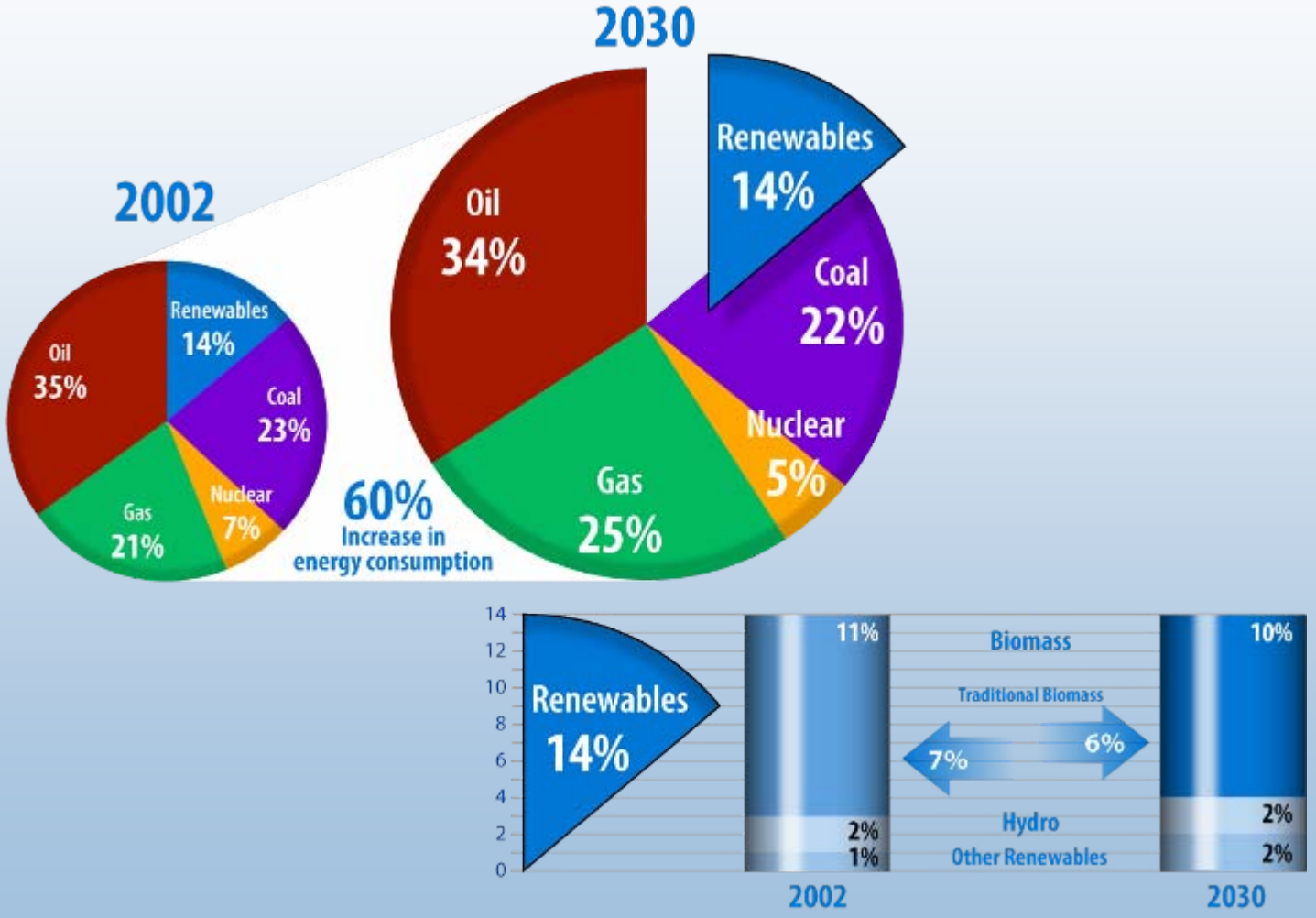
The Growing Significance of the New Biofuels

Presented at the Kennedy School of Government at Harvard University

February 5, 2007

Dan E. Arvizu
Director, National Renewable Energy Laboratory

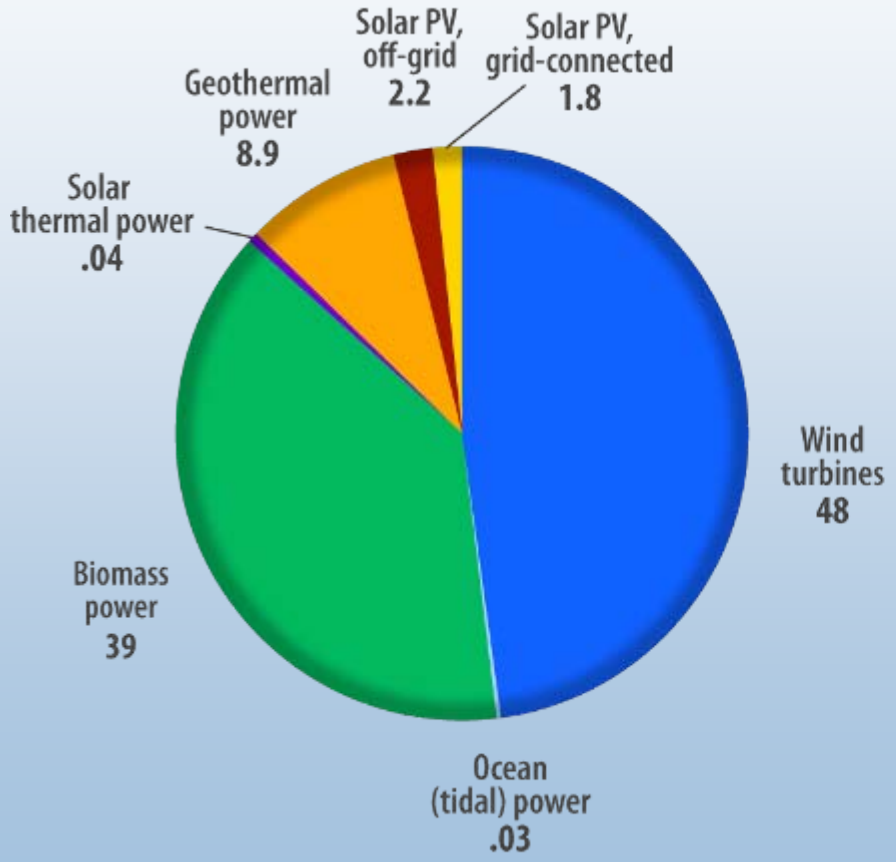
World Energy Supply and the Role of Renewable Energy



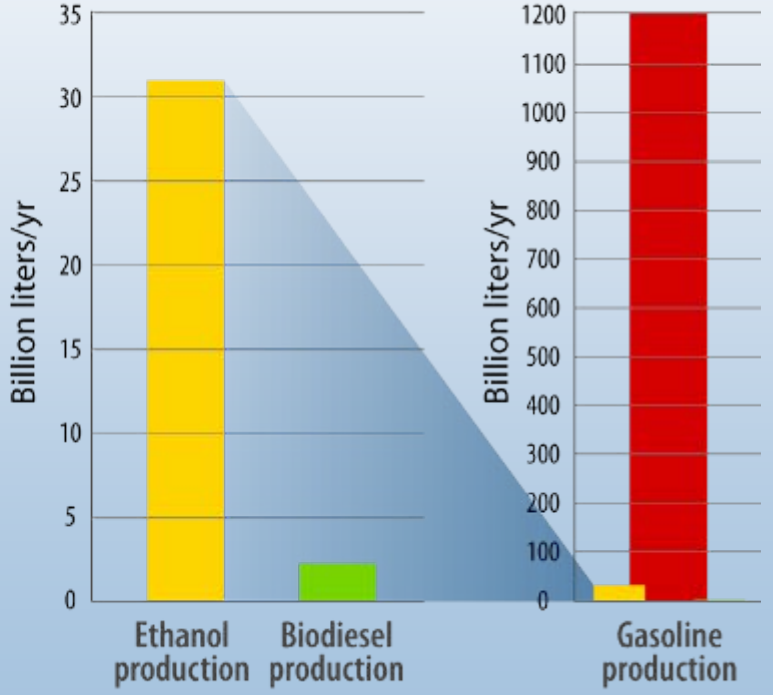
Source: OECD/IEA, 2004

Global Renewable Energy Indicators

Power Generation
Existing Capacity* – GW



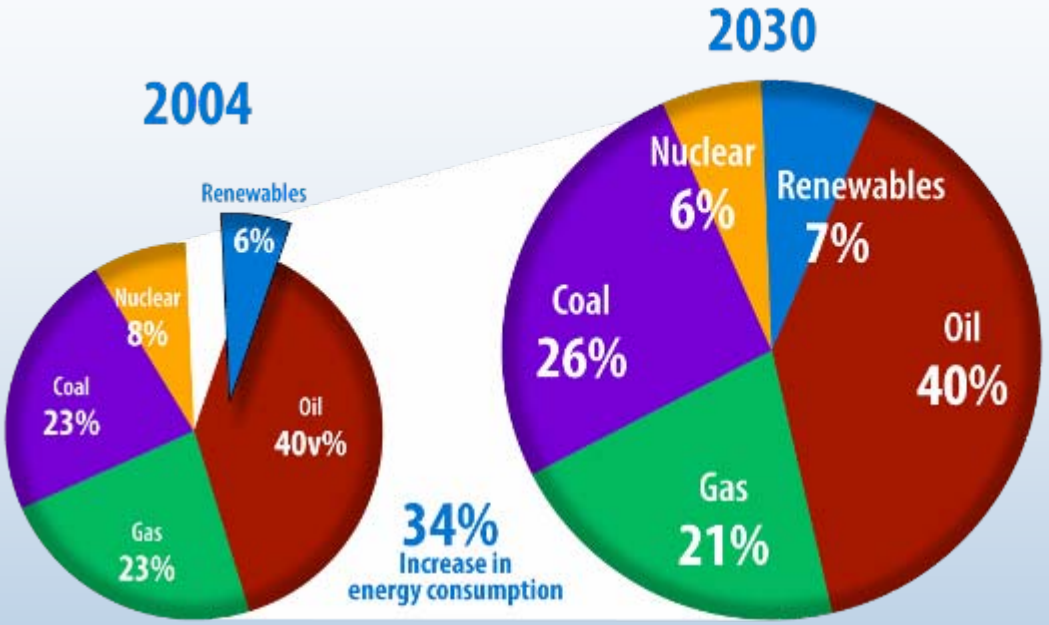
Transportation Fuels
Billion liters/year

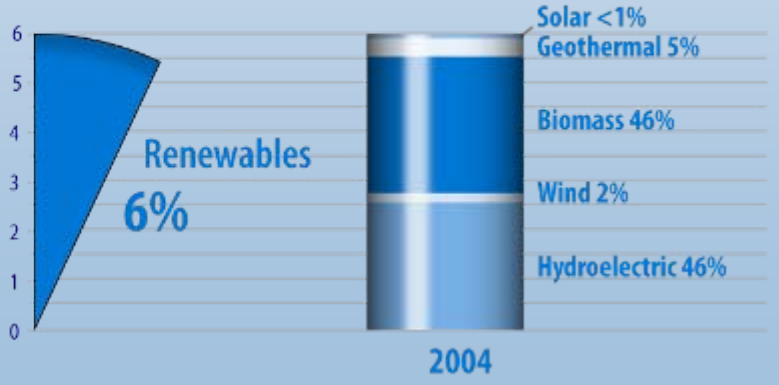


Note: Does not include hydropower.

Source: REN21 Renewables 2005 Global Status Report

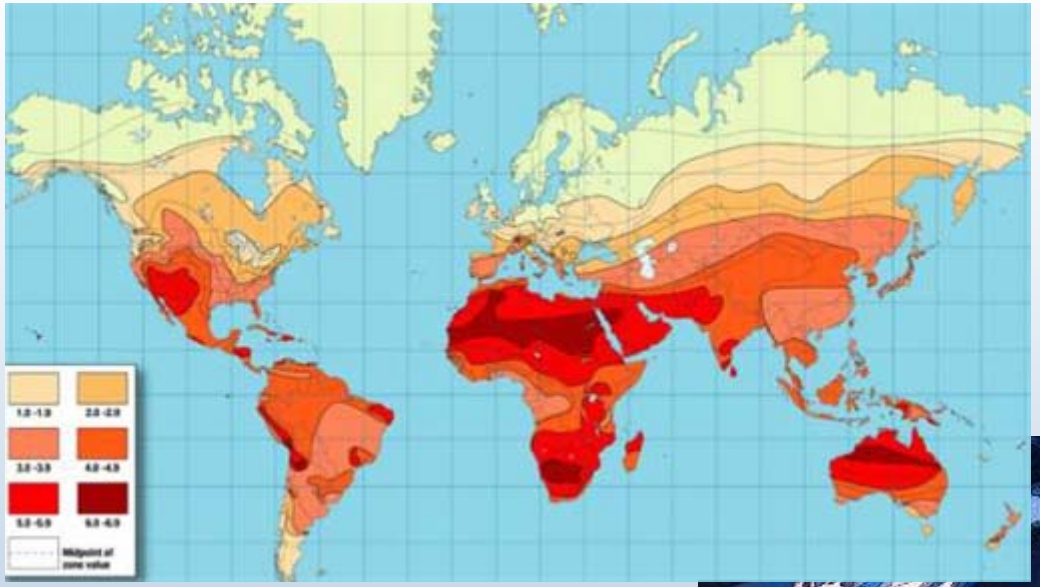
U.S. Energy Consumption and the Role of Renewable Energy





Source: Energy Information Administration, *Annual Energy Outlook 2006,* Table D4

Plentiful Resources

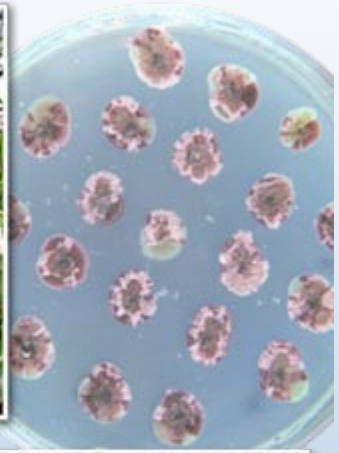


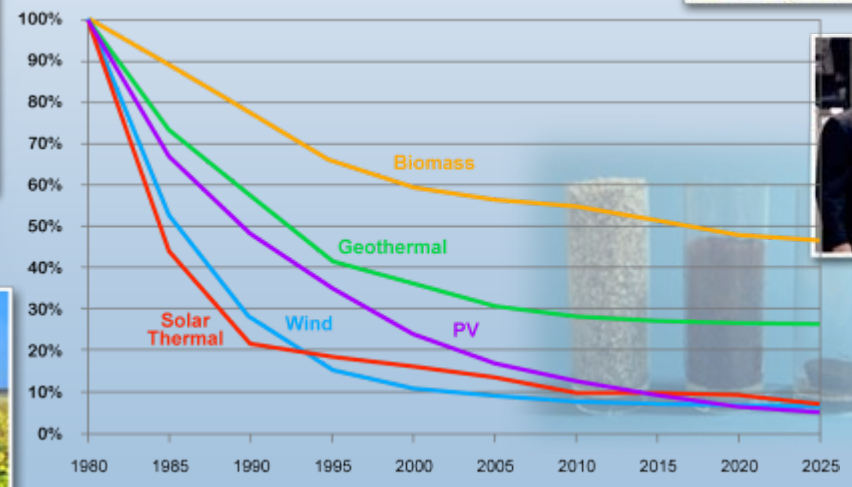
Solar

Wind

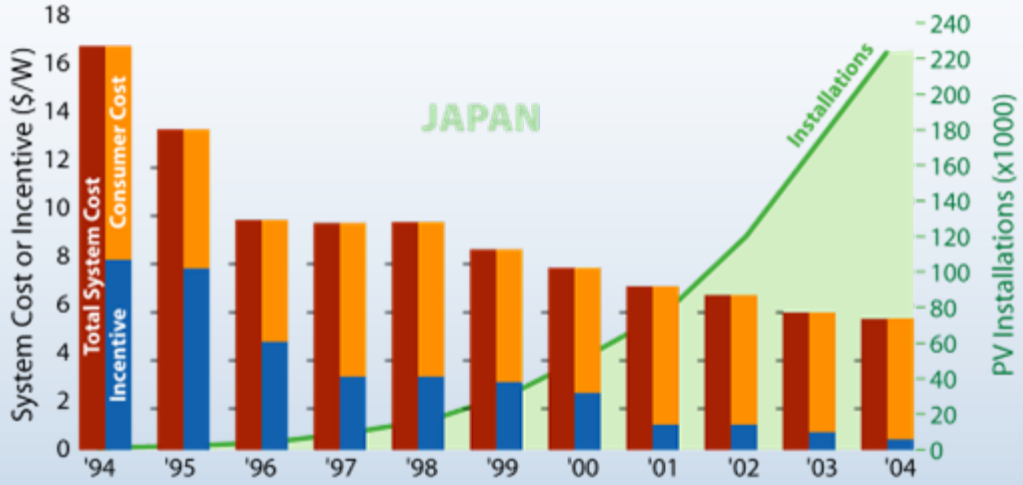
Source: http://howto.altenergystore.com/Reference-Materials/Solar-Insolation-Map-World/a43/
Pacific Northwest National Laboratory

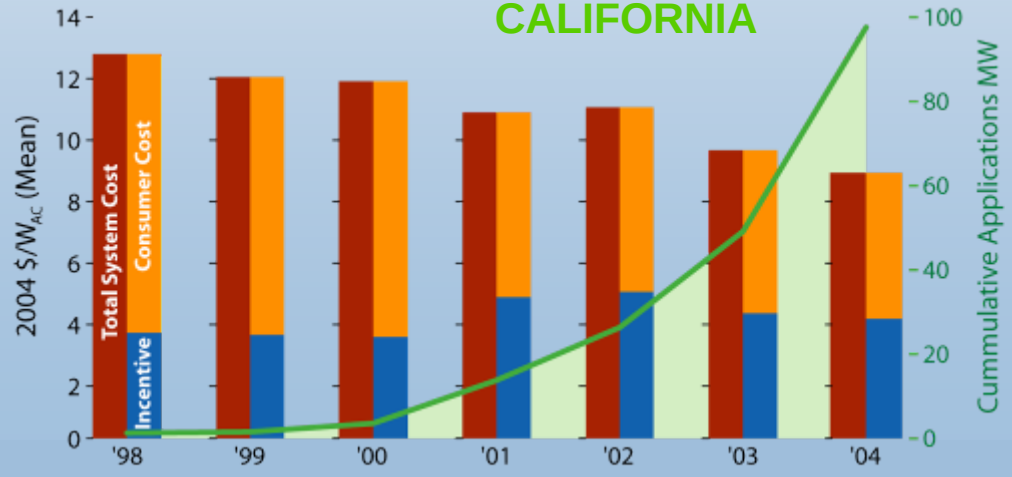
Impressive Cost Reductions

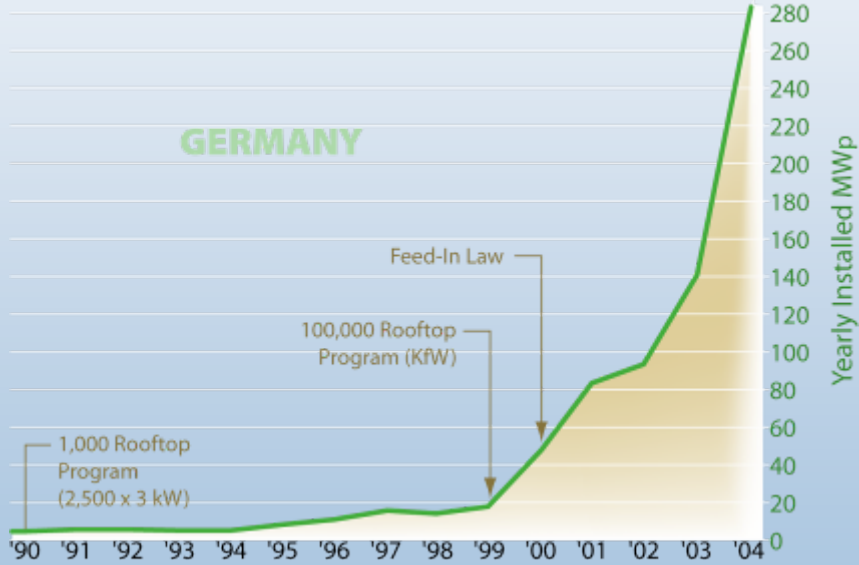




Worldwide Markets Have Driven Cost Reductions

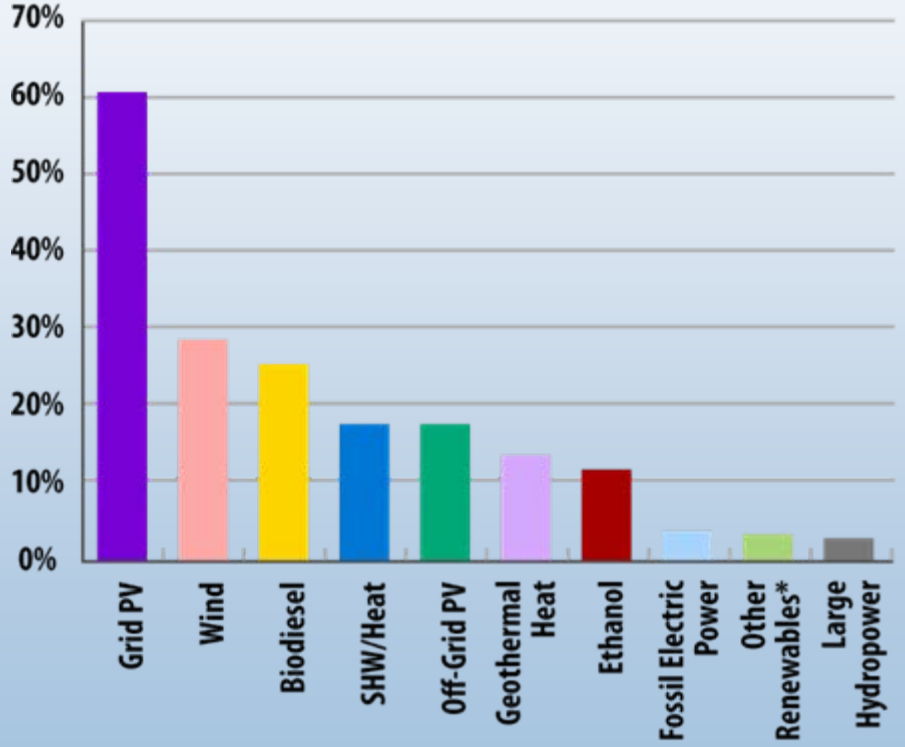




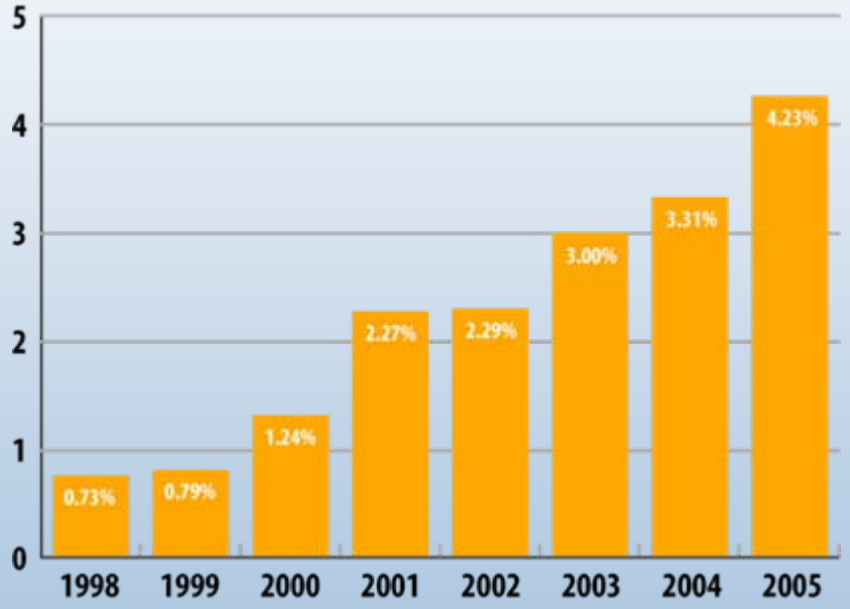


Investing in the Future

Global Renewable Energy Annual Growth Rates 2000-2004



Energy-Tech Investments Percent of Total U.S. Venture Capital



Sources:
Renewables 2005 Global Status Report, REN21
Clean Energy Trends 2006, Nth Power LLC

Putting the Pieces Together

Past Investments Have Had a Significant Impact

Created a commercial nuclear power option

Reduced emissions from coal-fired power plants

Enhanced oil recovery from wells

Enabled hybrid vehicles to enter the market

Brought utility-scale wind into our generation mix

Improved energy productivity

NREL Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal

Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science

Wind

Today's Status in U.S.

- 11,603 MW installed at end of 2006
- Cost 6-9¢/kWh at good wind sites*

DOE Cost Goals

- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

Long Term Potential

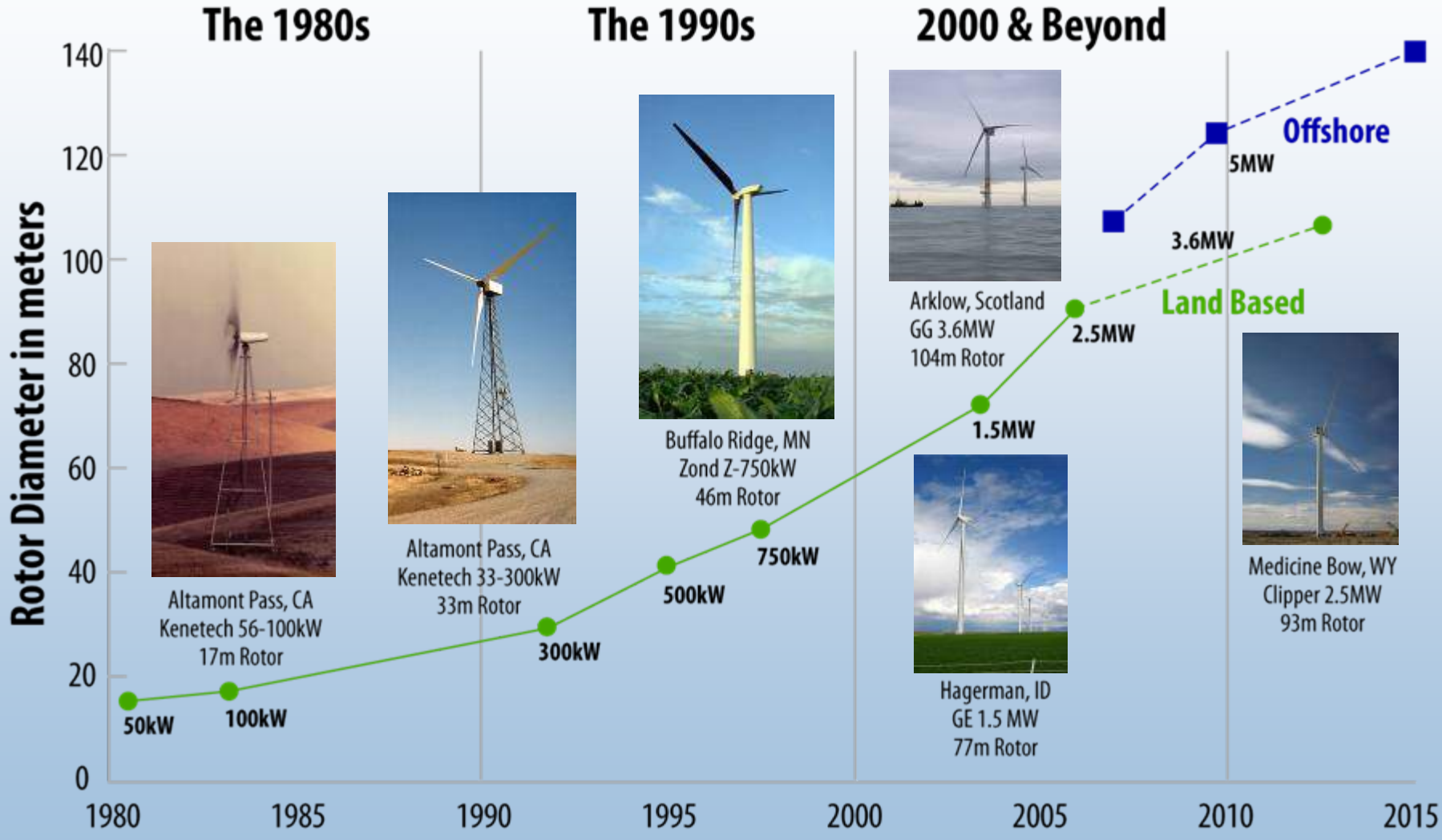
- 20% of the nation's electricity supply

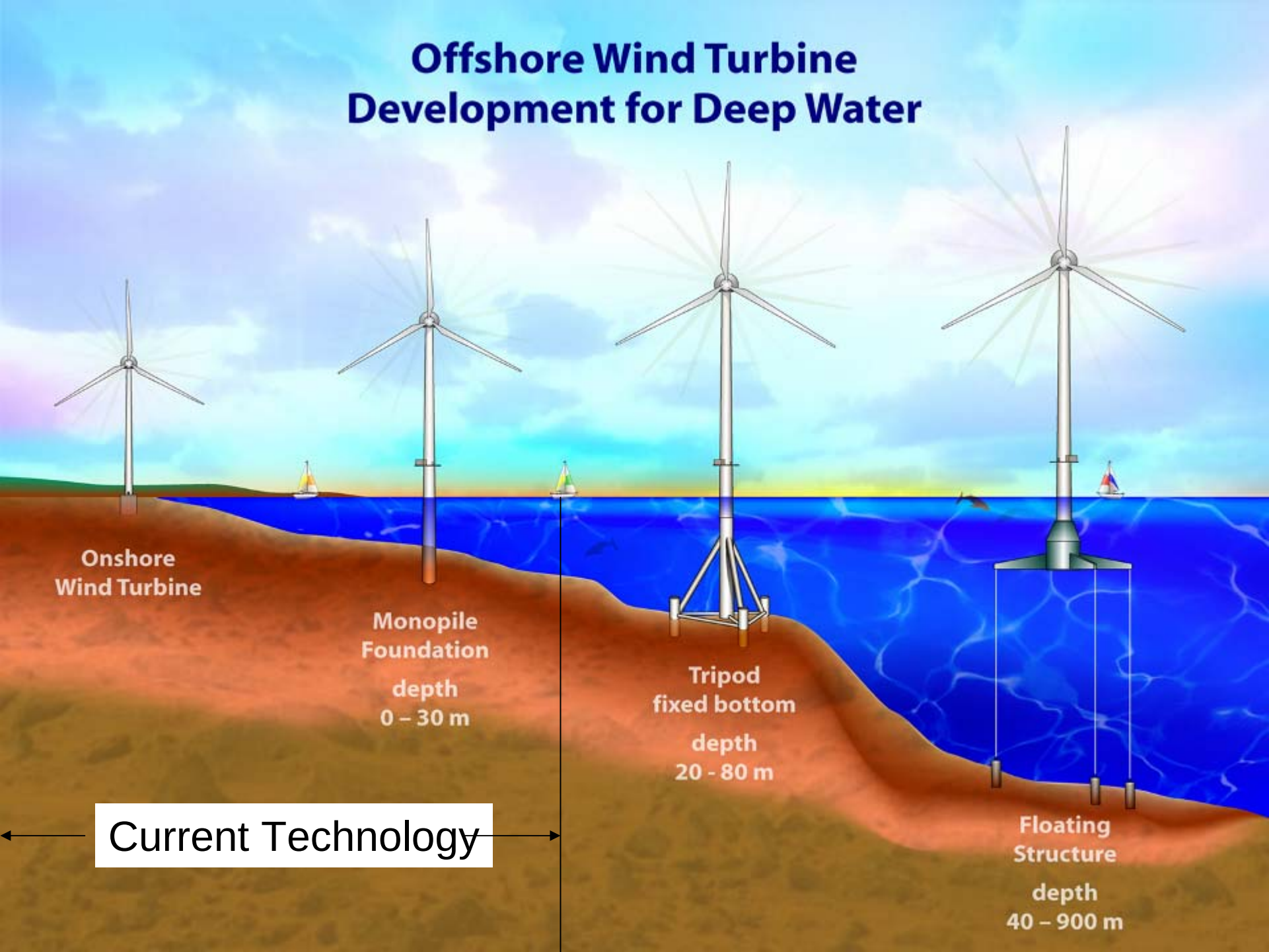
NREL Research Thrusts

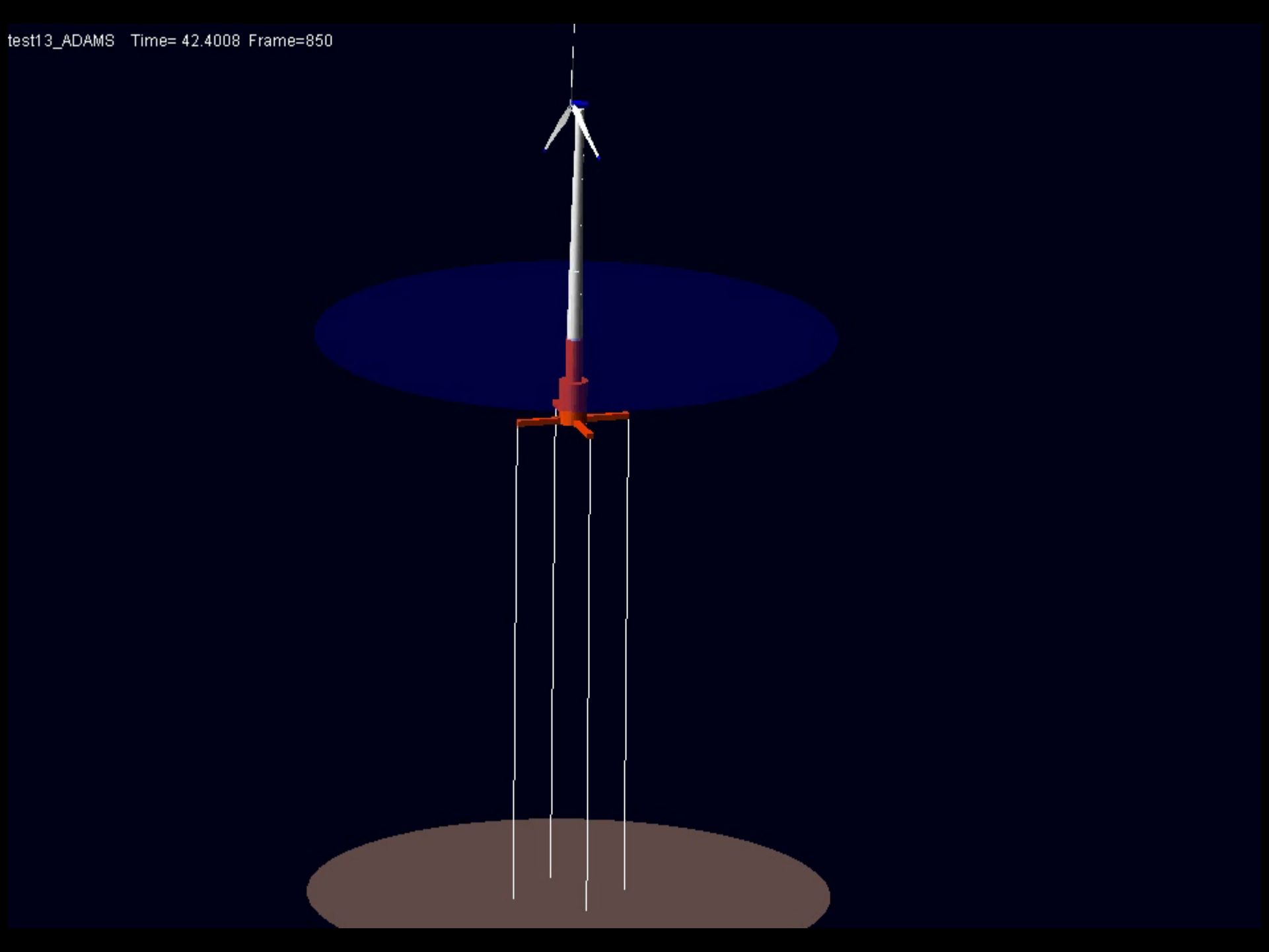
- Improved performance and reliability
- Distributed wind technology
- Advanced rotor development
- Utility grid integration

* With no Production Tax Credit
Updated January 23, 2007
Source: U.S. Department of Energy, American Wind Energy Association

Evolution of U.S. Commercial Wind Energy




Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology


test13_ADAMS Time= 42.4008 Frame=850

Solar

Photovoltaics and Concentrating Solar Power

Status in U.S.

PV
- 526 MW
- Cost 18-23¢/kWh

CSP
- 355 MW
- Cost 12¢/kWh

Potential:

PV
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP
8.5 ¢/kWh by 2010
6 ¢/kWh by 2015

NREL Research Thrusts:

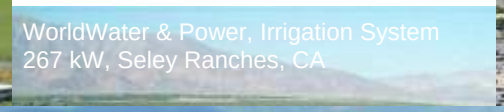
PV
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

CSP
- Next generation solar collectors
- High performance storage

Source: U.S. Department of Energy, IEA
Updated November 8, 2006

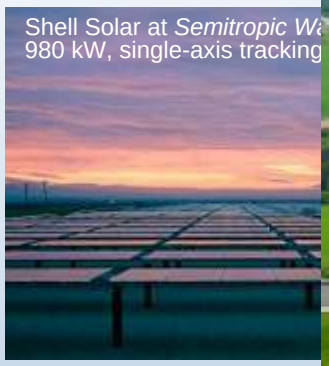
…toward our destination


Ridge Vineyards PV Rooftop 65 kW, CA


WorldWater & Power, Irrigation System 267 kW, Seley Ranches, CA


RWE Schott Stillwell Avenue Subway Station, PV Canopy Roof, 250,000 kWh/yr, Brooklyn, NY


Powerlight, Bavarian community 6.750 MW, single-axis tracking Mühlhausen, Germany

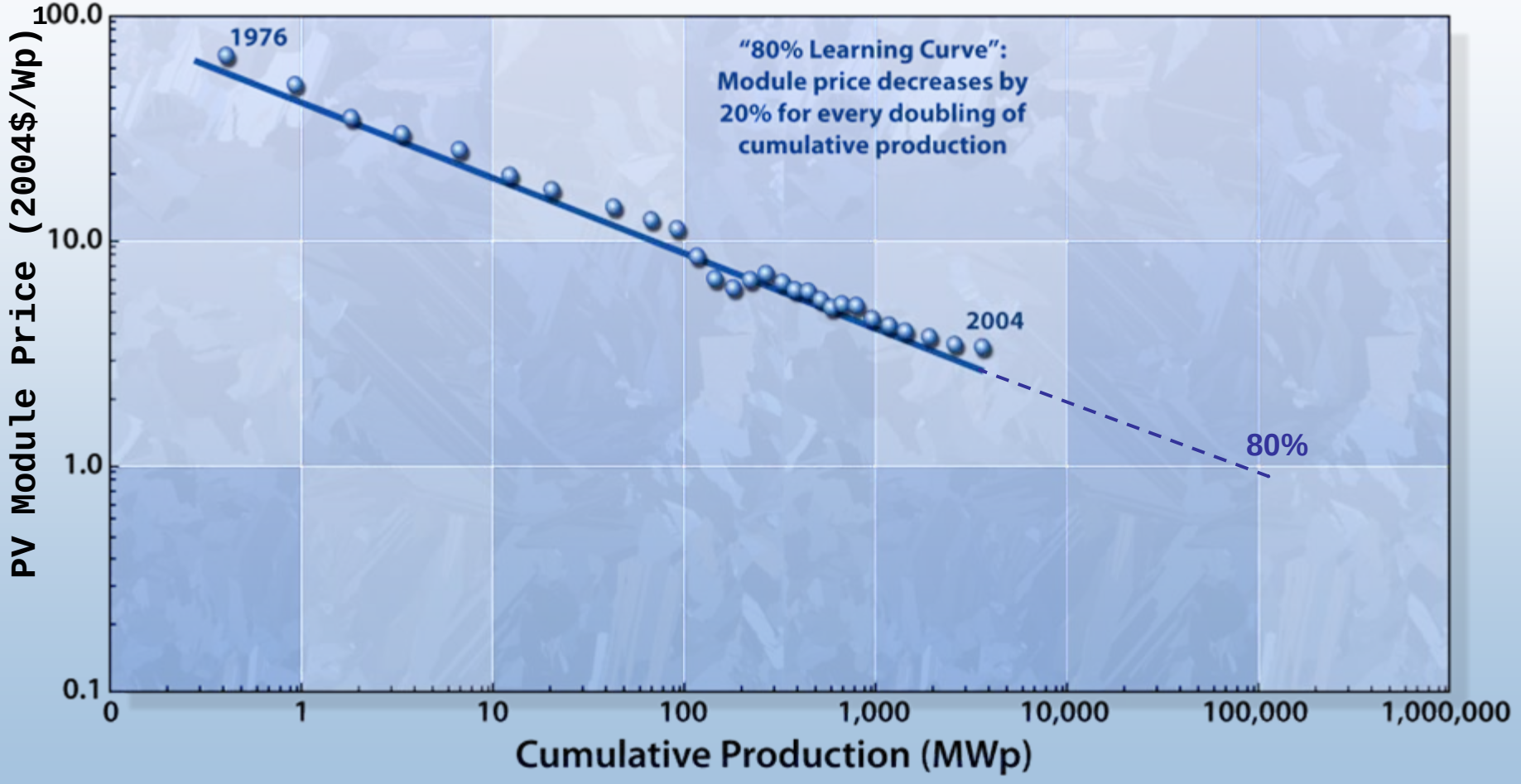

Shell Solar at *Semitropic Wa*
980 kW, single-axis tracking


er & Geothermal Energy Co.
stewater Plant, 622 kW,
CA

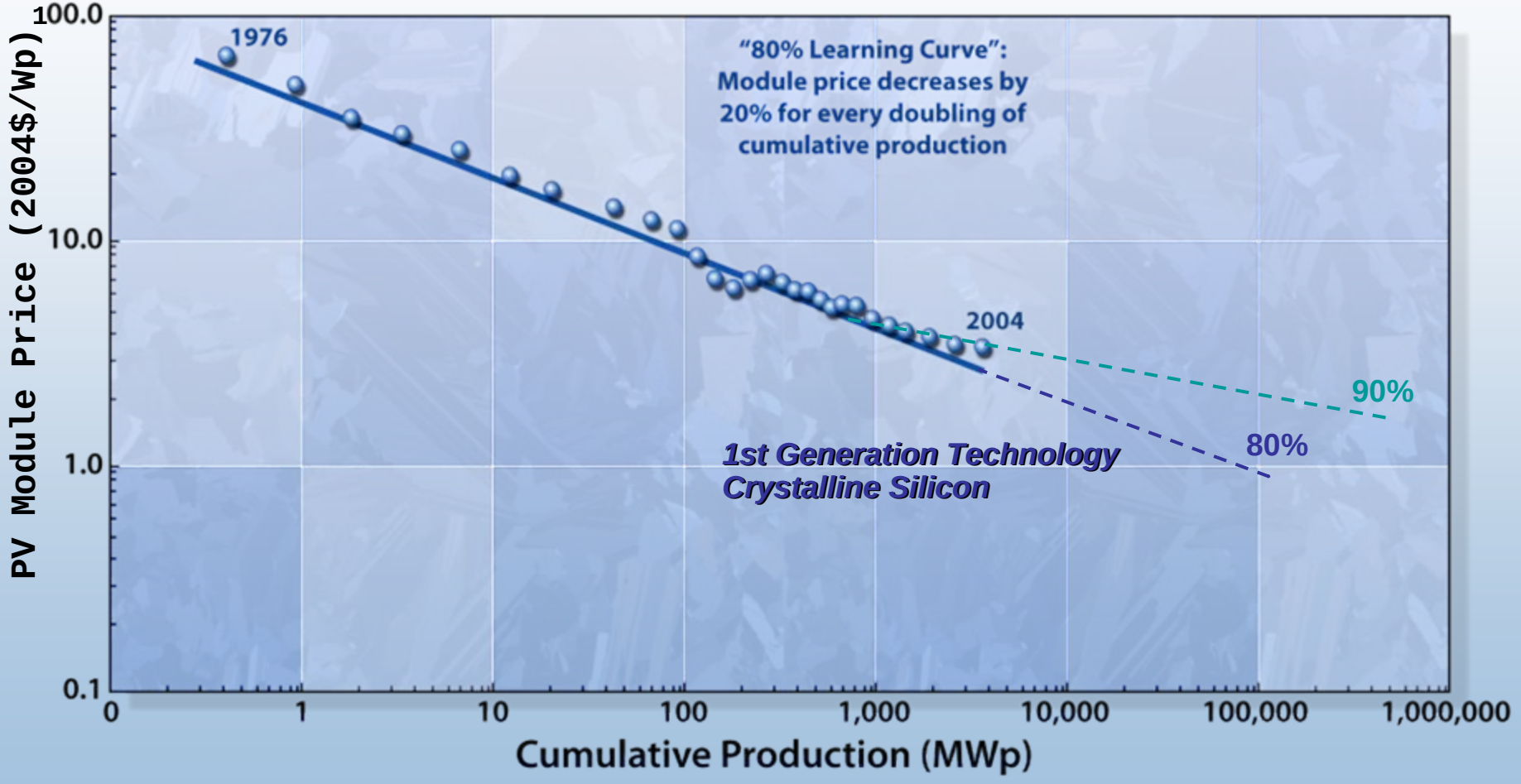

PowerLight PowerGuard
536 kW, Toyota Motor C


op system,

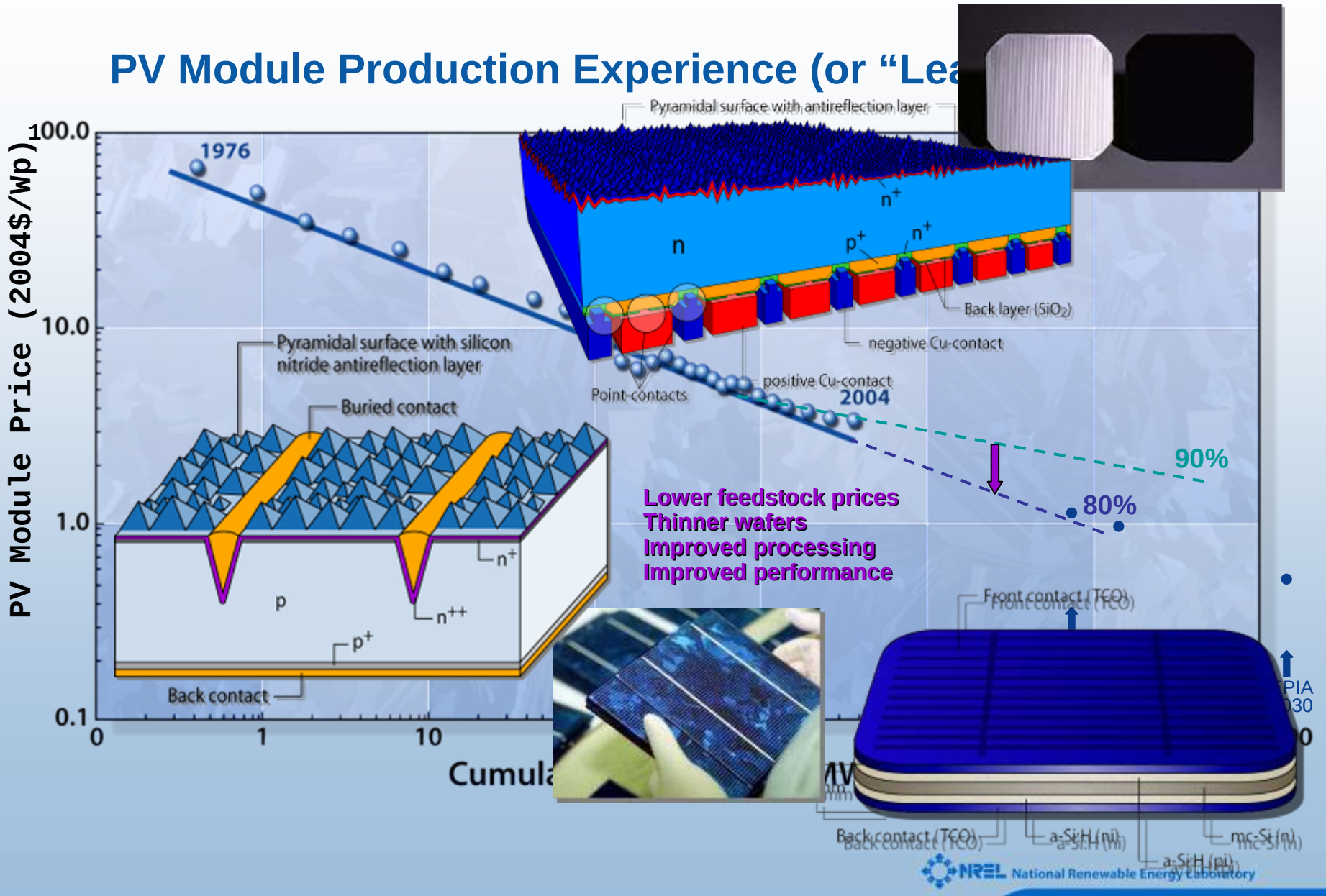
PV Module Production Experience (or “Learning”) Curve



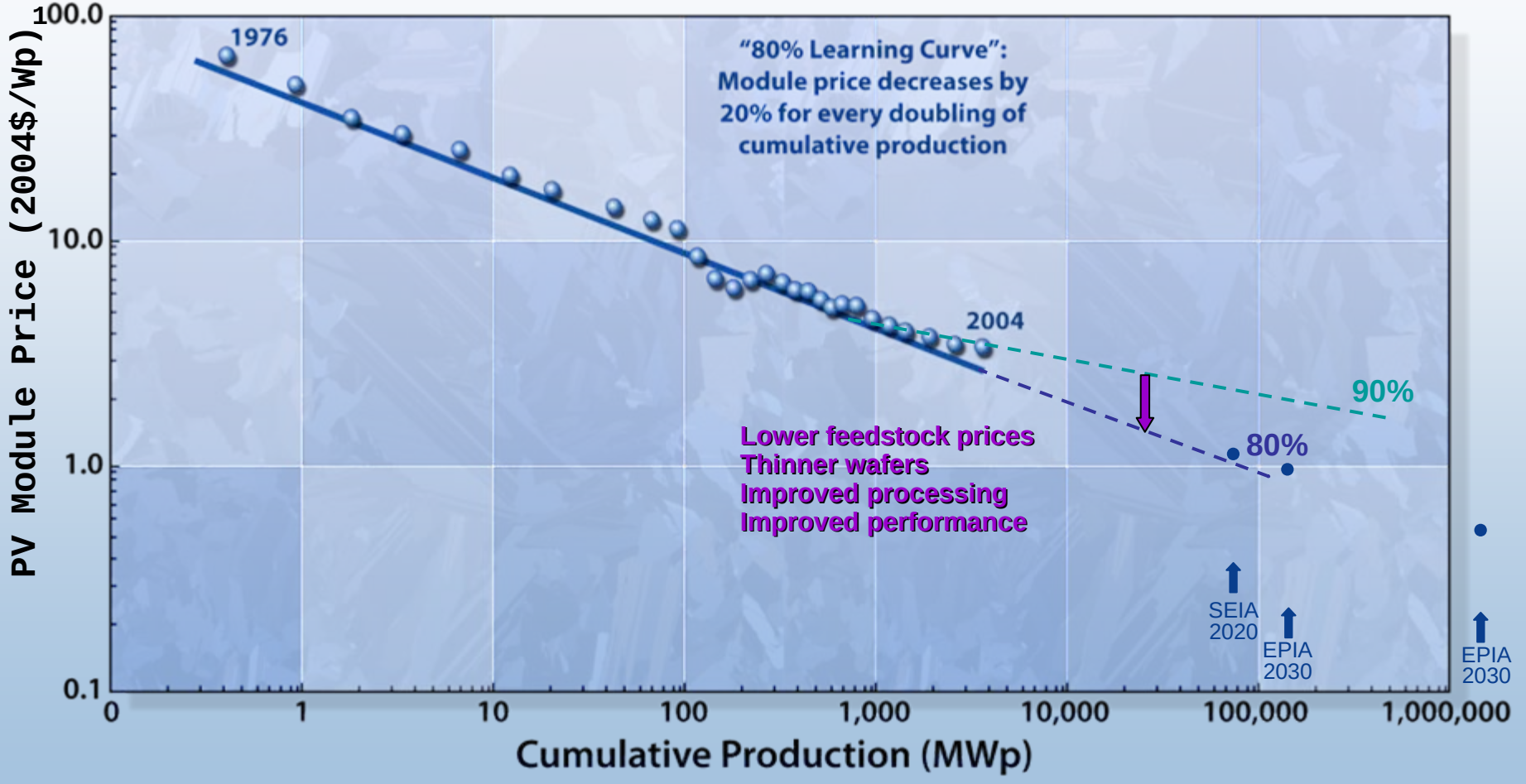
PV Module Production Experience (or “Learning”) Curve



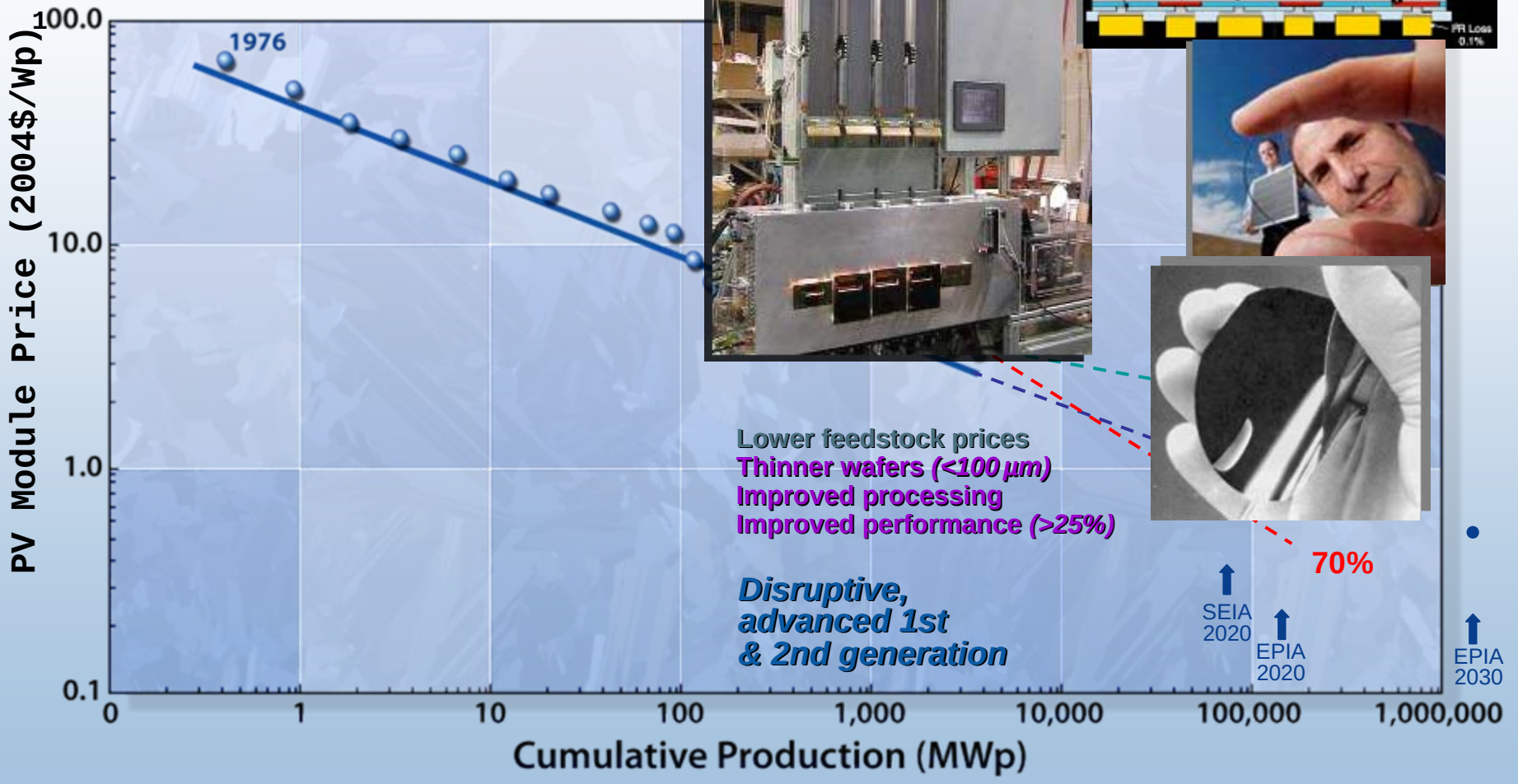
PV Module Production Experience (or "Lea



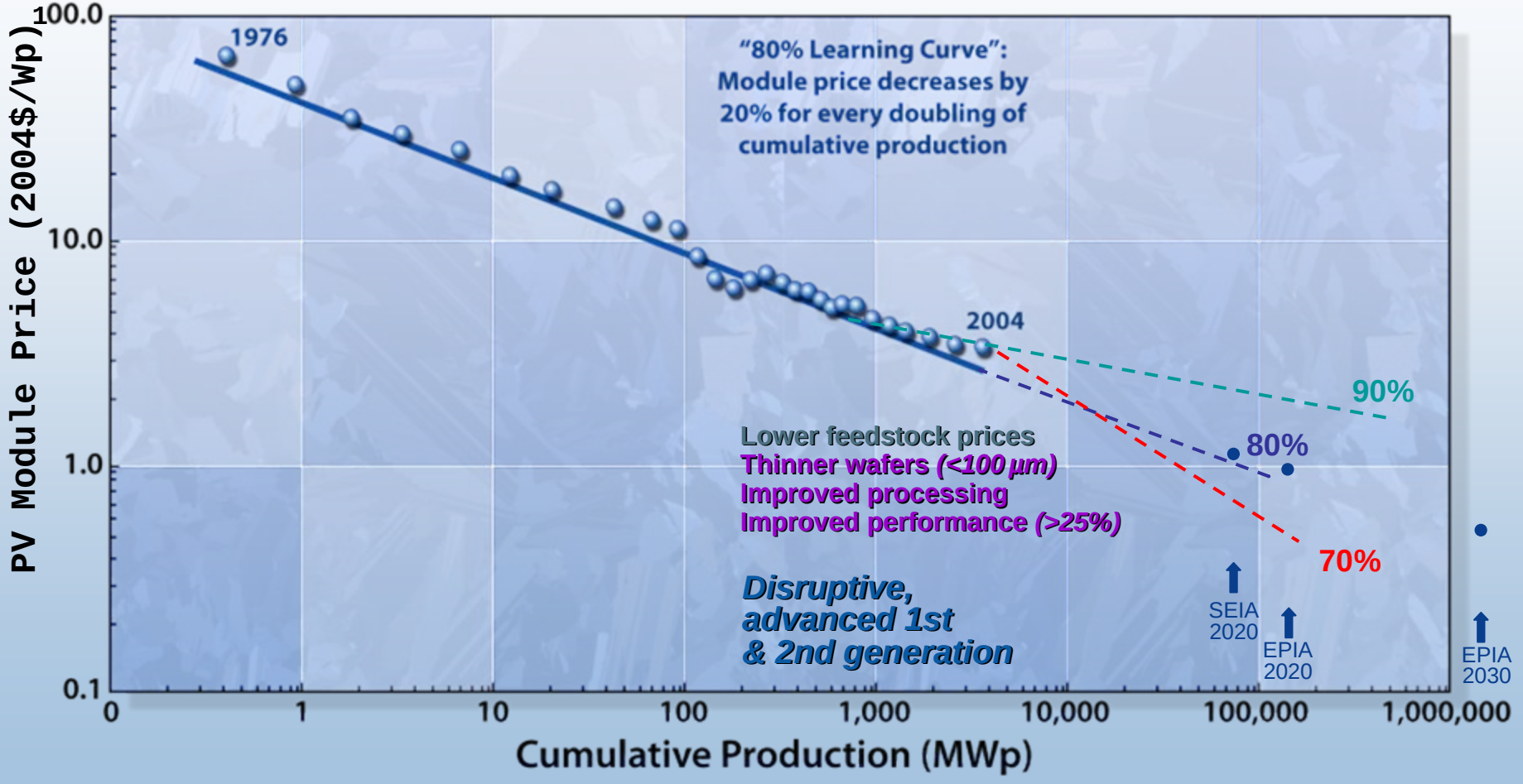
PV Module Production Experience (or "Learning") Curve



PV Module Production Experience (or "Le



PV Module Production Experience (or "Learning") Curve



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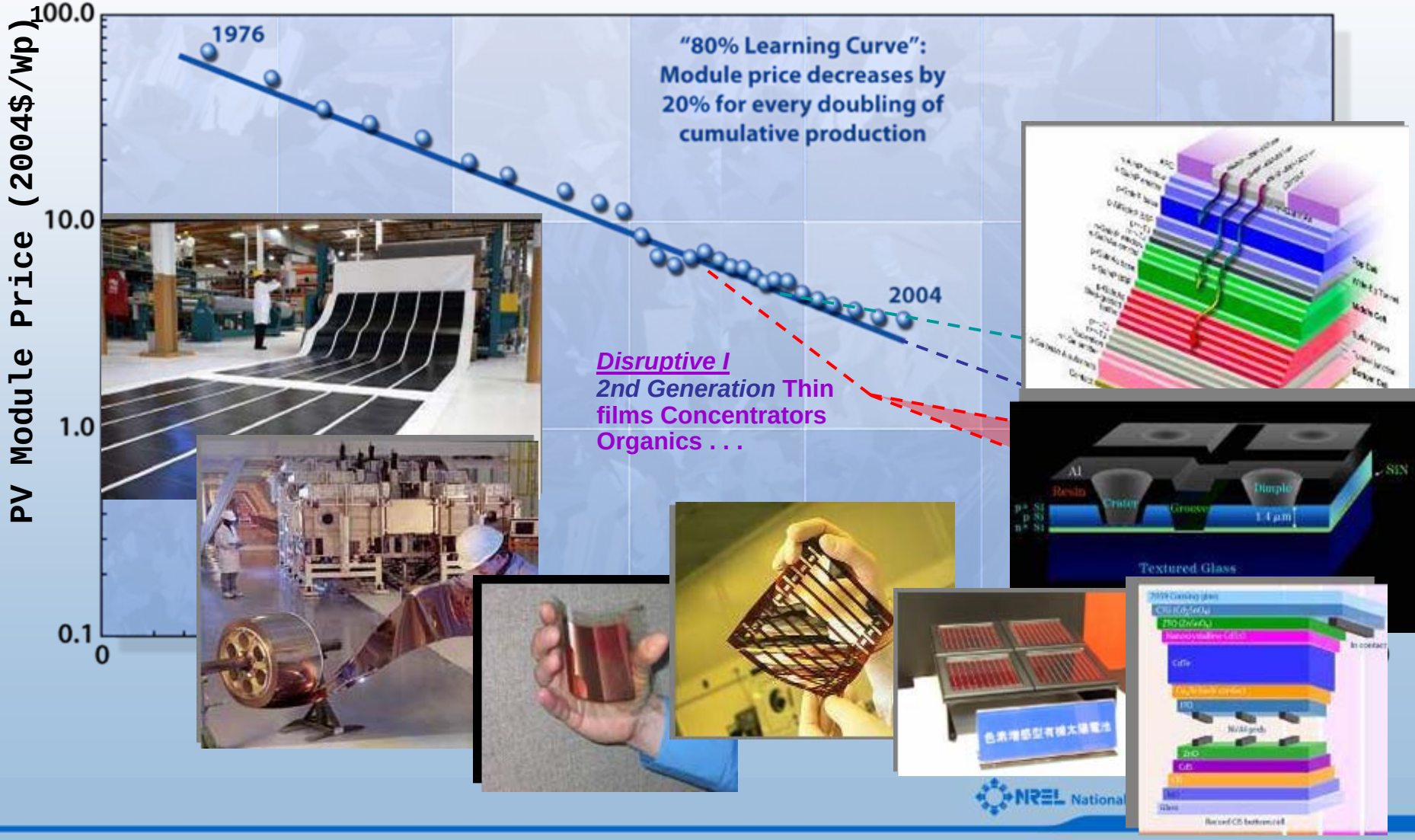
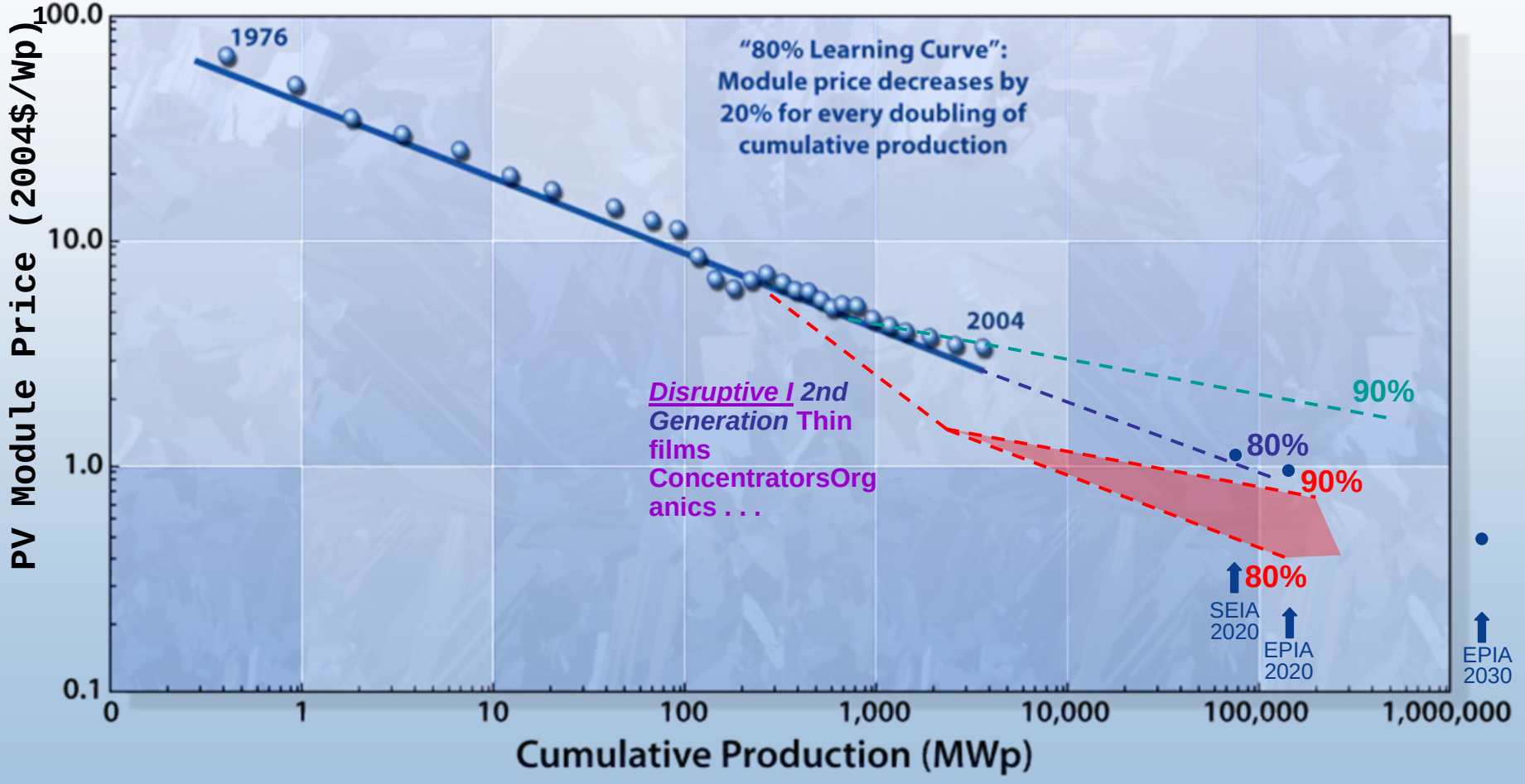


PV Module Production Experience (or "Learning") Curve

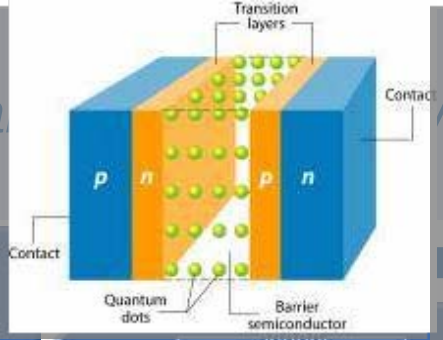


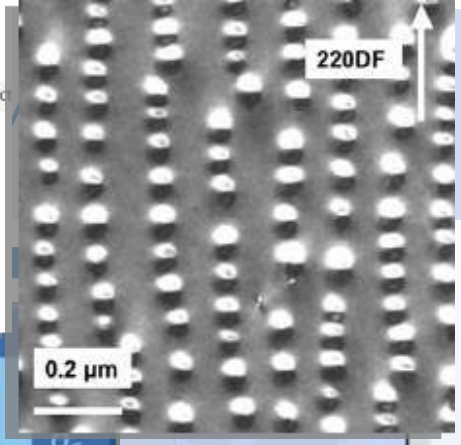
R&D

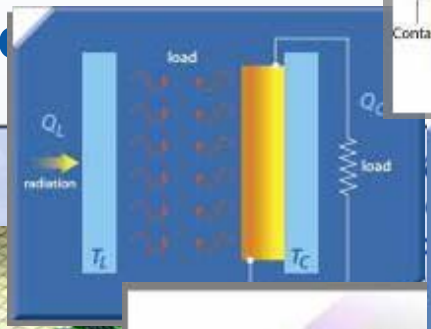
Ensures technology ownership, ena

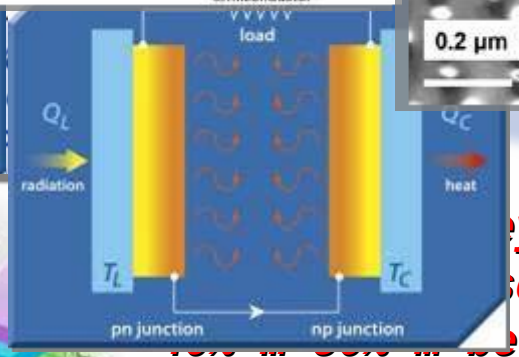
DOE is the STEWARD

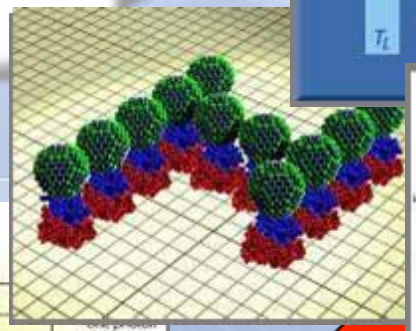
PV Module Pr

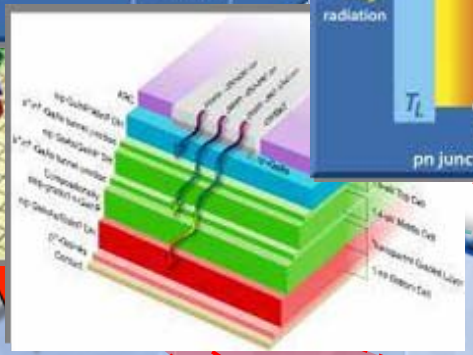


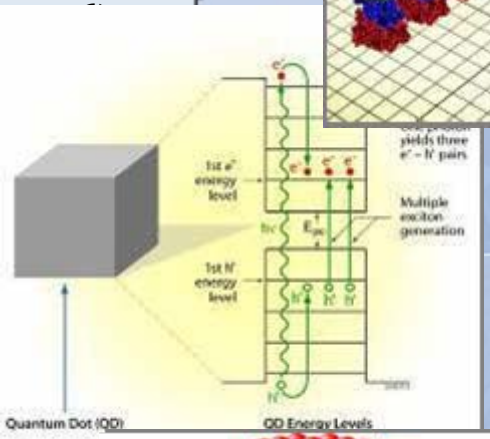


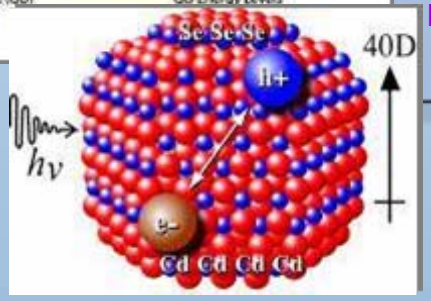












Disruptive II

3rd Gen and beyond

Quantum dots

Nanotechnology

Multi-multi-junctions

Thermophotonics, voltaics

Intermediate band . . .

eyond the

ser Limit

eyond?)

90%

80%

80%

70%

60%

SEIA 2020

EPIA 2020

EPIA 2030

(2004$/Wp)

100

10.0

10

100

1,000

10,000

100,000

1,000,000

Cumulative Production (MWp)

Technology Investment Pathways

The New Biofuels

The New Biofuels
President Bush's *"Twenty in Ten: Strengthening America's Energy Security"*

- Reduce U.S. gasoline consumption 20% by 2017
  - Require 35 billion gallons of renewable and alternative fuels by 2017 to displace 15% of projected annual gasoline use
- President's 2008 Budget will
  - Include nearly $2.7B for the Advanced Energy Initiative, an increase of 26% above the 2007 request
  - Provide $179M for the President's Biofuels Initative, an increase of $29M (19%) compared to the 2007 budget
- President's Farm Bill proposal will include more than $1.6B of additional new funding over ten years for energy innovation, including bioenergy research and $2B in loans for cellulosic ethanol plants

Biofuels

Current Biofuels status

- Biodiesel – 91 million gallons[1] (2005)
- Corn ethanol (Nov. 2006)
  - 106 commercial plants[2]
  - 5.1 billion gallon/yr. capacity[2]
  - 3rd Q 2006 rack price highly variable $3.50 – 5.50/gallon of gasoline equivalent (gge)[3]
- Cellulosic ethanol
  - Projected commercial cost ~$3.50/gge

Key DOE Goals

- 2012 goal: cellulosic ethanol ~$1.62/gge
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

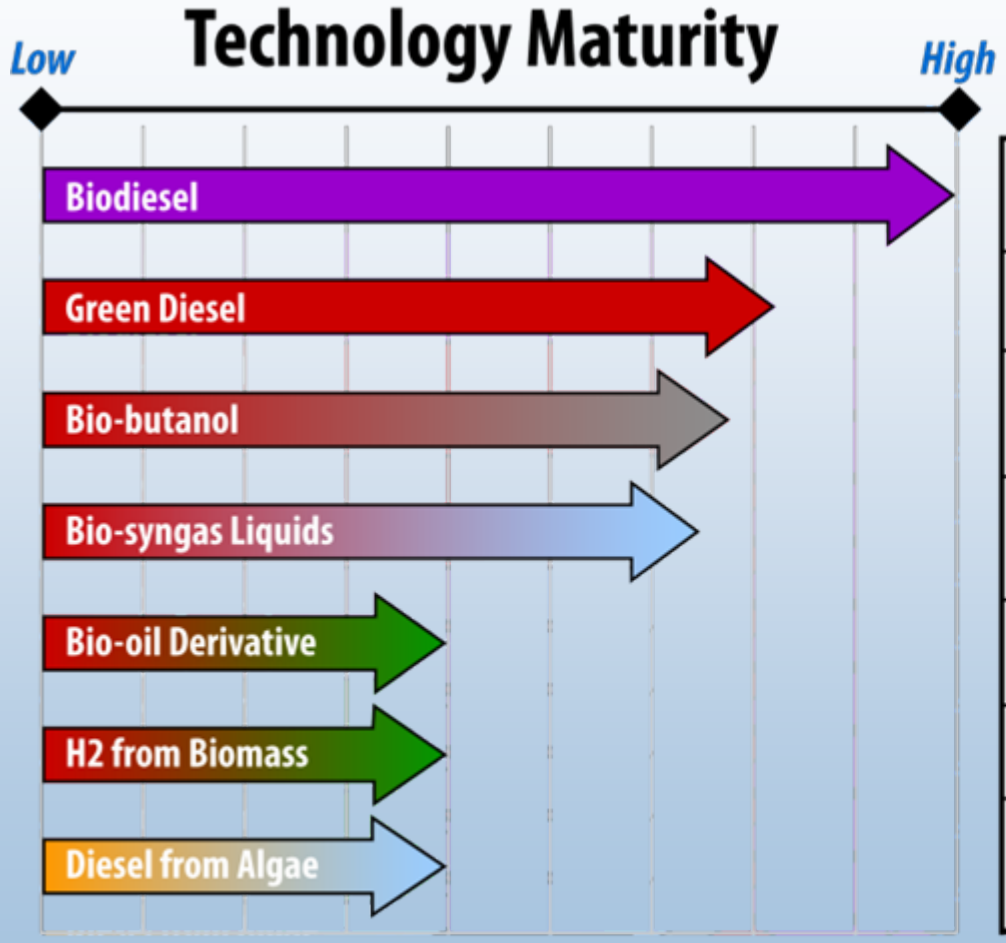
NREL Research Thrusts

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops

Updated November 10, 2006

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, 3 – American Coalition for Ethanol, all other information based on DOE and USDA sources

Biofuels R&D



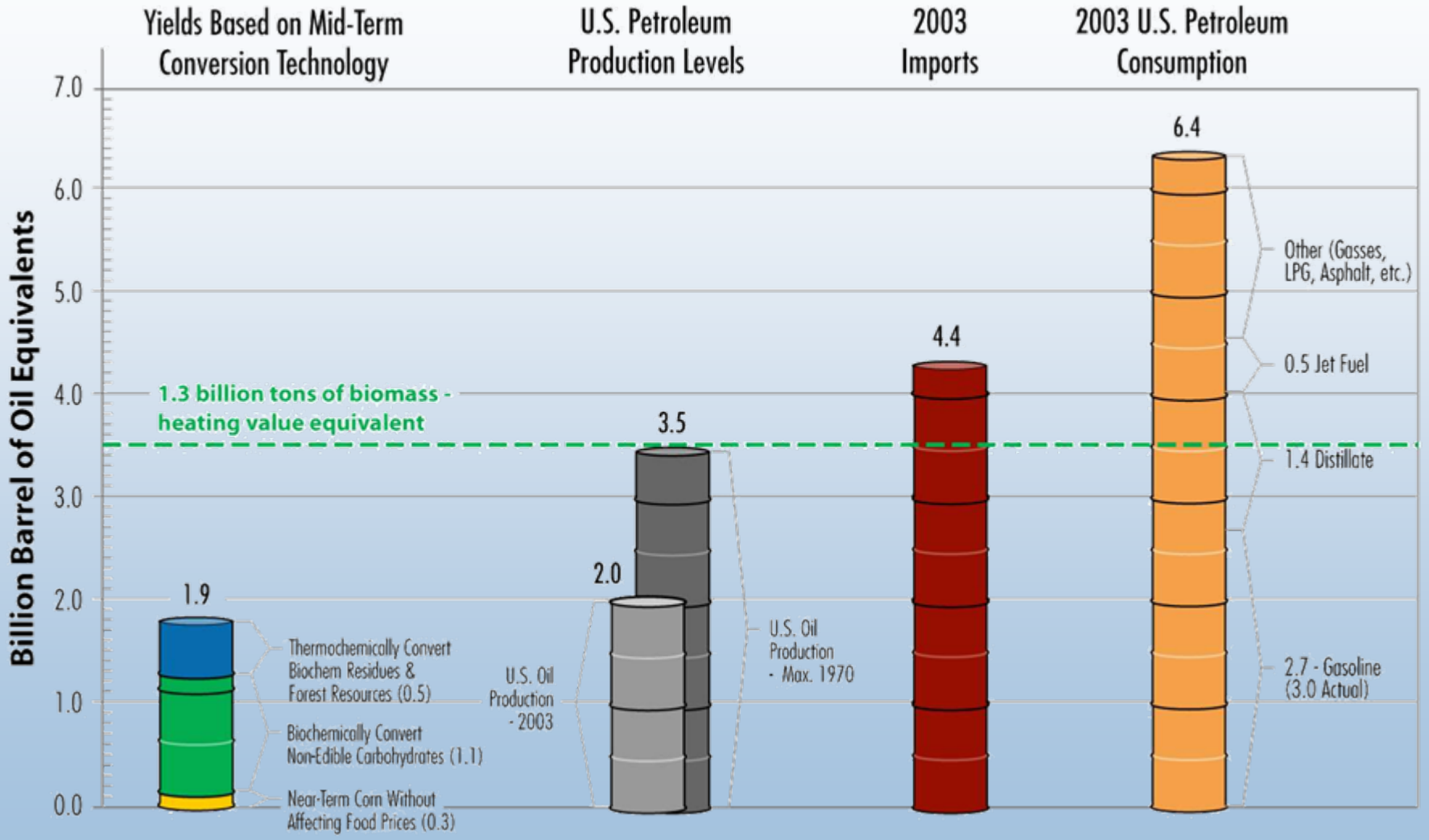
Key Drivers	Value Added
New market for excess oils, fats, and greases.	Petroleum compatible and biodegradable.
Lower cost and higher product quality than FAME.	Utilize existing assets. High quality jet fuel or diesel.
New market for grain and agriculture products. Large supply of lignocellulose.	Better gasoline blending properties than ethanol.
Integration of biomass with Coal, Coke, Shale, or Heavy Oils.	High quality jet fuel or diesel. Reduced criteria for sequestration, and economy of scale (in combination with fossil).
Technical fit with woody biomass and liquid bio-crude.	Potential to integrate into existing large scale refinery and pipeline infrastructure.
Potential transportation fuel from any fuel/power source.	Ideal feed for fuel cells, and lowest tail pipe emissions.
Lg. source of biomass on non-arable land, and capture of CO^2.	High quality jet fuel or diesel yield per acre, with both off-shore and on-shore potential.

Renewable Fuels & Low GHG Emissions

Organizations Leading the R&D

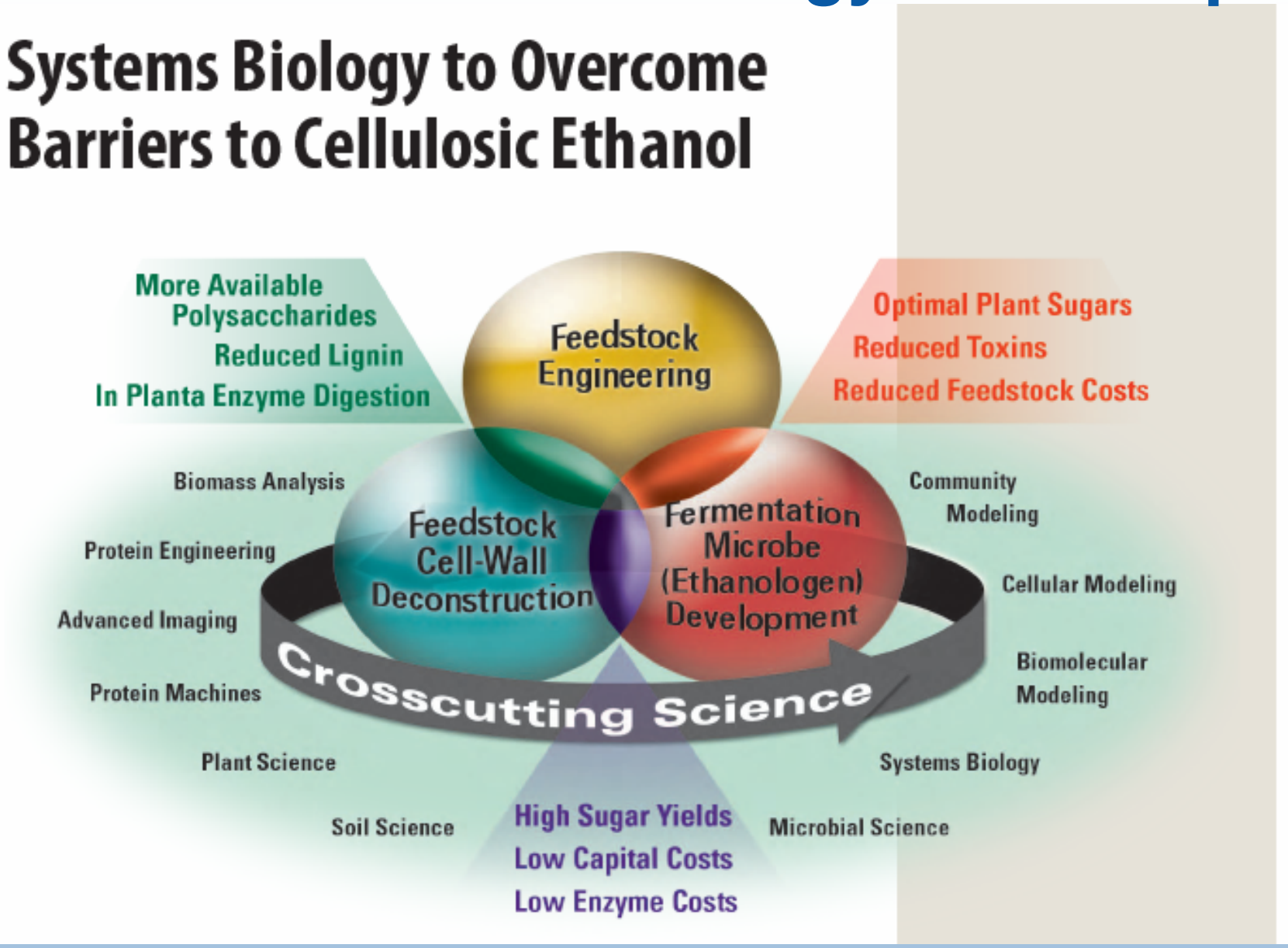
- Grain/Agriculture
- Petroleum
- Coal
- Forestry
- Chemical
- Academia & Startups

Significance of the 1.3 Billion Ton Biomass Scenario



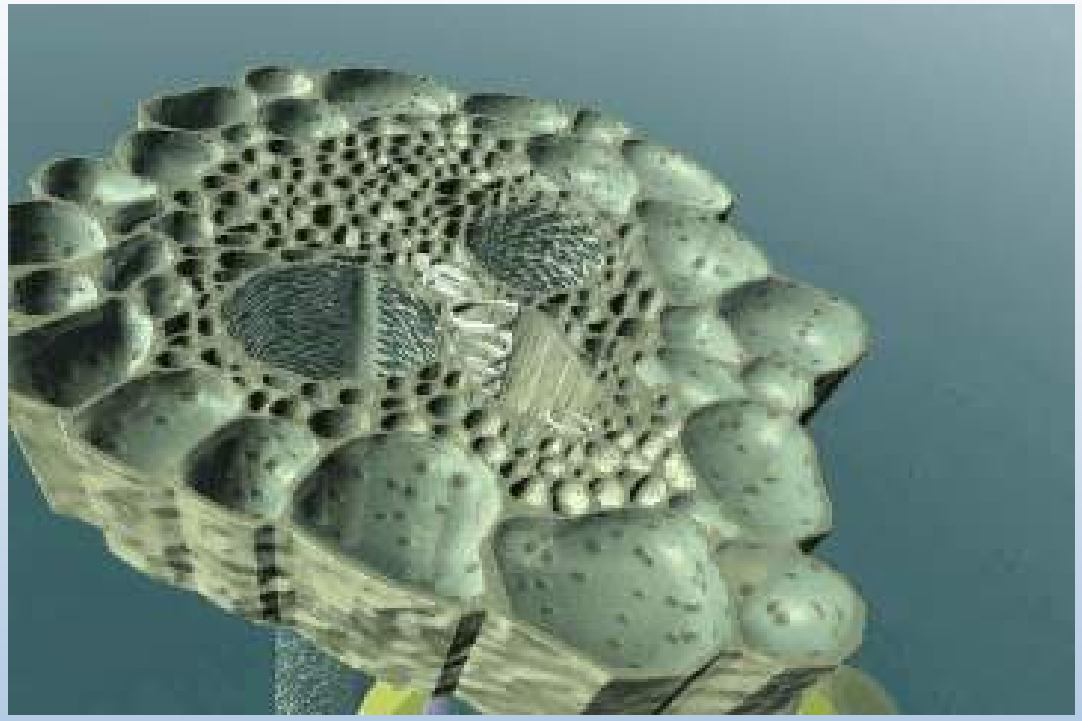
Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

From DOE GTL Bioenergy Roadmap



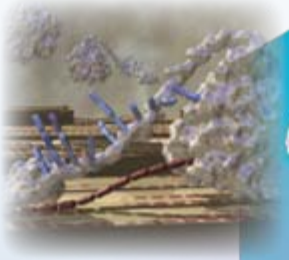
Feedstock Engineering

- Increase crop production (agronomics and plant engineering)
- Increase composition of desirable polysaccharides (cellulose)
- Decrease composition of undesirable polymers (lignins)



NREL “Corn Stem Tour”

Technology Investment Pathways
Renewable Fuels



Basic Research Driven

Deep Understanding

- Systems biology & HTP
- Structural biology
- Computational science
- Biomass ultrastructure
- Advanced imaging tools
- Photosystem biochemistry
- Enzyme engineering
- Photoelectrochemistry

Revolutionary
(10 years and beyond)

30X30 Report
OSC/EE Workshop on
Cellulosic Ethanol
IBRF Upgrade

Accelerated
Evolutionary
(3 years)

Disruptive
(3–10 years)

Industry Driven

Transportation Fuels

- Bioethanol pilot plant
- Technoeconomic analysis
- Performance testing for industry
- Biofuel cells
- Rapid biomass analysis
- Process unit testing

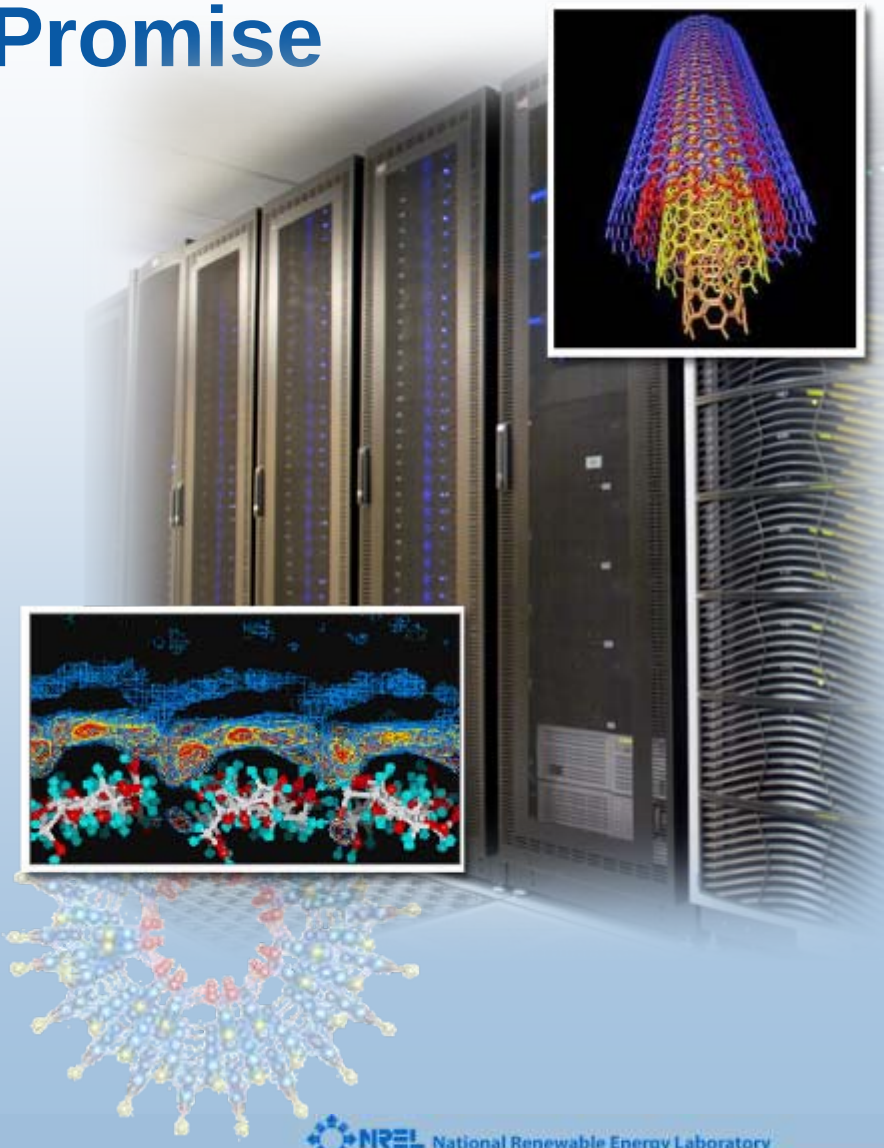
Technology Driven

Translational S&T

- Process consolidation
- Biological hydrogen
- Photoelectrochemical hydrogen
- Biomass pretreatments
- Mapping the plant cell wall
- Plant delignification
- Chemistry of biomass toxins

Harnessing Innovation in Renewable Energy Science and Technology: The Future Promise

- Supercomputers
- Genomics
- Nanoscience
- Cellulosic and biofuels applications
- Hydrogen



Nano/Bio/Info


The U.S. Department of Energy's
National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado