Renewables

Eldon Boes, NREL

Energy Options for the Future Meeting

Naval Research Laboratory

March 11 & 12, 2004

Renewables -- Presentation Outline

- Resources
- Technologies

Renewable Energy Technology

Renewable Resources

- Hydropower
- Wind
- Solar
- Biomass
- Geothermal

Energy Forms

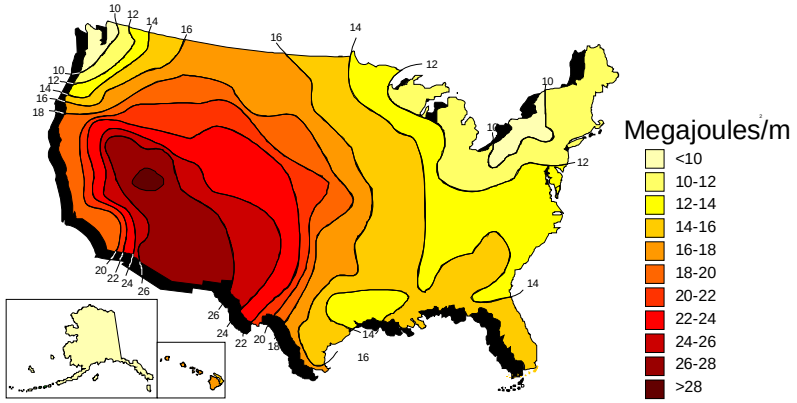
- Light
- Heat
- Electricity
- Hydrogen
- Fuel

Why Renewable Energy?

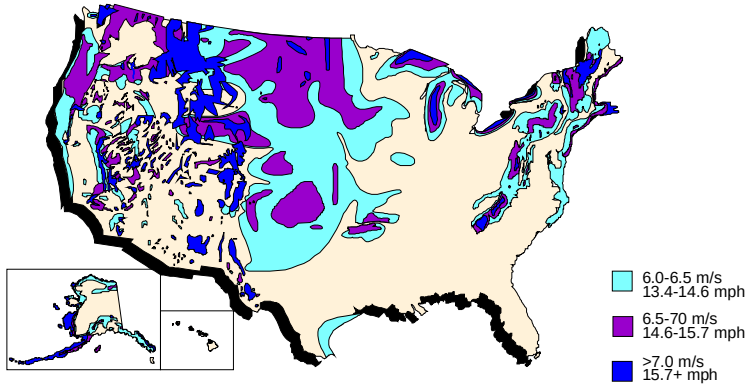
- Environmentally low impact
- Reduced dependence on imported fuels
- Increased diversity of energy supply
- Low or zero fuel cost, with no risk of escalation
- Job creation potential, especially in rural areas
- Strong public support

U.S. Renewable Energy Resources

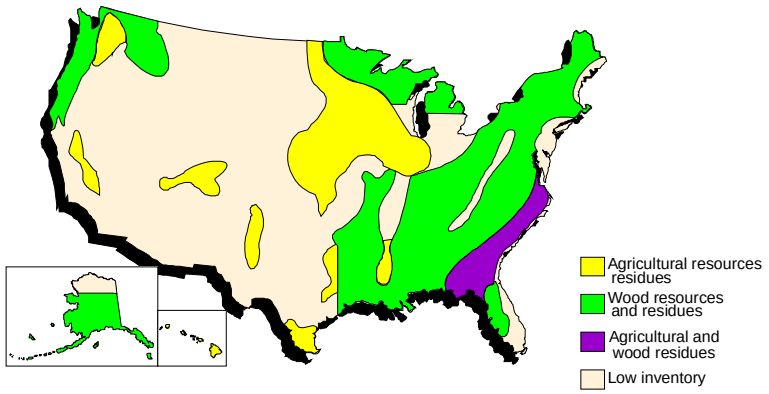
Solar



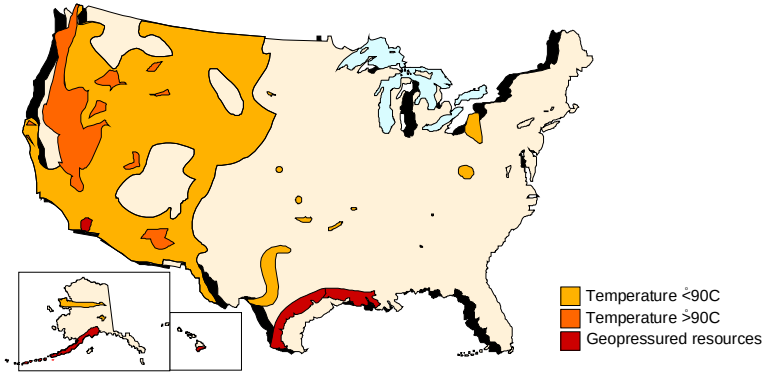
Win



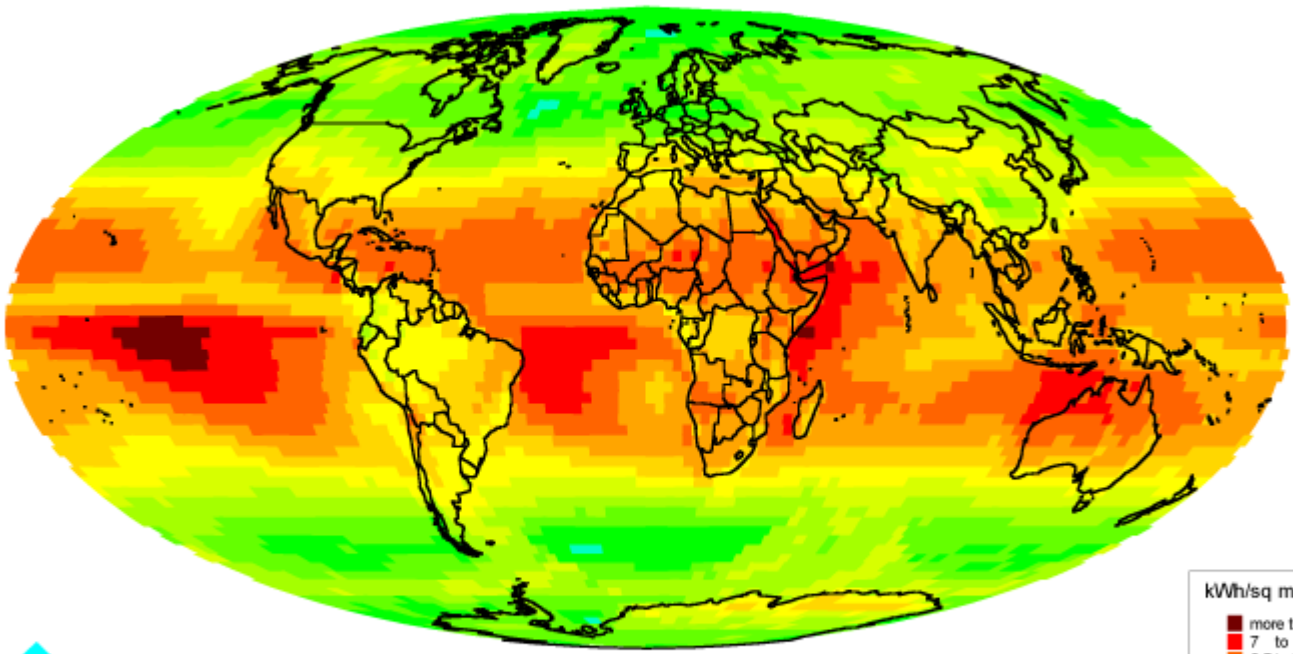
Biomass



Geothermal



Estimated Global Horizontal Solar Radiation
1985 to 1988 Annual Average



kWh/sq m per day
- more than 7.5
- 7 to 7.5
- 6.5 to 7
- 6 to 6.5
- 5.5 to 6
- 5 to 5.5
- 4.5 to 5
- 4 to 4.5
- 3.5 to 4
- 3 to 3.5
- less than 3

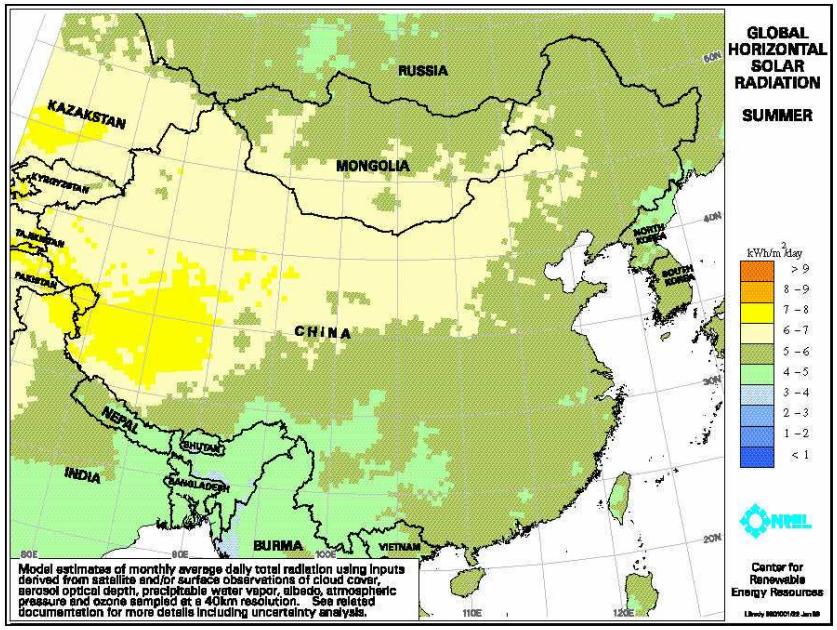
NREL

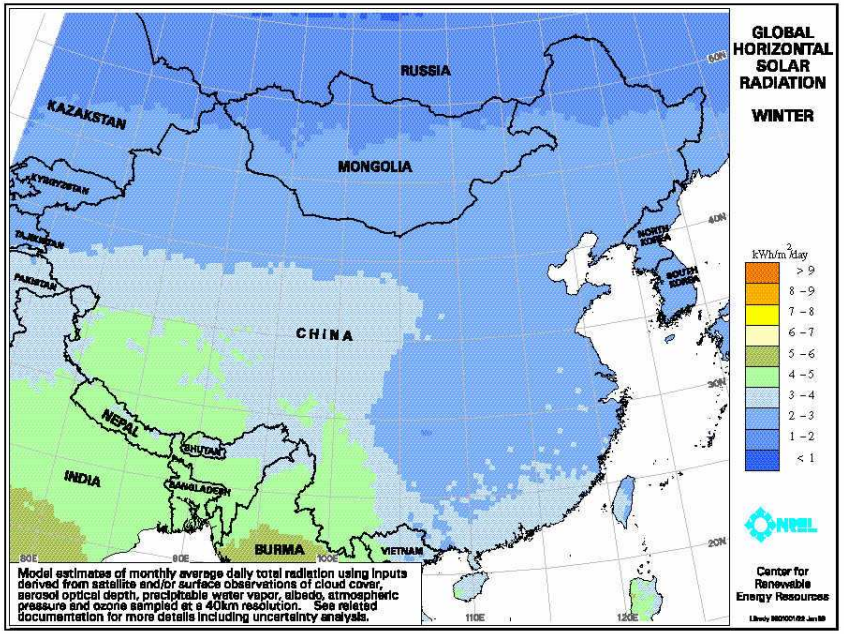
Preliminary satellite-derived estimates based on the method of Dr. Rachel Pinker, University of Maryland

Data source: World Climate Research Program data available from the NASA Langley DAAC
NREL contact: Dave Renne (303) 275-4648
Date: December 14, 1994

NREL #950020-001 14DEC94 SRH

Preliminary Medium-Resolution Solar Resource Assessment of Asia





SWERA* Goals

SWERA is a $6.3M program from the GEF designed to:

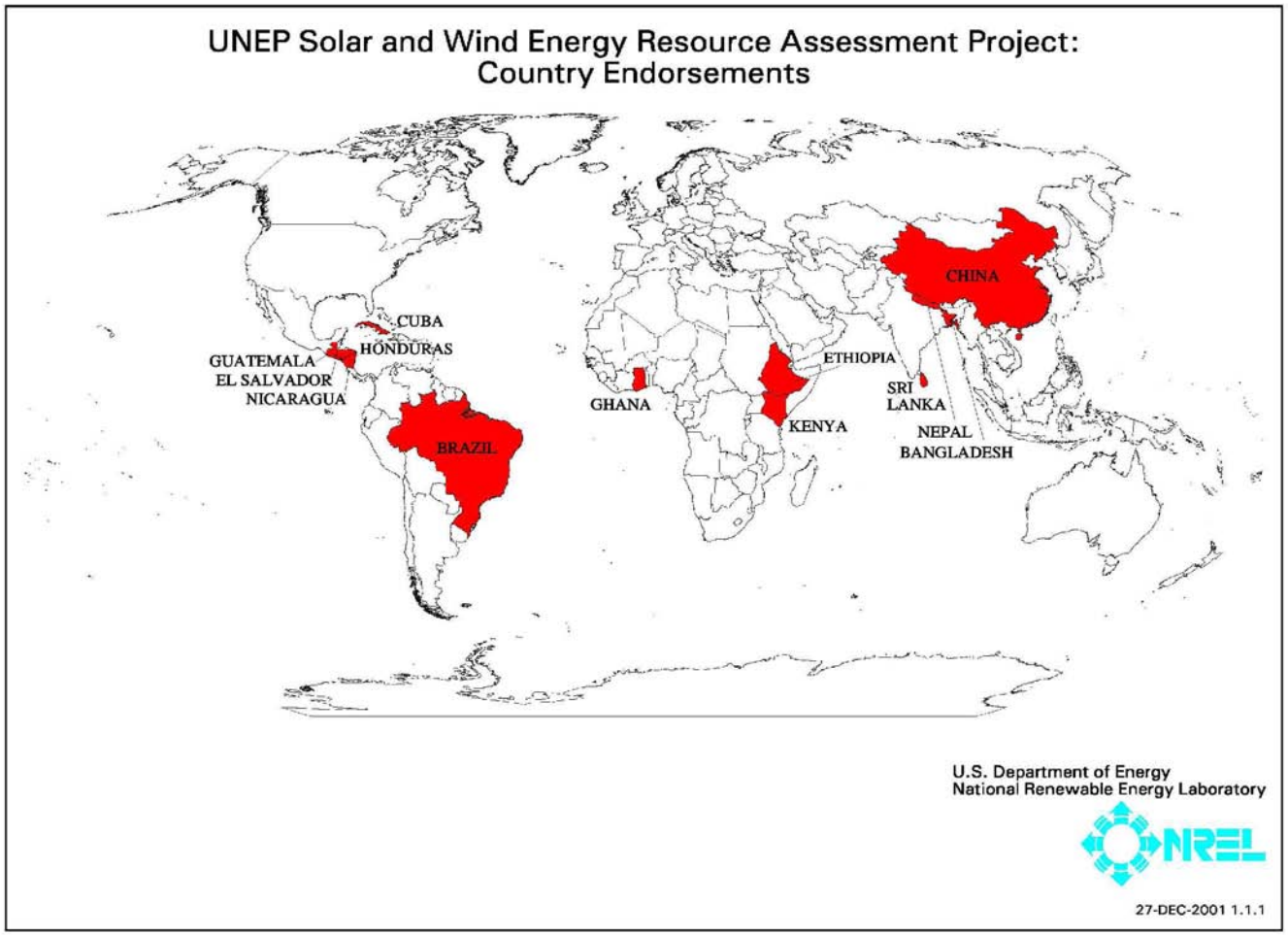
- Accelerate and broaden the investment in solar and wind energy technologies through better quality and higher resolution resource assessment
- Demonstrate benefits of assessments through 13 pilot countries in 3 major regions
- Engage country partners in all aspects of project

* SWERA = Solar and Wind Energy Resource Assessment

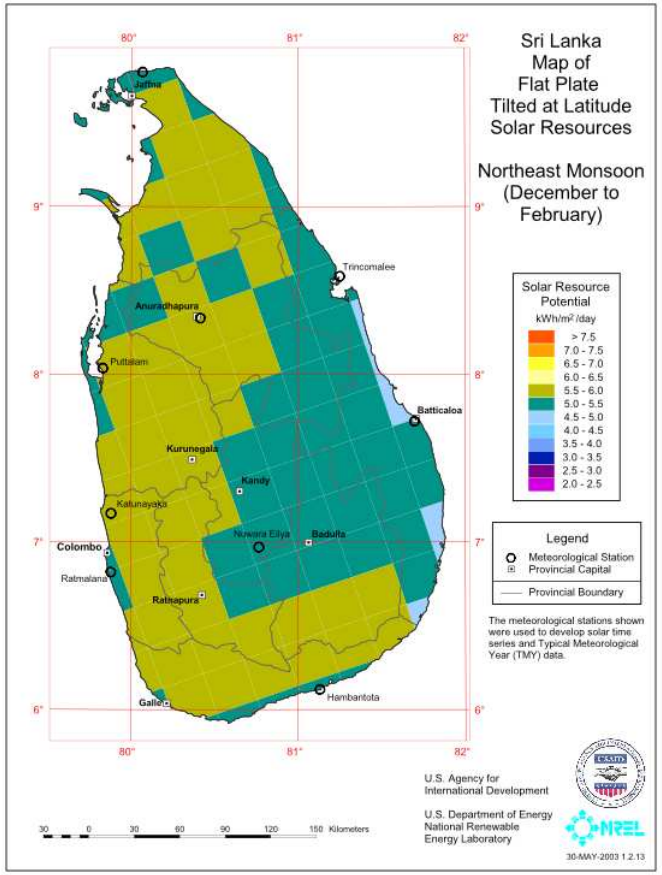
Project Countries

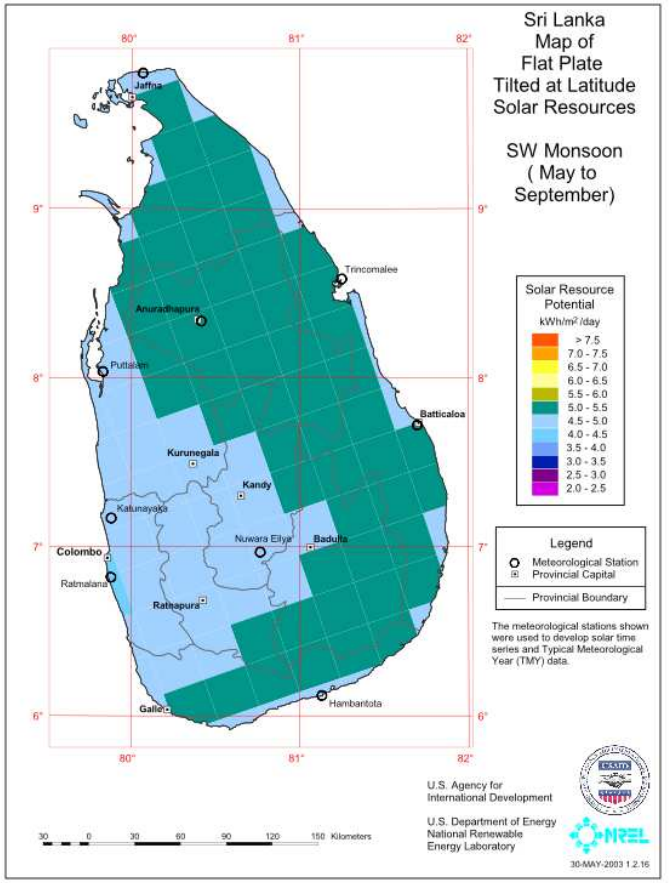
Countries

- Bangladesh
- Brazil
- China
- Cuba
- El Salvador
- Ethiopia
- Ghana
- Guatemala
- Honduras
- Kenya
- Nepal
- Nicaragua
- Sri Lanka



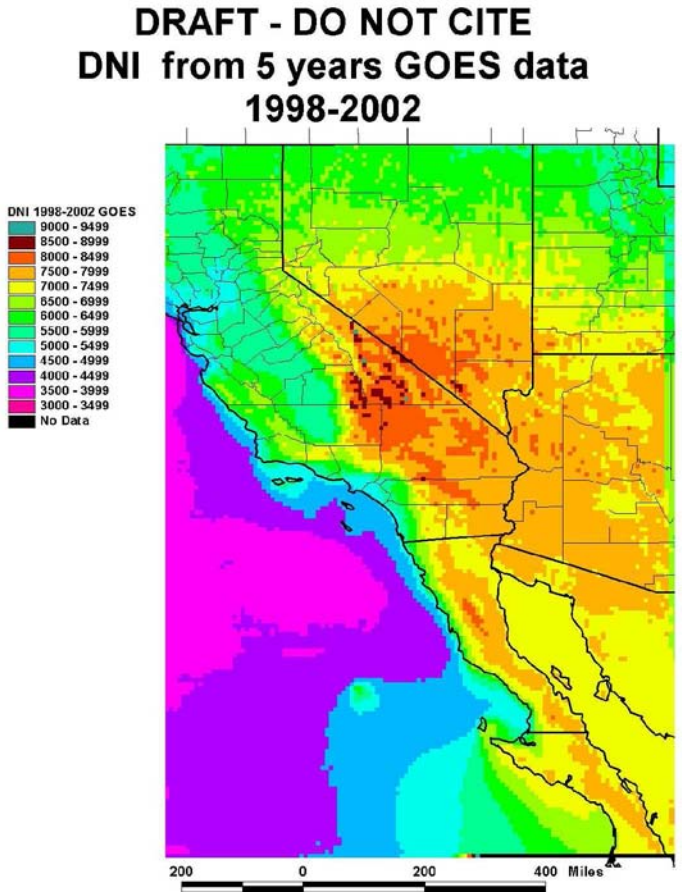
Medium Resolution Example: Seasonal Climatologies



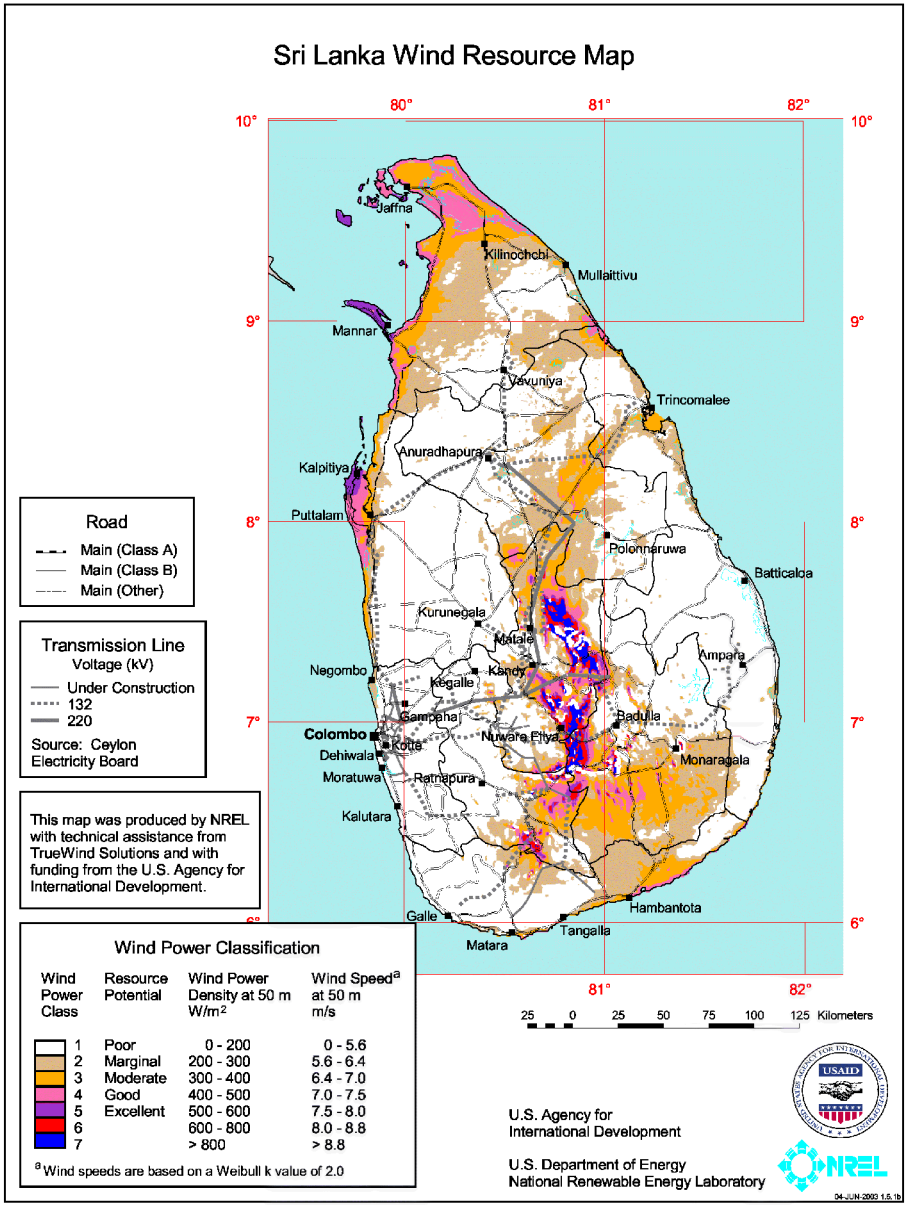


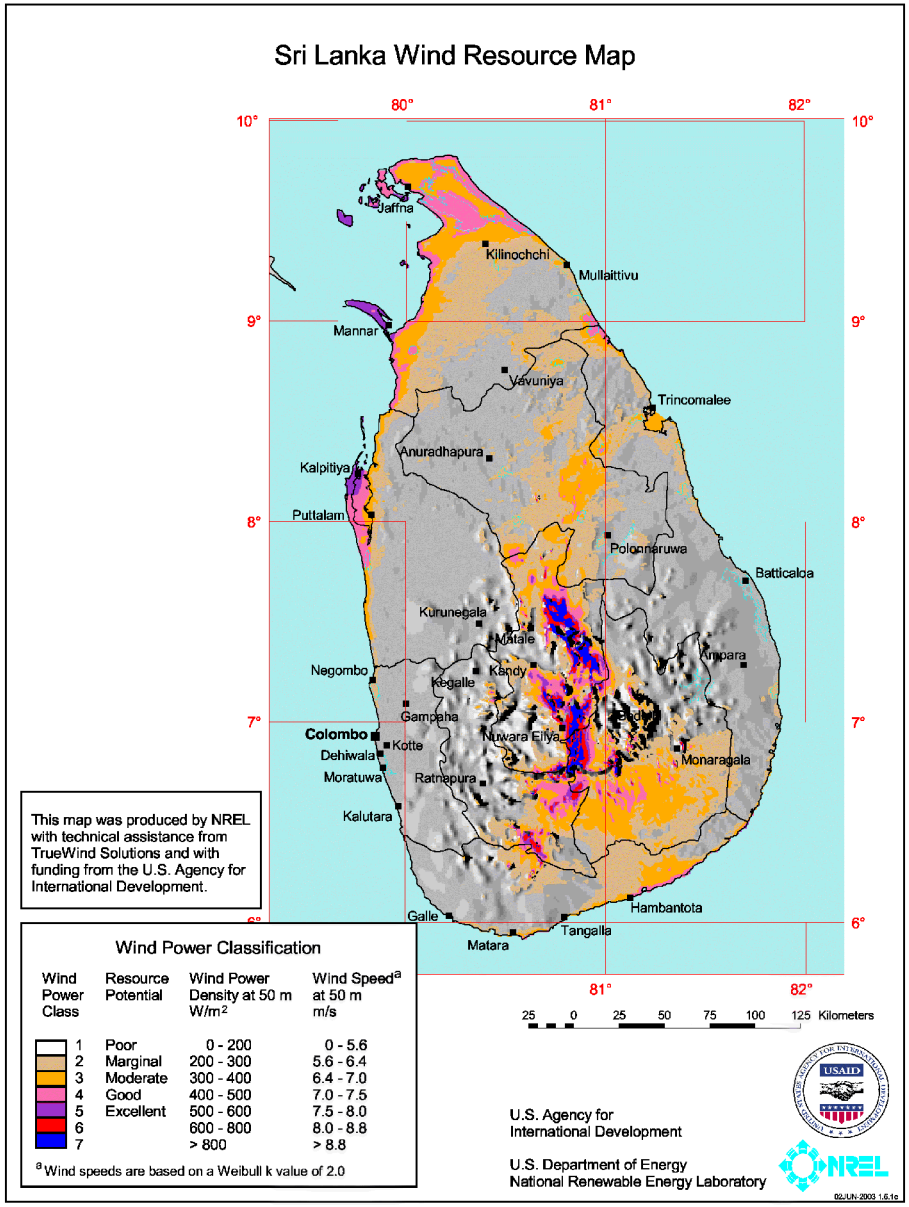
High-Resolution Assessment: SUNY/Albany

- 10-km site-time data for Central America/Cuba using GOES-8 and -10
- Visible channel
- Tools to generate long-term time series
- Collaboration with DLR on DNI calculations



Sri Lanka Wind Resource Maps





Wind Energy

Achievements and Status

- **Cost of energy reduced to 3.5 to 5.5 cents/kWh**
- **Wind resources are vast, but also vary considerably on both regional and micro levels**
- **Global capacity increasing at 20% per year**
- **Green power markets in US are stimulating 100's of MW's**
- **Recent energy costs are also accelerating interest in wind power systems.**
- **Bird kill issue appears to be local and manageable**

Likely Advances

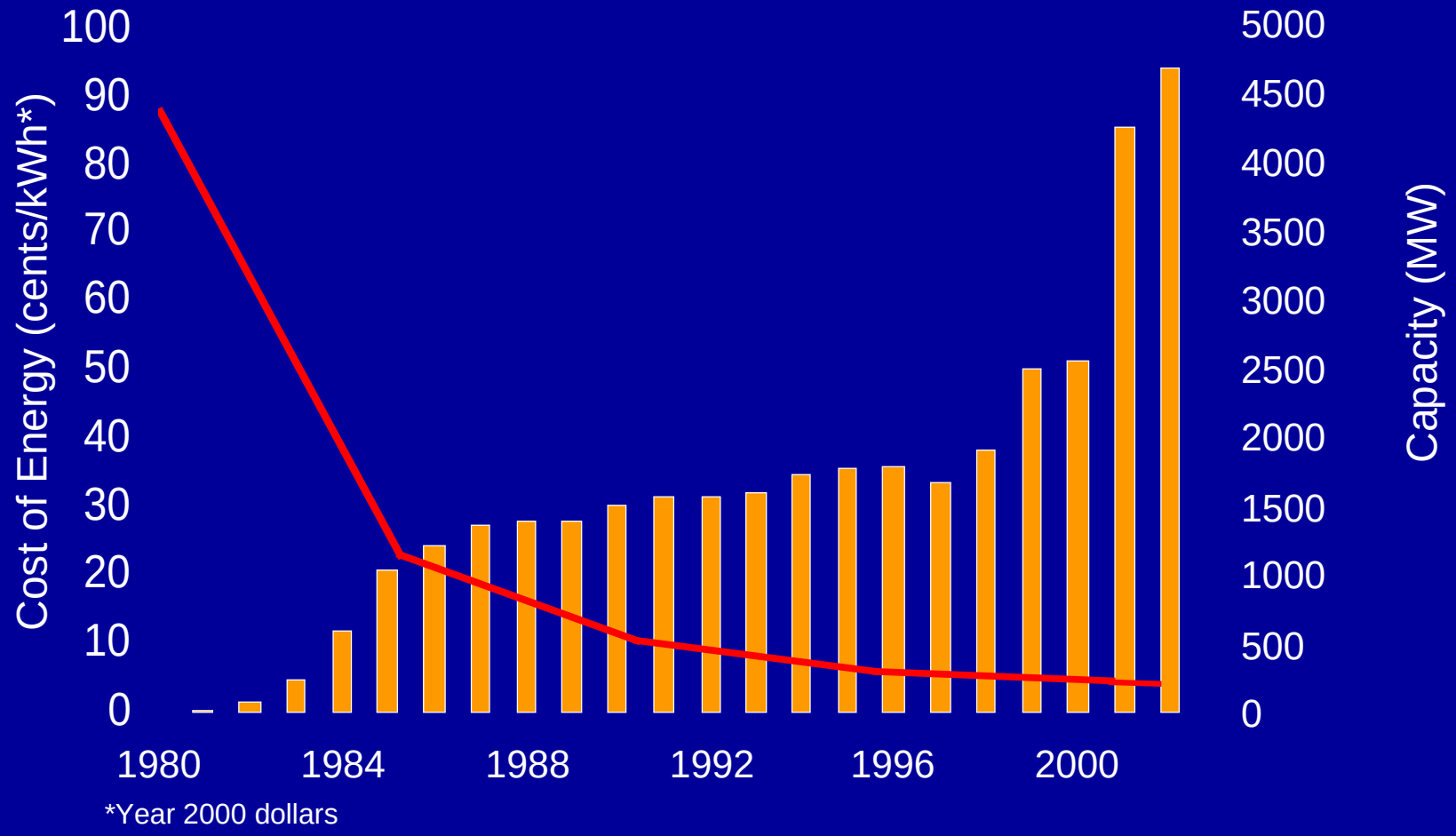
- **Larger turbines - 3 MW+**
- **Expanding field experience will support both technology and business development**
- **Low wind speed turbines**
- **Advanced power electronics**
- **Wind resource forecasting will enhance systems value**
- **Major transmission systems to tap Great Plains resources**
- **Offshore wind power plants, shallow and deep water**

Wind Power in Iowa

GE Wind Energy 3.6 MW Turbines

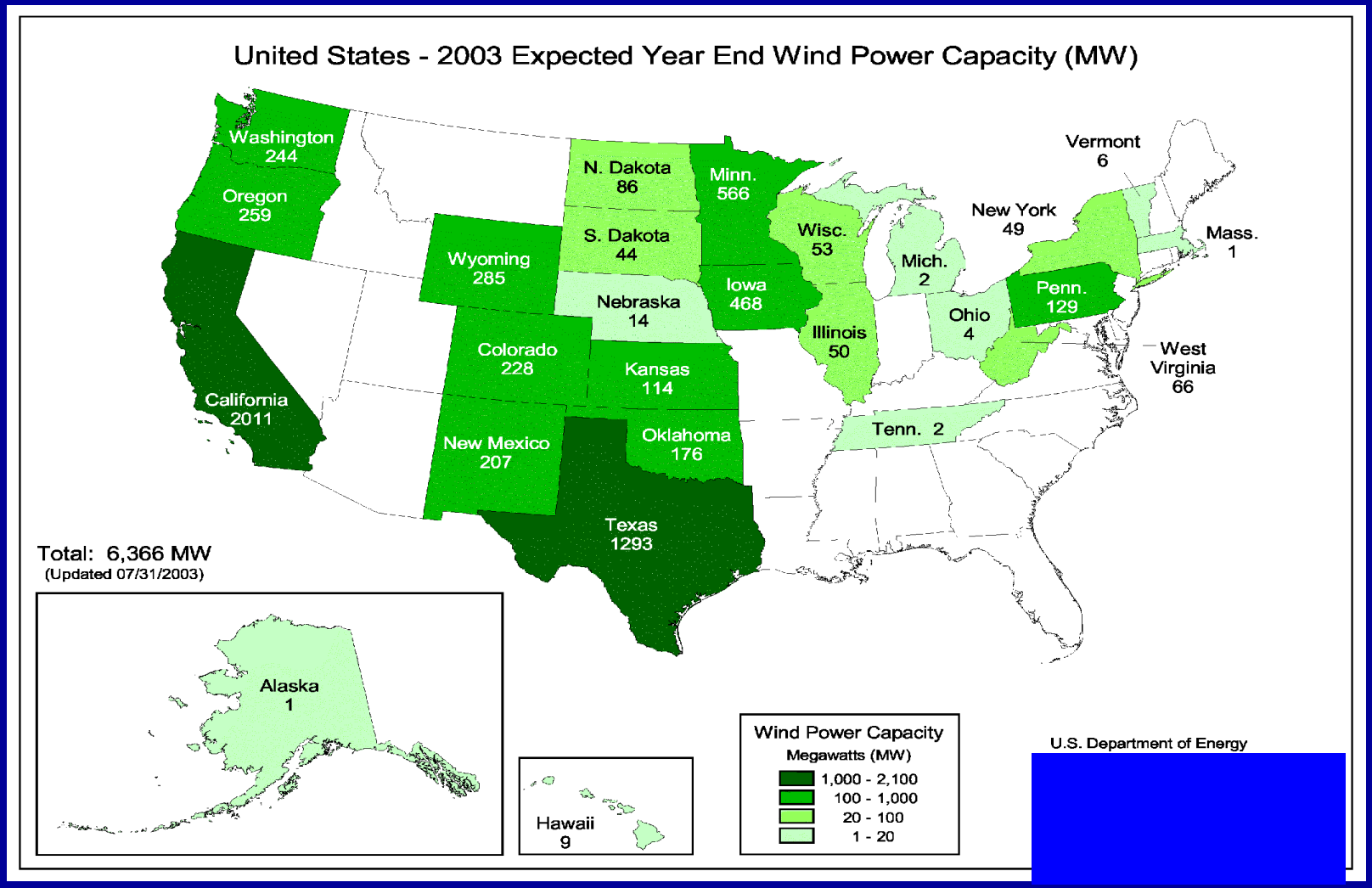

Boeing 747-200
GE WindEnergy
3.6 MW Prototype
Turbine in Spain

U.S. Wind Power Cost, Capacity Trends



*Year 2000 dollars

U.S. Wind Power Capacity



World Market Growth

Total Installed Wind Capacity

1. Germany: 14000 MW
2. United States: 6374 MW
3. Spain: 5780 MW
4. Denmark: 3094 MW
5. India: 1900 MW

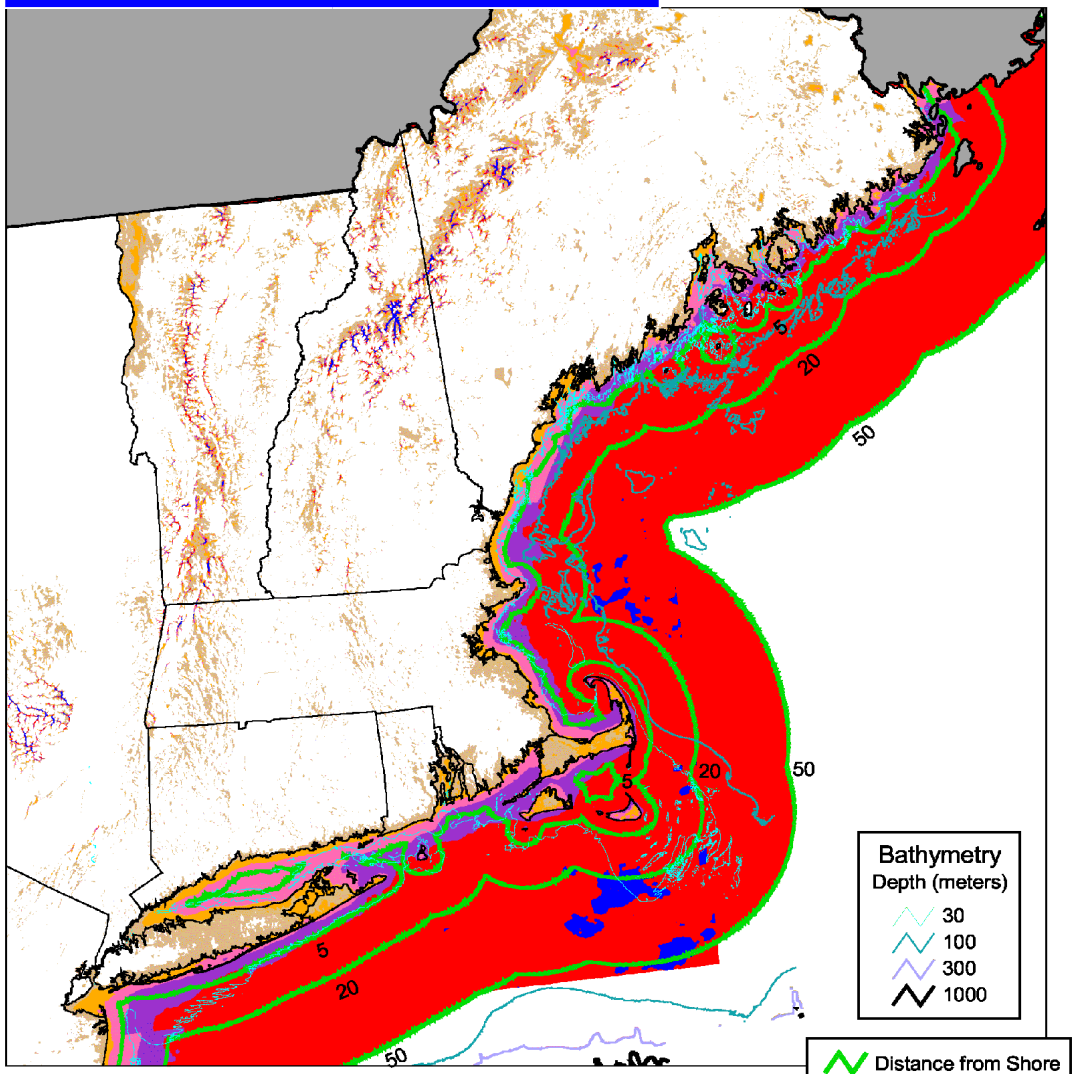
World total 2003: 37220 MW

Source: WindPower Monthly

Horns Rev 160MW

Northeastern U.S. Offshore Potential

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/m²	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

U.S. Department of Energy

Not In My Backyard?

Source: LIPA website www.lipower.org

Geothermal Power Plant

Geothermal Power Technology

Achievements and Status

- **Technology has been used at the Geyser's site in northern CA since 1960's**
- **Quite a few additional systems have been built in the past 20 years**
- **We have seen advances in resource mapping and access**
- **We've also seen advances in conversion technologies -- binary systems, heat exchangers**
- **High quality resources in the US are limited**

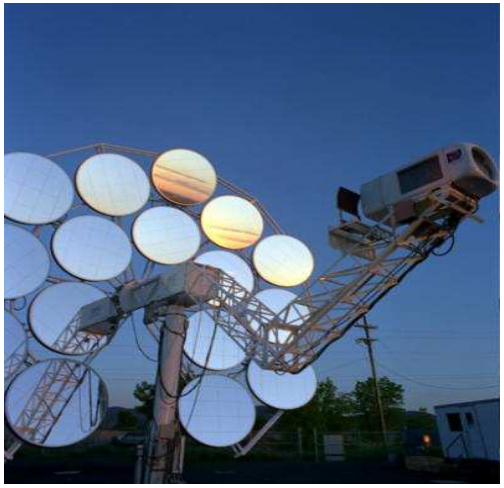
Likely Advances

- **Broad utilization of hi-quality resources around the globe**
- **The major challenge is resource characterization and extraction**
  - **Where is it, how large, how durable**
  - **Cheaper drilling**
- **This will benefit from seismic mapping and extraction technologies used in oil & gas industries**
- **Hot dry rock technology has long-term prospects**

Solar Thermal Electric

Trough Technology (Bulk Power)

Dish/Engine Technology
(Distributed Power)



Power Tower
Technology
(Bulk Power)

Parabolic Trough Systems

Power Tower Systems

Parabolic Dish Systems

Solar Thermal Power Technology

Achievements and Status

- **350 MW of parabolic trough plants built around 1990 still operating well**
- **Several power tower demonstration plants have established technology viability.**
- **Several dish systems have also operated successfully**
- **The challenges are system sizes and costs**

Potential Advances

- **There are major opportunities for technology advances, in**
  - **Collectors**
  - **Power conversion**
  - **Thermal storage**
- **New systems are planned in Spain and Nevada**
- **Success with new systems will catalyze manufacturing advances**

Solar Buildings

Water heating

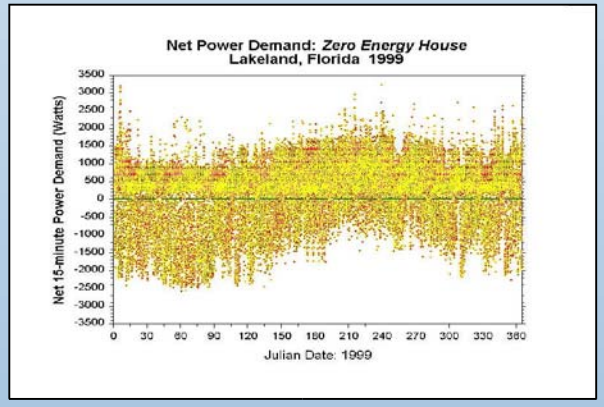
- 4.5 million water heating systems installed worldwide
- Cost of solar water heating systems of 8¢/kWh projected to drop to 4¢/kWh

Transpired collectors (air heating)

- Several hundred transpired collectors installed worldwide
- Current cost for transpired solar collectors is 2¢/kWh

Zero Net Energy Buildings

- Annual production equals use
- In early demonstrations




OPTICAL CAMERA TRACKING SYSTEM
MOGHO
NAVAL WEAPONS CENTER

Woman at a PV-powered water pump in India

50-watt PV systems installed in homes in Brazilian village to provide lighting

Building-Integrated Photovoltaics

Church in Sacramento, California (01096)

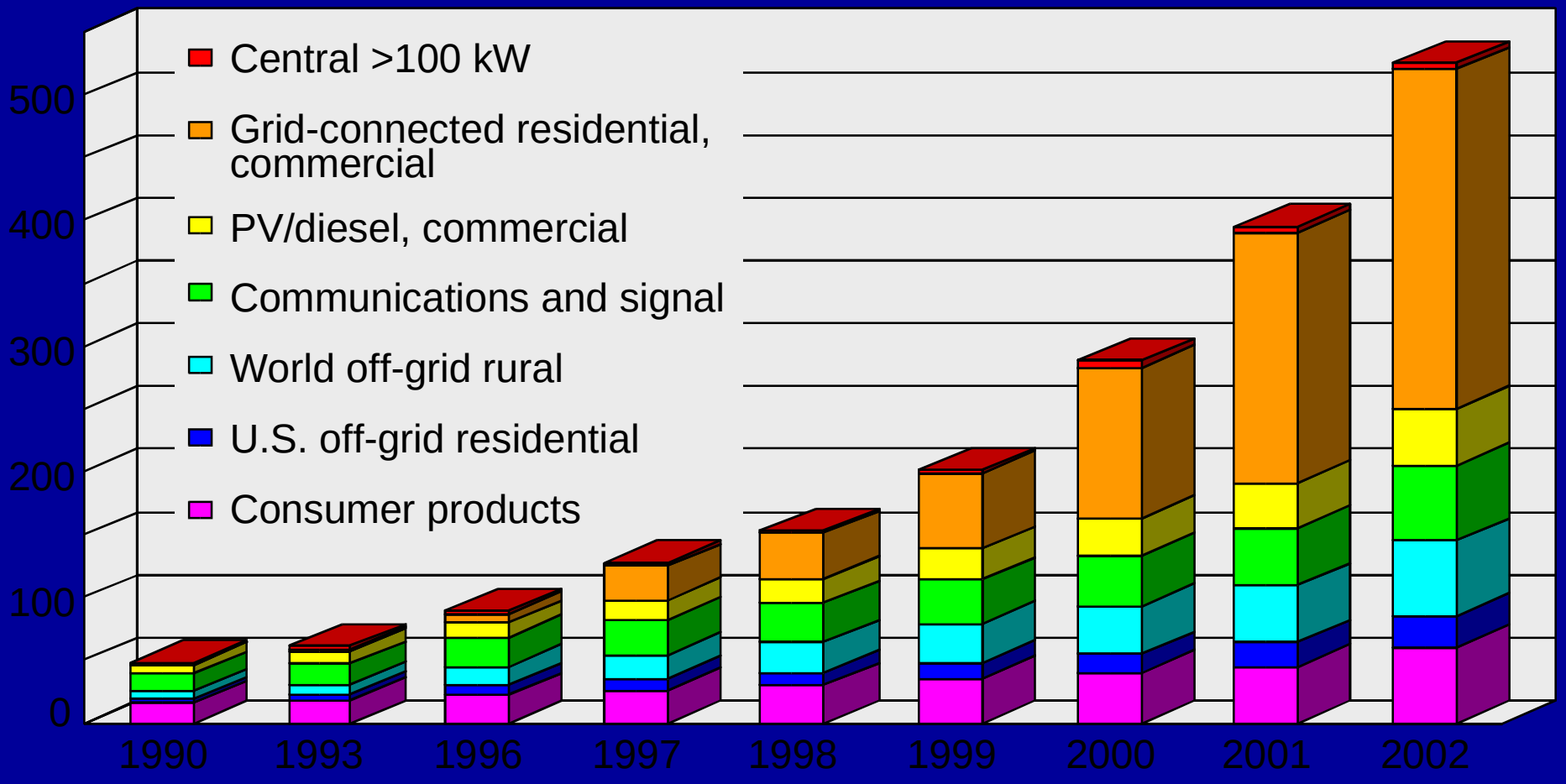
PV Shingles (04566)

House in Hopewell, New Jersey (04474)

Fort Dix, New Jersey (05180)

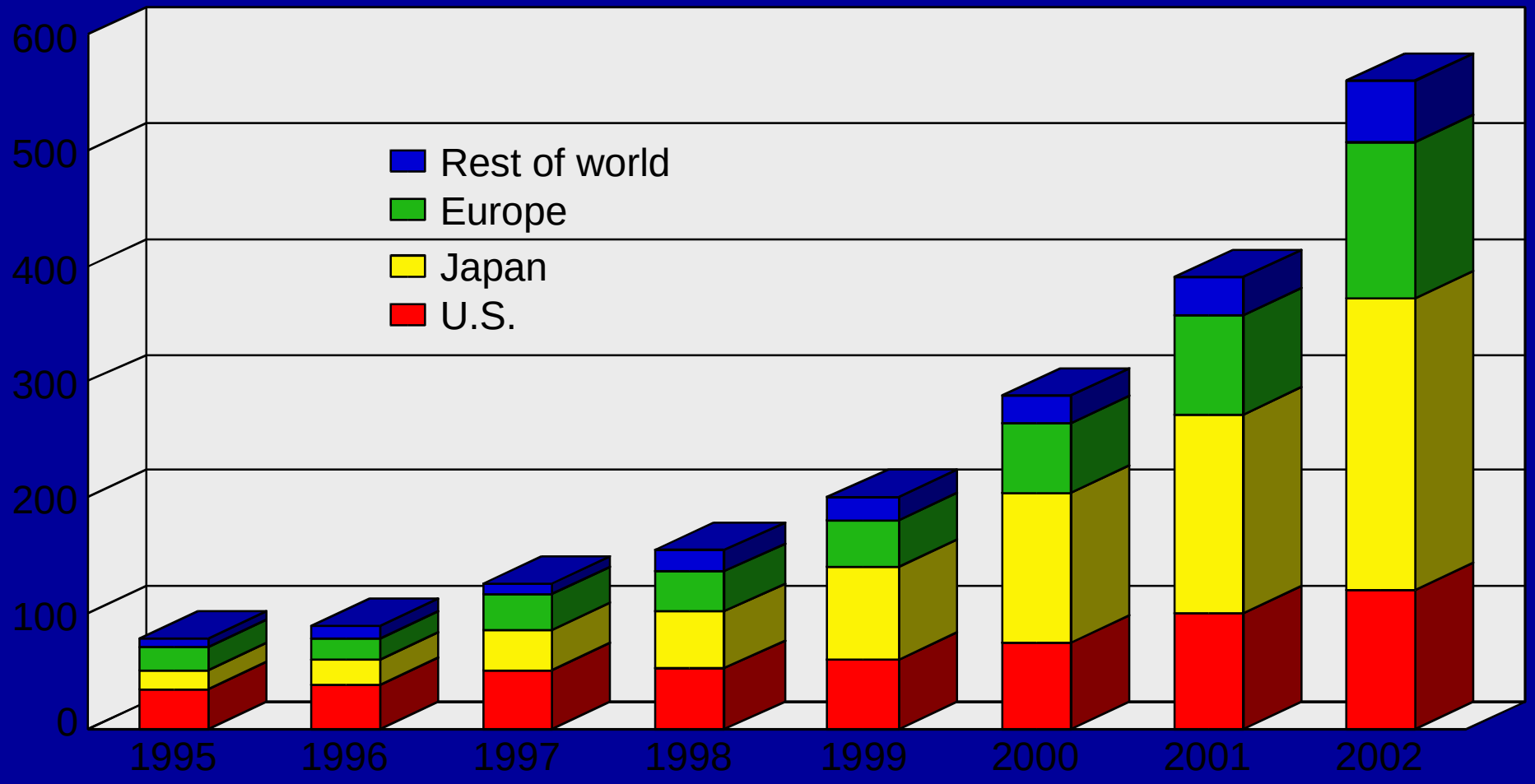
Commercial PV Systems

World PV Market by Application Area

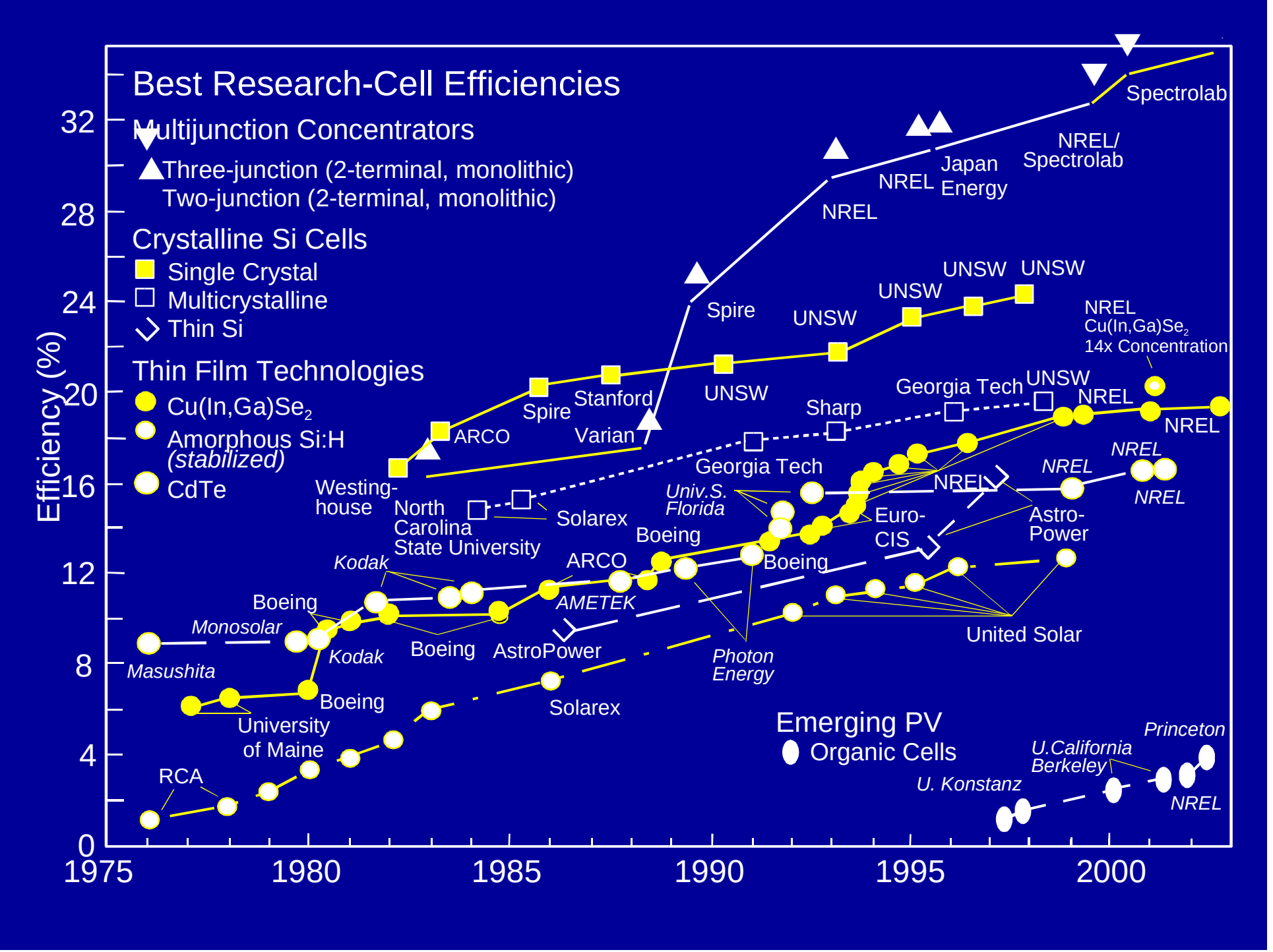


Source: *PV News*, March 2003

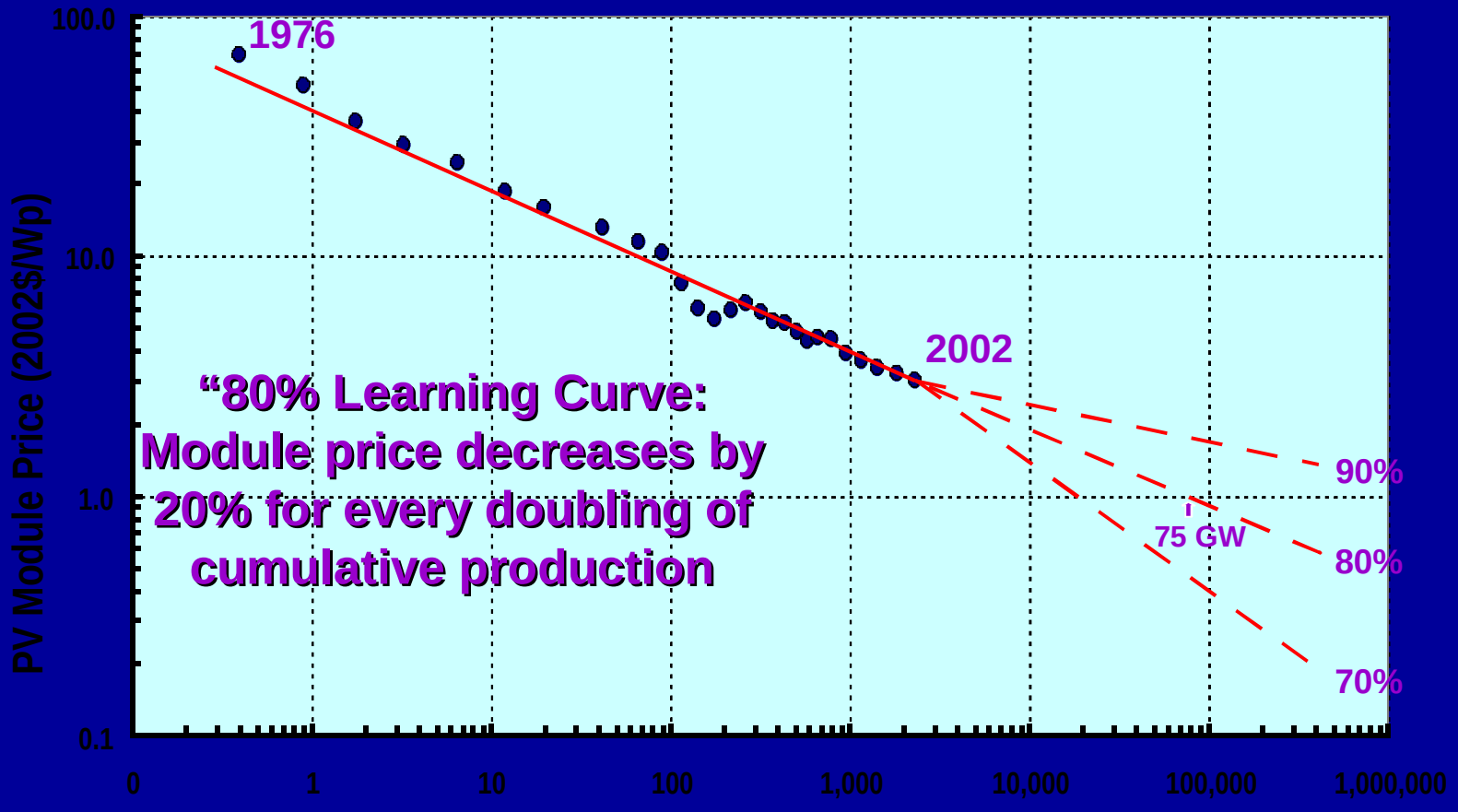
World PV Cell/Module Production Consumer and Commercial (MW)



Source: *PV News*, March 2003


Best Research-Cell Efficiencies
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Crystalline Si Cells
Single Crystal
Multicrystalline
Thin Si
Thin Film Technologies
Cu(In,Ga)Se2
Amorphous Si:H (stabilized)
CdTe
Emerging PV
Organic Cells
Efficiency (%)
0
4
8
12
16
20
24
28
32
1975
1980
1985
1990
1995
2000
Spectrolab
NREL/ Spectrolab
Japan Energy
NREL
NREL
Spire
UNSW
UNSW
UNSW
UNSW
NREL Cu(In,Ga)Se2 14x Concentration
Georgia Tech
UNSW
NREL
NREL
NREL
NREL
NREL
Sharp
Stanford
Spire
ARCO
Varian
Westing-house
North Carolina State University
Solarex
Georgia Tech
Univ.S. Florida
Euro-CIS
Astro-Power
Boeing
Boeing
ARCO
Kodak
AMETEK
Boeing
Monosolar
Kodak
Boeing
AstroPower
Photon Energy
United Solar
Masushita
Boeing
University of Maine
Solarex
RCA
Princeton
U.California Berkeley
U. Konstanz
NREL

PV Module Production Experience (or "Learning") Curve



Cumulative Production, MW

Solar Photovoltaics

Achievements and Status

- **Steady progress in increasing cell efficiencies for 20 years**
- **Sales increasing 25%/ year**
- **Major expansions of manufacturing capacities underway**
- **Value of building-integrated systems gaining recognition**
- **U.S. owned manufacturing is losing ground**
- **Very substantial subsidies in Japan and Europe**

Likely Advances

- **Large potential for technology and manufacturing advances**
- **Significant increases in conversion efficiency likely**
- **Organic and polymeric cells being researched**
- **Standardized power controls & interconnection equipment**
- **Better understanding of PV's distributed resource and peaking load values**

Biomass Resources

Wood chips

Switch grass

Poplar trees

Sugar cane residue

Municipal Solid Waste

Alfalfa

Biomass Electricity

- Direct combustion – 9700 MWe
- Cofiring with Coal – 400 MWe
- Biomass gasification
  - Small 3-5 kW systems in field verification tests
  - Larger systems demonstrated

Biomass Gasification

Small Modular Gasification System

Source: U.S. Climate Change Technology Program. Technology Options. DOE/PI-0002, November 2003

Ethanol and Bioethanol

Ethanol

2. Made from the starch in corn kernels
3. Available in blended motor fuels
4. Cost ~ $1.22/gal

Bioethanol

- Made from cellulosic materials – corn stalks, rice
- Technology under development
- Cost ~ $2.73/gal ⟶ $1.32/gal
- Near-term use as a fuel blend
- Longer-term as a bulk fuel will require energy crops

The New Bio-Industry

USES

Fuels:
- Ethanol
- Renewable Diesel

Power:
- Electricity
- Heat

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

Food and Feed and Fiber

Biomass Feedstock

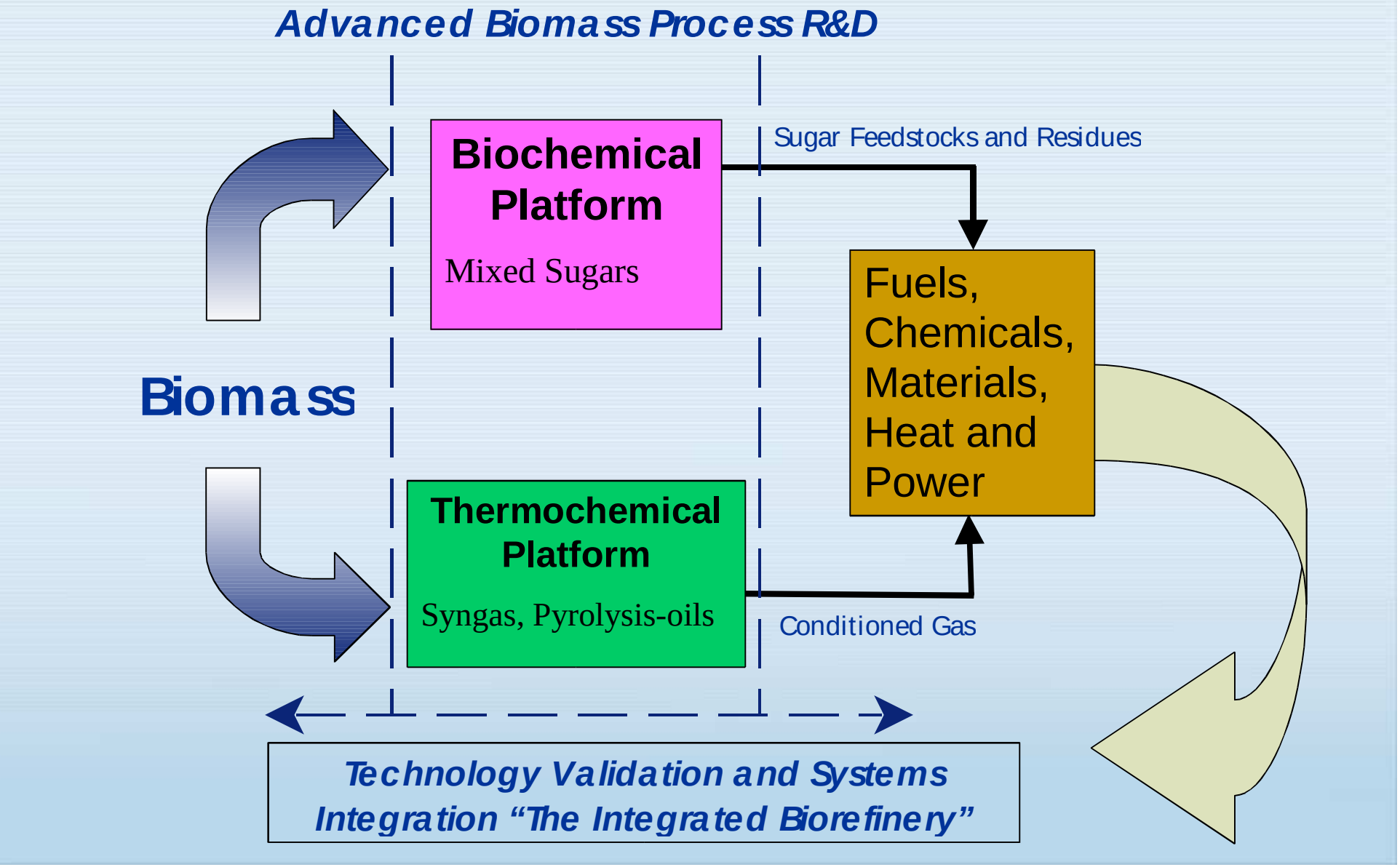
- Trees
- Grasses
- Agricultural Crops
- Agricultural Residues
- Animal Wastes
- Municipal Solid Waste

Conversion Processes

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

… and new concepts from plants to products

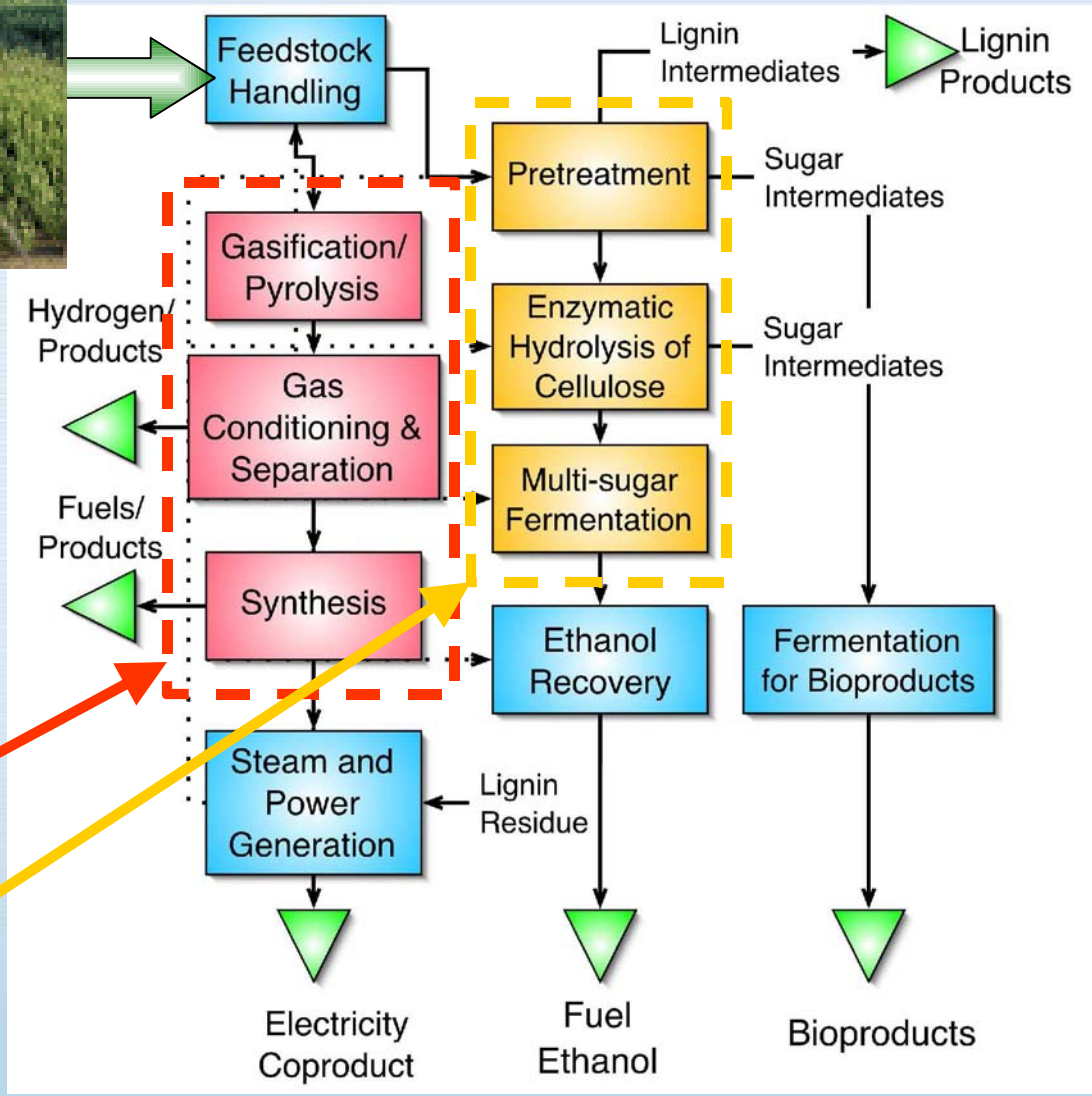
Biomass Conversion Technology *Platforms*



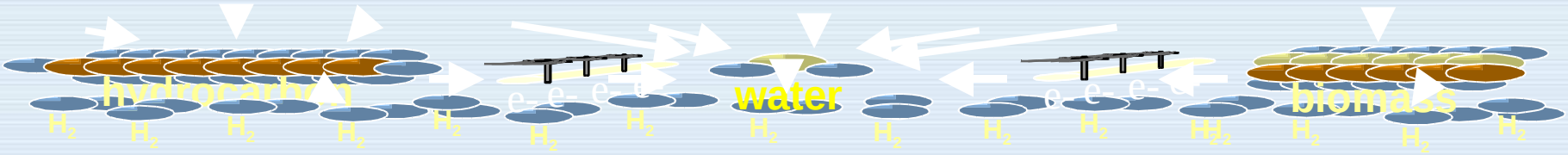
Cellulosic Biorefinery Vision

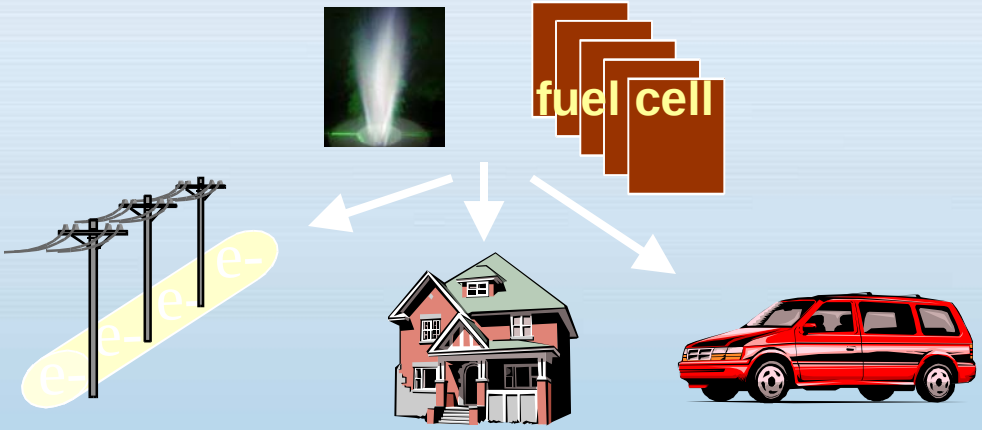
An integrated biorefinery makes use of:

- Thermochemical conversion technology
- **Biochemical conversion technology**
- Existing technology
  Available today



Hydrogen Pathways



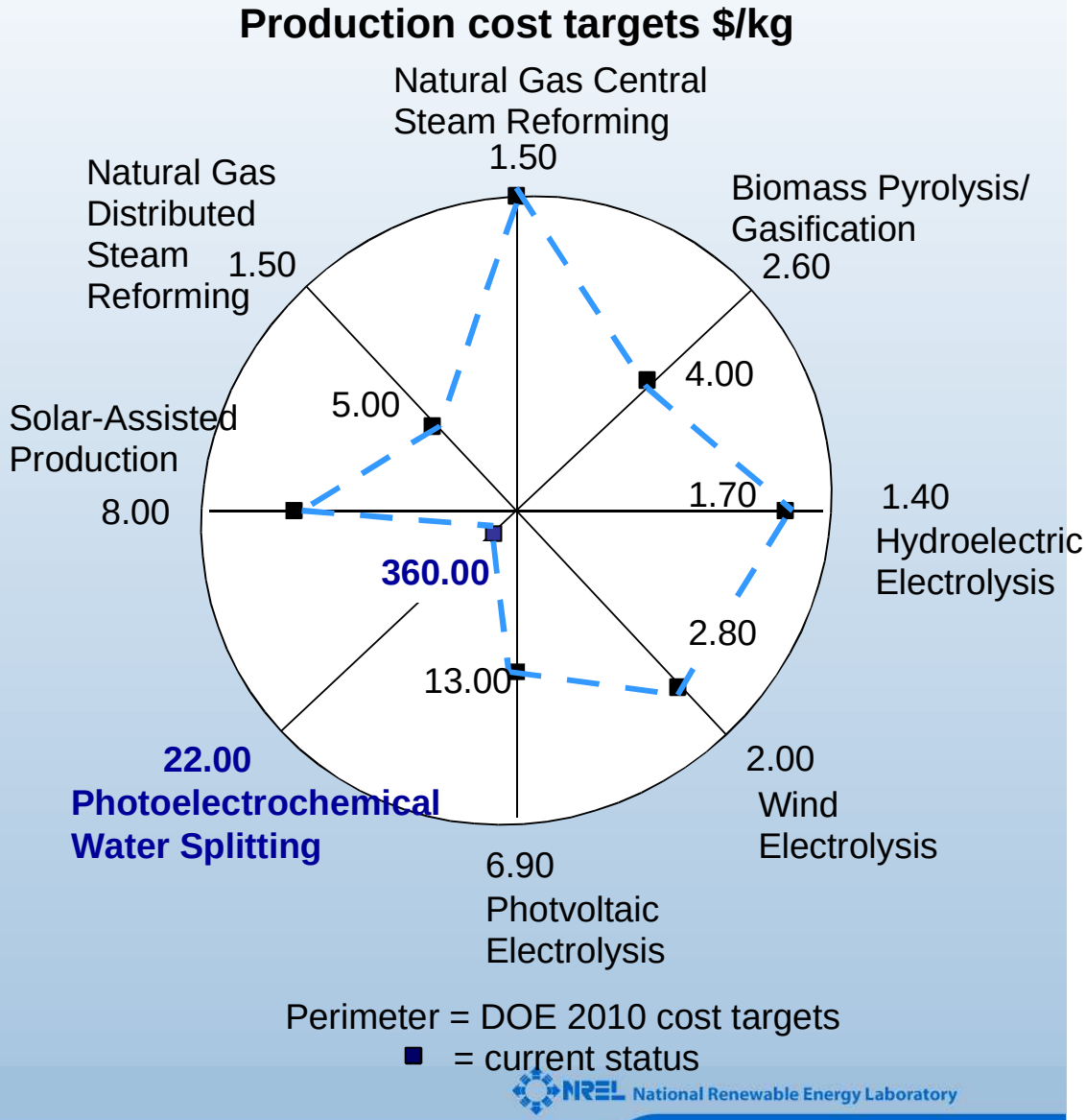


Hydrogen must be derived from other energy sources.

Hydrogen Production Stretch Goal

Photoelectrochemical Production of Hydrogen

Target: Achieve greater than 10% solar to H_2 efficiency, with projected durability of 10,000 hours, and a cost of $22/kg by 2008



A Transition to Renewables

1. Requires “getting serious” about adopting significant amounts
2. Doesn’t cost all that much

A “back of the envelope” outline of a

Transition Scenario

for the

Power Sector

The Scenario

- Adopting significant levels of (non-hydro) renewables as we add or replace capacity (starting in 2006):

	2006	2010	2015	2020
% Renewables	10	50	75	100

- Assume RE mix is:

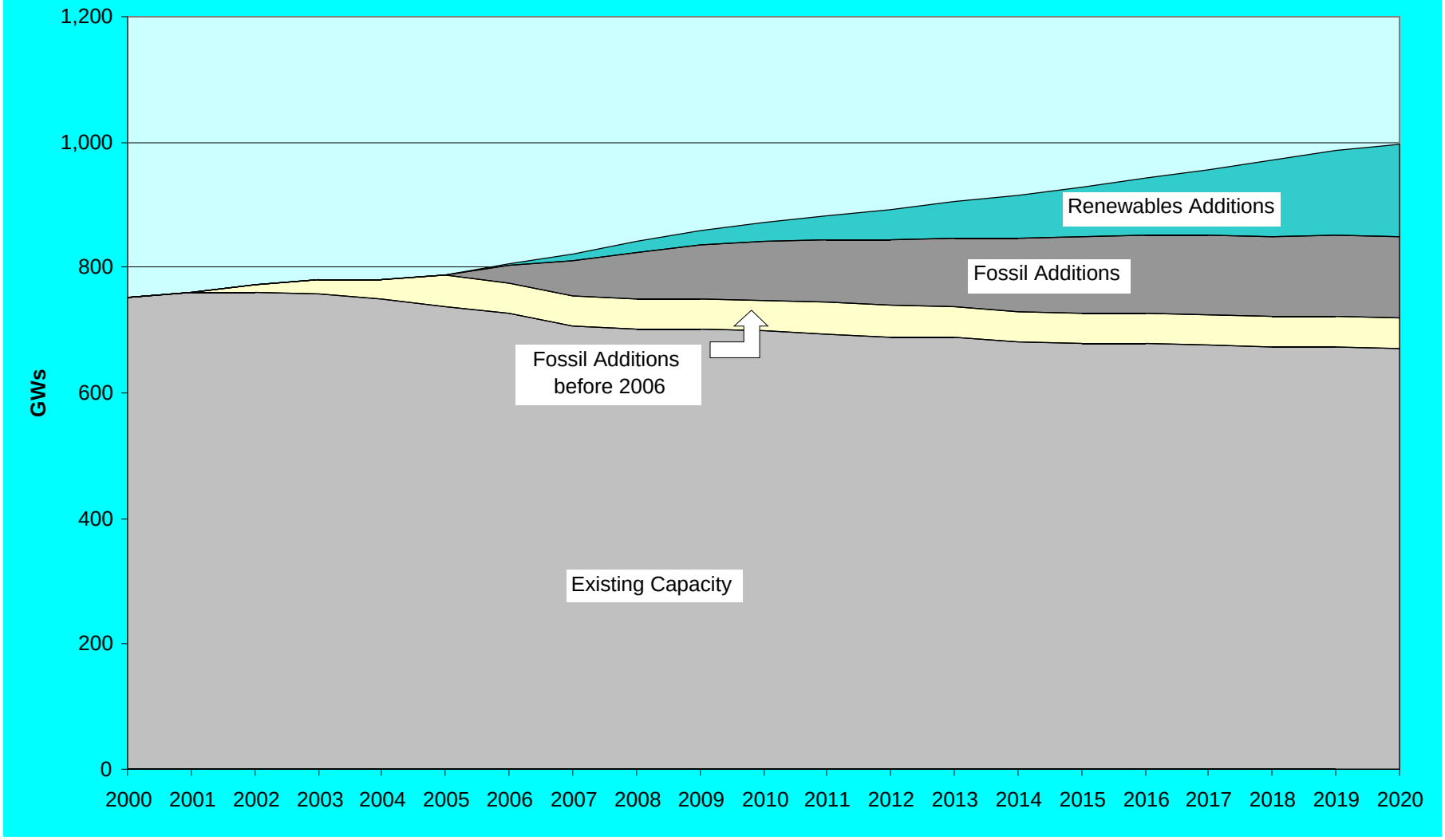
	Wind	Bio	Geo	PV	S. Th
%	55	25	10	5	5

- Use DOE/EPRI costs for Renewables, EIA costs for conventional power sources.
- Include added transmission cost for wind, geothermal, and solar thermal.

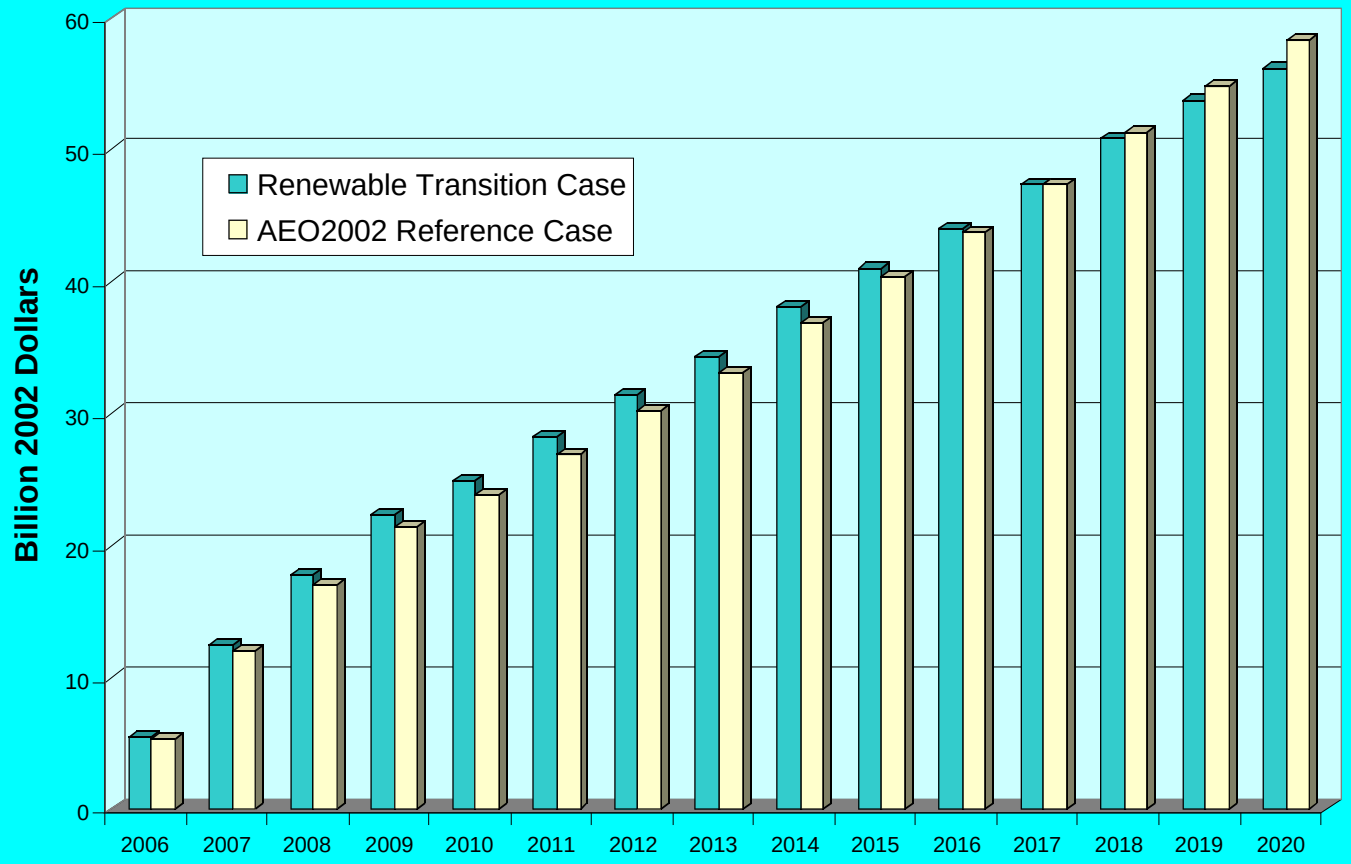
The Results

- About 150 GW of (non-hydro) renewables in 2020
  - That's 15% of total capacity in 2020
- In 2012 (worst year), annual cost increase is
  - About $1B for the nation
  - Residential share is about 25 cents per month per household
- In 2020, annual cost savings are about $1.5B, or 37 cents per month per household

Transition Scenario for the Power Sector



Total Generation Costs of New & Replacement Units
Renewable Transition & AEO 2002 Reference Cases



EIA Analysis Shows Similar Results

- Modeled 10% and 20% RPS (renewables portfolio standard) in 2020
- Used their assumptions re costs of renewables
- Results:
  - Electricity prices are 4.3% higher in 2020
  - Renewables mix is 58% biopower, 31% wind, 10% geothermal (Total of 800 billion kWh in 2020 in 20% RPS case)
  - Natural gas prices go down by 9%
  - *Total energy expenditures go down slightly*

Summary

"Renewable energy development is at a crossroads…. The momentum for renewables has never been greater, despite the fact that energy prices are low and there are few immediate energy concerns."

IEA 1999: The Evolving Renewable Energy Market

Resources

- National Renwable Energy Laboratory www.nrel.gov
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy www.eere.energy.gov
- U.S. Energy Information Administration http://www.eia.doe.gov/
- U.S. Climate Change Technology Program www.climatetechnology.gov
- International Energy Agency www.iea.org