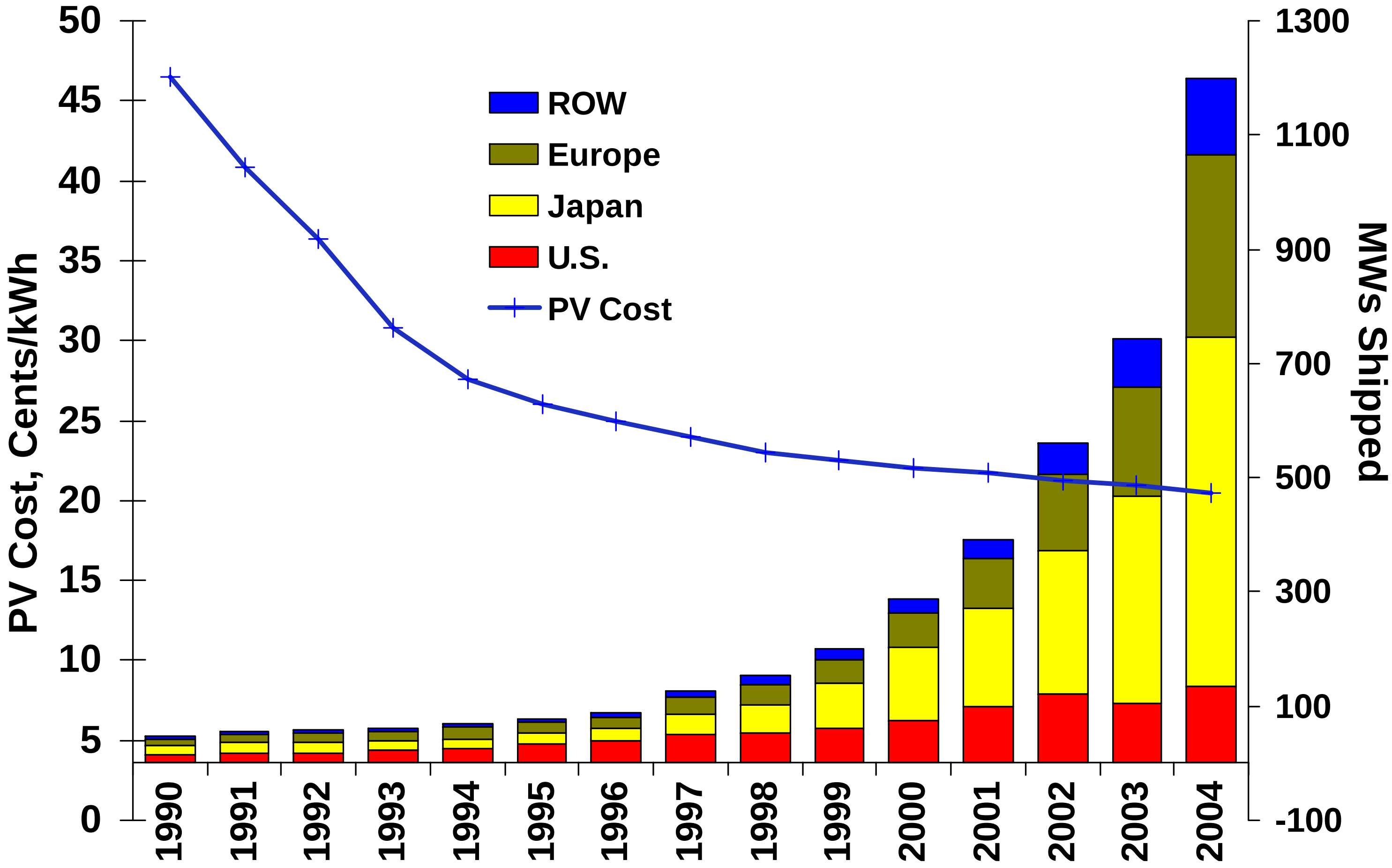
# Solar Energy

- 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 Costs and Shipments




Source for market data: Paul Maycock, PV News, Volume 24, No. 2 February 2005

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# R&D Activities

| Fundamental Research | Advanced Materials & Devices | Technology Development |
|---|---|---|
| **Measurement/Characterization**<br>•Electrical, optical, chemical, structural properties<br>•Solar cell/module performance<br>•Solar Resource Characteriztn | **Thin Film Partnership**<br>•National Ind/Univ/Lab Teams<br>•Thin Film Center of Excellence (Institute of Energy Conversion, University of Delaware) | **System Engineering/ Reliability**<br>•Field Test/Evaluation<br>•Balance of system developmnt<br>•Codes, standards, certification |
| **University Research Projects**<br>•Fundamentals of PV materials and devices<br>•Future Generation PV<br>•X-Si University Center of Excel<br>•Minority University Research | **Adv. Manufacturing R&D**<br>•Cost-shared industry R&D on in-line diagnostics & intelligent processing.<br>•R&D: yield, durability, reliability<br>•Modules/System Components | **Building-Integrated PV**<br>•R&D on concepts/components<br>•Coordination with other programs |
| **High Performance PV**<br>•Multijunction Concentrations and thin films<br><br>**Collaborative Crystalline Research** | **Module Reliability R&D**<br>•Module packaging for 30-year outdoor lifetime<br>•Accelerated environmental testing | **Outreach/Communication**<br>•Domestic/Intl. Market facilitation<br>•Training, education, tech asst.<br>•Solar Exhibits/Displays<br>•Communications plan/products<br>•Solar Decathlon |

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# Photovoltaics (PV)

## Goal: Market Competitiveness

**2020:** Reduce LEC for PV to $0.06/kWh (<$2/W systems)

**2006:** PV Modules with 14% efficiency ($0.17-0.22/kWh)

## Status:

**2005**: PV Modules achieved 13.5% efficiency at $1.95/W manufacturing cost ($0.18-0.23/kWh)

## Approach:

Aggressive, multi-path R&D:

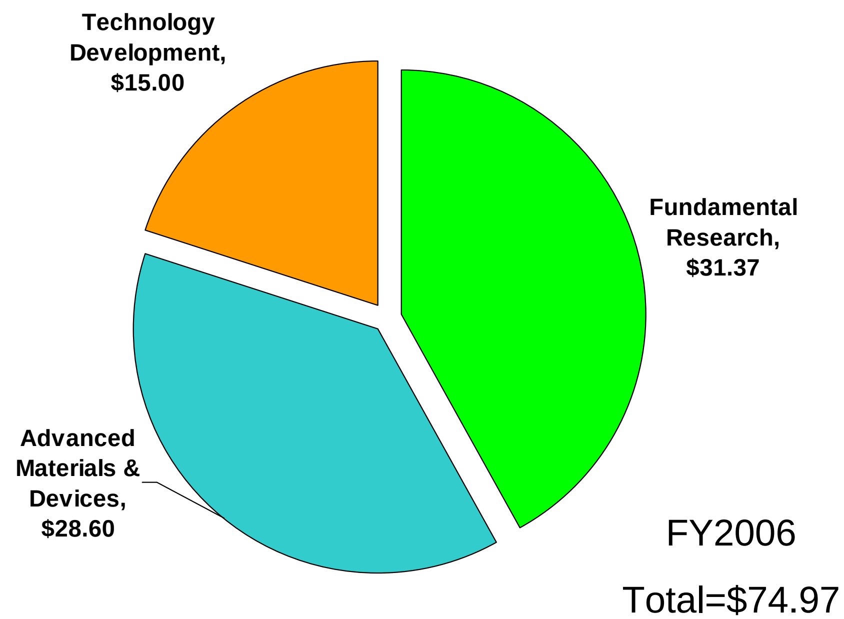
-Reduce manufacturing cost of cells and modules

-Improve cell, module and system efficiency

-Improve reliability and lower cost of the system and BOS components, e.g.inverters

-Improve understanding of materials, processes, and devices for advanced PV options, e.g. polymer cell

## FY 2006 (millions)



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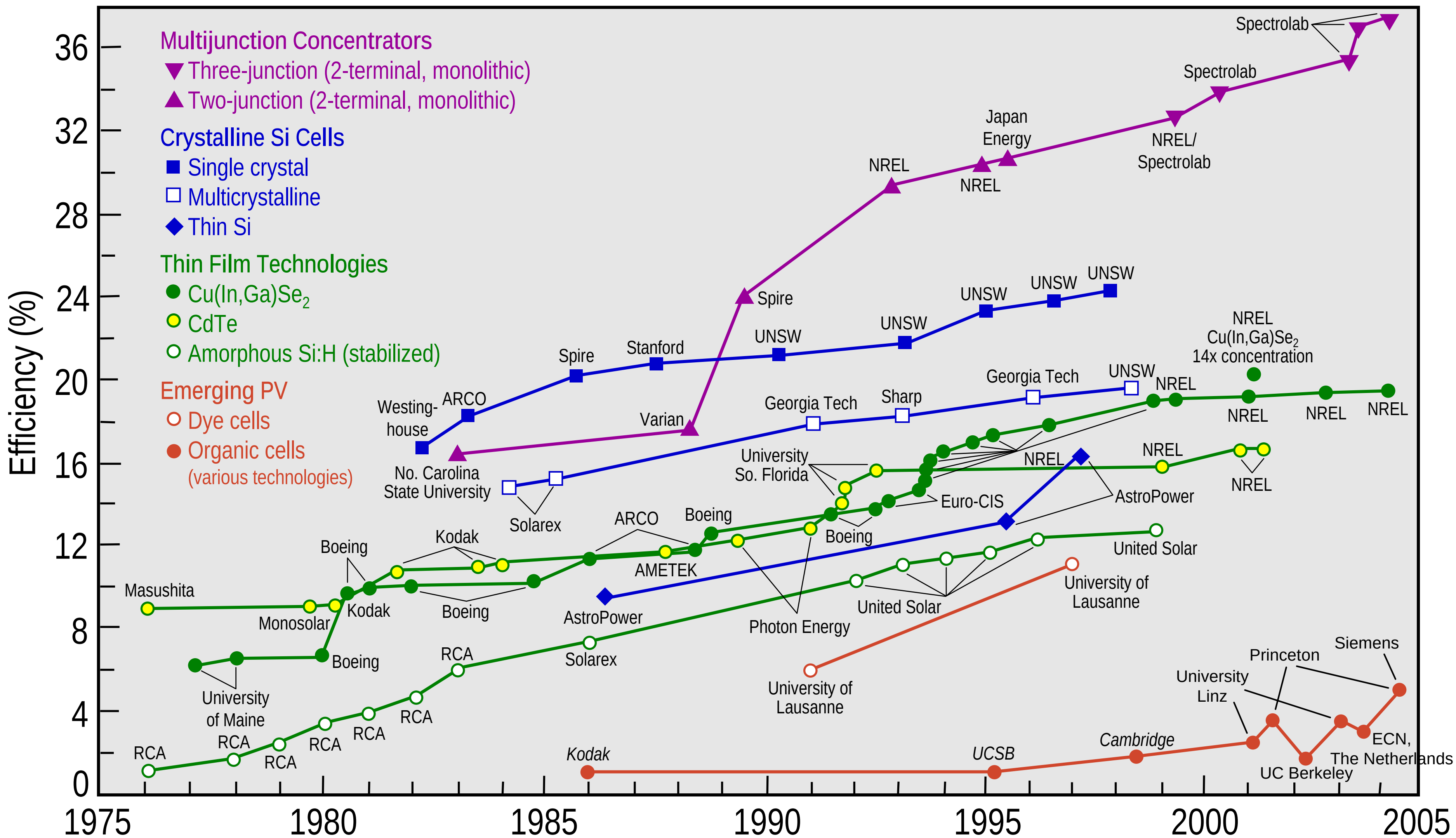
# Best Research-Cell Efficiencies

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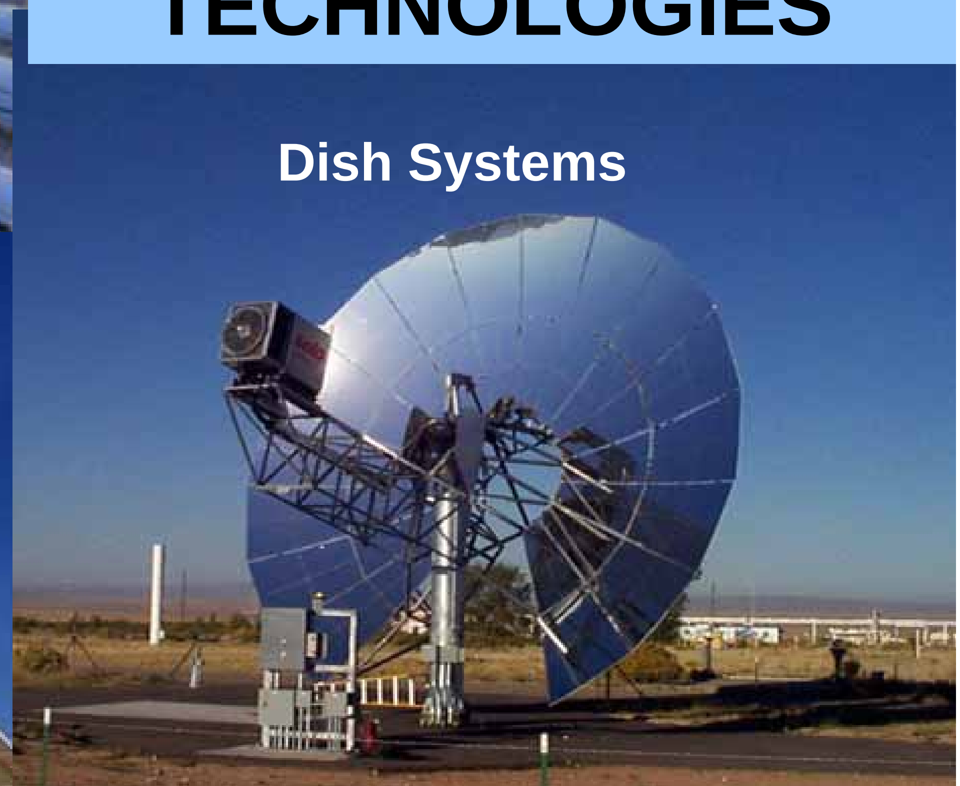
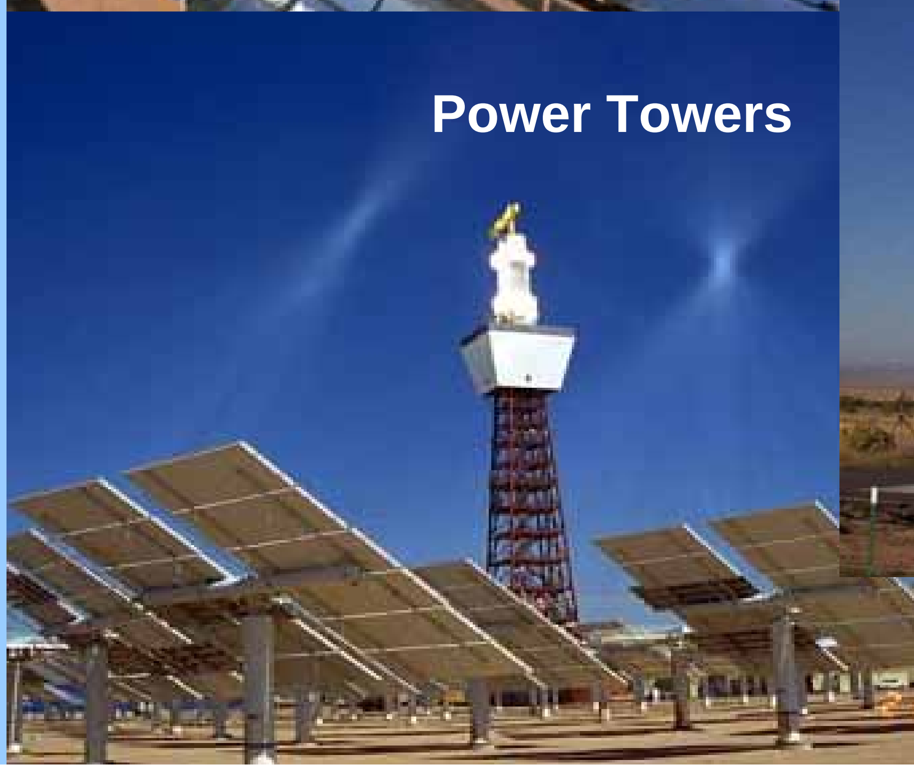
# CONCENTRATING SOLAR POWER TECHNOLOGIES

# Concentrating Solar Power

## Goal:

- Reduce LEC of large-scale CSP systems to 8-10¢/kWh by 2011
- Qualify 25kW dish/engine systems for utility-scale (1 MW) deployment
- Shepherd several state-led CSP deployments in the US Southwest

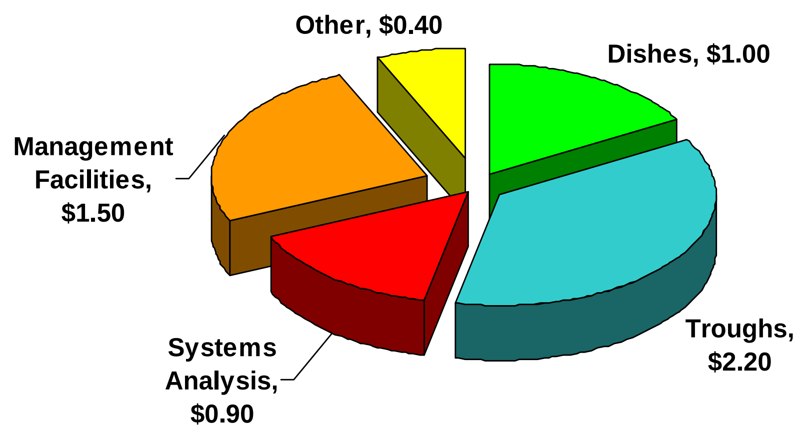
## Status:

- 354 MW of troughs operating reliably in Mojave Desert for 16 years
- Present LEC is 12-14¢/kWh (down from 36¢/kWh in 1985)
- Six-dish (150kW) mini power plant operating in Albuquerque, NM

## Approach:

- Incorporate thermal storage into trough systems to increase value
- Support dish industry efforts to improve system reliability
- Work with states to identify and quantify Southwestern markets

## FY 2006:




**Total=$6.00**

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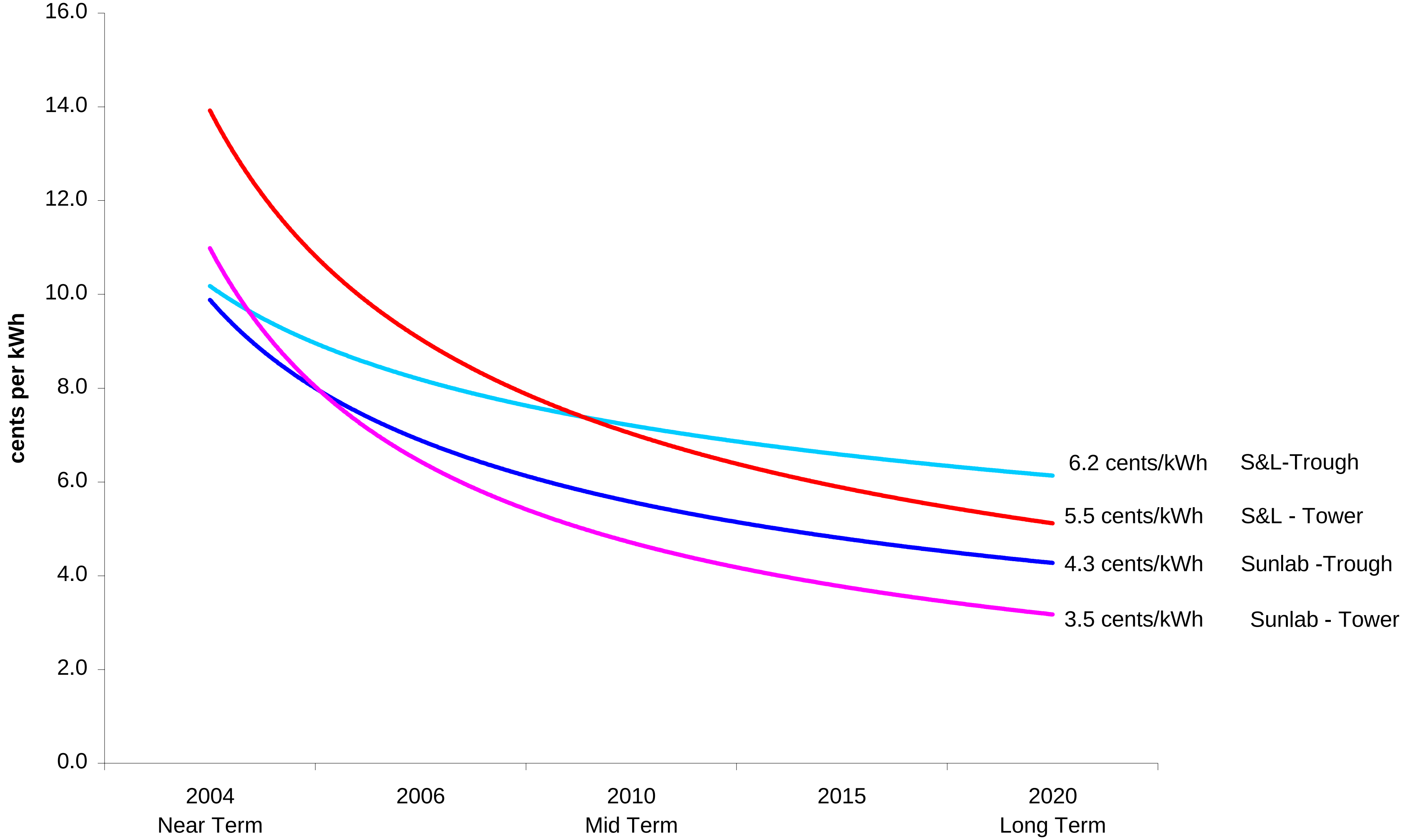
# CSP Cost Projections




Sargent & Lundy

# Solar Energy—S&T Challenges

- **Photovoltaics**:
  - Improve understanding of materials/growth/characterization and devices, esp. of CIGS, CdTe and Multi-junction thin films—interface chemistry, physics, defects, etc.
  - Innovative encapsulants
  - Transparent conducting oxides
  - Improved Computational methods
  - Quantum Dot cells, intermediate-band cells
- **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; Improved catalysts
  - PhotoElectrochemical redox couples with better band-edge matching
  - Electrolysis
  - PhotoBiological
- **Low Temperature Solar Thermal**:
  - New polymers that can withstand UV, hi/lo temperatures, and high pressures.
- **Cross-cutting Areas**:
  - Power electronics—wide-band gap materials; Reliable capacitors
  - Energy Storage

## **Solar Decathlon:** *"Energy We Can Live With"*; Sept. 29–Oct. 19

**Cal Poly – San Louis Obispo; Carnegie Mellon University; Concordia University; Cornell University; Crowder College; Florida International University; New York Institute of Technology; University of Madrid; University of Colorado – Boulder; University of Maryland; UMass Dartmouth; University of Michigan; University of Missouri – Rolla; University of Puerto Rico; Univ. of Southern California; University of Texas – Austin; Rhode Island School of Design; Virginia Tech; Washington State University**

# Buts?

- But renewables are intermittent?
- But R&D performance is poor?
- But technical progress has been slow?
- But market penetration has been slow?
- But DOE budgets never change?
- But DOE programs are never reviewed or killed?
- But DOE management of work is weak?

# But Renewables are Intermittent?

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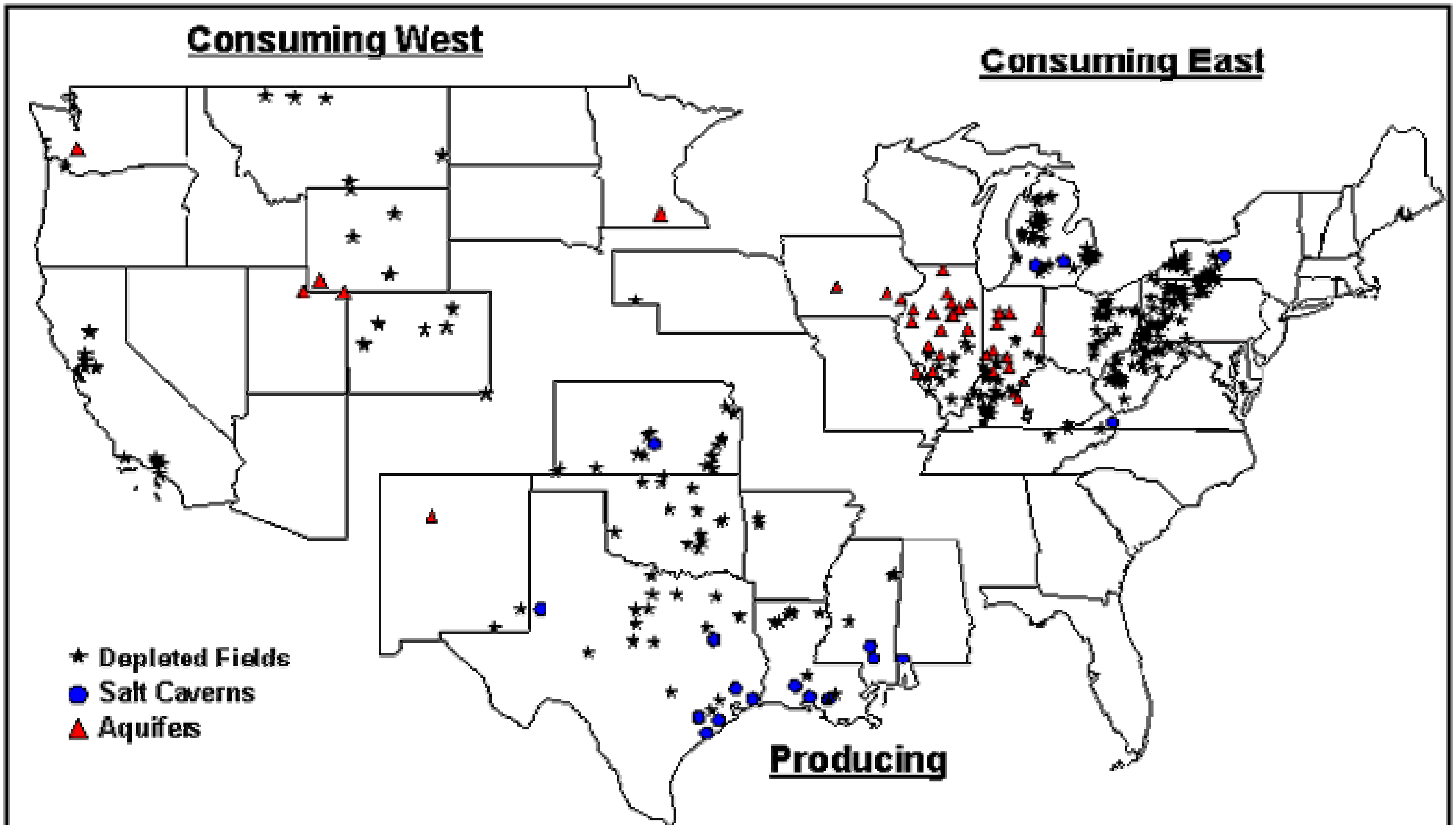
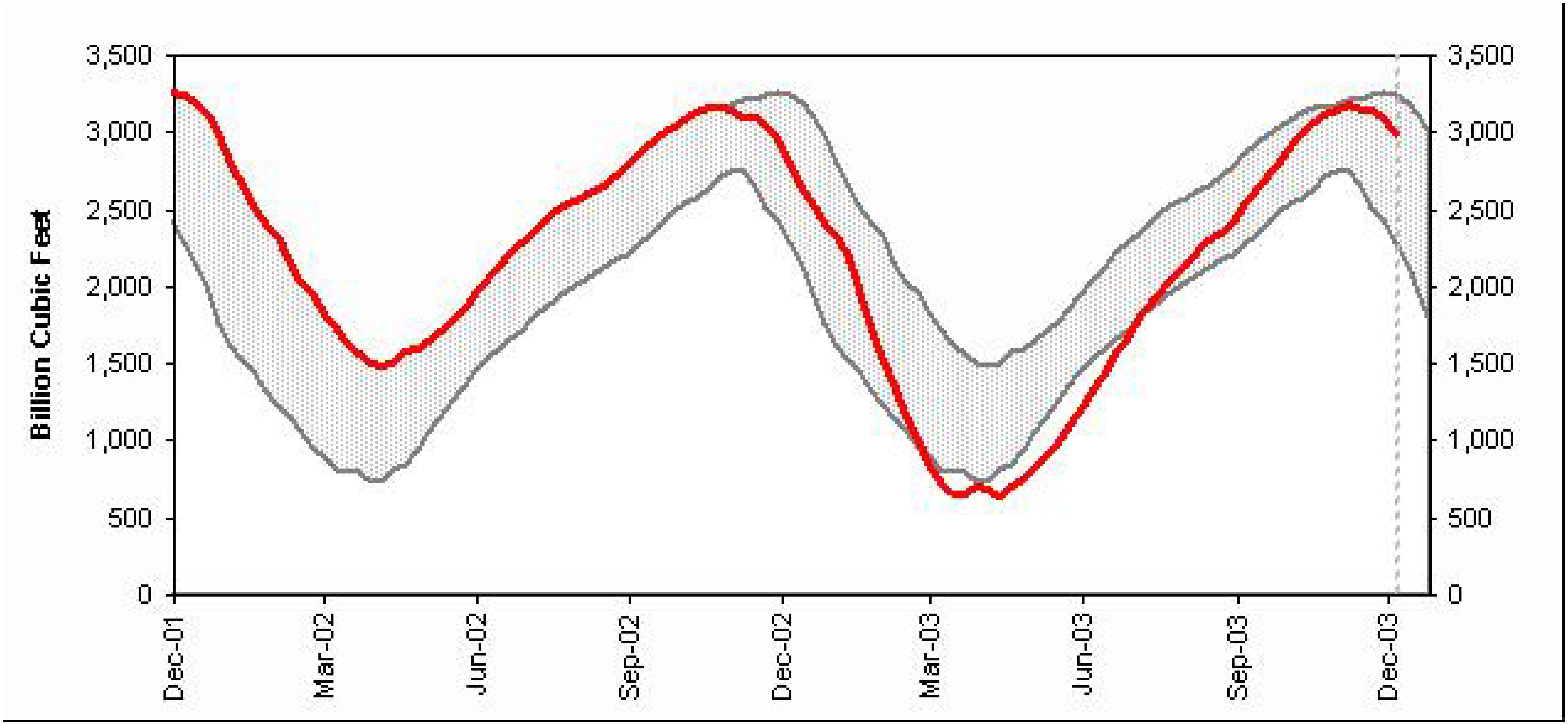
Figure 2. Underground Natural Gas Storage Facilities in the Lower 48 States




Source: Energy Information Administration, EIAGIS-NG Geographic Information System, Underground Storage Database, as of June 2002.

## Working Gas in Underground Storage Compared with 5-Year Range



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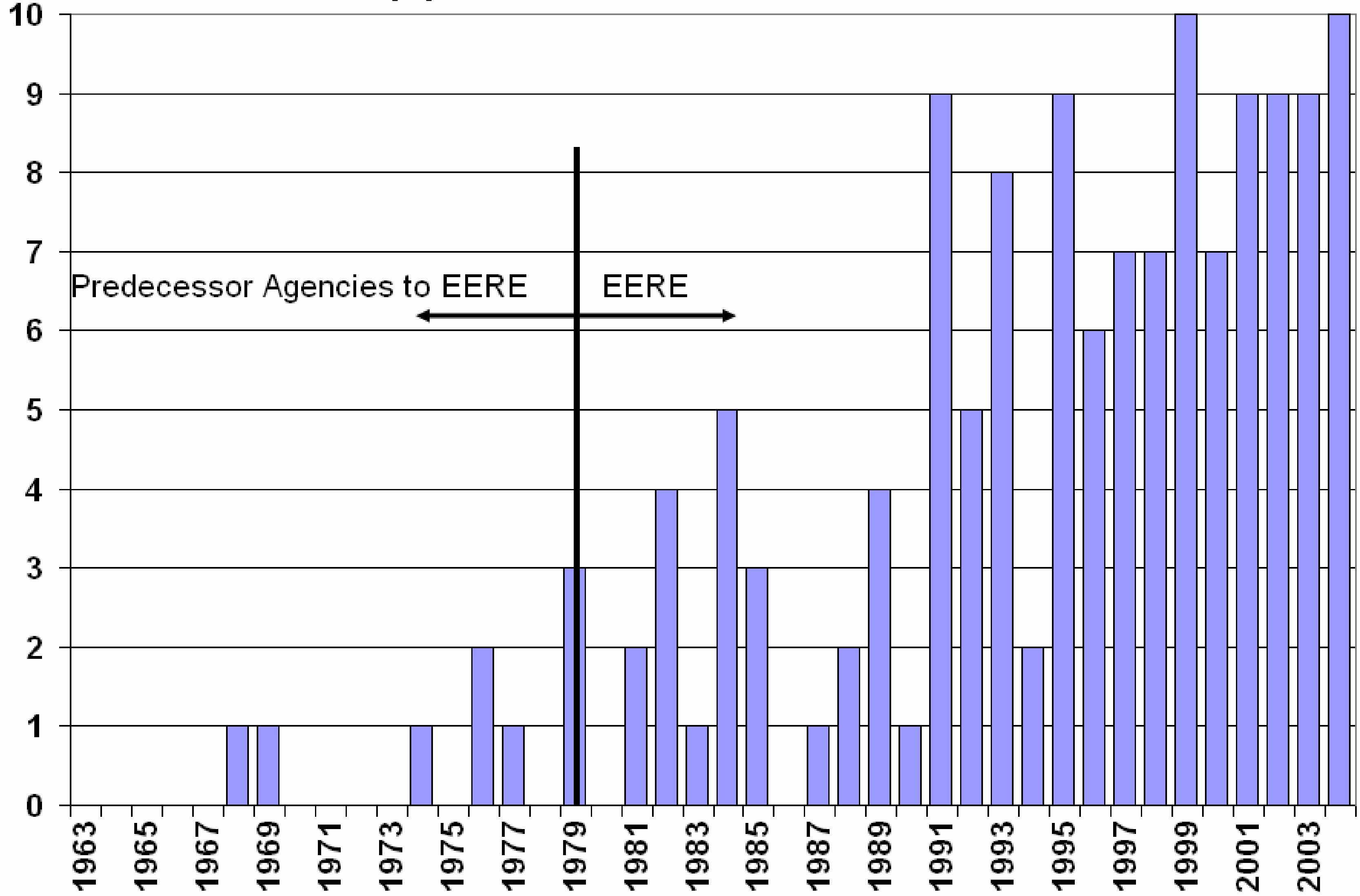
# But R&D Performance is Poor?

## EERE-Supported R&D100 Awards



# But Nothing is Ever Ended?

- Ocean Thermal Energy Conversion
- Bio: Hawaiian Biomass Gasification Commercialization
- Bio: Minnesota Agripower Program, others.
- Geothermal Magma Energy Extraction
- Geopressured Geothermal R&D
- Geothermal Heat Pumps
- Solar PV Thin Film Materials
  - $Cu_2S$, $Cu_2Se$, $Zn_3P_2$, $ZnSiAs_2$, InP, CdSe, InSb, others
- Solar Hemispherical Bowl Concentrators
- Solar Dish Brayton and Rankine Cycles
- Solar One and Solar Two Power Towers
- Solar Central Receivers with Rock/Oil Storage Systems
- Solar Photocatalysis for Detoxification
- Hydropower Improved Turbine Design
- Vertical Axis Wind Turbines

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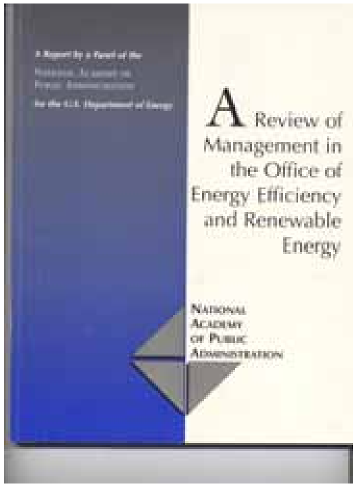
# But DOE Management?

- In 1999, Congress requested that the National Academy of Public Administration (NAPA) review EERE's management & organization. NAPA's review identified four major concerns: Fragmentation of EERE; Emphasis on process rather than product; Poor communications; Weak decision-making

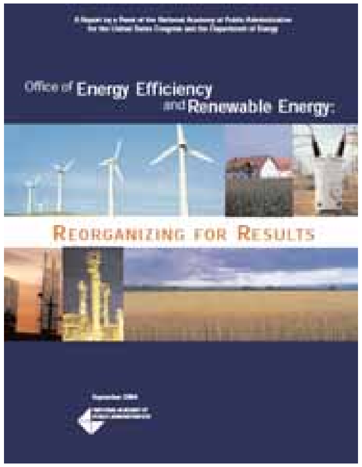



- Following EERE's reorganization, NAPA conduct another review :

  "The reorganization was not a one-time event. It has been a positive process that continues to evolve. This sweeping reorganization changed how EERE manages its programs, consolidated basic administrative functions, and changed how EERE awards and manages its research and development funds. ....

  EERE has made great strides to reinvent how it does business.

  The Panel believes that it is the responsibility of government leaders to invoke changes that improve public management and administration. As a result of its efforts the last two years, EERE leadership is well on its way to doing that. … The leadership of the Department of Energy should examine what EERE has accomplished and consider whether a similar approach would benefit other parts of the Department." (NAPA, September 2004)



# Time Constants

- Political consensus building ~ 3-20+ 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 ~100's-1000's
- Reversal of Land Use Change ~100's
- Reversal of Extinctions Never

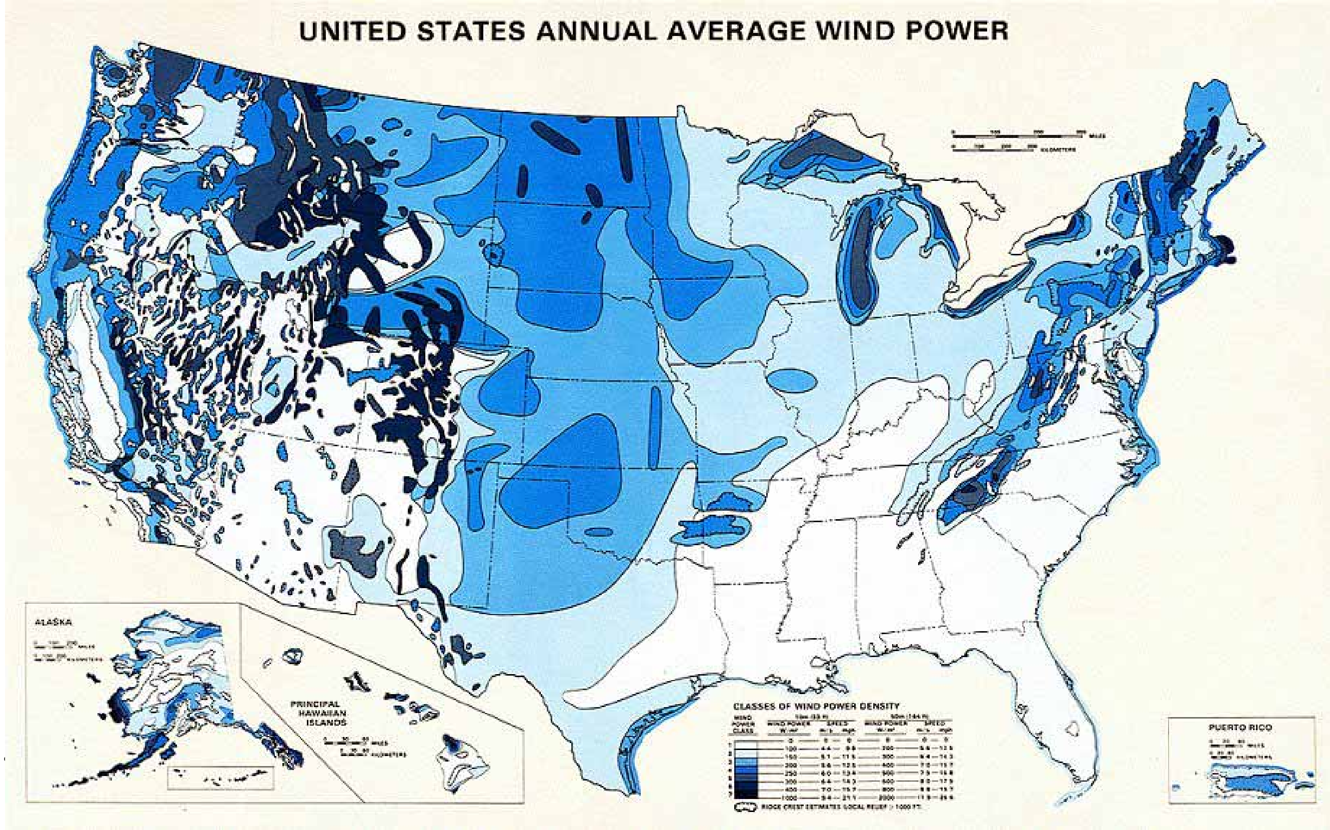
# For more information

# http://www.eere.energy.gov

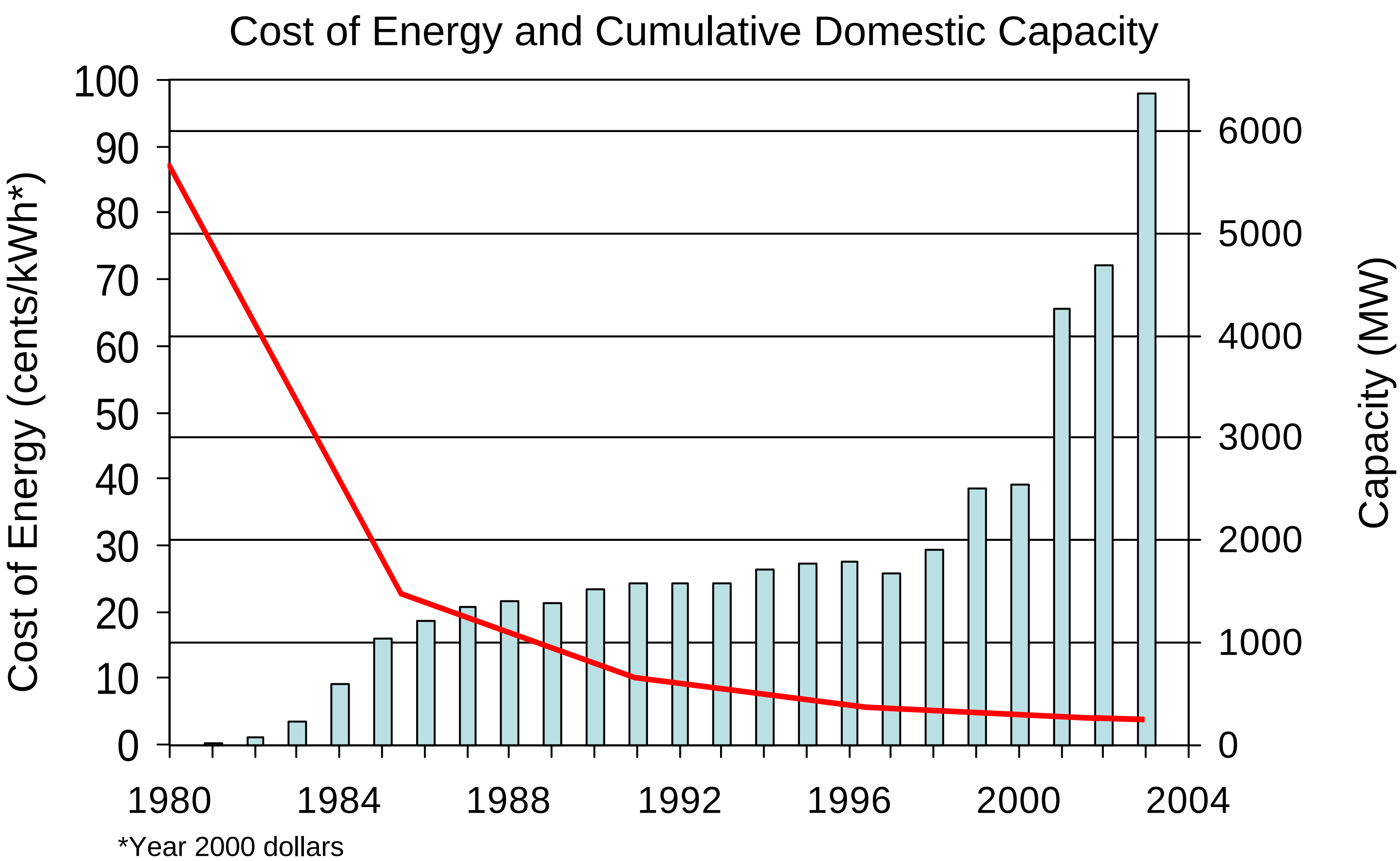
# SUPPLEMENTAL SLIDES

# Wind Energy

- R&D has reduced cost of wind power from 80 cents per kilowatt-hour in 1979 to a current range of 4-5 cents per kWh (Class 6), moving towards 3 c/kWh.
- New R&D focus: low speed wind tech.; x20 resource; x5 proximity
- LWST: 2010 target: 3 cents per kilowatt hour (in Class 4 and above regimes.



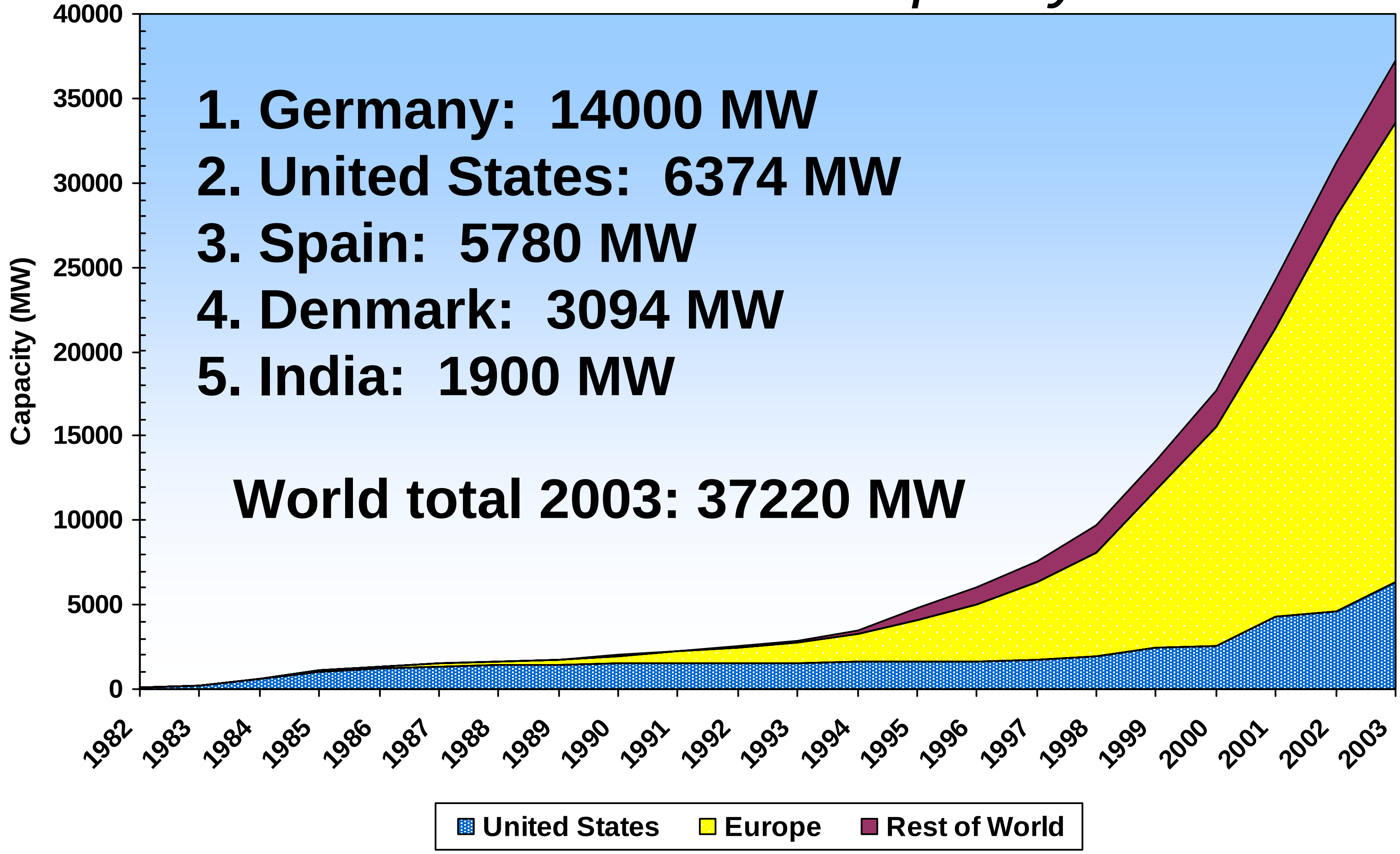
# U.S. Wind Capacity & Cost




Increased Turbine Size - R&D Advances - Manufacturing Improvements

# World Market Growth

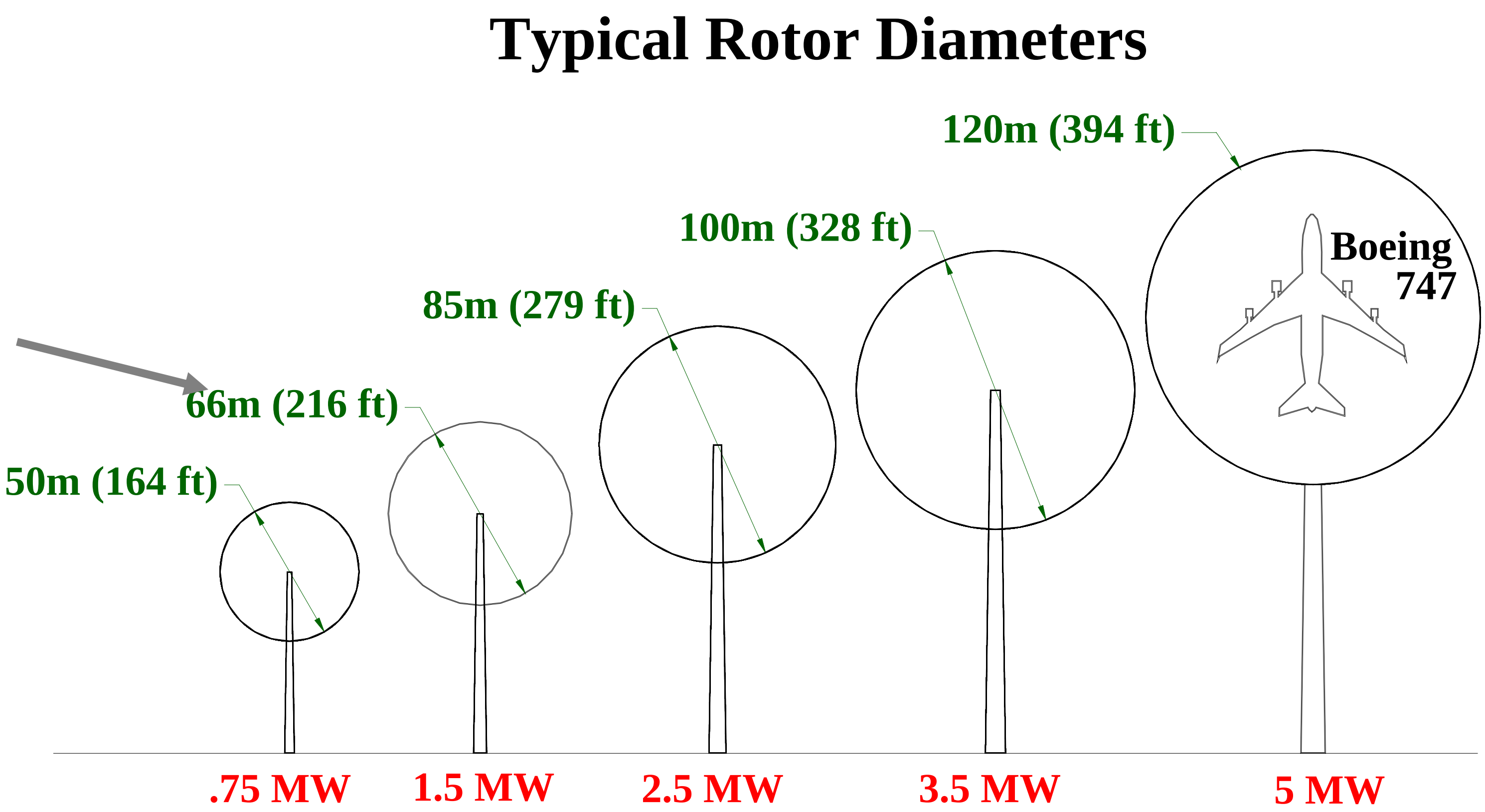
*Total Installed Wind Capacity*




*Source: WindPower Monthly*

# Big Machines, and Growing…

GE Wind 1.5 MW



# Wind Energy Futures

## 2004

**Bulk Power Generator**
**3-5¢ at 15mph**

- Land Based
- Bulk Electricity
- Wind Farms

**Electricity Market**

**Land Based Electricity Path**

**Land Based LWST**
**Large – Scale**
**2 - 5 MW**

**Transmission Barriers**

**Offshore Electricity Path**

**Offshore Turbines**
**5 MW & Larger**

**Cost & Regulatory Barriers**

**Advanced Applications Path**

**Land or Sea Based:**
- **Hydrogen**
- **Clean Water**

**Cost & Infrastructure Barriers**

## Future

**LWST Turbines:**
- 3¢/kWh at 13mph
- Electricity Market

**2012**

**Offshore Turbines:**
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind sites

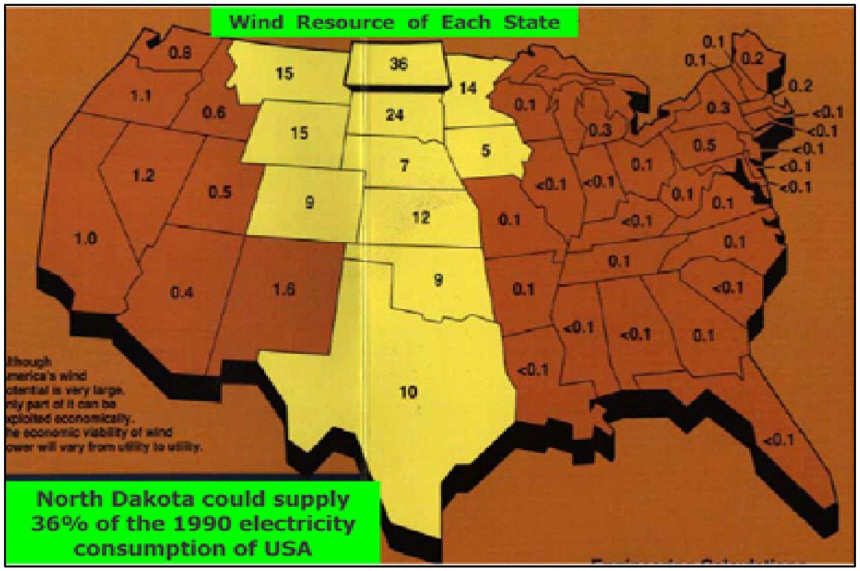
**2012 & Beyond**

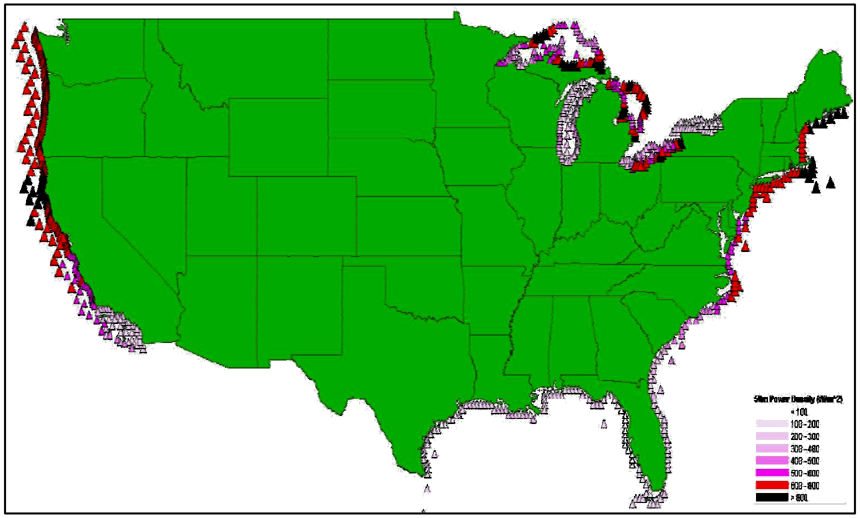
**Custom Turbines:**
- Electricity
- H2 production
- Desalinate water
- ? Cost
- Multi-Market

**2020 & Beyond**

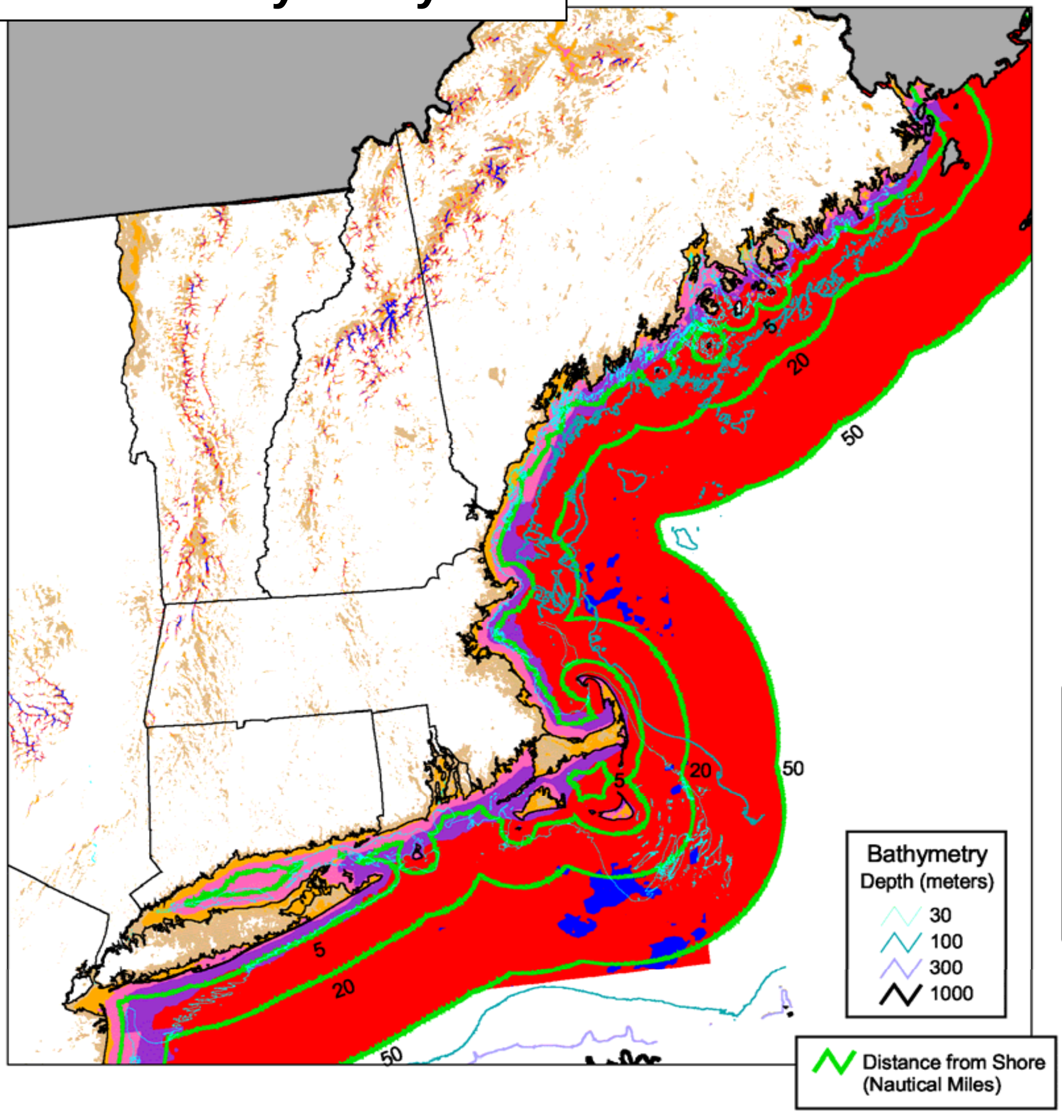
# Why Move Offshore?

- Higher-quality wind resources
  - Reduced turbulence
  - Increased wind speed
- Economies of scale
  - Avoid logistical constraints on turbine size
- Proximity to loads
  - Many demand centers are near the coast
- Increased transmission options
  - Access to less heavily loaded lines
- Potential for reducing land use and aesthetic concerns



# Preliminary Analysis




## New England Offshore Wind Resource Potential

All areas > 5 nautical miles offshore likely to be class 4 resource or better.

Area 5-20 nautical miles from shore (67% excluded):
- 10,300 sq. km. (51,500 MW)
- 1,980 sq km (9,900 MW) <30m depth

Area 20-50 nautical miles from shore (33% excluded):
- 33,800 sq. km. (169,000 MW)
- 540 sq km (2,700 MW) <30m depth

The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data, and has been validated by NREL.

The bathymetry contour lines were derived from NOAA's coastal relief models (nominal resolution 1 km) from NOAA's National Geo-physical Data Center.

Wind Power Classification

| Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m$^2$ | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph |
|---|---|---|---|---|
| 2 | Marginal | 200 - 300 | 5.6 - 6.4 | 12.5 - 14.3 |
| 3 | Fair | 300 - 400 | 6.4 - 7.0 | 14.3 - 15.7 |
| 4 | Good | 400 - 500 | 7.0 - 7.5 | 15.7 - 16.8 |
| 5 | Excellent | 500 - 600 | 7.5 - 8.0 | 16.8 - 17.9 |
| 6 | Outstanding | 600 - 800 | 8.0 - 8.8 | 17.9 - 19.7 |
| 7 | Superb | > 800 | > 8.8 | > 19.7 |

[a] Wind speeds are based on a Weibull k value of 2.0

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NREL

30-JUL-2003 2.1.2

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# Wind Energy—S&T Challenges

- **Two design pathways for wind turbines:**
  - Stiff, heavy machines that resist cyclic and extreme loads
  - Lightweight, flexible machines that bend and absorb or shed loads
  - Seeking 30 year life in fatigue driven environment with minimal maintenance and no major component replacement
- **Improve knowledge of wind inflow**, operative aerodynamics, and structural dynamics; Computational fluid dynamics to model turbulent flow for turbine design
- **Modeling of meso-scale atmospheric phenomena** for wind forecasting;
- **Composite materials**—materials strength, fatigue properties
- **Improve understanding of interactions** between wind input and among components as turbine size increases for high performance in lower wind speeds
- **Understand/mitigate operating system impacts on grid** to better accommodate intermittent wind resource
- **Optimize Turbine Designs for Ocean Deployment**: Wave Loading & Design Criteria; Wave spectrum; Extreme waves; Wind-wave correlation; Optimize Marine Foundations & Platform Designs For Wind Turbine Deployment; Design code enhancements & validation; Integrated turbine & platform response; Grid Integration and Transmission to shore; Ocean Operations and Maintenance

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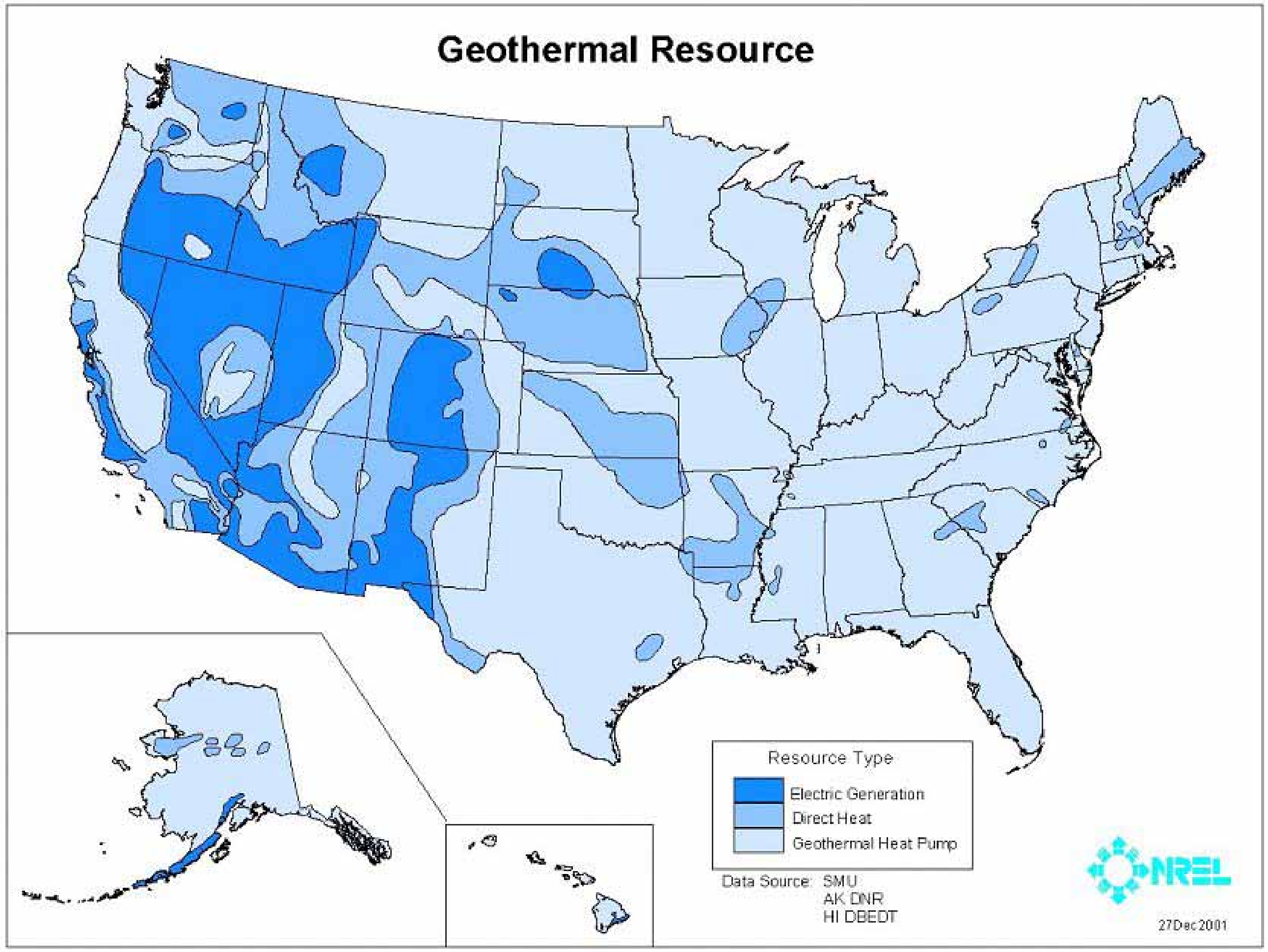
# Geothermal Energy

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



# Geothermal Energy

1980: 10-16 cents/kWh

2000:
5-8 cents/kWh

- Improved technology
- Reduced drilling costs
- Expanding resource base

2011 Goal: Less than 5 cents/kWh

# Resource Development

Double the exploration success rate from 20 percent in 2000 to 40 percent by 2011

- Develop a suite of preferred remote sensing and exploration techniques that can be used by industry for locating hidden geothermal resources
- Update assessments and characterizations of known resources.

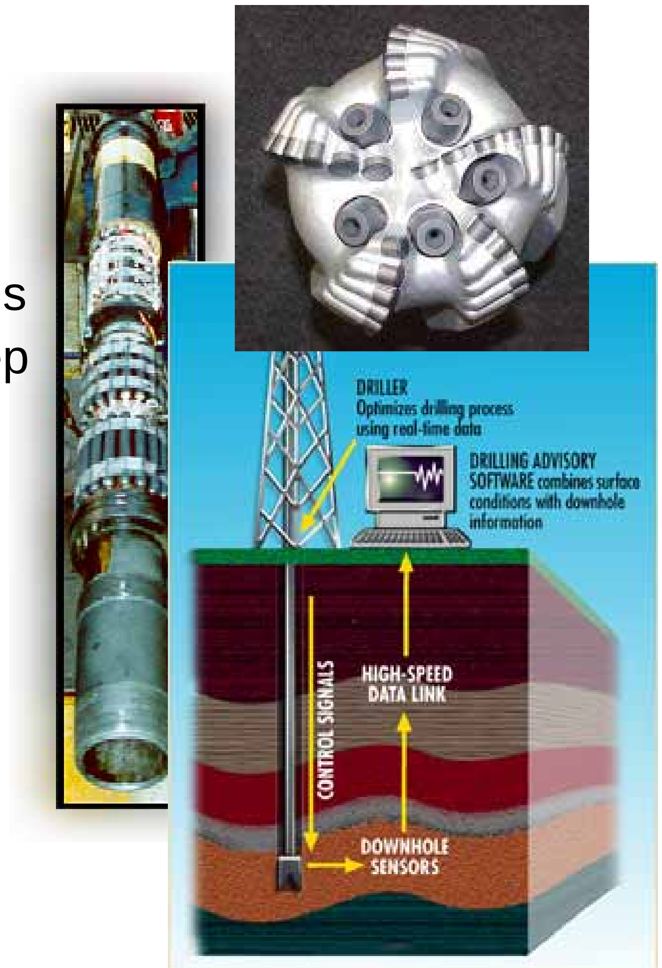
## Accomplishments to Date:

- Demonstrated that aeromagnetic surveys can help find hidden faults

# Advanced Drilling

## Reduce Cost of Drilling 25% by 2008 Compared to 2000 Costs

- Improve the component parts of a drilling system to perform essential functions quickly, reliably, and cheaply.
- Investigate revolutionary advances in drilling materials and techniques with the target of drilling twice as deep for the same cost.




**Accomplishments to Date**:

- Diagnostics While Drilling (DWD) proof of concept
- Hard rock drill bits
- Polyurethane grout for lost circulation control
- High-temperature integrated circuits for logging tool

# Heat and Power Systems

Reduce the capital cost of geothermal surface systems by 20 percent by 2011

- Develop heat rejection systems with major efficiency improvements, especially for lower-temperature resources.
- Develop advanced cycles using mixed working fluids that offer the potential for major efficiency improvements, especially for relatively low-temperature resources.
- Reduce operations and maintenance costs through optimized maintenance schedules, better construction materials, and hardier instruments.

Accomplishments to Date:

- Technology for Salton Sea metastable expansion
- Innovative condensers
- High performance coating materials