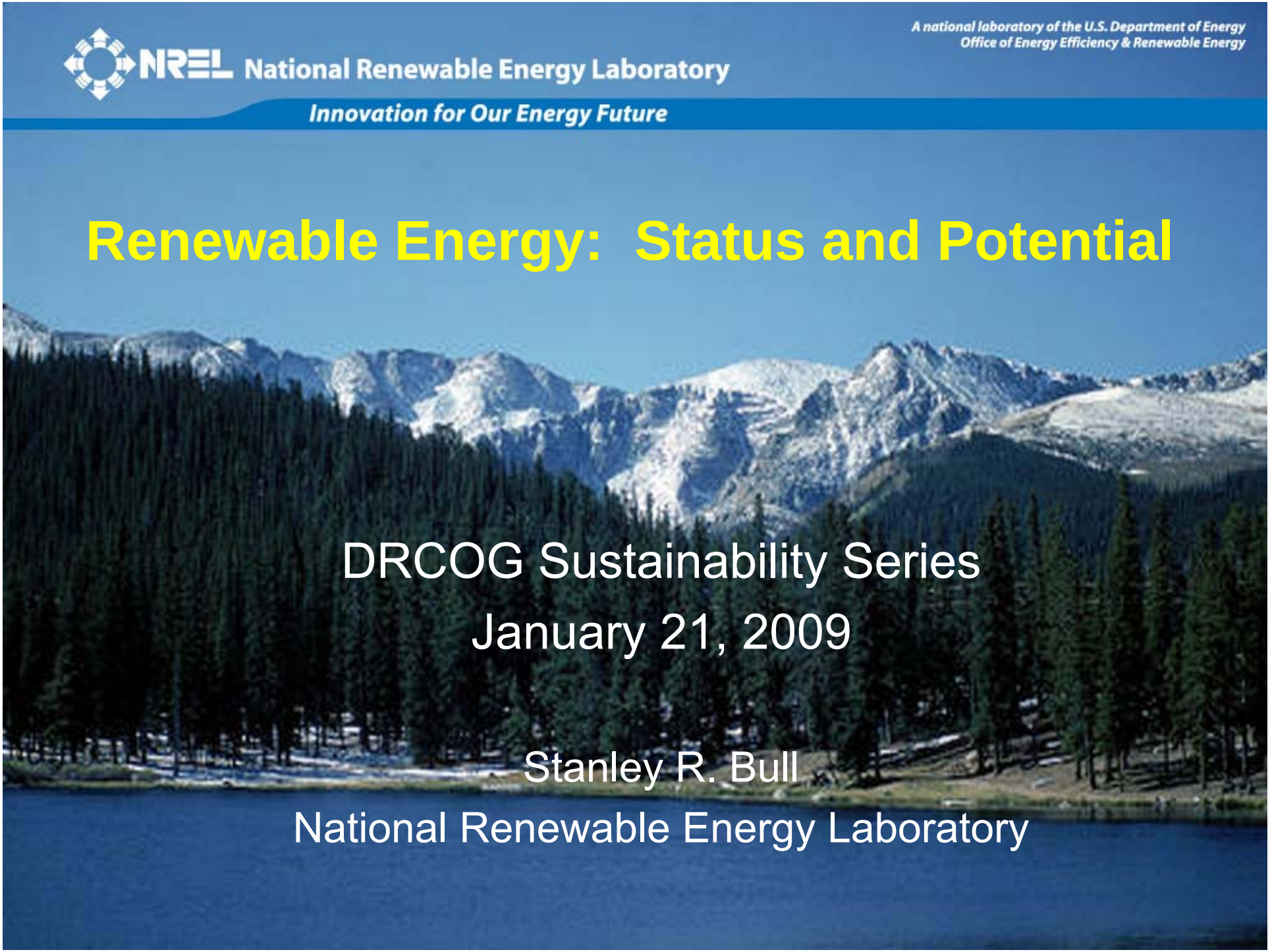


Renewable Energy: Status and Potential

DRCOG Sustainability Series

January 21, 2009

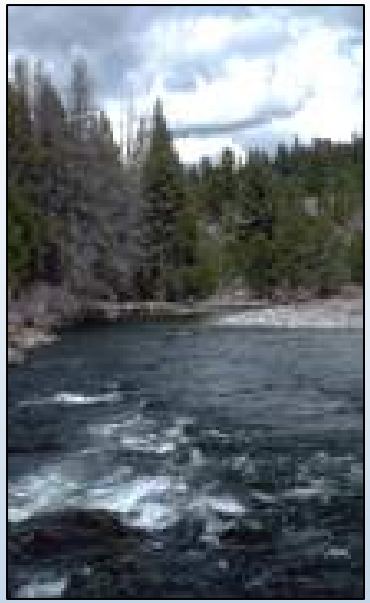
Stanley R. Bull

National Renewable Energy Laboratory

Energy Challenges are Enormous

Energy Security and Reliability

Economic Growth

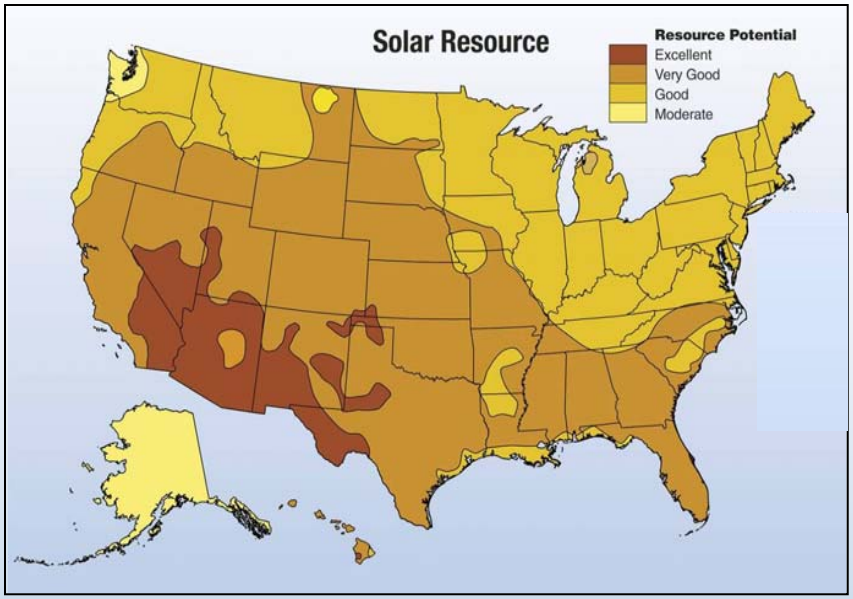


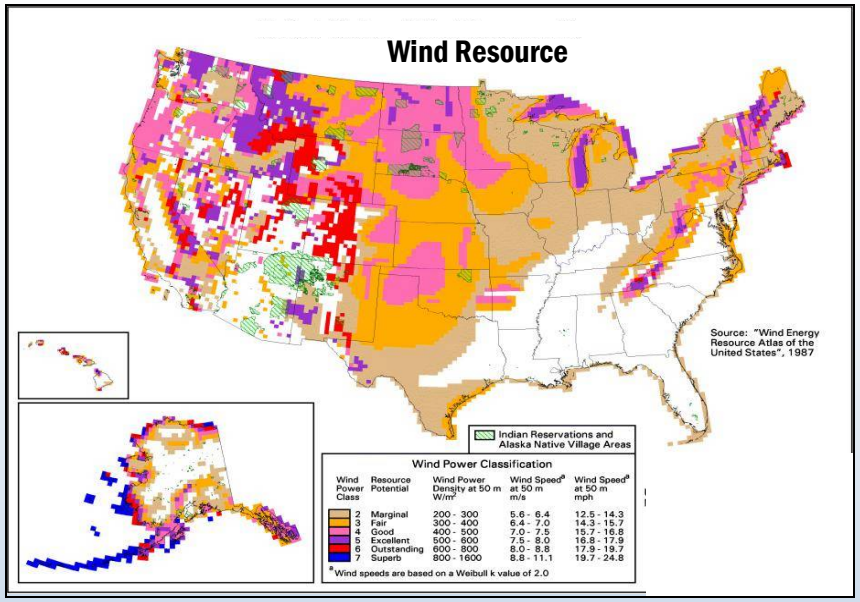
Environmental Impact

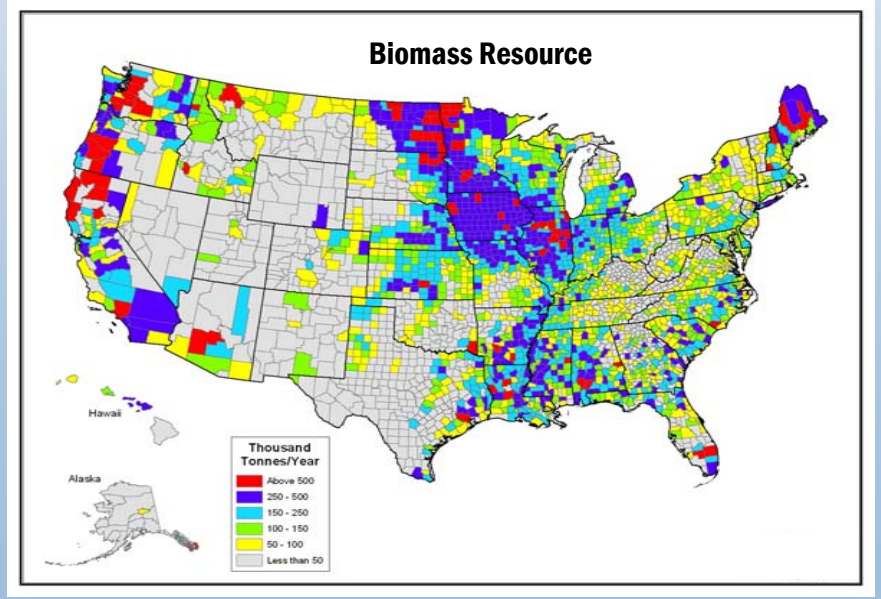
Natural Disasters

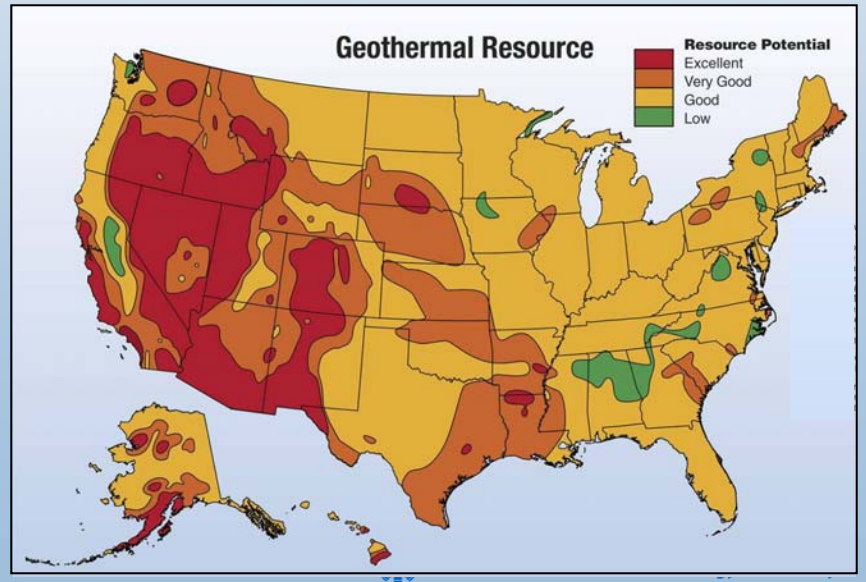
Renewable Energy

U.S. Renewable Energy Resources

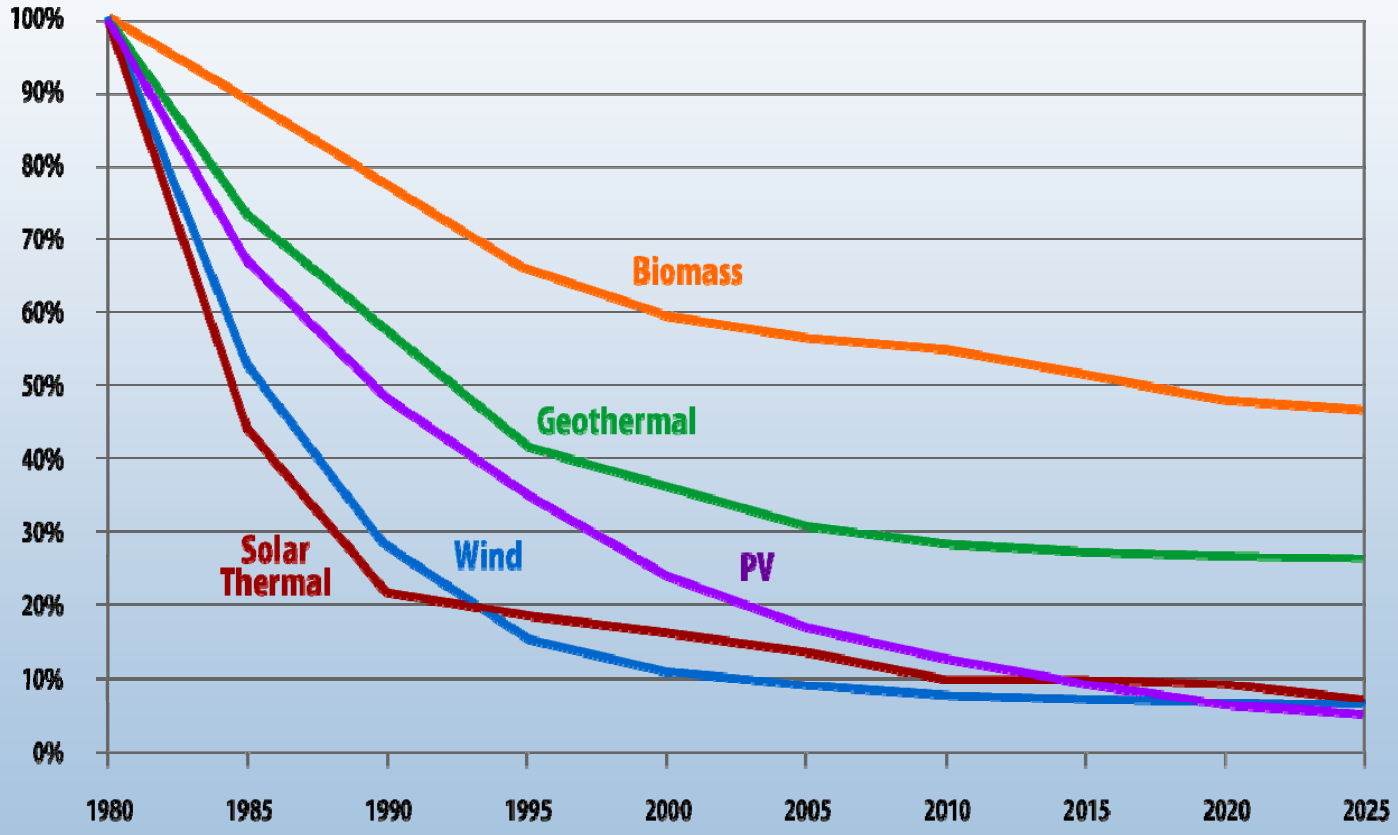


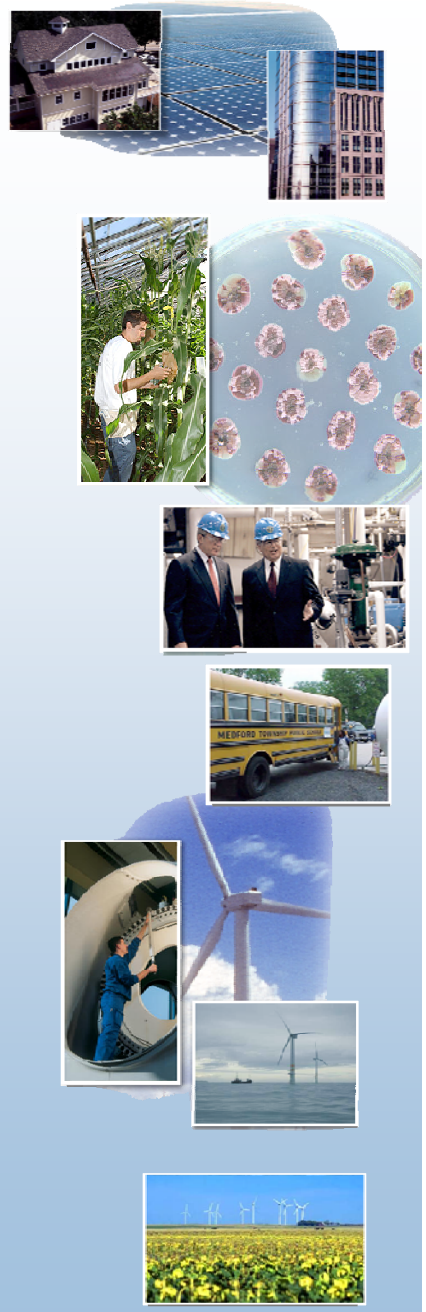






Past Investments Have Yielded Impressive Cost Reductions





Setting the Bar Higher

Electricity

Gigawatt-Scale Renewables

- **Solar Goal**
  PV cost of electricity parity by 2015

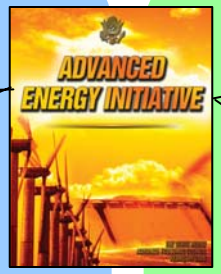
- **Wind Vision**
  20% U.S. wind electricity by 2030

- **Buildings**
  Net-Zero Energy at low incremental cost by 2025

- **State RPS Goals**
  Renewable electricity capacities

Infrastructure

- **TEAM Initiative**
  DOE meets or exceeds E.O. 13423



Fuels

- **Ethanol Cost Goal**
  Cellulosic ethanol cost competitive by 2012

- **Battery Initiative**
  40 mile all electric range for PHEVs

- **Hydrogen Fuel Initiative**
  - Technology Readiness by 2015
  - FCVs in showrooms by 2020

- **President's "20-in-10"**
  35 billion gallons of alternative fuels by 2017

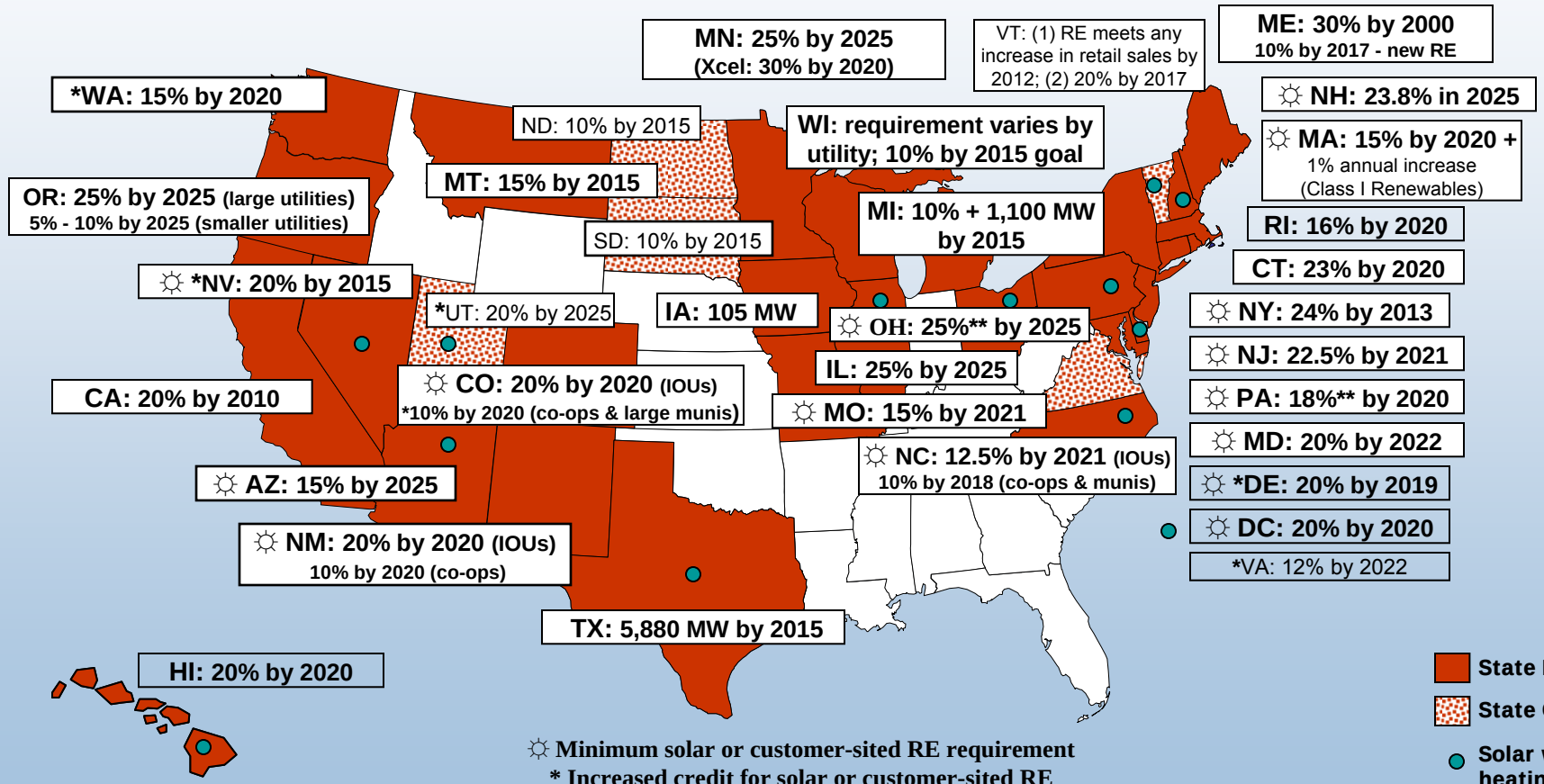
- **Energy Independence & Security Act 2007**
  36 billion gallons of renewable fuels by 2022

- **DOE "30x30 Goal"**
  60 billion gallons of ethanol by 2030

DSIRE: www.dsireusa.org

December 2008

Renewables Portfolio Standards



☼ Minimum solar or customer-sited RE requirement
* Increased credit for solar or customer-sited RE
**Includes separate tier of non-renewable "alternative" energy resources

NREL National Renewable Energy Laboratory

Renewable Energy Pathways from the Resource to the End-User

Renewable Resources

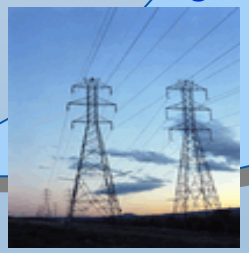
- Wind
- Solar
- Biomass
- Geothermal
- Hydroelectric
- Ocean

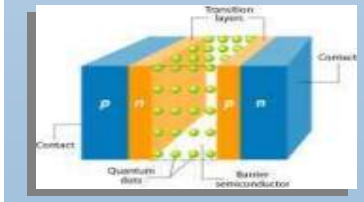
Efficient Energy Use

- Buildings
- Industry
- Transportation

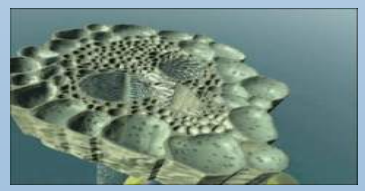
Energy Delivery and Storage

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





Foundational Science



Applied Science

NREL National Renewable Energy Laboratory

Primary Business Lines

Renewable Electricity

- Solar
- Wind
- Geothermal
- Electric Systems
- Building Systems

Technology Utilization

Technology & Systems Development

Foundational Science

Renewable Fuels

- Biofuels
- Hydrogen
- Vehicle Systems

From Science to Systems

Wind Energy

GE Wind's 1.5 megawatt wind turbine installed in Tehachapi, California

Vestas V-47 Turbines on wind farm in Kansas

Brazilian hybrid power system

Dyess Air Force Base, Texas (near Abilene)

Palm Springs, CA, wind farm

Wind

Today's Status in U.S.

- 16,740 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

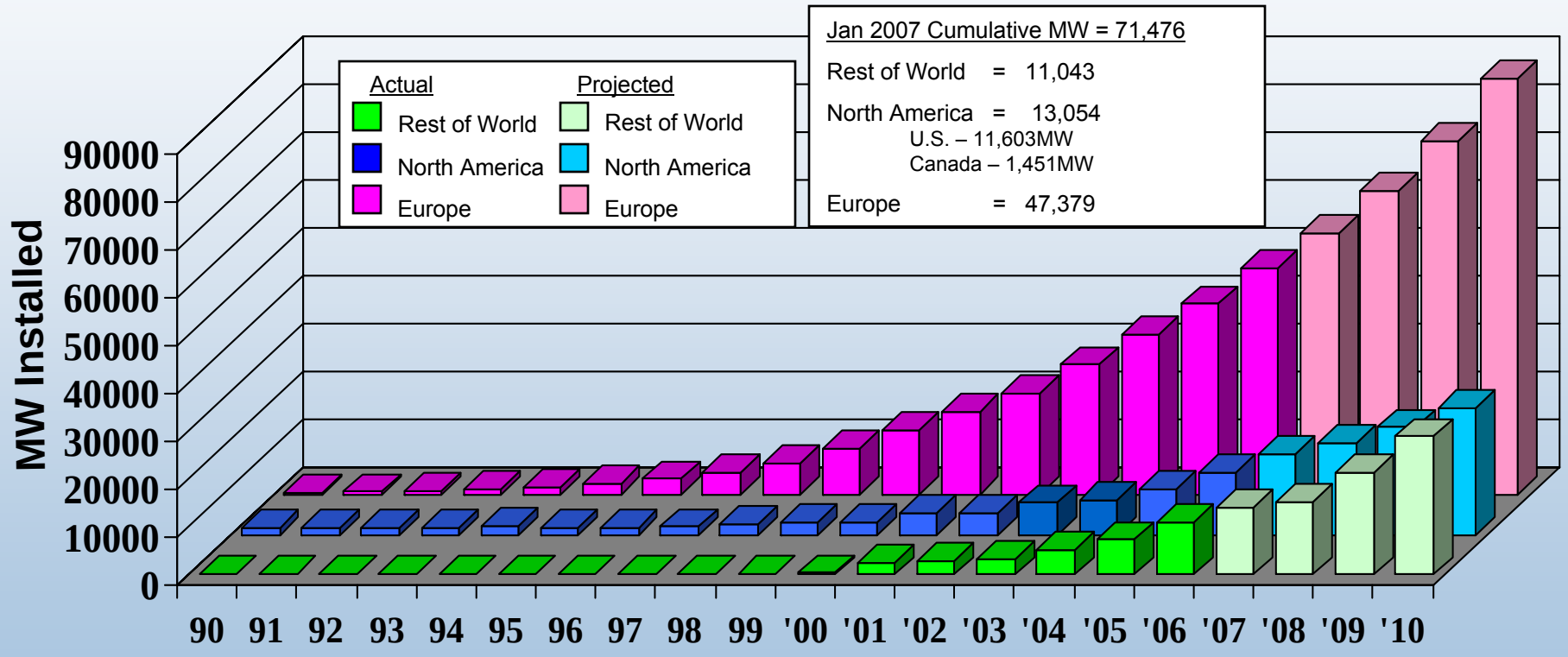
- 20% of the nation's electricity supply

NREL Research Thrusts

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

* With no Production Tax Credit
Updated January 28, 2008
Source: U.S. Department of Energy, American Wind Energy Association

Growth of Wind Energy Capacity Worldwide



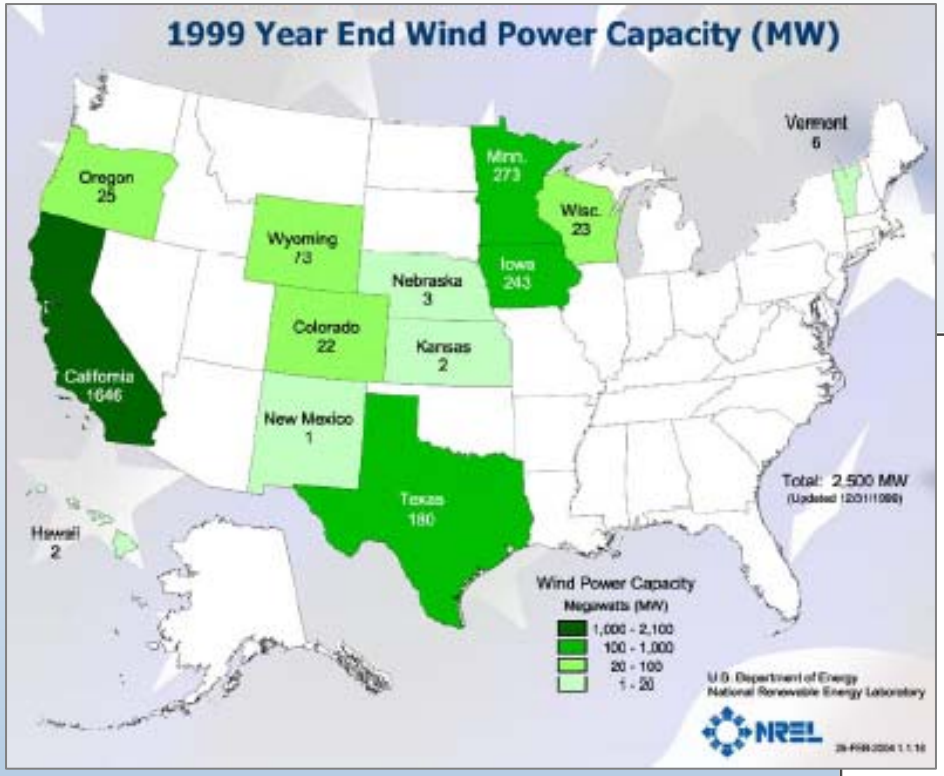
Sources: BTM Consult Aps, March 2005
Windpower Monthly, January 2007
*NREL Estimate for 2007

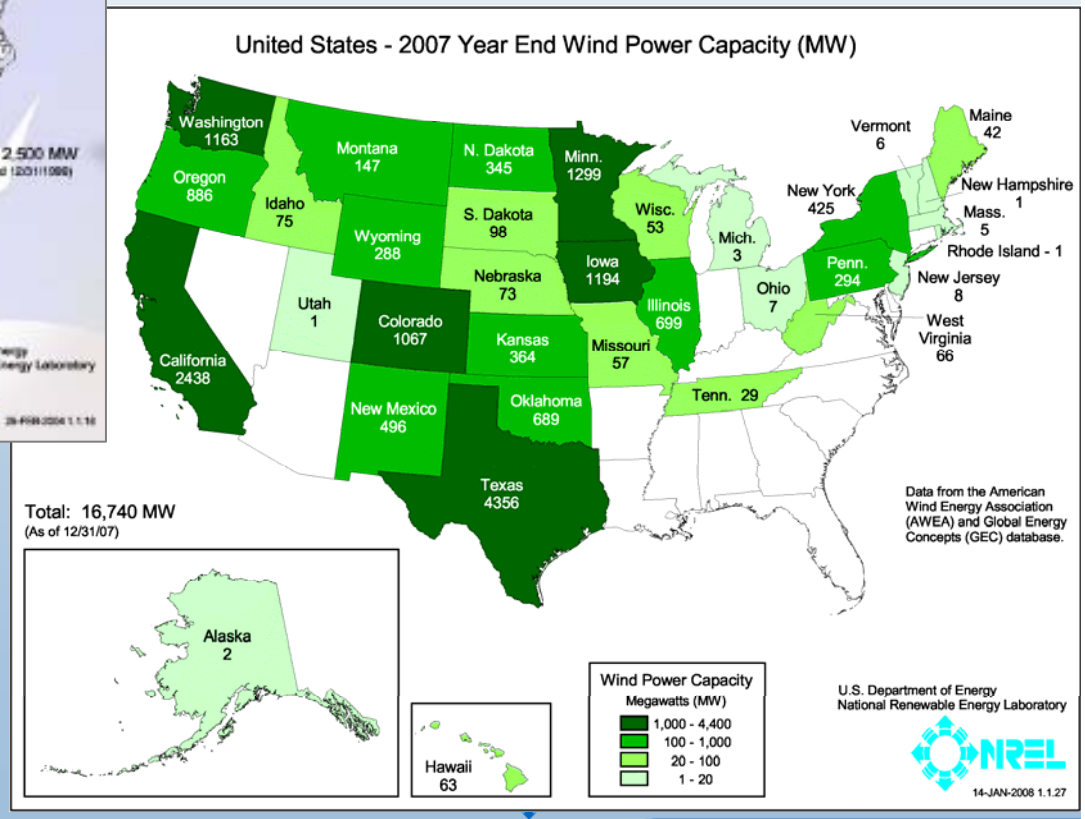
NREL National Renewable Energy Laboratory

GE WindEnergy
3.6 MW Turbine
Boeing 747-200
Arklow Banks Windfarm
The Irish Sea
Photo: R. Thresher

Installed Wind Capacity

1999 – Dec 2007*



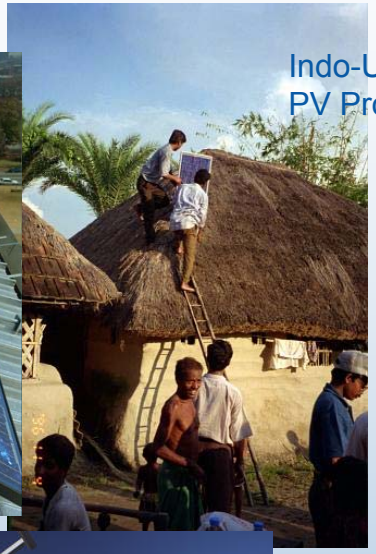


*Preliminary data

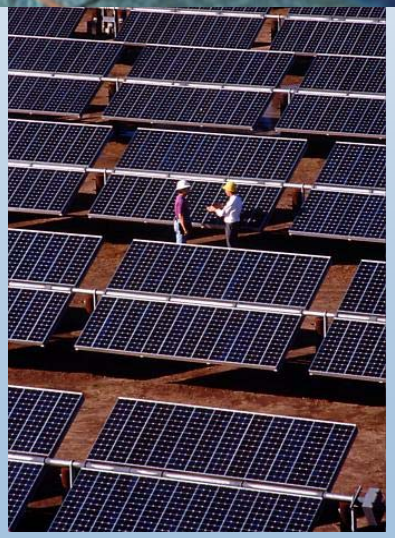
Solar Energy

PV roofing shingles

PV panels



Indo-US Cooperative PV Project

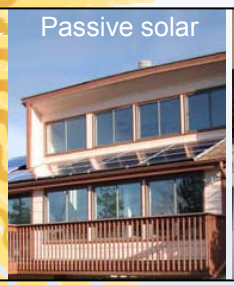


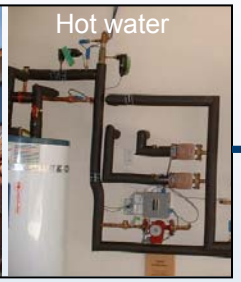
210 kW PV system at SMUD's Hedge substation

Solargenix 64 MW solar plant near Boulder City, Nevada

Applications of Solar Heat and Electricity

Solar Thermal





Photovoltaics (PV)

Concentrating Solar Power (CSP)

Distributed Generation, on-site or near point of use

Centralized Generation, large users or utilities

Transportation

Residential & Commercial Buildings

Industrial

Solar

Photovoltaics and Concentrating Solar Power

Status in U.S.

PV
- 824 MW
- Cost 18-23¢/kWh

CSP
- 419 MW
- Cost 12¢/kWh

Potential:

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

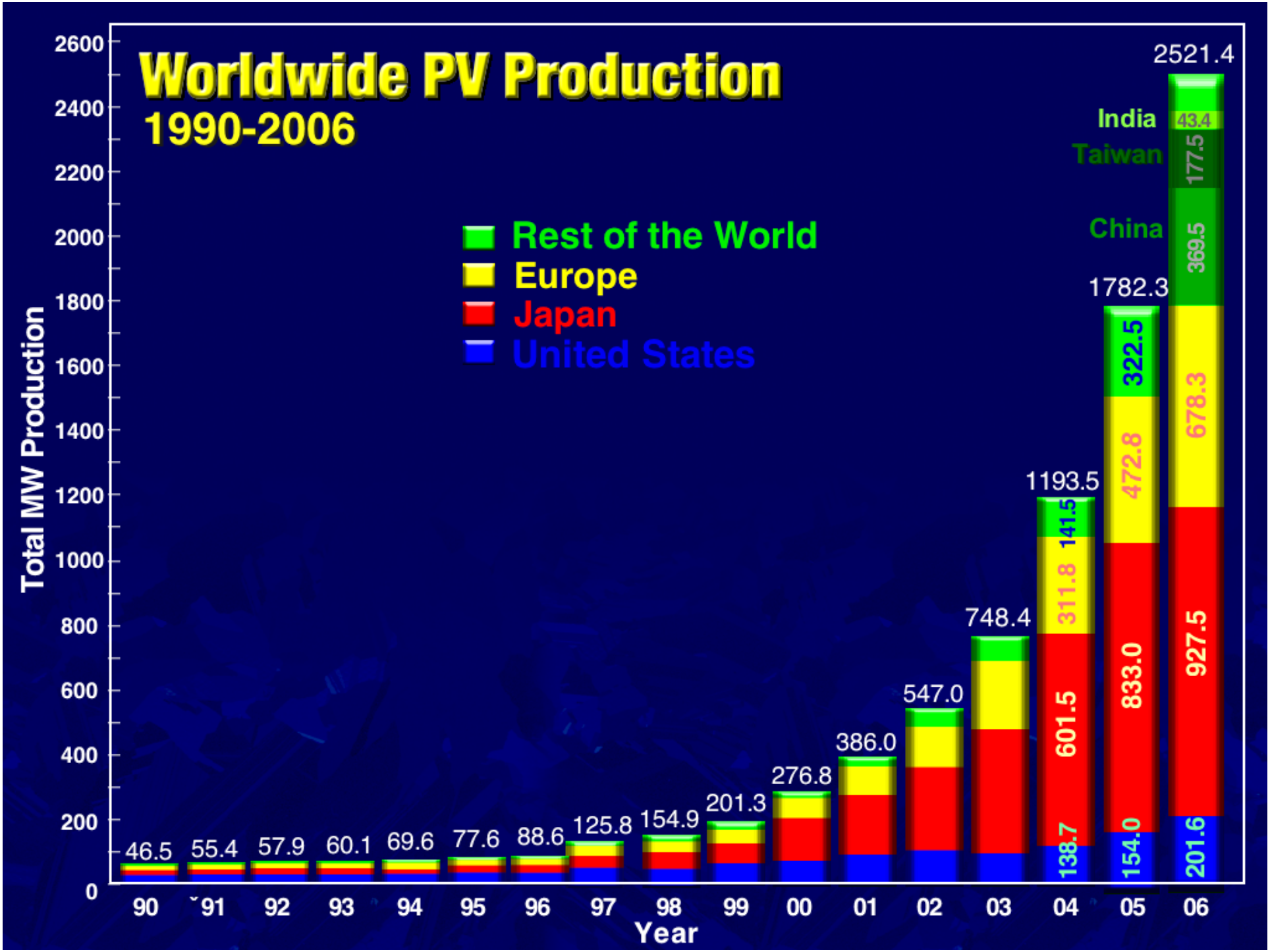
CSP
8.5 ¢/kWh by 2010
6 ¢/kWh by 2015

NREL Research Thrusts:

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

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

Source: U.S. Department of Energy, IEA
Updated January 28, 2008


Worldwide PV Production
1990-2006
Rest of the World
Europe
Japan
United States
India
Taiwan
China
Total MW Production
Year
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
90
91
92
93
94
95
96
97
98
99
00
01
02
03
04
05
06
46.5
55.4
57.9
60.1
69.6
77.6
88.6
125.8
154.9
201.3
276.8
386.0
547.0
748.4
1193.5
1782.3
2521.4
138.7
601.5
311.8
141.5
154.0
833.0
472.8
322.5
201.6
927.5
678.3
369.5
177.5
43.4

Typical Business Rooftop PV Application

64 MWe Solargenix Parabolic Trough Plant – Nevada Solar 1

•SolarTAC

•Solar Technology Advancement Center

Geothermal Energy

00412

Power production from concentrated brines

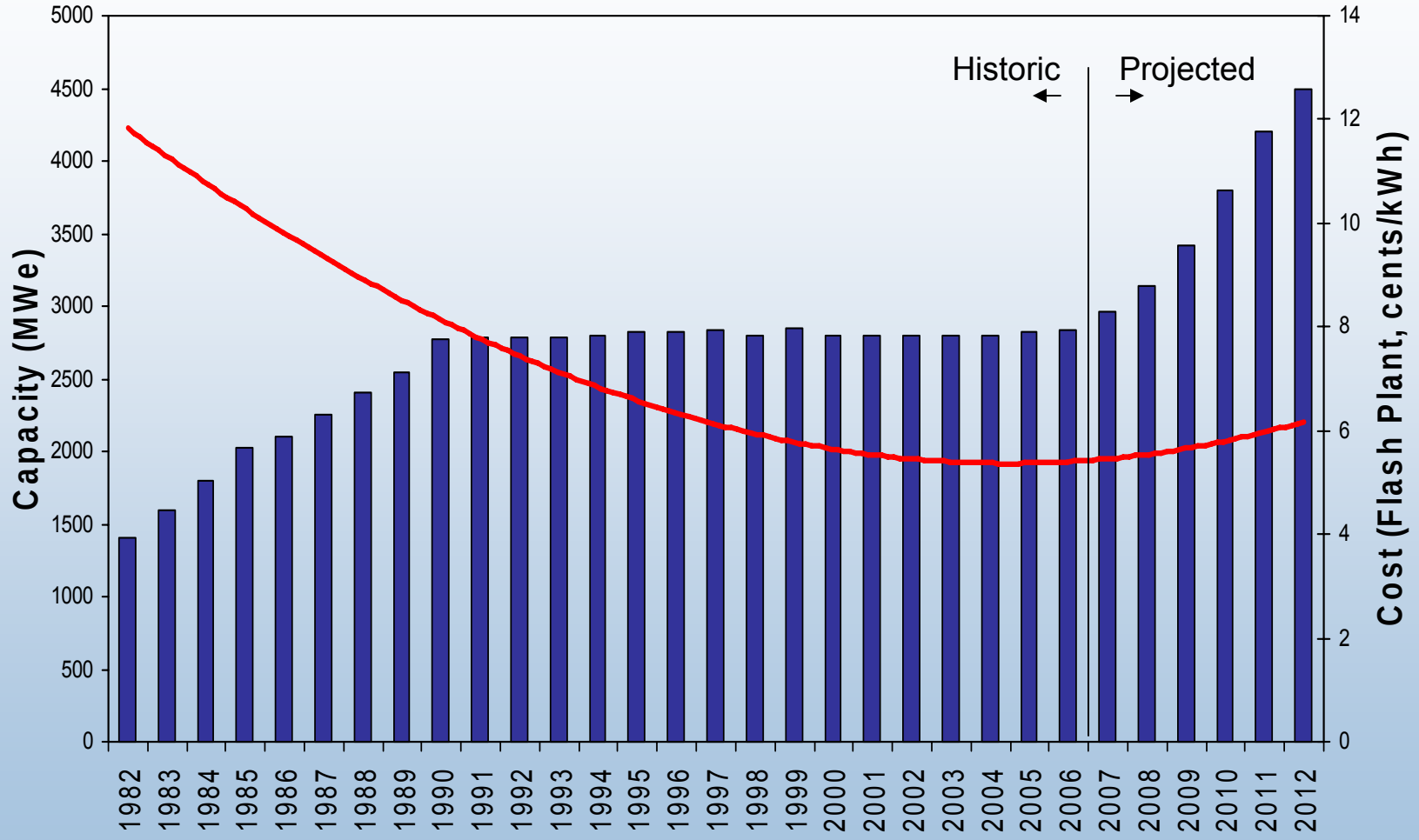
Geothermal power plant at The Geysers

00060

03694

Heat exchangers and circulation pumps

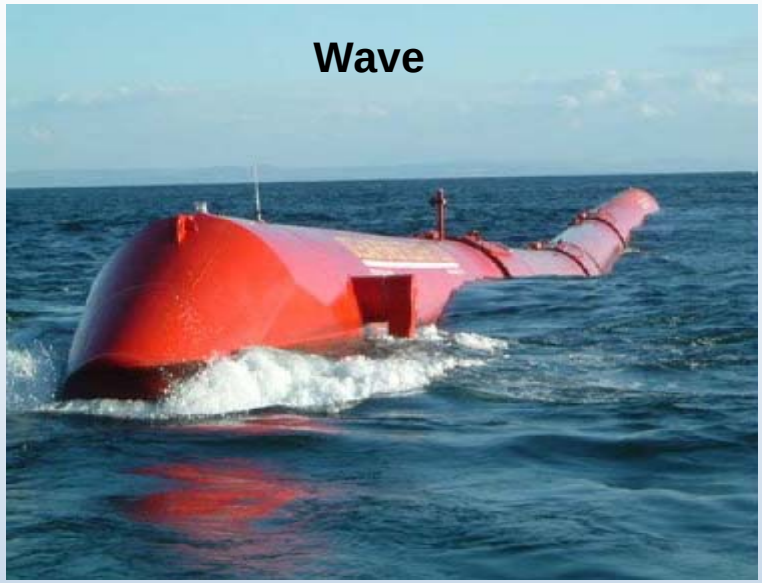
U.S. Geothermal Capacity



Projections of installed capacity based on documented projects in various stages of development (GEA, 2006)

Evaluating Potential New Directions

Ocean Kinetic Energy



Pelamis—Ocean Power Delivery

Verdant—Power RITE Turbine

Biomass Energy

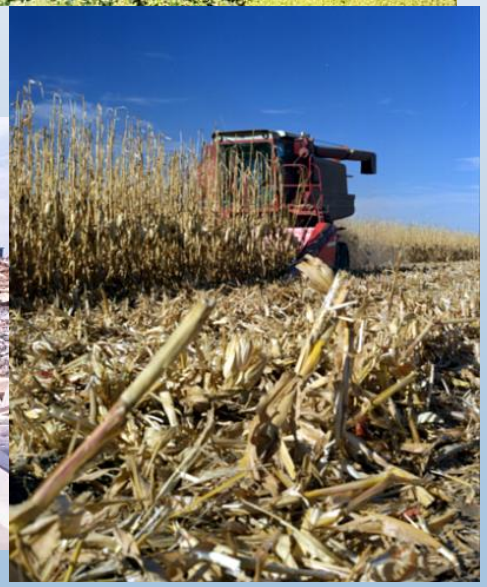
Wood chips

Switch grass

Poplars

Fats and Oils

Municipal solid waste

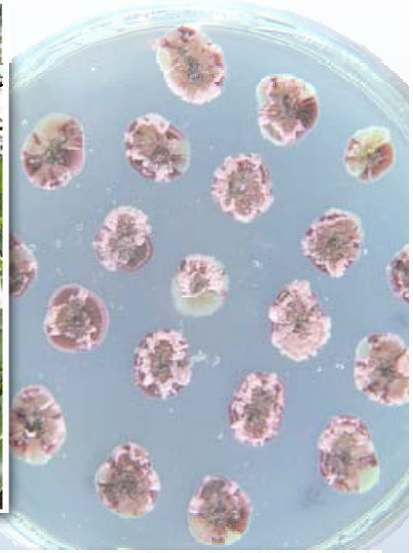


Corn Stover

Biofuels

Current Biofuels status

- Biodiesel – 450 million gallons[1]
- Corn ethanol (Dec. 2007)
  - 134 commercial plants[2]
  - 7.2 billion gallon/yr. capacity[2]
  - 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 January , 2008
Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, 3 – American Coalition for Ethanol, all other information based on DOE and USDA sources

The New Bio-Industry

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

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

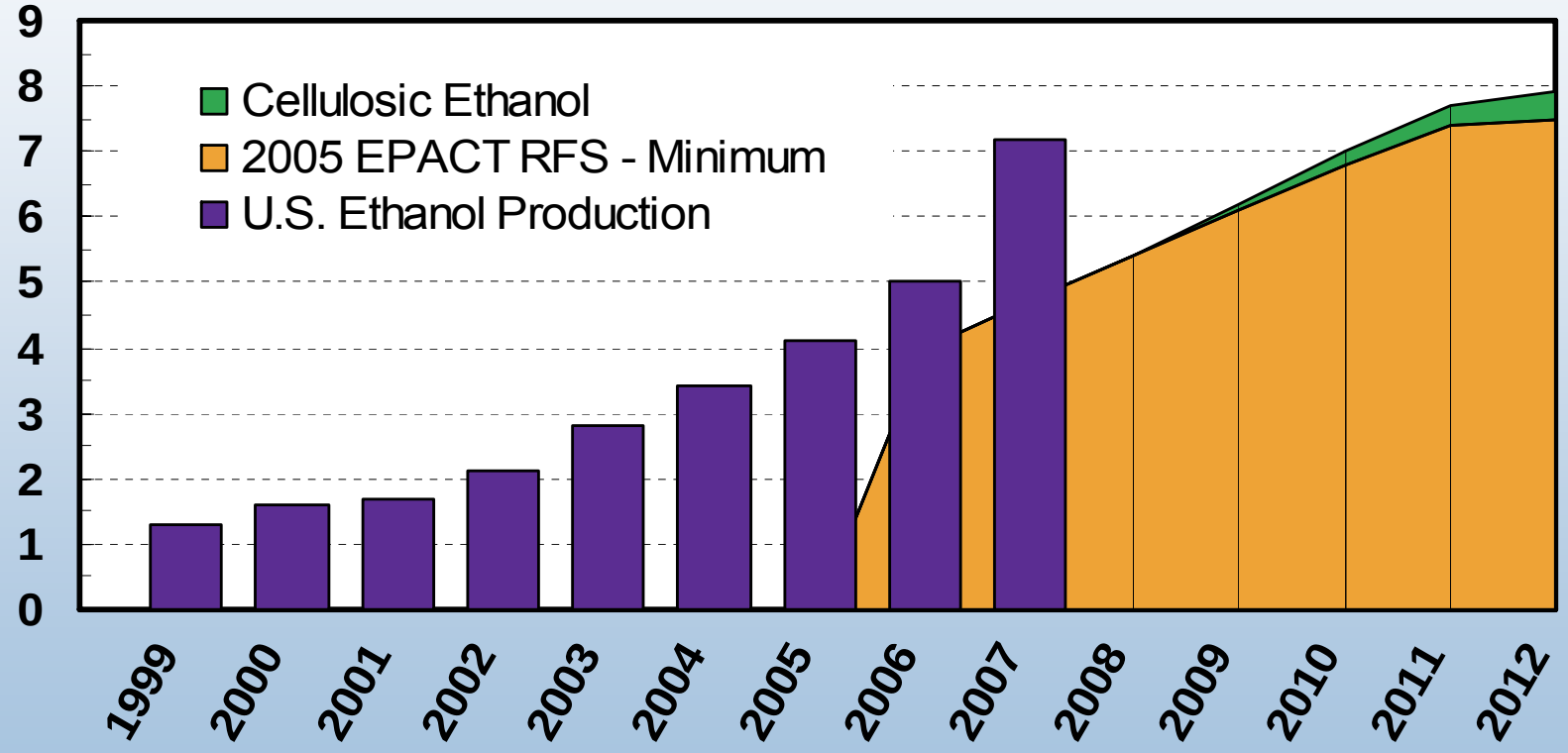
… and new concepts from plants to products

Ethanol Production

Actual and Projected U.S. Ethanol Production 1999-2012

Billion Gallons of Production

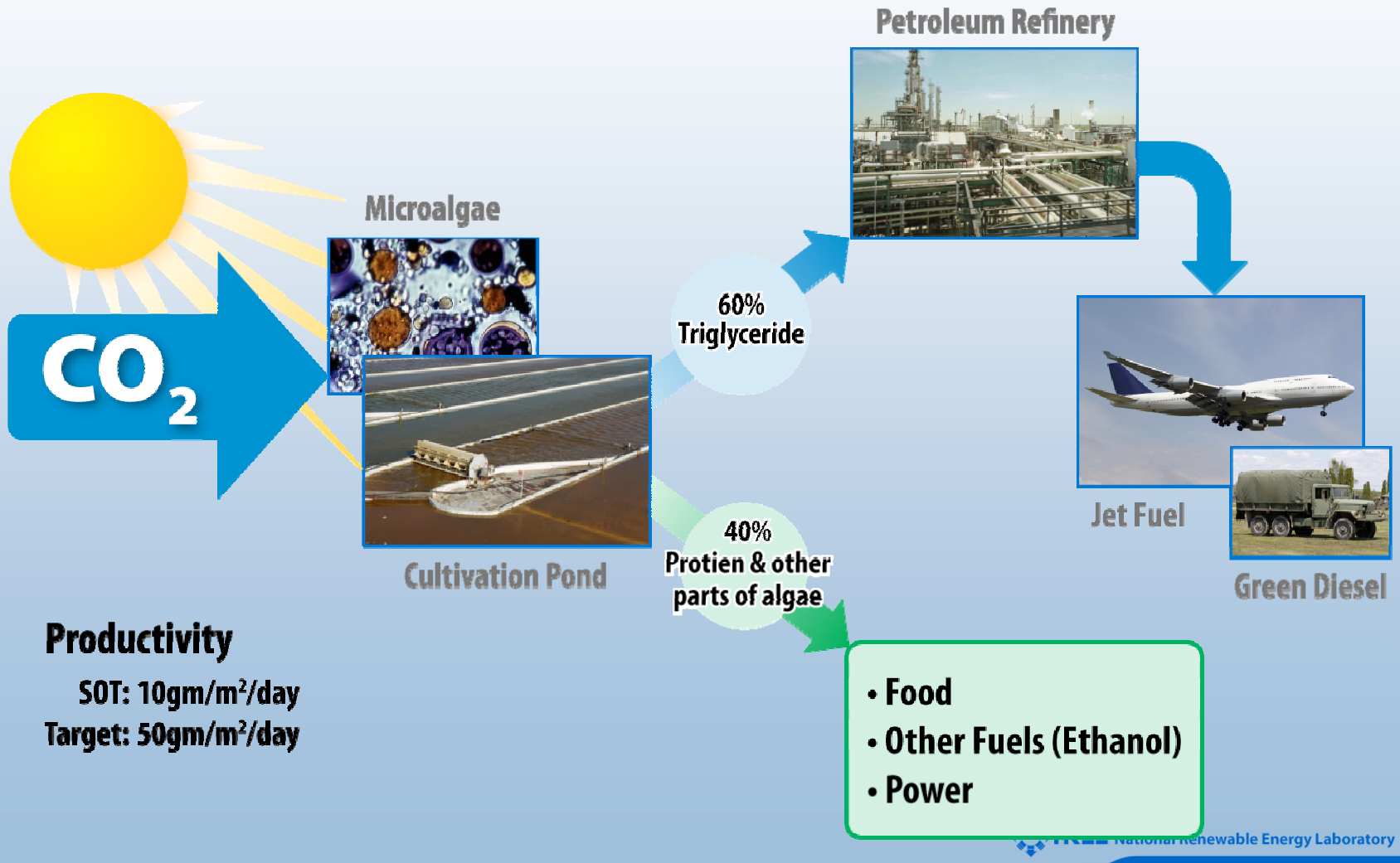
Source: December 2005 *Ethanol Today* Magazine



- Renewable Fuels Standard mandates 7.5 billion gallons by 2012
- Total US gasoline market ~140 billion annual gallons

A Novel Approach for making Jet Fuel From Biomass

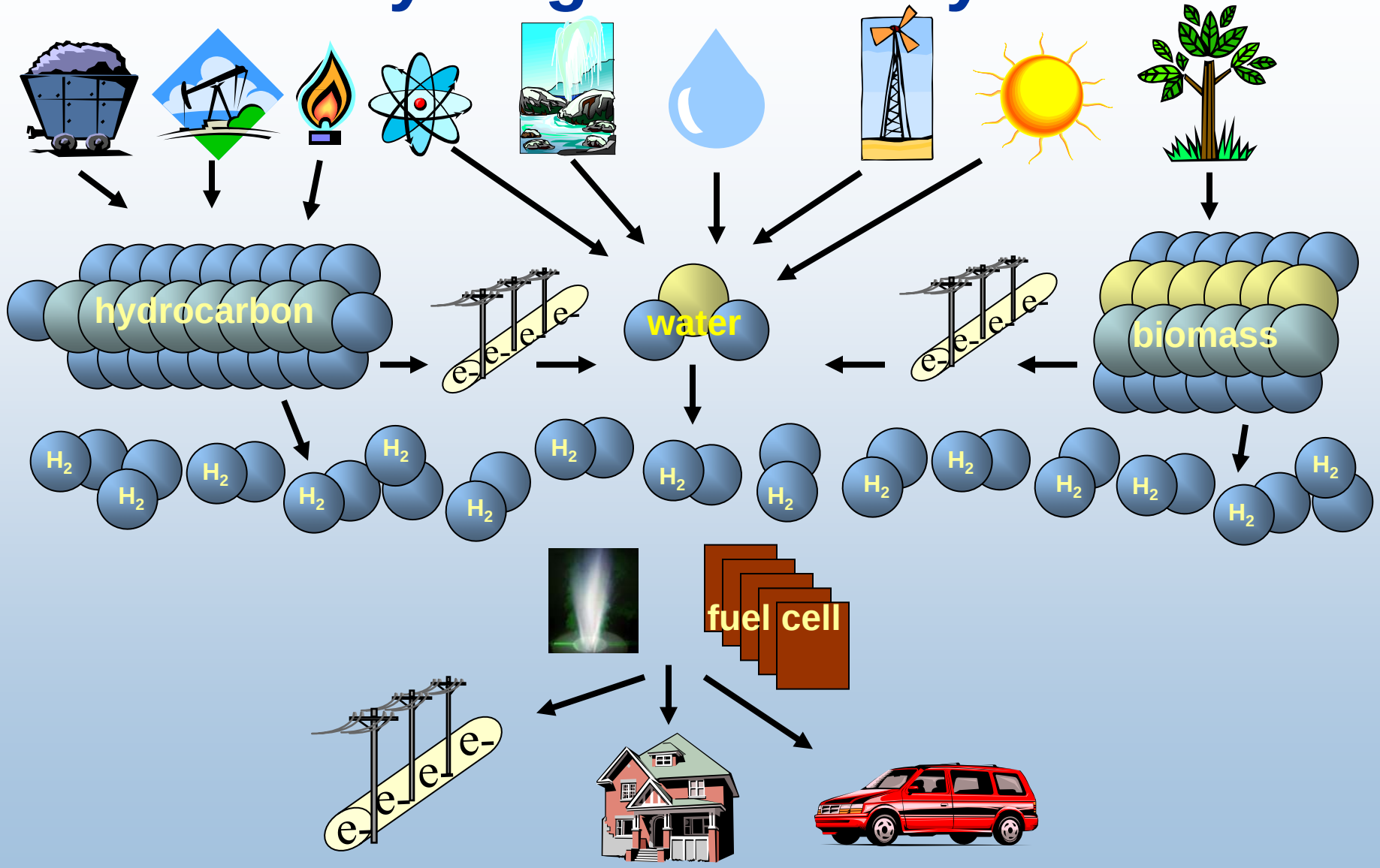
Combine two technologies: Algae & Green Diesel



Productivity

SOT: 10gm/m²/day
Target: 50gm/m²/day

Hydrogen Pathways



Hydrogen must be derived from other energy sources.

Hydrogen

Status

- Working with industry to develop technologies in quantities large enough, and at costs low enough, to compete with traditional energy sources.

Potential

- Commercially viable hydrogen and fuel cell systems by 2015

NREL Research Thrusts

- Hydrogen production, delivery, storage and manufacturing
- Fuel cells
- Safety, codes, and standards

Advanced Vehicles and Fuels Options

Conventional Vehicles

Hybrid Electric Vehicles

Plug-in Hybrid Vehicles

Hydrogen Vehicles—ICE or Fuel Cell

Corn Ethanol, Cellulosic Ethanol

Biodiesel, Fischer-Tropsch Diesel

Natural Gas other Petrochemicals

Electricity from Grid

Distributed Renewable Electricity

Hydrogen from Natural Gas

Renewable Hydrogen

Energy Efficiency - Buildings

Van Geet home located in Idaho Springs, CO

08226

21st Century Performance home

12245

11269

NREL's Solar Energy Research Facility

10229

Solar Patriot House

Buildings

Status US Buildings:

- 39% of US primary energy
- 71% of US electricity
- 38% of US carbon emissions
- 10% of global carbon emissions

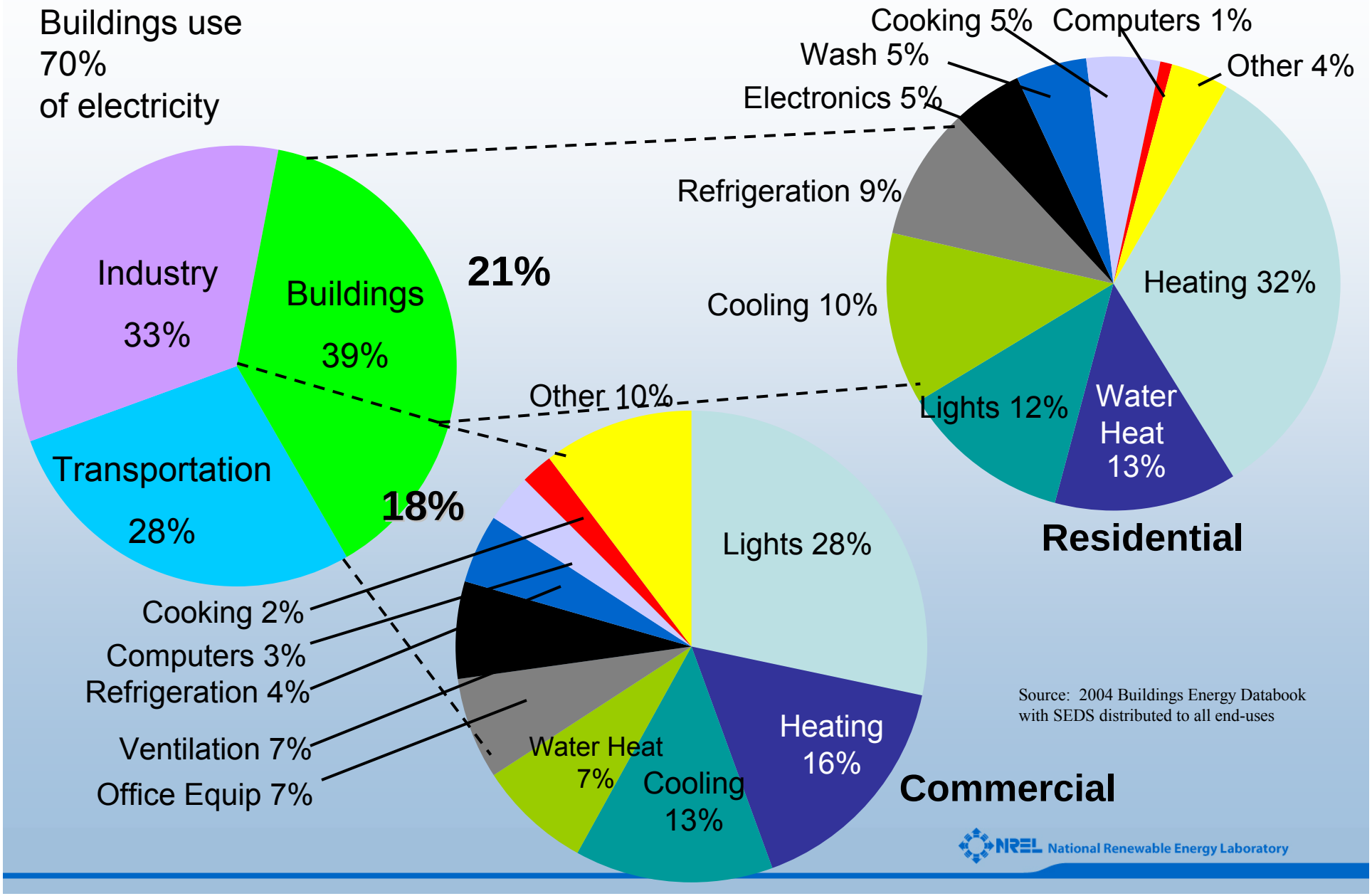
DOE Goal:

- 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
- Field experiments and monitoring
- PV/Thermal hybrid systems
- Building integrated PV
- Electrochromic windows

Building Energy Use



Source: 2004 Buildings Energy Databook with SEDS distributed to all end-uses

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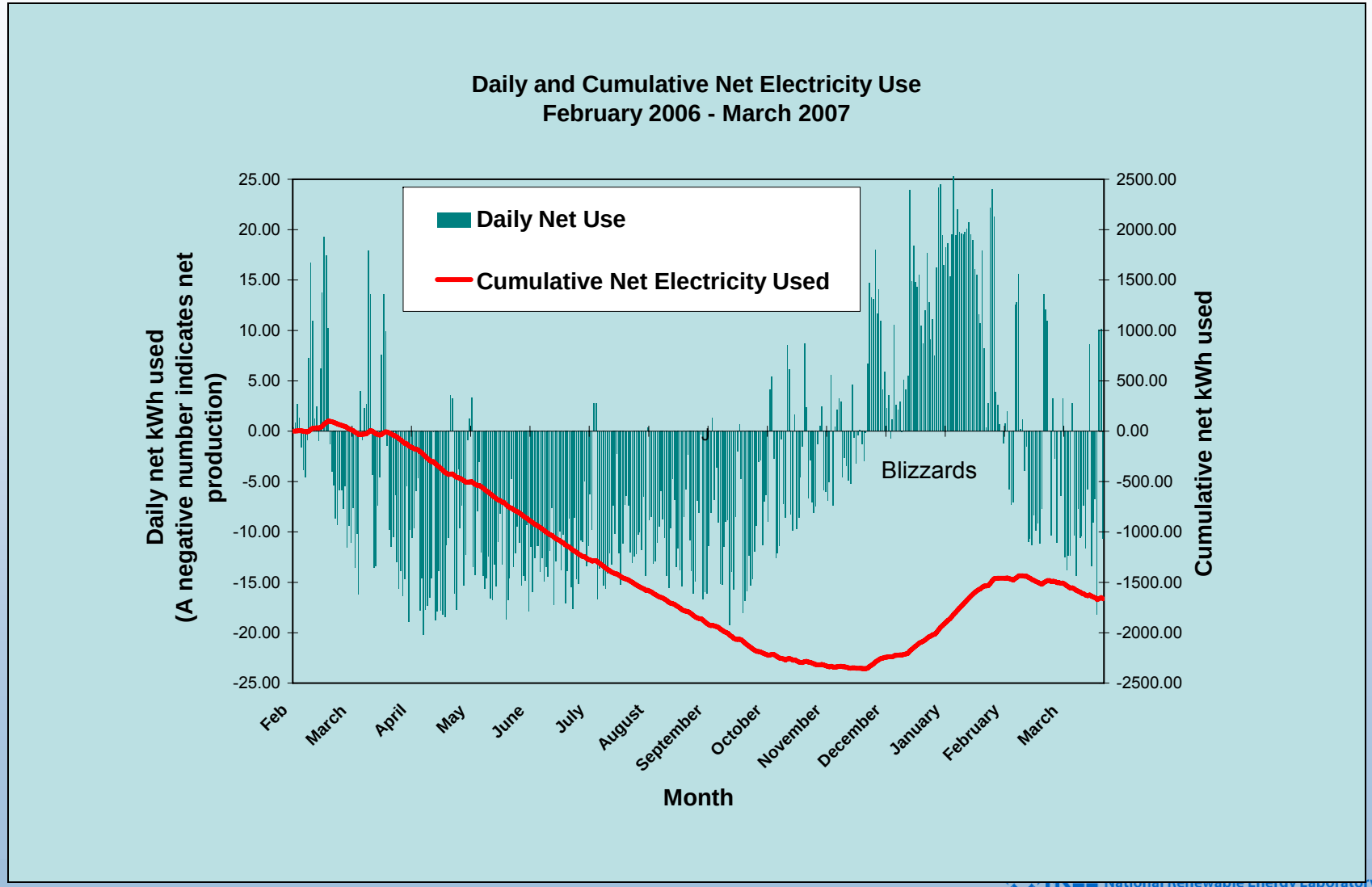
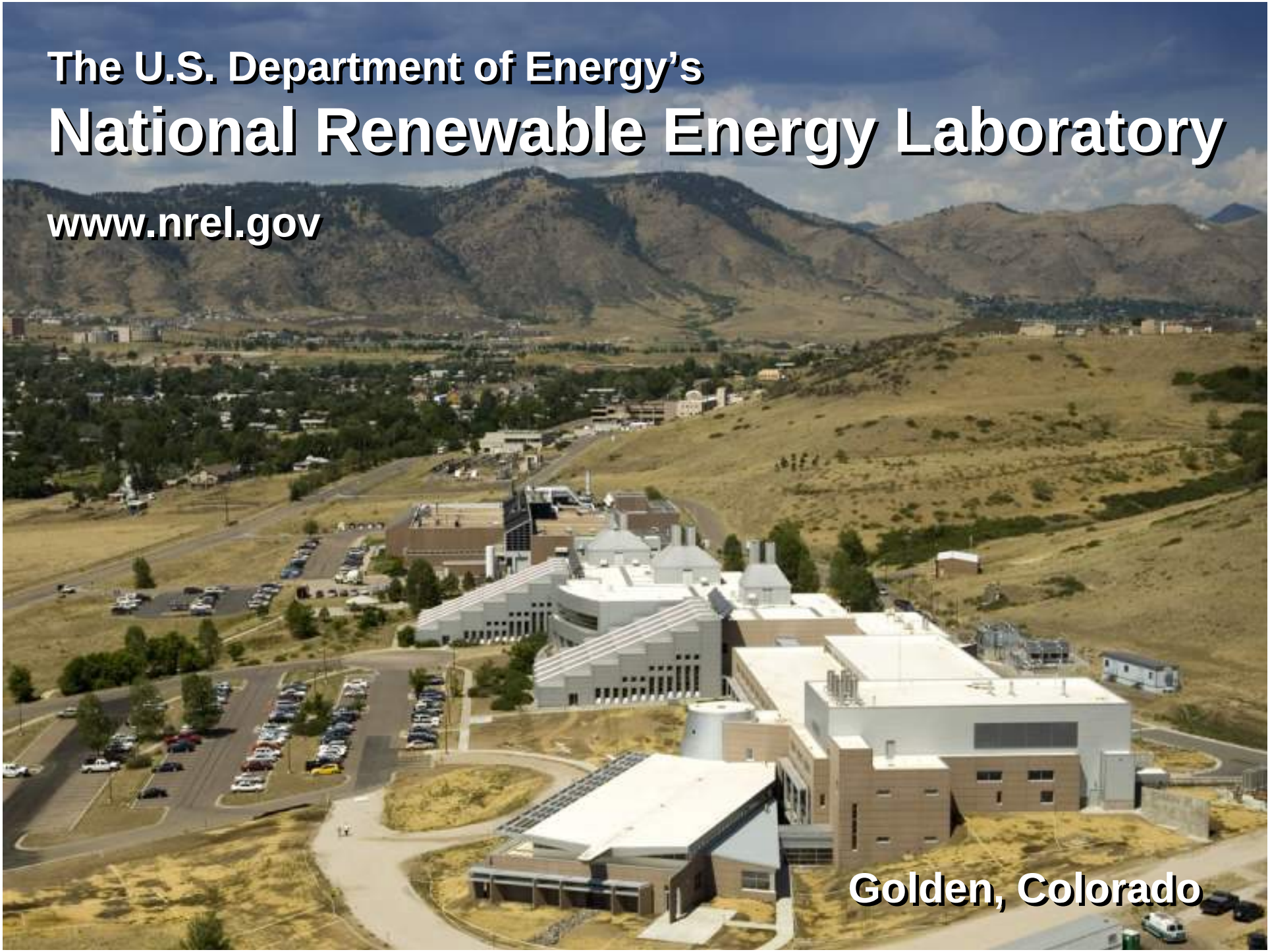
Low-Cost ZEB Housing

Habitat for Humanity Energy Performance

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National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado