Renewable Energy R&D – The Laboratory's Role

Chinese Academy of Sciences

Academy, Research Institution & National Innovation System Symposium

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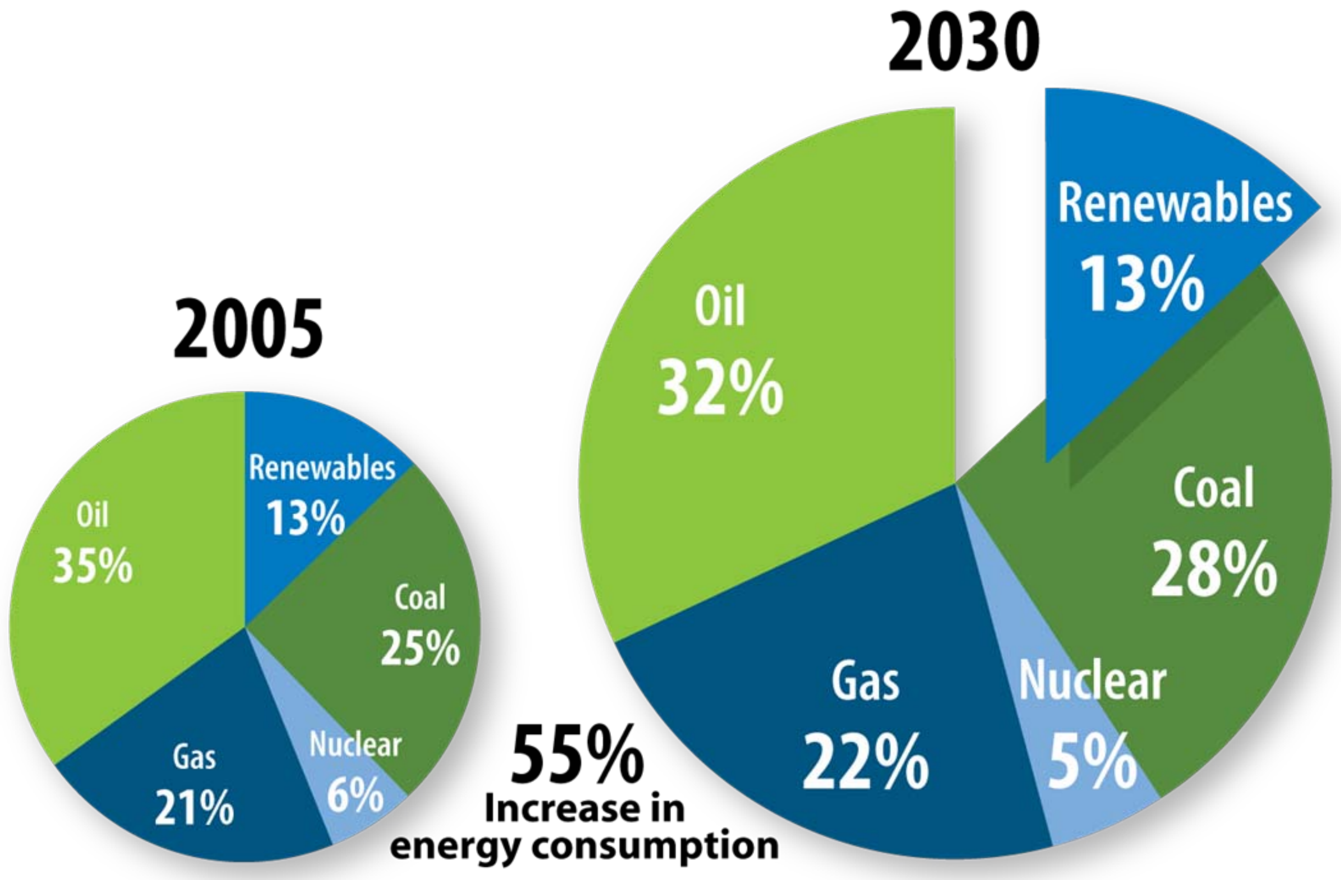
Laboratory Director

November 12, 2008

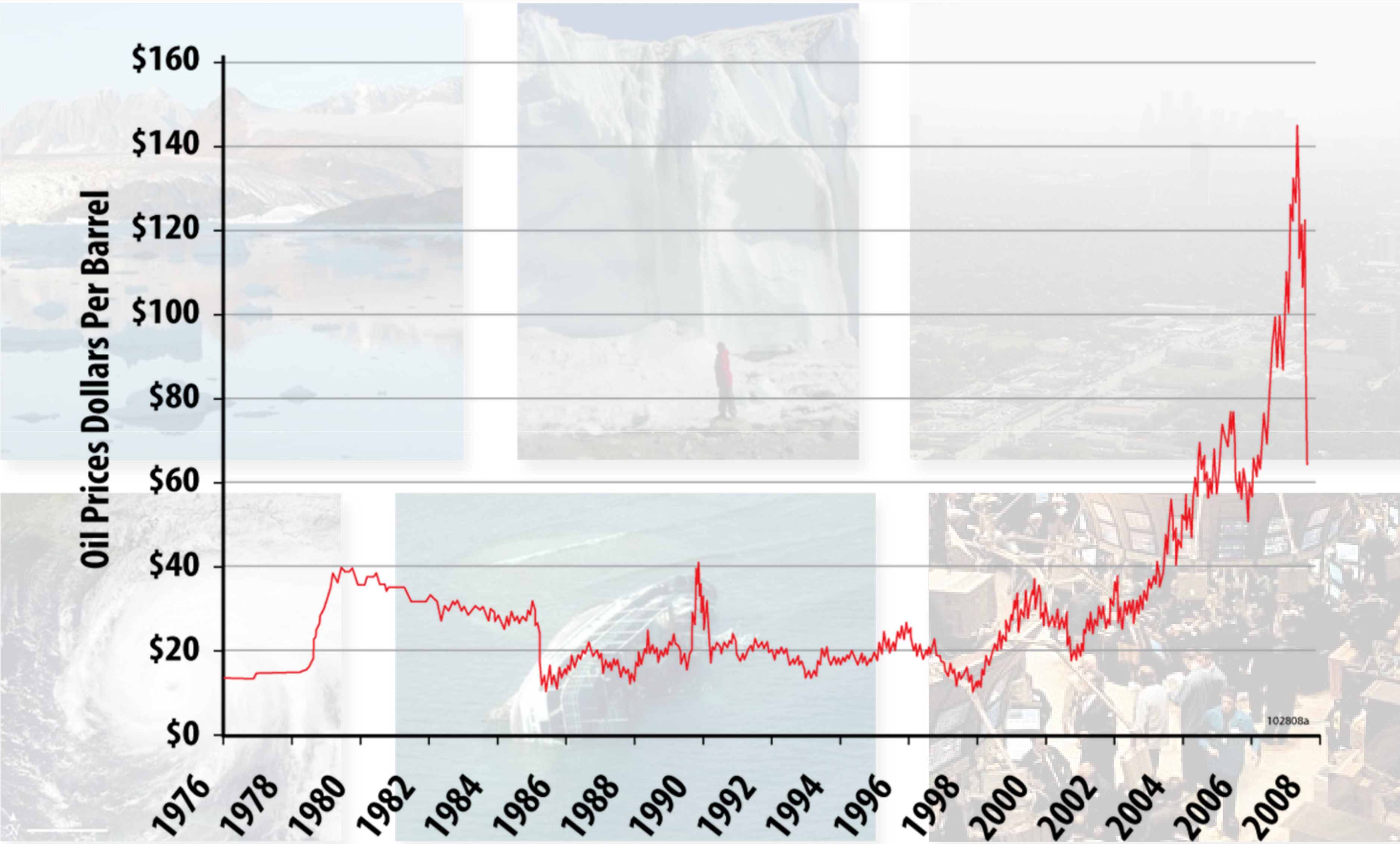
World Energy Supply and the Role of Renewable Energy



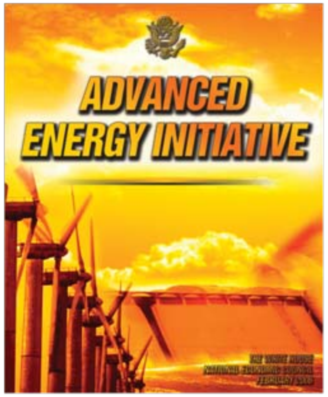
Source: IEA/OECD, World Energy Outlook 2007

Table: Reference Scenario: World, p. 592

A Confluence of Major Global Challenges

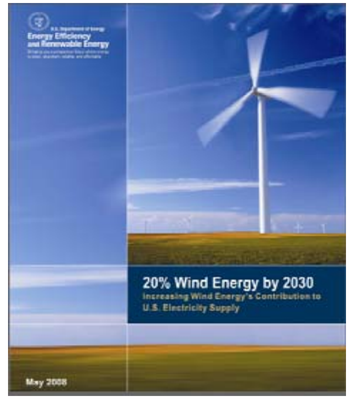


Setting the Bar Higher – Gigawatt-Scale Renewables



Solar Vision

10% U.S. electricity by 2025



Wind Vision

20% U.S. electricity by 2030

Energy Independence & Security Act 2007

36 billion gallons of renewable fuels by 2022

Requires investment in new infrastructure:

- Overall in U.S. = $2 trillion
- Worldwide = $22 trillion
  - Biofuels
  - Wind
  - Solar

$\left.\begin{array}{l}\text{Biofuels}\\ \text{Wind}\\ \text{Solar}\end{array}\right\}$ \$2 trillion (est.)

Getting to "Speed and Scale" – Key Challenges

Implementing Renewable Gigawatts at Scale

NREL 140-1

BARRIERS

- Cost of renewable electricity
- Performance and reliability
- Infrastructure robustness and capacity
- Dispatchability of renewables

Displacement of Petroleum-Based Fuels

NREL 139-1

BARRIERS

- Cellulosic ethanol cost
- Life cycle sustainability of biofuels
- Fuels infrastructure, including Codes/Standards
- Demand and utilization, including intermediate blends

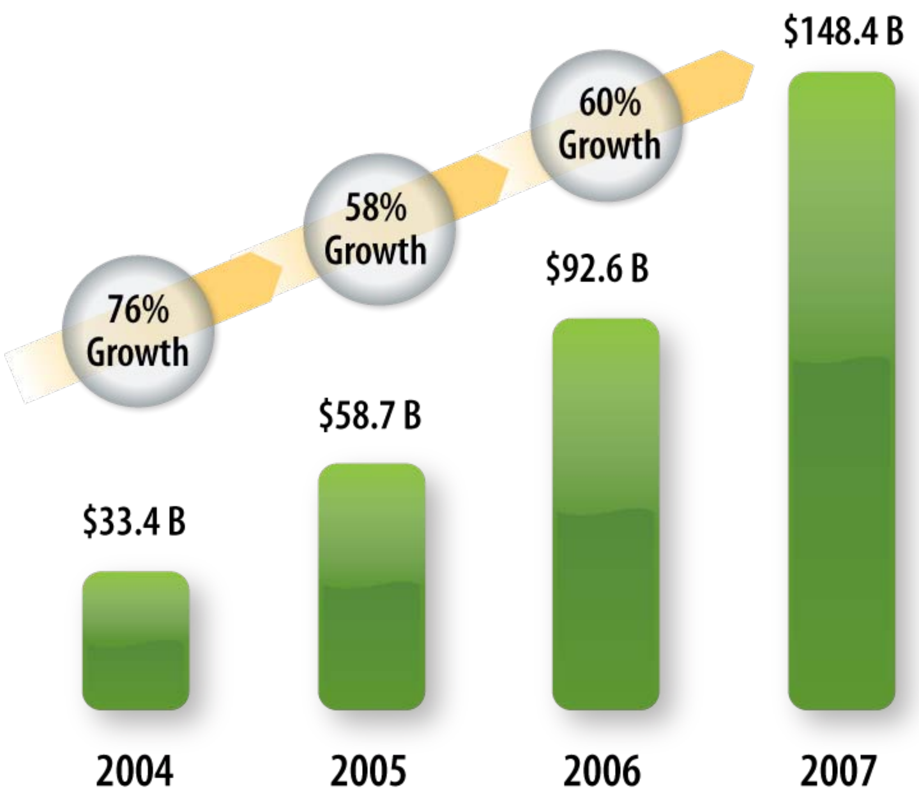
Reducing Energy Demand of Buildings, Vehicles, and Industry

NREL 196-1

BARRIERS

- Coordinated implementation of model building codes
- Market does not value efficiency
- Cost of energy efficient technologies
- Performance and reliability of new technologies

Global New Investment in Clean Energy



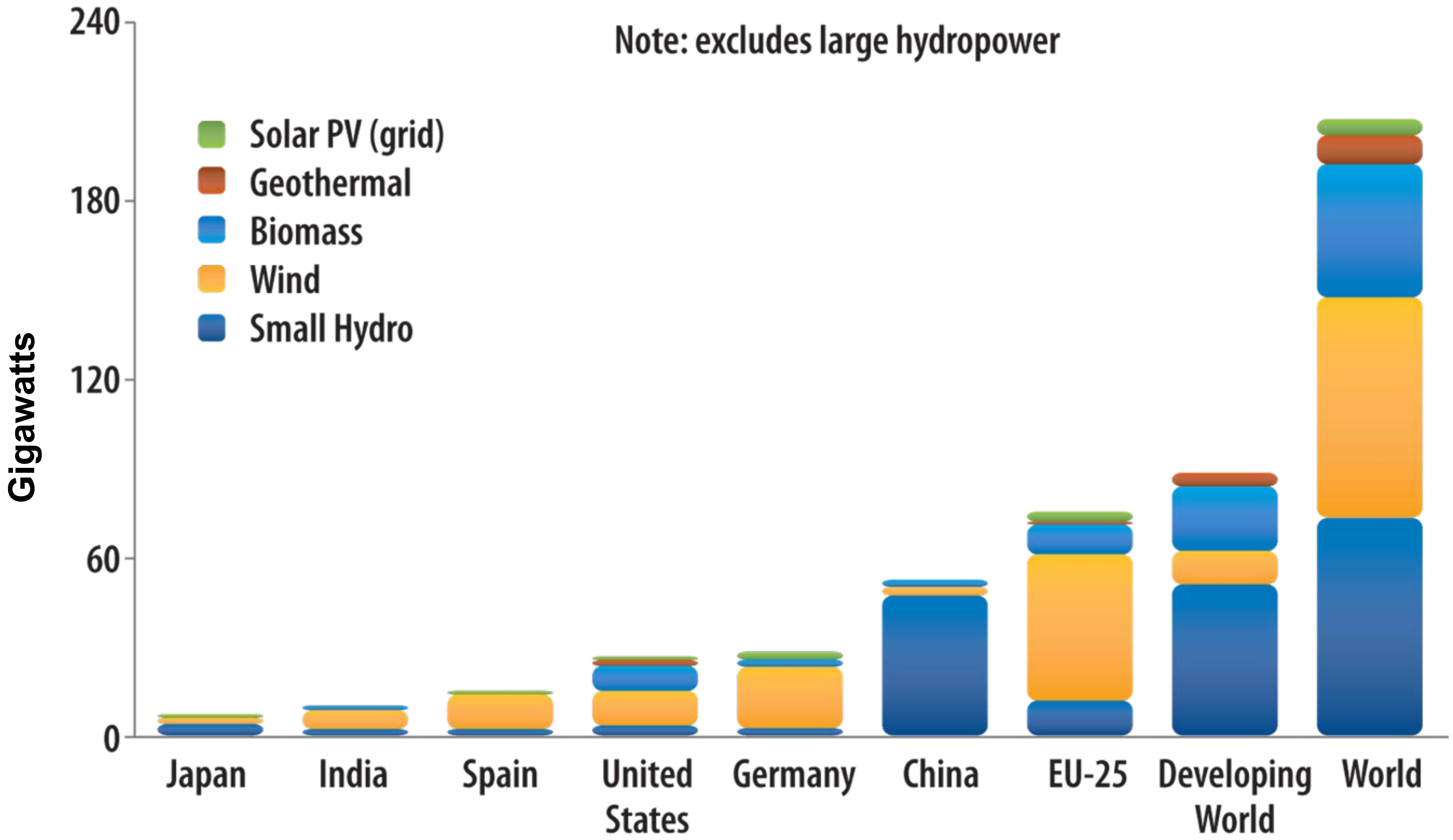
- **1%** of global fixed asset investment
- **10.5%** of global energy industry infrastructure investment
- **2.5 times** the size of commercial aircraft investment sector

Adjusted for reinvestment. Geared re-investment assumes a 1 year lag between VC/PE/Public Markets funds raised and re-investment in projects.

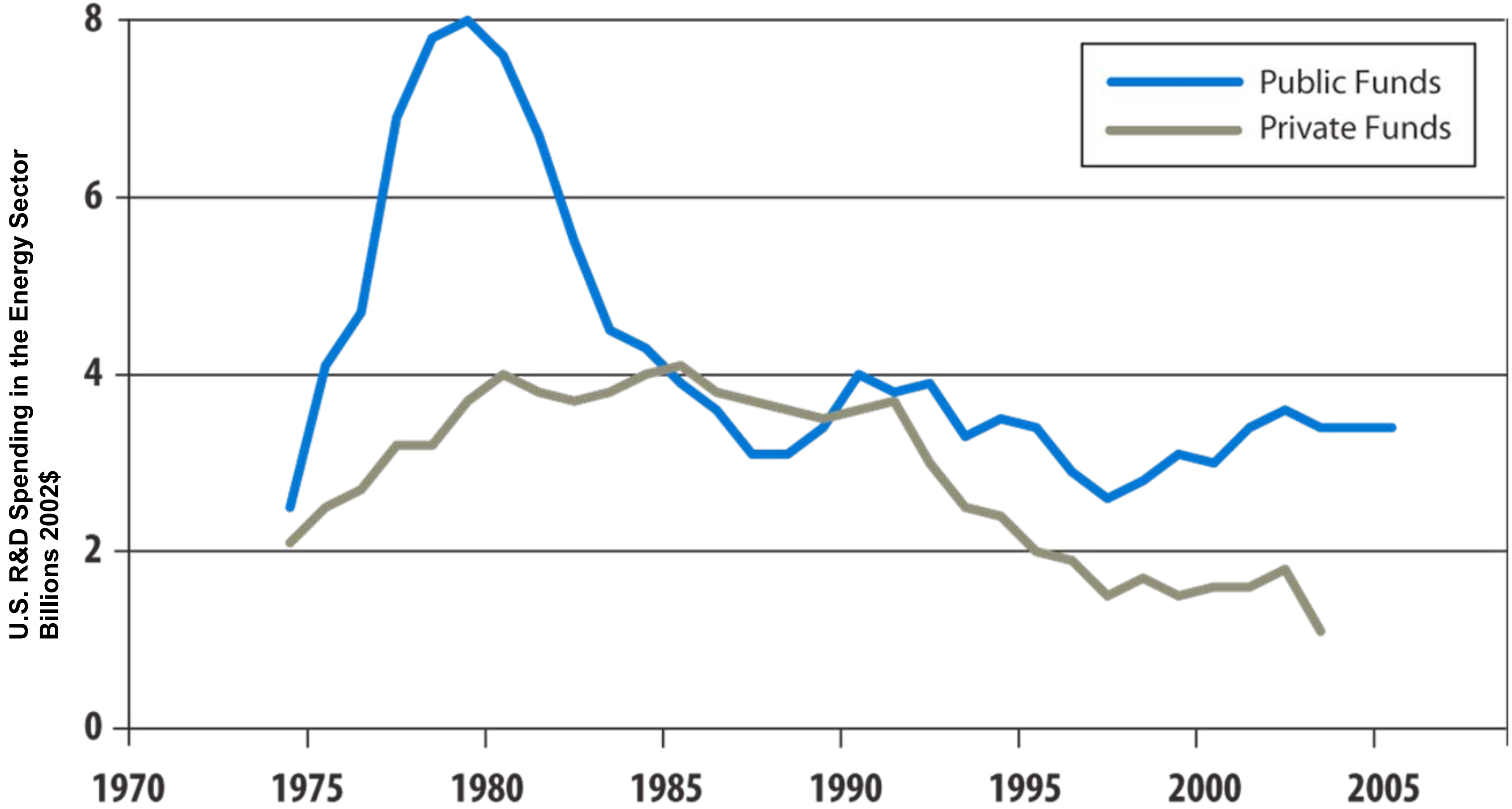
Source: New Energy Finance, IMF WEO Database, IEA WEO 2007, Boeing 2006 Annual Report

Global Renewable Electricity Capacity

Harvesting Past Investments, First Generation Technologies



Declining Energy R&D Investments…

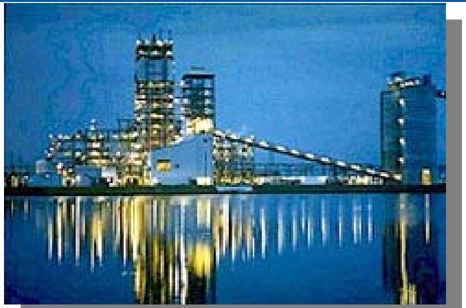


Source: Daniel Kammen, Gregory Nemet *Reversing the Incredible, Shrinking Energy R&D Budget* http://rael.berkeley.edu/files/2005/Kammen-Nemet-ShrinkingRD-2005.pdf
Table 10.3, Edition 25, *Transportation Energy Data Book* http://cta.ornl.gov/data/chapter10.shtml

A Quarter Century of U.S. Department of Energy R&D Contributions

Created a commercial nuclear power option

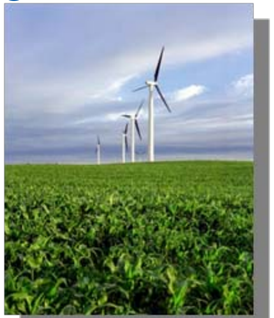
Reduced emissions from coal-fired power plants



Enhanced oil recovery from wells

Enabled hybrid vehicles to enter the market

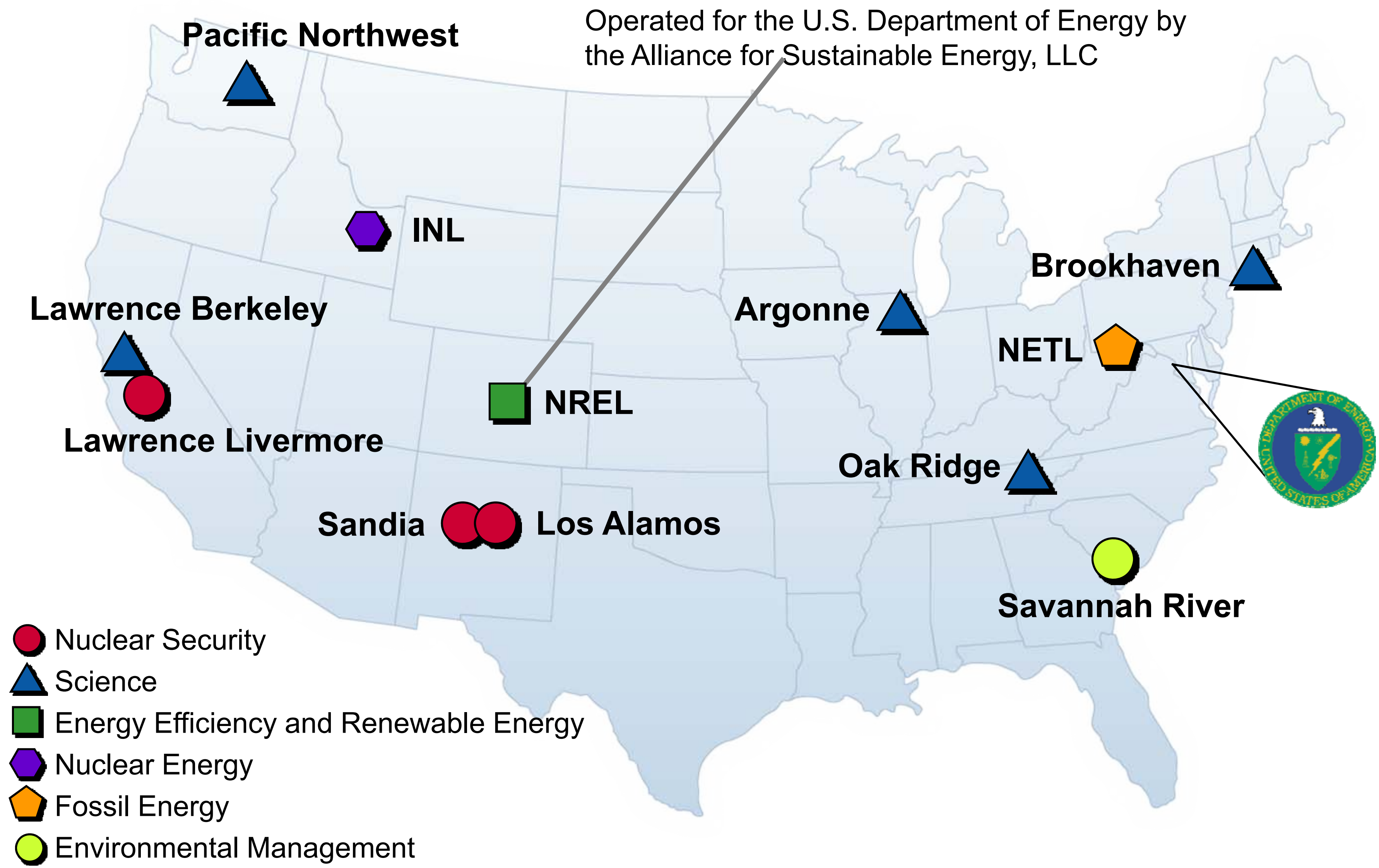
Brought utility-scale wind into our generation mix



Improved energy productivity

Technology innovations have had a significant impact

Major U.S. National Laboratories



National Renewable Energy Laboratory

- Only national laboratory dedicated to renewable energy and energy efficiency R&D, demonstration and deployment
- Collaboration with industry and university partners is a hallmark
- Ability to link scientific discovery and product development to accelerate commercialization

Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind and water
- Solar
- Biomass
- Geothermal

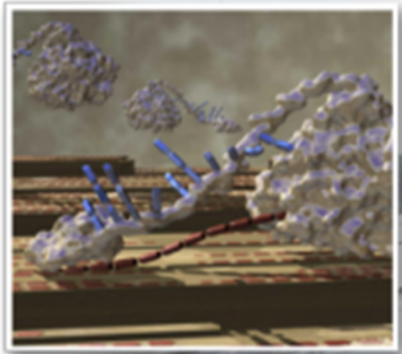
Energy Delivery and Storage

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

Foundational Science and Advanced Analytics

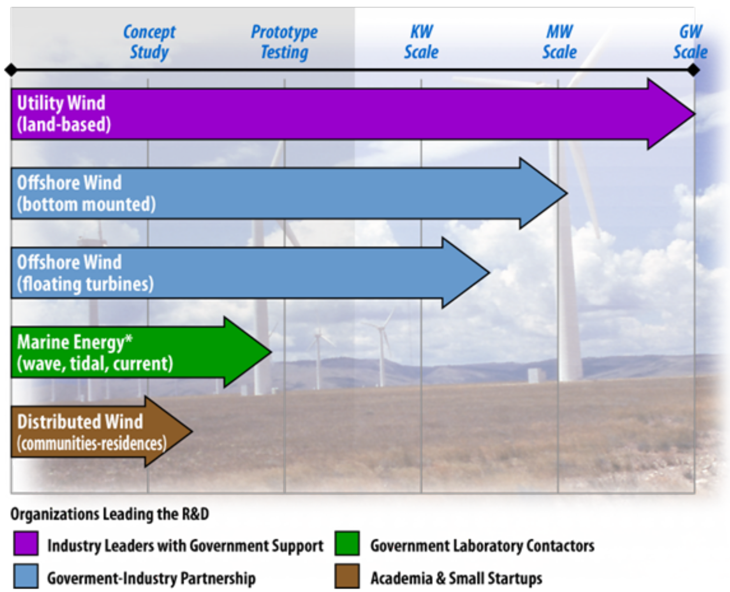
Technology Innovation Challenges Remain
The Next Generation

- Wind
  - Improve energy capture by 30%
  - Decrease costs by 25%
- Biofuels
  - New feedstocks
  - Integrated biorefineries
- Solar
  - Improved performance through, new materials, lower cost manufacturing processes, concentration
  - Nanostructures
- Zero energy buildings
  - Building systems integration
  - Computerized building energy optimization tools
- Advanced vehicles
  - Plug-in hybrids/electrics
  - Alternative fuels

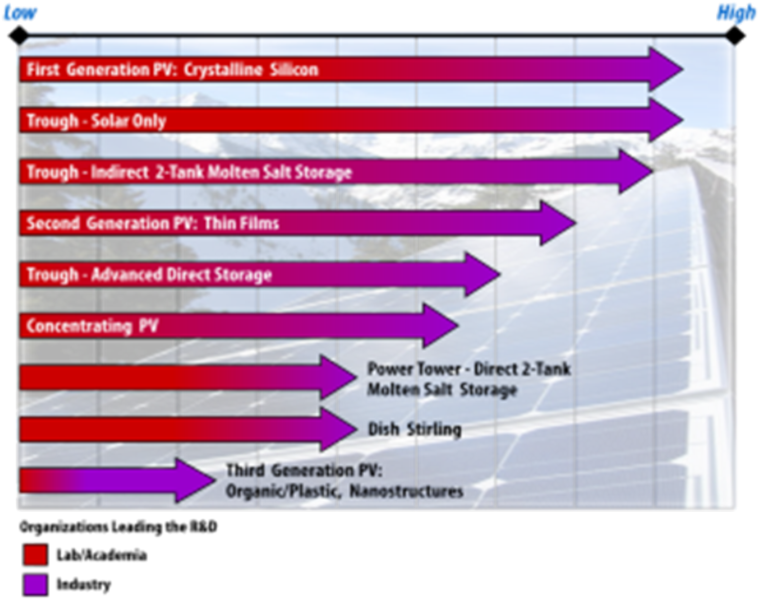


Technology Options Are Evolving

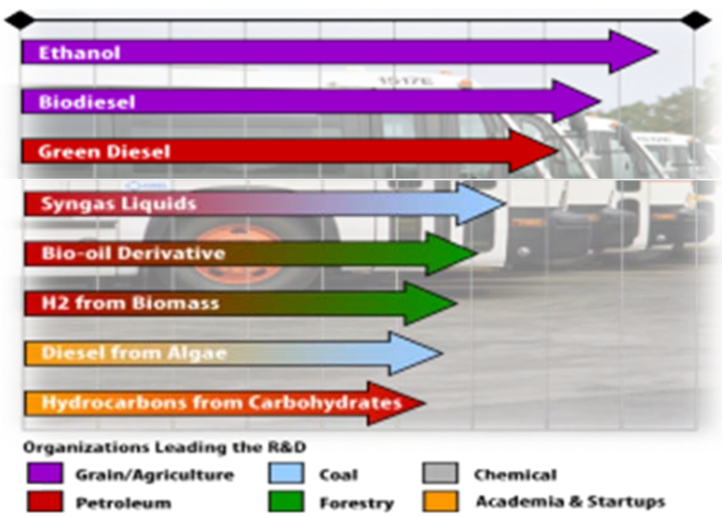
Wind & Water



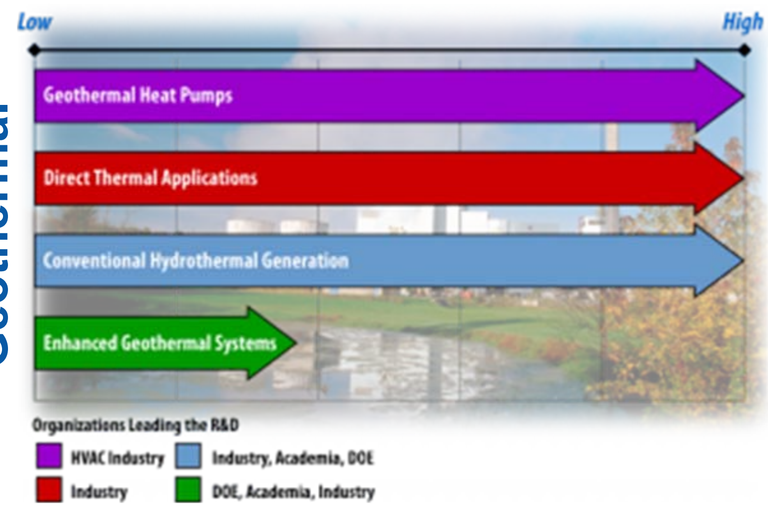
Solar



Biofuels

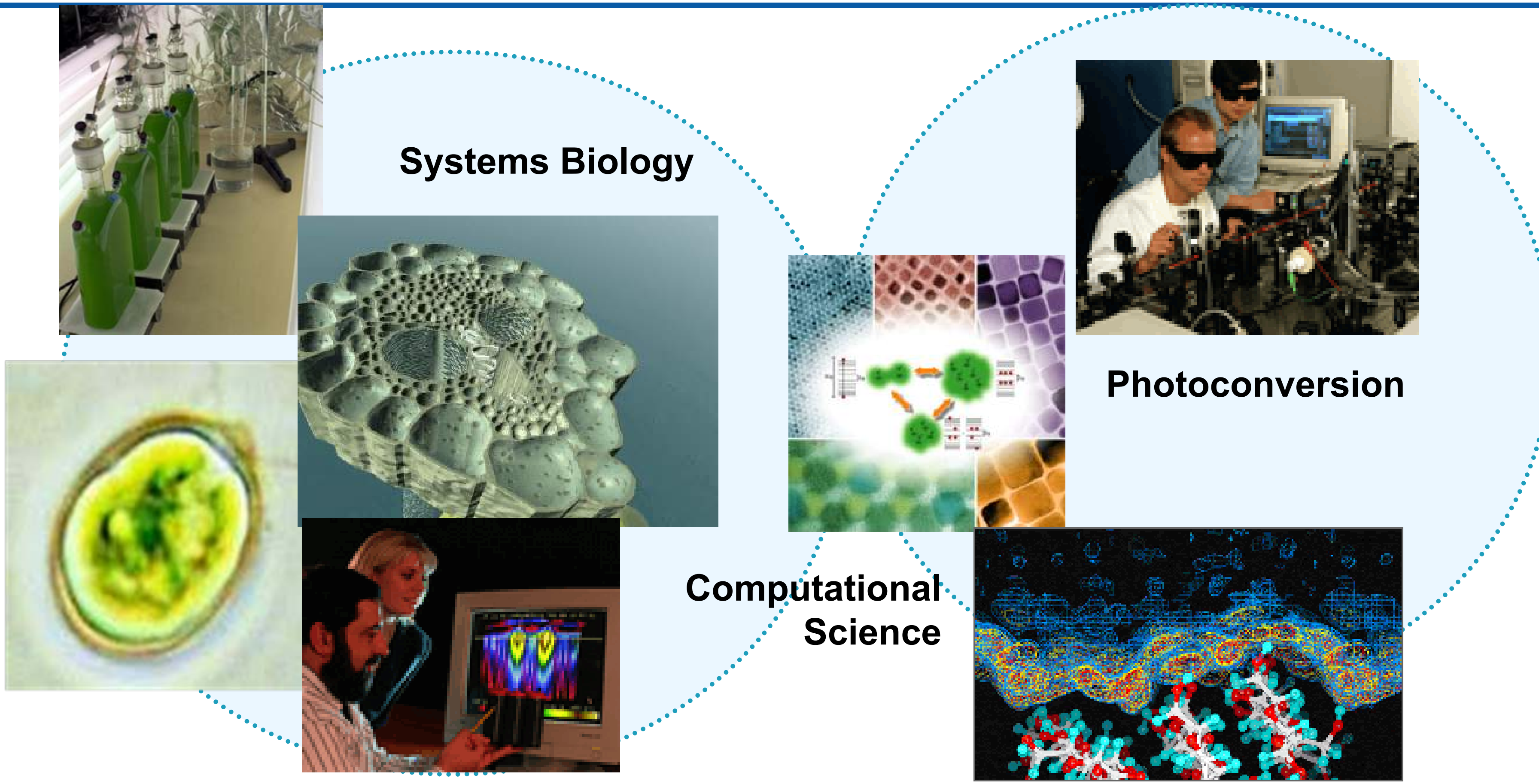


Geothermal



Translational Science

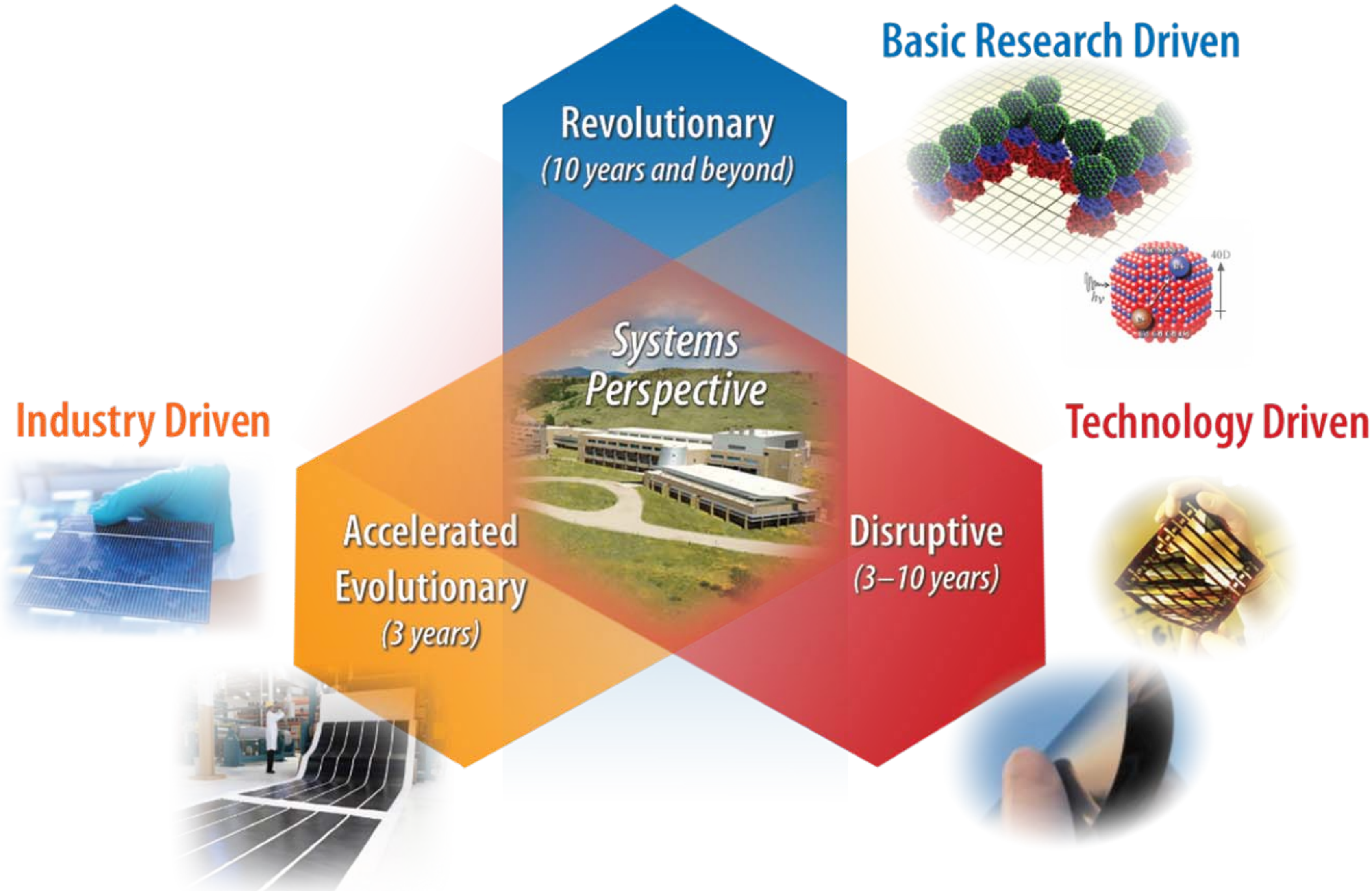
Key to Speed and Scale



Connecting new discoveries, via applied research, to the marketplace

Discovery Research | Use-inspired Basic Research | Purpose-Driven Exploratory Research | Applied Research & Development | Technology Maturation & Deployment

Achieving the Potential
Requires A Balanced Portfolio



Science at the Leading Edge of Energy Efficiency Research

Significant improvements are anticipated through:

- SmartGrids
- Super-strong lightweight materials
- Smart roofs
- Solid state lighting
- Superconducting electric T&D

New discoveries will have broad impact on daily life

Solar Energy

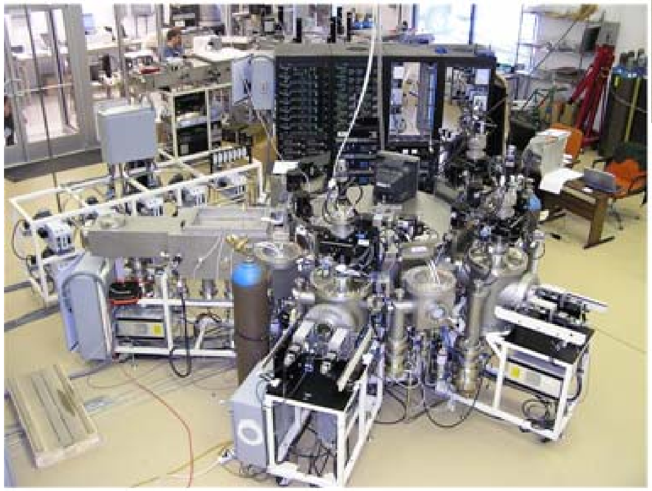
Photovoltaics Research

R&D Focused on Technology Roadmaps

- Wafer Silicon
- Film Silicon
- CIGS
- CdTe
- Concentrating PV
- Organic PV
- Sensitized Cells

Next-Generation

- Multiple-Exciton-Generation PV
- Intermediate Band PV
- Nano-architecture PV



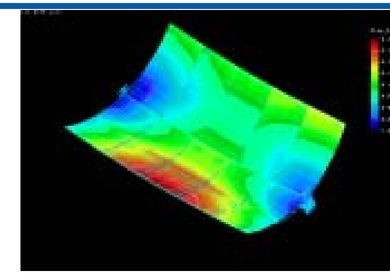
Process Development Integration Laboratory

Focus on Key Barriers
Technology Cost and Performance
Reliability
Grid integration
Manufacturing

Concentrating Solar Power Research

Parabolic Trough R&D

Optimize receiver and concentrator designs, develop next-generation collector design, and create advanced evaluation capabilities.



Thermal Storage R&D

Develop advanced heat transfer fluids for more efficient operation at high temperatures, and test innovative designs for low-cost storage options.

Advanced CSP Concepts

Next generation CSP systems and components

Technology Acceptance

Resource assessment, CSP penetration analysis, grid integration, land use

Focus on Key Barriers
Technology Cost and Performance
Technology Acceptance

Wind Energy

NREL Wind Energy Research

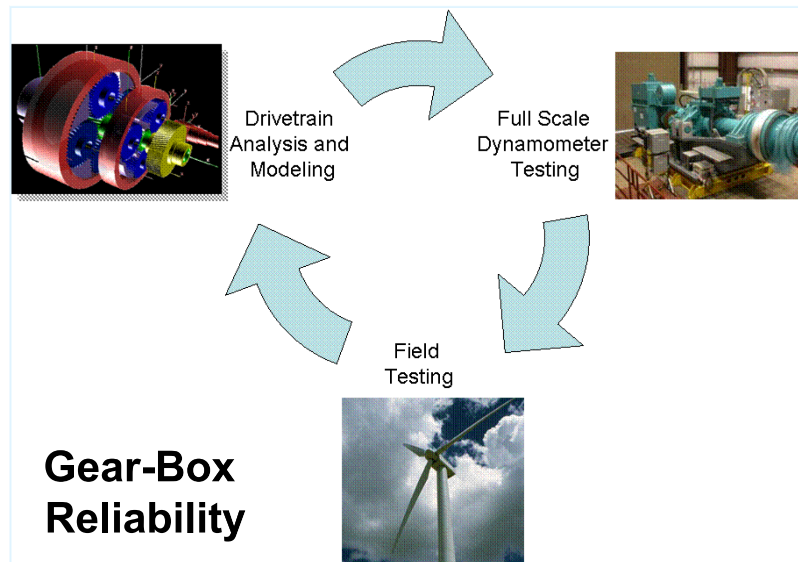
Capabilities

- Design Review and Analysis
- Modeling and Analysis
- Systems and Controls
- Utility Integration
- Wind Resource Assessment

Blade Test

Dynamometer

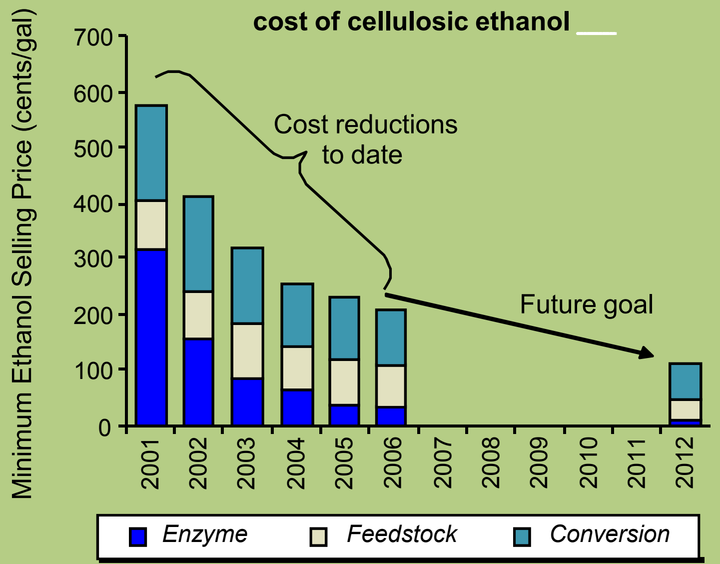
Focus on Key Barriers
Technology Cost, Performance, and Reliability
Transmission Capacity
Grid integration
Reliable Operation at High Penetration



Bioenergy

Biofuels Cost and Environmental Potential

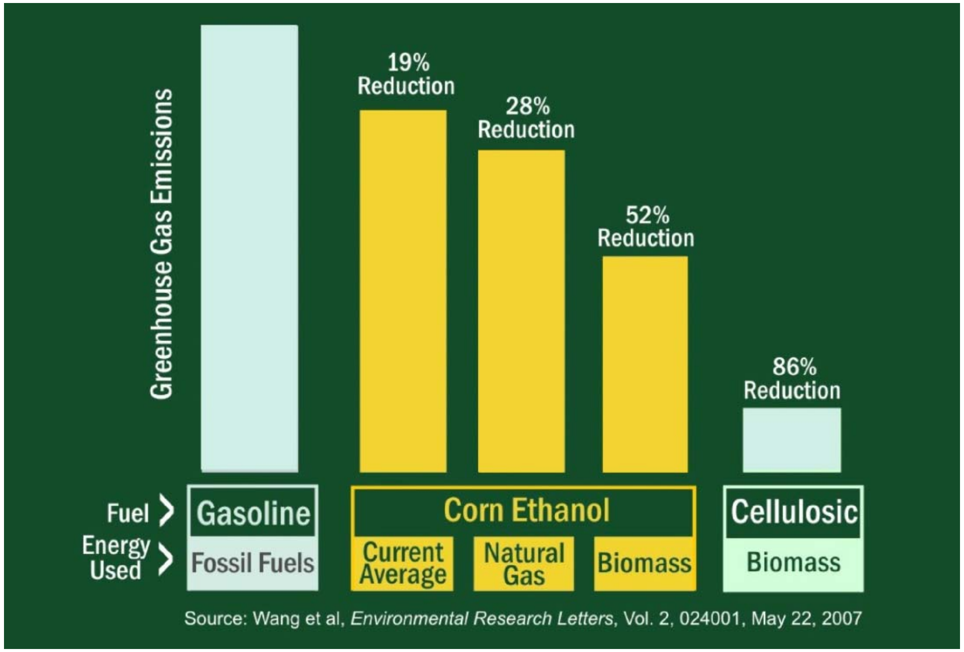
Historical and Projected Cellulosic Ethanol Costs



Source: Research Advances: NREL Leads the way: Cellulosic Ethanol. March, 2007. Figures are for biochemical conversion

Federal research has achieved major reductions in the cost of cellulosic ethanol

Lifecycle Greenhouse Gas Emissions Deductions Compared to Gasoline



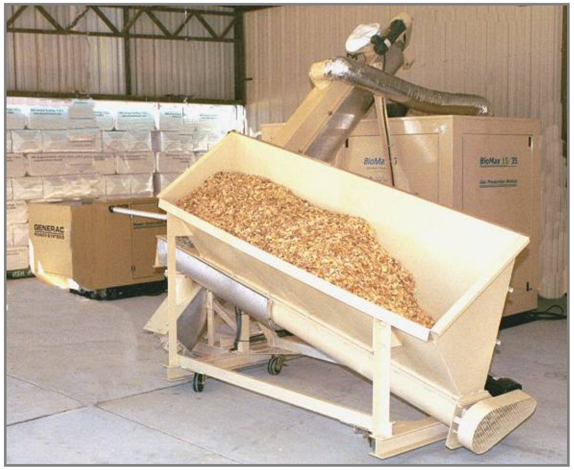
Small Modular Bioenergy Systems

Status

- First generation systems designed for village power (25-100kWe and motive power) to small towns (5MWe combined heat and power)

Future

- Small systems to produce electricity, motive power, heat, and fuel intermediates
- Both gasification and pyrolysis are being investigated



Village Power
Philippines,
U.S. Indian Reservations,
schools

Geothermal

Geothermal

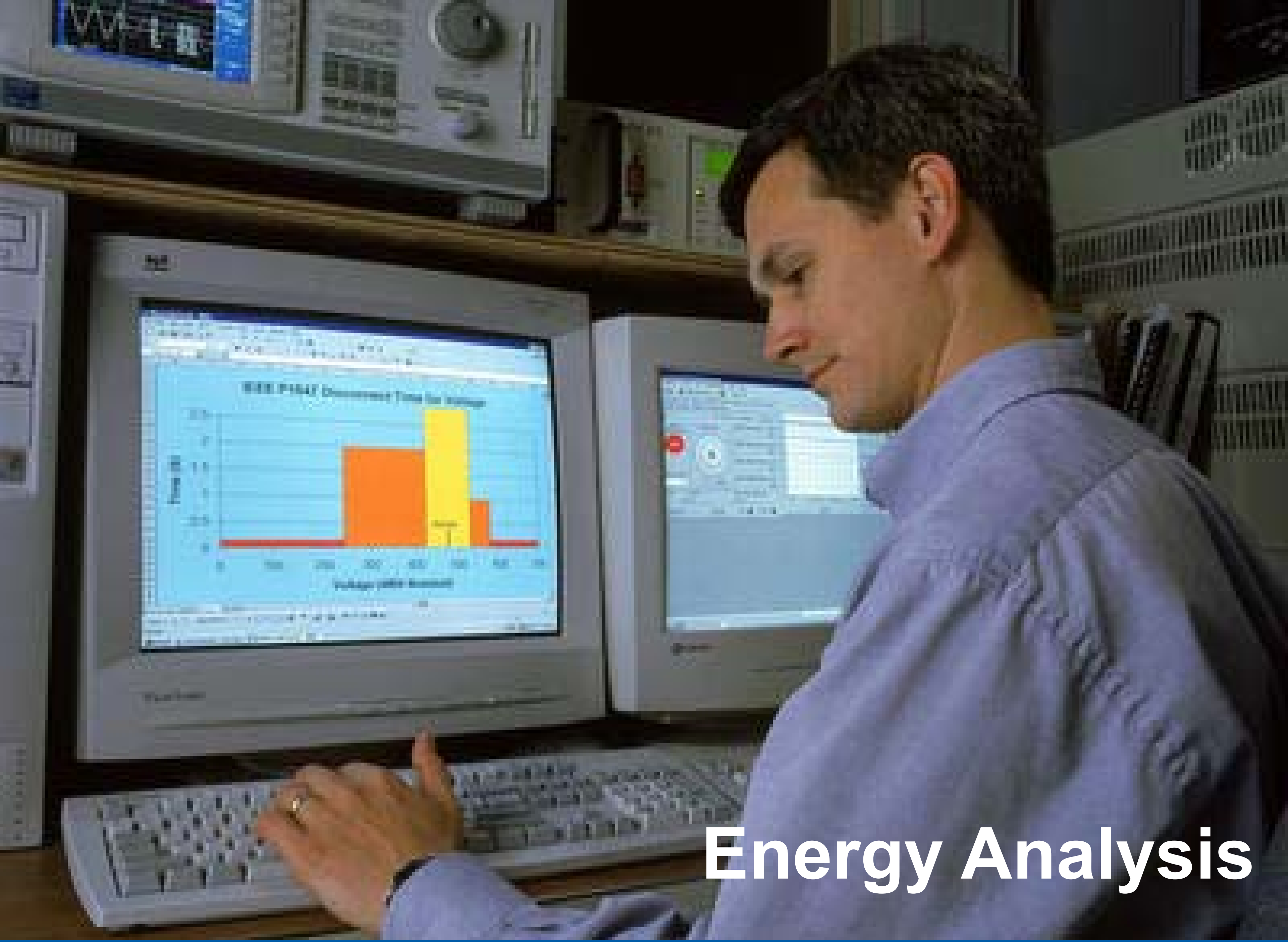
Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

April 10, 2008

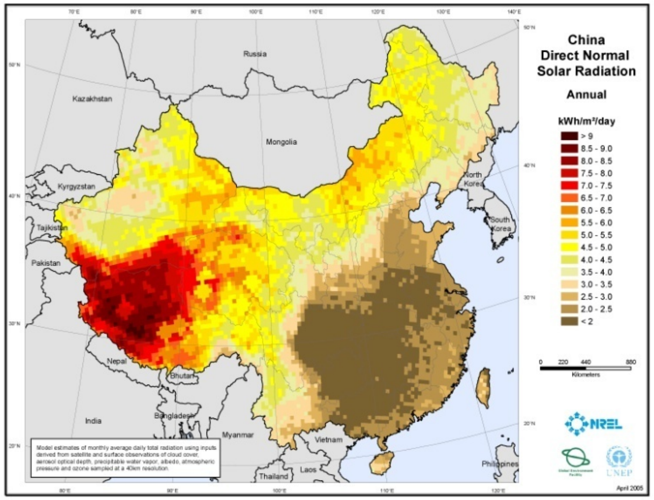


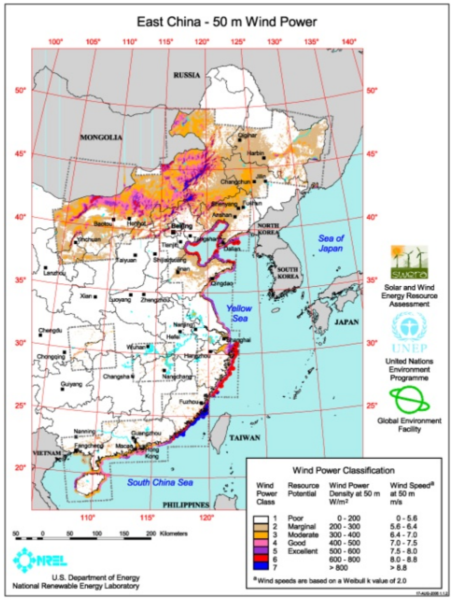
Energy Analysis

Resource, Technology, and Market Information

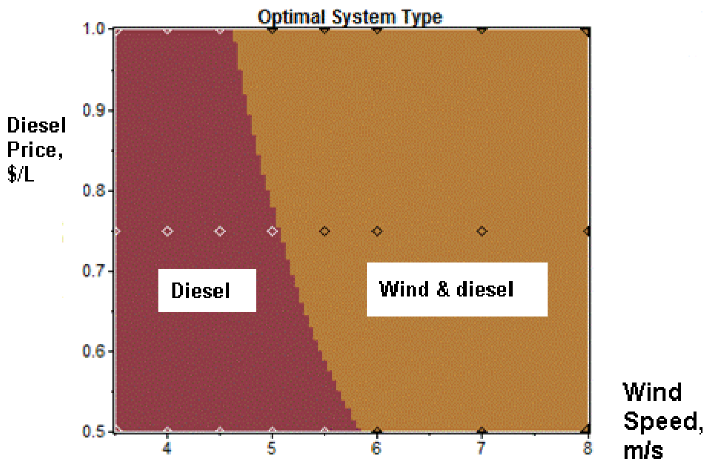
High-quality and timely data informs RE project decisions and policy development:

- Provide accurate resource assessment and mapping
- Collaborate on technology R&D
- Contribute timely and definitive analyses on technology, policy, and market issues that govern commercialization

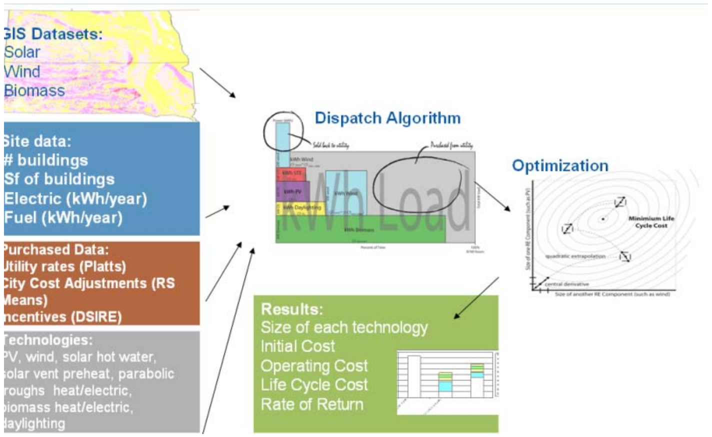




Examples of Analysis Tools and Models

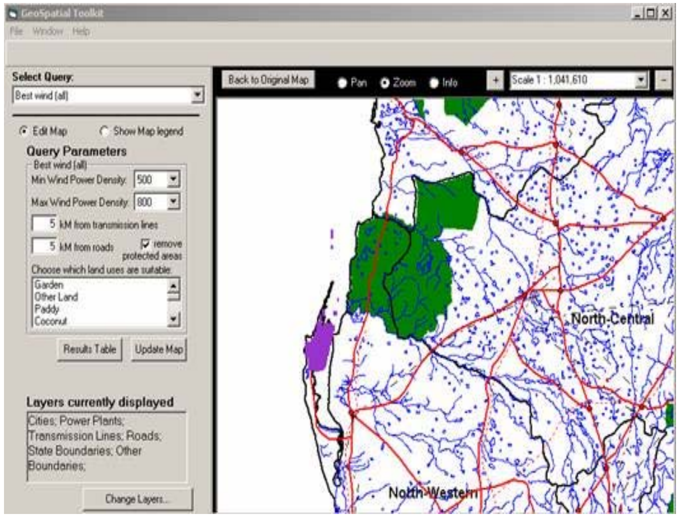


HOMER®
NREL's Hybrid Optimization Model



Renewable Energy Optimization (REO)

GeoSpatial Toolkit



Making Transformational Change

Requires an integrated approach

Unleashing market-driven innovation

FILL technology pipeline

INFORM decision makers about choices

ENSURE appropriate market price signals

The Laboratory's Role:

- Provision of data, tools, analysis, and information to help facilitate growth
- Evaluation of market opportunities and information exchange with U.S. technology suppliers
- Building R&D capacity in-country

Economies Benefit from Renewable Energy and Energy Efficiency R&D

National Renewable Energy Laboratory

Innovation for Our Energy Future

Visit us online at www.nrel.gov

Operated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by Midwest Research Institute • Battelle

Wind

Today's Status in U.S.

- 16,850 MW installed at end of 2007
- 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

* With no Production Tax Credit
Updated March 12, 2008
Source: U.S. Department of Energy, American Wind Energy Association

NREL Research Thrusts

- Improved performance and reliability
- Advanced rotor development
- Utility grid integration

Source: Megavind Report *Denmark’s future as leading centre of competence* within the field of wind power

Solar – Photovoltaics and CSP

Status in U.S.

PV
- 824 MW installed capacity
- Cost 18-23¢/kWh

CSP
- 419 MW installed capacity
- 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

Source: U.S. Department of Energy, IEA

Updated January 28, 2008

NREL Research Thrusts

- **PV**
  - Higher performance cells/modules
  - New nanomaterials applications
  - Advanced manufacturing techniques

- **CSP**
  - Low cost high performance storage for baseload markets
  - Advanced absorbers, reflectors, and heat transfer fluids
  - Next generation solar concentrators

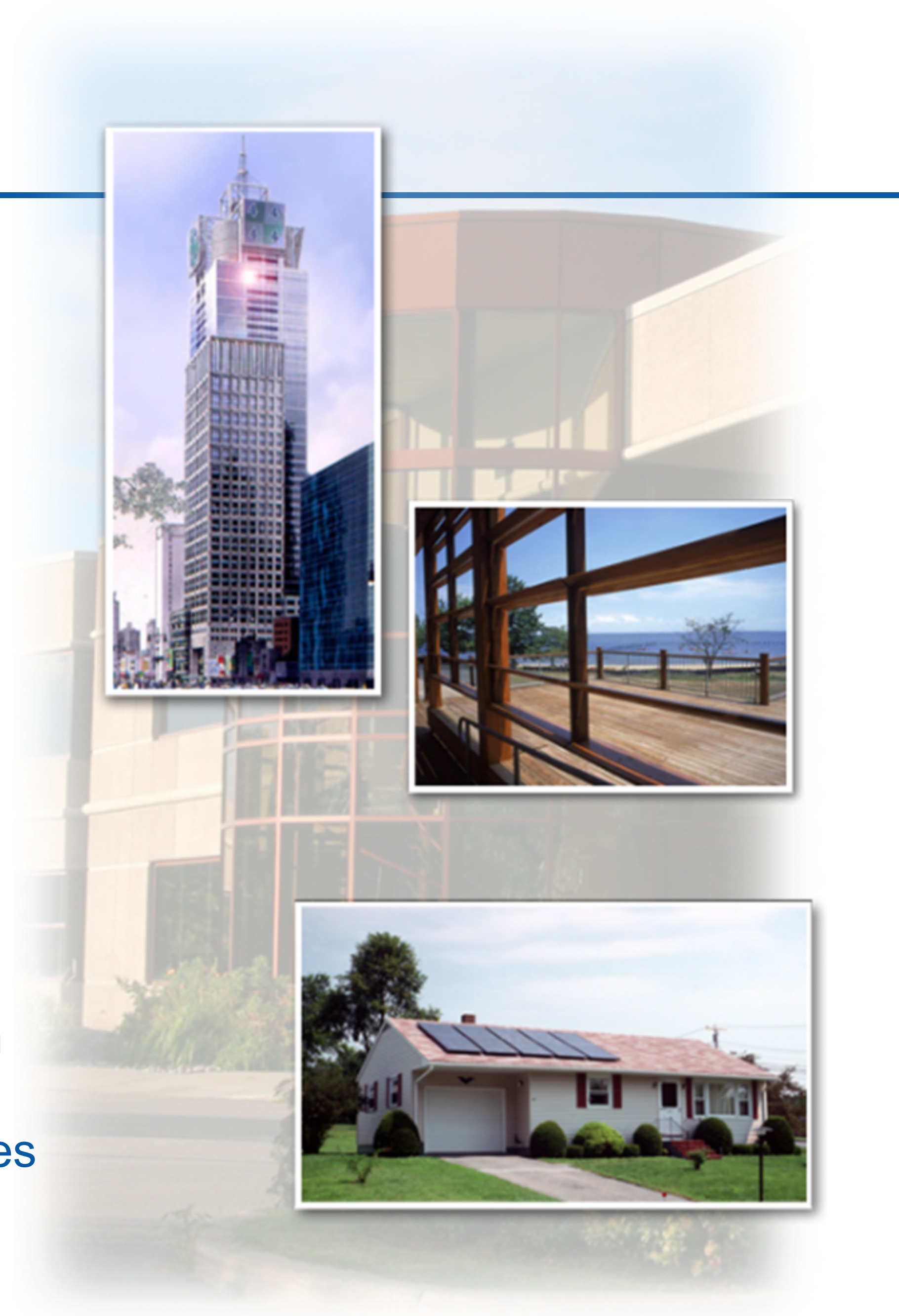
8.22-megawatt Alamosa, Colo., PV solar plant

Buildings

Status U.S. Buildings:
- 39% of primary energy
- 71% of electricity
- 38% of carbon emissions

DOE Goal:
- Cost effective, marketable zero energy buildings by 2025
- Value of energy savings exceeds cost of energy features on a cash flow basis

NREL Research Thrusts
- Whole building systems integration of efficiency and renewable features
- Computerized building energy optimization tools
- Advanced HVAC and envelope technologies
- Building integrated PV



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Plug-In Hybrid Electric Vehicles (PHEV)

Status:
- PHEV-only conversion vehicles available
- OEMS building prototypes
- NREL PHEV Test Bed

NREL Research Thrusts
- Energy storage
- Advanced power electronics
- Vehicle ancillary loads reduction
- Vehicle thermal management
- Utility interconnection
- Vehicle-to-grid

Key Challenges
- Energy storage – life and cost
- Utility impacts
- Vehicle cost
- Recharging locations
- Tailpipe emissions/cold starts
- Cabin heating/cooling
- ~33% put cars in garage

Geothermal

Today's Status in U.S.

- 2,800 MWe installed, 500 MWe new contracts, 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

DOE Cost Goals:

- <5¢/kWh, for typical hydrothermal sites
- 5¢/kWh, for enhanced geothermal systems with mature technology

Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

Biopower

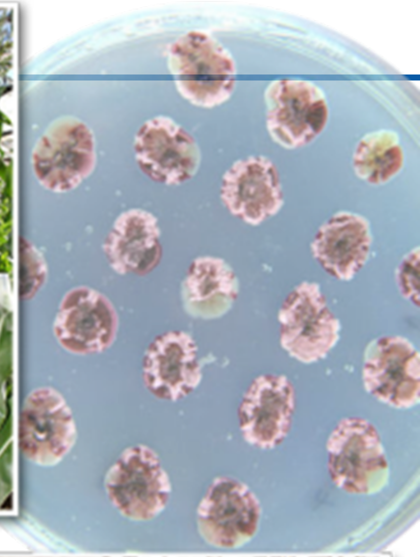
Biopower status in U.S.

- 2007 capacity – 10.5 GWe
  - 5 GW Pulp and Paper
  - 2 GW Dedicated Biomass
  - 3 GW MSW and Landfill Gas
  - 0.5 GW Cofiring
- 2004 Generation – 68.5 TWh
- Cost – 8-10¢/kWh

Potential

- Cost – 4-6¢/kWh (integrated gasification combined cycle)
- 2030 – 160 TWh (net electricity exported to grid from integrated 60 billion gal/yr biorefinery industry)

Biofuels



Current Biofuels Status in U.S.

- Biodiesel – 165 companies; 1.85 billion gallons/yr capacity[1]
- Corn ethanol
    - 134 commercial plants[2]
    - 7.2 billion gal/yr. capacity[2]
    - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
    - Projected commercial cost ~$3.50/gge

Key DOE Goals

- 2012 goal: cellulosic ethanol $1.31/ETOH gallon or ~$1.96/gge
- 2022 goal: 36B gal Renewable Fuel; 21B gal "Advanced Renewable Fuel"– 2007 Energy Independence and Security Act
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

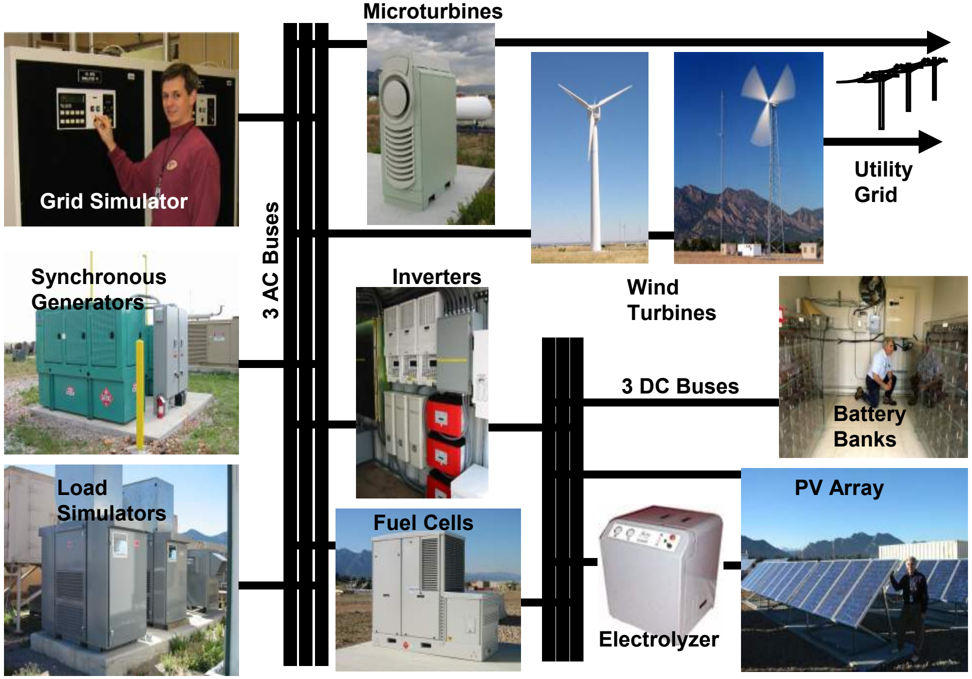
NREL Research Thrusts

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

Updated February 2008
Sources: 1- National Biodiesel Board
2 - Renewable Fuels Association, all other information based on DOE and USDA sources

Renewable Electricity at Scale

Focus on Key Barriers
Grid integration/Interconnection Technology
Reliable Operation at High Penetration



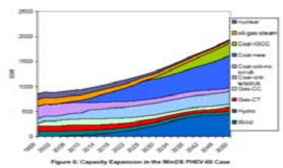
Strategic Energy Analysis

Technical and economic analyses to advance understanding of technology value in context of dynamic markets, policies, energy resources/loads, and infrastructure.

Increasing Attention to Carbon Mitigation Potential Analysis

Impact Analysis

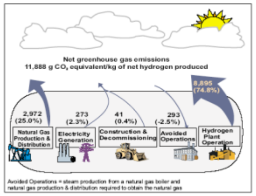
Analyze benefits and impacts of programs, portfolios, and policy options



System

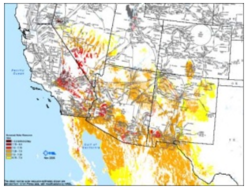
Analyze system performance and technology interfaces in the context of the overall system

Technology/Component



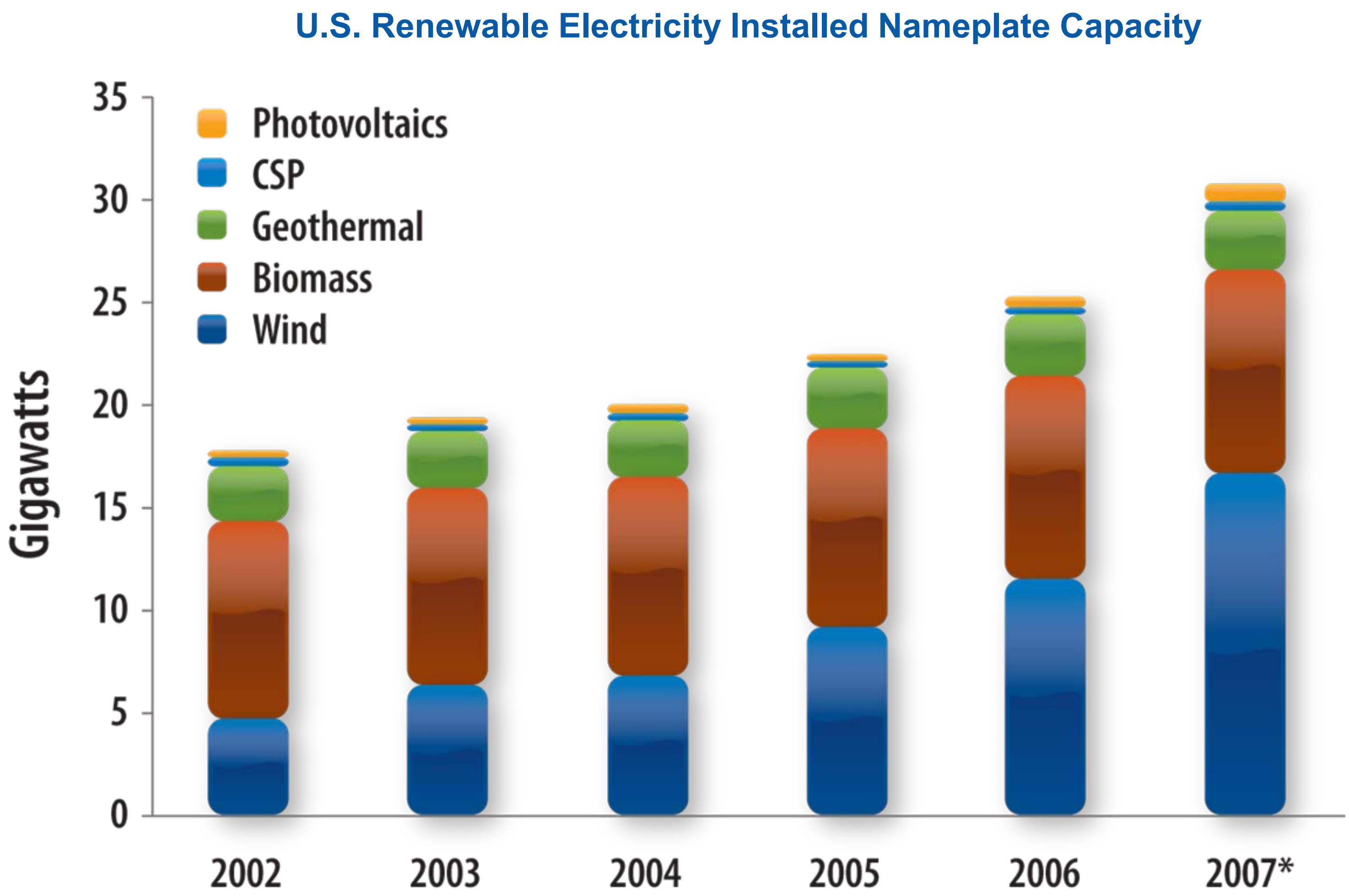
Analyze technology and component performance and cost

Resource



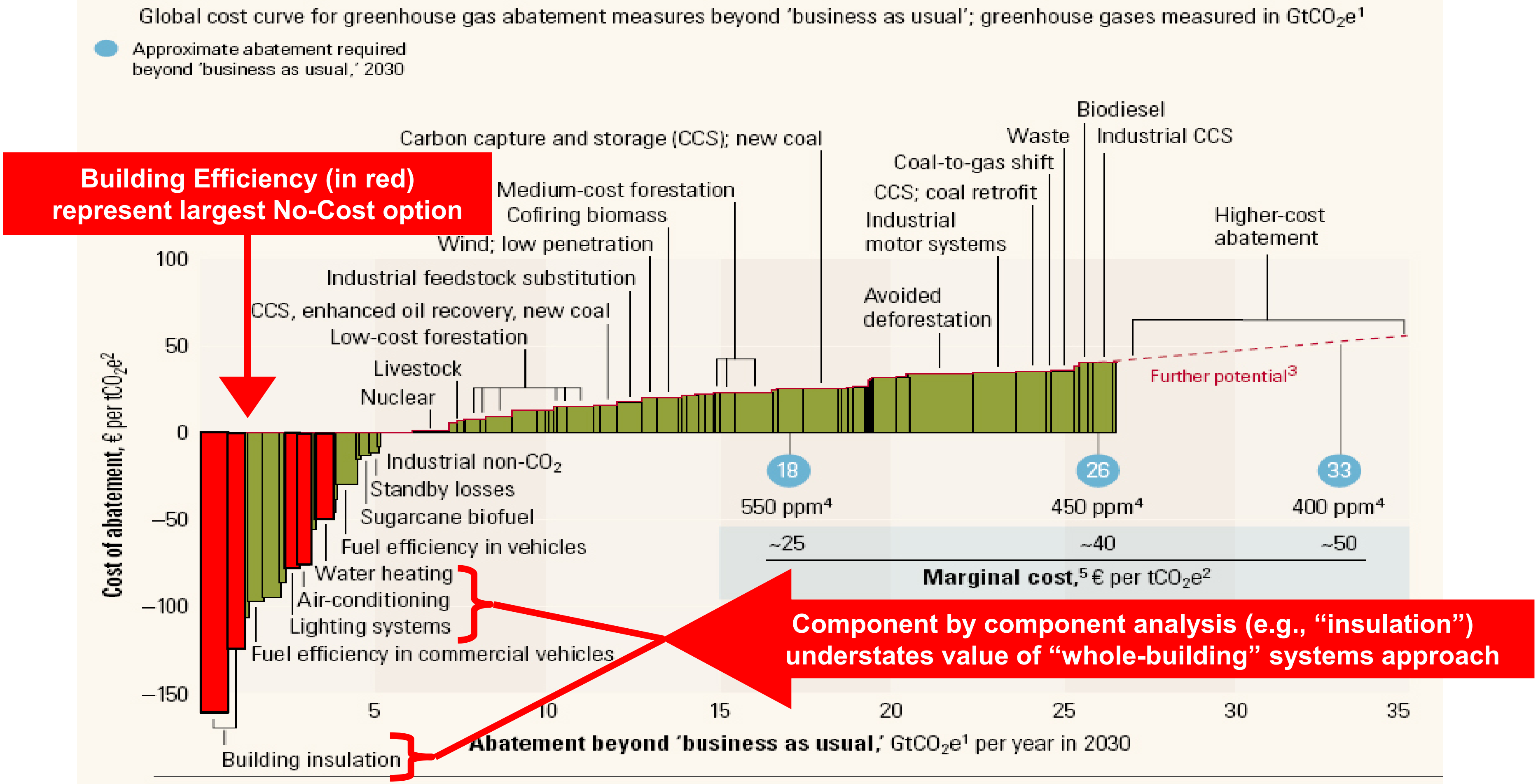
Assess resource availability and characteristics

Harvesting Past Investments
First Generation Technology



Sources: Chalk, AWEA, IEA, NREL, EIA, GEA

Energy Efficiency Offers Low or No-Cost Carbon Reduction Options



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

Source: McKinsey Global Institute, 2007